

SEPKA 2016

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## MONITORING LABORATORY SCALE RIVER CHANNEL PROFILE CHANGES USING DIGITAL CLOSE RANGE PHOTOGRAMMETRY TECHNIQUE

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**Abstract:** Measuring and monitoring of river channel evolution or changes under laboratory conditions is an important scope in hydraulic assessment. Measurement such as changes in river channel profile for instance, provides an important indicator on erosion and accretion rates in hydraulic modelling. Under controlled conditions, the changes in channel profile are usually measured using a high precision point gauge. However, when large numbers of points of river profile need to be measured, the use of point gauge method becomes laborious and time consuming. This study proposed a digital close range photogrammetry technique to measure natural river channel bed profile changes in laboratory. The objective of this study was to investigate the changes of physical river model profile for pre and post flooding simulations using digital close range photogrammetry technique. Small scale physical model experimental works were conducted in the Hydraulics and Hydrology Laboratory to observe the river profile evolution during the events. The flood flume utilized in this study is 4.95 m long, 1.38 m wide and 1.26 m deep with carved V-shaped natural main channel with a bed slope of 1:500. Data measured from digital close range photogrammetry technique during pre-flooding at  $t = 0$  second and post flooding events at  $t = 9660$  second were compared to determine the channel profile evolution or changes after simulation of flood event. The results show the changes in invert level or bed level between non-flooding and flooding events due to erosion is varies from 1 mm (minimum) to 6 mm (maximum) along the channel between chainage 0mm and chainage 2000 mm with total volume of erosion is  $1157 \times 10^3 \text{ mm}^3$  respectively. It can be concluded that the digital close range photogrammetry technique can be used as a complimentary method to measure and monitor the changes of river channel profile in the laboratory.

**Keywords** – *Photogrammetry, digital image processing, channel profile, erosion.*

## 1.0 Introduction

Topographical measurement in riverine environment has enabled numerous studies including roughness characterization, river channel evolution, erosion and deposition, scouring processes. The measurement of natural river profile changes using physical model in hydraulic laboratory can be used to assess the dynamic processes in a river system. The available conventional techniques such as point gauges only enabled longitudinal and cross-sectional profiles to be obtained with coarse measurement density and a long measuring time. Performing natural river profile measurement at a point or point wise of a natural river model using point gauges has an accuracy of 0.1mm. This method is also known as contact method. This method requires direct contact between the object surface and the point gauges, as shown in Figure 1. However this method suffers from major drawbacks, such as the points measured cannot be dense and well distributed and river profile changes can only be measured at required points where the point gauges are placed. In addition, when large numbers of points or river profiles are required or desired, using this method requires considerable time and effort.



Figure 1: Measurement of river channel profile using digital point gauge

Due to the number of drawbacks that have been highlighted and because of the difficulties in measuring natural river profiles physical model by using the existing contact method, many researchers have put their efforts to alleviate the existing problem on natural physical river model measurements by using non-contact methods using a digital videometry, digital close range photogrammetry technique, geodetic method by using precision robotic total station, and terrestrial laser scanning (TLS) system. Nevertheless, these methods require specialised equipment or sensors which render them to be not cost-effective for small studies. On the other hand, cameras have become important instruments in fluid mechanics laboratories experiments (Westaway *et al.*, 2001). Associated with computer vision and image processing techniques, 3D models can be extracted from stereo digital images by using off-the-shelves cameras that are

more affordable and accessible. Moreover, the advancement of computer technologies and storage capacity has made digital image processing task more reliable, faster and applicable to many applications that deal with digital images. The digital images captured by the digital cameras can then be downloaded to a computer for further images processing and analysis.

This study demonstrates the application of digital close range photogrammetry technique (DRCP) in hydraulics laboratory experiment to investigate the dynamic of natural river channel. The main objectives of the study are as follows; to model the three dimensional river channel physical model using DRCP measurement technique and to estimate the river channel profile changes using pre and post flooding event data obtained from DRCP technique. The scope of the work undertaken in this study can be summarised as follows; construction of river channel physical model, preparation of DRCP system including a digital single-lens reflex (DSLR) camera internal settings and camera calibration, installation of control points (CPs) on river channel physical surface model, measurements of CPs coordinates (X,Y,Z) using total station, image acquisitions of river channel physical model during pre and post flooding events using DRCP technique, to perform pre and post flooding events digital image processing (DIP) using Agisoft Photoscan software to generate pre and post flooding events digital terrain model (DTM) and to estimate the natural river physical model profile changes.

