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Experimental investigation of dam-break usinglow cost laser sources and image processing techniques

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ABSTRACT

Dambreak waves in a horizontal rectangular and smooth channel are measured using a number of low cost laser sources, fluorescent dies and Planar Laser Induced Fluorescence (PLIF). Even in such a simple configuration, the experiment are useful to investigate a number of factors such as: the initial wave formation process, the positive front propagation and the local velocity of the wave. The positive wave fronts and the shape of the waves are compared with analytically determined solution proposed by Ritter. The effect of the relative reservoir high on the wave maximum and shape is shown to reasonably agree with the Ritter solution. The results so obtained are discussed and allow a deeper insight into the mechanics of dam-break waves. The results are readily available for applications, and a significant modification regarding the initial flow conditions is described.

1. Introduction

Dam-break flows are of considerable practical and academic interests since the free-surface flow consequential from the abrupt collapse of a dam has enormous impacts on the downstream territory, including loss of life and devastation of critical infrastructure (). Truthful modelling of the wave propagation resulting from the dam collapse is a stimulating problem and has received considerable attention during the past decades. Nevertheless, most of the studies focused on the numerical aspects of dam-break while comparatively limited experimental studies exist. Among these studies only few explore the wave dam-break using laser sheets [1-8] and all of them very powerful and very expensive laser sources (5w and thousands of euros). In this study a number of low cost laser sources and fluorescent dies have been used to explore the shape and the velocity of the dam-break wave. In order to validate the new experimental facility the simplest configuration has been considered: the dam-break in a rectangular, smooth, horizontal and dry flume. Even in such a simple configuration, the experiment are useful to investigate a number of factors such as: the initial wave formation process, the front propagation and the local velocity of the wave. Finally, to investigate the effect of the water level upstream of the dam on the wave propagation and internal velocity, the experiments were carried out using several initial reservoir water depth.

2. Experimental Set-Up

The experiments were carried out in a rectangular channel 10 m long and 0.3 m wide. The bottom and the right wall were coated with 3mm black PVC and the left wall was of glass. The channel was fixed on upstream bearings and set on a downstream support (Figure 1). The simple static system allowed easy change of bottom slope from horizontal to a maximum of 0.50 (26.5 deg.).

