THE CHOICE OF AN APPROPRIATE BLOCK SHAPE FOR HEAVY INDUSTRIAL FLEXIBLE PAVEMENTS

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SUMMARY

This paper investigates the likelihood of a difference in structural performance between profiled and straight-sided block shapes, with a strong emphasis on heavy industrial pavements. The conclusion reached is that a simple block shape is likely to be less prone to failure than a more complex profiled shape when subjected to very high horizontal or vertical loads. The paper does not address in any depth the important issues of subbase design, block thickness and block strength, except where these issues affect the theories offered in this paper.

1. BLOCK APPLICATIONS IN HEAVY INDUSTRIAL PAVEMENTS

As far as we know, both profiled and straight-sided block shapes are used in Germany and the United Kingdom. In Australia, profiled blocks are in common usage while in Holland rectangular blocks are the norm. We assume that both types are manufactured in countries such as Argentina, Denmark, the United States, Canada and Indonesia.

This situation also exists in New Zealand, where concrete block pavements started to be manufactured, used and tested from the mid seventies onward.

To date, only a very small proportion of heavy industrial flexible pavements have been specified and laid in concrete blocks, and then mainly in the profiled type. The reasons for Owners to prefer asphaltic concrete pavements appear to be two-fold. Firstly, up to 1982 asphaltic pavements were cheaper. Secondly, there was a reluctance (and there still is to some degree) to change to a less traditional paving system. However, recent tender prices in New Zealand indicate that concrete block pavements are going to be more economical than asphaltic concrete pavements even from an initial capital cost point of view, and disregarding the longterm spin-offs of greater durability, ease of repair and constancy in performance of concrete blocks. In early 1982, a spectacular failure occurred in two concrete block pavement strips at a major industrial site near Auckland. At the same time, a less than satisfactory performance was observed at a port site which had been paved from some two years.

These observations have led to further investigations and to the writing of this paper.

2. HEAVY INDUSTRIAL LOADINGS

For dynamic loading, we have chosen a 20 ton wheel load with a tyre pressure of 1 N/mm^2 moving at moderate speed across the pavement and accelerating or decelerating rapidly, either by the carrier braking or slewing. (The effect of interaction between closely spread wheels is outside the scope of this paper).

The above load would seem unusually high, but it is in fact the load specified by the Owner for a New Zealand site development.

Static loads of up to 40 tons on very small contact areas are also briefly discussed.

3. BLOCK PERFORMANCE

The reasons for requiring the individual blocks to remain uncracked are several. If a crack occurs, it becomes an uncontrolled joint which will invite water penetration into the bedding layer. Almost invariably, the concrete on either side of the joint starts spalling, a process which rapidly accelerates as the number of wheel passes increase.

The cracks divide the blocks into smaller, less stable elements, and re-distribute the initial horizontal load transfer pattern; hence further cracking is generated.

It is obviously important to avoid block failure by cracking, and to investigate the reasons for such failure.

4. FAILURE DUE TO COMPRESSION

If one specifies compressive block strength as the main strength criterion, then one obviously expects compressive failure to be the main mode. But is this the case?

Take a 20 ton load on a tyre with a pressure of 1 N/mm^2. The interface between tyre and block pavement will be in the order of 0.2 square metres (see Figure 1) and the compressive load on the blocks is obviously in the order again of 1 N/mm^2. Hence, if an ideal load transfer to the subbase or subgrade is achieved, then a compressive block strength of say 30 N/mm^2 would give us an unrealistically high safety factor. In order words, one would certainly not expect a compressive type of failure.

With static container stacking, we have a situation of highly concentrated point loads that may impose a compression of 40 tons over 30,000 mm, or 13 N/mm^2 on the blocks. This is many times higher than that imposed by the static portion

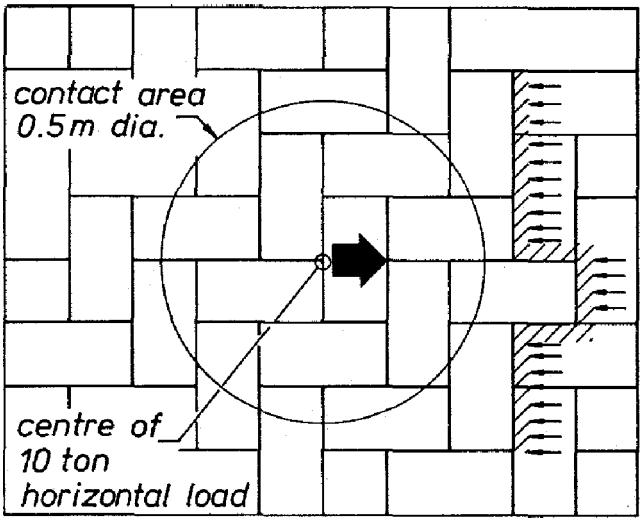


Figure 1: Braking force diagram for 20 tons wheel load

of wheel loads, but again a compressive block strength of 30 N/mm^2 should cope with this.

