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SUSTAINABLE DRAINAGE CHARACTERISTICS INFLUENCED BY ENVIRONMENTAL AND TOPOGRAPHICAL CONDITIONS

A. Strong*
Senior Lecturer, University of Ulster, UK
Nursetiawan
Research student, University of Ulster, UK
D. Woodward
Reader, University of Ulster, UK
A. Woodside
Professor, University of Ulster, UK

* School of the Built Environment, Shore Road, Newtownabbey, Co. Antrim, Northern Ireland, wa.strong@ulster.ac.uk

ABSTRACT

A series of laboratory experiments were carried out on two surfaces i.e. a 10mm hot stone asphalt surface mix and a smooth plywood wood surface. The purpose was to investigate their drainage characteristics. By applying various rainfall intensities and different crossfall slopes, it was found that the surface runoff increases rapidly to the peak value, followed by rapid decline that begins at the moment of rainfall cessation and then approaches zero slowly. The significant variation between the two trial surfaces assessed related primarily to their surface texture or texture depth. These initial findings suggest that the research will allow better understanding of highway surface rainfall runoff and its affect on adjacent land areas and watercourses.

KEY WORDS: SuDS, surface texture, crossfall, rainfall, permeability.

1. Introduction

Impervious surfaces such as roadways have been designed and constructed primarily to ensure the safety of users. This professional approach has therefore included for the rapid and efficient transport of storm water flows away from the surface and results in a significant change to the rainfall-runoff relationship for urban environments. The creation of any large impervious surface commonly leads to multiple impacts of hydraulic and pollution loading on the receiving stream systems. There is also the indirect impact of factors such as the reduction of water infiltration, which lessens groundwater recharge and potentially lowers stream base flows.

This paper investigates the performance of two surfaces i.e. a 10mm high stone content hot mix asphalt and plywood in relation to rainfall intensity and crossfall gradient. The research aim is to improve understanding of the hydraulic impact of highway surface rainfall runoff on adjacent land areas and watercourses. This understanding will allow improvement and development of better sustainable urban drainage systems (SuDS).

2. Literature Review

A review of literature has found that there has been relatively limited study of water overland flow and only limited experimental work on water film thickness on road pavement surfaces. This was primarily concerned with road safety with prediction of sheet flow depth due to rainfall runoff the main purpose of their research. Ross and Russam [1] developed a model for water depth on road surfaces as a function of pavement cross slope, flow path length and rainfall intensity. Gallaway et al. [2] developed a set of empirical equations for predicting water depths on road surfaces and added surface texture to the parameters of the Ross and Russam equation.

NCHRP [3] used one-dimensional kinematic wave approximation as the basis for its model to calculate water depth induced by rainfall on the road surface. This was based on hydraulic channel theory and included Manning's Roughness n to account for the effect of surface roughness on water depth. Domenichini and Loprencipe [4] developed a computer programme for predicting the steady state water depth caused by rainfall of given intensities. To validate the programme, the authors constructed a full-scale physical model to reproduce surface water flow during artificial rain events.

Simone et al. [5] conducted rainfall simulator experiments on two types of surface i.e. smooth PVC and road to study pollutant wash-off under different rainfall intensities. They also measured water depth on the road surface, flow rate and the reservoir effect of road surface water storage.

An extensive body of study on the performance of SuDS has been carried out by research centres such as the Construction Industry Research and Information Association (CIRIA) with key reports dealing with hydraulic, structural, maintenance and design issues [6, 7].

The type of 10mm high stone hot mix asphalt mix used in this study is known in the United Kingdom as a thin surfacing. This is a generic name used to describe a range of asphalt materials used for highway maintenance and new construction. They are proprietary surfacing systems with a typical high stone content and polymer modified binder. They have to pass a 2-year period to become certified by the British Board of Agrément (BBA) under their HAPAS scheme.

3. Methodology

The 10mm asphalt mix was compacted using a mini pedestrian roller to form a rectangular-shaped slab with dimensions of 600 x 1400 x 50mm. The texture depth of the compacted surface was 0.94mm using the volumetric sand patch method. The slab was installed into the test rig shown in Figure 1.

