UK research into concrete block pavement design

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Introduction

SINCE the first proposal to use concrete paving blocks as a highway pavement material in 1973, the development of design procedures has been conditioned by the need to persuade engineers that concrete blocks are effective structurally. In particular where design methods have been proposed, the proposer has recognised that the new method should embody existing design practice wherever possible. In particular the commonly adopted procedure for proportioning the thickness of a road's sub-base is based upon the recommendations of Road Note 29[1].

Compared to pavements designed according to western European practice, British pavements are frequently deeper and more accurately specified. This is seen by many as being both wasteful of material and indicative of regressive thinking. However, it is quite clear that if western European empirical design practice had been imported to UK, there would be no concrete block pavements subjected to vehicular loading in UK today. Furthermore, had a design procedure based purely upon laboratory and field observations been postulated, the development of concrete block paving would have been minimal. Therefore, in order not to inhibit the growth of concrete block paving in UK, those involved in design methods worked towards adapting existing flexible pavement design procedures to the design of concrete block pavements.

Initially, design research was orientated towards examining the efficiency of concrete blocks in dissipating vertically applied loading. An analysis of the initial results indicated that a layer of concrete blocks constitutes an integral pavement course having elastic properties analagous to those of conventional flexible pavement materials. This initial conclusion lead to recommendations for the structural design of pavements for residential roads[2 3]. At this time (1975), it was felt that blocks should be confined to lightly trafficked areas only until more experience had been gained.

Owing to pressure from UK block paving manufacturers, who were finding industrial paving uses for their products, research workers turned their attention away from highway design and developed design procedures for pavements subjected to frequent loading by the heaviest on-highway vehicles. Design procedures were published[4] in which the roadbase was included in the pavement structure for the first time. These procedures were based partly upon the original UK research work[2] and partly upon observed performance at several UK industrial sites.

The final development in design procedures was the formulation of a procedure for the design of pavements subjected to off-highway vehicles, particularly those subjected to loading by container handling vehicles. This work has been published in the technical journals of the container handling industry[5 6] and is to be presented in detail at this conference.

Since 1975, experiments have been conducted in order to verify previously postulated design methods. An experiment was undertaken to examine the residential road recommendations and this was published in 1979[7] and an experiment was conducted to examine the effect of relaxing the sub-base specification[8] in line with Dutch practice.

Throughout the period of growth of concrete block paving in UK, many have questioned the relative merits of different sizes and shapes of blocks. Indeed, this is one of the most commercially sensitive areas of design and specification. The technology of manufacture of concrete blocks is largely of West German origin whereas the pavement design procedures were based initially upon Dutch practice. West Germany is dominated by shaped blocks whereas the Netherlands have a tradition of rectangular blocks. Both shaped and rectangular blocks have developed in UK, since the introduction of rectangular blocks in 1974. Several experiments have been conducted to compare blocks of different shape[2 8] and although minor differences have been found, it has yet to be established whether these are due to inherent characteristics of the blocks or the peculiarities of the particular experiment. It is generally agreed that 80 mm thick blocks suffice in all loading conditions but that rectangular blocks should be laid in a herringbone pattern when subjected to vehicular traffic. Where traffic is particularly light, 60 mm blocks are sometimes used.

1. *Vertical interlock* (Figure 1)

If a vertical load were applied to a block without vertical interlock, that block would slide down vertically between its neighbours, placing high vertical stress into the underlying course. Vertical interlock is achieved by vibrating the blocks into a well

