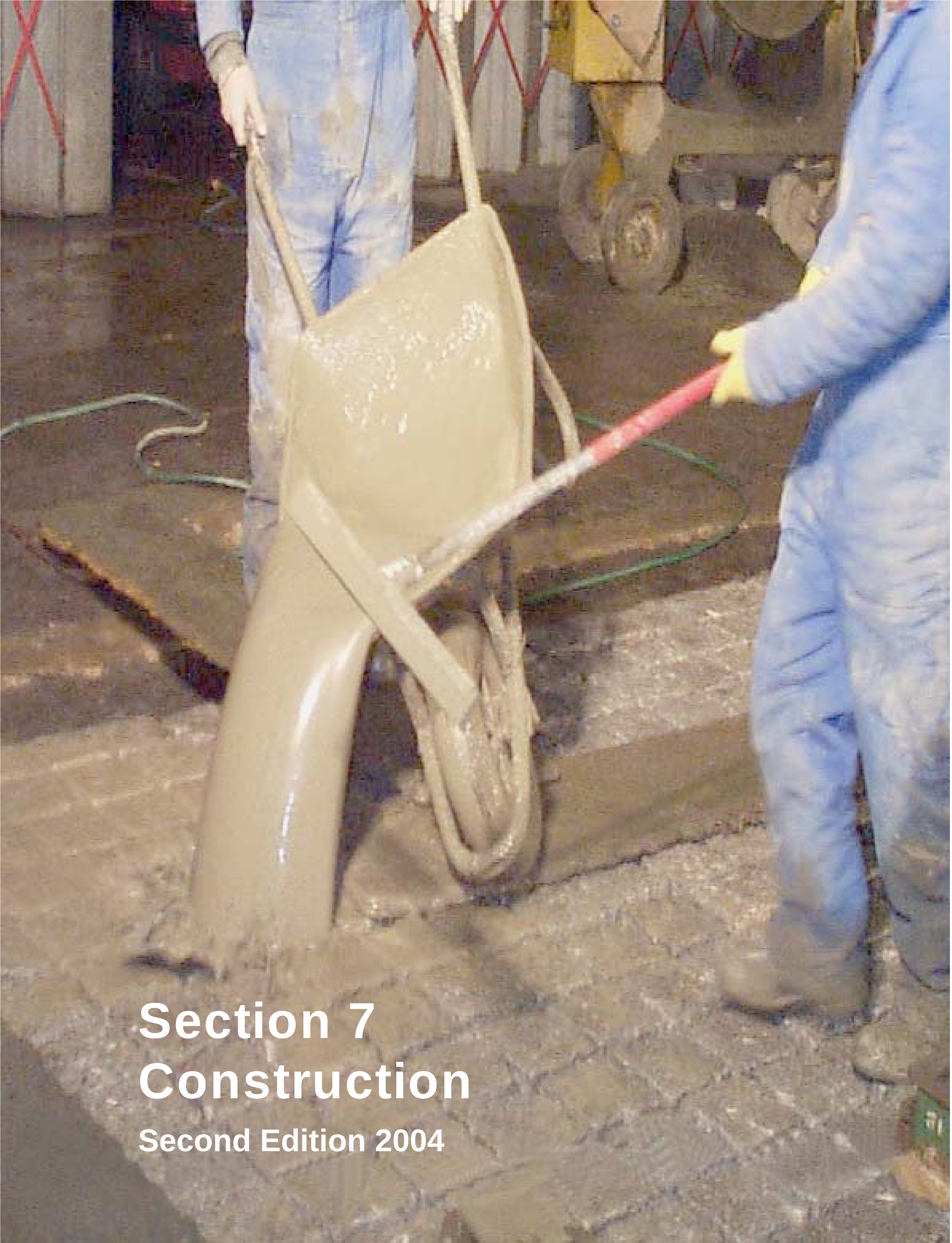

Section 7
Construction

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7 CONSTRUCTION

7.1 Introduction

This section deals with the construction process and gives guidelines for the different types of stone pavement identified in BS 7533. Part 7 of that document defines these as:

- **Flexible Construction**, with elements stabilised by friction using unbound aggregate and supported by a flexible roadbase construction. There are two categories of Flexible Construction depending on the units used: -

    - **Sawn Sided Units laid in the manner of concrete or clay pavers**
    - **Cropped or Textured Units**

- **Rigid Construction**, with elements stabilised by a cement mortar and supported by an asphaltic construction or a cement-stabilised aggregate. There are three categories of Rigid Construction depending on the consistency of the materials used for the laying course and the joint filling: -

    - **Moist laying course with moist joint filling**
    - **Moist laying course with plastic joint filling**
    - **Plastic laying course with plastic joint filling**

Part 7of BS7533 discusses the construction of the lower part of the pavement sub grade sub base and roadbase. It then defines materials for each form of construction. Various aspects of laying methods, which are common to both construction types, are set out, followed by more specific requirements for each form of construction.

This section of this Guide is divided into three parts. Firstly the process of sorting the stone elements and laying patterns, which are essential to the laying and performance of both types of pavement are discussed. Then each type of construction is considered with a fuller explanation of construction methods and guidance on how to achieve the required standards. Finally common features including cutting and trimming and the use of complementary fittings and special units and laying in inclement weather are discussed.

7.2 Sorting Elements and Surface Patterns

7.2.1 Sorting Elements

BS 7533 Part 7 identifies the sorting of elements as an essential step in achieving construction tolerances. This is because the tolerances permitted in BS EN 1342 are generous. Using units, which are manufactured to these, less stringent tolerances might not achieve the tolerance on joints and laying course required in BS7533 Part 10, which deals with structural design of the pavement. This is already been elaborated on in Section 4.

The selection of stone on site is discussed more fully in Section 6. The pre-selection is also important when re-claimed setts are being used, particularly where the surface is to carry greater than category 2 loading.

Selection of Stone on Site

An example of selection is given below in Figure 7.1. This is for a nominal 100mm wide sett with a manufacturing tolerance of +/- 20mm. This would allow the width of a stone unit to lie in a range between 80mm to 120mm. In order to meet the construction tolerances of say 10mm on joint width, these units would have to be selected to give bands of width as follows.

Figure 7.1 – Example of Bandwidth for Sett Courses

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

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

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

Sorting may also be required for depth to ensure laying course tolerances are achieved.

Equally it is important for the paver to identify elements with a marked taper and ensure that adjacent tapered elements, when laid, are not in contact and the joint tolerances are maintained (Figure 7.2). The principles that apply for tapered elements also apply to elements with marked indentations and protrusions.

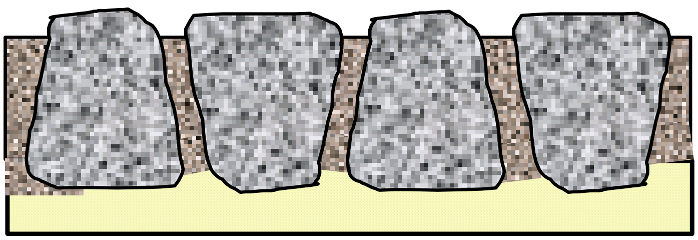


Figure 7.2 Laying elements with taper

Other shapes of stone units, cubes slabs and flags may require sorting in this fashion on site. All stone units are also sorted to suit the pattern of the surface. Therefore the actual sorting to size required on site for a particular pavement will be determined by the intended surface pattern and how the joint and laying course tolerances relate to the manufacturing tolerances applied to the units.

Guidance

Sorting of elements into appropriate size and shape groups prior to laying is essential if the required joint width tolerances, laying course depth tolerances and surface patterns are to be achieved.

7.2.2 Surface Patterns

Surface patterns for stone element surfacing need to take into account both the appearance of the surface and the contribution they can make to the flexural stiffness of the surface layer.
In flexible construction in particular certain patterns are essential to generate interlock and ensure the elements and joints act homogeneously. In BS 7533 Part 10 and Section 4 of this Guide, certain patterns are stipulated for certain loading conditions and site categories. As discussed in Section 4 there are high stress areas where horizontal forces are directly induced in the surface such as: -

- at stop / start lines
- at junctions where the flow of traffic varies
- at steep inclines where larger braking forces occur
- at marked changes of vertical gradient
- at surface features in the pavement

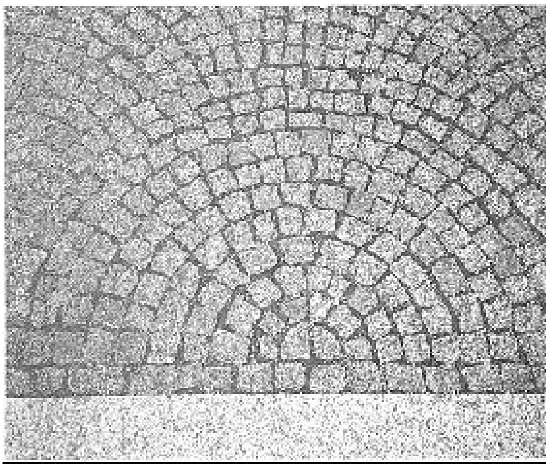
In these locations, a surface might benefit from the introduction of a pattern, which generates a higher degree of interlock than the standard pattern selected for the general area of the surface. As discussed in Section 4 this change of pattern might accompany other techniques to resist these unusual forces.

Common laying patterns for setts and cubes are noted below and illustrated in Figure 7.3.

- Stretcher bond
  This pattern generates low to moderate interlock in the surface. The units are laid in rows normally at 90 degrees to the direction of travel but with each row staggered by approximately half a length. This bond can tolerate some degree of variation in the length of the units but care has to be taken not to have joints in one row line up with joints in adjacent rows, normally bond should be maintained at a minimum of one third of the length of a unit. If the direction of travel changes i.e. at a corner or junction, then the orientation of the pattern should be changed to run at 90 degrees to the direction of travel. This criterion is difficult to meet in a corner or junction and consideration should be given to introducing a different pattern or further lateral restraints in the surface.

