A DESCRIPTION OF 'INTERLOCK' AND 'LOCK-UP' IN BLOCK PAVEMENTS

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SUMMARY

In many parts of the world segmental block paving is rapidly gaining popularity in applications as divergent as the heaviest industrial applications to light paving for footpaths. Specifiers who are familiar with pavement engineering terminology are often introduced to the possibilities of segmental blocks by non-technical sales promotional literature. Considerable variations in the meaning of the widely used terms 'Interlock' and 'Lock-up' exists and misunderstandings have occurred.

This paper describes some of the problems the misapplied terminology has produced and defines 'Interlock' and 'Lock-up' in a manner consistent with established pavement engineering terminology. Considerable experience in testing a wide variety of block pavements by Heavy Vehicle Simulators has been gained in South Africa. The pavements tested included those which had been just laid where any environmental effects had not yet occurred, and pavements which had been in service for some considerable time and subjected to both traffic and environmental effects. Typical curves of rutting plotted against time were generated from this work and are shown to confirm the definitions given. The improvements in the performance of block pavements that occurs with time are also discussed. The inter-relationship of individual blocks within their matrix by the jointing material is shown to be very important and this is further shown to provide the flexible response of the block pavement as a whole to induced loading.

1. INTRODUCTION

Two terms, "interlock" and "lock-up", are commonly used in connection with segmental block pavements. From discussions with both manufacturers and specifiers of blocks and paving bricks, there appears to be some misunderstanding as to the meaning of these terms. This paper attempts to clarify and define current usage of the two terms. It also describes an anomaly with respect to "lock-up", offers an explanation in terms of comparative pavement design and practice, and then suggests a redefinition of the two terms.

2. DEFINITION OF TERMINOLOGY

Modern blocks and paving bricks are manufactured with vertically-square side faces and may be shaped (in plan) to allow them to interlock with adjacent blocks. Many types of block are manufactured, but the two main types are those with interlocking shaped sides in plan, and those with non-interlocking shapes. The second type are commonly either paving bricks made of fired clay (of similar dimensions and shape to wall-bricks) or concrete bricks which abut with no interlocking effect. Blocks interlock due to compressive forces which keep individual blocks in place. Some shear interlock also occurs, but there is little tension interlock as with a piece in a jig-saw puzzle, for example. Any vertical interlock is restricted to forces within the joints. Interlocking blocks can be said to be geometrically interlocking in the horizontal plane provided that they are contained within kerbing or some similar means of restraint. Fully interlocking (ie S-A) and rectangular (ie S-C) blocks can be laid in a variety of bonds. The most usual are herringbone, stretcher or basket weave. The principle advantage of one bond over the other is aesthetic, although by laying the bonds where joints are at 45° to the direction of trafficking the blocks are less subject to the effects induced by the wheels of vehicles.

"Interlock" therefore refers to the geometric relationship between one block and its neighbour, and in this regard it can be said that a particular block type is either interlocking or non-interlocking.

"Lock-up" has been described by Marais and Lane(1), the Cement and Concrete Association of Australia(2) and Shackel (3) as a phenomenon which develops in block pavements after a certain amount of time has elapsed after construction. The construction of sand-bedded block pavements normally involves two passes of a small vibrating roller to bed the blocks into the bedding sand and to vibrate material into the joints between the blocks. After construction, owing to the action of traffic and weathering, the blocks are said to "lock-up". In this condition the blocks are thought to act as a composite whole rather than as individual units. It is interesting to note that areas which are not trafficked are also said to lock-up with time.

3. PERFORMANCE OF PAVEMENTS WITH TIME

The National Institute for Transport and Road Research has carried out many specialized tests, including Heavy Vehicle Simulator tests on many pavement types. These tests have shown that all pavement types, whether concrete, asphalt, tar or earth, behave similarly during what might be described as a settling-in period when pavements are subjected to environmental and/or trafficking stresses. Figure 1 shows an example of a graph of a type of surface deformation known as rut depth plotted against time for bituminous bases. The point at which the curve flattens (shown after time A on Figure 1) will vary according to the intensity and frequency of the applied loads and due to environmental factors. The final shape of the curve (at time C on Figure 1) will also vary and deterioration may be rapid or gradual. However, the shape is typical and shows that after a settling-in period when initial rutting is more pronounced, a more stable condition is reached and maintained for a large part of the life of the pavement. Similar curves have been obtained for block pavements (Shackel (3) and Clifford and Savage (4)) by Heavy Vehicle Simulator testing. Figure 2 shows a typical curve of rut depth against time for any pavement type. The flattening out of the curves on Figures 1 and 2 is a function of several factors such as density of subbase pavement thickness, but the pavement can support loads with little or no further rutting taking place during the working part of its design life, i.e. after the initial settling-in period and before the terminal conditions start to develop.

