EXPERIENCE IN APPLYING PERMEABLE INTERLOCKING CONCRETE PAVING IN AUSTRALIA

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SUMMARY

This paper assesses a range of permeable interlocking concrete pavements (PICP) that have been in service in Australia for periods of around 10 years. Each of the assessments was supported by a review of the properties and in-service performance of the pavements based on in-situ measurements and inspections, supplemented by laboratory test data. Factors studied included the infiltration rate, structural properties and performance together with lifespan and physical filtration efficiency. The effects of sediment load and pavement clogging were also examined.

Most of the pavements studied had not been subject to routine or systematic maintenance. Despite this, the study showed that, up to 10 years of service, most pavements were still capable of good infiltration. Sweeping the pavement surface was shown to be beneficial to infiltration and laboratory tests confirmed that most fine sediment was trapped in the upper portions of the jointing materials. Overall, the results tend to indicate that, under Australian conditions, the need to frequently and routinely sweep permeable paving may not be as important as is often assumed in the Northern Hemisphere.

1. INTRODUCTION

It is generally perceived that a major problem with permeable interlocking concrete pavements (PICP) is clogging. Closely related to this is the fact that permeable pavements can retain up to 90% of solids suspended in the water infiltrating the pavements (Pezzaniti et al., 2009). However, experience in Europe and laboratory simulations show reductions in PICP permeability due to clogging reach a near equilibrium condition between 5 and 10 years after construction (Dierkes et al., 2002; Borgwardt, 2006; Kadurupokune and Jayasuriya, 2009) as pollutants are retained in the pavement. This needs to be considered in the design of PICP (Shackel and Pezzaniti, 2010) and, for this reason, it is essential to quantify changes in the infiltration capacity of PICP over time.

Because of the clogging process, maintenance is often seen to be an integral part of any permeable paving system. Sweeping has been shown to be beneficial in laboratory-scale tests (Urban Water Resources Centre, 2002). Studies of full-scale pavements are less common but long-term field monitoring of PICPs (James, 2002; Borgwardt, 1997; 2006) has confirmed that the infiltration capacity of test pavements decreases as the amount of oil, grease and fine organic and inorganic matter accumulates within the gravel filling the drainage openings. Importantly, the tests have shown that the infiltration capacity can largely be restored by removing and replacing the top 10 to 25 mm of the drainage material in the paving joints and openings (James 2002, James and von Langsdorff, 2003). For systems with drainage openings this can be readily and economically achieved by using conventional street sweeping equipment but may be more difficult where paving with widened joints is used. For porous pavers, the use of jetting and vacuum cleaning has also been shown to be effective (Dierkes et al., 2002).

While some authorities in the USA require routine vacuum sweeping of PICP up to three or more times a year, experience in Europe and Australia suggests that such frequent maintenance is often unnecessary and that cleaning is only required when problems become evident. In this respect many pavements have performed adequately for periods of 10 to 20 years without systematic cleaning. In addition, the area of paving constructed is typically dictated by such operational requirements as the length and width of a street or parking area and this is normally much greater than the minimum area need to control runoff and infiltration. Accordingly, the effects of clogging are normally much less severe than might otherwise be expected.

Following many years of laboratory research and field trials (Shackel et al., 1996; 1997; 2000; 2001; Urban Water Resources Centre, 2002) construction of PICP in Australia began in earnest about 10 years ago including several well documented major paving projects (Mearing, 2000; Shackel et al., 2003). In Sydney alone the authors have identified more than 100 projects using PICP. Most of these pavements have performed well over time without being subject to any systematic maintenance. The prime objectives of the work reported here were to assess a wide range of these pavements using in-situ tests to measure their current infiltration rates, to examine clogging of the jointing materials, to evaluate the effects of sweeping the pavement surface and to assess the overall in-service performance of the pavements.

2. PAVEMENTS SELECTED FOR TESTING

In February 2009, seven permeable pavements were tested in New South Wales. These were selected from more than 100 candidate PICPs and were chosen because they had been in service for periods of at least eight and, in some cases, more than 10 years. A further three pavements were selected for testing in South Australia ranging in age between approximately 9 and 10 years. Details of the pavements are given in Table 1. All of the pavements had granular basecourses except for the Sydney Sports Ground paving which had a basecourse of recycled concrete overlain with a thin capping of aggregate. The pavements included pedestrian areas, car parks, roads and residential streets. The PICPs evaluated included two main types of pavers, namely those with drainage openings and those with widened joints. All of the NSW pavements used pavers with openings located along the paver joints whilst those in South Australia also incorporated pavers using widened joints to infiltrate stormwater runoff. In two of the South Australian pavements (Kirkcaldy Avenue and Victoria Road) the joints had been left unfilled to facilitate a high infiltration capacity.

