THINK BRICK AUSTRALIA

Manual 1

Clay Paving Manual

Clay pavers have a long and illustrious record of creating attractive and durable pavements in a wide variety of applications including paths, pedestrian areas, driveways, patios and recreation areas.

This manual is intended to provide guidance for clay pavers only, for the design and construction of flexible and rigid clay pavements. If your project uses concrete or cement pavers, you should refer to the CMAA Concrete Masonry Association of Australia for Technical Information.

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1. Introduction

This publication contains recommendations by Think Brick Australia for the use of clay pavers in flexible and rigid pavements (see Section 2, Definitions). It also has information on the specification, design, installation and maintenance of clay pavements.

Local experience may support the departure from these recommendations where the performance in the field has been demonstrated over a period of time.

The decision as to whether a flexible or rigid pavement is used depends on specific site conditions and a comparative cost analysis of the two systems. This decision must be made on an individual project basis and, therefore, no recommendations are made here as to which type of pavement system to utilise.

This manual supersedes and replaces Design Manual 1, Clay Segmental Pavements and Paver Note 1, Specifying and Laying Clay Pavers, both published by the Clay Brick and Paver Institute.

2. Definitions

Base course: The structural course or layer of granular material beneath the bedding course (see Figure 1). The base course distributes loads to the subgrade.

Bedding course: The layer or course of sand on which the pavers are bedded to form the pavement surface (see Figure 1). Generally a well-graded sand is used for this purpose.

California Bearing Ratio (CBR): An indicator of the shear strength of subgrade material.

Clay pavers: Fired clay units intended to form the surface course of a pavement (see Figure 1).

Edge Restraint: An existing or constructed element forming a boundary to the paved area. Edge restraints minimise lateral movement of the pavers and material loss from the bedding course (see Figure 1).

Flags: A large format solid paver with a gross plan area greater than 0.08 m^2

Flexible pavement: A pavement that does *not* rely on a rigid layer, such as a concrete slab, to distribute superimposed loads to the subgrade.

45° or 90° Herringbone bond: A laying pattern of the general form illustrated in Figure 2. This is the preferred laying pattern for pavements used by vehicles.

Interlock: The effect of frictional shear forces induced in the sand- filled joints between pavers that inhibits paver movement and transfers loads between adjacent pavers. Interlock accounts for the load-spreading capability of pavers.

Jointing sand: Fine sand that is swept and vibrated to fill the vertical joints between pavers (see Figure 1). It is important to note that bedding sand is not always satisfactory as a jointing sand.

Laying face: The working edge of the pavement, that is, where pavers are being laid during construction.

Light vehicular traffic: Areas subject to occasional light vehicular traffic, typically cars and station wagons, in applications such as off-street car parks. Access driveways, loading bays and other areas used by commercial vehicles with axle loads greater than 3.0 tonnes are excluded.

Rigid pavement: A pavement that relies on a rigid layer, such as a concrete slab, to distribute superimposed loads to the subgrade (see Figure 9).

Severe marine environment: The portion of land up to 100 m from a non-surf coast and up to 1 km from a surf coast.

Subgrade: The upper part of the soil, natural or constructed, that supports the loads transmitted by the overlying pavement layers (see Figure 1).

Surface course: A layer of pavers on a bedding course that act as a wearing course and a major structural element of the pavement (see Figure 1).

Wearing surface: The surface that the clay paver manufacturer has designated to be laid uppermost and trafficked.

Work size: The dimensions adopted for manufacture.

Figure 1. Section through a typical clay pavement and edge restraint

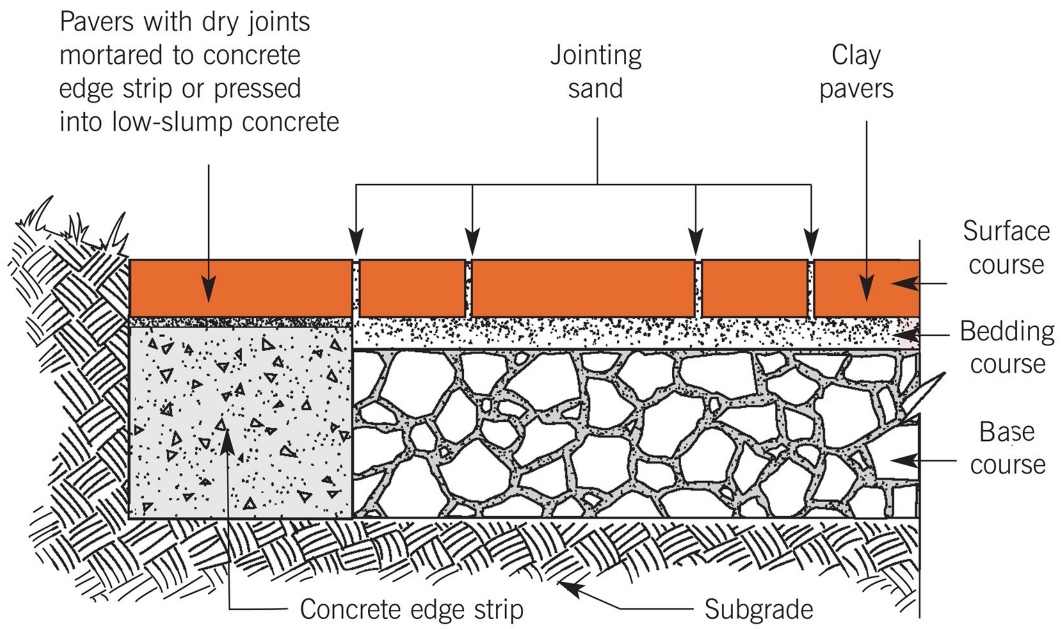
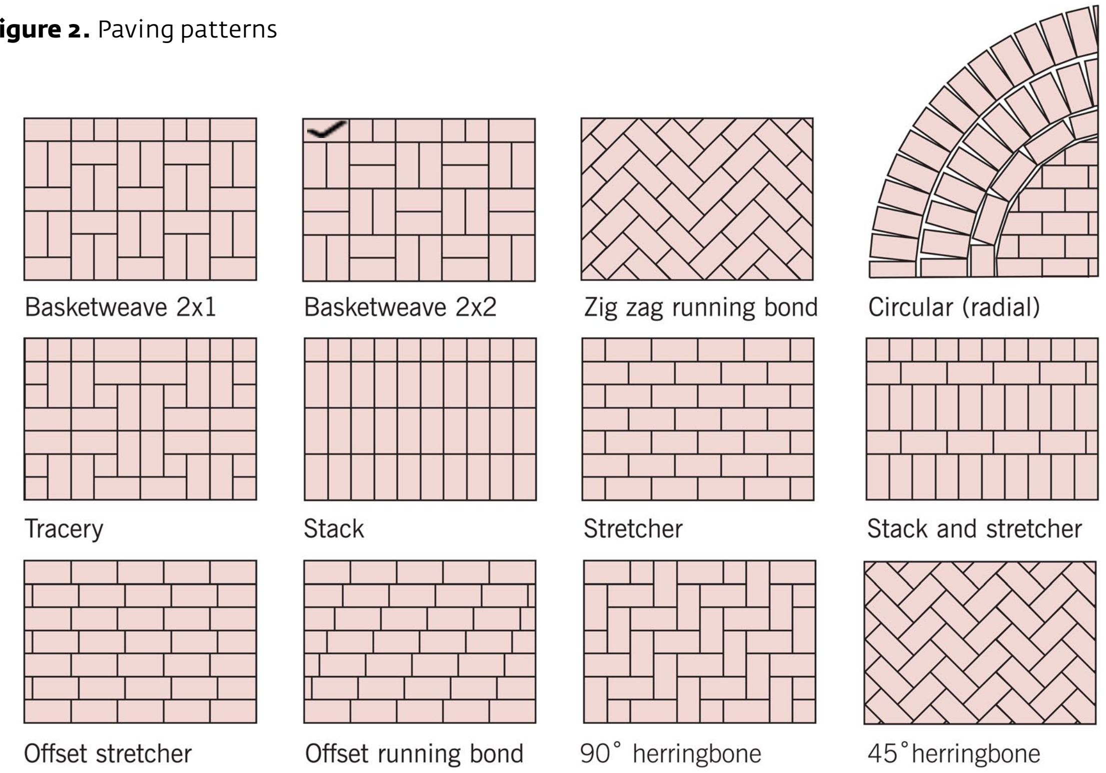


Figure 2. Paving patterns



3. Specifying Clay Pavers

3.1 General

This section contains recommendations by Think Brick Australia for the minimum requirements for clay pavers intended for use in the nominated applications.