The term settling-in of a pavement, which applies to all pavement types, may therefore be a more suitable description lock-up which is used only for block pavements.

Some degree of settling-in is attributed to environmental factors - in earthworks technology the term environment refers not only to the climatic parameters, but also to parameters of the subgrade upon which the pavement is constructed. The drainage and thermal properties of the subgrade are modified by the pavement overlying it. The relative influences of traffic and environmental settling-in are not yet fully understood.

4. THE SETTLING-IN OF BLOCK PAVEMENTS

The flattening of the curve of rut depth against time (Figures 1 and 2) shows that improvements in the structural properties occur after the initial settling-in period. This is not peculiar to block pavements, as mentioned before. The settling-in of a pavement structure can be explained with reference to a number of factors. Block pavements consist of blocks (whether interlocking or not) bedded into a thin (typically 20-25 mm in South Africa) sand layer with jointing sand between the joints of the blocks. The sand bedding layer lies on a subbase which in turn may lie on selected granular layers which overlay the subgrade.

The blocks should be laid in the bedding sand and vibrated into place with a small plate or wheeled roller. A second pass vibrates sand into the joints between the blocks. The climatic and environmental factors begin to affect the pavement immediately. The daytime and night-time temperatures vary and rainfall modifies the moisture content of the sand in the joints and in the blocks themselves. Passing traffic changes the quantity and density of sand in the joints either by wheel action or by the effect of wind generated by the moving vehicles. Any sand thus removed adds to the deposits of detritus lying on the surface of the pavement.

Detritus comprises particles of rubber, dust, organic matter and so forth. In time the detritus settles into the joints between the blocks and forms an upper plug over the jointing sand. Because of the complex nature of the detritus the plug formed helps to seal the joints thereby improving their waterproofing characteristics. An example of a jointing plug is given in Figure 3. In time a firm bond develops between the blocks and the jointing sand. The blocks themselves bed a little further into the bedding sand, which is also affected by its environment and absorb moisture, if present. The combined effect of all this is to compact the bedding sand and the jointing material to a somewhat higher density than that achieved immediately after construction. In this way the bonding of block, bedding sand and jointing sand is improved. This is the condition of the block pavement after the initial settling-in period.

In the settled-in condition the pavement is capable of supporting design loads with less accumulative rutting than immediately after construction, as is shown by the flattening of the rut depth time curves in Figure 2. A gradual deterioration of the pavement takes place during its working life - the curve is not flat during time B in Figure 2. The stage in which much more rapid rutting takes place is often due to degradation of the subbase and lower layers. This terminal behaviour of the pavement can cause excessive movement of individual blocks. Excessive deformation may also be caused by a very heavy load, causing differential settlement and rutting. Severe loads cause the bond between individual blocks in the jointing sand to be broken and the pavement becomes considerably more subject to water ingress and therefore rapid deterioration. A feature of segmental block paving is that the joints around the blocks can easily be re-established and the plug of detritus rapidly reformed to provide waterproof joints once more. Apart from the actual permanent deformation of the surface which may be unsightly, the pavement's strength remains unimpaired and it continues to be capable of supporting design loads.

5. REQUIREMENTS OF BLOCK PAVEMENTS

It has been stated in a number of reports on block pavements that the area must be "contained" within kerbs or by other means to stop lateral spread of the blocks (Clifford (5), Shackel (3) and the Cement and Concrete Association of Australia (2)). As has been stated above, the life of block pavements is long once a settled-in condition has been reached. One of the reasons for containing an area of block paving within kerbs is to stop lateral movement of the blocks which may be caused by trafficking. Lateral movement of the blocks would cause the joints to open out.

