SITE AND LABORATORY TESTING OF INTERLOCKING CONCRETE BLOCK PAVEMENTS

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SUMMARY
"Lockup" which converts an interlocking concrete block pavement from a flexible into a rigid structure has been reported but not adequately explained. In an attempt to first simulate and then monitor this phenomenon a series of block pull-out and related tests was programmed under laboratory and site conditions. The development of a pull-out device and preliminary testing are described and future work on the project is outlined.
The deterioration in skidding resistance of an interlocking concrete block pavement with trafficking and weathering is often quoted as a reason for restricting its use to low speed facilities. Results of tests carried out on pavements up to 6 years old have shown that, although skidding resistance values are declining, the levels vary seasonally and are, so far, well above standards set for low speed sites.

1. BACKGROUND TO TESTING PROGRAMME

The block pull out test programme was initiated after work during 1979 reported in MAVIN (1982). This early work demonstrated the "doming" which occurred when an attempt was made to remove a single block from an interlocking concrete block pavement (ICBP). At this time the pavement being investigated was a small scale (2m x 2m) laboratory test bed. The laboratory facilities available at RMIT are able to accommodate a much larger pavement however, it was considered that this area would be more than adequate for preliminary work. The basic hypothesis to be tested by the programme is that the progress towards "lockup" (referred to as "interlock" by SHACKEL (1980)) can be quantified in terms of the force required to remove single blocks from an I C B P as trafficking progresses. It was further envisaged that this work would be exetended to include "Pushing" tests under controlled laboratory conditions and maybe, eventually some site work. A more detailed discussion of these proposals is included later in the paper.

A number of interlocking concrete block pavements constructed in Melboune during the late 1970's have been used to monitor the deterioration in surface skidding resistance (measured by means of the BRITISH PENDULUM SKIDDING RESISTANCE TESTER). MAVIN (1982) reported results obtained during 1979 and this work has been continued since then. Skidding resistance values have also been recorded on two test pavements, details of which are presented by SHARP et al (1982). These results, which provide an insight into the seasonal variation in skidding resistance and the trend towards an equilibrium level, are described later in the paper.

2. THE ICBP & LOCKUP

The phenomenon of "lockup" or "interlock" is claimed to occur in ICBP's after a period of trafficking somewhere between 5000 and 10000 E S A's (SHARP et al (1982)). As a result of work at the National Institute of Transport and Road Research in South Africa SHACKEL (1980a) reports ".... block pavements develop interlock under traffic .... once interlock has been achieved the response of the pavement becomes independent of the magnitude of the wheel loads (within the range from 24 to 70 kN) and the number of load repetitions". This author further claims that lockup can be hastened by the attainment of "high standards of block laying" and by pre-loading the pavement prior to trafficking by means of a (light - medium) road roller. Other authors have advocated the use of the latter technique GERRARD (1982) suggests a vibrating roller and MAVIN (1980) specifies that it should be a 6 t roller.
If an interlocking concrete block surfacing adds to the structural capacity of a trafficked pavement it must do so by means of the interaction which occurs via the sand joints or by a wedging action, and the horizontal interlock due to the block shape. The latter depends upon the shape of the block (and the dimensional tolerances) and may occur on 2 or 4 (or more) faces. The vertical interaction is a function of the area of contact, the characteristics of the jointing sand and the horizontal forces applied.
Although examples of "lockup" are well documented, e.g. SHACKEL (1980a) as shown in FIGURE 1, there is speculation that the road sub-base actually "supports" the imposed load and the blocks merely provide a running surface. If a satisfactory explanation is to be provided for the functioning of an ICBP under traffic, then there are a number of questions which should be answered. The following may be pertinent:

1. Why does lockup occur, i.e what factors play a part?
2. When; in terms of trafficking/time, does lockup occur?
3. Does lockup occur in the wheel path first/only?
4. Are the techniques suggested for expediting lockup successful and are there any other means of achieving the same or better results?

