LABORATORY MEASUREMENTS OF WATER INFILTRATION THROUGH CONCRETE BLOCK PAVEMENTS

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SUMMARY. This paper reports a limited experimental study of the infiltration of simulated rainfall into newly laid concrete block paving. The tests were conducted at a single rainfall intensity of approximately 45 mm per hour. Factors studied included the pavement crossfall, the paver shape and thickness and the area of the joints. The experiments showed that upto about 65% of the rainfall pentrated the joints of the pavement. The amount of infiltration could be reduced by about 50% by sealing the joints with a water-based acrylic sealant.

INTRODUCTION

Relatively little is known about the movement of water into concrete block paving, CBP (1). Most work so far reported has concentrated on field measurements of infiltration (eg. 2,3). Typically, such measurements involve applying water to just a small area of the pavement and are consequently of dubious value because it is normally not possible to distinguish between water radiating horizontally from the measurement point along the joints and bedding sand from vertical infiltration. Controlled full-scale tests are so far rare, whether in the laboratory (4) or in the field (5). Such trials, however, indicate that significant infiltration of rainwater through CBP may occur. For example, in the Netherlands upto 45% of the annual rainfall has been reported to penetrate CBP (5)

EQUIPMENT

This paper reports preliminary results from an on-going study of water infiltration into CBP. This study was initiated at the University of New South Wales (UNSW) in 1992. The procedures adopted in the UNSW trials involved constructing 1.5 m square areas of CBP in a steel box which could then be placed at any required crossfall beneath a rainfall simulator. The equipment is illustrated schematically in Figure 1. To simulate rainfall a series of closely spaced water jets fed from a constant head water tank discharged onto a fine nylon mesh placed some 0.6 m above the pavement to be evaluated. This system gave a uniformly distributed simulation of rainfall across the CBP surface. The steel box containing the CBP was arranged so that water draining through the bedding sand and runoff from the pavement surface could be collected and measured separately.

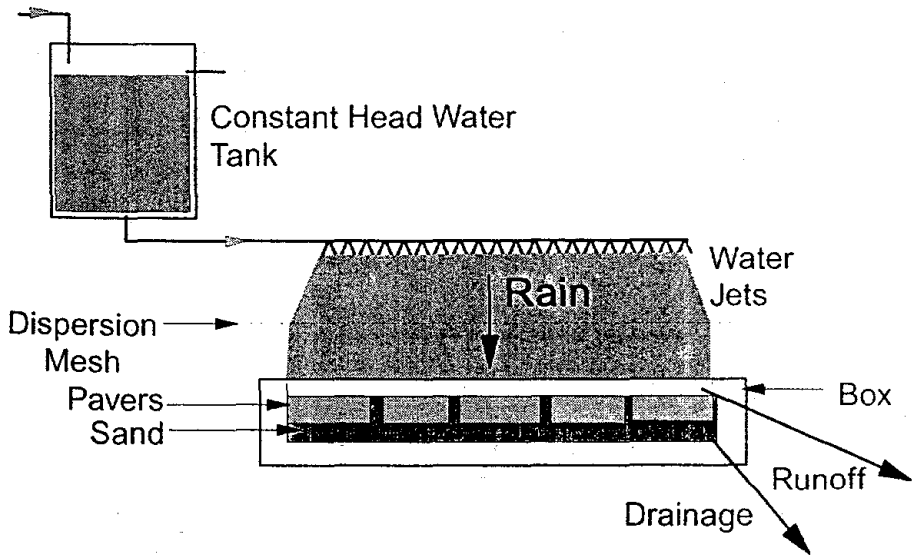

Figure 1. Schematic layout of the Experimental Apparatus.