- Herringbone bond
  This pattern generates moderate to high interlock in the surface. The units arranged alternatively long side to short side at right angles to each other and normally at 45° to the main direction of travel. This requires units, which are of a consistent size where the ratio of the length to breadth is 2:1 and inevitably requires pre selection of the units, unless they are manufactured specifically to shape and tight tolerance. The orientation at 45° to the normal axis usually means that the pattern automatically precludes long lengths of joints becoming parallel with the direction of travel. Thus, the pattern is suitable for use in corners or junctions

- Arc or bogen pattern
  This pattern generates high interlock in the surface. Here the units are laid in a series of inter-laced arcs. There are many varieties of this pattern depending on the range of sizes of the units, but successful installation is very dependent on the skill of the laying crew. It is most commonly used with cubes shape units where the layer may typically sort a batch of cubes into the following size ranges, 65-70, 70-75, 75-80, 80-85, 85-90 and 90-95. The smaller sizes are used in the inner arc of a pattern progressing through the sizes to use the largest size in the outer arc. The arc pattern precludes joints along the direction of travel. Thus, the pattern is suitable for use in corners or junctions



Bogen or arc pattern

Stretcher bond

Figure 7.3 Common laying patterns for setts and cubes

7.2.3 Patterns in Flexible surfaces

It is known that arranging units in certain patterns enhances the interlock of a flexible pavement, however the degree of enhancement has not yet been quantified. Patterns that preclude long straight lines in either direction and thus prevent movement developing under the action of traffic are preferred.

Stretcher and herringbone bonds are recommended for the first category of surface given in BS7533 Part 7, **Sawn Sided Units with narrow joints,** where with very tight tolerances on the manufacture of the stone unit, the surface can be laid in the manner of concrete or clay paving block.

Herringbone and arc patterns are recommended for the second category of surface using **Cropped or Textured Units with wide joints**. Stretcher bond has long lines of joints, which can become parallel to the direction of travel and is not recommended for the second category of surface. If stretcher bond is preferred then a rigid construction may be used.

Cubes may be laid in an un-bonded pattern, rows and columns, but this pattern provides little flexural strength and should only be used on hard standing areas, such as vehicle parking areas. Therefore it is recommended that Cubes (80 to 100mm) should be laid in curved patterns described as Bogen or arc pattern in vehicular trafficked areas. These cubes are laid in a curved pattern, the arc being in the direction of the traffic flow, or uphill. The curved pattern is thought to dissipate in-surface stresses to the verges of the pavement caused by vehicle traction and as a result, the joints are not stressed in direct shear. Small cubes laid in a curved pattern will cause the joint widths to vary, but elements should not be touching.

When curved patterns are used on inclines joints can be washed out, with the result that the surface stability is lost and frequent maintenance is required. On inclines the designer should consider stabilising the joint materials with a surface treatment such as a proprietary sprayed polymer resin. Alternatively, the designer should consider increasing the structural capacity of the surface by selecting deeper and perhaps different shaped units that do not rely on the surface pattern for structural performance. This would allow the pattern to be changed to one that will not suffer from wash out such as herringbone or stretcher bond.

It may also be prudent to consider constructing additional lateral restraints in the pavement in these areas as described in Section 4 and Section 7.3.

7.2.4 Patterns in Rigid Construction

Rigid surfaces are not so dependent on interlock for their load carrying capability, but it is thought likely that certain patterns assist rigid pavement to withstand localised horizontal forces described above. Again, the effect is not yet quantified.

The typical pattern in all categories of rigid surfaces is stretcher bond, which is the least demanding in terms of skill and pre-selection of units. However, at areas of localised high stress, consideration should be given to introducing limited areas of herringbone bond to prevent strains developing along the joint lines.

Another traditional technique which has proven to be effective at Tee and Cross junctions is to lay panels where stretcher bond is turned at 45' to the general axis of the laying pattern. Again It may be prudent to consider constructing additional lateral restraints in the form of a V or and X, to support the panels as discussed in Section 7.4.

7.2.5 Laying Techniques

A laying order that maintains an open face is stipulated in BS 7533- Part 7, which also requires that line and level are checked using where necessary string lines across the work.

In straight -line bonds herringbone and stretcher, string lines should also be used to ensure joints display straight line along the centre line of the joints. Given the variation in the width of units it would be impossible to achieve straight lines along the edge of the units themselves.

Guidance

Surface Patterns for stone surfaces must be chosen to meet location and construction criteria as well as appearance. Patterns enhance interlock between the stone units, which is crucial in flexible construction. BS 7533- Part 7 requires that certain patterns are used under particular loading conditions where a flexible constriction is used.

Suitable patterns include stretcher bond, herringbone bond and arc or bogen bond.

Stretcher bond pattern should only be used with units where the length is larger than the width and are not suitable for cubes. Rows in the pattern should always be at right angles to the direction of vehicular flow. Stretcher bond will generate a low to moderate degree of interlock.

Similarly, herringbone can be used only with units where the length is twice the width. Herringbone patterns will generate a moderate to high degree of interlock but when setts are being used, require very rigorous selection of units by a skilled layer.

Cubes should be laid in curved patterns described as Bogen or arc pattern in vehicular trafficked areas.

Where abnormal stresses occur such as stop/start, inclines, junctions, consideration should be given to changing the laying pattern or increasing the structural capacity of the pavement by introducing deeper, more stable elements. In either case consideration should also be given to introducing extra lateral restraints within the pavement.

7.3 Flexible Construction – Deeper stone units

7.3.1 Categories of Flexible Construction

As discussed earlier in Sections 2 and 4 flexible pavements are stabilised through friction and interlock. The elements are bedded into a laying course of fine aggregate, and the same material is used to fill the joints between the elements. **The effect is to 'lock' the elements together by friction. The degree of interlock generated is influenced by surface pattern**. The laying course allows a smooth surface profile to be achieved with elements of varying depth and provides the initial stabilisation of the elements. Blinding the surface with fine aggregate fills the joints. Compacting the surface consolidates the fine aggregate within the joints and laying course, generating friction between the materials. As surface loading increases, both vertically from axle weight and horizontally through traction, so deeper elements are required that can mobilise greater element 'lock-up' and produce greater resistance to displacement, greater layer stiffness, and greater resistance to flexing.

BS7533 Part 7 defines two categories of Flexible Construction depending on the sett type, one using sawn sided units with tight joints and one using cropped or sawn units with wider joints.

7.3.2 Sawn & Textured Sided Units Laid as Block Pavers

The first category uses sawn stone units, which have had the faces re-textured. Joints widths of 2 to 4mm are stipulated. This method is akin to the laying of concrete or clay pavers and it is thought that when laid in accordance with the relevant parts of BS 7533 this type of surface will sustain heavy loading.

This is not a traditional form of stone surfacing, most likely because of the high cost of manufacturing stone units to the very strict tolerances required. BS 7533 Part 7 permits length, width and diagonal tolerances of +/- 3mm. If stone units are not specially made then stringent pre selection of the units into very small width ranges will be required in order to form the joints, which will also increase the costs.

The procedure for constructing this form of surface is that the laying course is prepared with the predetermined surcharge; the units are laid and tapped lightly into position; the joints are filled; and the whole construction is compacted using a plate vibrator to achieve full compaction of the laying course at the final level of the surface. It is necessary to carry out site trials to determine the compactibility of the laying course materials as discussed in Section 6.

7.3.3 Cropped or Sawn & Textured Sided Units Laid in Traditional Manner

The second category ***cropped or sawn & textured sided units*** is sometimes called "dry bound" stone surfacing. This second category, which is a traditional form throughout Europe, has been found operating under all loading categories. As discussed in Section 4, after the review of their average performance, reinforced by testing undertaken for this Guide, the conclusion is that if designed using the Design Life method then these constructions are only capable of carrying the two lighter loadings. If this type of pavement is to be used under heavier load categories then it must be subject to a full analytical design with associated trials and test to prove its capabilities.

In terms of construction of the surface, the less precisely formed edges of cropped units need wider joints, which should be on average 10mm but lie in the range of 10mm to 15mm.

Sawn &Textured units have the sawn faces re textured to remove the polished surface created by sawing. This is required to ensure frictional interlock with the fine aggregate joint materials. When sawn and textured units are used in the second category of surface, the dimensional tolerances need not be as stringent as for the first category, but some pre-selection of the stone may be needed to achieve the patterns specified.

The laying course is prepared as above with the pre-determined surcharge; the units are laid and hammered into the layer to achieve an initial compaction of the bed but also for the bedding to grip the units; the joints are filled; and the whole construction is compacted using a plate vibrator to achieve full compaction of the laying course at the final level of the surface

B7533 Part 7 notes that skill and experience on the part of the paver is required to ensure that the laying course material is compacted to uniform density and final surface levels are within tolerance.

7.3.4 Support structure for Flexible Construction

The support structure must be compatible with the surface layer; i.e. a flexible surface layer requires a flexible support structure.

Experience has shown that the load response of a rigid support structure, such as that formed by a thick concrete layer is not compatible with the load response of a flexible surface. In this condition the fine aggregate of the laying course is prone to crushing; and vibration under loading can destabilise the surface layer through the unpacking of the aggregate in both joints and laying course.

The overall thickness of construction required including the support structure is prescribed by BS 7533 Part 10 and is described in Section 4. The requirements for laying the support structure are listed in BS 7533 Part 7 as: -

- Provide an adequate construction platform
- Surface levels are within the tolerances given in annex B
- Longitudinal fall and crossfalls of the of the completed pavement allow water to drain avoiding ponding as detailed in annex F
- The roadbase regulating layer and/or sub base is adequately compacted to achieve density
- Provision is made to stop the fine aggregate of the laying course migrating to the drainage systems
- The extent of site preparation includes for the provision of adequate foundation and backing for any edge restraint
- Any trenches across the works should be permanently re-instated to prevent local settlement

The sub-grade needs to provide an adequate surface for compaction of the sub-base and it will not do this unless it has a CBR value of at least 2 percent (TRL Application Guide, 1997). This will be the case in most instances. However, if the sub-grade is silt, or if it is sandy or plastic clay and construction conditions are poor, the CBR may be less than 2 percent. In such cases ground stabilisation or use of a capping layer is appropriate. A geosynthetic separator may be useful during construction to carry construction traffic but it should be noted that its use will not improve the CBR value of the sub-grade, and consideration should be given to installing a capping layer.

Typical flexible support structures are formed using a graded stone aggregate. In such cases it is essential that the material is compacted in accordance with Series 800 of the Manual of Contract Documents for Highway Works (MCHW) as detailed in Section 6. Where a higher stability and strength is required, a bituminous bound aggregate can be used.

