Flood discharge measurement Using ADCP

Yen-Chang Chen* Su-Pai Kao and Sheng-Reng Yu
* Department of Civil Engineering, National Taipei University of Technology, 1 Sec. 3 Chung-Hsiao E. Rd. Taipei, Taiwan (*Corresponding author, e-mail:yenchen@ntut.edu.tw).

Discharge measurements not only act as a vital piece of evidence to the national resource database but also become an indispensable source to hydraulic resource planning and developments. Subsequently constant periodical observations need to be made especially to compile crucial high flow data that was laborious and difficult in the past. However, due to the unique characteristics of topography and torrential downpours, Taiwan's rivers and streams inflate instantly during typhoon seasons, becoming quick-water. Combined with strong winds, these conditions may become a threat to hydrologists. To accurately measure discharges during high flow, therefore, an innovative measuring technique and modernized instruments must be introduced and developed.

The unsteady conditions during high flow are unfit to be observed and measured by everyday methods and instruments. Instead, an unorthodox method must be used. The efficient method presented herein uses acoustic Doppler current profilers (ADP hereafter) installed in a 300lb crane system to measure discharges during high flow. The advantages of the proposed equipment are the small and compact size, convenient to relocate and install, efficient to measure velocities and water depths by placing it just below the surface of water, and thus timely enough to complete the observation.

Keywords: ADP, discharge measurement, high flow, probability, velocity distribution

1 INTRODUCTION

The accuracy of conventional discharge measuring instruments and methods becomes venerable to the conditions of surroundings and climates. Methods of the past need longer observation time and are applied only in flows without dramatic changes. For instance, the stage-discharge rating curve resulted from long-term observation is used for establishing water levels and for estimating everyday flow rate within the observed rating curve. However, using it to estimate the unsteady flow conditions of high flow as shown in Figure 1 [1], the stage-discharge rating curve tends to underestimate flows during swells whereas tends to overestimate during retreats. With insufficient instruments and methods of the past, the grasp of flood flow of Taiwan river streams indeed has been enormously challenging and full of uncertainties. The river streams of Taiwan are drastically sloped, and are noticeably disproportioned in terms of water levels. Their cross sections are prone to become silted during discharges and their flow conditions change constantly; and the silt effect on their river beds during high flow varies dramatically. Therefore, the accurate discharge of high flow must be done through immediate first-hand measurements and not through water levels estimated by the stage-discharge rating curve.

The conventional flow measuring instruments all must be placed precisely at the target locations to obtain the needed information. However, during high flow seasons, they cannot be placed exactly at the desired location due to high velocity rapids. The flow conditions of swells, at the height of unsteady flow that both water level and flow change drastically, must be measured instantly and immediately to seize the accuracy. However, under the difficult conditions of high flow, mostly during typhoon invasions, both hydrologists and measuring instruments will be in danger of rapid flow disasters. Not to mention the cost and labor, it is highly unlikely and impossible to simultaneously obtain the velocity and cross-section area of a river.

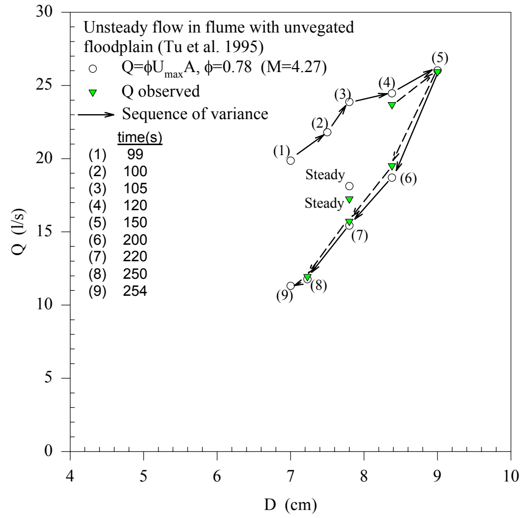


Figure 1: Stage-discharge relation during flood

Using conventional methods and equipments to measure during swells costs more time, thus prolongs hydrologists' time of exposure to danger, and complicates the process of obtaining accurate flow data. Hence, a simple, fast, reliable and accurate flow measurement method for high flow use must be developed.