The simulator was adjusted to apply a nominal rainfall intensity of 45 mm/hr. This lay midway in the range of rainfall intensities encountered in Australia (35 too 55 mm/hr). Measurements made using a tipping bucket rain gauge at 20 randomly selected locations beneath the simulator showed that the mean rainfall intensity was 43 mm/hr with a standard deviation (point to point) of 7.7 mm/hr. This simulated rainfall intensity was used throughout all the tests described herein.

EXPERIMENTAL PROCEDURES

The factors selected for study comprised:

1. Pavement Crossfall - Crossfalls of 1%, 2% and 5% were investigated
2. Paver Shape - Both rectangular and shaped (Unipave) concrete pavers were used.
3. Paver Thickness - Both 60 mm and 80 mm thick pavers were studied.
4. Joint Sealing - The effects of applying a water-based acrylic sealant to the joints was examined

TABLE 1. Sand Grading

Sieve Size (mm)	Cumulative Percentage Passing
4.75	100
2.36	93
1.18	86
0.60	56
0.30	15
0.15	5
0.075	2

The sand used in the experiments had the grading given in Table 1. The fraction passing a 2.36 mm sieve was used as the bedding sand whilst the fraction passing 1.25 mm served as the jointing sand. The sand was oven dried at 105 °C before use. The bedding sand was placed in a loose thickness of 30 mm in the steel box. The pavers were then layed by hand in herringbone bond orientated so that the paver axes lay parallel to the sides of the box. The pavers were guillotined to fit to the edge of the box. Gaps around the periphery of the pavement were filled with mortar. The pavers were compacted with three passes of a vibrating plate compactor and jointing sand was then brushed into the joints. A further three passes of the plate compactor were then applied. The weights of dry sand used to both bed and joint each pavement were recorded and are given in Table 2. Difficulty was experienced in bedding the 60 mm thick rectangular pavers firmly into place. Here a significant proportion of the jointing sand migrated into the bedding course. After compaction the joint widths were measured at 20 or more randomly selected locations using a calibrated steel mandrel which was pushed into the joints. The total lengths of the joints in each pavement were also measured. These data are summarised in Table 3.

TABLE 2. Weights of Bedding and Jointing Sand used in the Experiment

Paver Thickness (mm) & Shape	Weight of Bedding Sand (Kg)	Weight of Jointing Sand (Kg)
80 mm Rectangular	122.0	6.4
60 mm Rectangular	125.2	9.3
80 mm Unipave Shape	125.5	8.5

The box containing the compacted paving was placed under the rainfall simulator and was set to the required crossfall. This crossfall was applied in only one direction across the box. Simulated rainfall was then allowed to fall onto the pavement and measurements of the water draining through the CBP and across the pavement surface were obtained as functions of time. Generally, the experiments continued until these water flows achieved equilibrium values. Typically, this required test durations of up to about 250 minutes at the particular rainfall intensity used

TABLE 3. Joint Widths and Areas

Paver Shape	Paver Thickness (mm)	Average Joint Width (mm)	Average Joint Length (mm)	Joint Plan Area (sq mm)
Rectangular	80	2.5	33000	82500
Rectangular	60	2.8	31500	88200
Unipave Shape	80	2.7	38305	103400

RESULTS OF THE EXPERIMENTS

Effects of the Pavement Crossfall

Typically, for CBP a minimum slope around 2% is recommended (1). In the experiments described here crossfalls of 1%, 2% and 5% were studied. As shown in Figure 2 the percentage of rainfall draining from the top of the paved area increased almost linearly with increase in the crossfall. However, it may be seen that between approximately 30% and 35% of the incident rainfall penetrated the CBP.