Local experience may support departures from the specified provisions where satisfactory performance in situ has been demonstrated over a period of time. Manufacturers of clay pavers should be consulted for details.

3.2 Relevant standards

AS/NZS 4455.2 Masonry units, pavers, flags and segmental retaining wall units - Pavers and flags[1] sets out the information that is required to be made available by suppliers of clay pavers.

AS/NZS 4456 Masonry units and segmental pavers – Methods of test - General introduction and list of methods[2] describes the procedures that must be followed to determine the required physical properties of the pavers.

AS/NZS 4586 Slip resistance classification of new pedestrian surface materials[3] provides a means of classifying clay pavers according to their frictional characteristics and, therefore, their suitability for specific applications.

3.3 Relevant tests

3.3.1 Work size

AS/NZS 4455.2 requires suppliers of clay pavers to make available the work size of the units and is the one most commonly used for pavers. AS/NZS 4456.3: Masonry units and segmental pavers and flags – Methods of test - Determining dimensions, Method A: Determination of cumulative dimensions[4]. This test involves the overall measurement of 20 units for length, width and height.

Table 1 Dimensional deviations determined over 20 segmental pavers determined by cumulative measurement

Dimensional Category	Work Dimensions, mm		
	Under 150 (e.g. height and width of pavers)	150 to 250 (e.g. length of pavers)	Over 250 (e.g. length of width of flags)
DP0	No requirement		
DPA1	±50	±60	±75
DPA2	±40	±50	±60
DPA3	By Agreement between supplier and purchaser		

Dimensional deviation categories can also be determined using the individual method, as described in AS/NZS 4456.3. Masonry unit and segmental pavers and flags - Methods of test - Determining dimensions, Method B[4]. This is commonly used for flags due to their large size. In this method 20 units are measured individually. The mean and standard deviation of these measurements are then used to classify the flags into a dimensional deviation category, according to table below.

Table 2 Dimensional deviations determined for segmental pavers by individual measurement

Dimensional Category	Work Dimensions, mm			
	Plan		Height	
	Standard Deviation	Mean	Standard Deviation	Mean
DP0	No requirement			
DPB1	2.0	±3.0	3.0	±2.5
DPB2	2.0	±2.5	3.0	±2.0
DPB3	By Agreement between supplier and purchaser			

3.3.2 Breaking load

AS/NZS 4455 requires suppliers of clay pavers to make available the characteristic breaking load of the units. The breaking load is determined in accordance with AS/NZS 4456.5 Masonry units and segmental pavers and flags - Methods of test - Determining the breaking load of segmental pavers and flags[5].

In this test a paver is placed with its bedding face supported by a bar at each end. A load is applied through another bar on the centre of the top face. The load is increased until the paver fails. The maximum load is the breaking load of the paver.

It should be noted that breaking load, not compressive strength, is the strength criteria for assessing the performance of clay pavers.

3.3.3 Other tests

AS/NZS 4456.9: Masonry units and segmental pavers and flags - Methods of test, Determining abrasion resistance Method 9[6] sets out the procedure for testing the abrasion resistance of clay pavers when subjected to the impact and rolling action of ball bearings. Test results can be used to predict unit wear in its intended application.

AS/NZS 4586 Slip resistance classification of new pedestrian surface materials: Appendix A - Wet pendulum test method[7]. Results from this test are used to predict paver slip/skid resistance.

3.3.4 Durability

AS3700 Masonry Structures Section 5 Design for Durability[8] defines exposure environments and provides durability requirements for masonry units.

Exposure grade units are required for use in severe marine environments, areas with aggressive soils and salt water swimming pools.

Table 3 Recommended Specification for Clay Pavers

Pavement Application		Minimum Characteristic Breaking Load (kN)		Work Size Minimum Thickness (mm)		Dimensional Deviations Category		Maximum Abrasion Resistance (Mean Abrasion Index)
		Pavers	**Flags**	**Pavers**	**Flags**	**Pavers**	**Flags**	
Relevant Australian Standard		AS/NZS 4456.5[1]		NA		AS/NZS 4456.3[1]		AS/NZS 4456.9[1]
Residential	Pedestrians only (e.g.,paths, patios and outdoor areas)	2	5	40	40	DP0	DPA1 or DPB1	Note [3]
	Pedestrian and light vehicles only[2] (e.g.,driveways, parking spaces, and the like)	3	7	40	50	DPA1 or DPB1	DPA2 or DPB2	
	Pedestrian and commercial vehicles	5	7	60	60	DPA1 or DPB1	DPA2 or DPB2	
Public Space	Pedestrians only	2	5	40	40	DPA1 or DPB1	DPA1 or DPB1	Low Volume[4]:7 Medium Volume[5]:5.5 High Volume[6]:3.5
	Pedestrian and light vehicles only[2]	3	7	50	50	DPA2 or DPB2	DPA2 or DPB2	
	Pedestrian and commercial vehicles	5	Note [10]	60	Note [10]	DPA2 or DPB2	DPA2 or DPB2	
Trafficked Segmental Pavers	Minor and residential[7]	6	N/A	60	N/A	DPA2 or DPB2	N/A	N/A
	Local access[8]			60				
	Collector[9]			76				

NB: Notes for Table 1 are on the following page.

Notes:

1. Refer to AS/NZS 4556.2 Appendix B for alternative methods of demonstrating compliance.
2. "Pedestrian and light vehicles only" is the minimum application when prevention of vehicle access cannot be guaranteed, or when mechanical cleaning methods are to be used.
3. Abrasion resistance is not a mandatory performance requirement for residential paving application, but may be specified for aesthetic or other purposes.
4. Typical low volume pedestrian areas include paths in public gardens, schools or campus pavements, hard landscape areas, and common areas of residential buildings.
5. Typical medium volume pedestrian areas include suburban shopping area pavements and pedestrian areas and institutional buildings, sporting or recreational venues.
6. Typical high volume pedestrian areas include inner city and major suburban malls and paths, and pavements with high volume pedestrian traffic (over 30,000 passes per day) including about one-third with high-heeled shoes.
7. Minor and residential traffic areas carrying up to 400 vehicles per day.
8. Local access areas, carrying between 400 and 1000 vehicles per day.
9. Collector areas, carrying between 1000 and 2000 vehicles per day
10. Flags should be specifically designed for each application.

4. Flexible Pavements

4.1 Applications

Flexible clay pavements (see Section 2, Definitions) have been successfully used in a wide variety of applications for many years, including:

- domestic pathways
- patios
- domestic driveways
- pedestrian areas

In some locations, flexible pavements have provided effective service in applications where heavy vehicle traffic occurs. The manufacturer's advice should be sought as to their local knowledge regarding this point.

4.2 Laying

4.2.1 General

A flexible pavement consists of the following components (see Figure 1 and Section 2, Definitions):

- subgrade
- base course
- bedding course
- surface course
- jointing sand

The design of the lower courses is critical to the pavement's final performance. With the possible exception of domestic pathways, all flexible pavements should be designed around specific site conditions. It is up to the designer or contractor to ensure there is adequate information or that the required testing is carried out.

4.2.2 Subgrade

The California Bearing Ratio (see Section 2, Definitions) of the subgrade should be assessed when considered necessary by the designer or contractor. The CBR is an indicator of the shear strength of the subgrade material and widely used as a means of assessing subgrade strength for highway design.

The CBR of a soil can be measured directly or derived from a knowledge of other soil properties. The nature of clay paving projects is such that CBR values are often estimated rather than measured. Direct measurement can be made in the laboratory on undisturbed or remoulded samples. In the field a standard site test applies. Note however, that the objective is to provide the in-service moisture conditions under the constructed pavement and to measure the CBR under these conditions.

It is important to relate the scale of the site investigation to the size of the project. In small schemes, the cost of measuring CBR directly may be more than the saving that knowledge will permit. In large schemes, differences in soil properties across a site may suggest different designs for different parts of the site. In situ testing identifies the range of materials present. However an allowance must be made for the water content of the material tested with a comparison is made with laboratory-soaked CBR values.

Width of subgrade

The subgrade should be prepared to the required profile. It should be sufficiently wide to extend to the rear face of the proposed edge restraints or to the face of existing abutting structures.