With one exception (Shackel et al., 2003) none of the NSW pavements had been tested before but those in South Australia had been monitored systematically since construction (Pezzaniti et al., 2009).

3. METHODOLOGY

At each of the NSW sites the following tests were performed:

- Walkover inspections of structural and surface conditions.
- Double-ring infiltrometer tests at several locations.
- Sampling of jointing materials for subsequent laboratory tests.

Table 1 - Summary of Pavements Studied

AUSTRALIAN STATE	LOCATION	TYPE OF APPLICA-TION	DATE CON-STRUCTED	PAVER TYPE
New South Wales	Olympic Park, Homebush	Public Space + service vehicles	March 1998	80 mm Eco-Trihex
	Smith St, Manly	Residential Street	December 01	80 mm Ecoloc
	Shoalhaven St, Kiama	Road	October 1997	80 mm Ecoloc
	Terralong St, Kiama	Car park	April 1998	Ecoloc
	Victoria Park, Chip-pendale	Car park	December 1999	Eco-Trihex
	Karrabee Avenue, Gladesville	Car park	June 2000	Eco-Trihex
	Sydney Sports Ground, Moore Park	Public Space + service vehicles	November 1998	60 mm Eco-Trihex
South Australia	Kirkcaldy Avenue, Grange	Car park	July 1999	80 mm Formpave
	Victoria Road, Largs North	Car park	November 1999	80 mm Formpave
	Fletcher Lane, Woodville	Laneway	August 1999	80 mm Ecoloc

4. WALKOVER INSPECTIONS

Walkover inspections were made to assess the pavements serviceability. All of the pavements carried vehicular traffic ranging from cars and service vehicles to normal road traffic loads and had been in continuous service up to the time of infiltration testing (February/March, 2009). With the exception of Victoria Road, Largs North, all the pavements were serviceable for traffic. However, at the Victoria Road site the pavers were not tightly bound as there was little or no jointing material between the blocks. While this pavement was considered to be structurally unsound, it still fulfilled its water management functions and remained suitable for its intended purpose as a car park surface.

5. INFILTRATION MEASUREMENTS

Infiltration measurements were made using a double-ring infiltrometer. The equipment is shown in Figure 1. The inner and outer sections were made square with hinged corners. The inner section was 1m x 1m square so that a much larger area of paving was sampled in each test than has been common in previously reported infiltration tests conducted on PICP. The perimeter edges of the infiltrometer that were in contact with the pavements were provided with a bitumen-impregnated (BIP) seal to create a waterproof attachment to the pavement surface. Thereby, the use of silicone or other substances that can leave a permanent mark on the pavement surface was avoided. The determination of the infiltration rate through the surface of the pavement was calculated from the time taken for a 20 mm drop in the water level within the frame depicted in Figure 1. This procedure was based on Australian Standard AS4693.5–2004. Care was taken to ensure that the water depth in the outer section of the device remained close to the level in the inner section to ensure the boundary condition eliminated horizontal movement of water from the inner ring.