2 MODERNIZED MEASURING INSTRUMENT

There are several types of flow measuring instruments with advantages and disadvantages or confined within certain limits of usages. Selecting and applying measuring instruments to precisely measure flows during swells vary according to the gauge station's flow field and terrene. Several different types of instruments are tested in this study during high flow to collect flow field data, and the data analysis indicates that the refined Mini ADP of SonTek 1500 kHz coheres with the hydrological characteristics of the Nanshi River and is sufficient to collect the velocity and cross section data. In addition, a unique crane system (Figure 2) is developed to avoid the worst conditions of high flow. The crane system in this study is made of an 300 lb soundings and modified into ADP hanging equipment (Figure 3). It is then carried by a crane truck to be mobilized for observations. As for the immediate data of cross-sectional velocity, wireless equipment is used to transmit the data to the far end computer. The ADP instrument developed for this study is assembled with miniature acoustic Doppler current profilers (Mini ADP hereafter), Electronics Assembly, and necessary accessories.

Figure 2: ADP and sounding hanged by a crane for measuring velocity distribution.

Figure 3: ADP, sounding and wireless communication unit.

3 VERTICAL MEAN VELOCITY AND DISCHARGE MEASUREMENT

Each point velocity on the vertical segment can be obtained through ADP, but the cross-sectional rate is obtained after computation. Hence the velocity-area principle of midsection method [2-4] is applied and with the velocity data from ADP to measure flow rates. A channel cross-section is made of numerous sub-cross-sections. Thus the mean velocity of each sub-cross-section ($\bar{v}_n$) and sub-cross-section area (a_n) must be estimated to obtain the flow rate q_n, and the summation of each sub-cross-section rate becomes the stream flow rate (Q). Therefore,

$$q_n = \bar{v}_n a_n \tag{1}$$

$$Q = \sum_{1}^{n} q_n \tag{2}$$

The data of each sub-cross-section area and mean velocity required for the velocity-area principle are estimated by the water depth and the velocity distribution respectively. The velocity distribution equation by information entropy [5] is applied in here to calculate the mean vertical velocity, which is expressed as

$$u = \frac{u_{\max}}{M} \ln\left[1 + \left(e^{M} - 1\right)\frac{\xi - \xi_0}{\xi_{\max} - \xi_0}\right] \tag{3}$$

In above, u is the velocity at y; u_{max}, the maximum velocity; M, the parameter, ξ_{max} and ξ_{min}, the maximum and the minimum ξ respectively; and ξ, the isovel derived after transformation as shown

$$\xi = \frac{y}{D-h}\exp\left(1 - \frac{y}{D-h}\right) \tag{4}$$

where D is the water depth; y, distance from the channel bed; h, the location of u_{max}. By the way of regression analysis, after the velocity distribution equation of most possible cross-sectional velocity has been found, the mean vertical velocity can be obtained by integrating the equation [6-7](Chen , 2005 ; Chen and Chiu , 2002)

4. FLOOD DISCHARGE MEASUREMENT

During 2007, 7 flood discharge measurements were done at the study site. In the process, ADP was submerged only 20cm below water surface to measure velocity profiles. The immediate data by Mini ADP was then to be transmitted through wireless system into the computer for instant calculations of 3D velocity distribution, sonic and depth variations. Under the maximum velocity exceeding 5 m/s and the maximum depth of 5 m, ADP performed well under pressure and was able to provide the required flow field information.

The velocity profiles by ADP were applied to the velocity distribution equation based on probability to obtain the values of mean velocities and rates. Then the complete profiles were used to draw each cross-section's velocity profile segment. Each measurement was the result of the probability distribution equation calculating the mean velocity with the water depth and the midsection method for the flow rate.

Figure 4 displays the cross-section of the Lan-Shan Bridge with gage height being 111.57 m during Typhoon Krosa, and each serial number is shown on the vertical line. 18 water depths are made by ADP with the maximum water depth of 4.47 m. Figure 5 shows the actual measurements of velocity distribution on the 18 verticals, in which the point 15 is the velocity of the maximum vertical depth and the point 7 is of the minimum vertical depth. In addition, the maximum velocity (4.83 m/s)happened on vertical 22, and the flow rate is 447.61m3/s and the maximum cross-section velocity is greater than 5 m/s. The velocity distribution in Figure 5 can be used to draw the isovels, as shown in Figure 6.