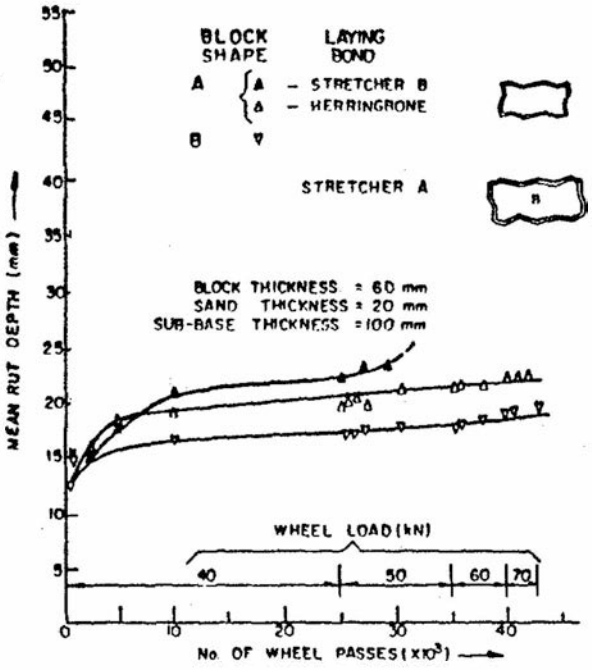


FIGURE 1. DEVELOPMENT OF INTERLOCK IN ICBP'S (AFTER SHACKEL (1980))

3. THE SKIDDING RESISTANCE OF I C B P'S

Preliminary research into the skidding of interlocking concrete blocks, e.g MAVIN (1982)1 SHARP et al (1982) SHACKEL (1980b) suggested that initially the pendulum skidding resistance value is high but that this decreases significantly following plate vibration then gradually falls as trafficking proceeds. Further, there was evidence that the skiding resistance value did vary seasonally, a phenomenon which has been noted to occur with other pavement surfacings. The questions which remained to be answered were whether the pendulum value of ICBP's would level off and if so, at what value this would occur.

4. PROPOSALS FOR PULL-OUT TESTS

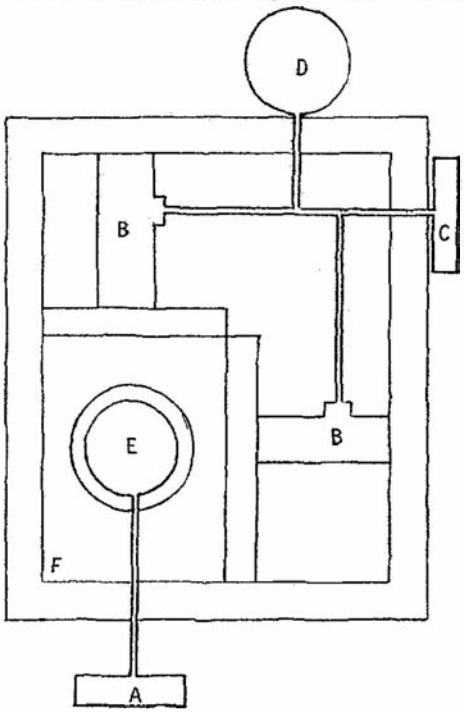
The first phase of the proposed programme, aimed at defining and describing "lockup", consisted of a series of pull-out tests. Preliminary laboratory testing involved determining the order of magnitude of the force required to pull a single block from a trafficked ICBP. This work had, as a second objective, the construction of a pull-out rig which could be used equally as conveniently in the field as in the laboratory. Finally, a series of field and laboratory tests were planned to investigate the variation in the pull-out force as other factors varied. The variables which were to be monitored were i) the horizontallyapplied force - in the laboratory test pavement; ii) the joint width; iii) the jointing sand; iv) the block shape and v) the influence of "doming". The phase addresses the first three questions listed previously, ie., Why, when and where does "lockup" occur? This phase will supply data to test mathematical models developed to describe the functioning of loaded blocks (FRICK 1983)

A second phase will examine the question of hastening any lockup which may occur.