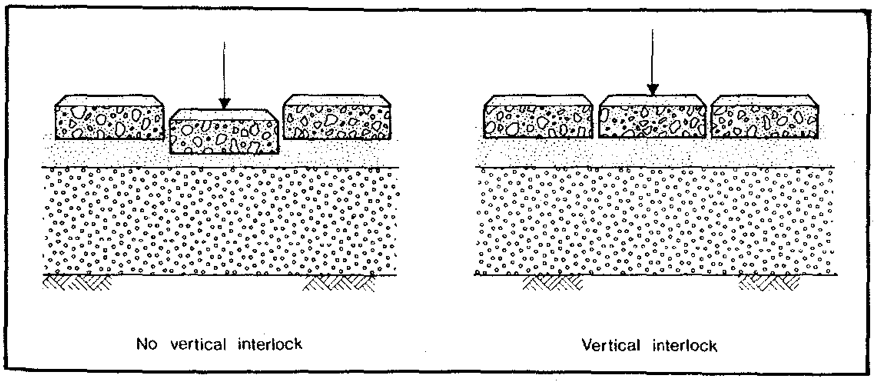

Figure 1: Achievement of vertical interlock

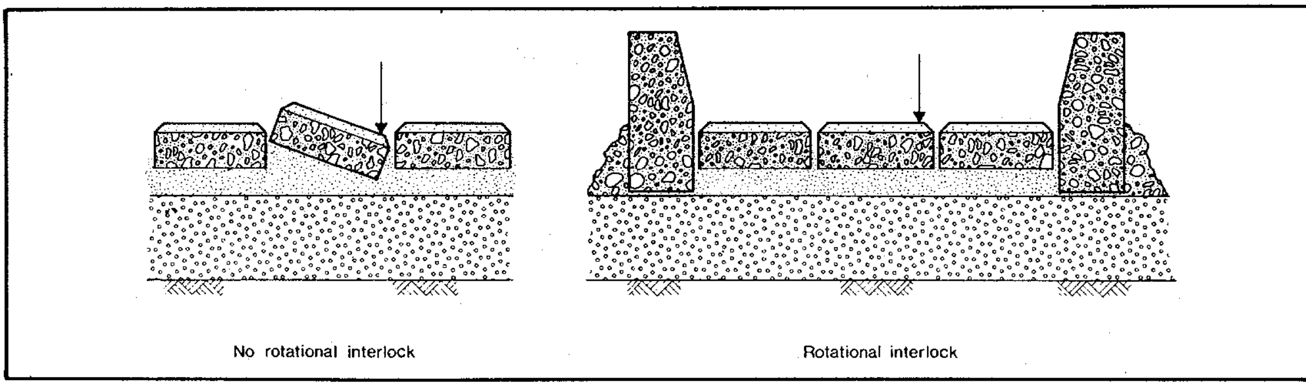

Figure 2: Achievement of rotational interlock

graded sharp sand during construction. This induces the sand particles to rise 25 mm into the gaps between the blocks. These gaps are from zero to 6 mm. A well graded sand has particles from almost zero to 6 mm. Therefore, in any position around the perimeter of a block, particles of sand wedge between neighbouring blocks so allowing a vertically loaded block to transfer its load to its neighbours through shear.

2. *Rotational interlock* (Figure 2)
A vertical load applied asymmetrically to a block tries to rotate that block. In order for an individual block to rotate, it must displace its neighbours laterally. Therefore, if the neighbouring blocks are prevented from moving laterally by edge restraint, an individual block is prevented from rotating and rotational interlock is achieved. Evidence also exists to support the theory that fine round sand brushed into the surface also helps to induce rotational interlock. A maximum particle size of 3 mm has been suggested for this sand and a builder's sand is frequently used for this purpose.

3. *Horizontal interlock*
The phenomenon of creep was observed in 1979, particularly when rectangular blocks were laid in stretcher bond pattern with their longer axis transverse to the principal direction of traffic. Horizontal braking and accelerating forces move blocks along the line of the road and eventually the blocks break as the corners of one row of blocks impart high local tensile stress into the next row. This phenomenon can be eliminated by using a shaped block or by using a rectangular block laid in a herringbone pattern. Although creep cannot be totally eliminated at severe braking locations, its effect can be reduced to a level whereby breakage is eliminated and there is no visual consequence.

A considerable amount of attention has also been focused upon the properties of the individual blocks. The most important in relation to structural design of the pavement is strength. The method of strength testing and the expression of test results have received considerable attention. Several procedures have been proposed and a British Standard publication is in course of preparation. The first strength test procedure[3] recommended that the blocks be compression tested, air dry, with insulation board cushioning the block surfaces. The total load was to be divided by the wearing surface area to obtain the failure stress. Ten such tests were to be undertaken and the characteristic strength obtained. Since that time, several changes have been made to this procedure. However, the authors are of the opinion that the discussion which has taken place on this issue is of little value since there is as yet insufficient recorded information correlating crushing strength with the more fundamental and important characteristic of durability. The authors are of the opinion that the characteristic strength concept is correct and must be retained by the British Standard Committee.