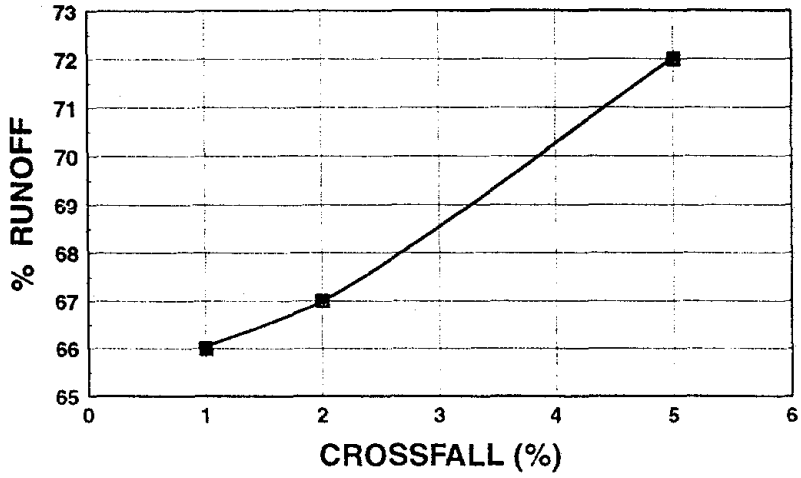

Figure 2. Effects of Changes in Crossfall on Runoff

It may be seen from Figure 3 that the water held in the joints and bedding sand, measured as a function of time, decreased as the pavement crossfall increased. Here the beneficial effects of increasing the crossfall were most pronounced when the grade was increased from 1% to 2%. Further increase to 5% only marginally reduced the amount of water penetrating the CBP. Changes in the pavement crossfall had relatively little effect on the water draining from the bedding sand. This is shown in Figure 4.

Overall, the experimental results indicated that, at least for the particular heavy rainfall intensity studied here, the minimum crossfall of CBP should be about 2%. This confirms the recommendations in practice noted earlier.

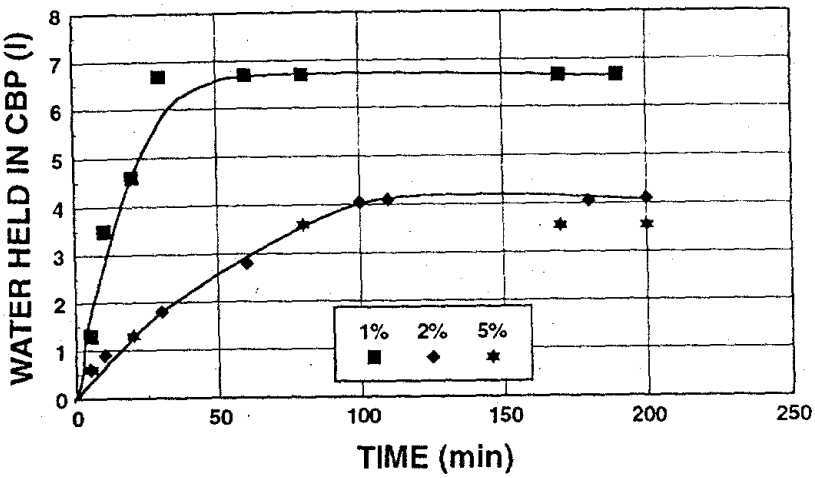

Figure 3. Effects of Crossfall on the Water held in the Joints and Bedding Course (80 mm rectangular pavers laid in herringbone bond).

