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Stormwater overflow in stepped channel

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Abstract

Sharp bends in drainage channels are sometimes engineered to suit local topography, especially in densely populated cities where land is limited. A hydraulic model study of a steep urban drainage channel is carried out to investigate the causes of an overflow incident in Hong Kong urban area, and to develop the drainage improvement measures to prevent flooding. The stepped drainage channel has a sharp bend in the middle and several trash racks are located along the channel. Experiments are performed on a 1:16 Froude scale model. In the first phase, experiments on a purposely built straight channel model are performed to study the bottom roughness of the stepped channel flow isolating the effect of the bend. After the straight channel experiments, four trash rack scenarios are tested in the exact model with detailed channel features. The flow in the drainage channel is supercritical and highly aerated. Based on the theory of skimming flow in stepped channels, a hydraulic assessment suggests that the bend and trash racks may be dominant causes of the overflow. The experiments show that sharp bend causes a spiral flow leading to significant lateral overflow. The trash racks are observed to generate a serious ski-jump type overshooting flow. It is found that the stormwater overshoot and flooding can be prevented by the repositioning of appropriately sized trash racks and the containment of the spiral flow. The proposed channel improvement design has been implemented on site and found to work successfully in heavy rainstorms after installation. The present study offers novel insights into the design of urban drainage works.

Keywords: Supercritical flow; Channel bend; Stepped channel; Trash rack; Aerated flow; Urban drainage; Physical model

1. Introduction

Sharp bends in drainage channels are sometimes engineered to suit local topography, especially in densely populated cities where land is limited. In addition, trash racks for screening debris are sometimes put in the drainage channels to protect the downstream drainage system. In the early morning hours of 24 June 2005, a serious flooding incident occurred in a drainage channel at Smithfield in Hong Kong. A large scale overshooting of stormwater runoff from the drainage channel was observed. Highly aerated flow overtopped the channel and ran down to the road below. The flooding channel is a 1.5 m wide rectangular stepped channel consisting of the upper channel, lower channel and steep cascade (Figs. 1 and 2). The total length of the channel is approximately 60 m with a 132° bend between the upper and lower channels. The Smithfield channel is located on a man-made cut-off slope, approximately 40 m above the street level (Fig. 2). On the day of flooding the channel was fitted with two trash racks in the lower channel in front of the entrance to the steep cascade. The flooding discharge is estimated to be 9.2 m^3/s and the overshooting from the drainage channel is a potential serious hazard to traffic as well as pedestrians.

The flow can be characterized as a supercritical stepped channel flow complicated by the presence of a sharp bend and trash racks. Stepped channels are commonly found in drainage systems to increase bottom roughness of the channel with a roughness length of the order of the size of the steps resulting in large energy dissipation. While there have been a number of studies on stepped spillways, most of the studies dealt with spillways with slopes greater than 40°. These studies showed that the Darcy-Weisbach friction factor in a stepped channel can be as much as 0.7–1.0, compared with a typical value of

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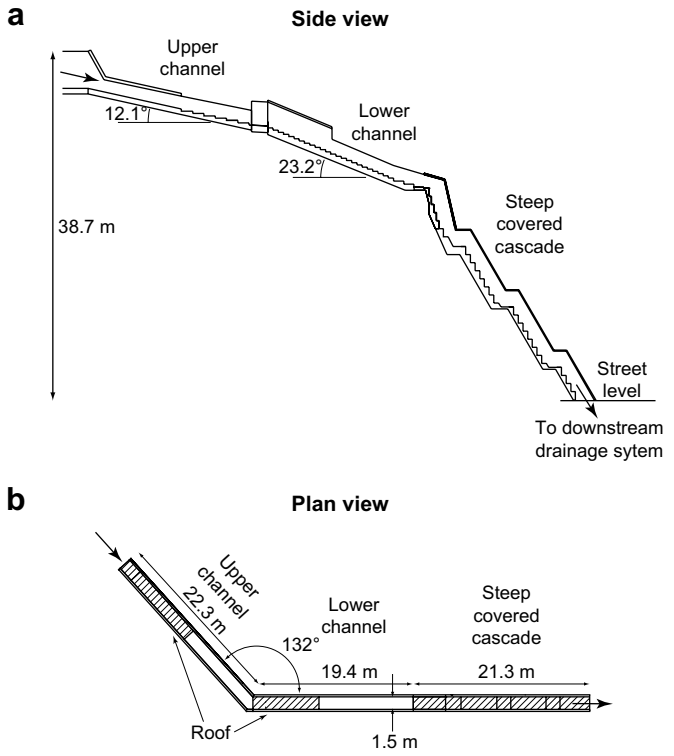