The remainder of this paper deals with the background to current design procedures for residential roads, heavily loaded pavements and port pavements.

Interlock

All the design procedures to be discussed depend upon interlock being achieved within the blocks. Interlock can be defined as the inability of a block to move in isolation from its neighbours. Three types of interlock must be achieved by adequate design and construction.

The effect of interlock in stress dissipation

The first UK attempt to quantify the effect of interlock in dissipating applied load was reported in 1976[2]. An area of 2 m x 2 m concrete block pavement was constructed over an array of 24 pressure measuring cells. A static vertical load was applied to the surface of the pavement as shown

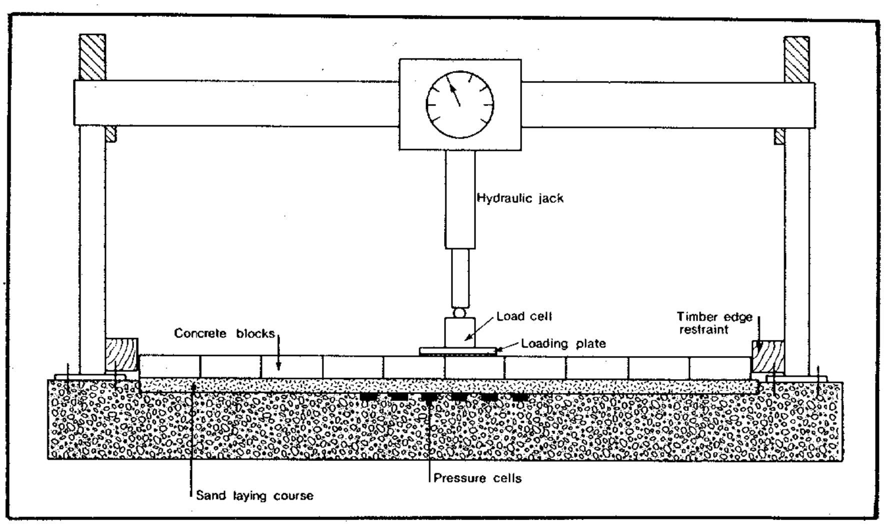

Figure 3: Application of static vertical load to the surface of the pavement

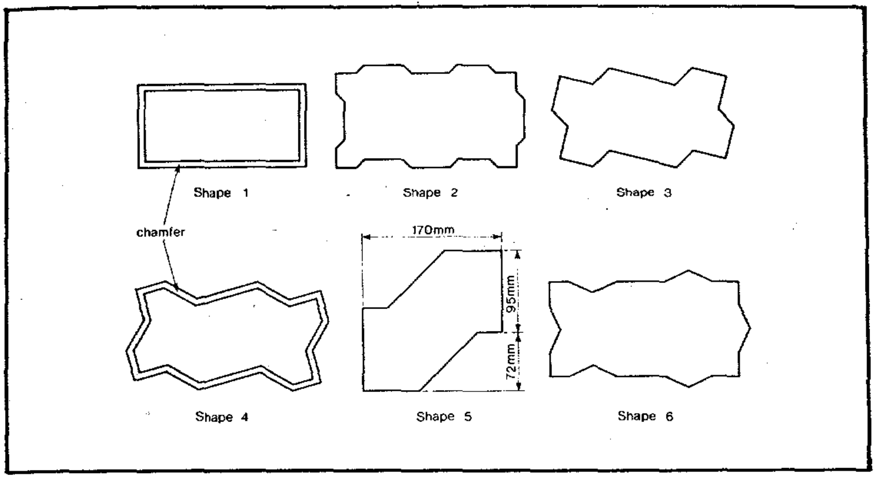

Figure 4: The six different block shapes tested

TABLE 1: Sub-base thickness for residential roads[3]