Drainage of subgrade

When necessary the excavation prepared for the pavement should have piped or channelled storm water and subsoil drainage. All drainage trenches within the paved area should be backfilled to ensure they perform similarly to the undisturbed ground. All piped and subsoil drainage construction located beneath the pavement should be completed in conjunction with subgrade preparation before the commencement of base course construction.

The objective of this requirement is to prevent the accumulation of subsurface water anywhere in the area excavated for the pavement. Water accumulating in this location could reduce the stability of the whole structure or bring efflorescing salts to the pavement surface and detract from appearance or durability.

Removal of unsuitable material

Any unsuitable material should be removed from the subgrade and replaced with appropriate material, such as properly compacted base course material. Proof rolling may be used to locate areas of unstable subgrade. Closely observing the effect of the slow passage of a wheel of a laden sand truck often clearly reveals unsuitable subgrade material. Bedding course sand should not be used as a replacement material.

Resurfacing

Clay pavers are ideal for resurfacing established formations and existing pavements such as residential streets, pedestrian precincts and footpaths. These can usually be regarded as a suitable subgrade.

4.2.3 Base course

Base courses should be designed on the basis of sound engineering principles and the CBR of the subgrade. The surface of the base should be close-knit to prevent bedding course material from moving downwards. It must be of good quality to avoid failure due to high stress concentrations immediately under the surface course of pavers.

The base course material should be spread and compacted in layers. The thickness of these layers must be consistent with the compaction capability of the equipment being used. Note that on large projects a vibrating plate compactor may not be suitable for this task; a vibrating roller may be required. This particularly applies to pavements carrying vehicles.

4.2.4 Bedding course

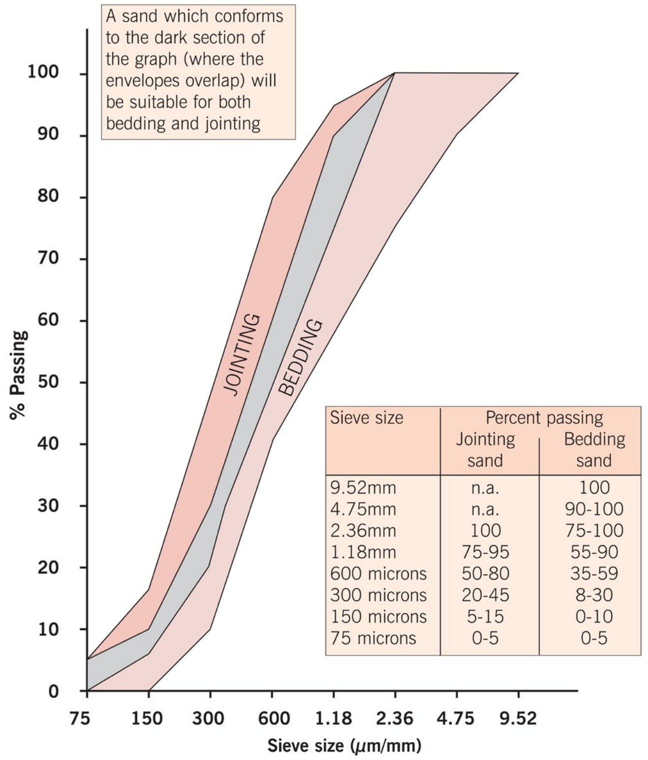
Geotextile materials

Geotextile materials can be used to great effect as drainage layers and separation layers. In both applications it is recommended the fabric be placed between the base course and the bedding sand. In this position it can drain the bedding layer and prevent bedding material being lost into the base course.

On reactive clay sites subgrade cracking may cause loss of bedding sand accompanied by subsidence. The separation layer of geotextile fabric prevents this and stiffens the pavement.

Bedding course material

Table 4 Bedding and jointing sand



Sieve size	Percent passing Jointing sand	Percent passing Bedding sand
9.52mm	n.a.	100
4.75mm	n.a.	90-100
2.36mm	100	75-100
1.18mm	75-95	55-90
600 microns	50-80	35-59
300 microns	20-45	8-30
150 microns	5-15	0-10
75 microns	0-5	0-5

Bedding course material should be a well-graded coarse sand. In the absence of other indications of suitability, sand of the sort used for making concrete should make a satisfactory bedding course. Salt attack and efforescence are problems with some clay paving and the capillary break provided by a coarse bedding sand is essential. Concrete sands containing less than four per cent of material passing through the 75 micron sieve should prove suitable. The sand gradings shown in Table 2 are recommendations only. The final selection of sand for bedding and jointing is dependent upon the grades commercially available in the region.

Fatty sands, loams or packing sands are difficult to adequately consolidate as a satisfactory bedding layer and do not form a capillary break.

Crushed stones with excessive fines, such as 'crusher dust' or dolomite, are unsuitable because although they can be compacted they fail to provide a capillary break.

Moisture content of bedding course
The moisture content of the bedding course should be uniform. Stockpiled material should be covered.

Waterproof membranes beneath the bedding course of pavers are not advised except where the paving is under cover.

Cement-stabilised bedding sand
Cement-stabilised bedding sands are not recommended where a well- graded bedding sand is available. If poor quality bedding sands must be used a very lean cement stabilisation may be appropriate.

Mixing in two to four per cent cement (by volume) to the bedding sand produces a cement-stabilised bedding sand. This is a method of retaining poor quality sands on sloping sites or where water may scour beneath the pavers.

For sections of paths with slopes of 1:15 or steeper, cement stabilising of bedding sand is a practical construction approach. For driveways with a sloping pavement length of 5m, a transverse concrete beam running between edge restraints should also be used. A capping course of pavers is mortared onto the sub-surface beam and the pavers up the slope from the beam are then laid on cement-stabilised sand. (See Section 4.3 for more information on flexibly paved sloping driveways.)

Bedding sand thickness
Following compaction, the bedding sand should be uniformly 30 mm thick with a maximum specified of 50 mm and a minimum of 20 mm. The thickness should only be other than 30 mm only when the need to achieve fixed levels precludes its specification. It is very important to achieve a uniform thickness of bedding sand.

Bedding sand construction
Either of the following installation procedures is acceptable:

- Spread the material loose and screed to the final level plus an amount to accommodate the reduction in thickness that will occur when the pavers are vibrated;

- Spread a loose uncompacted layer equal to the final required thickness. This sand is vibrated using the same vibrating plate compactor as that used for vibrating the pavers. Finally spread and screed a further layer to form a loose surface onto which the pavers can be laid.

In either method the sand should be disturbed as little as possible prior to paver installation. Any disturbance may lead to final surface undulations. Gaps between edge restraints or at the intersection with other pavements should be sealed to avoid loss of bedding sand.

4.2.5 Laying pavers

Selection
Pavers should be selected by reference to Section 3.0 as to their suitability for the intended application.

Laying patterns
Twelve laying patterns are shown in Figure 2. Herringbone (both 45 and 90 degree) is recommended for wheeled traffic areas. Many other decorative laying patterns are possible but are only suitable for pedestrian areas.

The chosen laying pattern will determine the way the pattern is gauge controlled. For example in running bond the paver unit width controls the gauge in one direction while the unit length controls the gauge in the other direction.

Herringbone pattern can be laid to a gauge based on the unit width only regardless of the aspect ratio.

Basketweave pattern is easiest to control when the unit length is twice the unit width plus the nominal joint width.

Pavers should be laid such that a joint width of 2 to 5 mm forms between each paver with a target joint width of 3mm thus ensuring there is no point contact between units**. Point contact between adjacent pavers produces high localised stresses that are known to cause edge chipping, reduce shear transfer and cause pattern distortion.**

This requires consistent gauging of the job to ensure that equal areas or lengths have equal numbers of pavers. Experienced paviors gauge by eye but still check with stringlines. Stringlines are recommended to maintain gauging on all jobs.

Mechanical force should not be used to bring pavers into intimate contact.

