Modeling of infiltration through interlocking concrete pavement

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Highlights

- Construction of interlocking concrete pavement (ICP) determine its Infiltration rates
- Estimated average infiltration rates for parking lots made of ICP are in range 2.5÷16.8mm/h
- Rainfall characteristics determine runoff coefficients for surface made of ICP

Introduction

Paved surfaces are the predominant type of surface in cities resulting in increased both peak flows and volumes discharged to water bodies. In Poland interlocking concrete pavement (ICP) has been used on a large scale since the beginning of the 90s, mainly for parking lots, sidewalks and bicycle paths). The use of ICP has been shown to decrease both volume of surface runoff and peak discharges in comparison to fully impervious surfaces (Collins et. al, 2008). There are significant differences regarding the infiltration rates for ICP due to its construction and local soil conditions, which increases uncertainty to drainage calculations as well as to hydrodynamic simulations. Current publications are focused mainly on surfaces defined as "permeable ICP", specially designed for infiltration of stromwater, usually characterized by high infiltration rates a very low values of runoff coefficient (Boogaard et. al, 2014). Research on ICPs infiltration rates are justified due to the limited availability of data and their poor precision.

Material and methods

The main goals of this study were as follows: a) point measurements of infiltration rates for ICP, b) estimation of runoff coefficients for parking lots made of ICP during rainfall events, c) estimation of runoff coefficient for ICP using SWMM software and Intensity-Duration-Frequency (IDF) curves as rain data input.
First stage - a total of 12 sites (parking lots in Czestochowa, Poland) were used to collect surface infiltration rates with different types of ICP. The selected locations differed in the types of cubes (the shape and the gaps between) as well as service time (from 5 to 25 years). The openings (typically filled with sand) in the paved surface were composed 4% to 9% of the paver surface area. Double-ring infiltrometers were used at each site to measure surface infiltration rates. For each location, measurements were made at three points to account for the spatial variability of the infiltration. Measurements were repeated for different antecedent dry period (ADP): from 1 day to 10 days.
Second stage – measurement campaign for selected four locations including simultaneous recording of rainfall intensity and outflow-rate from parking lot. Rainfalls were recorded in years 2016-2018 using conventional tipping bucket raingauge RG-50 located close (less than 1 km) to the monitored objects. Two ultrasonic flow-meters (NIUVUS PCM4) were used to record outflow from parking lots during measurement campaign. For each location 12-14 rainfall-runoff events were recorded, considering two limiting conditions: rainfall depth > 10.0mm and ADP > 2 days).

Recorded rainfall and measured outflow rates allow to calculate runoff coefficient defined as:

$$R_C = \frac{V_R}{V_P}$$

V_P - precipitation volume [m^3], V_R – runoff volume [m^3].

On the basis of recorded runoff hydrographs, the average infiltration (I_{av}) rate for each rainfall was estimated:

$$I_{av} = \frac{(V_{rain} - V_{run})}{t_r} \left[\frac{m^3}{h};\ mm/min\right]$$

V_{rain} - rainfall volume [m^3], V_{run} - runoff volume [m^3], t_r – rainfall duration [h].

Third stage: to estimate runoff coefficients a series of hydrodynamic simulation were made using SWMM 5.1. Simulations run on the numerical model of parking lot (main dimensions: 60m×30m) made of ICP with different infiltration rates: 5mm/h, 10mm/h and 15mm/h (values selected based on results obtained in the stage II). Other parameters of the hydrodynamic model: Manning's coefficient n=0.014, depth of depression storage 1 mm, average surface slope 1%, width of overland flow path: 30m. Rainfall data based on IDF relationship formula used in Poland to design drainage infrastructure (by Institute of Meteorology and Water Management) for rain durations: 10min, 15min, 20min and 30min and return periods c=1, 2 and 5 years. A series of simulations were made with dynamic wave flow routing (1 second time step).

Discussion and results

Measurements carried out have shown that permeable pavements differ greatly from each other, and their permeability properties may vary within a wide range from near to 150 mm/h to about 10-15mm/h. Significant differences were registered on single object - relative differences between minimum and maximum may reach to even 100%. The weather conditions also influence on infiltration rate – for antecedent dry period (ADP) more than 7 days the infiltration rate was almost twice as high as for the case of ADP=1 day. Another factors affected infiltration capacity are: type of permeable pavements (size of voids), subbase parameters, and vehicle traffic on the surface.