Type of road	Type of sub-grade				
	Heavy clay	*Silt*	*Silty clay*	*Sandy clay*	*Sand*
Cul-de-sac	380 (530)	380 (530)	180 (290)	130 (220)	80 (80)
Up to 25 PSVs/day	420 (570)	420 (570)	200 (320)	150 (250)	150 (150)
25-50 PSVs/day	450 (600)	450 (600)	220 (340)	170 (270)	150 (150)

(Figures in brackets apply when the water table is within 600 mm of the surface).

in Figure 3 and the stress at the bottom of a 50 mm layer of sand was measured. Loading of 50 kN was applied to a series of 8 pavements, using blocks of six different plan shapes, as shown in Figure 4.

The stress recorded by the pressure cells is shown in Figure 5 as a percentage of the applied surface pressure. The figure shows that as load increases, the percentage vertical stress at the bottom of the sand decreases, reducing to 60%, implying that the greater the applied stress the greater the load spreading ability of the blocks. The load spreading ability was found to be substantially independent of block shape, block thickness and bond pattern.

By comparing the load dissipating ability of concrete blocks with that of conventional flexible pavement materials, it was deduced that 80 mm blocks over 50 mm sand is equivalent to 160 mm of bituminous material. Although this deduction is based upon a tenuous argument, several full scale trial areas were being observed at the time and these observations verified this conclusion. Also, western European experience, which had already been documented,[9,10] pointed towards this direction.

The main conclusion of this early example of UK design research was that a concrete block pavement has considerably more strength than would be expected from a collection of individual blocks. Interlock allows a concrete block pavement to be considered as a flexible pavement. This is of fundamental importance as it gave rise to the development of design procedures for several types of pavement. Indeed, all subsequent UK structural pavement design thinking originates from this work. It must however be stressed that the initial conclusions drawn were based only partly upon the laboratory tests; the observations, particularly of deflections of pavements in the field, provided much of the confidence needed to allow the previously stated conclusions to be drawn.

Residential Road Design

Using the conclusions from the initial research, engineers at the Cement and Concrete Association published a design guide for residential roads in 1976[3] in which a concrete block road was assumed to comprise the elements shown in Figure 6. As far as possible, design followed conventional practice; minimum cross falls of 1:40 were recommended; conventional edge detail was suggested and advice on cutting to gully gratings and inspection covers was