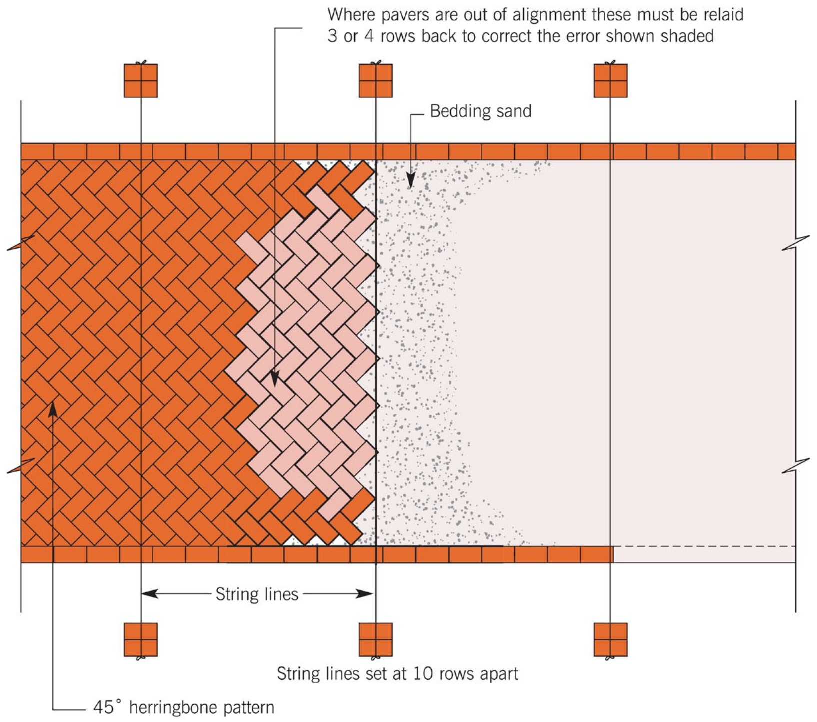
Figure 3 shows typical stringline arrangements. When pavers deviate from the stringline it will be necessary to remove pavers from several rows and re-lay to the stringline. The shaded pavers in the figure should be re-laid.

Trimming
Pavers should be trimmed to shape and size to form boundaries and to work around any obstructions. Accurate trimming can only be carried out using a masonry saw. It is recommended that the minimum size of a cut piece be not less than one-third of the area when cutting cross-ways or one-quarter when cut diagonally.

4.2.6 Joint filling

Procedure
A suitable fine-graded joint-filling sand (see Table 2) should be spread over the surface and swept into the joints. The use of dry material will assist in rapid joint filling. A sand containing clay that is likely to stain the surface of the pavers should not be used.

Figure 3. Typical stringline grid



String lines may be set perpendicularly as shown or alternatively at 45° in line with the long side of the paver.

Commercially prepared stabilised jointing sands may be used. The paver supplier should be consulted as to the suitability of these materials.

Joints and interlock

Interlock is developed during the installation of the pavers and can be defined as the inability of an individual paver to move in isolation from its neighbours. It can be divided into three components:

1. *Vertical interlock* prevents a loaded paver from sliding down the sides of its neighbours and is developed by the sand that enters the joints from below. This sand rises by approximately 20 mm during the vibration of the pavers and becomes wedged tightly between them. Vertical loads applied onto an individual paver are transferred into neighbouring pavers as a shear force through this sand, so generating vertical interlock.

2. *Rotational interlock* is developed by providing edge restraint to the paving and is completed by vibrating in fine jointing sand from above. An individual paver can rotate only if its neighbours move laterally to create the space needed for rotation. Edge restraints prevent this lateral movement and so generate rotational interlock. The inclusion of the fine sand in the joints shifts the potential hinge of rotation to the top of the paver and thereby adds further rotational interlock.

3. *Horizontal interlock* is achieved by ensuring that either the laying pattern or the shape of the paver eliminates continuous straight lines through the pavement surface. Horizontal interlock is achieved most commonly by laying a rectangular paver in herringbone pattern and there seems to be no structural preference for the alignment of the direction of the herringbone.

In order to facilitate the installation of the jointing sand, a fine round sand should be specified and this should be dry. Sand may be lost from the joints during the early life of a segmental pavement especially if the pavement has a steep longitudinal grade. Where loss occurs, joints should be 'topped-up' to avoid the possibility of pavers being displaced.

4.2.7 Compaction of the surface course

Compaction should follow laying and joint filling as soon as possible but should not occur closer than one metre to the unrestrained working edge of the pavement under construction. No area of paving should be left uncompacted at the completion of the day's work, apart from the edge strip of the laying face.

Compaction should be carried out by a vibrating plate compactor with a plan area of not less than 0.25 m^2 or a rubber-rollered mechanical vibrator. A vibrating plate compactor is best fitted with a glider attachment (Figure 5) or the plate may be wrapped in carpet. Alternatively a carpet square or a sheet of plywood can be laid over the pavers to protect them from damage. Compaction should continue until all paver faces are in the same plane.

The area to be compacted should be swept clean of joint filling sand and then receive at least two passes of the vibrating plate compactor. The joints should then be topped up by sweeping joint filling sand over the area prior to a final compaction consisting of at least two more passes of the vibrating plate compactor.

Figure 4 Well-filled sand joint

Figure 5 Vibrating plate compactor with glider attachment

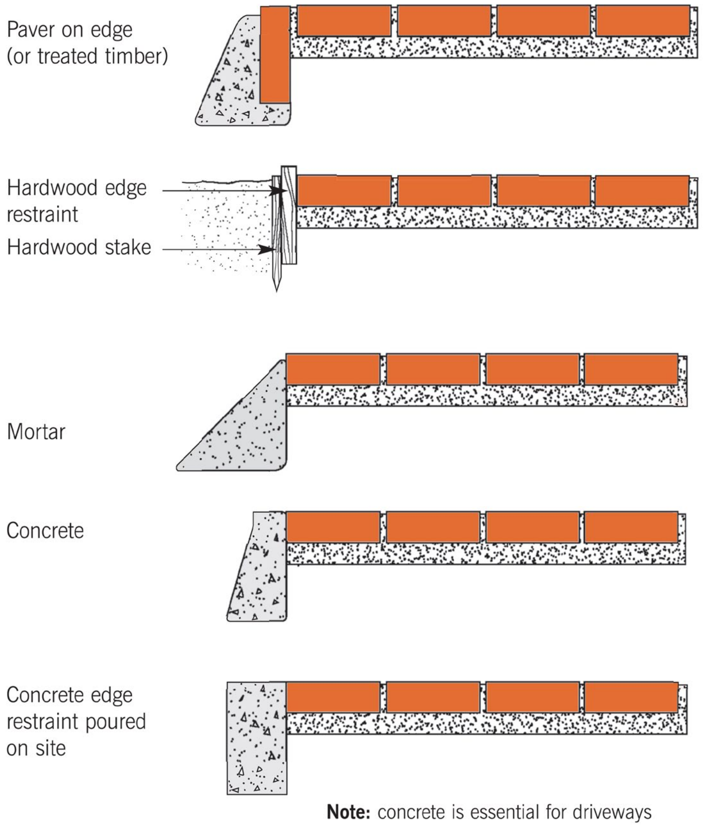
4.2.8 Edge restraints

The perimeter of all paved areas should be provided with edge restraints to prevent lateral spread of the pavers and consequent loss of interlock. These should be adequate to support the intended loads and to prevent the escape of bedding course material from beneath the paved surface.

Edge restraints should be formed before compacting adjacent units. Together with any concrete haunching, the edge restraints should be mature before vibration of the surface course is undertaken.

Haunching to an edge restraint should be continued down to the underside of the bedding course. Where appropriate, drainage should be provided at edge restraints to prevent the build up of a head of water in the bedding course.

Figure 6 Edge restraints



4.3 Flexible pavements for sloping driveways

4.3.1 General

This section deals with the general criteria to be used in the design and laying clay pavers on sloping residential driveways. The principles can be applied to multi-residential development sites and to sloping roadways.

The general design criteria may need to be further developed or modified for individual sites, depending on local soil types, drainage, slope and the volume and type of traffic. In some instances it will be necessary to have a site-specific design prepared by a structural engineer. The most common cause for concern on sloping sites is shunting and edge chipping of individual pavers. This problem is not confined to clay pavers, it is common to all paver types: concrete, clay and reconstituted stone.

In normal use, pavers will only chip if they are able to touch. Furthermore they will only shunt if the 2 to 3 mm gap between the pavers is able to close. Therefore shunting and chipping can be eliminated if the gap between the pavers is maintained.

This is relatively difficult, particularly on sloping, curved driveways. Even where the gap between the pavers has been completely filled with well- compacted jointing sand during the laying process, there is still the tendency for the sand to be washed out or 'pumped' out by wheel loads on the individual pavers during wet periods.

Localised rutting from inadequate sub base preparation, loss of the bedding sand (usually from poor sub-surface drainage), and localised movements particularly at edge restraints can also cause the pavers to push out resulting in eventual loss of sand, shunting and chipping.

