Investigation of the design considerations for Highway Filter Drains through the comparison of stormwater management tools with laboratory simulation experiments

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Enquête sur les considérations de conception des tranchées drainantes autoroutières via la comparaison d'outils de gestion des eaux pluviales avec des simulations en laboratoire

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RÉSUMÉ

Les drains de filtrage d'autoroute sont l'une des techniques de drainage les plus utilisées sur le réseau autoroutier du Royaume-Uni (~7000km). Ces systèmes de drainage durable (SuDS) sont également utilisés en Irlande, et des techniques de drainage fondées sur des principes similaires existent à travers le monde : États-Unis, Canada et Espagne. Les HFD et leurs comportements hydrauliques ont ainsi une utilité transnationale évidente. Cependant, peu de recherches ont été menées pour optimiser les caractéristiques de conception des filtres de drainage, ainsi que la précision des outils permettant leur conception. Combler ce déficit de connaissances pourrait permettre de prédire et améliorer les performances hydrauliques des HFD. Des recherches entreprises conjointement entre les Universités de Coventry et de Cantabrie tentent actuellement de réduire ce déficit en appliquant une nouvelle méthodologie s'appuyant sur une approche globale qui comprend des calculs théoriques et des simulations en laboratoire, ainsi que des comparaison avec les sorties de conceptions obtenues à partir du modèle de gestion des eaux pluviales (i.e., SWMM) de l'EPA et MicroDrainage. Cette méthodologie a été validée par des simulations en laboratoire, qui montrent des résultats très prometteurs et, potentiellement, facilement transférables à large échelle. Cela nécessitera, cependant, quelques améliorations mineures et, surtout, une validation appropriée à plus large échelle, qui devraient être entreprises lors des deux prochaines années.

ABSTRACT

Highway Filter Drains (HFD) are one of the most widely used road drainage techniques on the UK strategic road network, present on approximately 7,000 km of high speed road. These Sustainable Drainage Systems (SuDS) are also used in Ireland, and drainage techniques based on very similar principles exist in countries across the world, including the U.S., Canada and Spain. Therefore, HFD and their hydraulic behaviour have a clear transnational impact. However, little or no research has been done on the impact of changes to filter drain design, nor has much work been done on analysing the accuracy of the design tools in order to predict the hydraulic performance of HFD, representing a large knowledge gap in this field. Joint research between Coventry University and the University of Cantabria is attempting to tackle this issue through the application of a new methodology with a comprehensive approach, which includes theoretical calculations and laboratory simulations, comparing them with the design outputs obtained from the StormWater Management Model (SWMM) of the EPA and MicroDrainage. This methodology has been validated for laboratory simulations, showing very promising results to be readily transferred to a larger scale by being refined by further lab and field studies for full validation in the next 2 years.

KEYWORDS

Rainfall simulation, runoff simulation, transportation security, Stormwater Techniques, Water Sensitive Urban Design

1 INTRODUCTION

The strategic and local road networks are England's most valuable infrastructure asset valued at approximately £344 billion and are made up of roads and other infrastructure such as bridges, embankments and drainage systems (*House of Commons 2014*). Highway Filter Drains (HFD), kerbs and gullies connecting to pipes below ground, and surface water channels along the pavement edge are the main methods of dealing with surface runoff (*DMRB-UK, 1997a*). Approximately 50% of the strategic road network in England uses Highway FD (HFD) as its main drainage technique (*Coupe et al. 2015*). This means that approximately 7,000 linear km (counting both directions of the traffic flow) use HFD.

Other countries such as the Republic of Ireland use HFD as one of their main drainage assets. Visual inspections carried out by Desta et al. (*2007*) on dual carriageways and motorways in Ireland showed that more than 40% of these roads use FD. There are also other drainage techniques similar to FDs which use geotextiles in the device with similar purposes, such as the so called "edge drains" in countries such as the U.S. (*Kearns, 1992*) and Canada (*Raymond et al., 2000*). Other similar structures can be found in Spain (*Andres-Valeri et al. 2014*). Consequently, the transnational impact of this drainage technique has been clearly demonstrated.