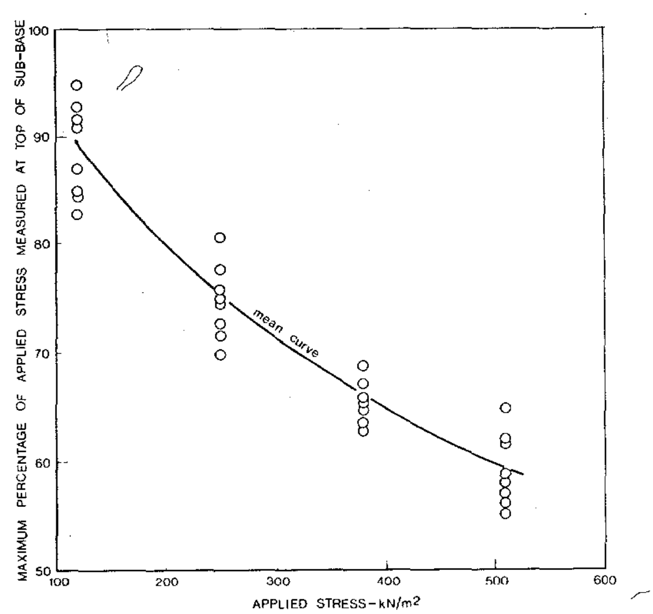

Figure 5: The stress recorded by the pressure cells

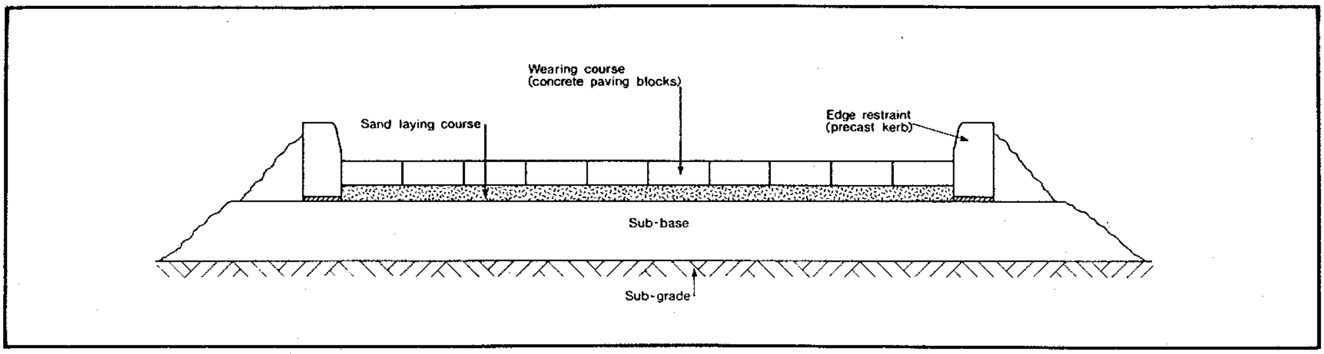

Figure 6: A concrete block road was assumed to comprise the elements shown (See reference 3)

provided. The document gave sub-base thicknesses assuming a 25 year design life (in a revised version, different design lives were used). These sub-base thicknesses are shown in Table 1.

The recommendations of this document soon found widespread use. Tables similar to Table 1 were used by most UK paving block manufacturers and concrete block paving was used on many residential developments. However, it became clear that residential roads were a less important use of concrete block paving than industrial areas. Therefore, engineers at the Cement and Concrete Association turned their attention towards this problem.

Industrial pavement design

Taking the results from the initial research[2] and calculating the thickness of roadbase plus surfacing required for a conventional heavily trafficked pavement, engineers at the Cement and Concrete Association determined the thickness of roadbase required for pavements subjected to a high number of standard axles[4]. By assuming 80 mm blocks plus 50 mm sand to be equivalent to 160 mm rolled asphalt, 225 mm lean concrete or 170 mm dense macadam, it was possible to deduct these thicknesses from the total thickness of surfacing plus roadbase specified in Road Note 29[1] to obtain the residual thickness of roadbase required underneath the sand. The resulting roadbase thickness is shown in Figure 7. As for residential roads, the sub-base is obtained from Figure 6 of Road Note 29[1].

Recommendations were also formulated for detail design. Crossfalls to drainage channels of 1:40 and longitudinal falls to drainage channels of 1:180 were suggested. The minimum block thickness recommended was 80 mm but the authors commented upon the use of thicker blocks in some pavements. No differentiation was made between block shapes and rectangular blocks received a good deal of attention by the authors.

Perhaps the most significant experimental work concerned with the use of heavy vehicles on a concrete block pavement was reported in the Proceedings of the Institution of Civil Engineers[8]. A pavement comprising a poorly graded sand sub-base, a 50 mm sand laying course and 80 mm blocks was constructed over a sub-grade with a CBR of 3%-5%. The pavement was trafficked by heavy commercial vehicles in an industrial yard and despite the poor quality of the underlying layers, the pavement performed much better than current design recommendations would have predicted. Where the pavement was constructed over a soft spot, a deformation of 100 mm took place rapidly. This deformation was made good, using the existing blocks, and no further severe deformation took place. It is interesting to note that although this pavement was grossly underdesigned in most respects, and although a localised serviceability failure took place, no structural failure was obtained.

On this experiment, both rectangular and a proprietory shaped block were used in almost identical situations. The authors believe this to be the first opportunity to compare rectangular blocks with shaped ones in a totally realistic industrial loading situation. No significant difference was recorded between the performance of the shaped block and the rectangular block, which reinforces the UK position whereby blocks of any sensible shape are considered equal structurally.