In order to minimise or eliminate shunting and chipping, those aspects previously discussed for flexible pavements must also be addressed when designing and constructing a sloping driveway, namely:

- sub-grade
- coarse base
- bedding and jointing sand
- surface and sub-surface drainage
- selection of pavers
- laying pattern.

Two additional items must also be considered:

- The use of a restraint system
- Ongoing maintenance in order to retain the jointing sand between the pavers.

The following sections detail the additional requirements for designing and constructing a flexibly-paved sloping driveway.

4.3.2 Restraint system

Plain concrete transverse beams should be strategically placed along the driveway, generally at 90 degrees to the direction of traffic flow. The intention of the transverse beams is to reduce the effective length of the driveway and hence the potential for shunting.

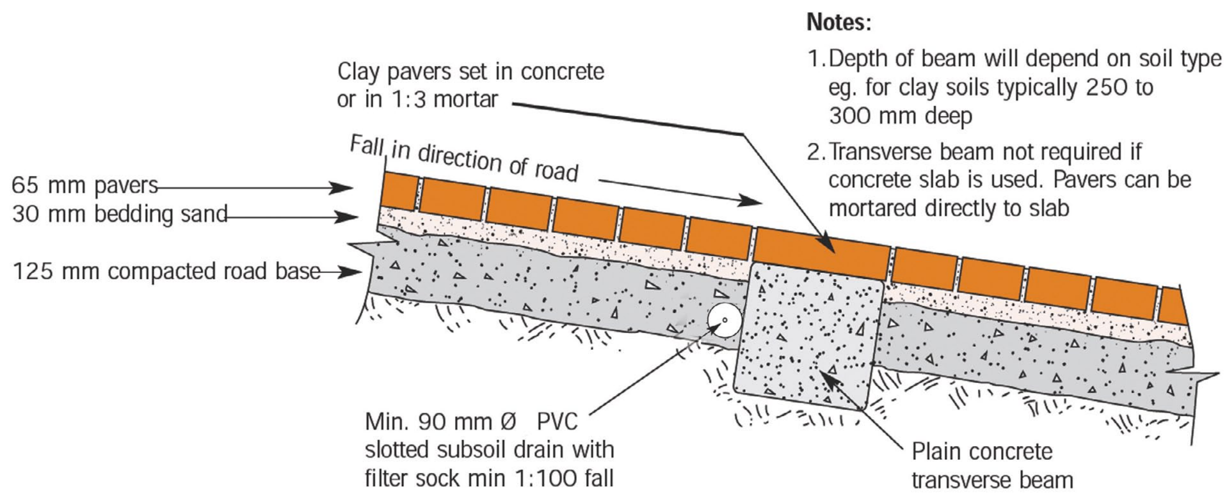
The spacing and size of transverse beams will be influenced by the pavement length, slope, soil conditions, traffic volume and type. Engineering advice should be obtained for difficult sites or those involving multi-residential developments or roadways.

A typical cross-section of a transverse beam for a single dwelling is shown in Figure 7. These should be used where the length of the driveway exceeds about 7 m, and spaced at about 5 to 6 m.

Concrete used in edge restraints, transverse beams, kerb and gutters and drains should have a minimum compressive strength of 20 MPa at 28 days.

Pavers laid over transverse beams, edge restraints and around pits and grates should be laid as a header course set in a mortar of one part Portland cement to three parts washed sand.

Figure 7 Typical plain concrete 230 mm wide transverse beam for a single residence driveway



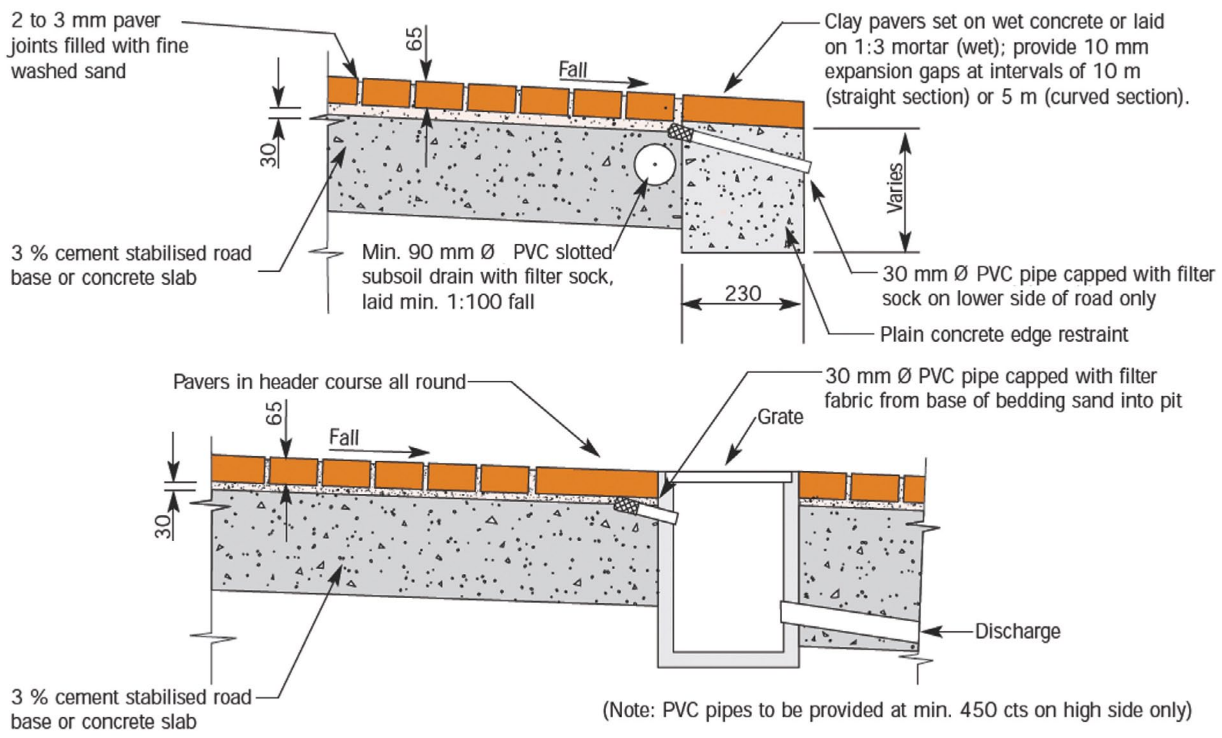
4.3.3 Drainage

Surface drainage is not normally a problem on sloping driveways. However, inadequate or non-existent sub-surface drainage is a common cause of failure in all pavements, particularly on sloping driveways and roads.

It is very important to ascertain any locations along the length of the driveway where sub-surface water may accumulate and provide drainage outlets at these locations. If this is not done the water will make its own way out, eroding bedding and jointing sand. Shunting and chipping is inevitable when this occurs.

Generally a drainage system must be provided where natural drainage through the sub-grade is not available or where sub-surface water is likely to pool or not drain freely under the pavers. Sub-surface water is likely to dam at the top side of transverse beams, the lower side of edge restraints, and at grates. Figure 8 shows typical drainage systems that can be adapted for these locations.

Figure 8 Typical Drainage systems



4.3.4 Laying pattern

Pavers should be laid in a 45 degree herringbone pattern. Due to its interlocking action this pattern provides the best interlock and resistance to shunting. **Other patterns are not recommended for vehicular traffic.**

4.3.5 Maintenance

It is critical to maintain the jointing sand between units in order to avoid movement that may result in paver shunting and/or chipping.

This may require frequent 'topping up' of the jointing sand particularly after periods of heavy rain. Alternatively, proprietary binders are available that effectively bind the sand particles together while maintaining the required flexibility to transfer load.

Pavers around drainage pits and service pits should be laid in header courses and set in a cement mortar, or a concrete surround used in lieu of the pavers. This reduces the erosion of sand by stormwater.

5. Rigid Pavements

5.1 Applications

Rigid clay pavements (see Section 2, Definitions) can be utilised in a wide variety of applications including:

- domestic pathways
- patio areas
- domestic driveways
- pedestrian areas.

5.2 Laying

5.2.1 Subgrade

The considerations with regard to the subgrade for a rigid pavement are the same as those for a flexible pavement.

