A review of concrete block paving in the UK over the last five years

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Introduction

IN 1974, the Cement and Concrete Association began a study in the United Kingdom into the viability of using concrete paving blocks as a pavement surfacing, mainly for roads in residential areas. The study began with an examination of work in Belgium, Holland, Germany and Denmark followed by laboratory and field studies in the UK. These studies led to the writing of publications giving recommendations on the design, specification and construction of pavements surfaced with concrete blocks.[1 2]. Additional publications covering more heavily-trafficked pavements and other aspects of the work have been published since[3 4 5].

The First International Conference on Concrete Block Paving provides an opportunity to review the early recommendations, giving reasons why they were made, and to examine how they have worked.

Despite the generally depressed state of the construction industry during the last five years, there has been considerable growth in the use of concrete paving blocks in the UK, although sales per capita are small compared to many other countries in northern Europe.

Concrete paving blocks were being produced, on a small scale, before 1975 but sales were limited because of lack of design and construction data. At that time, blocks were considered to provide an aesthetically pleasing surface but few believed that they had any engineering merit. Now the situation has changed and the majority of highway engineers responsible for the design of footways, highways, vehicle parks and pavements for dockside areas accept blocks as a viable alternative to the other surfacing materials.

The performance of any pavement depends upon many factors – the subgrade bearing value, traffic loads and frequency during the design life, and the structural properties of the various layers making up the pavement. In addition to structural performance, the retention of adequate skidding resistance and surface water drainage is important. In certain situations, appearance and colour may be of paramount importance.

All the factors mentioned above were considered when preparing the original recommendations. One aspect of paving blocks which is considered to give them a clear advantage over in situ paving is the ease of reinstatement in areas where access to underground services is necessary.

The rest of this paper examines the various parts making up a concrete block pavement in the light of knowledge gained since 1975.

Sub-base

The sub-base forms the lower structural layer of any pavement and is an integral part of a block pavement.

Materials

The structural design of new roads, in the UK, is usually based on the design charts in Road Note 29[6], using materials detailed in the Specification for Road and Bridge works[12]. The Specification also details methods of construction and standards of surface regularity for each layer of a pavement. Neither the Specification nor Road Note 29 refers to concrete paving blocks.

The publication, Concrete Paving Blocks for Roads[1], was intended to aid the designers of residential and similar roads surfaced with blocks. It recommended that the sub-base materials beneath the laying course should comply with Clause 803 (Type 1, unbound), 805 (Soil-cement), 806 (Cement-bound granular materials) or 807 (Lean concrete) of the Specification[7]. Materials complying with Clause 804 (Type 2, unbound) were not included as they can be sensitive to the ingress of moisture. It was also thought that there could be significant penetration of water through the joints in newly-laid blockwork. This fear has been justified by a later study by Clark[8]; although the joints normally become sealed with detritus, this may take a considerable time. It was thought prudent to avoid the use of Type 2 materials or any other material which could be moisture-sensitive. This view is still held although there have been cases of the successful use of Type 2 sub-base materials, not all of which are affected by moisture ingress.

In 1976, there was a failure of a small area of dockside paving surfaced with blocks. In this case, the blocks were laid on a Type 2 sub-base and the area was inundated with rain water a few hours after the completion of block laying. Under heavy lorries the surfacing moved, creating a "bow wave" ahead of the lorry wheels. The blocks were lifted, the Type 2 material replaced with the same thickness of lean concrete and the blocks relaid, since when the performance of the pavement has been satisfactory.

The surface of the sub-base must be close-knit so that laying material cannot penetrate. It may be possible

Figure 1: A five-year old block road on a 75 mm concrete sub-base.

to seal the surface of a sub-base to prevent the ingress of water or laying course material, using a tar or bitumen spray or plastic sheeting. It is not known if this has been done in practice but it could possibly allow the use of cheaper sub-base materials in certain parts of the country.

The recommended sub-base materials have high CBR values (over 30%). Experimental blocks have been laid on weak materials, with a CBR of approximately 2% and, in these cases, the blocks have been displaced downwards and suffered rotation and cracking as a result of trafficking. Similar defects have been seen under both heavy vehicle traffic and heavily-loaded trailer jacks but, in all cases, the quality of the sub-base was suspect. It appears that a fairly stiff layer is needed beneath the laying course to allow the development of vertical interlock.