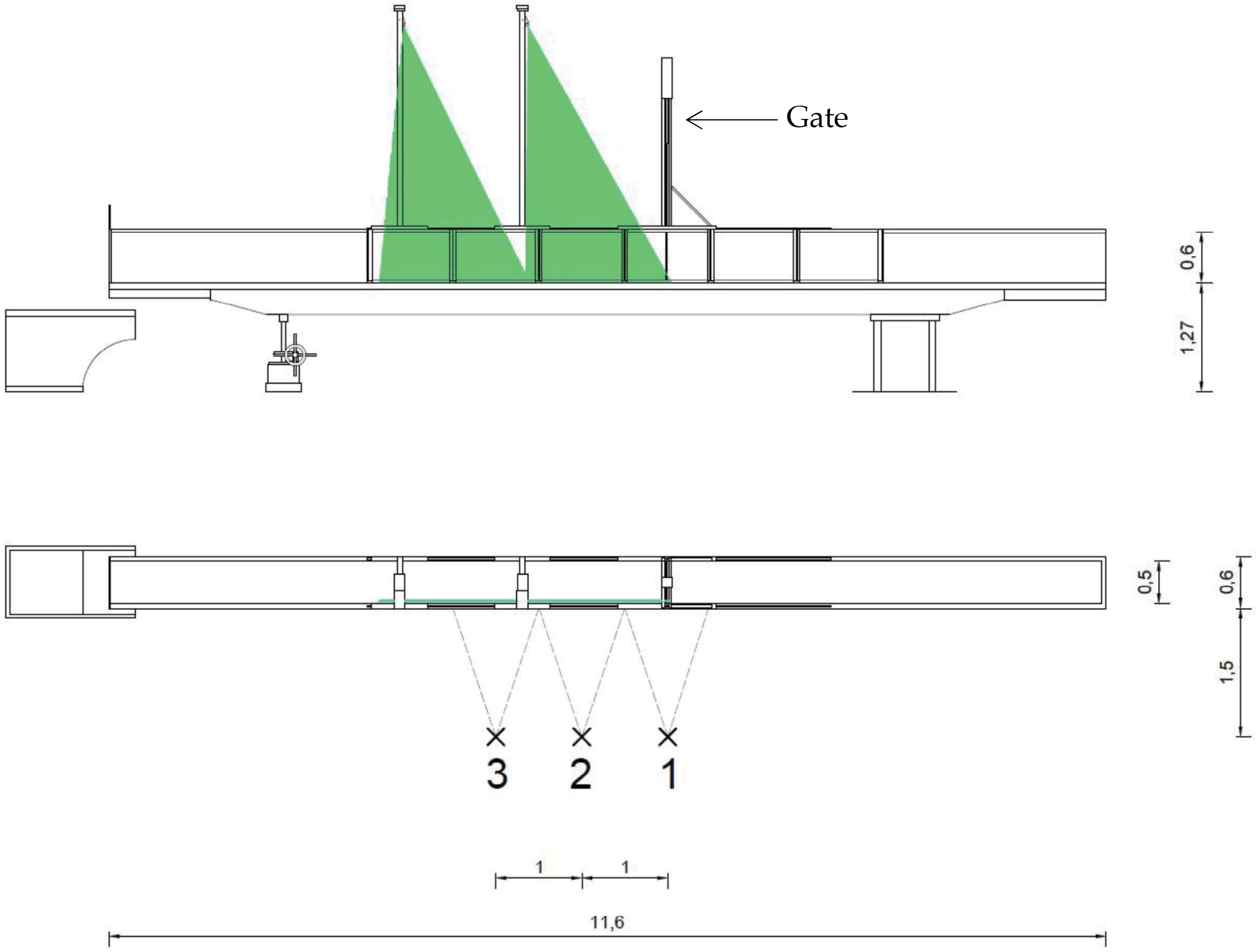

Fig. 1 Schematic of flume and experimental setup (measures in m).

A vertical slide gate was mounted at a distance of 4 m downstream of the upper channel end. The gate was driven by an air piston, and could be accelerated up to 5 g. Conventional tape was used to make the gate water proof. The water was recirculated from the bottom tank to the upstream end of the channel using a conventional pump. Prior to each experiment, the bottom downstream of the gate was carefully dried out to carry out experiments on dry tailwater channel.

