STUDY OF FLOW IN A NON-SYMMETRICAL COMPOUND CHANNEL WITH ROUGH FLOOD PLAIN

(Date received: 8.5.2007)

Charles Bong Hin Joo and Darrien Mah Yau Seng
Department of Civil Engineering, Faculty of Engineering, Universiti Malaysia Sarawak
94300 UNIMAS Kota Samarahan, Sarawak
Email: bhjcharles@feng.unimas.my

ABSTRACT

The practical interest to study the flow in compound channel section arises from the necessity for accurate discharge predictions during flood events and for a reliable stage discharge relation for flood control measures and management schemes. It has been long realized that traditional hydraulic methods of channel subdivision are inadequate for discharge calculation due to the significant interaction between main channel and flood plain that previously rarely taken into account of. This paper presented the results of experimental investigations carried out on a small scale non-symmetrical compound channel with rough flood plain in order to compare the different methods available for discharge prediction in a compound channel. The weighted divided channel method (WDCM) has been used to check the validity of the horizontal division method and the vertical division method in predicting discharge. Results from this experimental investigations have shown that for non-symmetrical compound channel with wider flood plain, the horizontal division method provide the more accurate predictions of discharge while for narrower flood plain, the vertical division is more accurate.

Keywords: *Discharge Calculation, Flood Plain, Main Channel, Non-Symmetrical Compound Channel, Weighted Divided Channel Method (WDCM)*

1. INTRODUCTION

The term ‘compound’ or two stage covers channel cross-sections having berm(s) or flood plain(s) that come into action at high flows but which are normally dry (see Figure 1). It has been identified that modification of the velocity distribution and the resulting changes in the discharge capacity caused by the turbulent interaction between the main channel and the flood plain exist [1]. Compound channels have traditionally been analysed by dividing the compound cross-section into relatively large homogeneous sub-areas which are easier to analyse. This method is termed the divided channel method (DCM). However, this approach assumes no interaction between the subdivided areas despite the existence of mean velocity discontinuities at the assumed internal boundaries.

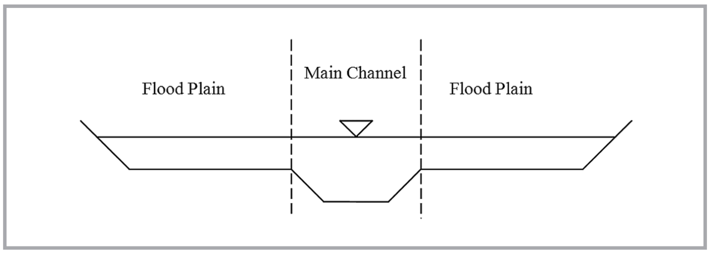


Figure 1: Compound channel section

Many experimental studies have been carried out addressing various aspects of the problem, ranging from the boundary shear distribution to the structure of turbulence in compound section and various methods as well as empirical formulas have been proposed for discharge calculation. The available studies on flow in compound channels include [2] - [5]. Despite the progress achieved so far, no consensus has been reached for the estimation of discharge in compound channel.

Since most of the available studies were done for symmetrical compound channel, this paper however addresses the results from experimental investigations done on a small-scale non-symmetrical compound channel model with rough flood plain. The objectives of the experimental investigations are:

(a) To study the flow characteristics for a non-symmetrical compound channel model with rough flood plain.
(b) To compare the validity of different methods available in predicting discharge for non-symmetrical compound channel through comparison of calculated and observed discharge values.
(c) To check which method produces the closest results to the observed data by using the weighted divided channel method (WDCM).

2. LITERATURE REVIEW

The hydraulics of flow in compound or two stage channels presents the drainage engineer with a problem. The problem arises in how to assess the stage discharge relationships for a situation where the flow may have radically different depths and roughness over different parts of the cross-section. Is it acceptable to treat the channel as if its overall hydraulic mean depth (defined as cross-sectional area over wetted perimeter) adequately describes its cross-section? How to incorporate the effect of variations of roughness over the various flow zones into a resistance equation? Are the usual resistance equations such as Manning’s able to cover complex sections, bearing in mind that they were derived for simple-section shapes? These questions have to be resolved if water levels to be expected during floods are to be assessed with reasonable accuracy and assurance.