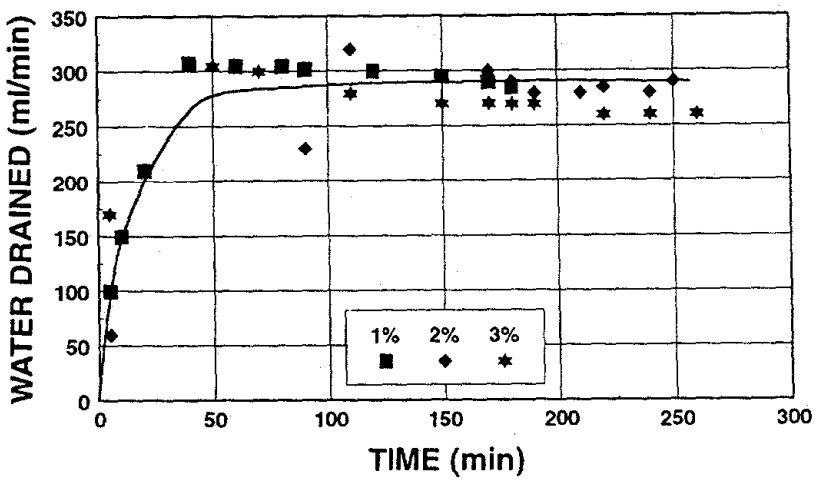

Figure 4. Effects of Crossfall on the Water Drained from the Bedding Course (80 mm rectangular pavers laid in herringbone bond).

Effects of Joint Width and Area

From Table 3 it may be seen that, for the pavements installed with rectangular pavers, the average joint spacing for the 60 mm thick pavers was greater than for the 80 mm thick pavers. This meant that the area of the joints available for water infiltration was greater for the 60 mm pavers than for the 80 mm pavers. Test measurements showed that the pavement having the greater joint area was associated with greater average absorption of water into the joints and bedding sand. At the same time the average runoff of water from the CBP surface was slightly reduced. In other words, as might be expected intuitively, an increase in the area of the joints led to more water entering the pavement. In this respect it is noted, however, that the bedding and jointing sands were dry at the commencement of the test. Further research is needed to determine whether joint area significantly affects infiltration and runoff where the bedding and jointing sands are initially saturated.

The Effects of Paver Shape

Where shaped pavers are used the practical consequences affecting pavement drainage are that:

a) the length of joints in unit area of CBP tends to increase (eg, vide Table 3).

b) the average gradient of the joints will be less than the crossfall of the pavement (because all or a proportion of the joints will lie in plan across the direction of the maximum crossfall).

Both of these factors would be likely to aid water penetration of the pavement.

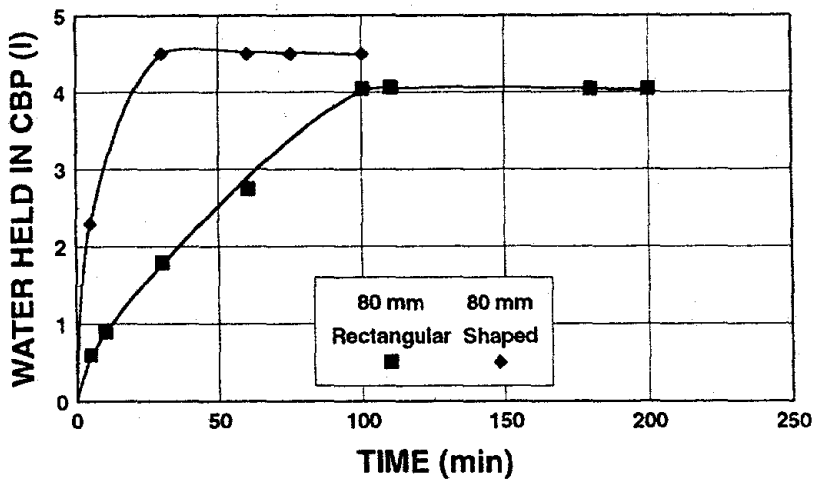

Figure 5. Effects of Paver Shape on Water Held in Joints and Bedding Sand (Crossfall=2%)

Figures 5 and 6 show a comparison between the water penetration data obtained for 80 mm thick shaped and rectangular pavers. It may be seen that, whilst the long-term or equilibrium values were little affected by shape, the initial build-up in both the amounts of water held in the joints and bedding sand and the amounts of water draining from the bedding course was much more rapid for the shaped pavers than for the rectangular pavers. Thus the test measurements tended to support the contention that, prior to saturation, CBP incorporating shaped pavers may facilitate water penetration. However, as shown in Figures 5 and 6, there was little difference in pavement drainage once the sand had been wetted-up. In other words, the effects of paver shape on water infiltration into CBP are only likely to be evident in initially dry pavements.