5. BLOCK PULL-OUT RESULTS

The development of a suitable pull-out device was complicated by the trade off between rigidity and portability. However, after a number of trials a device evolved which appeared to satisfy the many contraints (FIGURE 2, 4 & 6). Perhaps the most difficult problem faced during the development phase related to the attachment of the pull-out rod. Various techniques were tried and these are shown in Figure 3. The arrangements a) b) and c) have been employed in laboratory testing the latter two being successful. As the pull-out load increased it was considered that d) may be required however, this has not eventuated. Arrangement e) has been used successfully in the field although where predrilled blocks have been installed during the construction of an ICBP either b) c) or d could be employed.

Testing began with a simple comparison between a pavement with sand joints and one without jointing material. These tests were carried out under laboratory conditions with the rig shown in FIGURE 2 & 4 The procedure involved pre-loading, (horizontally) unloading and incremental loading with incremental loading with pull-out at specified horizontal loads. Although this procedure wasn't repeated to determine the statistical validity of the data, it did indicate the importance of the jointing sand in distributing horizontal loads.



A - Hydraulic Hand Pump

B - Hydraulic Cylinders

C - Electric Powered Hydraulic Pump

D - Hydraulic Gauge

E - Load Cell

F - ICBP 600 x 650

FIGURE 2 LABORATORY TEST PAVEMENT - SCHEMATIC LAYOUT

Indeed, this early work was carried out mainly to gain an appreciation of the magnitude of the pull-out load. Following the success of the pull-out device in the laboratory, arrangements were made to employ it in the field. The ICBP test pavement located at the Australian Road Research Centre in Melbourne was used for site testing. Site procedure involved firstly attaching (with an epoxy - resin based adhesive) pre-drilled blocks to the pavements as shown in FIGURE 3 (d) + FIGURE 7. The pull-out (FIGURE 6) of blocks followed after a curing/setting period of 24 hours. Results from these tests are presented in TABLE 1. However, again, this work was carried out mainly to assess the order of magnitude of the pull-out force rather than to establish significant trends. It can be seen that in a number of cases, pull-out was not possible because the loxin slipped or a block split. These failures lead to the development of a different means of attaching the pull-out rod - FIGURE 3 c).
As a result of the laboratory and site pull-out tests it has been established that the pull-out device is capable of extracting blocks within the range of pull-out loads likely to be encountered with trafficked pavements.

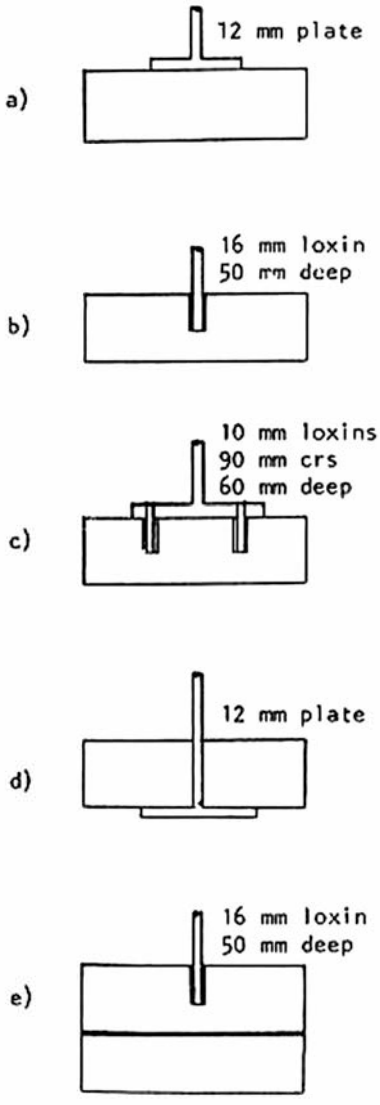


FIGURE 3. PULL-OUT TECHNIQUES

BLOCK SHAPE 

BLOCK THICKNESS mm	PULL-OUT FORCE kN	COMMENT
80	>16.2	loxin slipped
80	>11.9	block split
80	>11.5	block split
80	>10.0	loxin slipped
80	6.9	
80	7.7	
80	4.6	blocks
80	3.9	removed
60	2.7	
60	13.1	
60	7.7	
60	3.5	
60	7.3	
80	>10.8	block split
80	>5.4	" "