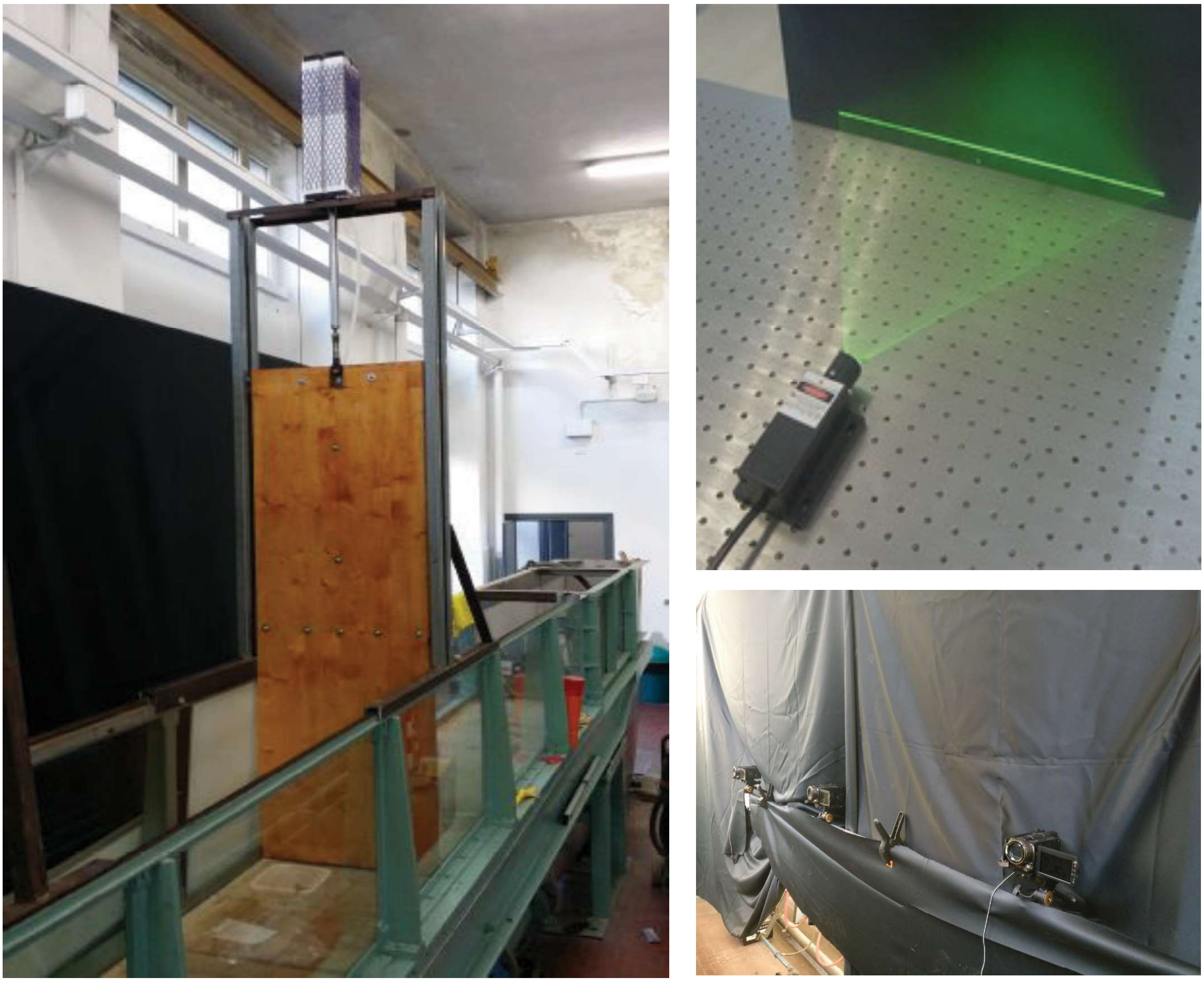

Fig. 2 The gate driven by the air piston, the laser and the camcorders.

In this manuscript both the free-surface profiles is presented. To be able to clearly identify the surface of the dam-break wave, some fluorescent dye (Rhodamine) was added to the water. The flow is visualized by a laser light sheet along the flume generated using two low cost 300 mw green laser source (CNI, Changchun New Industries Optoelectronics Technology Co., Ltd.)

mounted in the plane of the channel axis. The channel was covered with a black cloth to increase the visibility of the laser sheet. Observations were collected using three commercial full-resolution SONY cameras directed to the light sheet giving a field of view of about 0.5 m height and 3.0 m length. Moreover, to validate the images acquired with the commercial cameras, a very high resolution scientific camera (Andor Zyla 5.5 sCMOS Camera) was also separately used. The video images are recorded, for the Sony cameras, at effectively 30 frames/sec. The frame rate of the Zyla was 100 frames/sec. As an example, in figure 3 few frames acquired by the Sony cameras are shown. Figure 3 shows the video images of the flow evolution with time. To provide the whole field of the wave propagation, the frames from the three cameras have been joining into a single image.

Fig. 3 Few frames showing the evolution of the dam-break wave. The frames from the three video cameras have been joined using Matlab.