Annex B of the BS 7533 Part 7 gives the tolerances for different layers of the support structure and the maximum permissible deviations from design level, when measured over a 3m grid, of each layer from the required finish datum these are given in Figure 7.4.

Tolerances in levels are influenced by the size of aggregate included in the sub base or roadbase layer. A smaller aggregate size allows tighter tolerances to be achieved. Therefore consideration should be given to specifying the smallest aggregate size possible for these layers. The use of a lower and upper sub base or roadbase construction, where the upper layer has a smaller aggregate size may also assist in achieving tolerances.

Surface layers formed by elements stabilised using fine rock aggregate, are water permeable, particularly in their early life. The supporting structure should also be permeable, or the laying course aggregate made adequately permeable, to avoid damage resulting from moisture becoming trapped under the surface layer leading to a build up of pore water pressure.

Where frost penetration is likely to occur, moisture should not be able to be trapped anywhere in the surface, laying course or support layer, or in extreme cases, within the foundation. In such conditions all layers of the construction within the frost zone should be made permeable and adequate positive drainage provided.

To ensure the surface water is removed efficiently from the surface and to avoid ponding, the falls given in Figure 7.5 should be used.

FIGURE 7.4 TOLERANCES FOR PAVEMENT LAYERS

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

FIGURE 7.5 FALLS FOR DRAINAGE

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

Note 1 Some materials can be laid on slopes steeper than these gradients, but as most paved areas are shared with pedestrians they would be considered to be un-walkable, 8% is considered to a comfortable maximum.

Note 2 To ensure positive drainage, the finish level of the paving to the top surface of drainage inlets and channel should be minimum of 5 mm. This is important to avoid ponding around drainage inlets or channels.

Note 3 In large paving areas, it is important to consider the resultant fall from the combination of cross fall and longitudinal fall. Large areas need to be divided into panels, which can be drained particularly where levels are constrained by edges of buildings etc.

The gradient given in the above table relate only to requirements for drainage The actual gradients adopted for a pavement will take account of other factors such as use by the disable.

It is critical that all support materials (roadbase and sub-base) are compacted to ensure uniform support for the surface layer. Where this is not achieved, traffic loading will cause residual movement in the support layers, leading to deformation and a loss of surface profile.

These tables above do not however incorporate the most important guidance, which is that the profile of the surface of the support structure should follow the intended profile of the finished surface layer to within a tolerance of no more than 5mm over a 3m length in any direction. (Figure 7.4)

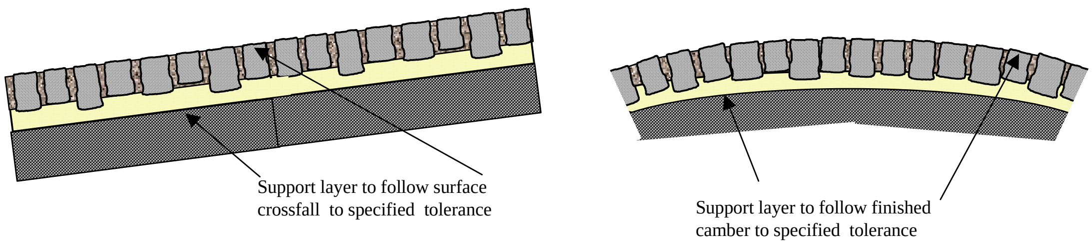


Figure 7.6 Profile of support structure

It is vital to control the level of the surface of roadbase otherwise the load bearing capacity and life of the pavement will be compromised. If the roadbase is too high the finished surface profiles will not be achieved to tolerance; if too low then the thickness of laying course will increase leading to uncertain compaction of the material. Similarly, if the roadbase level is variable, the thickness of the laying course will vary resulting in a non-uniform distribution of loading on the pavement surface

The fact that stone units vary in depth also has to be taken into account. This variation can also produce variations in the thickness of the laying course. Therefore, this guidance on achieving tolerances and following surface profiles has to be read in conjunction with the guidance on stone specification, selection for size on site, and methods of compaction. All of these factors can lead to variable laying course thickness and can combine to prevent the consistency of compaction needed if the laying course is to support the load for the length of the design life.

Guidance

The support structure must be compatible with the surface layer; i.e. a flexible surface layer requires a flexible support structure.

Adequate compaction of support materials is critical to ensure a uniform support for the surface layer.

The profile of the surface of the support structure should follow the intended profile of the finished surface layer to within a tolerance of no more than 5mm over a 3m length in any direction

7.3.5 Laying Course for Flexible Construction- Deeper stone units

The laying course allows a smooth finished surface profile to be achieved with elements of varying depth (Figure 7.7), and it provides the initial stabilisation of the elements. The laying course should not be too thick or too thin. There should be a maximum compacted layer thickness of 30mm when used with small cubes (less than 80mm) and 50mm with large cubes and setts, as required by the structural design tables in Section 4.

As described above it is vital that the variation in depth is minimized. This can be achieved by pre selection of units, and good level control of the support layer. Stone element size tolerance is dependent on traffic use and guidance is given in Section 3, and in Section 6.

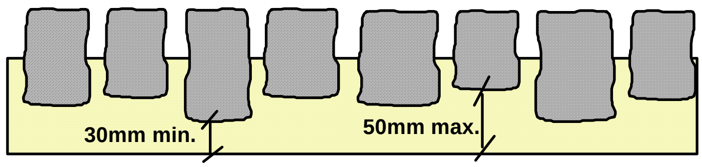


Figure 7.7 Laying Course thickness for setts

BS 7533 Part 7 gives two specifications for fine aggregates that can be used as laying course materials in Flexible construction depending on the texture of the face of the stone unit.

1 Fine aggregate for use with sawn side setts (e.g. sandstone)
Naturally occurring sand from the Quaternary geological series or sea dredged sands should be selected and graded according to use as given in Annex C Table C.1.

2 Fine aggregate for use with cropped side setts (e.g. granite)
Crushed igneous rock should be selected as given in Annex C Table C.2.

The grading for materials for sawn setts are given in Figure 7.8; for cropped setts the grading are given in Figure 7.9.

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

Figure 7.8 Fine Aggregate Grading for Sawn Setts

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

- The laying course should contain no cementitious material, which may detract from the flexible nature of the pavement
- The aggregate grading should be permeable to avoid the danger of pore water pressure build-up under trafficking.
- The laying course should have a depth to maximum aggregate particle size ratio of at least 6, e.g. minimum-compacted layer of 30 mm using 5mm aggregate.

Figure 7.9 Fine Aggregate Grading for Cropped Setts

7.3.6 Optimum Moisture Content for Laying Course Materials in Flexible Construction

As discussed above achieving consistency of compaction of the laying course is vital to the structural performance of a flexible pavement. Consistency of compaction is dependent on the moisture content of the aggregate for the laying course. This has to be determined for each aggregate by test

Flexible construction is sometimes termed "Dry Bound " but in fact the fine aggregates should not be dry but should be maintained at optimum moisture content for compaction. A protocol for laboratory tests to assess the compaction requirements of a fine aggregate is described in *Section 6.*

During construction, the materials must be moist but should not be saturated before or during laying. Before laying stockpiles should be covered. If the material becomes wet during laying it should be removed and dried before reuse.

The laying course is initially laid loose and requires a surcharge on its depth, to allow for effects of compaction. The degree of surcharge can be used as a site control as an alternative to measuring moisture content. Site trials are needed to calibrate the exact height of the surcharge required to achieve the degree of compaction required. These trials must use the aggregate and stone units specified. As a guide, 20 percent of the compacted height is typical.

BS 7533 Part7 does not deal with the laying course for a flexible construction using flagstones or slabs. It is considered that the gradings given above or for the fine aggregates used for the laying course for concrete blocks are appropriate.

Again consistent compaction of the layer is vital. Knowledge of the moisture content and compaction characteristics of the fine aggregate is critical and should be established by on site tests. The moisture content of the material should be maintained during construction operations

In all cases the fine aggregate laying course should be permeable to avoid flushing out of the finer aggregate particles, which will result in the subsequent loss of support to individual elements.

Guidance

A range of aggregate gradings suitable for use in laying courses in Flexible Surfaces are stipulated in BS7533 Part 7.

The moisture content of the laying course aggregate during compaction should be at, or close to, optimum, as determined by laboratory tests prior to construction.

The degree of surcharge can be used as an alternative to measuring the moisture content provided the height of the surcharge is calibrated to the degree of compaction in site trials prior to and during construction.

7.3.7 Jointing Materials for Flexible Construction – Deeper stone units

The materials for the aggregate used to fill joints prior to surface layer compaction for each of the two categories of flexible surfacing are stipulated in BS 7533 Part 7 and Section 6.

For sawn sided units where the joints are 2-4mm wide Annex C Table 1 of BS 7533 Part 7 gives the grading of naturally occurring sand from the Quaternary geological series or sea dredged sand; these are given in Section 6 of this Guide.

The use of sawn sided units with tight joints is akin to using block pavers. Laying methods are similar to those used in concrete and clay blocks and are described in BS7533 Parts 1, 2 & 3 and in the extensive literature on that type of paved surface.

For cropped or textured sided units where the design joint width is 10-15mm, Annex C Table 2 of BS 7533 Part 7 gives the grading of twice crushed igneous rock; these are given in Section 6 of this Guide.

Traditional dry bound sett surfacing uses cropped or textured sided units with a joint width of 10-15mm. **Emphasis must be placed on ensuring consistency of joints widths which will determine if the joint material will be consistently and fully compaction. This is critical to the structural performance of the whole pavement.**

With Bogen or Arc patterns it is inevitable that joint widths will vary. This can be minimised by employing skilled layers who know how to pre-select units in order to achieve the required degree of consistency in the joint widths. The tolerances for joint widths are given in BS 7533 - Part 10, and earlier in Section 4 Tables 4.3 and 4.4 of this Guide. In all cases it is very important that paving units should not be touching.

A flexible stone surfacing requires joints to be topped-up in its early life with additional aggregate as the system ‘shakes-down’ and ‘stiffens up’ under traffic loading. BS7533 Part 7 requires that the surface is inspected regularly and additional material complying with the original grading is brushed in.