2.1 Conventional Approach

The usual approach to analyse flow in compound channel is by splitting the section into subsections and applying the Manning's formula each in turn and the discharges can be summed. This conventional approach however does not take into account the interaction between the subdivided areas. The interaction between the slower moving flood plain flows and the main channel flow increases head losses significantly, so that the discharge calculated by conventional approach is expected to overestimate significantly the true channel capacity.

2.2 Discharge Adjustment Factors

The main features that affect the interaction and hence losses of discharge capacity in a compound channel when the flow is above bank are [6]:

(a) relative depth of the flood plain flow to the main channel flow
(b) roughness of the flood plain compared with the roughness of the main channel
(c) ratio of the flood plain width to the main channel width
(d) the number of flood plains
(e) the side slope of the main channel
(f) the aspect ratio of the main channel

In the case of small-scale smooth compound channels, the Reynolds numbers on the flood plains and in the main channel would have to be added to this list, but in almost all practical circumstances, viscous effects are not significant. The depth of flow on the flood plains relative to that in the main channel is a major factor. As soon as the flood plains become inundated, the flow in the main channel suffers interference of the slower flood plain flow. The maximum reduction in flow (referred to as the discharge deficit) may be anywhere in the range 10% to 20% [6]. As the relative depth increases further, the loss of conveyance diminishes again because there is likely to be less difference between main channel and flood plain velocities, but, in practice, the interference effect does not become negligible unless the berms are relatively narrow or the relative depth becomes considerable.

From experimental observations, an empirical correction coefficient method to estimate the discharge in compound channel which was terms as 'discharge adjustment factors' has been developed [6]. The degree of interference between the flood plain flow and the main channel flow shows different trends as the flow depth varies [6]. Flows have been divided into four regions with respect to relative depth [6]. Equations have been developed for these four different regions. However, as a set of predictive equations, these equations represent the observed flows to high accuracy, but, in practical, the tolerance in any application involves other tolerances as well as any errors in the predictive functions themselves. These include:

(a) discrepancies arising because of interpolations between, and extrapolations beyond, the conditions tested.
(b) uncertainty in knowledge of the geometry of the cross-section.
(c) any simplification of the actual geometry to suit the method.
(d) the basic friction law used in the calculation.
(e) the accuracy of the friction coefficients used.
(f) the hydraulic gradient and the assumption of steady uniform conditions.

2.3 Apparent Friction Factor on the Flood Plain and Main Channel Interface

Based on physical and dimensional analysis, an expression for the apparent shear stress in terms of the square of the velocity difference between the subsections has been proposed and it was showed that the respective apparent friction coefficient depends mainly on the width ratio [7]. This finding shows that width ratio B/b (see Figure 2) is the most important geometrical parameter in compound channel flows. By developing a straightforward method for predicting the apparent shear stress, consequently the discharge distribution and overall discharge in a compound channel at a given stage could also be estimated.

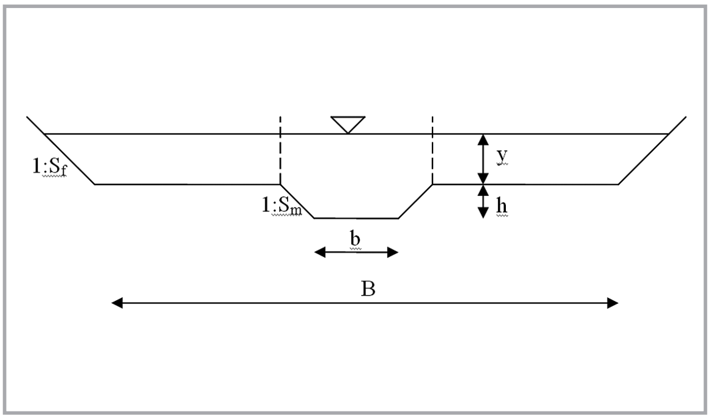


Figure 2: Notation sketch of a typical symmetrical compound channel

The apparent shear stress on the (imaginary) vertical interface between main channel and flood plain is expressed as:

$$T_a = \frac{1}{2}\rho c_{f_a}\ \Delta V^2 = \frac{1}{8}\rho f_a \Delta V^2 \qquad (1)$$

where ρ is the fluid density, ΔV is the difference of mean velocity in the two subsections and fa is an apparent friction factor analogous to the Darcy-Weisbach friction factor ($f_a = 4c_{f_a}$).

Assuming uniform flow and considering the balance of forces along the flow direction in the main channel leads to:

$$T_a 2y + T_m P_m = \rho g S_0 A_m \qquad (2)$$

where ρ is the fluid density, g is the gravity acceleration, S_0 is the bottom slope, T_m is the average shear stress on the main channel boundary, A_m and P_m are the area and wetted perimeter (excluding interface) of the main channel respectively.

If T_a can be estimated, Equation (2) could be used to evaluate the main channel discharge for a given flow depth, whereas the flood plain discharge could also be obtained by a similar manner. The apparent friction factor fa should in principle depend on the width ratio B/b of the compound section and to the Reynolds number on the flood plain. A plot similar to the Moody diagram is produced, where B/b takes the place of the relative roughness of pipe flow. This could be used to evaluate the apparent shear stress and consequently the discharge of the compound section.

2.4 Weighted Divided Channel Method (WDCM)

The weighted divided channel method (WDCM) is proposed to provide improved results to the conventional approach [5]. The WDCM method uses a weighting factor (ξ) to allow a transition between the velocity given by the vertical division channel method (DCM-V) and the velocity predicted by the horizontal division channel method (DCM-H). The weighting factor value varies between zero and unity that represents an infinite range of channel subdivisions between the traditional vertical division ($\xi = 1$) and the horizontal division ($\xi = 0$). The weighting is applied to both the main channel and the flood plain areas to give improved mean velocity estimates for these areas. The new velocity estimates are then used to determine the overall discharge. For the main channel region, the application of the weighting coefficient yields:

$$V_{mc} = \xi V_{mcDCM-V} + (1 - \xi)V \qquad (3)$$

where V_{mc} is the improved estimate of the main channel mean velocity, $V_{mcDCM\text{-}V}$ is the mean velocity in the main channel given by the vertical division channel method, $V_{mcDCM\text{-}H}$ is the mean velocity given by the horizontal division channel method and ξ is the weighting coefficient. A similar equation is used for the flood plain velocity and the "mc" subscript representing the main channel is replaced by "fp" for the flood plain region. The use of a single parameter to account for the momentum interaction has allowed this method to be quickly and easily applied in designs situations and could also be easily incorporated in water surface profile calculations.

3. METHODOLOGY

An experimental work project was carried out in the Hydraulic Laboratory of the Faculty of Engineering (Civil Department), Universiti Malaysia Sarawak (UNIMAS) to study the flow characteristics and the discharge estimation for a non-symmetrical compound channel with rough flood plain.

3.1 Experimental Arrangements

A non-symmetrical channel model was built using plywood (10 mm thick) and had a length of 5 m and a slope, s = 0.013. Water was fed into this channel from the tank by means of gravity flow and the built flood plain area was roughened by installing wire mesh. The arrangements and elevations of this channel model are as shown in Figures 3, 4 and 5.