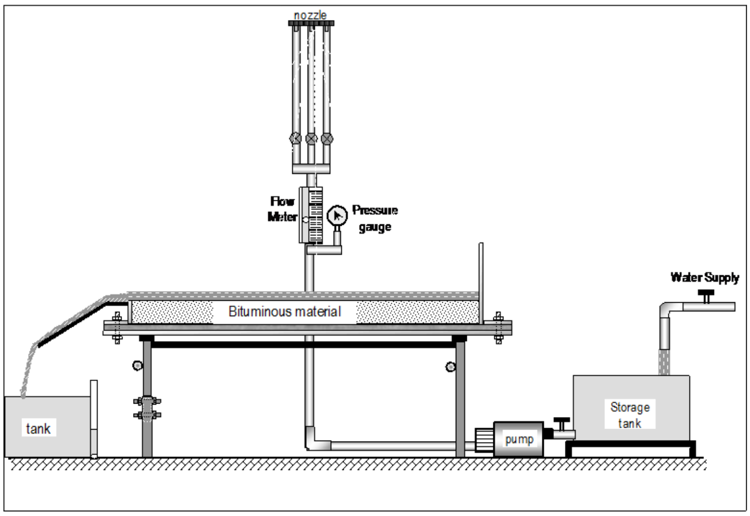

Figure 1, Experimental apparatus used

A rainfall simulator was designed to generate rainfall equivalent to natural rainfall and allowed control of volume, intensity and duration. This was based on the simulator developed by Simone et al [5]. Rainfall was provided by 3 nozzles fixed 1430mm above the test surface. Variation in rainfall intensity was controlled using 3 different nozzle sizes. The cross fall of the test surface could be adjusted using a hydraulic jack.

The rainfall intensity distribution across the width of the test surface was measured using catch cans over a 10 minute period. The rainfall intensity data was then assessed to determine its uniformity. The common formula to measure rainfall uniformity is the Christiansen uniformity coefficient (CU) [8].

$$CU = 100\left(1 - \frac{D}{M}\right)$$

Where:

CU = the Cristiansen Coefficient of Uniformity (%)

D = average absolute deviation from the mean = $\frac{1}{n}\sum_{i=1}^{n}\left|X_i - M\right|$

M = mean = $\frac{1}{n}\sum_{i=1}^{n} X_i$

Table 1 shows the CU for the 3 nozzle sizes. An example of the rainfall intensity distribution for the test surface using nozzle size 2 is shown in Figure 2.

Table 1, Nozzle performances used for the test

Nozzle size	Pressure (bar)	Flow rate (l/s)	Average Rainfall Intensity (mm/h)	CU (%)
1	0.75	2.00	31.40	86.59
2	1.20	4.20	54.18	91.17
3	1.60	5.75	78.25	85.70

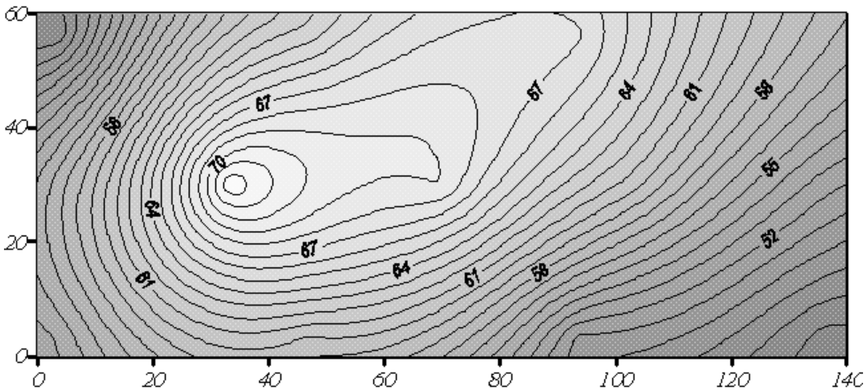

Figure 2, Contour map showing rainfall intensity (mm/hr) distribution for nozzle size 2