An example of a road with a stiff but thin sub-base is shown in Figure 1. This road was built in January 1975 during wet weather over a soft clay subgrade. It consists of a nominal 75 mm thick concrete slab, 50 mm thick sand laying course and 80 mm thick blocks. Since the road was built it has carried 2500 vehicles/week, of which some 10% are commercial vehicles. After 5½ years, no displacement of the blocks is detectable although the underslab contains at least two transverse cracks.

Bitumen and tar bound sub-bases could be satisfactory but are expensive.

Sub-base surface tolerance

It was decided to use the surface tolerance required for sub-bases given in the 1969 Specification[7], which was ±20 mm of the specified levels. It was assumed that this tolerance had been proved both practical and economic on other roads. Considering this tolerance in conjunction with the commonly-used compacted laying course depth of 50 mm, the actual laying course depth could vary between 30 and 70 mm. Experience indicates that thick laying courses settle under traffic leading to irregular surfaces. Shackel[9] claims thicknesses of 50 mm are undesirable — he would prefer a nominal thickness of 30 mm — but to make his suggestion practicable would need a severe tightening of the working tolerances on the sub-bases which, in turn, could increase costs.

There are indications that the final surface regularity of a road surfaced with blocks depends upon the regularity of the sub-base, but unless blocks are to be used for high-speed roads (say over 60 km/h) there does not appear to be a justification for demanding stricter standards than currently recommended. Conversely, a relaxation in the surface regularity of the sub-base could lower the final surface regularity of a block surfacing below acceptable limits.

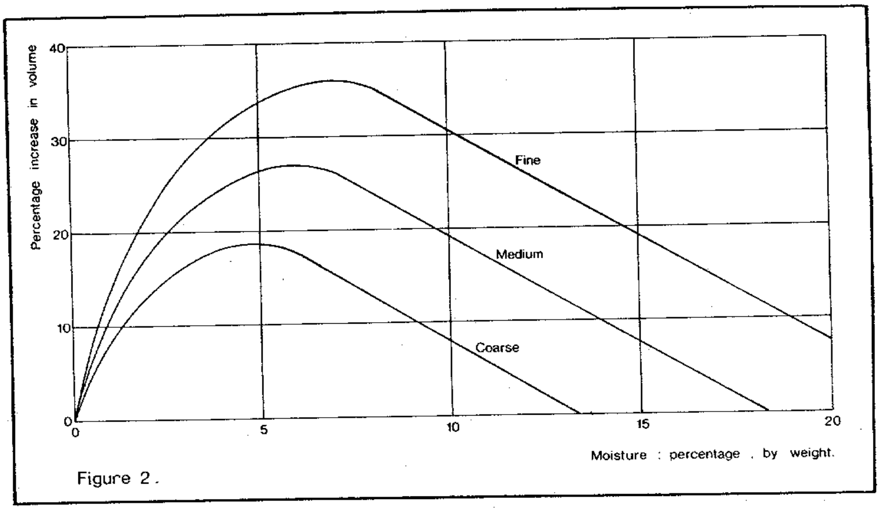

Figure 2: Bulking of loose sand (Taylor[10]).

Laying course

This provides a bedding and regulating layer for the blocks; usually it is made of sand although a small single-size stone has been used.

Types of material

Because the laying course is held in place by the sub-base, the blocks and the edge restraint, its structural properties are not of prime importance. However, it is necessary to consider problems which may arise during construction. For example, building sands which contain silt and clay are difficult to screed to a uniform level and density. Fine sands are also liable to vary considerably in volume with slight moisture changes. Figure 2 taken from Taylor[10] shows percentage volume change plotted against percentage moisture change for three gradings of sand. Examination of these curves shows that coarser sands bulk least and are therefore more readily "struck off" to a uniform loose density when being screeded. Grit materials would bulk very little but their use is not favoured as they would not contain the fines to enter the joints between blocks from below. The ability of fines to enter joints in this way is considered desirable to promote interlock and uniform block spacing during the initial vibration. All these factors lead to the recommendation of sharp sand for the laying course. It is also important to minimize, as far as practical, variation in the sand grading and moisture content.