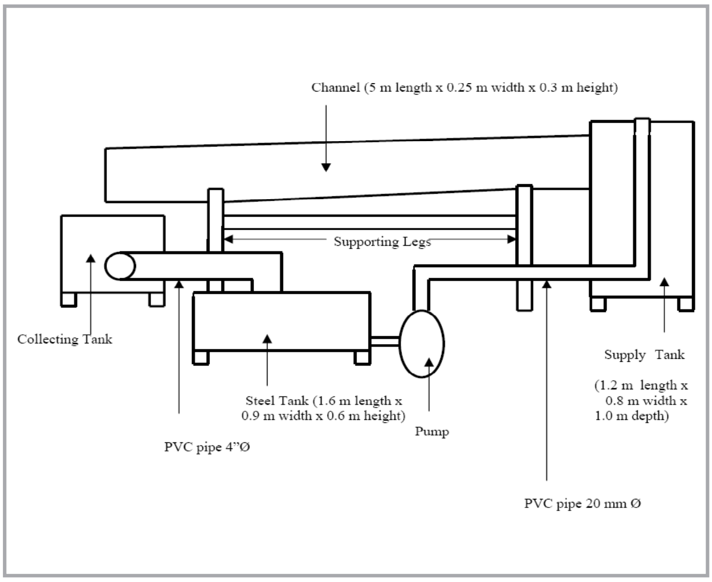


Figure 3: Side view of the experimental arrangements (not to scale)

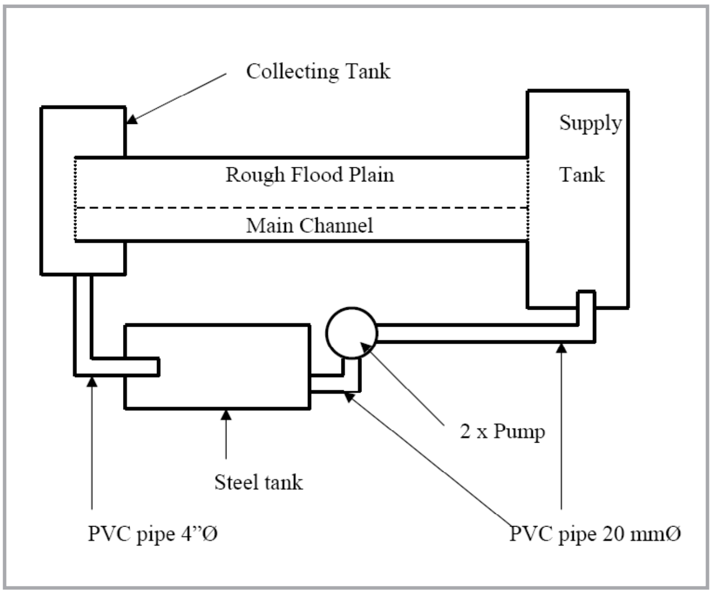


Figure 4: Plan view of the experimental arrangements (not to scale)

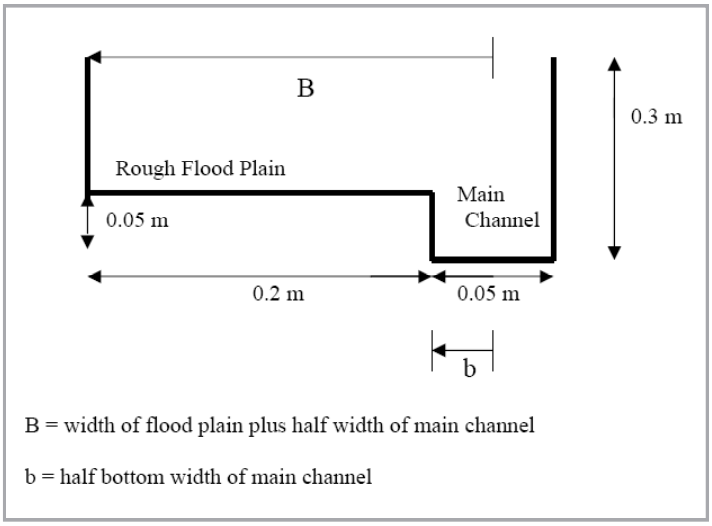


Figure 5: Cross-section of the non-symmetrical compound channel (not to scale)

In the experiment, the width of the flood plain was adjustable by installing flood plain wall/plywood which was hold in place by clench as shown in Figure 6. The bottom of the flood plain wall which met the flood plain was sealed using silicon sealant to prevent leakage. Figure 7 shows the view of the channel as seen from the end of the channel.