So why do blocks crack? Obviously, there are other modes of failure that should be considered.

5. THE EFFECT OF INTERLOCK ON VERTICAL LOADS

If the individual blocks are quite capable to transfer vertical loads to the subgrade, then why insist on interlocking to spread this load? The only reason would be, and we stress that we are now considering vertical loads only, that the subgrade would locally deflect to an unacceptable degree. This deformation can be reduced by load spreading, hence the desire for interlocking. All block shapes display some beneficial degree of interlocking when finally laid in the pavement. The degree of interlocking depends on the quality and width of the joints, but in practice any well-designed pavement has enough ability to competently transfer vertical loads to the sub-base without causing high differential pavement deflections. We therefore conclude that for vertical loading the block shape is of little consequence, provided that the interlock is more or less constant around all sides of the block.

From the results in a paper presented by Knapton and Barber called "UK research into concrete block pavement design", this conclusion is supported by a vertical load test conducted in the UK in 1976.
An area of concrete block pavement was constructed over an array of pressure cells just below the bedding layer. Various block shapes were vertically loaded and the degree of load spreading ability between the various shapes measured. This ability was found to be substantially independent of block shape.

Let us now consider the situation where there exists a marked difference in interlock around the block, such as perfect interlock along the short sides and no interlock along the long sides. The block then acts as a deep beam in bending.

For a 20 ton wheel load uniformly distributed over 10 blocks, each block is loaded by 20000 Newtons. The section modulus of a 200 x 100 x 80 mm thick block in a vertical plane is 107000 mm^3. The resulting flexural tensile stress is 5 mPa.

The above loading conditions assumes that the resistance in the end joints is higher than the load-carrying capacity of the underlying bedding layer. However, this assumption is not so unrealistic given that for a concrete modulus of elasticity value of 35000 mPa, the deflection under load is only 0.015 mm. This is very small and easily accommodated by the bedding layer without contributing a noticeable reaction.

We conclude that block failure due to vertical loading is unlikely provided that the flexural tensile strength of the block is high.

An even interlock condition around each block remains desirable.

6. THE EFFECT OF INTERLOCK ON HORIZONTAL LOADS

We consider a 20 ton wheel load decelerated from 10 metres per second to nil in 2 seconds. The corresponding horizontal loads is 10 tons over a front of 3 equivalent block widths (see Figure 1), or approximately 30000 Newtons per block.

Such a force will cause no problem in any shape of block if the joint strength is equal along all sides.

However, there is a problem if this is not the case. In Figure 2, two systems are pictured. The first system shows the transfer of load from one block to another when the joints are constant in strength and quality. The block is mainly subjected to pure compression, hence no problem exists.

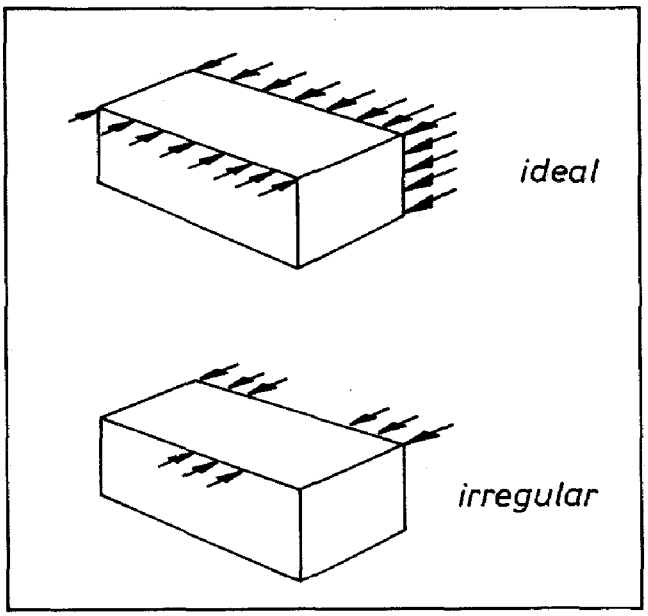


Figure 2: Horizontal load transfer between blocks

The second system shows the condition where the joints provide an irregular load transfer, in this case through full interlock along the short sides and inadequate joints along the long sides. The block then acts as a deep beam in bending.