## 2.0 Photogrammetry

Photogrammetry is a technique to measure position, size and shape of any physical object, using two dimensional photographic images or, using digital images of the object (Luhman *et al.*, 2016). With the availability of digital cameras, storage media, computer hardware and software at affordable cost, there is a dramatic increase in the use of digital photogrammetry in fields that requires precise measurements. Comparatively, it is more convenient than traditional photogrammetry as the acquired images are in digital format and this allows for the relevant processing to be undertaken. The fundamental task of photogrammetry is to establish geometric relationship between 2D image of an object and 3D space coordinates, at the instant when the image is captured. Once this relationship is established, the relevant calculations can be done to determine the position, size and orientation of the object, with respect to the selected coordinate system.

Photogrammetry is also being categorised as aerial and terrestrial photogrammetry. The areal photogrammetry has been widely used in topographic mapping for land development and exploration for natural resources. On other hand, the terrestrial photogrammetry is commonly used at ground level for small-scale surveying, manufacturing and industrial applications. There are also researchers that defined the terrestrial photogrammetry as close range photogrammetry (CRP) (Luhman *et al.*, 2006).

### 2.1 Close Range Photogrammetry

The term CRP is defined as a technique for measuring an object at a distance of less than about 100 m and the camera is positioned close to the object (Cooper and Robson, 1990). A number of researchers advocate that 300 m as maximum limit for CRP (Luhman *et al.*, 2006), while minimum distance is a fraction of a millimetre CRP (Kennert and Torlegard, 1980). Recently, with the image is captured and stored in digital format, the digital close range photogrammetry is commonly known as DRCP. DRCP is a method where the three dimensional measurements are made from two dimensional digital images taken on one object. In general, digital images are taken from an object from at least two camera positions. From each camera position, there is a line that runs from each point on the object to the perspective centre of the camera. Using a principle of triangulation, the point of intersection between the different lines of sight for particular points is determined mathematically to identify the spatial or three dimensional locations of the object points.

In civil engineering the DRCP techniques is widely applied in various applications such as to monitor and measure soil erosion; to study beach profile changes; to monitor and evaluate progress of construction project; to monitor soil excavation activities at construction site for measurements in laboratory experiments on construction materials (Maas and Hampel, 2006; Barazzetti and Scaioni 2009; 2010; Roncella *et al.*, 2004, 2012; Fedele *et al.*, 2014; Radzuan *et al.*, 2012; Mustaffar *et al.* 2012 and Scaioni *et al.*, 2014) and in laboratory experiments for hydrogeological risk assessment (Barazzetti *et al.* (2013). While in hydraulics and hydrology laboratory experiments, DRCP technique had been used to monitor changes in bed topography by Chandler *et al.* (2001); Westaway *et al.* (2001) used aerial photographs to measure the morphology of clear-water, shallow and gravel-bed rivers; Chandler *et al.* (2002) also adopted close range photogrammetry technique for hydraulic measurements on flume surface; while Rapp *et al.* (2012) used photogrammetry technique to determine the 3D evolution of a scour hole; Butler *et al.* (2002) measured through-water the organisation of gravel particles, both in the laboratory and field measurement, with ground resolution DEMs of 3 mm using photogrammetry technique. In other laboratory experiment, Udin *et al.* (2014) carried out assessment of digital camera in mapping meandering flume using close range photogrammetric technique. In summary, previous studies have shown that there is potential of the use of close range photogrammetry technique in the hydraulics and hydrology laboratory experiments.

### 3.0 Hydraulics Laboratory Experiment Setup

Figure 2 shows the flow-chart of laboratory experiments adopted in order to achieve the objective of the study. The following sections will discuss the laboratory experiment setup which cover the construction of river channel physical model, DRCP system

configuration, CPs preparations, hydraulics laboratory experiments, digital image acquisition during laboratory experiments, digital images processing and river channel changes analysis.