Fig. 1. Smithfield drainage channel.

around 0.03 for a smooth concrete channels (Rajaratnam, 1990; Chanson, 1993). A recent study (Ohtsu et al., 2004) has reported skimming flow characteristics on channels with slopes in the range of 5–20°.

There are limited studies on the effect of trash racks on the flow. The headloss coefficient of trash racks of various shapes are found in Miller (1978). Abt et al. (1992) carried out an experimental study on the blockage at a trash rack in a supercritical flow. In their study, different blockage ratios that cause flooding for standard trash rack design are investigated. A parabolic shape trash rack design with emphasis on safety issues and sweeping of the floating objects was proposed by Allred-Coonrod (1994).

The objective of this study is to investigate the causes of the stormwater runoff overshoot through a physical model study. A hydraulic assessment of the channel capacity is carried out based on the stepped channel flow theories. From the results of the physical model study, improvement measures are proposed and successfully implemented.

2. Description of drainage channel and experimental setup

2.1. Drainage channel description

The channel consists of an upper channel, a lower channel and a steep cascade. The upper channel is 22.3 m-long with bottom slope of 12.1°; the channel is partly stepped, with 0.3 m high and 1.4 m long steps (Fig. 1). The upper channel turns through a 132° bend into a 19.4 m-long lower channel. The steeper lower channel has a bottom slope of 23.2° with 0.3 m high (h) and 0.7 m long (l) steps. The upper part (8.6 m) of the lower channel is covered with a roof. The width and wall height of the lower channel are 1.5 m and 1.6 m, respectively. The flow from the lower channel enters a 28 m-high covered steep cascade that leads to the downstream drainage system.

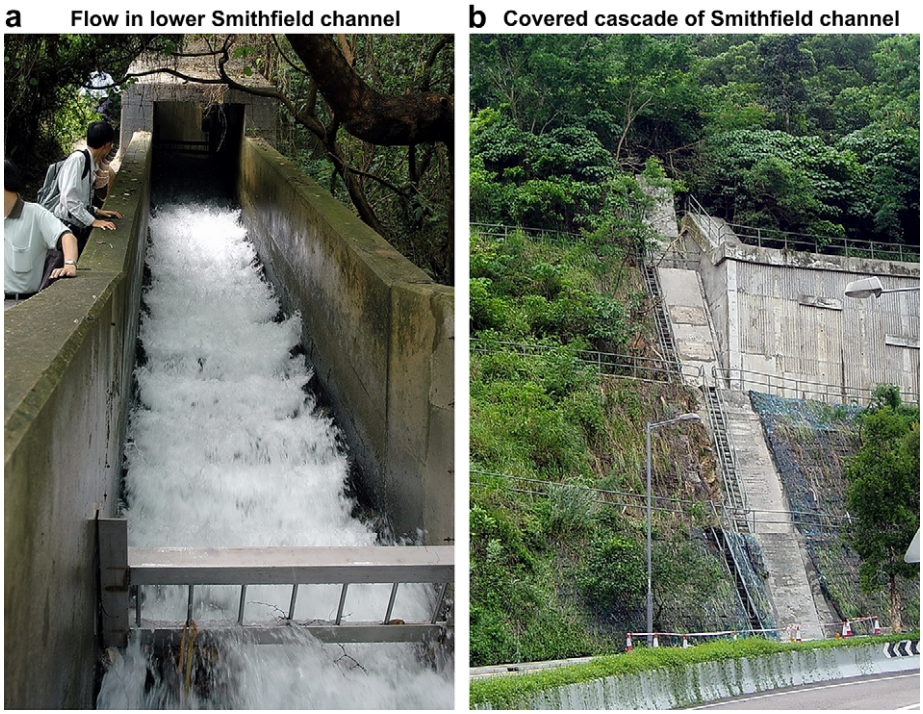

Fig. 2. Smithfield drainage channel site.