HFD are designed to cope with a wide range of storm events, being designed to avoid flooding problems in the roads. Thus, the Design Manual for Roads and Bridges (*DMRB-UK, 2004*) in Volume 4 Section 2 (Drainage) defines that highway drainage systems are designed to catch rainfall from high intensity events in a few minutes (short durations) with return periods of 1 year (for no surcharge of piped systems or road-edge channels) or 5 years (no flooding in the carriageway).

This research has been developed with the double aim of adding more clarity onto the hydraulic performance of HFD under the combination of several rainfall intensities and short duration storm events, as specified in the design rules for highway drainage systems by the DMRB-UK (*2004*). These scenarios examined the stress on HFD systems under design conditions in order to check whether HFD were performing to design requirements.

2 METHODS

2.1 Small-scale laboratory simulations

A standard HFD design composed of Type B aggregate (*BSI, 2006*) was simulated in the laboratory. Four replicates of this design were used for statistical replication, helping in the comparison with the design tools. The rigs used in this experiment were composed of plate-glass and their dimensions were 21.5 cm x 21.5 cm x 65.0 cm for a total volume of material of 0.030 m^3. No bottom pipe was used in these models in order to get the infiltration rates of the Type B material and avoid the limitations given by the pipe, allowing a more accurate comparison with the outputs obtained by using the software from design tools.

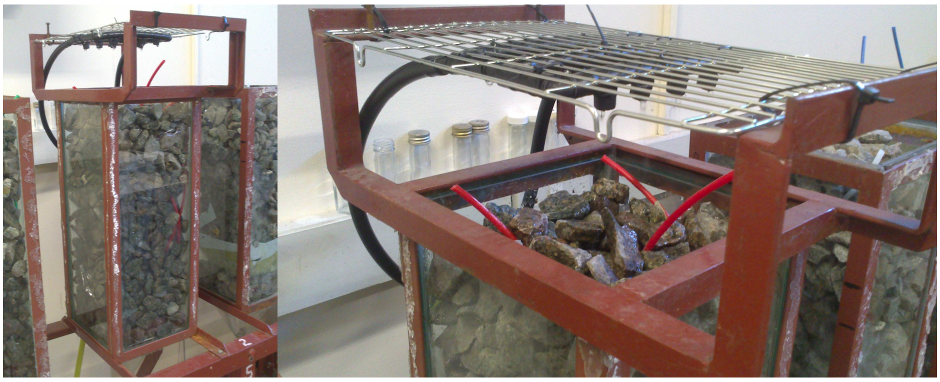

Figure 1. Scheme of the laboratory experiment and the rainfall simulation device.

The hydraulic characterisation of the HFD laboratory models was carried out through the generation of hydrographs of performance under several rainfall intensities (100, 200 and 400 mm/h) and different storm durations (5, 10 and 15 minutes). Neither sediments nor oil were added in order to obtain the hydraulic performance of these designs under newly built conditions to be able to compare those with the scenarios simulated with the design tools provided by the 2 software simulations.

These rainfall intensities simulated rain directly over the rig surfaces producing a flow of 0.070, 0.140 and 0.280 L/min for the 100, 200 and 400 mm/h rainfall intensities respectively, by using the Rational Method (*Woods-Ballard et al., 2015*) recommended for small-scale catchments. Therefore, those volumes of water corresponded to the following rainfall intensities raining over a highway surface consisting on 2 carriageways (6 m) and a hard-shoulder (1.8 m) and a HFD length representative of the laboratory models (0.215 m) (see Table 1). The results were scaled up to a 100 m length HFD for their comparison with the design tools as per shown in the last column in Table 1.

Table 1. Surface runoff flow for a 100 m length HFD produced by the simulated rainfall events for a contribution area consisting on 2 carriageways and a hard-shoulder (7.8 m width).