Note: All blocks between wheel paths

TABLE 1 BLOCK PULL-OUT ARRB TEST PAVEMENT

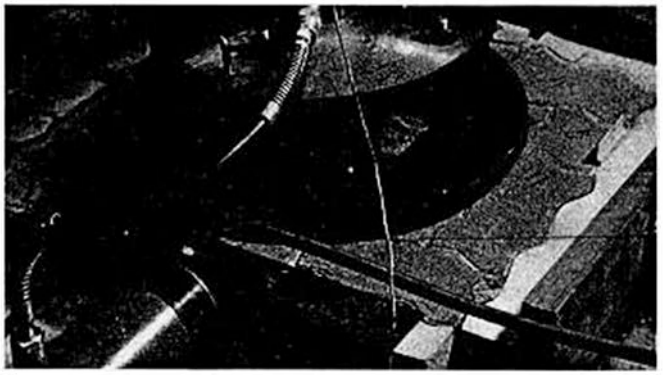


FIGURE 5. LABORATORY TEST PAVEMENT

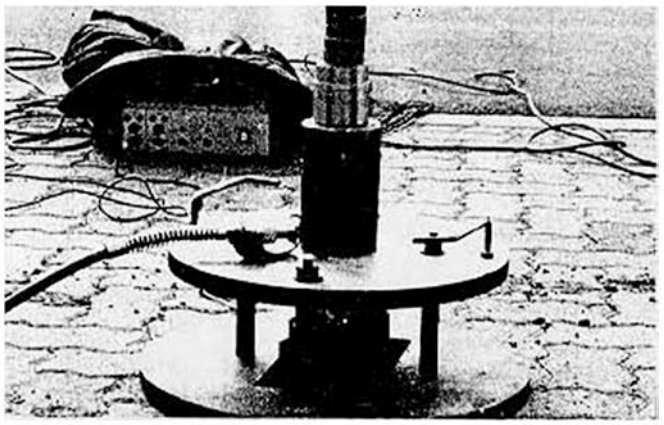


FIGURE 6. PULL-OUT TEST ON A.R.R.B I.C.B.P

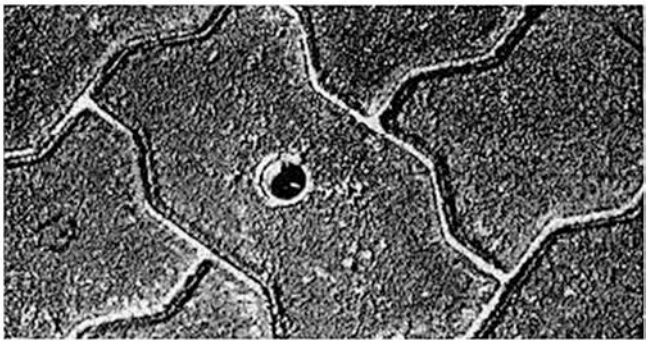


FIGURE 4. PRE-DRILLED BLOCK IN LABORATORY TEST PAVEMENT

This early development work is to be followed by laboratory tests aimed at gaining an understanding of the relationship between the pull-out load and the applied horizontal force. The first phase of this work has involved establishing a reproduceable, procedure covering laying, vibrating, loading and extraction. The project has advanced to this stage and data collected so far are presented in FIGURE 8.
If pull-out occurs without block-block contact then the form of curve shown in the figure results. However, if contact occurs (in tests carried out so far this occurs occasionally with horizontal forces above 20 kN) the pull-out load increases appreciably (by up to 90%). Early indications are that the block pull-out procedure developed can be employed to study any "lockup" which occurs in a trafficked I.C.B.P.

