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Hydraulic Interaction of a Gully System

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Abstract

This paper presents the experimental data collected in a series of tests to measure the hydraulic interaction of a typical gully inlet used in the UK. A full-scale laboratory rig was constructed at the University of Sheffield consisting of a testing platform fitted with grated inlets and a gully pot. The gully pot outlet serves both as an outfall and as an inlet to allow surcharge flow into the system. The aim of this paper is to address the shortfall in knowledge, of the flow into and from (surface and below surface) a typical gully system especially during surcharged conditions. This interaction is expressed in terms of head-discharge relationship and is important for the sewer flow simulations of urban flood prediction models. Ultimately, this information may be used by engineers and manufacturers for the design of surface drainage system and for the calibration/validation of coupled urban flood prediction models.

Keywords: gully; inlets; grates; head-discharge; urban flood modelling.

1. Introduction

Urban flooding is a significant issue that comes as a result of poor planning and rapid urban development. As urbanisation increases, the capacity of natural and existing drainage are exceeded, often resulting in frequent and severe urban flooding events. In order to predict these events, different types of models have been designed to generate flood maps showing information on the spatial extent and depth of inundation of these events. The dual drainage flood models have been introduced predict the urban flooding event. Dual drainage modelling has been described by [1] as an approach to rainfall runoff simulation in which the numerical model takes into account not only the surface flow but also with surcharged sewer systems and its interaction.

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A dual drainage model consists of double network formed by an upper network (major system) and a lower network (minor system). An upper network consists of open channels (street gutters), natural flow paths, retention basins in local depressions or artificial control structures such as brinks and ponds whereas a lower network consists of closed conduits (sewer pipes) with known stormwater inlets and manholes [1, 2]. However, in the dual drainage model, it was found that not much is understood about the hydraulics of the linking element of the model.

The linking elements between the above and below ground drainage system for urban drainage models – identified as manholes and gullies are important elements that have complex hydraulic interactions due to its unidirectional flow. During normal rainfall events, gullies allow the drain of water from the surface to the sewer system. However, during severe flooding, the sewer might become pressurised and excess water may gush out of the sewer onto the surface. This phenomenon is called surcharged flow or reverse flow [3, 4, 5]. Flow in both directions may be under free flowing conditions or it may be partially or fully submerged, with transition zones between the regimes. Whilst changes in surface flow rates may usually be considered as gradual, pressure changes in sewer pipes may be quite rapid following surcharging. The three-dimensional flow that occurs within the different geometry of gully structures and manholes also adds to the complexity of the describing the flow [6].

Urban flood modellers are often faced with the concern on how to model and reproduce the hydraulic behaviour of these elements [4,7,8]. In urban flood models, gullies are usually modelled as a broad-crested weir. The length of the weir is represented by the perimeter of the gully and the weir crest is set at the bottom of the road level. Discharges through the gully are described using the common weir equation, which can represent both the free and submerged flows. This is because by assuming a weir to describe the connection between the pipes and the street system, a restriction can be applied to both, water from the streets entering the pipe system and the water flowing from the pipes into the streets. In a fully surcharged condition however, it is more accurate to use an orifice equation instead of the weir equation. This is because in a fully surcharged condition, the driving head is the difference in head between the pressure in the sewer and the water level on the surface. However, this equation is not accurate in cases where the orifice is not full flowing [9].

In the process of modelling and managing the inflow of stormwater into sewer systems and infiltration into sewers, the understanding of these processes is crucial since it will depend on whether or not these flow devices are operating under a ponding situation or are subjected to a flowing state [10]. A study by [10] attempted to determine the usefulness and practicality of describing the flow through stormwater inlets that were used in City of Edmonton by using the orifice type equation when the gratings are submerged, and the effect of the flow on the discharge coefficient (C_d). However, there is still a concise lack of information on the correct C_d and the head-discharge relationship of the flow, which is the fundamental information in describing the interaction of flow between the above and below ground drainage systems.

Previous studies of manholes and gullies have been conducted but most research only focuses on the surface flow and neglects to consider hydraulics when there is surcharge or overflow in the system. Studies on gullies – experimentally and numerically is even more rare because of the cost of the experimental facilities and the length of the computational time [4]. There is a lack of dataset and fundamental understanding of the hydraulics at these linking elements especially of a gully system. Therefore, predicting the behaviour of flow at these elements is difficult and inaccurate. Hence, there is a need to establish a fundamental understanding of the hydraulics at these elements and to express the interaction at the inlets. It is also crucial to establish a wide dataset of the head-discharge relationship at these elements. The understanding of the complex interactions is essential for the calibration and reliable application of the coupled 1D/1D urban flooding models [9] and 1D/2D models [11,12].