In every case the pavement designer and/or the contractor must consider all measures necessary to determine the site conditions that will impact on the long term performance of the pavement including, but not limited to:

- Loadbearing capacity of the subgrade (CBR) (see Section 2, Definitions)
- Subgrade drainage
- Removal and replacement of unsuitable material

5.2.2 Base course

The base course for a rigid pavement is a concrete slab having the following properties:

- Strength to be consistent with expected traffic loading and subgrade strength but, in general terms, should always exceed an ultimate strength of 20 MPa.
- Thickness to satisfy predicted loading.
- Reinforced to satisfy predicted loading.
- Finished slab to have falls for drainage.
- Finished to a smooth surface by floating with a 'helicopter trowel'.
- Allowed to harden for 28 days before pavers are laid.

5.2.3 Paver laying

Pavers should be selected as to their suitability for the intended application by reference to Section 3.0. Pavers can be laid once the concrete slab base course had hardened sufficiently to resist deformation, usually overnight.

Pavers should be laid using a cement based tile adhesive that is suitable for clay pavers or terracotta tiles. The cement based tile adhesive should be applied using a 12mm notched trowel to apply adhesive to the slab. The adhesive should cover at least 95% of the underside of the paver.

The perimeter pavers are laid first, generally as a header course around the job. They are bonded to the hardened slab either by a cement: sand 1:3 mix or by a cement:lime:sandmix 1: 1/2 :3 or by an adhesive.

Once the perimeter pavers have been installed, the main body of the pavement can be laid in the chosen pattern. For rigid pavements that will be used for vehicular traffic it is strongly recommended that a 45 or 90 degree herringbone pattern is used.

The gaps that are essential between pavers in a flexible pavement are still necessary in rigid pavements, but can be smaller depending on the size/dimensional deviation of the pavers.

It must be noted that with this system there is no allowance for the variation in the depth or height of the pavers as they are being laid on a hardened concrete base. Therefore any variation in height of the units will show up in the finished pavement. Pavers that have a bevelled or rounded arris can disguise this variation.

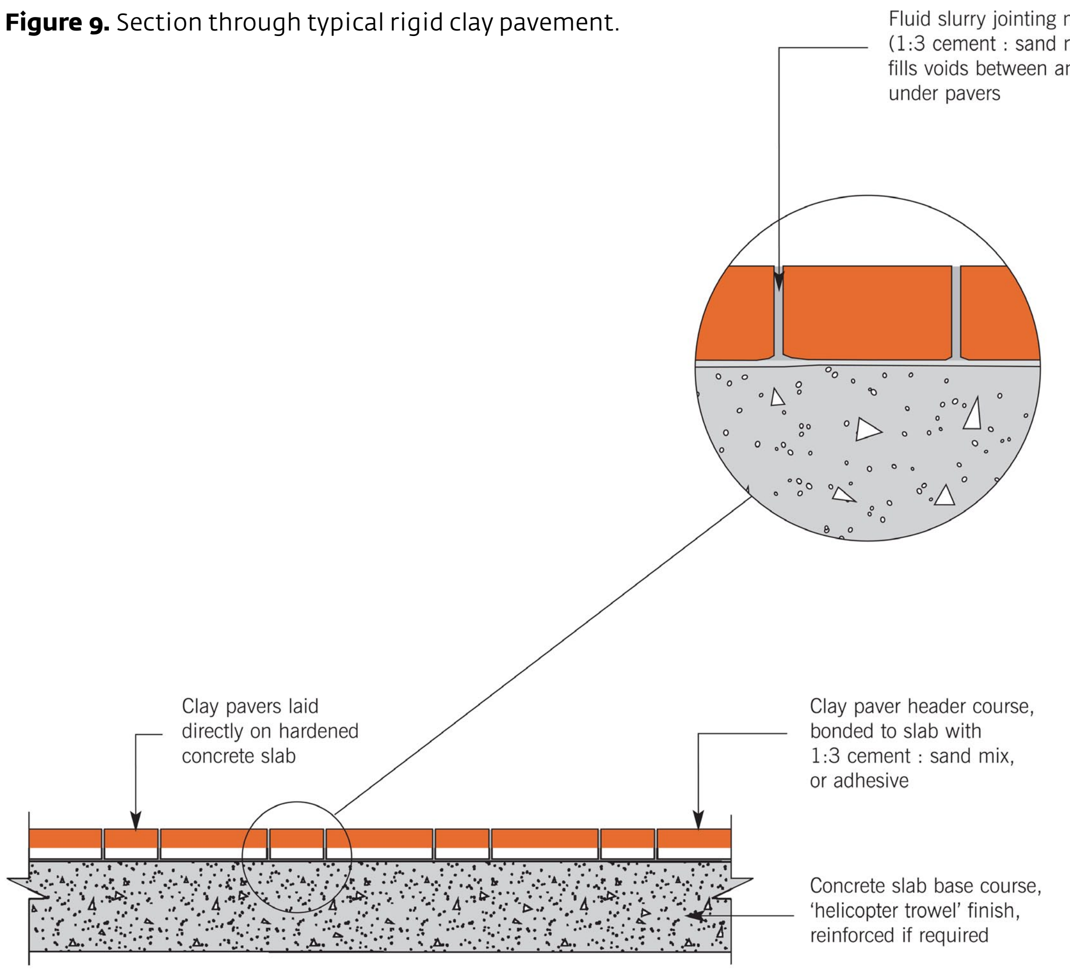
5.2.4 Expansion joints
Expansion must be considered when laying a rigid pavement. The gaps between pavers in a flexible pavement allow for thermal and long-term moisture expansion of clay pavers to be taken up. In a rigid pavement this does not occur. Therefore expansion joints are required in rigid pavements. The paver manufacturer should be consulted for advice on the location of such expansion joints.

5.2.5 Joint filling
Once all the full and cut pavers have been laid it is time to fill the joints. The jointing mix is 1:3 cement: fine sand mixed with sufficient water to turn it into a fluid slurry. The mixture must be sufficiently fine so that the slurry mix can flow around any gaps in the paver and fill any voids underneath them.

Finally once the slurry filling of the joints is complete the surface of the pavers should be hosed down using a high-pressure, fine mist spray to remove the excess slurry.

Vehicular traffic should be prevented from traversing the pavement for at least four days.

Figure 9. Section through typical rigid clay pavement.



6. Recommended Procedure For Laying Clay Paver Pool Coping

Unless the concrete ring beam is smoothly finished there will be a need to lay a leveling mortar bed to give a level surface to lay the coping. The clay coping pavers should be laid using a flexible adhesive such as Bostik Seal 'N' Flex or equivalent and used in accordance with the manufacturers recommendations. Based on tests at The University of Newcastle, it is recommended that the adhesive used should have an elastic modulus less than 1 MPa at 100 percent elongation. Prepare the levelling bed and the clay coping paver in accordance with the Bostik recommendation and lay the pavers on an even bed of adhesive 3 to 5 mm thick (see Figure 10). The location and width of expansion gaps is usually specified by the pool designer (for typical locations see Figure 11). However, the gaps should be sufficiently wide (minimum of 10 mm) to accommodate the combined expansion of these short runs of pavers, the shrinkage in the concrete and thermal expansion. Their intention is to break the pool coping into lengths shorter than 5 metres. The expansion gap must extend the full depth of the paver and adhesive layer down to the substrate and it is essential the gap is free of any waste material.