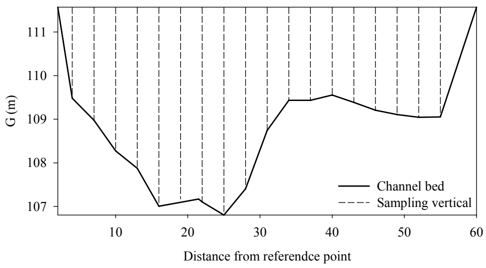
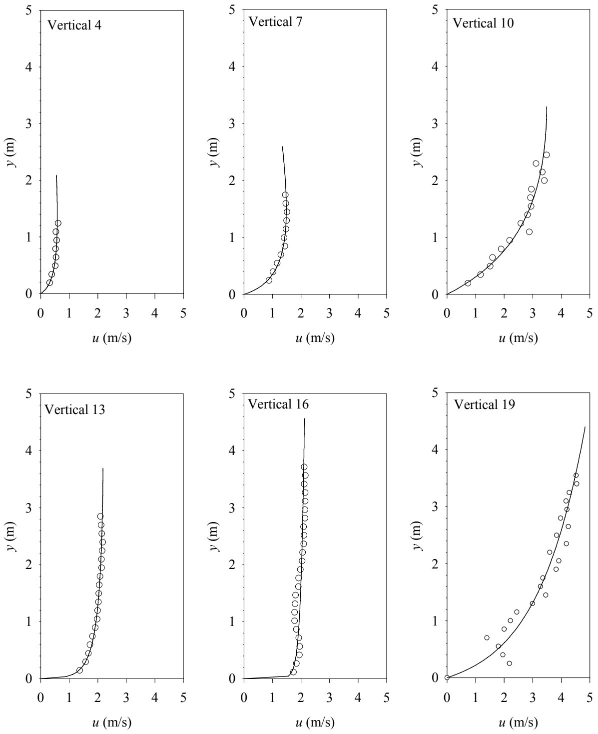


Figure 4: Cross section and sampling verticals during Typhoon Krosa.