Therefore, an extensive research programme has been conducted within the UK Flood Risk Management Research Consortium (FRMRC) Work Package 3.7, Phase 2 – to address the issue. The work programme is divided into a 2-part programme – the first is the experimental work developed at the University of Sheffield [13] and the second is the 3D-CFD model developed by the University of Exeter to compare the numerical and experimental findings. The experimental system used in this study has been reported briefly as an introduction to the findings of the 3D-CFD [6].

1.1. Experimental Materials and Method

A full-scale experimental rig was constructed in the Water Laboratory at the Department of School and Structural Engineering, University of Sheffield, United Kingdom. The objective of the set-up was to mimic the hydraulic interaction between the above and below ground drainage system of a typical gully inlet used in the UK. The laboratory rig consists of a testing platform, with a smaller tank on both left and right hand side of the platform to serve as an inlet/outlet tank. The testing platform is a rectangular platform 4.27m (L) x 1.83m (W) and drains a total area of 7.814 m^2. The dimension for the inlet and outlet tank itself is 0.61m (L) x 2.44m (W). Both of these tanks are each equipped with a sluice gate to allow control of the hydraulic depth on the testing platform. The flow for the entire system is provided by an overhead tank and is circulated through the entire system before being transferred into a sump. The gully pot used in this study had a diameter of 375mm with 750mm of nominal depth and was tested over a range of flowrates of 0 – 50 *l/s*. The laboratory rig has also been designed to test for horizontal slope (flat bed), 1/100 slope and 1/30 slope. The limitation of this experimental programme is that it is only able to test for horizontal slope and not crossfall.

The laboratory system can be altered to mimic 3 different gully systems. The three systems are – (i) terminal, (ii) intermediate and (iii) surcharged system. Terminal system is a system which does not permit any significant amount of flow to past through. In this system, it is assumed that all of the approaching flow will solely be intercepted by the gully system and that the approaching flow (Q_a) is equivalent to the intercepted flow (Q_i). Intermediate systems are gully system, which permits a portion of the approaching flow to flow past the system and into the next downstream gully. Therefore, the approaching flow (Q_a) is the total of the intercepted flow (Q_i) and the bypassed flow (Q_b). Surcharged system is a gully system, which mimics the surcharge condition in a real gully system – when the drain have reached its capacity and begins to flow onto roads and highways. In this paper however, only the results of tests that were conducted with the flow from both tanks such that the flow to the gulley is in two directions (terminal system) of the flat bed were reported.

Seven pressure transducers were used for this experiment with six pressure transducers positioned on the bed of the chamber to record the flow depth to the gully. One pressure transducer is positioned at the bottom of the gully pot to obtain the depth of water in the gully pot itself. Two types of grates were tested, Grate Type A with clear opening of 400mm x 432mm (HA 102 – R) and Grate Type B – with 325mm x 437mm of clear opening (HA 102 – S)[14]. Figure 1 shows the laboratory rig that was initially set-up for use for the experimental work. Further to this, the laboratory rig was retrofitted with pressure transducers as an upgrade from the point-gauge measuring system. The laboratory system is configured in National Instrument Measurement and Automation Explorer (NI MAX) to allow it to function as a remote system, which then allowed the author to programmatically control the testing and accumulation of data wirelessly through Virtual Instruments (VI's) of the LabVIEW interface.