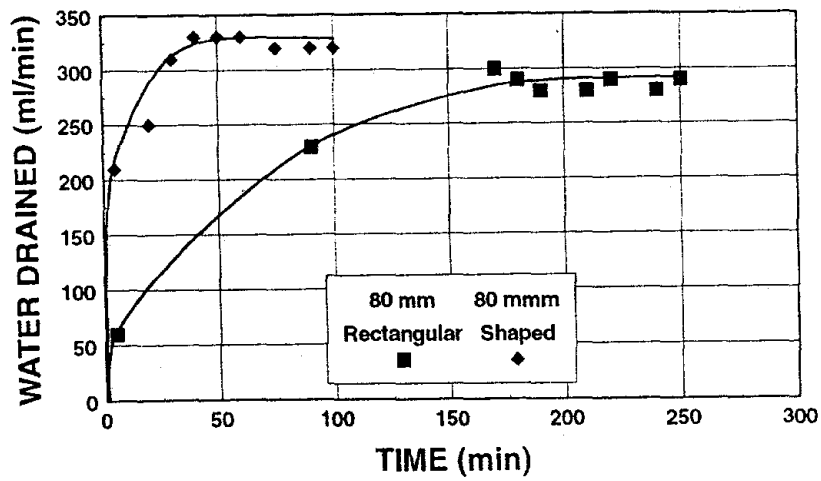

Figure 6. Effects of Paver Shape on Water Draining from the Bedding Sand (Crossfall=2%)

Effects of Paver Thickness

In the tests described here it was not possible to properly isolate the effects of paver thickness from other factors affecting water infiltration. Accordingly research is still needed into the possible effects of paver thickness on the drainage of CBP.

The Effects of Joint Sealing

Following the completion of the measurements described above, several of the pavements were sealed using a water-based acrylic sealer. This was applied by spraying the sealant onto the pavements at a nominal rate of 1.0 l/sq m so as to flood the joints. Normally sealing is best achieved when the jointing sand is dry. For this reason attempts were made to dry out the pavements before sealing by the use of heaters directed at the paver surface. However, it is unlikely that the jointing sand was completely dry at the time of sealing. Accordingly, the results reported here may not represent the optimal performance of the sealant.

The effects of sealing the joints are summarised in Figure 7 for the pavements laid in both 80 mm shaped pavers and 60 mm rectangular pavers. This figure is plotted in terms of the measured water flows in the pavements expressed as percentages of those in the unsealed pavements. From Figure 7 it may be seen that sealing the joints reduced by 50% or more the amounts of water penetrating the pavement (ie. water held in the joints and bedding course and water drained from the bedding sand). At the same time, the surface runoff increased to a maximum of about 140% of that observed for the unsealed pavements.