The position of free surface of the flow, in pixel, was determined with edge recognition function which refers to the process of identifying and locating abrupt changes of red color intensity in the image. The accurateness of digital image measurements is impacted primarily by sensitivity and resolution of the camera, recording distance, reasonable threshold value for sharpening edges. It is difficult to accurately detect air–water interface during experiment, particularly on wave front when the wave breaks or presence of air entrainment causes foaming in the flow. Hence, in order to minimize this, the water–air interface can be accurately defined by contrast enhancement. In particular, air–water boundary was demarcated as an edge where the color changes from black to red.

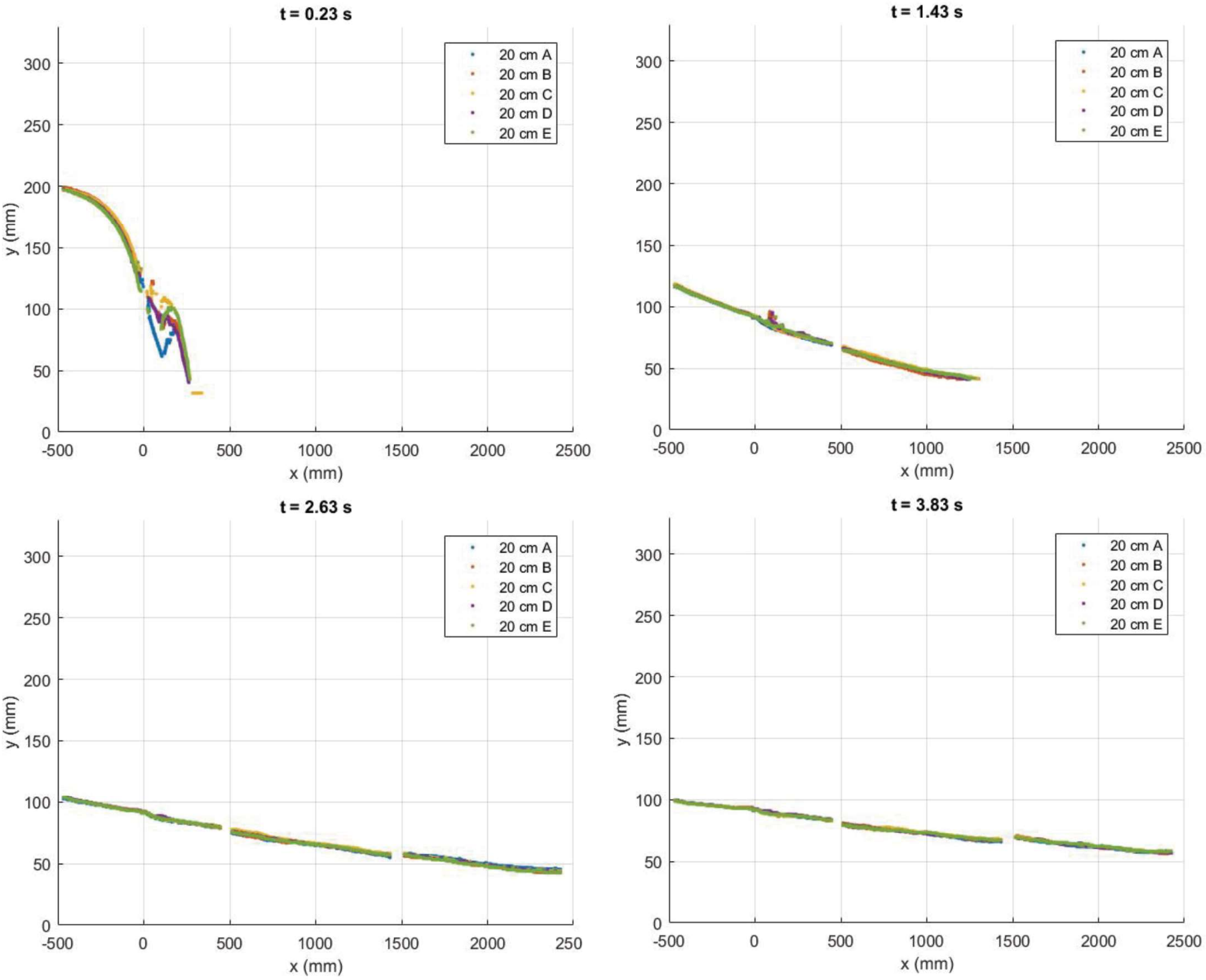

Fig. 4 The water surface profile for the five simulated dam-breaks with 0.20 m of still water in the reservoir.

This procedure was automatically reiterated for each images extracted from the three videos and then calibrated pixel coordinates were transformed into metric values. In this sense, the exact position of the free surface in the real space is obtained from the digitized images and a plane white board with a uniform square mesh printed on it and placed in the plane of the laser sheet with the flume full of water so that the distortion of the mesh may be quantified and any position in a video frame can thereafter be interpolated relative to the mesh. The coordinate transformation from pixel to the real space (mm) is important from the accurateness of the analysis. This value was calculated as about 0.1 cm/pixel. The estimated error in measurement of the water level was found between 0.5 and 1 mm at still water condition. Therefore, image processing can produce water level time evolution with a reasonable accuracy without causing any disturbances to the flow.