It is difficult to make an opening in a block pavement, particularly if the pavement is made of interlocking blocks (S-A). Invariably the first unit must be broken to remove it. Thereafter removal of single blocks is easier. Interlocking blocks are more difficult to remove than non-interlocking blocks since their shape allows little sideways movement and they

must be removed by lifting them vertically, which requires the bond on the sides of the blocks in the jointing sand to be broken at the same time.
Non-interlocking blocks can be raised more easily by a combination of vertical and rotational movements. Once an opening has been formed in an area of block pavement, the blocks whether interlocking or non-interlocking, must be kept apart by timbering or a similar method. If this is not done the blocks creep slowly towards the opening even if they are not subjected to trafficking. This slow movement of the blocks towards the opening is an indication of the forces built up in the jointing material, which becomes pressurized due to the action of trafficking and environmental stresses. This pressurization is desirable because it helps to secure individual blocks within the matrix and assist local transfer and dissipation of stresses. As the blocks creep slowly towards an opening the forces within the joints are dissipated thereby reducing the bond generated in the joints. The reduction of the jointing stress also reduces the ability of the joint to resist the ingress of water.

6. STRUCTURAL AND ARCHITECTURAL USE OF BLOCKS

Where areas of block paving are built for trafficking purposes, whether for light traffic, as in the case of car parks, or for heavy industrial applications such as container stacking areas or factory yards, the function of the blocks together with the sub-layers is structural. However, in applications such as the paving of embankments where curved surfaces are required, the blocks are used not only to support light loads occasionally, but to stabilize the embankment and protect it from environmental distress. An impressive example of such work, which can best be described as architectural applications, is given in Figure 4. In such cases interlocking units have a definite advantage over non-interlocking units because the interlocking action, especially in three-dimensionally curved paving, assists in locating the blocks in their bonding pattern. The possibility of differential settlement in such embankment work is much greater since the densities of the embankment fill are often specified to a lower standard than those of trafficked pavements. Interlocking blocks are allowed greater individual movement and are kept in place by bearing on neighbouring blocks even if parts of the subbase or the jointing are washed away.
An improvement can be made in the current practice of using interlocking blocks for architectural purposes to bridge weak or eroded areas: blocks designed to provide a three-dimensional geometric interlock can be used, which should have the advantage of more effectively bridging voids. Such blocks would also keep jointing sands in the joints for a longer period. Ingress of water into sub-layers would also be reduced. Figure 5 shows a subbase washaway bridged by three-dimensionally interlocking blocks. The suggested three-dimensional interlocking block is shown in Figure 6. However, the additional effort and care needed to manufacture a more complex block shape, together with the possibility of spalling of some of the corners, may negate any advantage such a shape may have for architectural applications.

7. CONCLUSIONS

The term interlocking describes the process by which certain types of paving block became bonded within the pavement matrix according to their physical shape. Some blocks interlock in one direction only (S-B blocks), and others interlock in two directions(S-A blocks). The latter are also known as double interlocking blocks. A structurally fully interlocking block has been proposed, for civic and architectural uses where block-paved areas are not really flat, which would interact three-dimensionally.
Certain changes take place in a block pavement in time. Environmental aspects affect block pavements soon after construction and with the action of trafficking a plug of road detritus forms over the jointing sand thereby giving the joints themselves better waterproofing characteristics. The sand in the joints also adheres closely to the sides of the blocks. The blocks themselves bed further into the bedding sand during this settling-in period, effecting additional compaction of the bedding sand. These developments, which occur during the settling-in period, have been described as lock-up. It has, however, been shown in this paper that all pavements undergo a similar settling-in period during which the rutting caused by applied loads is more significant. The term lock-up refers to a phenomenon held to occur in block pavements, but since this phenomenon is not unique, the term lock-up should be dropped and the block pavement should be described as settled-in. This term also refers to other pavement types.
Before settling-in occurs, the blocks are not closely joined to one another and firmly embedded in the bedding sand. During heavy rains it is possible that water can enter the subbase layers and cause saturation. If such a saturated state is related, rapid distress will be caused by trafficking. Care should therefore be exercised during the settling-in phase of block pavements to limit trafficking if heavy rains occur.

8. REFERENCES

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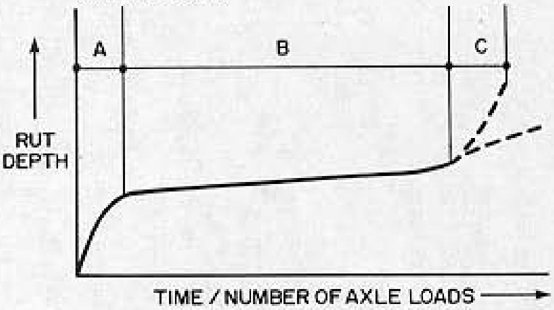