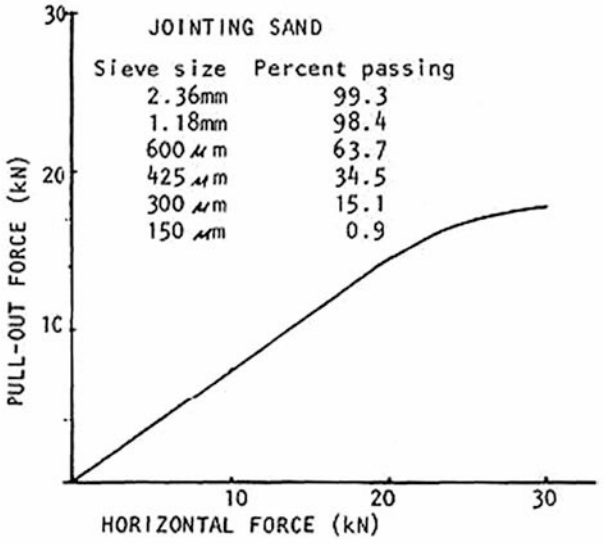


FIGURE 8. PULL-OUT RESULTS FROM LABORATORY TEST PAVEMENT

6. SKIDDING RESISTANCE RESULTS

The surface of the road pavement may be described in terms of its microtexture and macrotexture. In a surface dressing of aggregate the latter relates to the geometry, orientation and spacing of the aggregate and the microtexture is the texture (surface irregularities) of the aggregate itself. In an ICBP the surface of the block represents the microtexture and the jointing pattern constitutes the macrotexture. The skidding resistance properties of a pavement is influenced by both macrotexture and microtexture (OLIVER (1982)) "Macrotexture provides drainage channels for water displaced by the tyre and this becomes increasingly important as the vehicle speed rises. Both levels of texture contribute to hysteresis friction which is the major frictional effect in the tyre/wet road situation". For a given macrotexture it has been observed that the skidding resistance at a specified speed is related to surface microtexture. The macrotexture determines how rapidly the skidding resistance deteriorates with rising speed. Thus, with the deep macrotexture available in an ICBP surface, the level of skidding resistance for a specific vehicle speed will be determined by the available microtexture. The British Portable Skidding Resistance Tester is designed to simulate sliding between a road surface and the tyre of a vehicle travelling at 50 k p h. (TRRL (1969)).
The pavements studied were three off-street car parks (sites 1, 2 & 3) and a quarry access road (site 4, part of an Australian Road Research Board test programme) all located within Melbourne The car parks were constructed in 1977/78 and the quarry road in 1981. Details of the latter is included in SHARP et al (1982) and the three car parks are described in LUDGATE (1979).
Values of skidding resistance were recorded at each site using a portable skidding resistance tester, the results being corrected for temperature variations (OLIVER (1982)). The results, shown in TABLE 2 indicate that there was a significant reduction in skidding resistance following plate vibration and then a gradual decline with trafficking/time. At the quarry access road the skidding resistance of an asphalt surfacing (already trafficked for approximately seven years) was used as a control (sites 5 & 6). The sections tested were all on a downhill slope and, in part, on a horizontal curve. The values of skidding resistance for the ICBP and the asphalt control were recorded at intervals based upon the number of equivalent standard axles (E.S.A.'s) applied to the block pavement. In an attempt to monitor the influence of weathering on skidding resistance