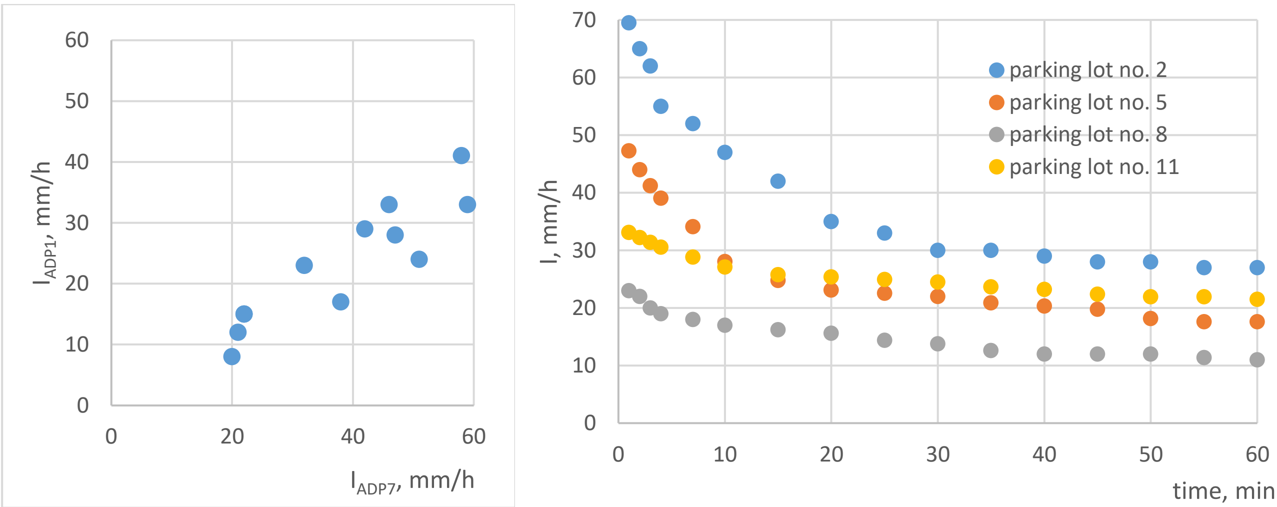

Figure 1. Measurement results using the double-ring infiltrometer: a) relationship between infiltration rate for ADP = 1 and ADP> 6, b) change of infiltration rate with time for 4 selected parking lots (for ADP>7).

During measurement campaign in stage II (tab. 1) estimated average infiltration rates did not exceed 17mm/h for any recorded rainfall event (median I_{av}=4.5÷7.7mm/h). However, the minimum values slightly exceeded 2.5 mm/h. Such large discrepancies between the values obtained in stage I and stage II are due to limitations of double-ring infiltrometer method (Nicholls et. Al, 2014) as well as to assumptions for the calculation of I_{av}. Median values of Rc for particular parking lots were in range from 0.27 to 0.42 while outliers were: minimum Rc=0.09, maximum Rc=0.63. The calculated runoff coefficients differed mainly due to the duration and maximum intensity of rainfall events.

Table 1. Runoff coefficient and average infiltration values estimated for parking lots during measuring campaign in years 2016-2018.

Site	Runoff coefficient Rc (-)			Average infiltration I_{av} (mm/h)		
	min	mediana	Max	min	mediana	Max
Parking lot no. 5	0.11	0.33	0.52	3.2	6.7	11.9
Parking lot no. 8	0.20	0.42	0.63	2.5	4.5	9.2
Parking lot no. 11	0.08	0.29	0.45	2.9	6.5	12.8
Parking lot no. 2	0.15	0.27	0.42	3.8	7.9	16.8

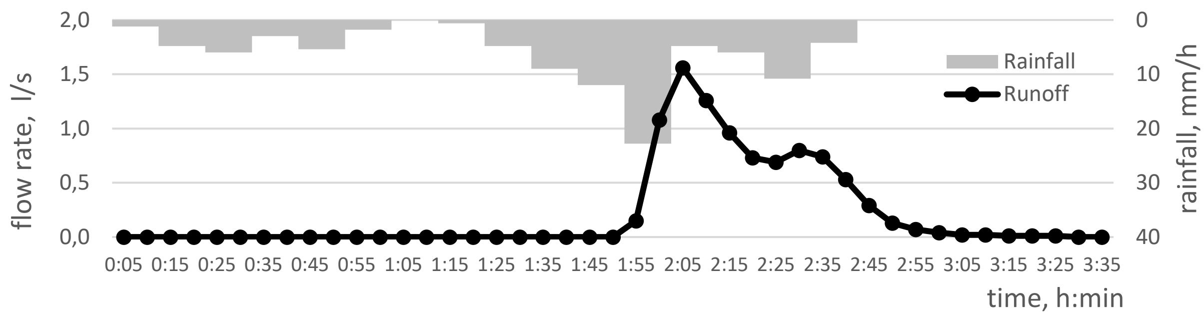

Figure 2. Sample outflow hydrograph registered for parking lot no. 3 during rainfall event on 2.07.2016.