4. DISCUSSION OF TEST DATA

When a rainfall of constant intensity falls over a surface the series of events can be divided into 3 stages [2]. Initially, a certain amount of water is required to fill the interstices of the surface before runoff occurs. Runoff then begins. The runoff rate increases to an equilibrium value and for an impermeable surface this rate is equal to the rainfall intensity. It is during this time interval that amount of water retained on the surface increases to a maximum value. When rainfall ceases the runoff rate decreases to zero while the depth of water held by surface detention also decreases to zero.

A series of experimental tests were carried out under three rainfall intensities (31.40, 54.18 and 78.25mm/hr) and three cross slopes (2, 4 and 6%). The data for the 10mm asphalt mix is plotted in Figures 3, 4 and 5. The time required for the rate of runoff to reach steady state is called the equilibrium time or time of concentration.

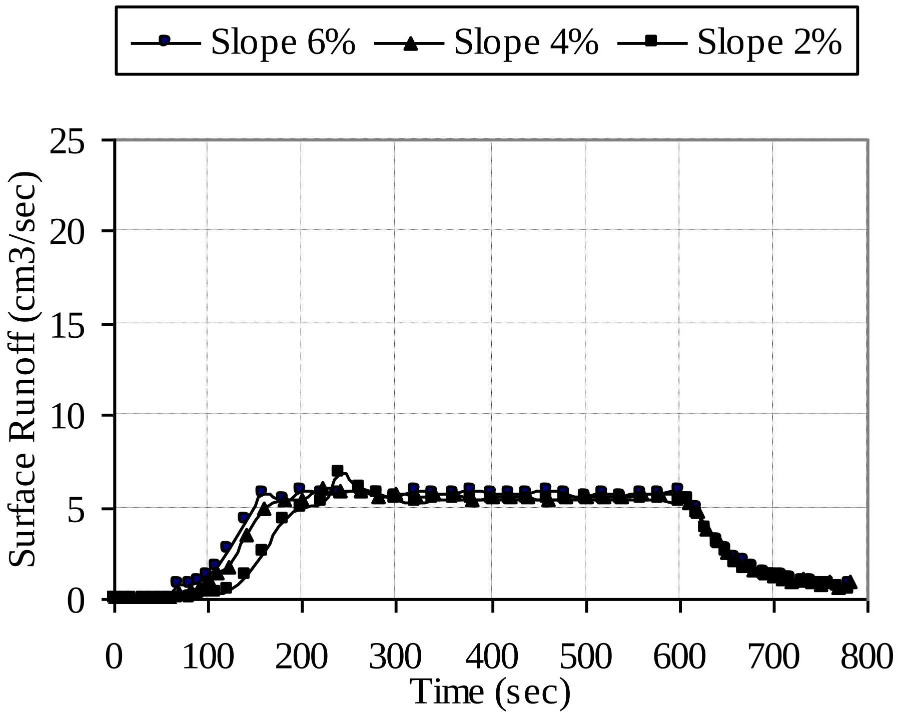

Figure 3, 10mm asphalt mix hydrograph for a rainfall intensity of 31.4 mm/h

The three plots show that the starting time of runoff, equilibrium and peak runoff value are dependent on rainfall intensity. The lower rainfall intensity results in a longer surface runoff starting time, a lower peak flow time and a smaller runoff. After the cessation of rainfall, the remaining surface water drains off the steeper cross-falls more quickly. Surface runoff decreases rapidly when rainfall ceases and then approaches zero slowly.