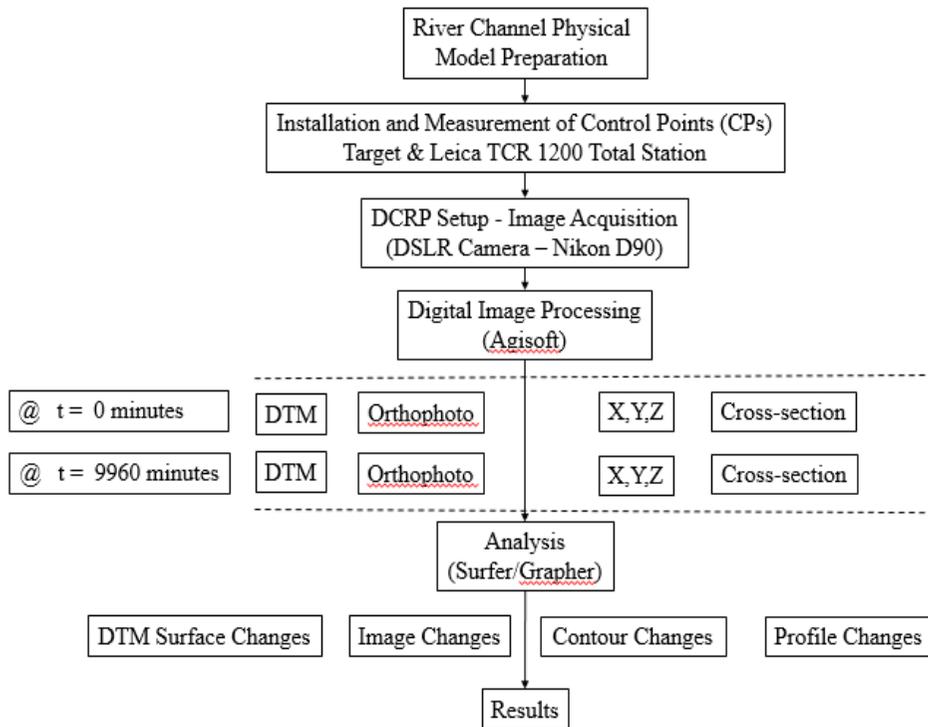


Figure 2: Laboratory experiment setup

### 3.1 River Channel Physical Model

The research was carried out in the Hydraulics and Hydrology Laboratory, Faculty of Civil Engineering Malaysia, Universiti Teknologi Malaysia (UTM), Johor Bahru. A physical model known as “Natural River Model” was constructed in the laboratory. It is part of research on the behaviour of natural river under different study environments. The scopes of the experimental work were design of natural river model with computer aided of AutoCAD 2013 and SketchUp 2014 softwares. A 4.95 m long, 0.69 m wide and 1.26 m deep rectangular flume was used in this study to simulate as a catchment which consisted of a natural river, as shown in Figure3. The catchment consisted of a straight V-shape main channel with double flat floodplains. The experiments were conducted under steady state flow condition. Small sump is used to locate all the outlet water for taking outflow testing before washed out to the laboratory tank as shown in Figure

3. The experiments were conducted under steady state flow condition with  $Q = 0.2 \text{ L/s}$  and  $Q = 0.6 \text{ L/s}$  during non-flooding and flooding events respectively.

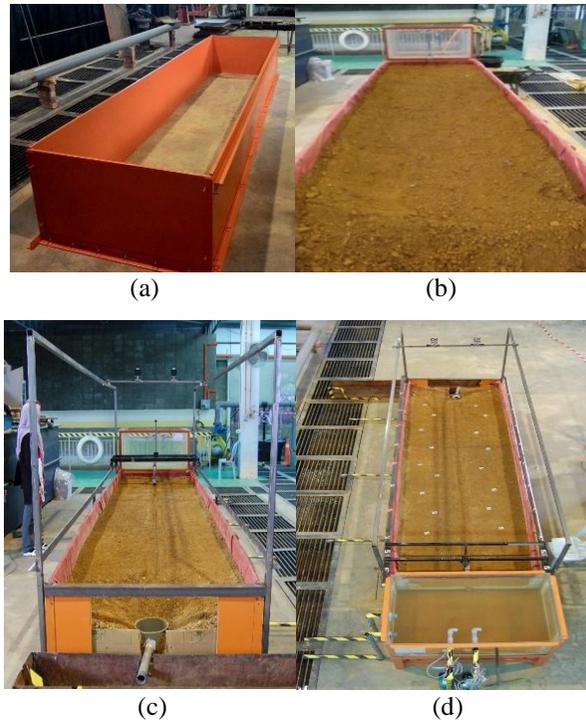


Figure 3: Construction of natural river model(a) Flume using plywood,(b) Fill soil inside the flume, (c) Natural river model and (d) Distribution of CPs

### 3.2 Control Points (CPs)

Leica TCR1200 Robotic total station (Figure 4) was used to measure precisely the spatial coordinates (X,Y,Z) of all CPs. A total number of 12 CPs were used in the study. The CPs were required for image registration purpose during DIP to generate DTM and orthophoto using Agisoft PhotoScan software. The DTM data were used to create 3D model and contour plot of river channel surface model.