Figure 10 Expansion gap construction detail

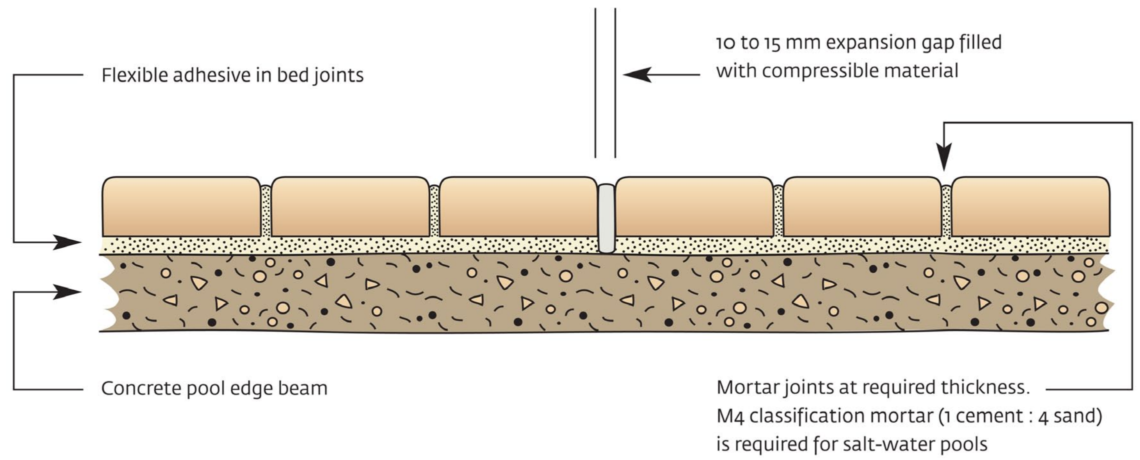
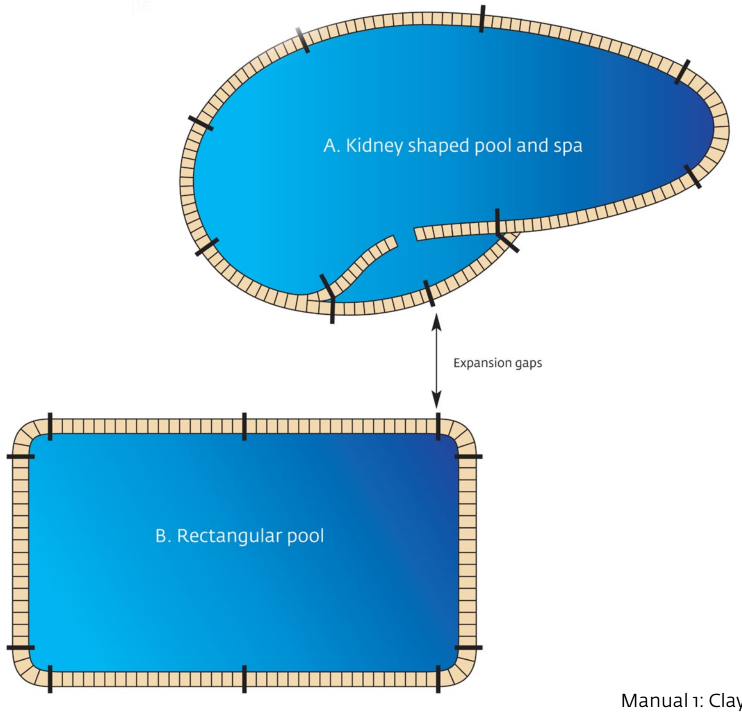


Figure 11 Typical location of expansion gaps around pools

These locations are indicative only. The number and actual locations may vary depending on the paver properties, type of concrete, climatic conditions and pool dimensions.



6.1 General recommendations

These recommendations aim to minimise shrinkage in the concrete ring beam and mortar levelling bed, maximise the bond between the coping paver and the bed joint adhesive and minimise the effect of the expansion from the clay coping paver.

6.1.1 Design

In the pool design, avoid sharp radius corners which can increase the local stresses between the pavers and the bed joint.

6.1.2 Selecting pavers

- Choose low expansion pavers with an 'e' factor of less than 1.0 (ask the manufacturer for the characteristic expansion properties).
- Allow as much time as possible for the pavers to age before laying – the rate of expansion reduces rapidly with time after the pavers leave the kiln.
- Pavers used around swimming pools should be classified Exposure Grade.

6.1.3 Pool concrete

- Pool concrete should comply with AS 3600.
- Avoid construction in hot, dry weather as shrinkage of concrete is greater at high temperatures and low humidity. Increased rates of drying will lead to increased shrinkage
- Allow as much time as possible between casting of the concrete ring beam and the laying of the pavers as shrinkage of concrete is faster at an early age (even a few days can be beneficial).
- As far as practicable ensure a level, true finish to the concrete ring beam, with a rough surface (not trowelled) to maximise adhesion.
- Ensure ring beam is clean before applying levelling mortar bed or adhesive.

6.1.4 Mortar levelling bed

- Avoid construction in hot, dry weather – shrinkage is higher at high temperatures and low humidity. Increased air movement (wind) will also increase shrinkage.
- Use the minimum practical water content.
- Allow as much time as possible between laying of the mortar bed and laying of pavers – shrinkage is faster at early age (even a few days can be beneficial).
- Cure the mortar by keeping it moist, especially in hot, dry weather.
- Consider the use of shrink limited (SL) cement, if practical, for the bedding layer.
- Avoid the use of high cement content in the bedding mortar (1:5 cement:sand by volume should be adequate).
- Use a uniform thickness bedding layer of mortar, preferably between 20 and 40 mm thickness.
- Use a screeded or wooden float finish (not steel trowelled) to maximise adhesion of the pavers.
- Use a clean sharp sand with minimal clay content for the bedding layer mix (not brickies loam).
- Do not use workability enhancing admixtures in the bedding mortar.

6.2 Bostik adhesive recommendation

The following is Bostik's recommendation for fixing of clay coping pavers to the horizontal plane of the ring beam of concrete pools in exposed locations with proximity to chloride environments. The recommendation does not apply to areas below the overflow level of the pool where the product will be immersed in pool water. Clay coping pavers are porous by nature. Even pavers with a decorative finish must be assumed to be porous, without protection from external moisture. The following procedures, using polyurethane adhesive, will maximise adhesive performance and give maximum protection to the bond line on both substrates, however, exposed adhesive will be subject to softening and loss of adhesion over time.

6.2.1 Concrete substrate

- The substrate should be clean and dry with no contamination present. Prior to the application of adhesive the substrate should be fully cured (minimum 28 days) and structurally sound.
- Once the substrate is cured, clean and dry apply Simson Primer P as per the Bostik Technical Data Sheet which is available with the purchase of Seal 'N' Flex FC.
- To minimise staining of the substrate not covered by the coping paver it is recommended that the template provided with the Simson Primer P be used.
- Allow minimum one hour after the application of the primer before applying Seal 'N' Flex FC.
- Due to the proximity to a chloride environment, adhesive must be applied to the entire area of concrete to be covered by the coping pavers. Intermittent, beaded or spot-fixed application is not recommended as increased concentrations of chlorine may become trapped in the adhesive bed voids.

6.2.2 Coping paver base

- The base of the coping paver must be clean and dry with no contamination.
- To the base of a clean and dry coping paver apply Simson Primer P.
- Co-ordination of the priming sequence to both the concrete substrate and the coping paver is required for optimum results.
- Bed the coping pavers into the adhesive a minimum of one hour after application of Simson Primer P to the paver and as soon as practicable after application of Seal 'N' Flex FC to concrete substrate.
- The dry film thickness of the adhesive must be a minimum 1 mm, however 3 mm to 5 mm is recommended. Care should be taken to ensure maximum contact and transfer to both interfaces (see Bostik Technical Data Sheet).

6.2.3 General

- Not using a primer prior to the application of the adhesive may provide short to medium term success of up to five years due to the possible effect of saturated porous substrates.
- Seal 'N' Flex FC or similar products should not be used in areas subject to constant or periodic immersion in pool water.
- Full bed application of adhesive to primed substrates will limit the effect of softening to the exposed adhesive due to splashing from chlorine or salt treated water. Adherence to these recommendations will provide the best possible result for the long term sustainability of the pool coping.

7. Maintenance

7.1 Early trafficking and cleaning

If the pavement has unbound joints, traffic may use the pavement immediately after the final pass of the vibrating plate compactor. Cleaning with hoses or powered vacuum cleaners is not recommended during the first three months of the pavement use. Cleaning should be by hand broom only during this period.

7.2 Basic cleaning principles

7.2.1 General

All pavements are subject to spillages and soiling and a build-up of dirt and grime. The careless use of cement-type materials during the laying of a pavement can also lead to soiling. Frequent sweeping and washing reduces the effect of dirt and grime and maintains the attractiveness of a pavement.

The removal of stains is not always easy but by following these principles and procedures the cleaning of a clay pavement need not be a problem.

7.2.2 Select correct cleaning chemicals

The first question should be: "Is the use of chemicals necessary?" If dry sweeping or washing with clean water and a detergent fails to bring the pavement to an acceptable state of cleanness, the answer could be "yes".

However rather than automatically using an acid cleaner such as hydrochloric acid, it is essential to identify the substance to be removed. Some useful hints to help you identify stains on pavements are given later. If this is not enough, consult your supplier or a professional knowledgeable in the subject.

7.2.3 Follow correct cleaning procedures

Follow the instructions given here or on the label of the selected proprietary cleaner. If you are inexperienced, test the selected chemical on a small, inconspicuous patch before tackling the whole pavement. This could save time and effort if, for instance, the method used or the chemical selected is not effective.