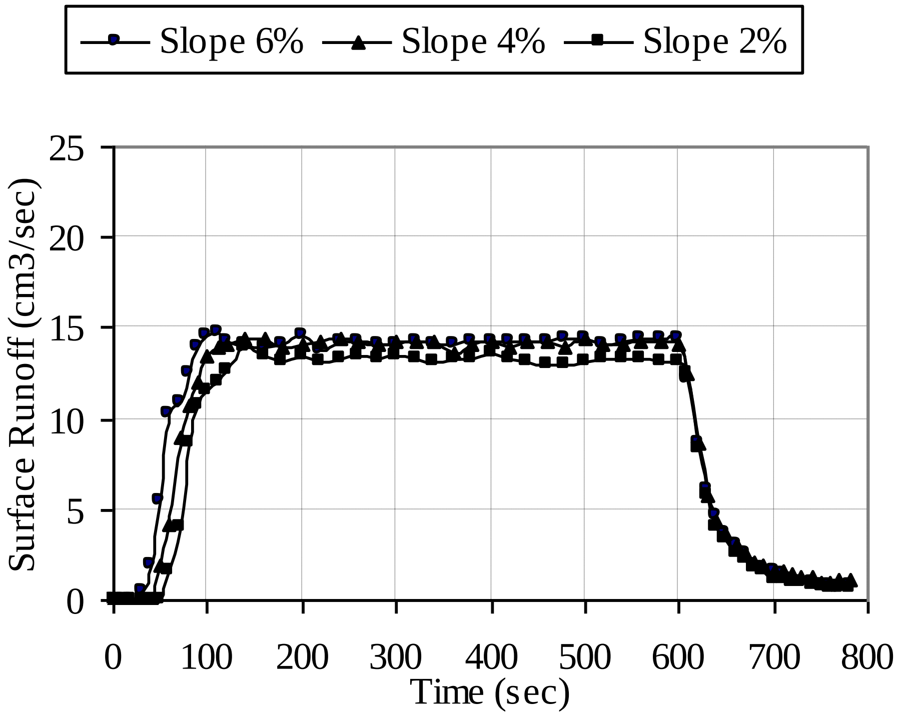

Figure 4, 10mm asphalt mix hydrograph for a rainfall intensity of 54.18mm/h

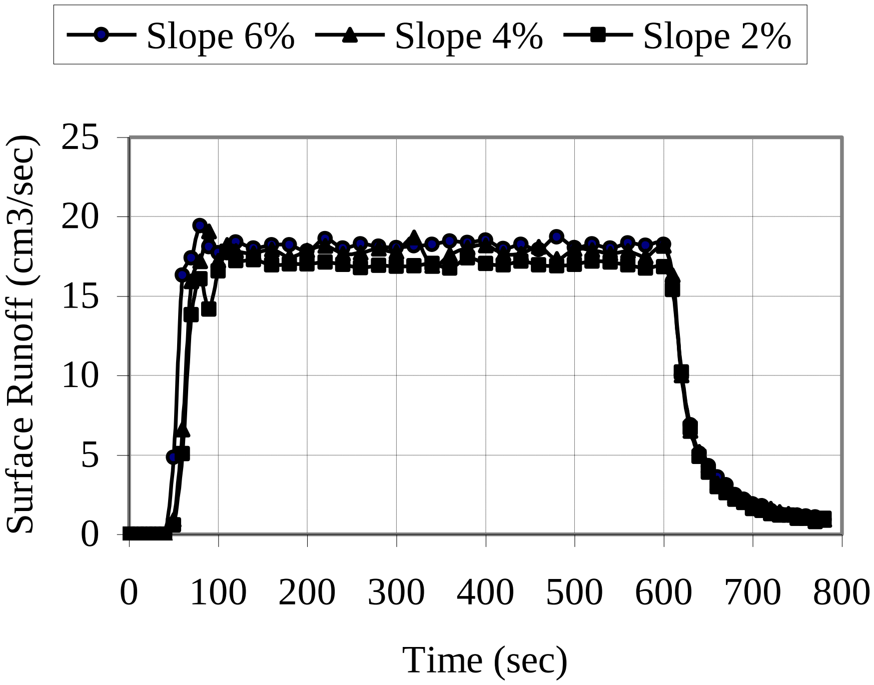

Figure 5, 10mm asphalt mix hydrograph for a rainfall intensity of 78.25mm/h

Similar surface runoff testing was carried out on the plywood surface. This material was chosen to represent a smooth, impermeable surface. Table 2 compares the hydrograph characteristics of the two surfaces.