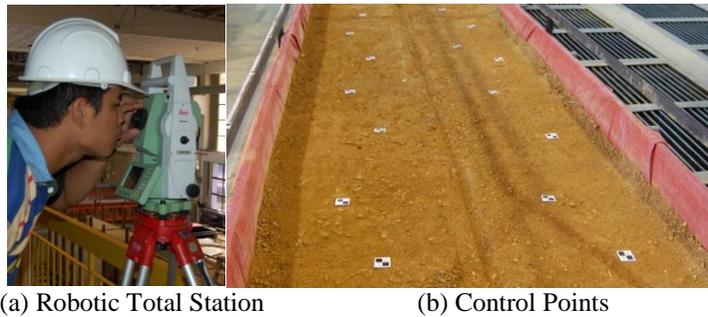


Figure 4: CPs measurement

### 3.3 Image Acquisition System

A unit of Nikon D90 DSLR camera was used to capture series of digital images of river channel model in the flume, as shown in Figure 5. The Nikon D90 DSLR camera came with a sensor array of 4288 x 2848 pixels. The dimension of the sensor was 23.7mm x 15.6 mm resulting in each pixel having the size of 5.6 x 5.6  $\mu\text{m}$ . The camera was fitted with fixed focal length (21 mm), F-stop setting (f/3.8), exposure time (1/second) and ISO speed (ISO 800) throughout the experiments. While the Nikon DSLR D90 camera was fixed at the hollow steel bar, placed 1.4 m above the rectangular flume (Figure 5). During image acquisition the camera was moved above the model at interval of 0.25m along the river channel to capture the digital images of river channel physical surface model. A total number of 38 digital images of river channel surface model were captured during pre and post flooding events.



Figure 5: Image Acquisition Setup Using DRCP Technique

### 3.4 Digital Image Processing

All digital images captured during laboratory experiments were then transferred to computer for DIP using Agisoft PhotoScan software. The digital images were aligned and registered relative to the position of camera using photogrammetry triangulation technique (Figure 6). The CPs coordinates obtained using total station required for photos alignment processed. The aligned photos then were used to generate and export 3D surface model, dense cloud, mesh, ortho mosaic and ASCII XYZ data. The ASCII XYZ data obtained then used to generate the DTM of the river channel surface model using Surfer Golden Software. As a result, two 3D surface models and contour plots were produced; one was for pre-flooding events (i.e. at  $t = 0$  minute) and the second one was post-flooding (i.e. at  $t = 9960$  minutes). A total number of nine cross-sections of river channel profile were extracted from the both DTMs (pre and post flooding events) along river channel (from chainage0mm to chainage2000mm with cross-section at 250mm interval). The cross-section profiles obtained from both DTMs (pre and post flooding event) were compared to estimate the river channel profiles changes.

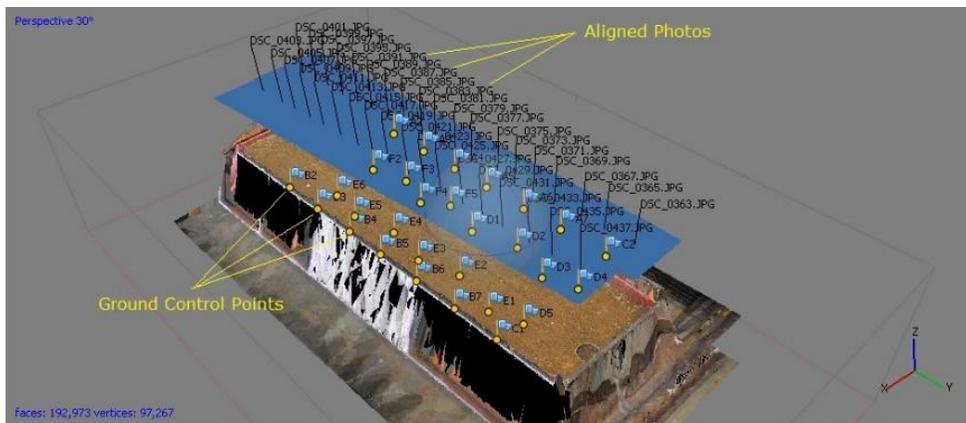


Figure 6: Images Alignment and Registration Using Agisoft Photoscan Software

## 4.0 RESULTS AND DISCUSSION

The results of pre-flooding at  $t = 0$  minutes and post flooding at  $t = 9960$  minutes events in various forms including 3D surface model, contour plots and river channel profiles were then used to estimate the river profiles changes.

#### 4.1 River Channel Surface Model

Through DIP technique, full coverage of river channel surface model was generated. Pre and post flooding events surface models were compared each other to determine the river channel profile changes. Figure 7 shows the 3D surface model of river channel physical model for pre and post flooding events.