7.2.4 Safety precautions essential

There are few chemicals that are entirely safe and those used for cleaning paving are often potentially dangerous. A few elementary precautions are necessary:

- Protect yourself against inhaling dangerous fumes and against acid burns on your skin or in your eyes.
- Wear protective clothing.
- Dilute acids in the open with the breeze behind you.
- Always add acid to water, NOT water to acid.

While working with these chemicals, keep people (especially children) and animals out of the area. Upon completion ensure the chemicals are safely stored.

7.3. Removing common stains

7.3.1 Efflorescence

This is a powdery deposit of salts (usually white or yellow), often found on the surface of clay pavers after rain. The source of this stain could be the pavers but more often it comes from the surrounding materials, for example the soil under the pavement, or from cement (if the soil was stabilised), or both.

Efflorescence is usually harmless and can be removed by dry brushing and hosing. However sometimes it is necessary to follow this up with a wash of weak acid or a proprietary cleaner.

7.3.2 White scum

Do not confuse this with efflorescence. White scum is a thin white film on the surface of pavers. This film is invisible when the pavers are wet but shows up as the surface begins to dry. It often appears after an attempted removal of mortar stains or after the sanding of the joints with a 'clayey' sand (that is, sand with a high clay content).

White scum is particularly difficult to remove. Water, detergents or hydrochloric acid often do not have any effect on it. However scrubbing with a proprietary cleaner will often improve the appearance of pavements affected by this stain.

7.3.3 Dirt and grime

Frequent sweeping and hosing will usually ensure a clean pavement. If this is not enough, washing with a detergent or proprietary cleaner may be required.

7.3.4 Vanadium stains

Light-coloured clays often contain vanadium salt that may appear as a yellow, green or reddish-brown discolouration of the pavers.

Vanadium stains are naturally occurring and are neither permanent nor harmful and do not indicate any defect in the pavers. Stains in exposed areas generally wash off in time but their removal can be hastened by chemical treatment.

A number of treatments are available. It is best to test the efficacy of these chemicals on a test area to determine the most suitable treatment to use. Vanadium stains can be removed by:

(a) *Sodium hypochlorite*
The active ingredient in household bleach and swimming pool chlorine, sodium hypochlorite is an inexpensive treatment for mild cases of vanadium staining. Spray or brush the chemical onto the stain without pre-wetting, allow it to stand until the stain disappears, and then rinse off.

(b) *Oxalic acid*
Probably the best-known chemical for removal of vanadium stains. However it must be followed by a neutralising wash. If this action is omitted (as it commonly is) further staining of a serious nature can result. The correct procedure is:

- Mix 20 to 40grams oxalic acid per litre of water (preferably hot water).
- Apply to the stained pavers without pre-wetting.
- Neutralise the oxalic acid by applying a solution of 15grams of washing soda per litre of water. Do not wash off.

(c) *Potassium hydroxide or sodium hydroxide (caustic soda)*
Mix 150g of potassium or sodium hydroxide per litre of water and apply to the stained pavers. Leave until the stain disappears, then wash off. A white residue may appear after this treatment and this should also be hosed off.

(d) *Proprietary cleaner*
A general-purpose clay brick and paver cleaner that rapidly removes the stain. Apply to dry paver and wash off after the stain is removed, contact the paver manufacturer for recommendations.

7.3.5 Fresh mortar stains

The simplest way to remove wet mortar is to lightly cover the pavement before the mortar sets hard, with clean, but slightly damp, washed sand. Sweep the sand towards the edges of the pavement. If necessary repeat this until the surface is almost clean. The most important point to remember is that the sand MUST be free of clay.

Follow up with a further sweep with dry washed sand. Any sticky wet mortar residues that escaped the wet sanding will be removed. Once again the sand must be free of clay.

One or two days after the pavement has dried, some mortar residues may still be visible as a faint white film. Normally this will weather away. The appearance of efflorescence is almost certain but do not panic, just follow the instructions above.

7.3.6 Hardened mortar stains

Experiment on a small section of the pavement with decreasing proportions of water mixed with hydrochloric acid, starting with one part of acid to ten parts of water.

Once you have determined the appropriate proportion of acid to water, the type of propriety cleaning solution needed, process as follows:

- Slightly wet the pavement with a fine spray of water
- Using a stiff brush, apply the acid over approximately one square metre. Vigorously scrub the areas stained with mortar. When scrubbing is not sufficient loosen thick mortar patches with a hard implement such as

a steel scraper. Work on the mortar stain until it is dissolved.

- Give the area a good hose-down. A pressurised water spray unit is useful for this job.

Repeat these steps until the whole pavement has been cleaned. A final rinse of the pavement with a high-pressure water jet is often beneficial. However there are some pavers that could be damaged by the overuse of high-pressure water jets. Care must also be taken not to remove sand from the paver joints.

7.3.7 Fungi, moulds, moss and lichens

These are common, particularly in shady or damp parts of the pavement. They sometimes appear as localised dark stains or patches of green, giving a dirty and unsightly appearance.

Alternatively these growths may add to the appearance of the pavement. They will not damage the pavement but may cause it to become slippery.

To remove these growths, vigorously brush the affected area when it is dry. High-pressure water may also be used. Although the surface may now appear to be completely cleaned it is necessary to sterilise the area with a poison or a strong fungicide that should be allowed three to four days to act. Blue crystals (copper sulphate) is one such poison whereas sodium hypochlorite (liquid chlorine or bleach) and formaldehyde are fungicides. Other proprietary brands are available from plant nurseries. The surface should be brushed again when dry.

Warning: Some of the poisons in fungicides may discolour the pavement. Check their effect on a small part of the pavement before proceeding to clean the whole area. Pay attention to nearby garden plants or lawn, especially on the lower side of the paved area being treated.

7.3.8 Oil, bitumen and tar

These stains usually need two treatments with a commercial emulsifying agent. First, mix the emulsifier with kerosene to remove the stain. Then clean the kerosene off with the emulsifier mixed only with water.

When dealing with petroleum asphalt and bituminous emulsion, scrape off the excess material and scrub the surface with scouring powder and water. Chilling the surface with ice or solid carbon dioxide can cause brittleness in the asphalt and assist removal.

For petrol or lubricating oil stains, free oil must be mopped up immediately with an absorbent material such as paper towelling. Wiping should be avoided as it spreads the stain and tends to force the oil into the pavement. Hardened oil must be scraped off.

The area affected should then be covered with a dry absorbent material such as diatomaceous earth, fine white clay, kaolin or whiting and the procedure repeated until there is no further improvement. Subsequently use detergent to clean up, and rinse well with clean water.

7.3.9 Food stains and tyre marks

Scrub with a full-strength commercial detergent and rinse well.

7.3.10 Chewing gum

In large areas, wire brushes free from rust should remove the majority of chewing gum. This may require several attempts. Careful application of high-pressure water jets can also be successful.

For smaller areas freeze each piece of chewing gum with a carbon dioxide aerosol or dry ice. The chewing gum can then be chipped off with a scraper or chisel.

8. References

1. AS/NZS 4455.2:2010 *Masonry units, pavers flags and segmental retaining wall units - Pavers and flags*, Standards Australia, Sydney, 2010.

2. AS/NZS 4456:2003 *Masonry units and segmental pavers and flags - Methods of test - General introduction and list of methods*, Standards Australia, Sydney, 2003.

3. AS/NZS 4586:2004 *Slip resistance classification of new pedestrian surface materials*, Standards Australia, Sydney, 2004.

4. AS/NZS 4456.3:2003 *Masonry unit and segmental pavers and flags – Methods of test – Determining dimensions, Method A: Determination of cumulative dimensions*, Standards Australia, Sydney, 2003.

5. AS/NZS 4456.5:2003 *Masonry unit and segmental pavers and flags – Methods of test – Determining the breaking load of segmental pavers and flags*, Standards Australia, Sydney, 2003.

6. AS/NZS 4456.9:2003 *Masonry unit and segmental pavers and flags – Methods of test – Determining abrasion resistance*, Standards Australia, Sydney, 2003.

7. AS/NZS 4586:2004 *Slip resistance classification of new pedestrian surface materials: Appendix A – Wet pendulum test method*, Standards Australia, Sydney, 2004.

8. AS3700 – 2011 *Masonry structures Section 5 Design for durability*, Standards Australia, Sydney, 2011.

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