The analysis of nearly 50 hydrographs of the outflow from monitored parking lots (fig. 2, tab. 1) was the basis for series of hydrodynamic simulations using EPA SWMM 5.1. The results of the simulations showed significant variability of runoff coefficient depending of return period and infiltration rate of ICP surface: from around 0,20 (C=1 year, I=15mm/h) to maximum value R_C=0,70 (c=5years, I=5mm/h) which is over the maximum value recommended in literature (R_C=0,6). Maximum flow-rates from modeled parking lot were reduced by 55% (for I=15mm/h) to 68% (I=5mm/h) in comparison to fully impervious surface made of asphalt (fig. 3b).

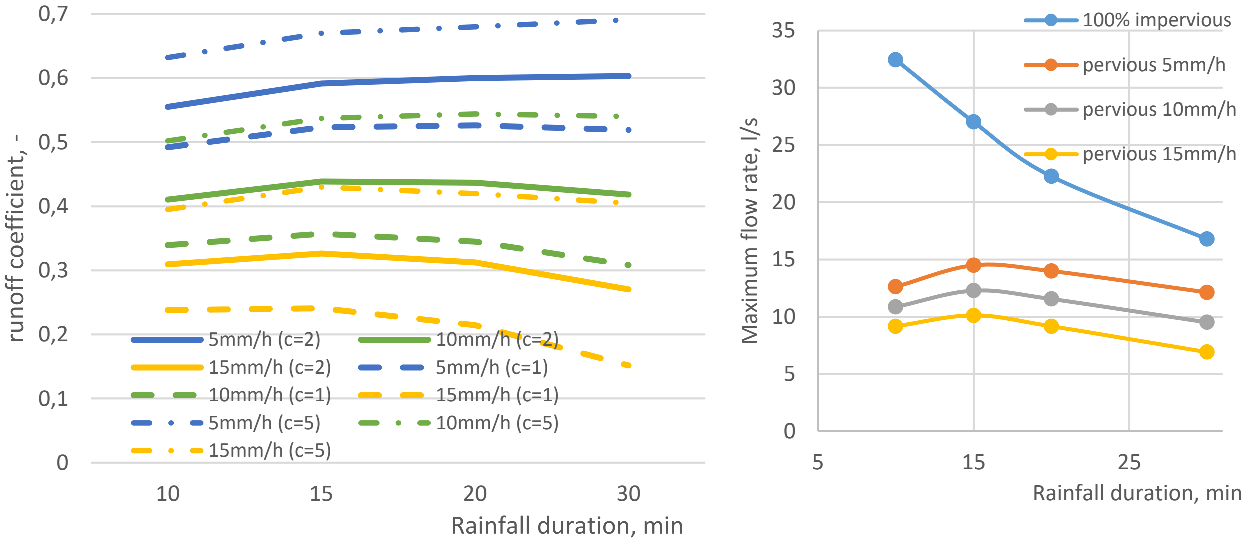

Figure 3. Results of simulation for different infiltration rates of ICP: a) runoff coefficients, b) comparison of maximum flow rates from parking lot made of impervious and pervious material, c=2 years.

Conclusions

Interlocking concrete pavements is a material increasingly used in the construction of sidewalks and parking lots. During the design process for a permeable pavement surface it is important to consider expected rainfall intensities for the area to predict the runoff expected from the surface. Tests carried out using the double ring infiltration set show the infiltration rates range from 30 mm/h to even 150 mm/h depending mainly on type of material and construction. Verification of these values for real rainfall events showed the effective average infiltration rates are significantly lower (less than 10mm/h). Runoff coefficients for ICPs estimated using hydrodynamic simulations (local IDF rainfall model) were from 0,2 to 0,6, depending on infiltration rates and assumed return period of rainfall (while duration of rainfall has moderate impact).

References

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