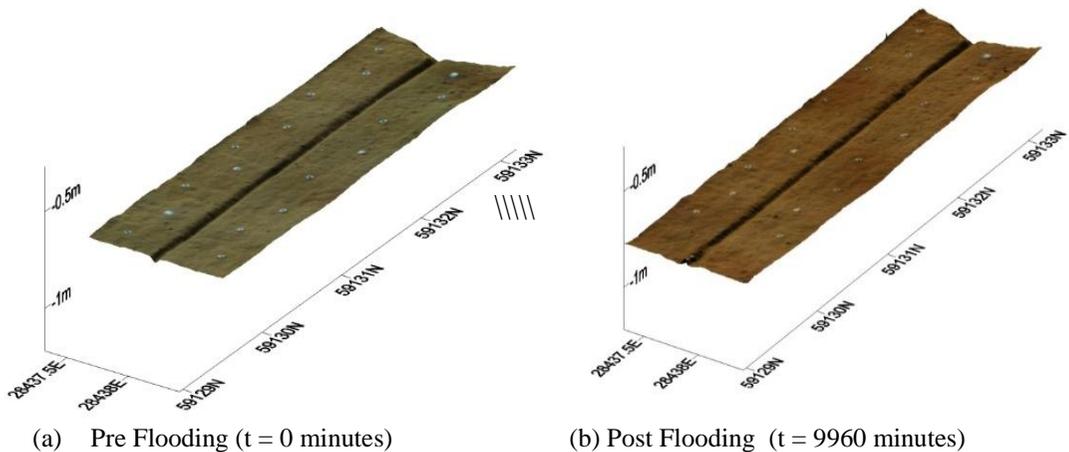


Figure 7: River Channel Surface Model

Figures 8(a) and 8(b) show the condition of river channel surface pre and post flooding events at  $t = 0$  minutes and  $t = 9960$  minutes respectively. Figure 7 depict the river channel contour changes due to erosion and deposition between  $t = 0$  minutes and  $t = 9960$  minutes respectively. Comparison of Figure 7 (a) and Figure 7 (b) show the size of surface area above the contour line  $-0.8\text{m}$  has decreases against the area of contour lines below  $-0.8\text{m}$ . This indicate the surface area of erosion are more evident against surface area of deposition.

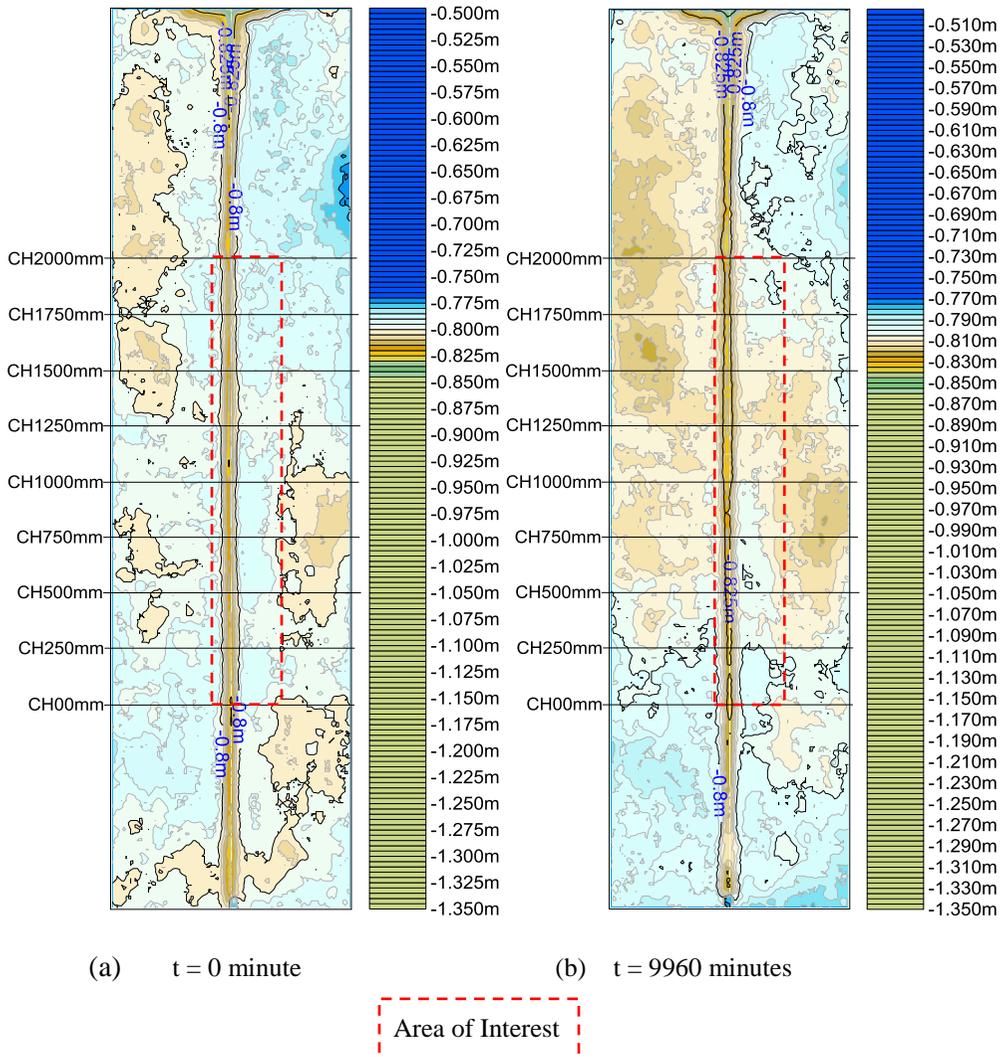
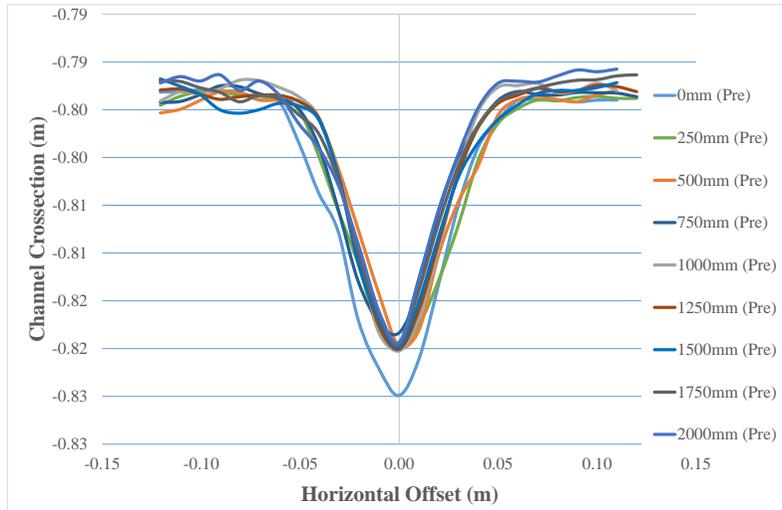