Shackel[9] has suggested that a sand laying course settles a significant amount under the action of traffic. This hypothesis is questioned. Over the last three or four years changes in surface levels of pavements surfaced with blocks have been monitored on several sites. All these sites have had fairly high vehicle weights and frequency. One is the exit from a bus station, another carries full bulk cement lorries and the other carries the bulk of the construction traffic entering Central Milton Keynes new city development. In all these cases, only very small surface displacements have been detected, much less than values reported by Shackel. Local deformations have, however, been seen in other areas where the laying course has had a chance to escape, e.g. through voids in the edge restraint. This suggests that the reported "shake down" attributed to compaction of the laying course by traffic is more likely to be due to loss of the laying course sand through an open-textured sub-base or voids in the edge restraint.

The use of a cement-treated sand as a lyaing course has been considered, but its use is not favoured for the following reasons:

(a) mortar would reduce the ability to remove and re-use blocks. It would adhere to blocks and unless they were thoroughly cleaned they could not be readily reinstated:

(b) mortar may break down under the action of frost and therefore money spent on mortar would be wasted;

(c) mortar would be relatively expensive to produce and spread; an expense which is not justified from experience with sand.

Thickness

As stated earlier, the normal thickness of the laying course is 50 mm and to reduce this significantly would increase the costs of sub-base construction. Very thick layers (100 mm or more) are undesirable as settlement can occur because of the action of traffic. This arises because a thick layer may not be compacted fully when the plate vibrator is used because the development of interlock reduces the compactive effort transmitted to the sand.

Screeding
The use of hand-held screed boards on the tops of the edge restraints is an effective and simple method of screeding. If the laying course is a clean sharp sand and the width screeded is not more than about 4.5 m, hand screeding is practicable. For wide areas, temporary screed rails, supported on "windrows" of sand, are often used.

It is now realised that screeding is more difficult and labour-consuming than originally thought. For large jobs, mechanized screeding is economically attractive; for example, for the construction of a large lorry park in London the majority of the area was screeded using a timber beam supported on scaffold tubes bedded, to level, in sand. The fork-lift truck used to take blocks from the delivery vehicles and to deliver them to the laying faces was also used to pull the screeding beam to spread and level the sand. In this case, four men laid, consistently, more than 2000 m^2 of blocks per week, the rate being largely controlled by the time needed by the fork-lift truck to carry out all its various tasks.

Compaction
It was recommended, by the Cement and Concrete Association[1 2 3 4 5], that the blocks should be laid on a loose laying course. Under the action of the plate vibrator, sand from the laying course should work up the joints some 15 to 30 mm, developing interlock. Some other organizations recommend that the laying course should be compacted prior to placing the blocks. This recommendation appears to increase the effort in block laying because, after compaction, the laying course will need rescreeding. Also, little or no sand will enter the joints from below and therefore interlock will not be developed until sand is brushed in from the surface. To fill joints from the surface may take several attempts, separated by days; sand arches in the joints preventing more sand entering and it therefore seems sensible to partially fill the joints from below.

Moisture content control
The amount of bulking in a loose laying course material depends upon its particle grading and moisture content. From an examination of Figure 2, it is apparent that the grading of a sand should not be allowed to vary much as the degree of bulking will also vary. It is also advisable to minimize the variations on the moisture content of the sand until it has been laid and screeded.

Laying a sand either dry or fully saturated would seem advantageous because bulking would be nil. However, under either of these states the sand would be nearly fully compacted prior to vibration, which would possibly reduce the entry of sand into the bottom of joints, as explained in the preceding section.

The blocks

Dimensions
After work abroad had been studied, it was decided that only blocks able to be held in one hand would be recommended. An impression was gained that large blocks, often with mechanically interlocking sides, were more difficult to make and place. The joints between these larger blocks were often wide and the sand was "sucked" out of the joints by traffic. It was also thought that the interlock between these larger blocks was not as good as with the plain-sided smaller blocks but this has not been confirmed by experiment. It was also apparent that an area of block paving would be laid more quickly with the "one-hand" size block. Having decided that a "one-hand" size was best, a width dimension of about 100 mm seemed sensible.