Table3, Comparison of hydrograph characteristics

Rainfall Intensity (mm/h)	Slope (%)	10mm asphalt		Plywood	
		Equilibrium time (s)	Average Qmax (cm^3/s)	Equilibrium time (s)	Average Qmax (cm^3/s)
31.40	2	120	5.51	100	6.13
	4	140	5.66	80	6.69
	6	160	5.74	70	6.91
54.18	2	140	13.06	70	15.02
	4	120	14.06	60	15.19
	6	100	14.25	50	15.15
78.25	2	120	16.92	60	20.23
	4	100	17.85	50	20.73
	6	80	18.18	50	21.14

All type of surfaces will drain surface water rapidly if cross slope is sufficiently steep. The advantage of a steep cross slope is the reduced amount of water which can pond in the surface texture. However, the slope must be within the guidelines required for safety [9]. During this investigation, the test surface was tilted in one direction with the resultant cross slope controlling the direction of water flow i.e. parallel to the direction of tilt. However, on real road surfaces water flows along the line of greatest slope which is the combination of both cross slope and longitudinal gradient. Another method to control water film thickness is to maximise the texture of the pavement surface. This is its macro-texture and is a function of aggregate size and gradation.

After each set of rainfall simulation the water trapped on each surface was collected. This is known as depression storage and calculated to an equivalent water depth by dividing the volume of water by the catchment area. Figure 6 shows the depression storage of the 10mm asphalt in relation to rainfall intensity and cross fall slope.