Figure 8: Contour plots of (a) Pre flooding and (b) Post flooding events

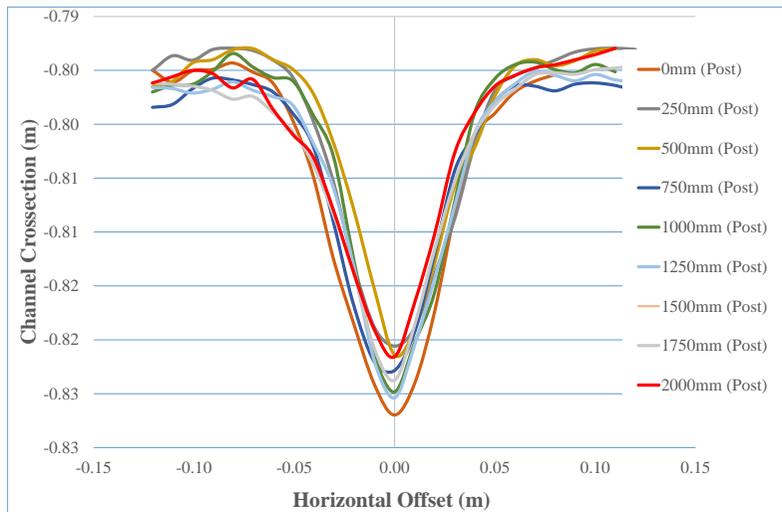
#### 4.2 River Channel Profile Changes

Figures 9(a) and 9(b) show the river channel profile characteristics (with offset distance 120 mm to the left and right from river channel centre line) for both scenarios of pre and post flooding events. The graphs show the river channel profile changes from CH00mm to CH2000 mm. The results show that the invert level or bed slope for flooding case is steeper than non-flooding due to the erosion process as shown in Figure 9(a), Figure 9(b) and Figure 10 respectively. The change in invert level or bed level between flooding and

non-flooding events due to erosion is varies from 1 mm (minimum) to 6 mm (maximum).



(a)  $t = 0$  minute



(b)  $t = 9960$  minutes

Figure 9: River Channel Cross-Sectional Profiles for (a) Pre flooding, and (b) Post Flooding Events