This is particularly relevant with deeper stone elements as it is difficult to provide adequate energy at the time of placing to ensure that the lower section of the joint is fully compacted and achieves full lock-up’ of the elements. In order to achieve full aggregate packing and generation of maximum joint friction consideration may be given to using a coarse aggregate grading that is close to single size, such as 2-5mm. The joint may be topped up with fine dust (0-3mm) to lock the top layers of the coarse aggregate particles, restrict particle movement and build layer stiffness. Where dust is applied, the surface is blinded and washed with a fine water spray. Alternatively, air borne dust will be washed into, and continue to fill the joint aggregate throughout the early life of a paved area.

With deep stone elements full final compaction is commonly achieved by traffic action as the elements ‘rock’ under tyre action. When the small voids within the joint aggregate have been filled with dust and the pavement is then subject to traffic action, a level of friction is created that can achieve measured values of shear stress of $0.1 N/mm^2$, or 100kPa, which are similar to the values of shear stress achieved in concrete block paving.

With small setts and cubes the joint materials should be of the full grading (0-5mm) since it is practicable to apply sufficient energy by vibrating the surface to achieve the full compaction and the necessary lock-up during construction. As before final lock up will occur after trafficking. It will also be necessary to top up the joints during this process.

Joints are subject to loss of materials by the action of mechanical sweepers, wash out by surface water or suction from high-pressure tyres. BS7533 Part 7 allows for the application of surface coatings to inhibit the unwanted removal of joint material. Such coatings may have the added benefit of reducing the ingress of surface water through the joint. However, surface applications may affect slip skid resistance and this should be ascertained by an in-situ trial. They may also affect the colour of the surface. Coatings should not be applied until after the shake down period when the joint may need to be topped up with material.

Another option that can potentially protect against the loss of materials from the surface and reduce the maintenance requirement of a flexible surface in relation to street cleaning regimes is the use of a fine aggregate made from limestone. When compacted a limestone aggregate can create a "flexibly bonded" matrix, which will partially self-seal.

Guidance

A range of aggregate gradings suitable for use as joint material in Flexible Surfaces are stipulated in BS7533 Part 7 and are given in figure 7.8 and 7.9 of this Guide. Joints in flexible surfaces should not be filled with cement mortars whether cubes, setts, flagstones or slabs are being installed.

The moisture content of the fine aggregate during compaction should be at, or close to, optimum, as determined by laboratory tests before construction.

With Deeper stone units, consideration should be given to filling joints in a two-stage operation to ensure the joint materials are fully compacted.

Flexible stone surfaces require joints to be topped-up with additional aggregate in their early life, as the system 'shakes-down' and 'stiffens up' under traffic loading. Further topping up of joints may be required depending on traffic type, volume and environment.

Surfaces are prone to loss of material from the top of the joint due to the action of water, trafficking and certain cleaning activities. After the initial shake down period, consideration should be given to sealing the surface.

7.3.8 Restraints

Restraints along the outer edge and intermediately within the surface are critically important in a flexible pavement construction. They are required to resist the horizontal forces and thus allow required interlock to be generated between the units.

7.3.9 Edge restraints

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. A sloping face on the restraint might allow the units to ride up the face of the edge under the action of imposed loads.

Consideration of the details at the intersection of a sett pavement and asphaltic/bituminous construction is required. The different responses of each material under load might cause differential movements at their junction. This movement might induce a failure in both materials but is likely to affect the sett surface more, causing units to become loose. A concrete log should be installed along the edge of the stone surface with its surface set below the surface level to accommodate the wearing course of the asphaltic/bituminous surface.

It is most important that edge restraints have sufficient mass to withstand the horizontal forces generated in the loaded pavement. Experience has shown that a kerb and concrete haunch equivalent to 0.1m3 per metre run of kerb provides the mass required. This can be provided through stone or concrete kerbs, deep stone channels or by setting units themselves in concrete. In each case, the units should be well secured with a concrete log and haunching.

7.3.10 Intermediate Restraints

Where a surface is in a normal road then the horizontal restraining forces required to generate interlock will be provided by edge restraints only. On larger open areas such as car parks or pedestrian squares, intermediate restraints must be provided.

There are a number of other complementary factors, which should be considered when considering intermediate restraints. Surface drainage often requires large areas to be broken down into discrete panels to produce cross-falls and drainage channels. Large areas will have to be constructed in discrete panels using temporary screed rails to install the laying course to line and level. Intermediate restraints may also be required on steep slopes in the order of 6% to 10%. This is particularly relevant to Flexible Construction not only to prevent downhill creep but also to safeguard against wash out of the joint materials by fast flowing surface water. These factors suggest that any intermediate restraints are detailed in the form of a drainage channel or a surface feature.

Experience has shown that a panel width of 15m across the general flow of traffic meets the combined requirements of surface drainage, buildability and restraint and this is confirmed in BS 7533 Part 7, which states that maximum spacing of intermediate restraints where they are required is 15m.

7.3.11 Temporary Restraints

BS 7533 Part 7 notes that during construction temporary restraints are required to prevent the surface from moving when it is being compacted under vibration. Temporary restraints are also required if the unfinished surface is to be trafficked by construction vehicles or left open at the end of a working period. Normally temporary restraints are in the form of temporary screed rails. An alternative is to extend the surface by a metre beyond the area to be compacted, with this un-compacted section being lifted, re-laid and compacted in subsequent operations.

Guidance

A robust support must be provided at all edges of a flexible pavement construction. A kerb and concrete haunch equivalent to 0.1m3 per metre run of kerb provides the mass required.

In Flexible Construction consideration should be given to intermediate restraint on large areas and on steep slopes. Where they are required, the maximum spacing of intermediate restraints is 15m apart.

Temporary restraints are required at day joints during construction of the surface.

7.4 Methods of Laying Flexible Construction – Deeper stone units

BS 7533 Part 7 describes the methods of laying each of the two categories of flexible surfacing as follows:

7.4.1 Extract from BS 7533 Part 7

7.3.2 Flexible laying

7.3.2.1 Sawn sided setts

When laying on a sub-base or roadbase the target laying course thickness after unit compaction should be 40 mm.

The laying course is prepared by spreading the loose material in a uniform layer, and screeding it to the thickness required, including the surcharge to give the specified design thickness after the units have been laid and vibrated into place.

Where previous experience of a particular material is lacking, a small trial area is needed to determine the surcharge.

Following careful removal of the screeding rails, the disturbed area should be filled and re-screeded with laying course material.

The area of laying course prepared should generally be such that at the end of a working day its boundary is not less than 1 m ahead of the laying face.

All areas of prepared laying course material should be protected and not left exposed overnight.

The units are laid with a joint width typically between 2 mm and 4 mm. The joint width is influenced by the unit shape and the laying pattern. The width of the joint should not include the chamfer dimension (if any).

The units are laid onto the laying course by each unit being tapped to line and level. Before final compaction joint filling material is brushed in and then a plate vibrator used as described in Para 9 to compact until refusal. The joints should be totally filled with jointing material.

The laying course material is spread loosely and is adjusted for each sett individually to ensure that after hammering into position of each sett, the correct line and level including surcharge is achieved.

The skill of the layer ensures that the laying course material achieves uniform density.

7.3.2.2 Cropped or textured side setts (e.g. granite)

The setts should be laid with a nominal joint width of 10mm, with a maximum width of 15 mm. After the setts have been tapped into position the laying course material should rise up the joint to hold the sett in place.

The joint filling material is swept into the joints filling it completely and the units compacted down to refusal using a plate vibrator as described in Para 9. The fine topping aggregate is spread over the surface to a thickness between 5 to 10mm and to ensure the joints are completely filled, the surface is sprayed with a fine water spray to wash the material into the joints.

Note: Dry sand and cement mixtures should not be brushed into the joint as this is not durable and has poor adhesion properties.

7.3.2.3 Additional work after early trafficking on Flexible surfaces

The surface course should be inspected soon after completion and at regular intervals thereafter and additional material brushed in, where necessary.

Joints gradually become semi-impervious due to the sealing effect of accumulated dust etc. Until this has occurred the paving should only be brushed by hand. Mechanical sweepers and in particular sweepers with high suction forces should not be used, or used with care to avoid the risk of losing the jointing sand from between the paving units which will affect the performance of the construction.

When the joints needs to be stabilised, surface applied coatings may be applied in strict accordance with the manufacturers instruction. This treatment inhibits the unwanted removal of jointing material by suction cleaners and at the same time helps to prevent the ingress of water through joints. This treatment may effect on the colour of the surface of the paving unit and initially its slip/skid resistance.

End of extract

Guidance

The emphasis in laying must be on achieving consistency in width of joint and depth of laying course, because this will ensure a consistent degree of compaction of the joint and laying course materials.

Materials should be used at optimum moisture content for compaction.

It is also important to ensure the joints are fully filled.

Skilled labour is essential to ensure a flexible surface is laid correctly in terms of pre-selecting the units, assessing the surcharge required on the laying course, placing the units in the selected pattern to tolerances achieving consistency of compaction and filling the joints.

7.5 Rigid Construction – Deeper stone units

7.5.1 Categories of Rigid Construction

BS 7533 Part 7 defines two primary categories of rigid construction depending on the joint type; one is a moist mix of fine concrete and one is a plastic mix of fine concrete.

The categories are not based on sett type because only cropped or sawn and textured stone units are recommended for use in rigid pavements. Sawn units, which have not had the faces re-textured, are not recommended in rigid construction. The surfaces should be textured by ‘picking’ or shot/sand blasting as described in Sections 3 and 4. Each type of joint mix may be used with either cropped or sawn and textured units.

7.5.2 Surface elements stabilised through cement binding

Rigid pavements are generally stabilised by the setting action of the fine concrete joint material. It is thought in a rigid pavement that the shear strength at the interface between the unit and the joint material is the primary source of resistance to load. Higher surface loading, both vertical from axle weight and horizontal through traction, requires larger elements that can mobilise greater shear capacity in the pavement. This can create greater resistance to displacement and greater layer stiffness, which in turn increases the resistance to flexing. Normal or unmodified fine concrete does not develop high tensile capacity, typically in the range of 0.7N/mm for standard mortars. Additionally adhesion values are low when used with stone materials. Research is underway to examine modified fine concrete and polymer bound materials, which will provide higher tensile strength and better adhesion. These contemporary materials also have an added advantage that they set and cure much faster, cutting time to trafficking from 28 days to 2-3 days. Their disadvantage is their higher cost.
The action of the laying course is thought to be of secondary importance in terms of overall load capacity, however it is vital to provide resistance to punching shear from concentrated loads.