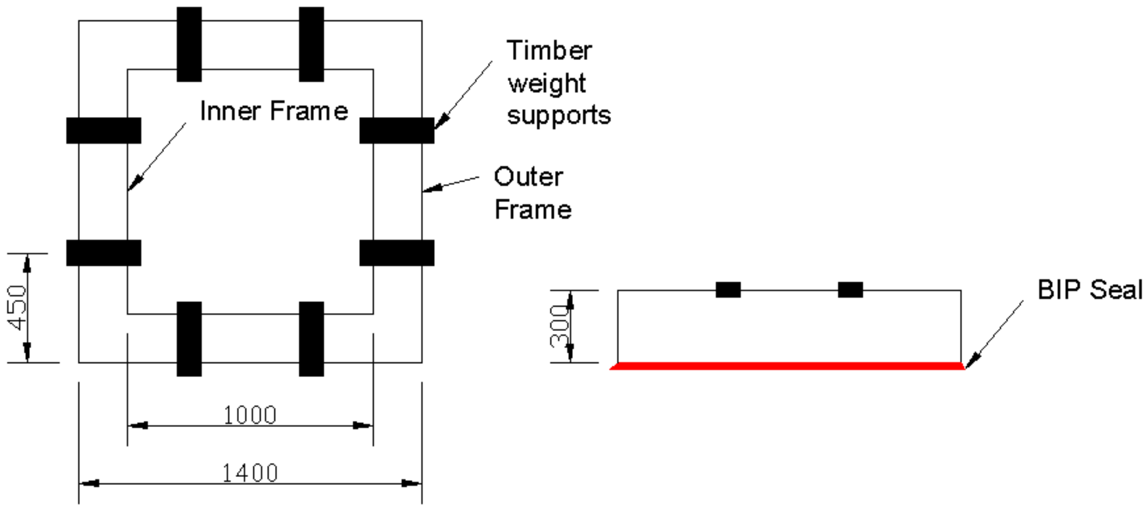

Figure 1. Double Ring Infiltrometer (all dimensions in mm).

All of the pavements assessed displayed crossfalls and longitudinal grades that are considered to be typical of PICP (0.5% to 2.0%). For various reasons, permeable pavements will not build-up sediment loads in a uniform manner and will tend to exhibit zones where sediment build-up is more concentrated. For this reason a testing regime was devised to ensure that infiltration tests would be conducted in both high and low sediment load areas. Where possible each pavement was tested at the lowest and highest elevations and, in some cases, at intermediate positions. Tests were also conducted below or adjacent to trees so that the effects of leaf litter could be evaluated.

In general, the paving was tested “as found” without any attempt to clean the surface prior to infiltration measurements. However, in three locations, tests were also conducted after the surface had been vigorously swept with a stiff broom. In all cases, before measurements commenced, the surface was flooded with water. Repeated measurements were made at each test location to ensure that the tests were conducted under saturated conditions.

The lowest infiltration rates recorded from the repeated testing at each site are summarised in Table 2. From this table it may be seen that, for the pavements laid using pavers provided with drainage openings along the joints (Ecoloc and EcoTrihex), the measured infiltration rates ranged from 27 to 1 080 mm/h/m^2 (75 to 3000 l/s/ha). The lowest values were recorded at Olympic Park, Sydney. Subsequent investigation established that all of the low infiltration rates came from tests that had been inadvertently conducted over sewers, water mains or other buried services. It is possible that, in these locations at Olympic Park, the service trenches had not been backfilled with permeable materials.

If the data from the tests known to be located over buried services or obtained from pavements laid without jointing material are excluded the infiltrations rates will be seen to range from 70 to 1 080 mm/h.m^2 (193 to 3 000 l/s.ha). It was observed that often, but not invariably, the infiltration rates measured at the lowest elevations in the pavement were less than those measured at higher elevations, presumably because of sediment migration to the low points.

Table 2 – Summary of Infiltration Measurements

AUSTRALIAN STATE	PAVEMENTS	TEST LOCATION	MINIMUM INFILTRATION RATES	
			mm/h.m^2	l/s.ha
New South Wales	**Olympic Park, Homebush, Sydney**	Recently swept area under trees along Olympic Boulevard	282	784
		Between trees and Boulevard	27*	75*
		Pedestrian approach to station – top of slope between Jacaranda trees	65* 99* 36*#	181* 275* 101*#
		Approach to station – bottom of slope between Jacaranda trees	176 246	490 683
	Smith St, Manly	Eastern side in car parking lane	818	2272
		In road adjacent to driveway	168 306#	438 851#
	Terralong St, Kiama	Roadway	145 240	405 667
		Car parking spaces adjacent to asphalt road	70	193
	Victoria Park, Chippendale	High point	1080	3000
		Low point	147	408
	Karrabee Avenue, Gladesville	Car parking along asphalt road – High point	192	533
		Car parking along asphalt road – Low point	335	930
	Sydney Sports Ground, Moore Park	High point	253	702
		Midpoint adjacent to trees	216 320#	601 889#
		Low point	112	312
South Australia	**Kirkcaldy Avenue**	High point	16	45
		Low point	240	667
	Victoria Road, Largs north	High point accepting initial runoff	High¶	High¶
	Fletcher Lane, Woodville	Centre of pavement	180	500
* Over buried services # After sweeping ¶Infiltration rate too high to measure accurately.				