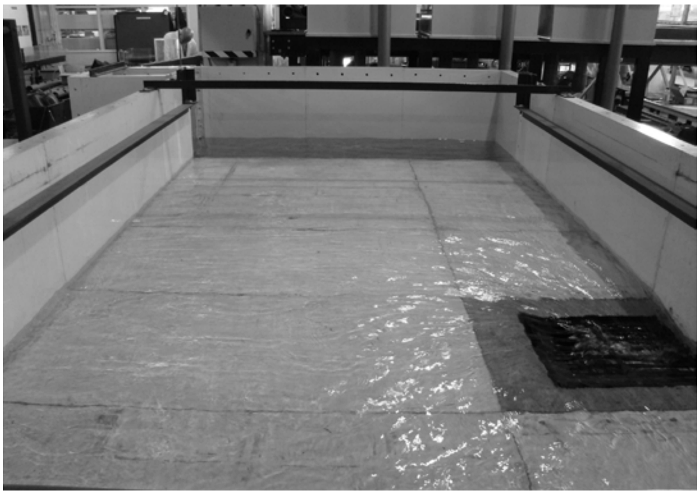

Figure 1: Laboratory rig

1.2. Results and discussion

The head-discharge relationship of Grate A and Grate B for the horizontal bed are presented in Figure 2. The flow depths are taken as the average of all six-pressure transducers to represent the hydraulic depth on the surface. This is because in the case of a terminal test, the depth of water on the testing platform is reasonably constant and the average of all six-pressure transducers therefore provides an appropriate representation of the hydraulic head going into the gully system. Based on this figure, it can be seen that the head-discharge relationship of both Grate A and B displays a similar behaviour throughout the flow range – with a gradual increase of inflow depth as the flowrate increases. The inflow depth for Grate B is marginally higher as compared to Grate A for the same flowrate. This is a probable indication that Grate A has a higher rate of removal compared to Grate B because the clear opening area of Grate A is larger than Grate B. In addition there is a deviation from a smooth curve at flowrates in the range 34 to 40 litres/s and this has been further explained by reference to the monitored depth of flow in the gully pot as shown in Figure 2.

Due to the similarity in the monitored depth in the gully, the corresponding depth of water in the gully pot is presented for grate Type A only and is as shown in Figure 3. The gully depth (h_G) has been presented as a negative depth (mm) where 0 mm is the grate surface parallel to the platform surface. Hence, a value of -825 mm represents the bottom of the gully -750mm nominal gully depth plus 75mm grate depth.

It can be seen that there is a steady increase in gully depth with flowrate. However, after reaching a peak in depth (point. 2, Figure. 2) at approximately -25mm and between 30-35 *l/s*, there is a change of depth in the gully. This can be seen by the rapid decline in depth between 34-40 *l/s* followed by a steady increase in depth again. The explanation for this change may be made by reference to the level of the gully pot outlets, which become surcharged with pressurised flow. The outlets act like an orifice with pressurised flow with a corresponding increase in the flowrate through the outlet. Subsequently the flow dynamics result in a lowering of the flow depth in the gully pot (as outflow is greater than inflow), which reaches a minimum at point. 4, Figure 3. Subsequently there is a gradual increase in flow depth. A more detailed picture of these changes has been made by reference to captured video images, shown in Figure 4. These images have been extracted from a continuous video recording over the duration of the test. The images shown correspond to the key points of change as shown in Figure 3.