FIGURE 1

RUT DEPTH DEVELOPMENT WITH TIME IN BITUMINOUS AND GRANULAR BASES

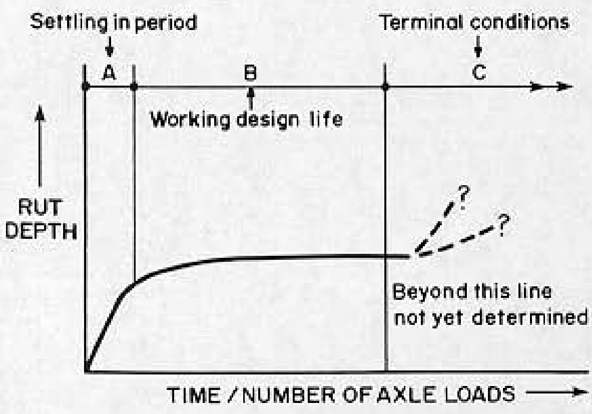

FIGURE 2

TYPICAL CURVE OF RUT-DEPTH WITH TIME MEASURED AT THE SURFACE OF A BLOCK PAVEMENT

FIGURE 3

EXAMPLE OF JOINTING-PLUG WHICH FORMS OVER JOINTING SAND WITH TIME TO IMPROVE WATER-PROOFING CHARACTERISTICS OF JOINTS

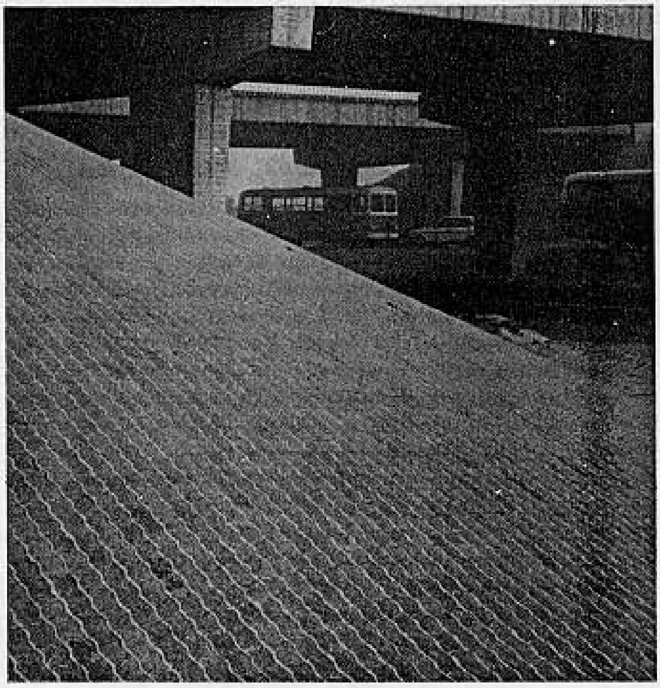

FIGURE 4

BONDING OF JOINTING SAND TO INDIVIDUAL BLOCKS

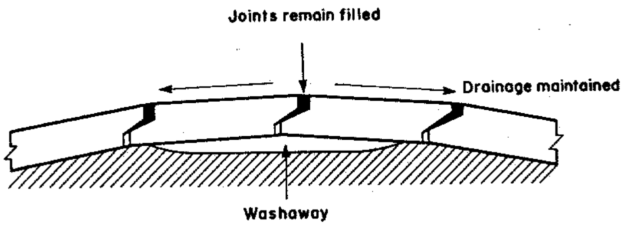

FIGURE 5

INTERLOCKING BLOCKS OVER WASHAWAY

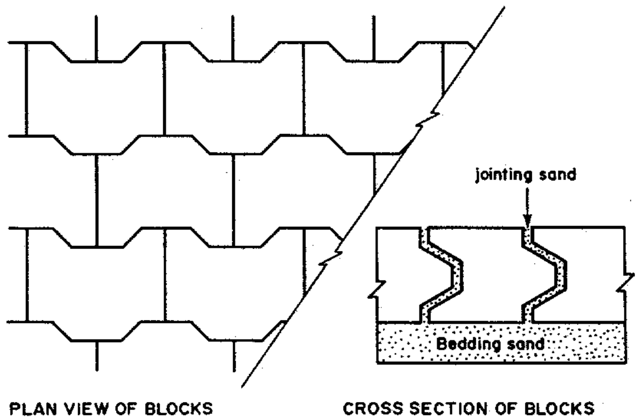

FIGURE 6

SUGGESTED THREE DIMENSIONAL INTERLOCKING BLOCK