Toward Rapidly Cleaned Out Permeable Interlocking Concrete Pavers: Initial Field Tests

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Abstract

Special drainage cell geometries, called cupules, in specific permeable interlocking concrete pavers (PICP), were tested under moving regenerative-air pickup heads in a laboratory rig, and early results were discussed in a previous paper. Reported here are follow-up field tests on three different, parking lot pavements at one installation, of rapidly-cleaned-out PICP (RCPP) using a wide range of readily available street cleaning equipment. Rapid cleanout of the special purpose cupules at various sweeper speeds is measured and reported for a regenerative air sweeper, two types of mechanical sweepers, and a portable blower, two pickup head directions of travel and for different filter media.

Keywords: Concrete pavers, permeable pavement, street sweeping, restoration of infiltration.

1 Introduction

Whether planning, designing, constructing or managing a PICP installation, it is morally imperative to provide and sustain surface infiltration capacity over the long term, allowing an adequate volume of stormwater to be captured and treated by the facility. PICP infiltration capacity is dependent upon factors such as drainage cell density and permeability; surface slope; surface ponding; pavement base permeability, drainage and void volume; grading and quantity of surface dust and dirt applied; duration and intensity of applied surface loads (such as traffic); and, above all, upon proper pavement management. Designing and constructing a new system to provide appropriately high infiltration capacities is not problematic, but maintaining infiltration capacities over several decades has proven to be a concern, if not actually challenging. The obvious solution is pavers that are quickly, easily and cheaply restored by a variety of sweeping equipment, and this is the nub of the present paper.

An earlier paper (James and von Langsdorff, 2016) described laboratory tests on a new PICP designed to be readily cleaned out. Where clogging of drainage cells in permeable interlocking concrete pavers (PICPs) is dominantly in the upper parts of the filter media, as it is in most cases, infiltration rates in special PICPs may be rapidly restored if the PICP design is dovetailed to the fluid mechanics of the street cleaning equipment. PICPs described in this paper have special purpose "cupules", or concave filter recesses in the upper surface of the block; more generally, "cupules" are recesses in a larger body, as seen in anatomy and archeology; they have one surface which is generally concave, whereas a cup has both an internal concave and an external convex surface. In our application, the cupules are designed to facilitate rapid removal of filter media and filtrate by routine street cleaning equipment at economical speeds. Below the cupules, the drainage conduits are designed to provide specified maximum or controlled drainage flow rates, as shown in Figures 1 and2. Furthermore, geometry of these cupules also meets the requirements of the Americans with Disability Act, as well as certain requirements for mass production.

Our earlier paper demonstrated that infiltration rates in these new PICP, denoted RCPP, may be rapidly restored if their design is dovetailed to the aerodynamics of the regenerative air street sweepers (RASS) at the pavement surface. In that earlier paper, we describe experiments carried out in Guelph, southern Ontario, using a rig designed to reveal the air flow at the pavement surface of a simulated RASS pickup head moving horizontally over test blocks having geometry similar to the RCPPs. Cupules in the test blocks were filled with dry, non-cohesive and uncontaminated filter media. That paper described our experimental rig and demonstrated the cleanout principles, including CAD files of detailed drawings of the components of the rig and test blocks, and a slow-motion video clip of the clean out processes (James and von Langsdorff, 2016). In the present paper we describe tests on a real PICP pavement constructed in Ayr, Ontario, using RASS and mechanical street sweepers (MSS) with stiff bristles rotating vertically in the plane of the direction of sweeper travel.

We have not discovered any previous literature covering the design of drainage cells in PICP for rapid cleanout by conventional street sweepers. While Scholz and Grabowiecki (2006) review current trends in research and industry on permeable pavement systems, and recommend future areas of research and development, they do not mention PICP with attributes such as the RCPP presented here.

In their manual Permeable Pavements, the American Society of Civil Engineers (ASCE, 2015) states that permeable pavement will continue infiltrating if their top surfaces are cleaned regularly, “with regenerative vacuum sweepers at a recommended minimum of twice per year”. Surfaces that are clogged due to lack of regular surface cleaning, can be restored by RASS, which are recommended for regular cleaning, while pure vacuum type units (VSS) are recommended only for restoration of severely clogged surfaces that have not been vacuumed regularly. Simple (mechanical) broom sweepers (MSS) are not recommended since “they do not collect and remove accumulated debris”. The Interlocking Concrete Pavement Institute (ICPI, 2006) reiterate precisely the same injunctions, and so do other authorities. However, neither manual covers RCPP such as those discussed here, so it is not surprising that our results may to some extent contradict their (and derivative) recommendations.