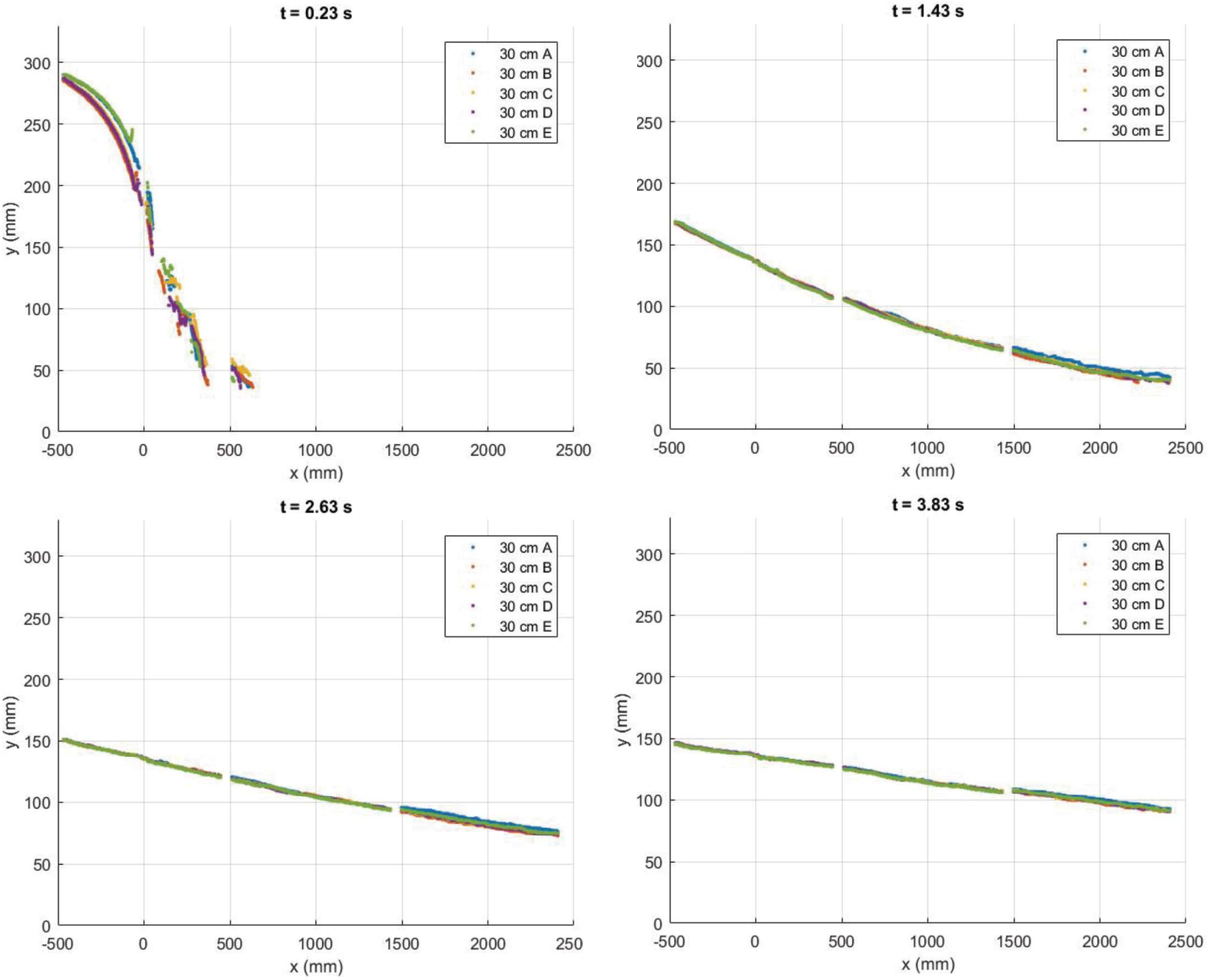

Fig. 5 The water surface profile for the five simulated dam-breaks with 0.30 m of still water in the reservoir.

2. Results

The temporal evolution of the water level along the flume for five runs with identical still water high in the reservoir (0.20 and 0.30 m respectively) is shown in Figure 4 and 5. From these figures it's appreciable how the results are repeatable between one run and another. This gives us confidence on the robustness of the method used and of the experimental set-up.