It should be remembered that the apparent strength of the cementing action of fine concrete should not be seen as a substitute for the stability that must be achieved through full compaction of the concrete. Consistency of compaction is vital to the performance of the pavement under load. **Semi – dry concrete should not be used** in either the joint or the laying course, as the cement will not fully hydrate and the concrete will not compact in a consistent manner. The optimum moisture content for fine concretes is discussed later in this section and in Section 6.

Guidance

Rigid Construction pavements are stabilised by the setting action of the fine concrete joint material. Shear and adhesion between the units and the joint materials provide the primary resistance to load. The Laying Course provides resistance to punching shear.

Unmodified fine concrete has low values of tensile strength and adhesion with stone. Current research is examining contemporary materials with enhanced tensile, adhesion and curing properties.

Consistency of compaction of the fine concrete in joints and laying course is vital to structural performance. Concrete should be used at optimum moisture content.

7.5.3 Support structure

The support structure must be made compatible with the surface layer; i.e. a rigid surface layer should be supported on a rigid or very stiff support structure. If a rigid surface is laid over a flexible sub structure then the pavement will flex to such a degree that tensile stresses will be induced. These will overstrain the bond between the units and the joint material or the joint material itself.

BS 7533 Part 10 determines the overall thickness of construction for the intended use, including the support structure based on the CBR of the sub grade refer to Section 4. BS 7533 Part 7 lists requirements for the laying of the support structure: -

- Provide an adequate construction platform
- Surface levels are within tolerance given in annex B (refer table 7.3)
- Longitudinal fall and crossfalls of the of the completed pavement allow water to drain avoiding ponding as detailed in annex F (refer table 7.4)
- The roadbase regulating layer and/or sub base is adequately compacted to achieve density
- Provision is made to stop the sand laying course migrating to the drainage systems
- The extent of site preparation includes for the provision of adequate foundation and backing for any edge restraint
- Any trenches across the works should be permanently re-instated to prevent local settlement

The sub-grade needs to provide an adequate surface for compaction of the sub-base and it will not do this unless it has a CBR value of at least 2 percent (TRL Application Guide, 1997). This will be the case in most instances. However, if the sub-grade is silt, or if it is sandy or plastic clay and construction conditions poor, the CBR may be less than 2 percent. In such cases ground stabilisation or use of capping layer is appropriate. A geosynthetic separator may be useful during construction, to carry construction traffic but it should be noted that its use will not improve the CBR value of the sub-grade, and consideration should be given to installing a capping layer.

There are a variety of sub-structures and these may be combined to form the support structure.

Cement bound road-base

These are generally used in the form of un-reinforced or reinforced slabs. With these cement-stabilised bases, expansion and contraction of the layer requires to be considered. Reference should be made to the relevant standard and specifications for concrete roads for guidance.

Contraction joints should be detailed into the roadbase at 8-10m centres. . Contraction joints may be created by a ‘crack inducer’ placed under the roadbase

Expansion joints, where required, should be located every third joint. With a pavement quality roadbase, dowel bars should be considered across the expansion, contraction and construction joints to ensure shear continuity.

Bituminous bound aggregate systems.

The sub-base and or road base must be stiff and made with a low viscosity binder. The material should be specified in accordance with Figure 4.13.
Reference should be made to the relevant standard and specification for guidance.

With such low viscosity care is required to ensure that full aggregate packing through the compaction process is achieved to avoid secondary compaction under traffic load.

Cement-stabilised aggregate sub bases

These are the most used support layers in continental Europe. They are made permeable in locations where frost damage is possible.

Again reference should be made to the relevant standard and specification for guidance.

Combinations of these might be considered, for example where frost resistance requires that the support structure is deeper than required for purely structural reasons, a cement bound aggregate layer might be laid below a concrete slab.

Annex B of the BS 7533 Part 7 gives the tolerances for different layers of the support structure and the maximum permissible deviations from design level, when measured over a 3m grid of each layer from the required finish datum these are given in Figure 7.10.

Tolerances in levels are influenced by the size of aggregate included in the sub base or roadbase layer. A smaller aggregate size allows tighter tolerances to be achieved. Therefore consideration should be given to specifying the smallest aggregate size possible for these layers. The use of a lower and upper sub base or roadbase construction, where the upper layer has a smaller aggregate size may also assist in achieving tolerances.

Supporting structures should be permeable, to avoid damage resulting from moisture becoming trapped under the surface layer leading to a build up of pore water pressure.

Where frost penetration is likely to occur, moisture should not be able to be trapped anywhere in the surface, laying course or support layer, or in extreme cases, within the foundation. In such conditions all layers of the construction within the frost zone should be made permeable and adequate positive drainage provided.

To ensure the surface water is removed efficiently from the surface and to avoid ponding, the falls given in Figure 7.11 should be used.

FIGURE 7.10 TOLERANCES FOR PAVEMENT LAYERS

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

FIGURE 7.11 Falls for Drainage

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

Note 1 Some materials can be laid on slopes steeper than these gradients, but as most paved areas are shared with pedestrians they would be considered to be un-walkable, 8% is considered to a comfortable maximum.

Note 2 To ensure positive drainage, the finish level of the paving to the top surface of drainage inlets and channel should be minimum of 5 mm. This is important to avoid ponding around drainage inlets or channels.

Note 3 In large paving areas, it is important to consider the resultant fall from the combination of cross fall and longitudinal fall. Large areas need to be divided into panels, which can be drained particularly where levels are constrained by edges of buildings etc.

The gradients given in the above table relate only to requirements for drainage. The actual gradients adopted for a pavement will take account of other factors such as use by the disabled.

It is critical that all support layers are installed to ensure uniform support for the surface layer. Where this is not achieved, traffic loading will cause differential movement in the surface, leading deformation and a loss of surface profile.

These tables above do not however incorporate the most important guidance, which is that the profile of the surface of the support structure should follow the intended profile of the finished surface layer to within a tolerance of no more than 5mm over a 3m length in any direction. (Figure 7.12)

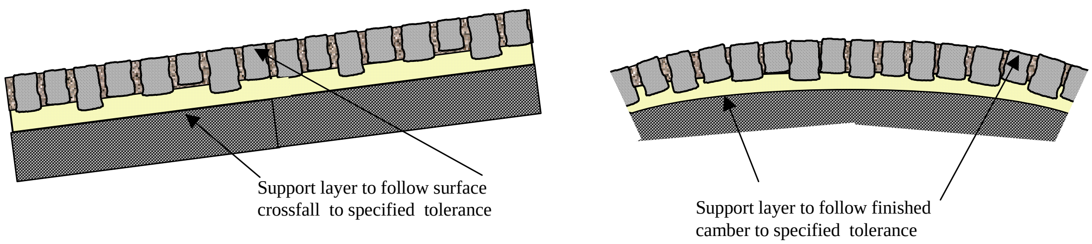


Figure 7.12 Profile of support structure

It is vital to control the level of the surface of roadbase otherwise the load bearing capacity and life of the pavement will be compromised. If roadbase is too high the finished surface profiles will not be achieved to tolerance; if too low then the thickness of the laying course will increase leading to uncertain compaction of the material. Similarly, if the roadbase level is variable, the thickness of the laying course will vary resulting in a non-uniform distribution of loading and the pavement surface will deform.

The fact that stone units vary in depth also has to be taken into account. This variation can also produce variations in the thickness of the laying course. Therefore, this guidance on achieving tolerances and following surface profiles has to be read in conjunction with the guidance on stone specification, selection for size on site, and methods of compaction. All of these factors can lead to variable laying course thickness and combine to prevent the consistency of compaction needed if the laying course is to support the load for the length of the design life.

Guidance

The support structure must be made compatible with the surface layer; i.e. a rigid surface layer should be supported on a rigid or very stiff support structure.

With cement-stabilised roadbases, expansion and contraction of the support structure requires to be considered.

Bituminous roadbases need to be well compacted to avoid secondary compaction under traffic.

The profile of the support structure should follow the intended profile of the finished surface layer to within a tolerance of no more than 5mm over a 3m length in any direction.

7.5.4 Laying Course for Rigid Construction – Deeper stone units

The laying course plays a very important role in a rigid construction. It ensures that the surface layer has adequate direct support, and that composite action is achieved with the lower construction. It allows small variations in the depth of the units to be accommodated. As discussed above the thickness of the laying course is critical to the stiffness of the direct support provided to the surface layer and should be a maximum compacted thickness of 30mm with small cubes (less than 80mm) and 50mm with larger cubes and setts. The layer should also be made permeable, particularly in climates that result in a depth of frost penetration. Variations in the thickness of the laying course can be minimised by the skill of the layer, pre-selection of stone units and good level control of the substructure as described above.

BS7533 Part 7 gives two specifications for the laying course materials in Rigid Construction: -

Fine Concrete

Moist mix
A mixture of crushed rock conforming to Annex C of Part 7, comprising 5 mm all-in grading and Portland /PFA cement or Portland blast furnace cement to produce a moist concrete.

Plastic mix
A mixture of crushed rock conforming to Annex C of Part 7 comprising 5 mm all-in grading and Portland /PFA cement or Portland blast furnace cement to produce a plastic concrete.

For both specifications the strength range is 15 to 30 N/mm2, when cured in water at 20' C for 28 days.

BS 7533 also describes **Modified Fine Concrete** i.e. concrete, which has been modified to enhance its properties. However there is no guidance on which characteristics or on the degree of enhancement. It is left to the designer to decide on the use of proprietary modifiers, which can be added to the formulation. This will usually require detailed discussions with the manufacturer.

Fuller specifications for fine concrete for laying courses in Rigid Pavements are given and discussed in Section 6.

The specifications given in BS 7533 Part 7are considered to be very prescriptive and appear to rule out the use of natural sand aggregates. There is some evidence that any well-designed fine concrete using sands with a maximum aggregate size less than 1/6th of the depth of the laying course, which has a degree of permeability, is acceptable. Further guidance on the design of laying course mixes can be found in Section 6.