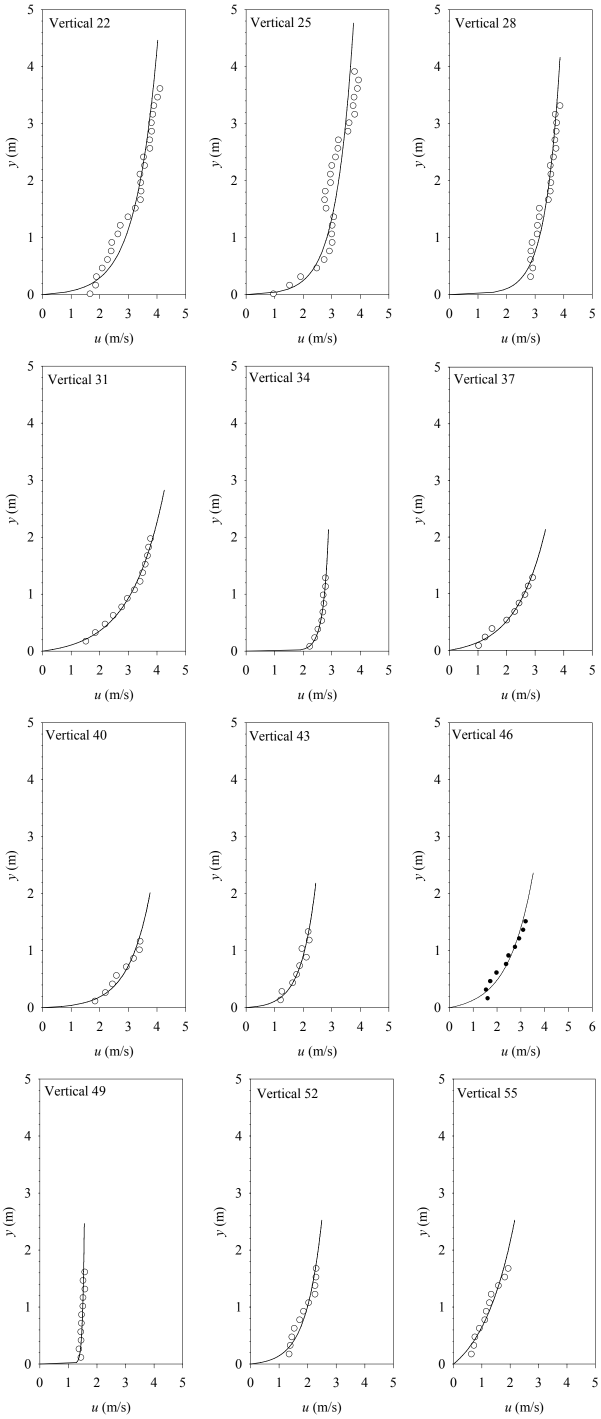


Figure 5: Velocity distribution on the verticals during Typhoon Krosa

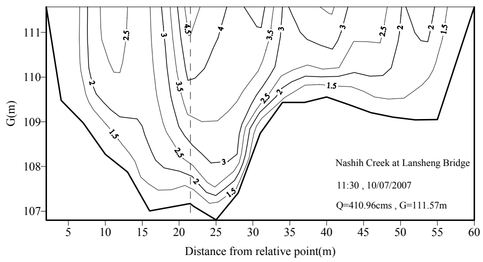


Figure 6: Isovels of the Nanshi River at Lanshan Bridge during Typhoon Krosa

The relationship between gage height and cross-sectional area is established as seen in Figure 7. The data analysis indicates that the maximum velocities occur constantly at the vertical 19. Figure 8 shows the relationship between the maximum and mean velocities, which is the straight segment passing through the origin. Hence, the maximum velocity can be measured hereafter at this location and be multiplied by the cross-section coefficient so to estimate the cross-sectional mean velocity. Consequently the flow rate is the multiplication value of the cross-section area derived from the water level and the estimated mean velocity.

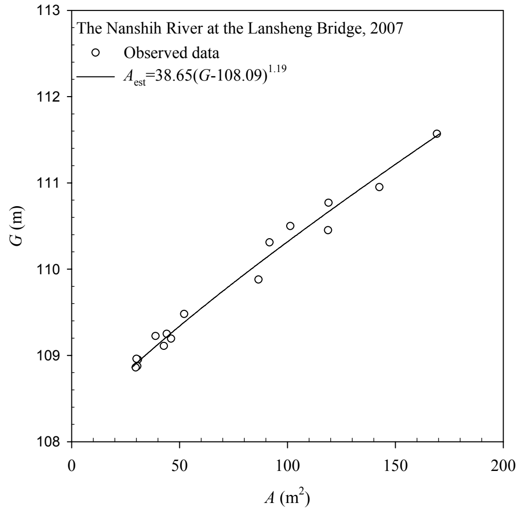


Figure 7: G-A relation of the Nanshi River at the Lanshin Bridge

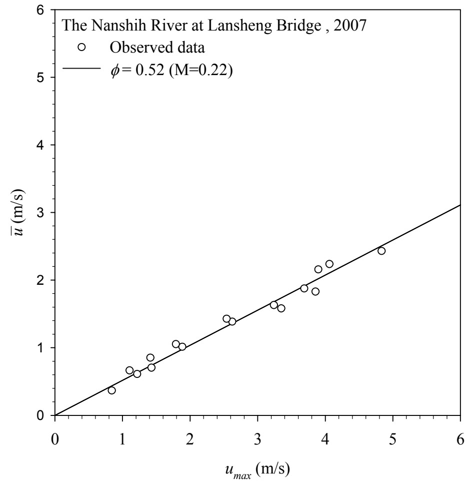


Figure 8: Mean and maximum velocities relation of the Nanshi River at the Lanshin Bridge

5 CONCLUSIONS

By means of the proposed method and modernized instruments, the velocity distribution, flow pattern and water depth during high flows, difficult to obtain in the past, was successfully measured efficiently and accurately. The excellences of the proposed method are the instant and accurate velocity measurement. This is the most simple calculation with fewer parameter modifications for the mean velocity and the accuracy and efficiency enhancement in measurements. However, the downsides are the high cost of the instruments and the power necessary to operate the crane equipment. Also in shallow waters, there appears to be a blanking at the beginning stage of measuring which causes the point of measure to be insufficient making it impossible to proceed to the cross-section velocity analysis. From the experiment, it is learned that ADP in coordination with the velocity distribution based on probability is suitable for use when the cross-section depth reaches above 1.6m. However, with the high frequency ADP, the blanking can be avoided and the minimum depth can be lowered.

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