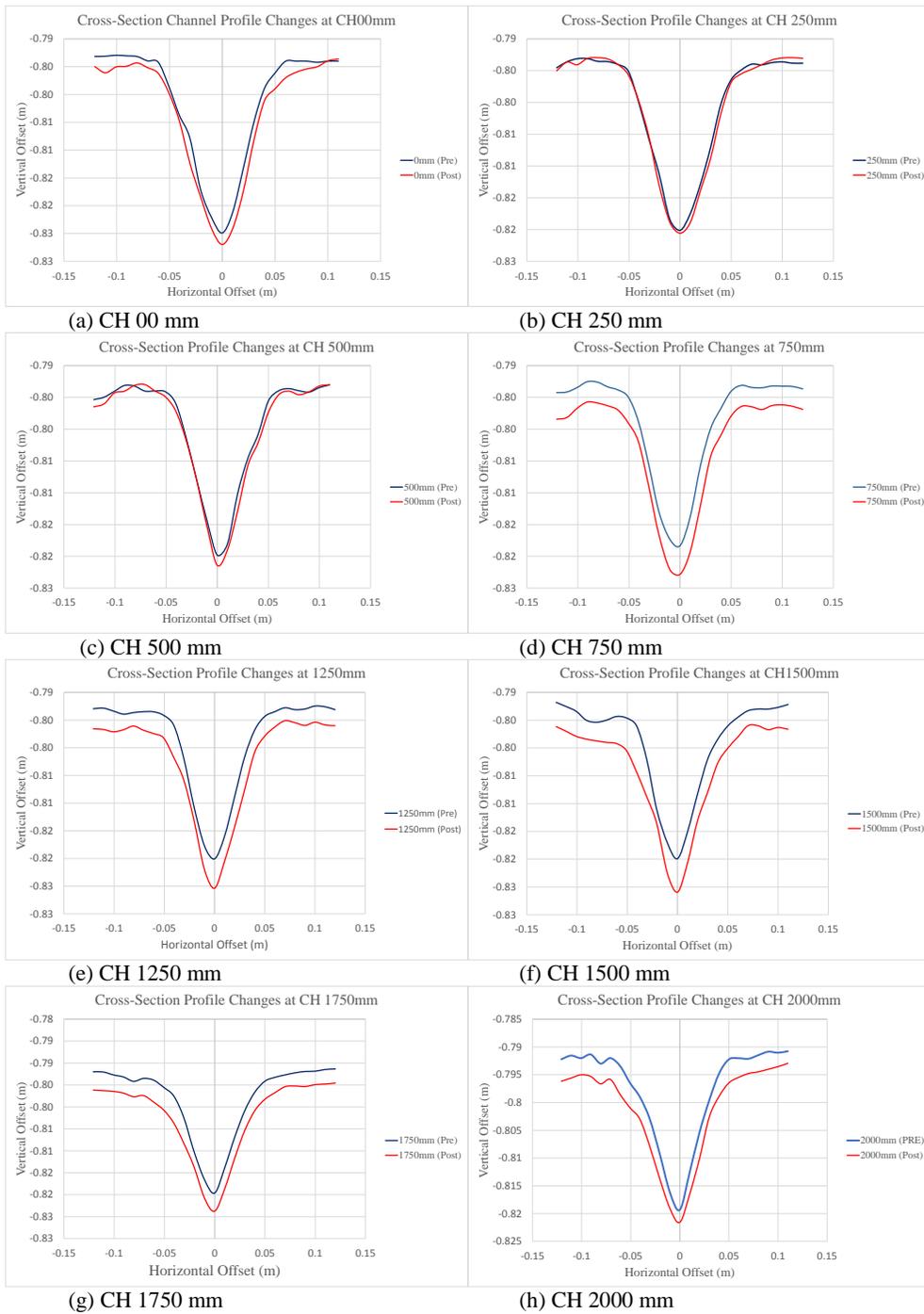


Figure 10: River Channel Profile Changes at Selected Chainage

While, Table 1 presents the calculation of area and volume of erosion using series of cross-section profile with 0.12m offset distance to the left and right from the river centre line at 250mm interval between CH 00 to CH 2000. Areas and volumes were calculated using the trapezoidal rule and end area method.