The strength of the laying course is determined from the design tables and can be different from that of the joint materials. However specifying two concretes might lead to confusion on site and it is recommended that the strength of the laying course material is the same as the joint materials (refer Section 4).

As with any concrete the laying course materials must be compacted at their optimum moisture content. Cement-stabilised bedding should not be laid dry, or semi-dry, and wetted after the placement of elements.

For the **Moist mix** the correct water content can be assessed practically by being able to form a ball of the mixture in the hand and it should not exude moisture or collapse due to lack of cohesion.

For the **Plastic Mix** trial cubes should be made and tested in a laboratory to determine the water content required to produce a concrete with the consistency of a slurry but which will achieve the strength.

In both cases the laying course will require to be laid with a surcharge since the material will fill the lower part of the joint. The surcharge has to be determined by on site measurements of the fine concrete, refer to Section 6.

Guidance

The uniformity and thickness of the laying course is critical to achieving consistent compaction of the fine concrete and in turn to ensuring the stiffness of the direct support provided to the surface layer.

It should be compacted at its optimum moisture content. Dry or semi-dry mixes should not be used.

The fine concrete should have strengths required by the structural design but should be no less than 15N/mm2, however consideration should be given to specifying laying course materials to be the same strength as the joint materials to avoid confusion on site.

7.5.5 Jointing Materials in Rigid Construction- Deeper stone units

BS 7533- Part 7 stipulates that the material for filling the joints shall be a fine concrete grout in a slurry form designed to provide adhesion, non-shrink properties and suitable stiffness. It should have strength in the range of 10–40N/mm2 depending on the structural design requirements and a maximum aggregate particle size of 3mm.

There are no restrictions on the cement types but it is recommended that the specification for laying course material be adhered to i.e. Portland /PFA cement or Portland blast furnace cement.

In terms of the aggregate it is considered acceptable to use crushed rock or natural sand provided the characteristic properties given in Annex C2 of Part 7 are achieved.

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

There are a number of primary characteristics of the concrete that should be specified; strength, durability, shrinkage, workability, development of strength during curing and these are discussed in detail in Section 6

These primary characteristics must be achieved consistently during the construction process to ensure that the intended design life is achieved.

Joint tolerances

Joint tolerances are critical to the performance in Rigid Construction and are stipulated in BS 7533 - Part 10, and earlier in Section 4 of this Guide. **Emphasis must be placed on ensuring consistency of joints widths which will determine if the joint material will be consistently and fully compacted and achieve even distribution of the stresses in the joints and at the bond between the concrete and the stone faces. This is critical to the structural performance of the whole pavement.**

The importance of achieving the "design" joint width is discussed fully in Section 4. Where joints are out of tolerance, the capacity and design life of the surface will be reduced.

This is why Bogen or Arc patterns are not recommended in Rigid Pavements because it is inevitable that joint widths will vary.

The variation in joint width can be minimised by employing skilled layers who know how to pre-select units in order to achieve the required degree of consistency in the joint widths. In all cases it is very important that paving units should not be touching. The need to pre-select units into size ranges before laying as a precursor to achieving the construction tolerance required is discussed earlier.

Joints should be filled with fine concrete to the specified depth. The faces of the stone units should be pre-wetted to ensure full interface contact between the concrete and the units.

Guidance

With cubes, setts and blocks the depth, strength and width of joints will be the primary factors controlling resistance to loading. If joints are out-with the tolerances required for the design then the load bearing capability of the pavement will be severely reduced.

Pre-selection of units may be needed to ensure joints are within tolerances.

Fine concrete for filling the joint should be specified to fill a defined depth of joint and must be used at optimum moisture content to ensure full and consistent compaction.

Time to opening to traffic can be an issue with a rigid construction. A minimum compressive strength of joint material requires to be defined that defines time to first loading. This is loading category specific (see Section 4, Table 4.17). If early loading is to be considered either specify a higher strength concrete or a high performance quick curing proprietary material. In both cases the rate of strength gain must be checked. Taking small insitu cores from the laid surface and testing these in a laboratory is recommended.

7.5.6 Restraints in Rigid Construction

Restraints along the outer edge and intermediately within the surface are only required in structural terms in Rigid Construction if the sub base or road base is bituminous or asphaltic where horizontal forces are resisted by interlock in the base layer. Where cementitious binding is used then such restraint is a secondary support.

However restraints are important in building the pavement to tolerance for surface profile and drainage. Thus BS7533 Part 7 applies the same requirements for restraints in Rigid Construction as it does for Flexible Construction. The guidance given earlier in this section for flexible pavements is repeated here with some amendments for Rigid Construction.

7.5.7 Edge restraints

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. A sloping face on the restraint might allow the units to ride up the face of the edge under the action of imposed loads.

Consideration of the details at the intersection of a sett pavement and asphaltic/bituminous construction is required. The different responses of each material under load might cause differential movements at their junction. This movement might induce a failure in both materials but is likely to affect the sett surface more, causing units to become loose. A concrete log should be installed along the edge of the stone surface with its surface set below the surface level to accommodate the wearing course of the asphaltic/bituminous surface.

It is most important that edge restraints have sufficient mass to withstand the horizontal forces generated in the loaded pavement. Experience has shown that a kerb and concrete haunch equivalent to 0.1m3 per metre run of kerb provides the mass required. This can be provided through stone or concrete kerbs, deep stone channels or by setting units themselves in concrete. In each case, the units should be well secured with a concrete log and haunching.

7.5.8 Intermediate Restraints

Where a surface is in a normal road then the horizontal restraining forces required to generate interlock will be provided by edge restraints only. On larger open areas such as car parks or pedestrian squares, intermediate restraints must be provided.

There are a number of other complementary factors, which should be considered when considering intermediate restraints. Surface drainage often requires large areas to be broken down into discrete panels to produce cross-falls and drainage channels. Large areas will have to be constructed in discrete panels using temporary screed rails to install the laying course to line and level. Intermediate restraints may also be required on steep slopes in the order of 6% to 10%. This is particularly relevant to Flexible Construction not only to prevent downhill creep but also to safeguard against wash out of the joint materials by fast flowing surface water. These factors suggest that any intermediate restraints are detailed in the form of a drainage channel or a surface feature.

Experience has shown that a panel width of 15m across the general flow of traffic meets the combined requirements of surface drainage, buildability and restraint and this is confirmed in BS 7533 Part 7, which states that maximum spacing of intermediate restraints where they are required is 15m.

7.5.9 Temporary Restraints

BS 7533 Part 7 notes that during construction temporary restraints are required to prevent the surface from moving when it is being compacted under vibration. Temporary restraints are also required if the unfinished surface is to be trafficked by construction vehicles or left open at the end of a working period. Normally temporary restraints are in the form of temporary screed rails. An alternative is to extend the surface by a metre beyond the area to be compacted, with this un-compacted section being lifted, re-laid and compacted in subsequent operations.

7.5.10 Movement Joints in Rigid Construction

The need for movement joints is discussed in Section 4 of this Guide.

A movement joint in the surface layer is required above any joint in the roadbase. Within the surface layer containment of the stone elements is critical at a joint. This may be achieved using stainless steel angle sections bolted to a concrete roadbase. An alternative detail is to use a low stiffness modulus polyurethane filled aggregate to fill the joints in the locality of the movement joint. The toughness of the polyurethane allows the roadbase to move and the joint remain sealed, whilst still providing adequate confinement to stone elements.

This can generally be accommodated in conjunction with an edge or intermediate restraint.

Guidance

A robust support must be provided at all edges of a flexible pavement construction. A kerb and concrete haunch equivalent to 0.1m3 per metre run of kerb provides the mass required.

In Flexible Construction consideration should be given to intermediate restraint on large areas and on steep slopes. Where they are required, the maximum spacing of intermediate restraints is 15m apart.

Temporary restraints are required at day joints during construction of the surface.

Movement joints should be considered in rigid pavements – where they are required they can generally be accommodated in conjunction with other forms of restraint

7.6 Methods of Laying Rigid Construction

7.6.1 Cubes Setts and Blocks in Rigid Construction

BS7533 Part 7 applies to cubes setts and blocks when laid as a Rigid Construction and gives thee basic types as follows

- Moist Mix Laying with Vibratory Compaction

This method may be referred to as "joint topping" construction and is suitable only for lightly loaded areas.

This is a two-part process. Firstly the units are rammed into a moist laying course that has a generous surcharge to allow the laying course materials to fill the joints initially from the bottom. Fine concrete is then put into the joint from the top. This is compacted using a plate vibrator. The joints are then raked back to a depth of 30mm to receive a topping of fine concrete slurry.

- Moist bed with full depth slurry

This method is sometimes referred to as the full joint method and is capable of carrying the highest loading categories.

Here the units are rammed into the moist laying course, which should not rise more than 15-20mm up the joint. The joints are then filled with the fine concrete, which must be self-compacting. The fine concrete can be applied in a variety of ways: -

- Pouring the grout over the area and brushing the material into the joints
- Pouring the grout into the joints through a nozzle
- Injecting the grout into the joints with a hand gun

- Plastic mix laying

This method is sometimes referred to as the "slurry joint" method and again is capable of carrying the highest loading categories.

Here the units are bedded in a plastic laying course with minimal surcharge, which is allowed to take an initial set. The area is then flooded with fine concrete grout to fill the joints

Care has to be taken with this method at the grouting stage so as not to dislodge the units which are only held in a thin laying course. Consideration should be given to boarding over the immediate work face to avoid disturbance.

The exact manner of laying as described in BS 7533 Part 7 is given in the following extract from the Standard.

7.6.2 Extract from BS 7533 Part 7

7.3.4 Rigid Laying

When laying on a roadbase, the target laying course thickness, after unit compaction, should be 40 mm for moist bedding and 25mm for plastic bedding.

Note: the use of dry or semi-dry mortar for bedding and jointing is not recommended. It leads to inadequate support, poorly filled joints and uncertain performance in-service.

Surplus mortar should be quickly removed. The surface of the unit should be wiped clean, with care being taken not to allow excess mortar to stain by entering the surface texture. Care must be taken to ensure the slurry does not choke or pollute drainage systems.

Mortar spot bedding should not be used

7.3.4.1 Moist mix laying with vibratory compaction

a) Moist bed with topping joint.

The moist laying course is spread out, including surcharge, and units rammed into place to partially compact the laying course. The laying course material should rise up in the joint to about halfway.