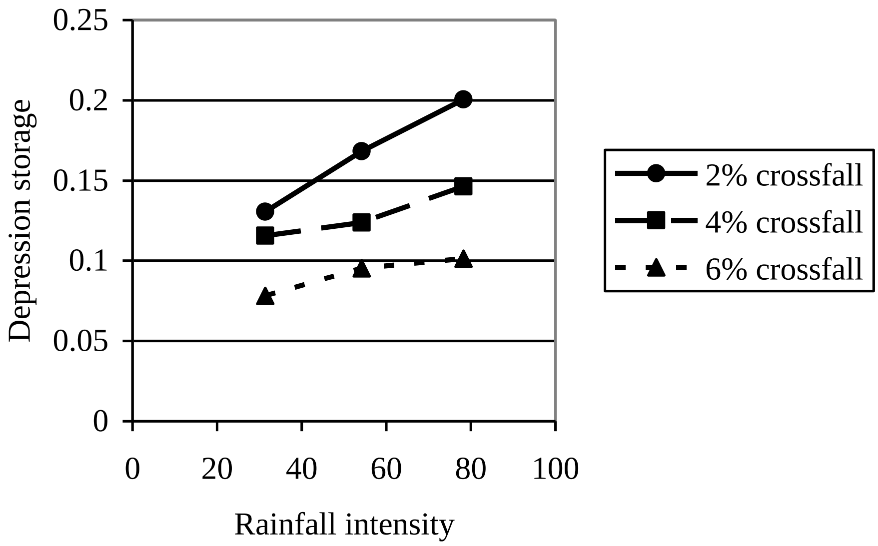

Figure 6, Depression storage for the 10mm asphalt

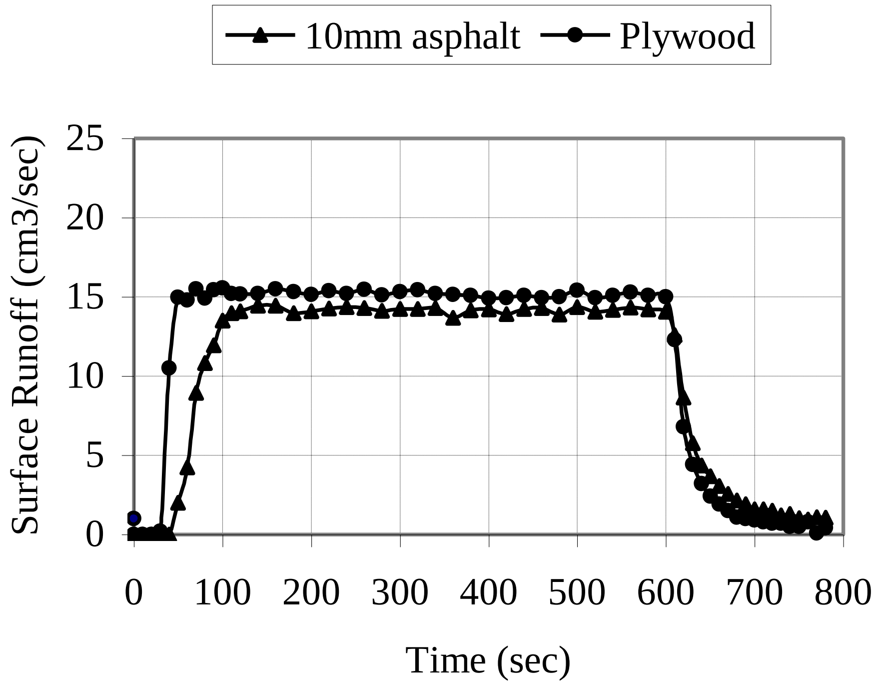

Figure 7, Comparison of both surfaces for a 4% cross slope and 54.18mm/h rainfall intensity

Figure 7 compares the performance of both surfaces for a 4% cross-fall. This shows that the impermeable plywood surface has a faster growth to peak flow, a more intense runoff and a faster return to zero flow.

5. CONCLUSIONS

The initial research reported in this paper has shown that it is possible to determine fundamental hydraulic characteristics of differing materials using simple laboratory rainfall simulation. It has been found that water runoff is influenced by surface permeability or texture depth i.e. more permeable (greater texture depth) surfaces cause slower runoff. Cross-fall influences water runoff i.e. steeper cross-fall results in faster and higher runoff. Testing using a range of rainfall intensities causes a change in the hydrograph profile i.e. the higher rainfall intensities cause a steeper build up to the peak flow, the peak flow is greater and the flow falls off more rapidly. The initial findings of this investigation indicate that the methodology developed will assist in the design of improved sustainable urban drainage systems.

REFERENCES:

[1] Ross, N.F. and Russam, K. The Depth of Rain Water on Road Surfaces. Road Research Laboratory, Report LR 236, UK 1968.

[2] Gallaway et al. The Effects of Rainfall Intensity, Pavement Cross Slope, Surface Texture, and Drainage Length on Pavement Water Depths. Research Report Number 138-5, Texas Transportation Institute, TAMU College Station, Texas, USA, 1971.

[3] NCHRP, Improved Surface Drainage of Pavements. Final Report, The Pennsylvania Transportation Institute, Transportation Research Board, National Research Council, USA, 1998.

[4] Domenichini, L. and Lopencipe, G. Validation of DESTTRA Water Film Depth Prediction Model. The SIIV 2nd International Congress, Italy, 2004.

[5] Simone, A., Vignali, V., Bragali, V. and Maglionico, M. (2004) Surface Runoff: A Rainfall Simulator for Wash-Off Modelling and Road Safety Auditing Under Different Rainfall Intensities. The SIIV 2nd International Congress, Italy, 2004.

[6] CIRIA publication C523 Sustainable urban drainage systems – best practice manual, UK, 2001.

[7] CIRIA publication C609 Sustainable Drainage Systems – Hydraulic, Structural and Water quality advice, UK, 2004.

[8] Zoldske, D.F. and Solomon, K.H., Coefficient of Uniformity – What It Tells Us? Irrigation Notes, California State University, USA, 1988.

[9] Highways Agency, Design Manual for Road and Bridges, Volume 7: Pavement Design and Maintenance, HSMO, London, 1999.