The lowest infiltration rate, at Kirkcaldy Avenue, Grange (SA), represents an exception to this trend. This pavement has a low surface slope and previous measurements (Pezzaniti et al., 2009) show the development of a 'clogging front' extending from the upstream region of the pavement. As noted earlier, this pavement was installed without jointing material between the pavers and was therefore more vulnerable to sediment completely clogging those joints upstream of the clogging front. The infiltration rate for Victoria Road, Largs North (SA), shown in Table 2 is recorded as too high to be measured using an infiltrometer. This reflects the fact that the pavement was laid with open unfilled joints which allowed considerable lateral movement of water away from the infiltrometer as well as infiltration down into the pavement substructure. Whilst this site showed the highest infiltration rate of those observed and is in agreement with previous studies (Urban Water Resources Centre, 2002 and Pezzaniti et al., 2009) the results must be treated with caution because the use of unfilled joints. Open joints also permit sediments to travel down to the bedding layer rather than being trapped in the jointing aggregate. This is shown in Figure 2 (after Pezzaniti and Beecham, 2008) for the Kirkcaldy Avenue site. Here sediment can be seen to have reached a geo-textile laid on top of the base. Such sediment can only be removed by completely lifting and relaying the paving rather than by sweeping the surface. Moreover, as noted above, unfilled joints allow pavers to move under traffic and, thereby, impair structural integrity. For these reasons, the use of unfilled joints is neither recommended nor desirable practice for PICP.

Figure 2. Excavation at Kirkcaldy Avenue showing penetration of sediment down open joints

As noted earlier, some pavements were tested both in areas that were unmaintained and in areas that were first pre-swept manually with a broom. As shown in Table 2, the infiltration rates measured for the swept areas were significantly higher than for the unswept areas. This was consistent with earlier laboratory results (Urban Water Resources Centre, 2002).

Overall, the results demonstrated that, even for pavements that had received little routine maintenance, the infiltration rates 8 to 10 years after construction remained in a serviceable condition.

6. JOINTING MATERIAL

For each of the tested pavements, the upper and lower 30mm of jointing material was sampled (i.e. to a total depth of 60 mm below the upper surface of the laid pavers). These samples were retrieved at 14 locations. The samples were dry sieved in accordance with Australian Standard AS 1289.3.6.1 to determine their particle size distributions.

Based on Australian research (Shackel et al., 1996; 1997) it is customary in Australia to specify jointing materials for PICP as a clean uniform 2 to 5 mm aggregate, similar to the US ASTM #9 gradation. Few specifications or construction records remain for the pavements shown in Table 1. However, from the sieve analyses, it was found that the jointing materials generally had a maximum particle size of approximately 6 to 7 mm with 10% or more passing the 1.18 mm sieve and up to approximately 5% passing the 0.3 mm sieve size (e.g. Figure 3). This meant that the gradations typically lay towards the fine limits of the ASTM #9 grading commonly recommended in Australia based on extensive testing (Shackel et al, 1996). Because such a material is finer than the ASTM #8 grading commonly specified in North America and Europe it has the advantage that it can be used both as a bedding and to fill the joints.

At 10 of the 14 locations it was found that there were more fine particles in the upper 30 mm than in the lower 30 to 60 mm of jointing material. Typical results are shown in Figure 3. These indicated that the increase in fines generally occurred in the particle size range of 0.2 to 2.0 mm.