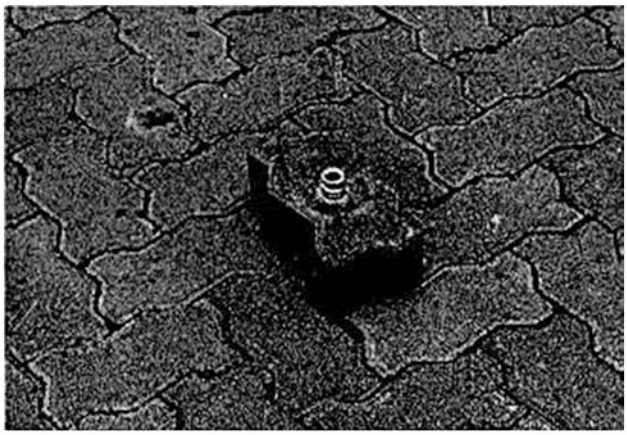


FIGURE 7. PRE-DRILLED BLOCK ATTACHED TO A.R.R.B. TEST PAVEMENT

TIME	NO. of E.S.A.'s	SITE 1	SITE 2	SITE 3	4	5	6
	New Block		81		78		
	After Vibration		74(70-82)		67		
NOV'79		59(56-63)	56(52-60)	61(59-65)			
MAY '80		68(64-71	61(58-65)	69(66-72)			
MAY '81		62(58-64)	65(58-69)	73(68-78)			
JULY '81						60	40
SEPT '81	8700				45	50	31
OCT '81	14500				42	40	24
DEC '81	20000				57	43	46
FEB '82	33250				51	40	43
APRL '82	47800				54	44	42
JLY '82	75000				65	53	54
JAN '83			54(52-57)				
MAY '83		64(62-68)	56(50-66)				
			58(55-63)				
JUNE '83	132500				62	52	45
JLY '83		61(58-64)	53(49-56)	58(57-60)			
		67(66-69)	62(59-66)	64(60-68)			
AUG '83		56(53-58)	53(50-55)	61(60-62)			
		62(61-63)	58(56-59)	62(61-64)			
SEPT '83	150000				64	46	51

TABLE 2 SKIDDING RESISTANCE, ICBP'S MELBOURNE

(Mean Skidding Resistance (Range))

Note: 1. Results have been corrected for the effect of temperature on the rubber slider (OLIVER (1982))

2. The no. of E.S.A's applied to 4, 5 & 6 have been estimated from truck volumes/ axle loads.

3. The sites 5 and 6 are asphalt control sections which have been trafficked for about seven years prior to the installation of the ICBP.

readings at the three car parking sites have included untrafficked blocks. A recent report on the seasonal variation in skidding resistance (OLIVER (1982)) indicated that the maximum change from summer to winter, with asphalt or surface dressings in Melbourne was 25 units. Further work is required to establish the seasonal variation which may be expected with ICBP's. However, it is apparent that the skidding resistance values of concrete block, even after six years of trafficking, are above accepted standards for trafficked routes (see FIGURE 9).

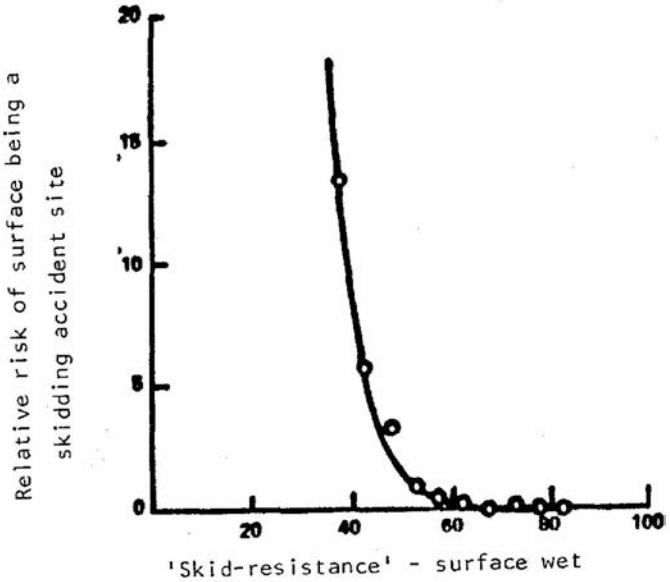


FIGURE 9. RISK OF SKIDDING ACCIDENT FOR DIFFERENT VALUES OF SKID RESISTANCE (GILES et al reported OLIVER (1982))

7. CONCLUSIONS

As a result of work carried out on a small labortary pavement and on a full-scale test pavement a procedure has been developed for extracting blocks from an inter-locking concrete block pavement. By extending this work it is intended to examine the lockup phenomenon - the crucial stage in the life of an interlocking concrete block pavement - following which increased loading has nil or negligible effect. The pull-out of single blocks by means of the device described will provide an insight into why lockup occurs, when it may be expected to occur, its extent with respect to the pavement cross-section and techniques, which may be employed to hasten its occurrence.

Further work, on the skidding resistance of inter locking concrete block pavements has shown that there is a significant reduction in the pendulum test value following vibration of the blocks. The change in skidding resistance which follows, due to trafficking and weathering is difficult to predict because of seasonal variations. It is hoped that further work will explain this latter effect. However, it appears that the skidding resistance of individual blocks does not drop below accepted standards for facilities commonly employing interlocking concrete block pavements.

8. REFERENCES

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