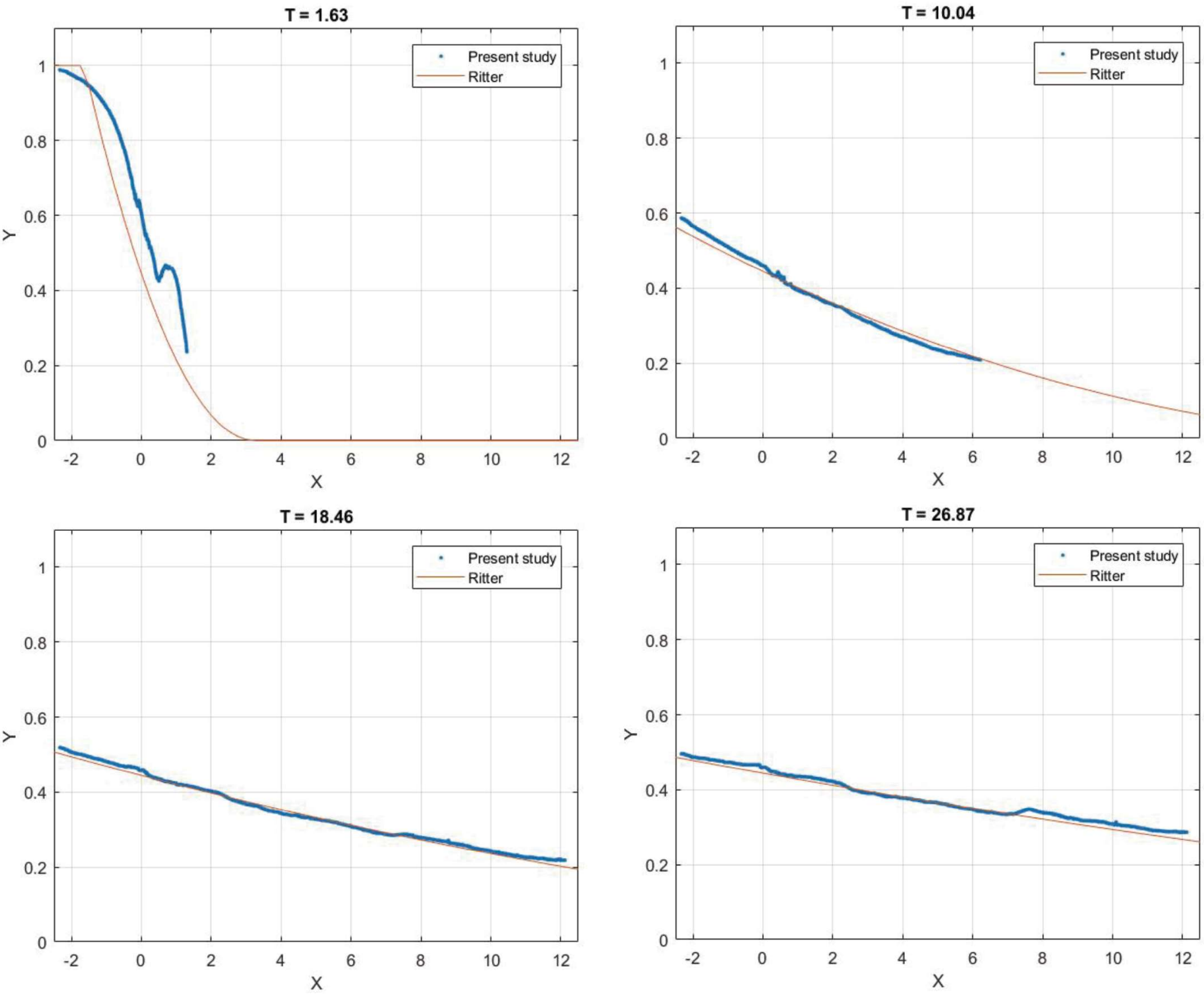

Fig. 6 The comparison between the water surface profiles from the Ritter solution and those obtained from averaging the five simulated dam-breaks shown in figure 4.

Here, as a first evaluation of the experimental setup, we show the comparison between the measured wave surface and the theoretical solution proposed by Ritter (1892).