Additional laying course material is spread over the surface and brushed to completely fill the joint and final compaction is completed by vibratory compaction as detailed in Clause 10. The area is then soaked. Ensure that at least the joint finishes at least 30mm below the top surface before re-grouting to fill the joint completely. The joints may be left open for a period of time before grouting takes place.

b). Moist bed with full depth slurry joint

This method is particularly dependent on the skill of the installer.

The moist laying course is spread out, including surcharge, and units rammed into place to partially compact the laying course to a consistent degree. This is dependant on the skill of the operator and the consistency of the moisture content of the laying course material. The laying course material should rise up in the joint to no more than 15 to 20mm, at this point do not attempt to fill the joint. The bed is allowed to cure to reach initial set, e.g. one day.

To fill the joint, the fine concrete jointing material in a flowable self- compacting grout should be applied to fill the joint in one operation. This can be by pouring the grout over the area, and using a squeegee or by using a can with a fine nozzle or injecting with a hand gun to fill the joints. Surplus grout on the surface must be kept moist until the grout has begun to set. When the jointing mortar has achieved its initial set (approximately 4 hours), the surface of the units is rinsed clean.

Note: where coloured grout is used particular care is required to prevent staining of the stone.

The area may be opened to traffic when the jointing material has achieved sufficient strength to withstand the traffic over-riding the pavement without causing failure. Guidance is given in BS 7533: Part 10. Strength may be measured by tamping the mortar into 100mm cube moulds and storing under wet hessian in the open close to the site.

7.3.4.2 Plastic mix laying

Spread out the bedding layer with the surcharge, the units are placed on the bed and tapped to final level. The bed is allowed to cure to reach initial set e.g. one day. The area is flooded with the grout ensuring the joint is fully filled. The surplus grout is removed from the surface.

The area should not be open to traffic until the bedding and jointing materials have achieved sufficient strength. Guidance is given in BS 7533: Part 10. Strength may be measured by tamping the mortar into 100mm cube moulds and storing under wet hessian in the open close to the site

7.3.4.4 Ascertaining strength of laying course and joint filling materials.

Strength of the material may be measured by producing samples made in a 100mm cube mould from actual mixes being used on site. These should be stored under wet hessian in the open, close to the site. The cubes should be tested to determine the strength of the insitu material at ages of 3, 7, 10, 14 and 28 days, this will depending on when opened for use.

End of extract

7.6.3 Cleaning of Rigid Surfaces after Joint Filling

The cleaning of surfaces after joints have been filled is critical to the quality of surface finish achieved with a paved area.

In all three methods joint material may be brushed or applied with a squeegee over the surface to fill the joints. The recommended way of cleaning is to keep the surface slightly moist while the joint material takes an initial set, then the material on the surface of the units can be wiped off by a light spray of water and squeegee. The grading of the fine aggregate is critical to effective 'wash-off' of surplus joint mortar.

One traditional method was to coat the surface with sawdust and brush this off. However there is some concern that the application of sawdust for surface cleaning can result in a loss of durability of joint mortar. If sawdust is to be used it should be applied wet.

Cleaning of surfaces is a critical environmental issue. Washing diluted mortar down drainage systems can result in loss of capacity and permanent damage to filter drainage systems. Therefore the method used should allow for the capture of excess materials for safe disposal.

With one proprietary mortar application system, surface mortar is removed by a machine that absorbs the surplus mortar onto a belt formed by a continuous sponge. Such equipment can have limited ability with highly textured cropped surfaces. The equipment is becoming more widely available.

An alternative approach is to lay elements with sawn top and bottom surfaces. After joint filling with a fluid mortar the whole surface is then sand or shot blasted to provide the surface texture and clean the surface efficiently. Shot blasting machines vacuum the fine surface material created in the blasting process. This method would preclude the need to treat the top of the units before laying and might be preferred as a way to give definitive insitu skid and slip resistance, particularly in areas of heavy braking.

High performance materials can also be applied by a hand held gun, or can be pumped under pressure through a wide bore needle. With care and skill no surface spillage should result with this process.

Guidance

The emphasis in laying must be on achieving consistency in width of joint and depth of laying course, because this will ensure a consistent degree of compaction of the joint and laying course materials.

Materials should be use at optimum water content for compaction.

It is also important to ensure the joints are fully filled.

Skilled labour is essential to ensure a rigid surface is laid correctly in terms of pre-selecting the units, assessing the surcharge required on the laying course, placing the units in the selected pattern to tolerances, achieving consistency of fine concrete mix, achieving consistency of compaction and filling the joints.

Flexible construction - Shallower stone units

7.6.4 Categories of Flexible Construction

BS 7533 Part 4 BS 7533 Part 4 - Code of practice for the construction of pavements of pre-cast concrete flags or natural stone slabs, which deals with the installation of these type of surfaces defines three basic categories of construction depending on the size of the stone units, the type of laying course and the width and material used in the joint: -

- Units over 450x 450 on mortar laying course with wide joints filled with mortar
- Units over 450 x 450 on mortar laying course with narrow joints filled with sand or lime mortar
- Units below 450x450 on sand laying course with narrow joints

Any of these categories may be used with a flexible or rigid type of sub base

It is important to note that part 4 of BS 7533 was published in 1998 before the research for this guide was underway and that it did not have the benefit of the results which indicate that combining inflexible mortars in either laying course or joints with flexible materials in laying courses or support layers is not good practice when pavements are to be subject to loading traffic. Therefore only construction forms in the third category where the various layers are compatible with each other is discussed below, other forms of construction are not considered.

7.6.5 Support structure

As discussed in Section 4, only Part 8 of BS 7533 published in 2003 which deals with the structural design of pavements built with shallow stone units, did have the results of the research to consider and implicitly suggests that flexible surfaces should be combined with flexible sub-bases when the pavement is to be subjected to vehicular traffic loadings. A primary recommendation of this guide is that the **support structure must be compatible with the surface layer; i.e. a flexible surface layer requires a flexible support structure.**

Experience has shown that the load response of a rigid support structure, such as that formed by a thick concrete layer is not compatible with the load response of a flexible surface. In this condition the fine aggregate of the laying course is prone to crushing; and vibration under loading can destabilise the surface layer through the unpacking of the aggregate in both joints and laying course.

The overall thickness of construction required including the support structure is prescribed by BS 7533 Part 8 as described in Section 4. The requirements for laying the support structure are listed in BS 7533 Part 4 as: -

- Provide an adequate construction platform
- Surface levels are within the tolerances
- Longitudinal fall and crossfall of the of the completed pavement allow water to drain avoiding ponding
- The sub base is adequately compacted to achieve density
- Provision is made to stop the fine aggregate of the laying course migrating to the drainage systems
- The extent of site preparation includes for the provision of adequate foundation and backing for any edge restraint
- Any trenches across the works should be permanently re-instated to prevent local settlement

The sub-grade needs to provide an adequate surface for compaction of the sub-base and it will not do this unless it has a CBR value of at least 2 percent (TRL Application Guide, 1997). This will be the case in most instances. However, if the sub-grade is silt, or if it is sandy or plastic clay and construction conditions are poor, the CBR may be less than 2 percent. In such cases ground stabilisation or use of a capping layer is appropriate. A geosynthetic separator may be useful during construction to carry construction traffic but it should be noted that its use will not improve the CBR value of the sub-grade, and consideration should be given to installing a capping layer.

Bs 7533 Part 4 specifies that either Type 1 or Type 2 granular sub bases complying with Series 800 of the Manual of Contract Documents for Highway Works (MCHW) as detailed in Section 6 can be used and stipulates the type of compaction plant and the number of passes per compacted layer thickness. Again it should be noted that the document was published in 1998 and that this form of method specification may be replaced with performance specification where the compaction is measured in terms of achieving a specified density.

Part 4 has no requirements for the tolerances of the sub base and it is recommended that the same tolerances given in Annex B of BS 7533 Part 7 be used. The tolerances for different layers of the support structure and the maximum permissible deviations from design level, when measured over a 3m grid, of each layer from the required finish datum these are given in Figure 7.4.

Where frost penetration is likely to occur, moisture should not be able to be trapped anywhere in the surface, laying course or support layer, or in extreme cases, within the foundation. In such conditions all layers of the construction within the frost zone should be made permeable and adequate positive drainage provided.

To ensure the surface water is removed efficiently from the surface and to avoid ponding, the falls given in Figure 7.14 should be used.

The gradient given in the tables relate only to requirements for drainage The actual gradients adopted for a pavement will take account of other factors such as use by the disabled.

It is critical that all support materials (roadbase and sub-base) are compacted to ensure uniform support for the surface layer. Where this is not achieved, traffic loading will cause residual movement in the support layers, leading to deformation and a loss of surface profile.

FIGURE 7.13 TOLERANCES FOR PAVEMENT LAYERS

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

FIGURE 7.14 FALLS FOR DRAINAGE

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

Note 1 Some materials can be laid on slopes steeper than these gradients, but as most paved areas are shared with pedestrians they would be considered to be un-walkable, 8% is considered to a comfortable maximum.

Note 2 To ensure positive drainage, the finish level of the paving to the top surface of drainage inlets and channel should be minimum of 5 mm. This is important to avoid ponding around drainage inlets or channels.

Note 3 In large paving areas, it is important to consider the resultant fall from the combination of cross fall and longitudinal fall. Large areas need to be divided into panels, which can be drained particularly where levels are constrained by edges of buildings etc.

7.6.6 Laying course for flexible construction in shallower units

Units below 450x450 laid on a sand laying course with narrow joints are considered an appropriate form of construction. The laying course should comprise naturally occurring sand with a grading which allows full compaction at optimum moisture content as given in Figure 7.15

Sieve size	Percentage passing each sieve	
Mm	Bedding Naturally occurring	Jointing
10	100	100
5	89 – 100	100.00
2.36	65 – 100	100.00
1.18	45 – 100	90 – 100
0.6	25 – 80	50 – 100
0.3	5 – 48	15 – 60
0.15	0 –15	0 – 15
0.075	0 - 3	0- 3

Figure 7.15 Fine Aggregate Grading for slabs and flags

The laying course provides the initial stabilisation of the elements and the primary means of resistance to load, it is the crucial layer in terms of structural performance of the surface constructed with shallower stone units. It is vital when the depth of the units varies that the units are selected to ensure that the thickness of the layer is not compromised by the need to produce a smooth finished surface profile.