Dimensional tolerances
Uniformity of dimensions is desirable for various reasons. Variations in the length and width dimensions prevent the maintenance of good joint lines which, in turn, could adversely affect appearance and/or lead to variations in joint width. It is believed that joints much wider than about 5 mm may not allow interlock between neighbouring blocks. Uniformity of dimensions is also important for areas where blocks are broken out and some new blocks are required for a reinstatement.

The stricter the tolerances demanded, the greater will be the cost of blocks. The blocks are made in expensive hardened steel moulds which can be used several hundred times per day and therefore suffer rapid wear. A tolerance of ± 2 mm was suggested for the length and width dimensions and, as far as is known, this tolerance has proved acceptable to both producers and users.

A greater tolerance was suggested for block thickness. It was not considered that thickness variations were so important as length and width variations. Manufacturing techniques also make greater tolerance in thickness desirable and a value of ± 3 mm was proposed. This is $\pm 6\%$ of the nominal laying course thickness. Much larger tolerances would probably adversely affect the final surface regularity. Morrish[11], referring to experience in The Netherlands, suggests that large variations in block thickness will lead to irregularities in the final surface some time after completion of the pavement.

Aggregate
Experience with in situ concrete has shown that the fine fraction of the aggregate has a major influence on the retention of good low-speed skidding resistance. Sands containing a high proportion of limestones polish quickly. Following the relevant clauses in the Specification[7] it was recommended that the aggregate passing 5 mm sieve should not contain more than 25%, by weight, of calcium carbonate in the fraction retained or passing the 600 μm sieve. The working in the Specification[12]. has now been modified to read "acid soluble" instead of "calcium carbonate"; this has also been used in the Interpave block specification[13].

Two car parks are known to have been constructed in the UK with blocks made with a high content of acid soluble material in the sand fraction. These blocks became highly polished within a few weeks of opening to traffic and were not satisfactory from the skidding resistance viewpoint.

Shape
One-hand sized blocks are supplied rectangular or in polysided shapes. Work by Knapton[14] and later by Clark[15] has shown that the load-spreading capability of both shaped and rectangular blocks is similar. This view is confirmed by practical performance in the UK. Shackel[9] claims that some polysided blocks perform better than rectangular blocks.

Chamfers
Most blocks produced in the UK are now chamfered. The introduction of a chamfer may aid laying by indicating the top face of the block. The chamfer reduces sharp edges which, in turn, makes work more comfortable for the layer who handles several hundred blocks in a day.

Chamfers also reduce spalling and reduce the effect of minor differences in level between adjoining blocks, as shown in Figure 3. Normally a chamfer reduces the surface area of a block by some 20%; a maximum reduction of 30% was recommended to avoid very large chamfers[1].

Durability
Durability is the subject of a paper to this Conference by Clark[16] who examines the factors influencing the resistance of blocks to damage by freezing and thawing in the presence of de-icing salt.

Most countries require blocks to have compressive strengths of about 50 N/mm^2 or the equivalent. This has proved satisfactory in the UK for the last five years.

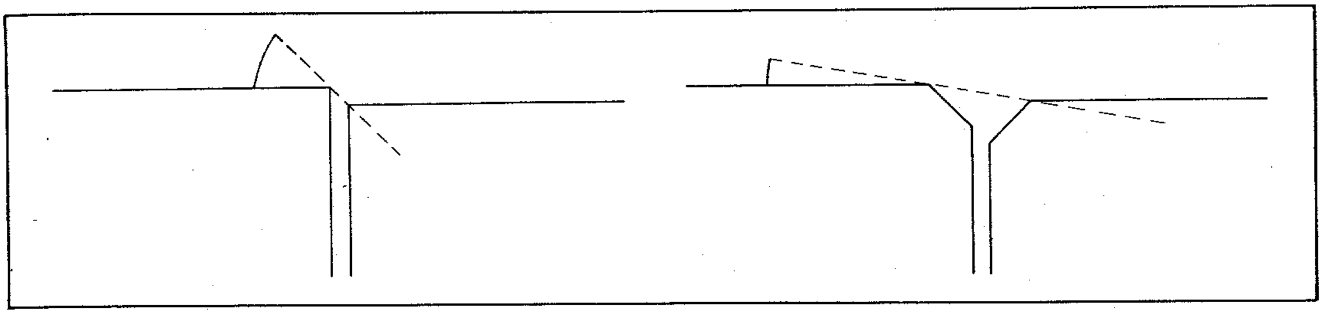

Figure 3: Reduction in the slope of a "trip face" through using chamfered blocks.