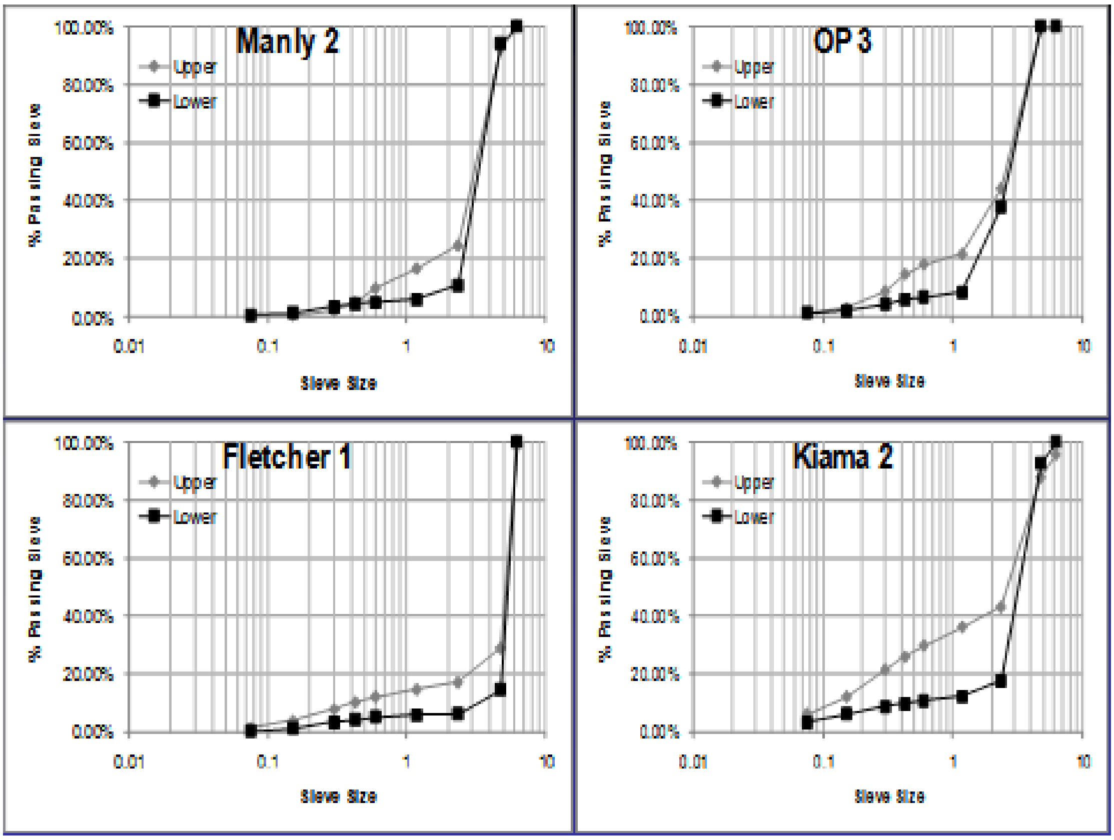

Figure 3. Typical jointing gradations comparing upper and lower joint material.

Of the samples showing little change in grading between the upper and lower portions of jointing material, three were from Olympic Park where mechanical sweeping was used routinely. The fourth sample was collected near a tree on the Karrabee Avenue parking area for which the maintenance history is unknown. The jointing material sampled from areas known to have been swept showed no change in fines between the upper (0 to 30 mm) and lower jointing depths (30 to 60 mm). This indicates that most of the fine clogging materials observed in the upper depths of the joint material for unswept pavements would have been located immediately at the top of the joints, i.e. from where it could easily be removed by sweeping. Overall, the results suggest that whilst routine sweeping is beneficial it is not essential to good performance.

Although not widespread, weed growth along the joints or in the drainage openings was observed in a few lightly trafficked areas. The most heavily infested area is shown in Figure 4 and was located at Fletcher Lane, Woodville, SA. Excavation showed that the weed growth extended the full depth of the joints. Nevertheless, as shown in Table 2, the infiltration rate after 10 years was 80 mm/h

(500 l.sec/ha). This appeared to be because the high infiltration rates provided by the drainage openings compensated for any clogging.

Figure 4. Weed growth on a lightly trafficked laneway (Fletcher Lane, Woodville, SA)

7. CONCLUSIONS

This study investigated the hydraulic conductivity of a number of full-scale field installations of permeable pavements in both New South Wales and South Australia. Two general types of pavers were tested, namely pavers with drainage openings located along the joints and pavers that had widened joints. The study showed that clogging was a natural process but that the majority of the sediment causing clogging was retained in the upper horizons of the jointing material and that this sediment could be removed with sweeping. However, the testing also indicated that frequent sweeping was not required for most pavement installations.

Despite clogging over period of 8 to 10 years, the test results showed that the pavements still exhibited good infiltration rates. As noted above, previous studies have shown that little change in pavement conductivity occurs after periods in service of 6 to 10 years. Accordingly, it may be concluded that, subject to the correct choice of design parameters, PICP can be expected to serve satisfactorily for periods comparable to other forms of pavement.

An important finding was that "as new" infiltration rates should not be used for the design of permeable pavements. Instead, a clogging factor needs to be applied to allow for the incremental clogging that occurs with these types of pavements. This needs to be considered in the design of PICP (Pezzaniti and Shackel, 2010). Future research needs to focus on quantifying these clogging factors for design purposes.

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