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Figure 1: Typical test block enclosed in a plexiglass ampule: remnant of white aggregate in cupule, dark aggregate in conduits and bedding layer, cupule width is 12.5mm. Test cupules had sharp edges.

Figure 2: Pavement constructed from two L-shaped PICP blocks with cupules of two different lengths aligned in the direction of sweeper travel. Real cupules have rounded edges; cupule width is 12.5mm, block joints are typically 2 mm wide.

2 Factors that affect clogging

List A: Factors that affect clogging (a to f) that have been repeatedly researched and reconfirmed since the very earliest tests:

a. Quantity of filtrate or particulate matter, formerly called dust and dirt (i.e. mass rate, gradation, chemical nature),

b. Quantity of general waste and organics such as leaves and paper products,

c. Formation of a surface crust of low permeability,

d. Type of street cleaner,

e. Time since last cleaning,

f. Run-on from adjacent areas, especially if concentrated.

List B: Factors that affect clogging (g to q) that, though obvious, are generally left unstated:

g. Application of deicers,

h. Age, material and condition of the pavement,

i. Consolidation of and surface drainage of the pavement itself (e.g. depressions),

j. Subgrade and slope,

k. Pavement and tyre wear caused by traffic (viz. frequency, speed, weight, tyres),

l. Vegetation sprouting and decaying in the pavement,

m. Biota within the drainage cells,

n. Antecedent rain or lack thereof,

o. Moisture content of the filter media, bedding layer, base and subgrade,

p. Stormwater flows over the surface,

q. Other weather (e.g. climate, snow, ice, wind, heat).

List C: Factors that affect clogging (r to y) that, from an admittedly selected review, we found were ignored in previous studies, and are hypothesized here as novel and potentially noteworthy considerations:

r. Consolidation of the particulate matter in the drainage cells by impressed loads,

s. Quality of the street cleaners,

t. Operational performance of the street cleaners,

u. Operational settings for the street sweeper, including speed over the ground,

v. Grain size distribution of the combined filter media and filtrate,

w. Type and wear of the concrete blocks and filter media,

x. Airflow in the pores of the filter media and bedding,

y. Vibration of the pavers caused by traffic.

3 Types of Street Sweepers

For manifold activities (e.g. Industrial, Municipal, Agricultural, Civil Engineering, Highways, Land Development, Construction, Institutional, Landscaping and Homeowners), manufacturers offer suites of machines and tools for picking up, transporting, storing and disposal of debris of all kinds. Street sweepers are a case in point.

Wikipedia gives a brief historical background description of street sweepers and their development. In England, ca. 1843, Joseph Whitworth invented a mechanical street sweeper, and the first street sweeping machine was patented in the USA in 1849, the first selfpropelled street sweeper truck in 1895. When the concern for water quality emerged in the 1970s, street sweeper goals changed, as reflected in street sweeper patents in the 1990s.

3.1 Categories

Categorisation by manufacturer is not attempted here, since there are too many; Environmentalexpert.com alone lists 82 street sweeper manufacturing companies (see link listed in the references). Manufacturers of equipment commonly seen in Ontario include: Elgin, Johnston, Schwarze, Tennant and Tymco (their URLs are given at the end of this paper).

Classification by capacity or purpose may be more sensible, such as, for instance: freeway and highway cleaners, or large parking lot cleaners, or small lot cleaners, or sidewalk cleaners, or private property cleaners, and so on. We decided to test a small number but wide variety of equipment, since the effort will likely help equipment operators and pavement owners select a single piece or (better) combination of cleaning equipment (for tandem cleaning).

Once cleaned out the cupules may be fully or partially refilled. Refilling openings or joints is currently (written 2016) done by manual or mechanical broom sweeping of selected aggregate into openings and joints.