Concrete blocks are resistant to most chemicals likely to be spilt on a highway or parking area, such as oil or petrol. Concrete is damaged by acid but paving blocks have been used in the UK in an area where acid is liable to be spilt. In this case, the blocks have been regarded as a sacrificial layer which can easily and cheaply be replaced when damage reaches an unacceptable degree.

Laying patterns
Only two laying patterns have been recommended – stretcher bond and herringbone[1 2 3 5]. Certain shaped blocks can only be laid in stretcher bond. The majority of shaped and rectangular blocks have a length: width ratio of 2 and can be laid in either bond.

Recommendations[1 2] made in 1976 were that rectangular blocks carrying vehicular traffic must always be laid in herringbone to provide horizontal interlock and to prevent creep. This recommendation was based on work seen in The Netherlands where examples of creep of blocks laid stretcher bond had occurred. This creep had led to the opening of joints and even the cracking of blocks.

Unfortunately, the validity of this recommendation was confirmed in the UK when a large car park was paved with rectangular blocks laid in stretcher bond. Under traffic, many of the blocks were displaced and moved in the major direction of traffic flow, particularly where vehicles braked or accelerated. This implies a greater coefficient of friction between vehicle tyres and blocks than between blocks and the laying course. Where traffic travelled across the length of blocks, creep of the type shown in Figure 4 has been seen. In other areas where traffic moved along the length of the blocks, the blocks moved closer together leaving wide gaps 25 to 75 mm at entry ends of the paved areas. In practice, repairing the second defect has not presented a problem; the gaps at the ends have just been cleaned out and additional blocks cut to fill the spaces. This fault may have been aggravated by the block layers, who probably widened joints to minimize the block cutting.

Experience indicates that laying blocks in a herringbone pattern produces greater laying rates.

Surface regularity
A generally smooth surface is required for roads both to provide adequate riding comfort and to minimize ponding of water on the surface. Ponding can be minimized by the provision of adequate falls, the actual falls being related to the surface regularity of the pavement.

For high-speed road and airfield pavements, a surface regularity of 3 mm in 3 m is often specified. The same value is often used for low-speed roads although it does not seem necessary. A surface tolerance of 10 mm in 3 m would seem satisfactory, based on surveys of existing estate roads. Unlike in situ concrete or bituminous surfaces, it is simple to lift and re-lay a block pavement and the adoption of a needlessly strict standard could have led to a great deal of needless block re-laying.

The recommended falls for drainage were taken from those suggested by The Concrete Society[17], i.e. not less than 1:40 for crossfalls nor less than 1:180 for longitudinal falls. For very shallow longitudinal falls channels should be provided.

Edge restraint
Edge restraint is an essential part of any concrete block pavement, its functions being:

(a) prevention of block migration outwards because of thermal movements or displacement by traffic;

(b) retention of the laying course at the edges.

Traditional precast kerbing was recommended[1] and is satisfactory but many alternatives have also been used. It is now concluded that the choice of edge restraint is very wide, giving the designer a great deal of freedom. As long as the edge restraint is robust enough to resist damage when hit or overridden by the type of traffic using the pavement, it will be suitable.

Experience gained since the original publications were written has shown that a flush edge detail has merit over a detail with an upstand such as a kerb. With a flush detail, such as a channel in front of a kerb, marking blocks to be cut becomes very simple as the operator just holds a block above the void and marks it for cutting. If there is an upstand, measurements must be made before the block is cut which greatly slows the fitting of cut blocks at edges.