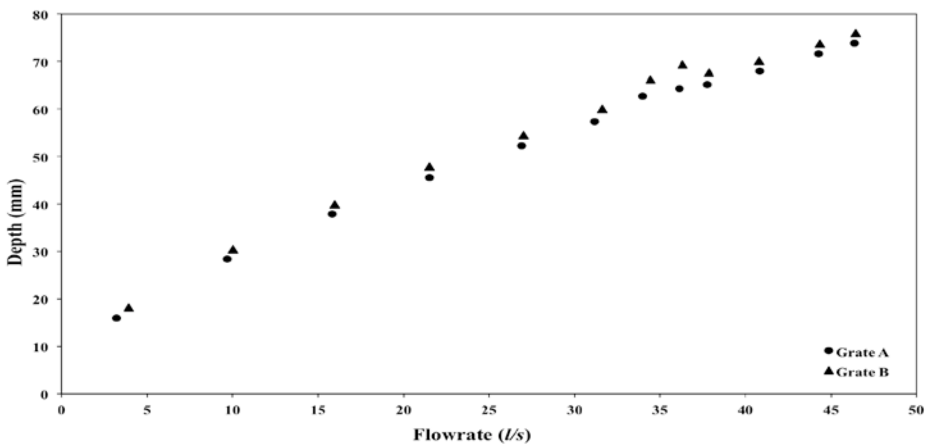

Figure 2: The head-discharge relationship of Grate A and B with a flat bed

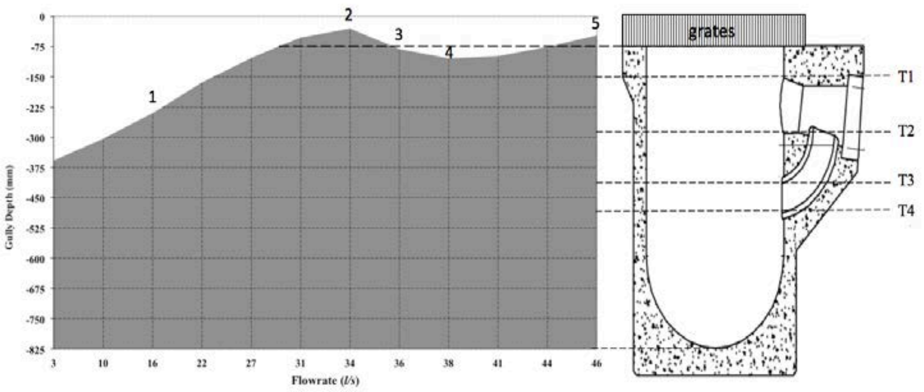

Figure 3: The corresponding depth of the gully to the outlet depth

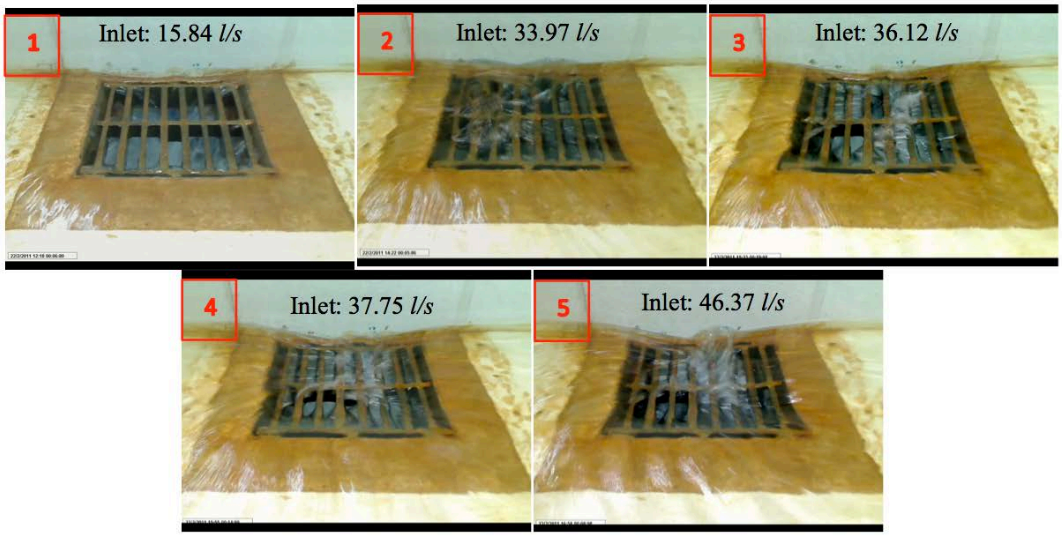

Figure 4: The behaviour of flow at the Grate A inlet at different flowrates

Figure 4 presents images that highlight the change in surface flow pattern at the grate. Based on the changes from image 1 to image 2, there is a change in flow regime with a transition from an orifice flow to one of a surcharged flow regime. Images 3, 4, and 5 show a gradual return to orifice flow. Hence, it is concluded that the flow conditions at the gully are very much a function of the gully pot and that the relationship between flow depth and flowrate is a function of the geometry of each individual grate, the geometry of the gully pot, especially the height of the outlet pipe and the dynamics of the flow that enters the gully. The results presented herein is only preliminary results. The coefficient of discharge and the relationship between the hydraulic depth and Froude number will be presented subsequently.

1.3. Conclusion

It can be concluded from the experimental work that the flow conditions at the gully are very much a function of the outlet capacity of the gully pot. The relationship between flow depth and flowrate was a function of the geometry of each individual grate but similar trends in the head discharge relationship for each grate were observed. The head discharge relationship for Grate A, in general, resulted in a lower head for the same flowrate when compared to grate B and hence concluding that Grate A is more efficient in capturing flows when compared to Grate B for the flat bed. Experimental results presented in the paper demonstrates a crucial need to understand the hydraulics of these linking elements namely of the interactions between above and below ground drainage systems. The establishment of the head-discharge relationship plays a vital role for the calibration and validation of existing dual drainage model.

It is also recommended that further studies be made to consider the crossfall of the road and the qualitative aspects of the stormwater.

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