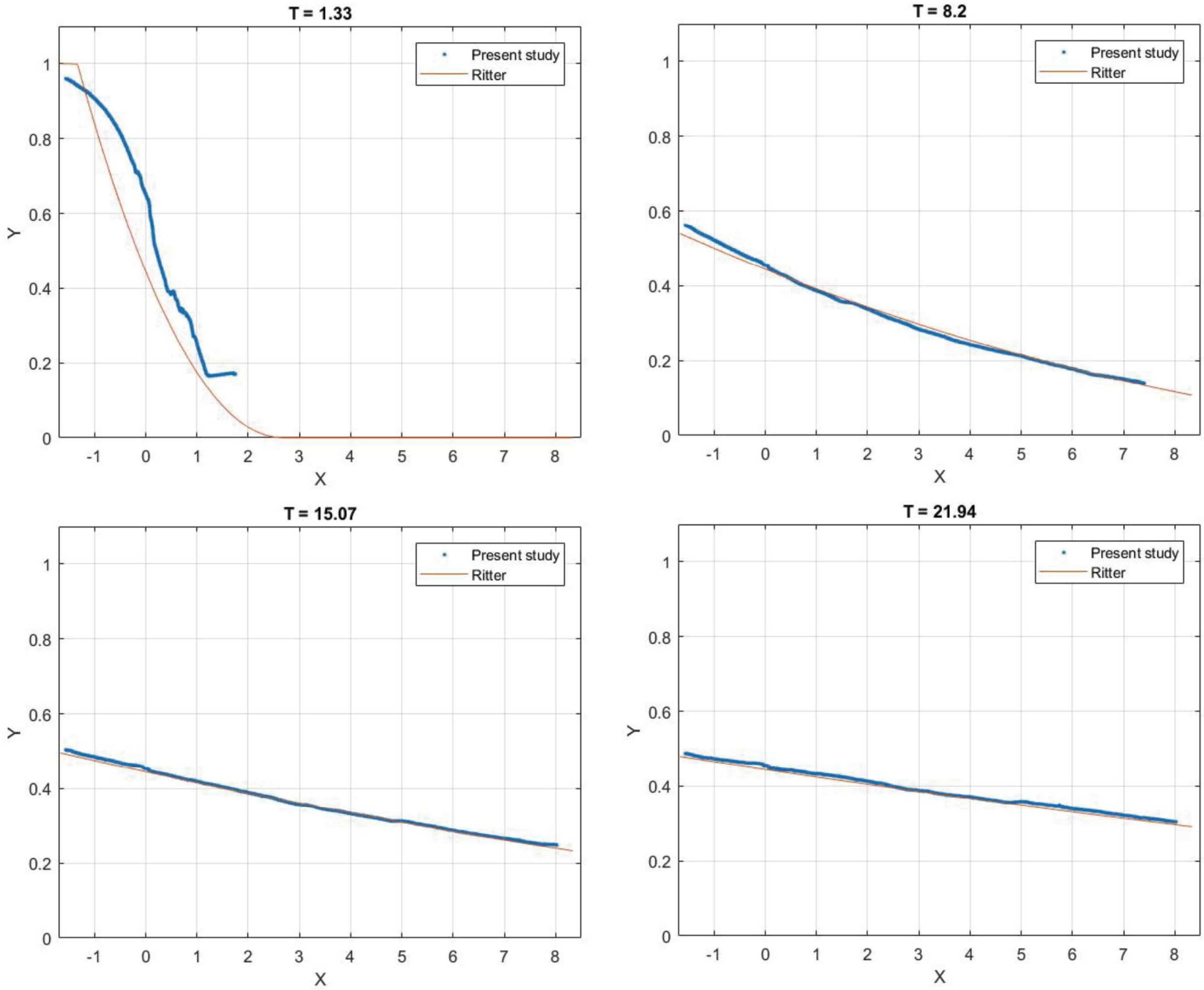

Fig. 7 The comparison between the water surface profiles from the Ritter solution and those obtained from averaging the five simulated dam-breaks shown in figure 5.

Ritter considered a horizontal channel with a reservoir extending infinitely upstream. He defined the non-dimensional coordinates $X = x/h_0$, $T = (g/h_0)^{0.5}t$, $Y = y/h_0$, $V = v/(gh_0)^{0.5}$, and $Q = q/(g{h_0}^3)^{0.5}$, based on which the Ritter's solution reads

$$Y = \left[\frac{1}{3}\left(2 - \frac{X}{T}\right)\right]^2$$

$$V = \frac{2}{3}\left(1 + \frac{X}{T}\right)$$

$$Q = \frac{2}{27}\left(1 + \frac{X}{T}\right)\left(2 - \frac{X}{T}\right)^2$$

where x the downstream location from the dam section, t time, ho the initial reservoir water depth, v the time-averaged velocity, and q the discharge per unit width. Ritter's solution is typically used to estimate the dambreak waves due to a sudden dam removal since it reproduces the overall features of the wave quite well, at least for wave propagation on a dry tailwater channel with a semi-infinite reservoir extension.

3. Conclusions

A novel experimental dataset of dam break waves in a horizontal, dry, smooth and rectangular channel has been acquired using digital image processing in a rectangular prismatic channel. Implemented measuring technique is non-intrusive and it provided valuable results concerning stage hydrographs through the whole channel without necessity of any physical device within the flume. The profiles have been measured experimentally using low cost laser sources, cameras and fluorescent dies. The shape of the waves is also determined from the classical equations from Ritter, and the agreement with the results obtained using the low-cost experimental set-up is quite good and promising for future experimental campaigns.

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