Joint filling
After the blocks have been vibrated

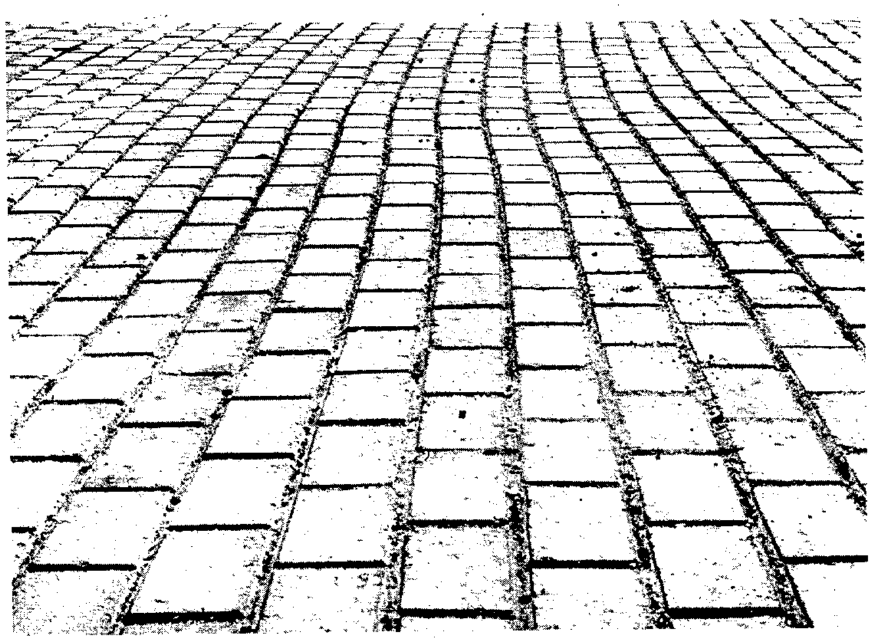

Figure 4: An example of "creep" in blocks laid in a stretcher bond pattern.

to level it is necessary to complete the interlock by filling the joints with sand.

Method
Joint filling is a simple operation carried out when most of a day's work has been completed or when it is convenient. Usually, sand is brushed over the blocks and encouraged to fall into the joints by a plate vibrator. The job is most easily carried out when the surface and the filling sand are dry. The plate vibrator crushes larger particles to form dust which enters the joints more easily than sand fractions.

In wet weather, the sand can be encouraged into the joints by washing the surface with water.

Materials
The most convenient material to use is that used for the laying course but some laying specialists believe that the use of a very fine sand aids the joint filling.

Pulverized fuel ash has been used, apparently successfully. Although no problems have arisen to date, one possible objection to the use of pfa is the risk that lime liberated from the blocks could generate a pozzolanic reaction with the ash, cementing the blocks together. If this cementing occurred the flexibility of the surfacing would be destroyed. For a similar reason, cement is not considered to be a suitable filler.

Laboratory trials[8] and experience indicate that detritus will fill the joints most satisfactorily and that this form of sealing will not be flushed out by heavy rain or hosing the surface. However, this "natural" sealing may take some time.

Vibration
Plate vibrators were recommended for compacting the sand and producing a plane surface[1 2]. A range of different plates was examined but no clear indication was obtained for a preferred machine. Larger plates complete the work quicker than the smaller units but productivity is rarely controlled by the rate of surface vibration. However, on some large areas, contractors have used two or more plates ganged together to reduce the labour requirement.

The future
Block paving is not new. It was used very successfully 150 years ago in London in a form almost identical to current recommendations[18]. Using concrete paving blocks is relatively new in the UK but it can now be said, with confidence, that they will be more widely used in the future.

Success on the Continent and in the UK provides the evidence for future growth and shows applications well beyond the lightly-trafficked roads considered five years ago.

To develop a market size comparable with those in other parts of Europe will mean that many more production plants will be needed. Also a better distribution of plants through the country will reduce the cost of paving blocks by lowering haulage costs, which can be large.

No major changes are foreseen except, possibly, improvements in block handling methods. It can be fairly claimed that the construction method is well established and can now be considered as another paving method added to those commonly used. The establishment of the method will be greatly aided by the publication of a British Standard for Concrete Paving Blocks, which is expected within two years.

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