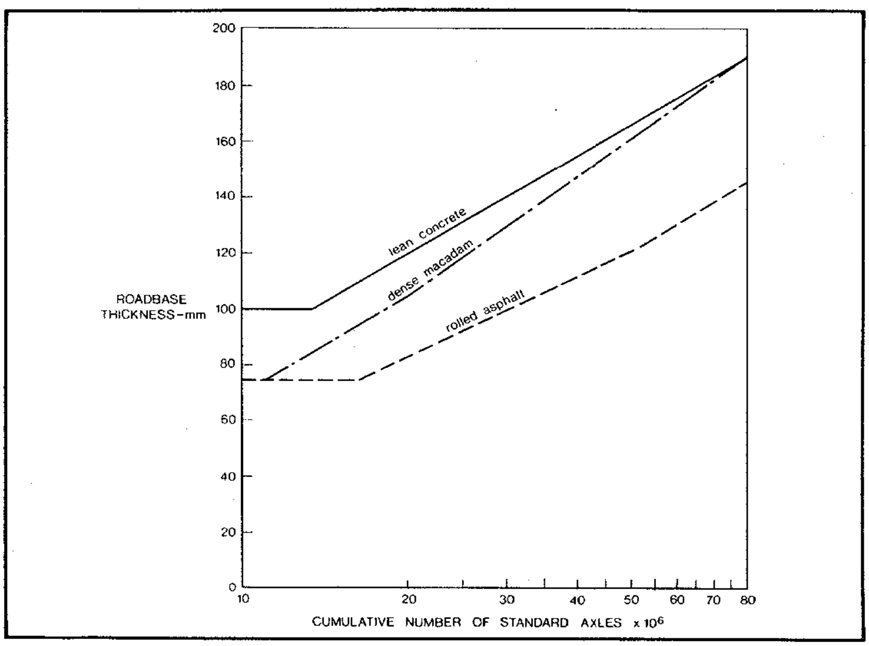

Figure 7: Roadbase thicknesses required beneath blocks for pavements carrying up to 80 million standard axle loads

Port pavement design

Although concrete blocks have been used in several European ports for many years and several major port pavement projects have been executed in UK, there was until recently no unified design method available to port pavement designers. This problem is equally true for more traditional port pavement materials. The publication of a port pavement design method at Ro-Ro/80[6] and at this Conference represents a major step forward, both in port pavement design generally and in the use of concrete blocks in the heaviest load situations. As the method is described in detail elsewhere, it is not described here.

The method is based upon the PAWL (Port Area Wheel Load) concept whereby the damaging effect of a vehicle can be read from a table and the design life of a trial pavement can be assessed in terms of the number of passes of the vehicle. The method can deal with a mix of vehicle types and gives the designer freedom in selecting the strength and thickness of the roadbase. It is proposed to extend the concept from purely a structural pavement design method to a procedure allowing the designer to select the optimum cost combination of pavement area, vehicle characteristics and pavement thickness to deal with his particular operational constraints.

The reasons for favouring concrete blocks as a port area surfacing material have been documented[5]. As well as having structural advantages, concrete blocks are durable and are resistant to oil spillage and other aggressive agents frequently present in ports. They are particularly suitable where severe settlement is predicted, for example on reclaimed areas and development areas where older dockworks have been filled to provide pavement facilities more in keeping with present day operations. There is also a considerable cost advantage associated with concrete block paving in ports.

Conclusions

Compared with most countries to which concrete block paving has been introduced, market development in UK has been slow. This is due largely to the well established practices in competitive pavement materials. It has also been influenced by the relatively high cost of UK paving blocks and by the low level of capital investment since 1973. However, growth is being maintained, particularly in trafficked situations. Undoubtedly, without the research into design methods described in this paper, growth would have been less and block paving development would have been seriously retarded.

The UK approach to design has been criticized by many who regard the adoption of Road Note 29[1] sub-base design curves as conservative. Technically, this criticism has some justification but there is no doubt that the use of a familiar design technique has been of major benefit to the development of block paving in UK. Also, virtually all UK block pavements are performing satisfactorily and first time users frequently respecify the material for subsequent work. It is also true that the formal approach to design adopted in the UK has prompted engineers in traditional block paving countries to reassess their approach to design.

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