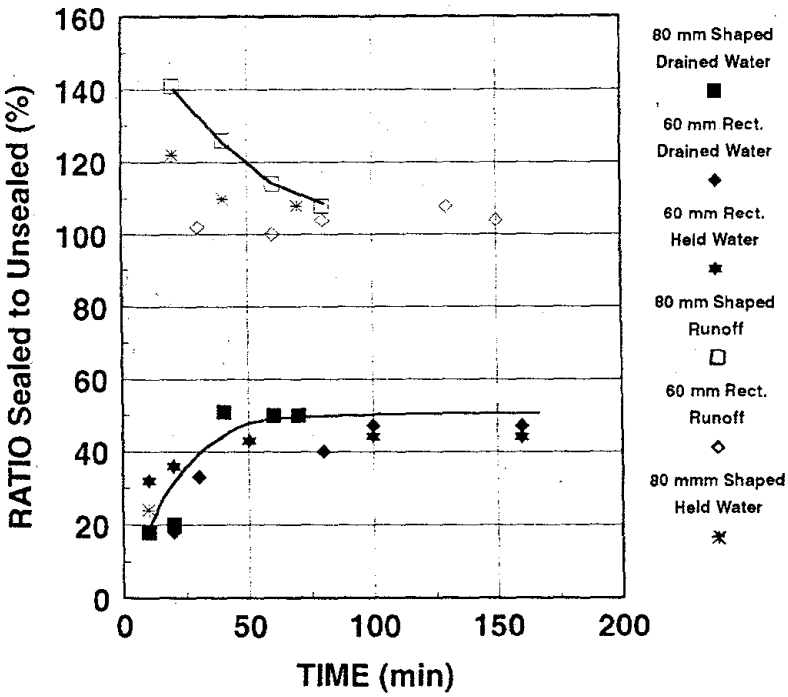

Figure 7. Effects of Sealing the Joints for both 80 mm Shaped and 60 mm Rectangular Pavers laid in Herringbone bond (Crossfall=2%)

Overall, the use of a sealant was found to reduce but not totally eliminate the penetration of water into the pavements. However, it is important to recognise that the sealant may have been installed in a less than optimal way. Further study of sealants is warranted.

CONCLUSIONS

Although the work described in this paper is only the first stage in a long-term study it is, nevertheless, possible to draw a number of useful conclusions. These can be stated as follows:

1 .Between 30% and 35% of the simulated rainfall penetrated newly laid, untrafficked and unsealed concrete block pavements

2. Increase in the pavement crossfall was beneficial in increasing surface runoff and, for initially dry CBP, in reducing the amount of water held in the joints and bedding sand. In the case of water held in the pavements, increase in the crossfall beyond 2% was only of marginal benefit. This tends to confirm that 2% is the minimum practical crossfall for CBP.

3. Increase in the pavement crossfall from 1% to 5% had little effect on the rate with which water drained from the bedding sand.

4. Water penetration tended to increase and runoff to decrease with increase in the surface area of the joints in initially dry CBP.

5. The use of shaped pavers promoted more rapid initial drainage of water into the pavement than for rectangular pavers. However, there was little difference in the long-term drainage performance of block pavements incorporating shaped and rectangular pavers once the jointing and bedding sands had become saturated.

6. The application of a water-based acrylic sealant to CBP containing moist sand in the joints reduced the water penetration into the pavement by 50% or more but did not totally seal the pavements.

7. It was not possible to discern any effect of paver thickness on the drainage of CBP. Further study of this effect is warranted.

It is cautioned that the work described in this paper was limited in scope and is only reported for a single high but representative rainfall intensity. It is also noted that the pavements were initially dry in many of the tests. Further work is needed to study the effects of different rainfall intensities, the influence of the initial saturations of the jointing and bedding sands and the use of joint sealants. Nevertheless, the work reported here shows that significant water penetration can occur in newly laid untrafficked block pavements. The consequences and control of this water penetration deserve further study and it is intended to continue this research at the University of New South Wales.

REFERENCES

1. SHACKEL B The Design and Construction of Interlocking Concrete Block Pavements. Elsevier Applied Science Publishers, London, 229 pp 1990

2.CLIFFORD J M Evaluation of Tests to Determine Waterproof Characteristics of Segmented Block Pavements. NITRR, CSIR, Pretoria, Tech Rpt TP/39/81. 1981

3. HADE J D and SMITH D R Permeability of Concrete Block Pavements. Proc 3rd Int. Conf. on Conc. Block Pavements, Rome pp 194-198. 1988

4. CLARK A J Water Penetration Through Newly Laid Concrete Block Paving. Cement and Concrete Assn. Tech Rpt. 529, November, 1979

5. LEENDERS P The Water Porosity of a Concrete Block Pavement and the Use of Waste Materials in Paving Blocks. Proc 3rd Int. Conf. on Conc. Block Pavements, Rome pp 194-198. 1988

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