3.2 Effectiveness of Cleaning Equipment

No purposedesigned equipment for cleaning PICP, let alone RCPP, has been discovered by the authors in extant literature. However, work has been done designing and building experimental cleaning equipment for pervious pavements.

4 Pavement Surface Cleanout Processes

With a little imagination, we propose the following (non-exhaustive) list of processes that may inform the RCPP cupule cleanout function (some are repeated from the list of clogging processes above):

1. Geometry of the drainage cells
2. Alignment of the cupules
3. Filter media in the cell (size, gradation)
4. Nature and gradation of clogging filtrate in the filter media
5. Movement of air through the cell from below
6. Type of cleaning equipment
7. Speed of the cleaning equipment
8. Alignment of the cleaning machine
9. Operational efficiency of the cleaning equipment
10. Shape, length and rotational speed of brushes, if any
11. Water velocity at the cell, if any
12. Air jet velocities at the cell, if any
13. Vacuum velocities at the cell, if any
14. Fluid mechanics (e.g. turbulence) of airflow at and in the cell
15. Lift, entrainment and removal of the largest filtrate particles
16. Vibration of the pavers caused by the cleaning equipment

17. Freezing temperatures

18. Consolidation and compaction of the particulate matter in the drainage cells

19. Wear caused by traffic (viz. frequency, speed, weight, tyres)

20. Supply of general waste and organics such as leaves, forming a crust

21. Vegetation sprouting in the pavement

22. Biota within the drainage cells

23. Type and quality of the street cleaners, and their operational performance

24. Operational settings for the street sweeper, including speed over the ground

25. Time since last cleaning

26. Antecedent rain or lack thereof

27. Moisture content of the filter media, bedding layer, base and subgrade

28. Local run-on from adjacent areas

29. Other weather conditions (e.g. snow, ice, wind)

30. De-icer chemicals

31. Age, material and condition of the pavement

32. Consolidation of and surface consistency of the pavement itself (depressions)

33. Slope

5 Tests on New RCPP

New RCPP pavers (James and von Langsdorff, 2016), designed to meet the American Disability Act (ADA, 2010), were installed in a parking lot at the Unilock Plant in Ayr, Ontario, November 2627, 2016, and the construction is seen in a 2minute video attached to this paper https://youtu.be/gx39ejkvlcg. In a single installation, three different pavements were built, each having different cupule filter media:

a. Cupules arranged in the direction of travel, white aggregate,

b. Cupules arranged in the direction of travel, "HPB" (a common class of Ontario aggregate) in conduits (drainage cells below the cupules), paver jointing sand (PJS) in the cupules,

c. Cupules arrange transverse to the direction of travel, HPB in the cupules.

Tests of transverse cupules were included as some permeable pavement owners would not want the cupules cleaned out when performing frequent sweeping (daily or weekly, typically intended not to regenerate infiltration but simply to remove trash and debris) when having to refill aggregate could be problematic.

At the outset, it must be noted that our tests and conclusions are for single passes of the sweeping equipment.

Field cleanout tests were conducted November 23rd, 09h0011h00, under overcast conditions, air temperature minus 5 deg C, overnight minus 10 deg C. Conditions were distinctly suboptimal as tests were conducted on a pavement that was essentially at a temperature noticeably below freezing infiltration and water scour tests were impossible. The likely effect of sub-zero paver temperatures would have been for moist frozen aggregate to bind to the pavers, though this was not noticed. However, the PJS, supposedly dry in sealed plastic bags, had frozen solid, with the result that it was difficult to break up, spread and sweep into the cupules. In the end, a heavy forklift truck was driven over frozen clumps of sand, to break them up, effectively compressing them into the cupules – not a typical pavement situation, but still of interest (one could use this method for accelerated aging tests). For these reasons, the tests did not produce systematic scour of filtrate in the cupules.

As shown in our second accompanying video https://youtu.be/pCxzxF_5AHo two street cleaners were operated by dedicated, experienced operators at two speeds, first approximately 7 km/h and then a second pass followed at about 2.5 km/h. In neither machine were the controls optimized.