Table 1: Area and Volume Calculation of Soil Erosion

Horizontal Offset from Centre Line (m)	Left/Right	CH 00mm (mm <sup>2</sup> )	CH 250mm (mm <sup>2</sup> )	CH 500mm (mm <sup>2</sup> )	CH 750mm (mm <sup>2</sup> )	CH 1000mm (mm <sup>2</sup> )	CH 1250mm (mm <sup>2</sup> )	CH 1500m m (mm <sup>2</sup> )	CH 1750m m (mm <sup>2</sup> )	CH 2000mm (mm <sup>2</sup> )
0.12	L	-24.09	-2.56	-10.94	-41.03	-30.76	-37.40	-44.04	-42.05	-40.07
0.11	L	-25.48	-4.94	-6.56	-36.40	-31.12	-37.95	-44.78	-40.02	-35.25
0.10	L	-19.92	-4.63	-5.80	-32.35	-26.24	-32.88	-39.52	-37.16	-34.80
0.09	L	-15.15	2.94	-3.79	-32.48	-18.90	-26.32	-33.74	-35.87	-38.01
0.08	L	-11.86	4.93	5.80	-31.40	-21.18	-28.96	-36.75	-37.06	-37.37
0.07	L	-16.09	2.03	5.02	-30.81	-28.59	-36.48	-44.37	-44.57	-44.78
0.06	L	-15.91	-3.04	-4.08	-36.25	-26.64	-40.18	-53.73	-50.87	-48.01
0.05	L	-10.97	-2.00	-9.99	-36.21	-28.42	-49.65	-70.87	-56.62	-42.38
0.04	L	-27.57	3.15	-8.09	-32.81	-22.43	-48.87	-75.32	-59.95	-44.59
0.03	L	-29.06	-6.43	-2.74	-35.03	-17.53	-31.99	-46.45	-46.78	-47.10
0.02	L	-16.46	-10.89	-5.29	-41.86	-27.31	-33.73	-40.15	-38.52	-36.88
0.01	L	-20.28	-4.57	-12.72	-46.34	-38.43	-48.07	-57.71	-41.64	-25.58
0.00	CL	-25.13	-9.26	-12.67	-50.16	-39.96	-49.14	-60.41	-44.64	-30.95
0.01	R	-35.41	-12.22	-18.24	-59.05	-47.64	-49.93	-60.41	-47.85	-43.49
0.02	R	-36.86	-13.81	-19.32	-53.47	-59.86	-56.85	-60.41	-46.38	-38.93
0.03	R	-27.24	-16.23	-12.22	-43.15	-47.62	-49.42	-60.41	-43.47	-35.73
0.04	R	-25.25	-9.74	-15.60	-40.59	-34.08	-37.77	-60.41	-41.59	-41.71
0.05	R	-29.17	-5.19	-12.25	-36.07	-25.58	-31.65	-60.41	-38.04	-38.35
0.06	R	-24.93	-7.12	-5.12	-31.79	-19.90	-25.55	-60.41	-30.85	-30.49
0.07	R	-16.99	-3.89	-5.08	-32.38	-18.46	-23.47	-60.41	-28.41	-28.33
0.08	R	-10.98	2.28	-2.84	-32.55	-19.67	-26.61	-60.41	-32.19	-30.83
0.09	R	-3.67	5.19	1.54	-30.09	-22.27	-29.44	-60.41	-32.48	-28.36
0.10	R	2.22	7.41	1.37	-30.35	-21.73	-31.05	-60.41	-31.93	-23.50
0.11	R	1.89	8.19	0.12	-31.81	-21.13	-30.94	-60.41	-32.67	-21.94
0.12	R	0.00	3.84	0.00	-16.15	-10.50	-14.48	-30.20	-16.06	-11.00
Total Area of Erosion (mm <sup>2</sup> )		464.36	76.57	159.47	920.57	705.96	908.79	1342.51	997.67	878.41
Volume of Erosion ( x 1000 mm <sup>3</sup> )		0	54.09	23.60	108.00	162.65	161.47	225.13	234.02	187.61
Total Volume of erosion (x 1000 mm <sup>3</sup> )						1157				

### 4.3 Discussion

The findings of this study can be summarised as the effect of the slope due to the erosion and deposition processes interacts with channel hydraulics. It depends on the amount of discharge in the river where higher discharge occurs in flooding case as compared to non-flooding. Therefore, the river bed slope for flooding case is steeper

than non-flooding due to the erosion and deposition processes in the river as shown in Figure 8 and Figure 9 respectively. In Table 1, the results indicate the minimum ( $23.6 \times 10^3 \text{mm}^3$ ) and maximum ( $234.02 \times 10^3 \text{mm}^3$ ) volume of erosion was detected between CH 250 to CH 500 and CH 1500 to CH 1750 respectively. While, the total volume of erosion between CH00 and CH2000 was  $1157 \times 10^3 \text{mm}^3$  as shown in Table 1.

This study shows that the DRCP technique is capable to be utilised as complimentary method to measure the river channel evolution in the laboratory experiments. However, the use of DRCP technique requires precise measurement of CPs spatial coordinates. The application of a radio controlled device to mobilise the cameras from one position to another during the image acquisition work is capable to speed up the DRCP data acquisition process.

## 5.0 Conclusion

This study has demonstrated the application of DRCP technique to generate the 3D surface model of river channel for pre and post flooding events under laboratory condition. The results show that 2D and 3D surface models of river channel can be used to determine the river profiles changes between the studied events. The DRCP technique can provide more detailed information on river channel profile changes as compared to conventional measurement using point gauge technique.

## 6.0 Acknowledgements

The authors wish to acknowledge the staffs in Hydraulics and Hydrology Laboratory and Survey Unit of Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM) for providing laboratory facilities and DRCP measurement tools during the laboratory experimental works. The research is financially supported by the Research Management Centre (RMC), UTM under Potential Academic Staff grant vote no. 02K00.

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