The section modulus of a 200 x 100 x 80 mm thick block in a horizontal plan is 130000 mm^3. The resulting flexural tensile stress is in the order of 6 mPa.

This load condition is in our opinion not uncommon, and calls for:

a high flexural tensile concrete strength, and/ or a greater section modulus.

It seems clear that an even load transfer is of importance to avoid high tensile stresses.

7. THE EFFECT OF BLOCK SHAPE

So far, we have attempted to show that joint performance is very important to the behaviour of a heavy industrial block pavement in particular under horizontal loading conditions but certainly not excluding vertical forces.

So which shape will give us the greatest practical chance of an even joint pattern?

It is our opinion that the simpler the block shape, the more chance of a consistent interlock. Such a shape is not profiled, but simply rectangular or square.

A further change in horizontal load transfer takes place when hinges form at the joints in accordance with the Prandtl Theory. This phenomenon was reported at the last congress by Van der Vlist.

Prandtl's theory assumes waves forming in front and behind the passing wheel load. These waves cause the formation of hinges between blocks, either at the top of the blocks under the load or at the bottom of the blocks directly in front of and behind the wheel.

Now consider such hinge formation in a profiled block (Figure 3).

It may be seen that when hinges form between profiled blocks, the inside joint opens up (from j to j + Δj). Although this widening is minute, it will probably cause a change in the mode of load transfer which will now take place at points A only.

Consequently, one would expect high stress concentrations at these points A which are far in excess of the stresses induced by a line load such as would be transferred between the straight faces of rectangular blocks. Hence, one would expect cracking generated from these serrations. And this is in fact what we have observed at our test site in New Zealand.

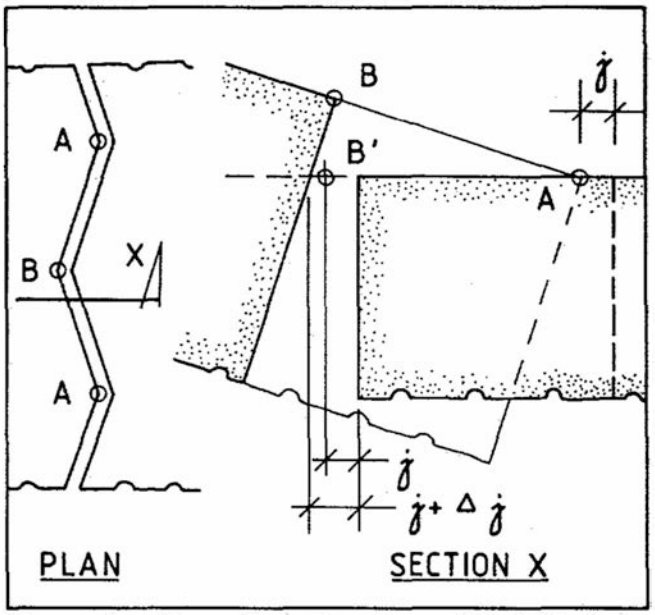


Figure 3: Hinge formation in profiled blocks

8. CONCLUSIONS

For heavy industrial block pavements, we suggest that a block shape with straight sides is the appropriate choice, for the following reasons:

(i) There is a better chance of a constant quality interlock around all sides of the block. The degree of interlock is less than for profiled blocks but its constancy is of greater importance.

(ii) A rectangular block is less prone to stress concentrations than a profiled block under horizontal loads, hence less chance of flexural tensile failure.

(iii) A rectangular block pavement behaves better when subjected to traffic wave deformations than profiled blocks as horizontal forces will be transferred as line loads rather than point loads.

(iv) From a practical point of view, rectangular blocks are easier to uplift and replace when services need to be installed under the pavement. This happens frequently at industrial sites.

We would have no hesitation to specify high strength profiled blocks in New Zealand for light to medium industrial pavements, as their basic interlocking capacity is superior to rectangular blocks.