1. RASS: Johnston RT655, full vacuum but no water, the blast jet and vacuum air speeds were adjustable, but not tested over their ranges. Vacuum was maximised. A rubber skirt was missing. http://www.johnstonnorthamerica.com/products/truckmounted/rt655/

2. MSS: Tennant SweepMaxPlus S30, with worn (55 mm) brushes, set to their lowest elevation. http://www.tennantco.com/amen/equipment/sweepersrider/midsizedridersweeper/s30

The maximum surface curvature (for drainage) of our test pavement was estimated by straight edge, to be ca. 10 mm downwards over 2m, which may not suit RASS. In the end, both machines produced comparable results, about 15 mm scoured at higher speed and about 20 mm at the lower speed. Despite the conditions, this was better scour than we had seen at any field tests on other PICP. Results were probably aided by the fact that the cupules in both longitudinal pavements were oriented in the direction of travel of the sweeping equipment. The pavement segment with cupules arranged transversely showed no scour for both machines, a result we had hoped for and we were never required to recharge those cupules. The tests proved that both MSS and RASS are effective at rapidly cleaning cupules aligned longitudinally, to the extent suggested by all authorities, where pavements are maintained by sweeping twice a year (beginning and end of winter). For deeper scour and faster speeds some optimization is recommended (e.g. use lighter, round grain sand in cupules; adjust main brush elevation in the transverse brush to reach the invert of the cupule; adjust the blast jet air velocity; install the pavement as flat as possible, to ensure that the cleaning head fits flush with the surface). Tandem cleaning is recommended in the literature.

Field cleanout tests were again carried out November 28th, 13h3015h00, under overcast conditions, air temperature plus 8 deg C, overnight plus 2 deg C. Conditions were cool but reasonably dry, while the pavement aggregate was damp. Tests were conducted using two inexpensive but commonly available devices: a personal gasoline-powered mechanical sweeper (like a homeowner's snow blower) and a lightweight portable gasoline-powered (leaf) blower. Infiltration tests were not carried out. Tests over the cupules covered in PJS showed less scour than the white aggregate or HPB, so PJS was not used to refill the cupules; coloured aggregate and HPB was used for refilling instead. The cupules were left filled for the winter 2016/7, after which further tests are envisaged (first warm weather, likely April 2017).

The two devices were operated at walking speed, the roller brush at ca. 2 km/h and the leaf blower at about 60 m/h. Both had a coverage of about 0.7 m width.

3. 196cc 24 inch Power Sweeper: Power Fist (brand new): http://www.princessauto.com/en/detail/24inpowersweeper/Ap8617409e

4. 24.5cc blower: Makita MM4 model BHX2500CA (brand new). “145 MPH max air speed”. https://www.makitatools.com/products/details/BHX2500CA

The roller brush produced ca. 25mm scour, if anything slightly deeper than the previous equipment, and, again, did not scour the transverse cupules. On the other hand, the blower produced exceptional results, about 75 mm scour, tending to throw the aggregate back up at the operator. HPB was, if anything, even more effectively scoured than the white aggregate, and transverse and longitudinal cupules were equally scoured. Blowers are more than adequate for complete cupule cleanout, though progress through an entire parking lot will obviously be slow a simple cost analysis is given below. Again, this was better scour than we had seen at any field tests on PICP. Results supported orientation of cupules in the direction of travel of the sweeping equipment. As suggested by almost all authorities, viz. that PICP be maintained by sweeping twice a year (beginning and end of winter), we intend to test again as soon as the weather warms up in early 2017.

Our results may contradict the ASCE and ICPI manuals and others that recommend that RASS are effectively the best at cleaning PICP. Of course, these earlier researchers did not embrace RCPP. We have not yet tested VSS. Again, we remind readers that standard manuals ignore blowers.

6 Discussion and Conclusions

This paper describes field observations of three different RCPP pavements. All had the identical RCPP block, in a single installation, and all were cleaned using four widely differing street cleaning devices, ranging in capital cost over more than three orders of magnitude, from ca. $350K to ca. $0.15K (2016 $CAD). All pavements were, at the least, satisfactorily cleaned by all devices.

One major finding ostensibly contradicts prevailing wisdom, in that expensive truck mounted RASS machines, though quick, were found to be not necessarily better than MSS machines, or indeed blowers, at least for our RCPP. On this point, we postpone final recommendations until we have completed our post winter pavement sweeping tests in Spring, 2017.

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