Flow simulated in the laboratory models for the rig's surface (0.046 m^2) (L/min)	**Equivalent rainfall intensity for 2 carriageways + hard shoulder (1.677 m^2) and 0.215 m length (rig's length) (mm/h)**	**Surface runoff produced by the intensities in the central column raining over a contribution area defined by the 2 carriageways + hard shoulder and 100 meter length (7.8 m^2) (L/s)**
0.070	**2.5**	**0.54**
0.140	**5**	**1.09**
0.280	**10**	**2.17**

2.2 Design tool applications

The Nash–Sutcliffe and adjusted R^2 coefficients were used to check the efficiency in assessing the predictive power of the hydrological results registered in the laboratory (hydrographs of performance) and their comparison with the hydrographs obtained using the SWMM and MicroDrainage design tool software.

2.2.1 SWMM

The Stormwater Management Model (SWMM) is the only free rainfall-runoff modelling software that includes a specific module for the simulation of SuDS, called the LID Control Editor (*Rossman, 2010*). This module enabled the replication of the scaled HFD lab conditions through three layer tabs: surface (roughness and slope), storage (thickness and void ratio) and drain (outflow characteristics).

2.2.2 MicroDrainage

MicroDrainage is the UK industry standard drainage-modelling tool which contains modules designed to integrate SuDS into a drainage plan (*Hubert et al. 2013*). The Source Control module focuses on the role of single devices and therefore was used to replicate the HFD lab conditions; focussing on pipe characteristics, size of the system, porosity and safety factor.

3 RESULTS AND DISCUSSION

3.1 Hydrographs of hydraulic performance

The comparison between the data obtained in the laboratory and the data resulted from the calculations carried out by using the 2 design tools showed a very close pattern of performance as can be seen in Figure 2.

The rainfall event with the highest rainfall intensity and longest storm duration (I=10mm/h and t=15minutes corresponding with a 1 in 11 months rainfall in the West Midlands, UK) was selected in this extended abstract amongst all the events simulated for being the most representative example of a design rainfall for the HFD. The Nash-Sutcliffe coefficient was 0.98 for the SWMM data and 0.97 for the MicroDrainage data when comparing with the laboratory data. Furthermore, the adjusted R^2 was 0.99 for the SWMM and 0.98 for the MicroDrainage.

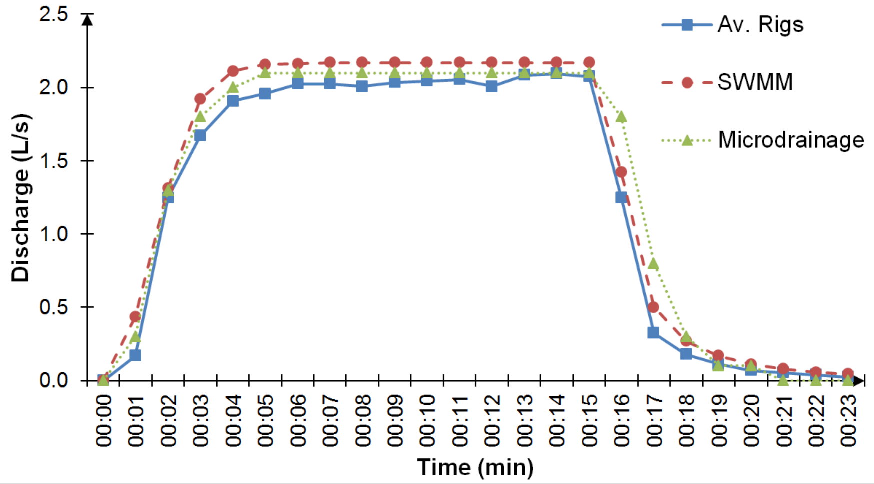

Figure 2. Hydrographs for the 10mm/h rainfall intensity and 15 minutes storm duration for a 100 m length HFD extrapolated from the results obtained for the laboratory models.

4 CONCLUSIONS

Small-scale laboratory models have shown a high level of accuracy for the understanding of the hydraulic performance of a Highway Filter Drain as per demonstrated by their comparison with the simulation tools SWMM and MicroDrainage through the use of the Nash-Sutcliffe and adjusted R^2 coefficients.

A full-scale experiment in the field is recommended as the final step to fully validate the methodology presented in this paper.

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