Good level control of the support layer is also required to ensure that the compacted thickness of the layer is not compromised.

Figure 7.16 details the depths and tolerances stipulated by BS 7533 Part 4, however given the crucial impact the layer has when the surface carries traffic it may be that the tolerances on the 30mm compacted layer should be reconsidered to +5 / -5 mm.

The laying course has to be pre-compacted before laying the surface units and therefore an extra thickness surcharge is required in the un-compacted layer. The amount of surcharge required depends on the material and the optimum moisture content for compaction. This should be ascertained by site trials, just ahead of laying.

Pavement location and use	Compacted laying course thickness	Tolerance
Footway along side carriageways and other pavements used by vehicles	30	-10 +5
Areas that are only used by pedestrians i.e. no vehicles		-20 +15

Figure 7.16 Thickness of laying course for shallow units

7.6.7 Joint materials for flexible construction in shallower units

The materials for the aggregate used to fill joints prior to surface layer compaction are stipulated in BS 7533 Part4 and the gradings are given in Figure 7.15.

BS 7533 part 4 also stipulates that the joint width should be between 2mm and 5mm, with no tolerances allowed on the width.

A flexible stone surface requires joints to be topped-up in its early life with additional aggregate as the system ‘shakes-down’ and ‘stiffens up’ under traffic loading and the surface should be inspected regularly and additional material, complying with the original grading, should be brushed in.

Joints are subject to loss of materials by the action of mechanical sweepers, wash out by surface water or suction from high-pressure tyres. The application of surface coatings to inhibit the unwanted removal of joint material should be considered rather than applying mortar to the joints. Such coatings may have the added benefit of reducing the ingress of surface water through the joint. However, surface applications may affect slip skid resistance and this should be ascertained by an in-situ trial. They may also affect the colour of the surface. Coatings should not be applied until after the shake down period when the joint may need to be topped up with material.

Another option that can potentially protect against the loss of materials from the surface and reduce the maintenance requirement of a flexible surface in relation to street cleaning regimes is the use of a fine aggregate made from limestone. When compacted a limestone aggregate can create a “flexibly bonded” matrix, which will partially self-seal.

7.6.8 Edge, intermediary and temporary restraints

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. A sloping face on the restraint might allow the units to ride up the face of the edge under the action of imposed loads.

Consideration of the details at the intersection of a sett pavement and asphaltic/bituminous construction is required. The different responses of each material under load might cause differential movements at their junction. This movement might induce a failure in both materials but is likely to affect the sett surface more, causing units to become loose. A concrete log should be installed along the edge of the stone surface with its surface set below the surface level to accommodate the wearing course of the asphaltic/bituminous surface.

It is most important that edge restraints have sufficient mass to withstand the horizontal forces generated in the loaded pavement. Experience has shown that a kerb and concrete haunch equivalent to 0.1m3 per metre run of kerb provides the mass required. This can be provided through stone or concrete kerbs, deep stone channels or by setting units themselves in concrete. In each case, the units should be well secured with a concrete log and haunching.

Where a surface is in a normal road then the horizontal restraining forces required to generate interlock will be provided by edge restraints only. On larger open areas such as car parks or pedestrian squares, intermediate restraints must be provided.

There are a number of other complementary factors, which should be considered when considering intermediate restraints. Surface drainage often requires large areas to be broken down into discrete panels to produce cross-falls and drainage channels. Large areas will have to be constructed in discrete panels using temporary screed rails to install the laying course to line and level. Intermediate restraints may also be required on steep slopes in the order of 6% to 10%. This is particularly relevant to Flexible Construction not only to prevent downhill creep but also to safeguard against wash out of the joint materials by fast flowing surface water. These factors suggest that any intermediate restraints are detailed in the form of a drainage channel or a surface feature.

Experience has shown that a panel width of 15m across the general flow of traffic meets the combined requirements of surface drainage, buildability and restraint and this is confirmed in BS 7533 Part 7, which states that maximum spacing of intermediate restraints where they are required is 15m.

Temporary restraints are also required if the unfinished surface is to be trafficked by construction vehicles or left open at the end of a working period. Normally temporary restraints are in the form of temporary screed rails.

7.6.9 Methods of laying flexible construction in shallower units

The laying course should be spread with the required surcharge and be compacted with a plate vibrator and then the top 10mm should be loosened using a rake to allow the stone units to be placed. An alternative method is to lay out a 25mm layer compact this and then place a further 10mm or so in to which the stone units are placed. The 10mm or so loose layer should be tested to ensure the compacted thickness is achieved within tolerances. If the prepared laying course is disturbed then the material should be re-screeded and re compacted.

The stone units should be placed initially on the prepared laying course and be bedded in with a hammer. The units should be laid away from the previously laid areas if possible and should not be laid within 1m of an unrestrained edge or the edge of the laying course.

The joints should then be filled with dry joint materials brushed over the surface. Joints should be filled on the same day as the laying of the stone units. With the joints filled the surface should be compacted with a plate vibrator as stipulated in BS 7533 Part 4 fitted where necessary with a neoprene shoe to avoid damage to the stone units. The process of brushing the joint material over the surface and compacting with the plate vibrator should be repeated until the integrity of the surface ha been established

7.7 Rigid construction – Shallower stone units

7.7.1 Tiles, Slabs and Flagstones in Rigid Construction

BS 7533 Part 4 - Code of practice for the construction of pavements of pre-cast concrete flags or natural stone slabs, which deals with the installation of these type of surfaces does recognise that shallow stone unit are traditionally laid in a rigid form of construction and draws a distinction between two different forms of construction as discussed above If this form of construction is being considered then reference should be made to BS 7533 Part 4

However as discussed in Section 4, BS 7533 Part 8 implicitly implies that Tiles, Slabs and Flagstones are not suitable in structural design terms in Rigid Construction for traffic loading. If this is necessary then a specific analytical design is required for that particular site. Alternatively a proprietary system might be appropriate with sufficient guarantees from the supplier.

In areas subject to light vehicle loading only, they might be considered for Rigid Construction. They should be bonded to an appropriately stiff support layer, e.g. a concrete base to provide adequate stiffness. The bond may be between the flagstone and the laying course with the laying course bonding to the base.

There is a current theory that stone tiles might perform well under medium to heavy loading if bonded directly to a rigid sub-structure using high performance adhesive grouts. This methodology is still at an early stage of development and is dependent on the stone type. It is strongly recommended that any innovative system be subjected to extensive trials before adoption.

7.8 Features common to both Flexible and Rigid Construction

7.8.1 Complementary Fittings

Stone products do not lend themselves to the manufacture of specials, for example quadrants and edge blocks, at cost effective prices and it is not common for complementary fittings such trims and channels to be readily available. Therefore cutting and trimming of stone units in-situ is the normal method of dealing with edges.

7.8.2 Cutting and Trimming of Setts

BS 7533- Part 7 gives full guidance on this aspect and this is repeated here

Extract from BS 7533 Part 7: -

Cropped setts may be cut using a bolster chisel, sawn-sided units should be sawn by disc cutter or masonry saw.

The paved area should be covered as far as possible with full sized units. Where units need to be trimmed, sizes smaller than a third of the original plan size of the large sett should be avoided. No plan dimension should be less than 50mm. When using small setts (40 to 60 mm) avoid cutting if possible

Whole large units are laid first followed by units cut around obstructions and adjacent to edge restraints. This can be achieved by inboard cutting where necessary. Cutting and laying cut units should be completed as soon as it is practical, preferably in the same working day and before any fine concrete laying course has set.

The joint between the cut unit and the full unit or the edge restraint should comply with the requirements for the requisite joint width depending on the system of bedding used.

Where running bond pattern is to be used, particularly with sawn side setts, the units should be laid along a string line. The bond pattern should be checked using a second string line at right angles to the first.

Cut setts or complementary fittings should be incorporated into the curved lengths of running bond patterns to prevent cross-joints coinciding and to re-establish the correct pattern.

For trimming and laying around ironwork, units should be trimmed to fit after laying full paving units around any obstruction with joints between ironwork and units not exceeding 5 mm. Alternatively, the iron work may be trimmed around using a smaller sized units set in concrete and jointed with fine concrete to form a shape suitable for the larger stones to fit into. The smaller units may be in either the same stone material or in a different stone material can be used. These smaller units may require regulation of the sub-structure with fine concrete locally to maintain finish levels

Where this is not possible the obstruction should be surrounded in advance of laying the units with C35 air entrained concrete or equivalent (maximum aggregate size of 10 mm) to form a more regular shape of sufficient dimension. The thickness should be at least the total depth of the sett and laying course or at least the depth of the ironwork, whichever is the greater. To provide structural integrity, the width should be not less than 100 mm. Wherever possible when new ironwork is being used in conjunction with setts, a careful choice of shape and size of these products should be made to ensure minimum cutting.
Colour matching should be carried out by a careful selection of raw materials. Proper curing of the concrete is essential. The use of bitumen sprays, curing agents, wet material or plastic sheeting held in place is effective. Care should be taken to avoid staining the finished face of the units with cementitious material.

Concrete should be mixed and laid as dry as possible to obtain the surface finish. Compaction in place should be carried out to remove air bubbles and voids. Rapid setting cementitious mortar may be used in accordance with manufacturers' instructions.

End of Extract

7.8.3 Construction in Inclement weather

BS 7533 Part 7stipultes that paving should not occur below 3°C on a falling thermometer or below 1°C on a rising thermometer.

If frost is likely then the laid surface should be covered and if necessary heated to prevent freezing of the materials.

The surface of the sub structure should not be frozen before or during laying.

Either of these events will seriously damage the pavement and lead to early failure.

It should also be noted that cold temperature will slow down the curing action of cement based materials and will increase the time required for the specified strength to be achieved. This could lengthen the time to first opening to traffic of a Rigid Construction pavement.

In damp weather conditions unless preventative measures are taken, the materials for the laying course and joints will become wetter. This could influence the moisture content of the materials when being placed, which could lead to sub standard compaction and thus to a reduction in load carrying capacity.

BS 7533 Parts 4 & 7stipulate that when weather conditions are such that the performances of the pavement may be jeopardized all operations should be discontinued.