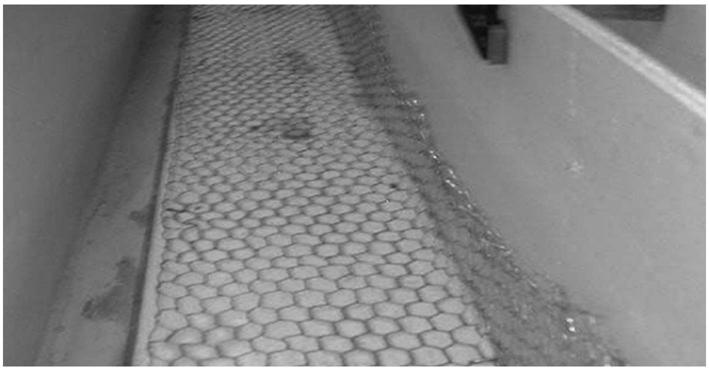


Figure 6: The flood plain wall which is clenched in place

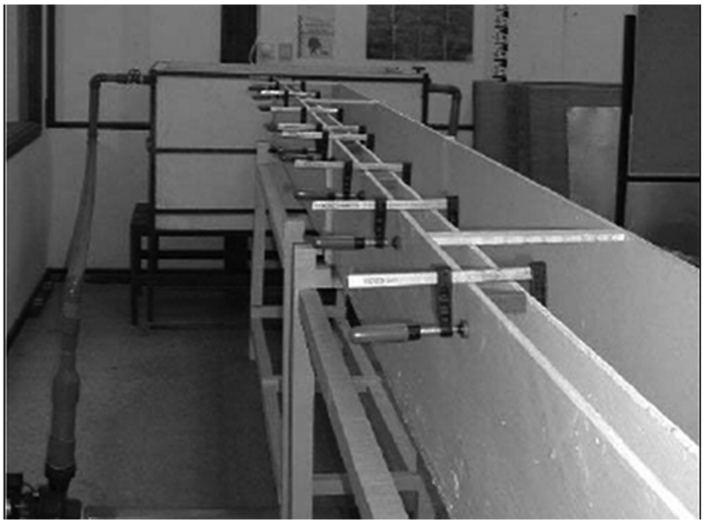


Figure 7: View of the channel with the supply wooden tank as seen from the end of the channel

3.2 Procedures of Experiment

The procedures for the experiment were divided into three parts; which were:

(i) determining the roughness cofficients, Manning's n;
(ii) measuring the point velocities;
(iii) determining the discharge

3.2.1 Determining the Roughness Coefficients, Manning's n

The roughness of the main channel was determined by measuring the velocity of water flowing along the main channel (not overflowing the flood plain) for several elevations. From this velocity data, the discharge and finally the Manning's roughness coefficients, n were determined as in Equation (4). This process was repeated several times with different flow stage and the average for all the calculated n were taken as the Manning's roughness coefficients, n for the main channel.

$$n = \frac{AR^{2/3}s^{1/2}}{Q} \qquad (4)$$

where n is the Manning's roughness coefficient, A is the wetted area, R is the wetted perimeter and Q is the discharge.

As for the case of rough flood plain, the value for the roughness coefficients were determined using the similar method but this time, the main channel have to be roughened by installing wire mesh. From the calculation, it was found out that for smooth surface of the model channel, the roughness coefficients, n = 0.008 and for the roughened surface, the value is n = 0.016.

3.2.2 Measuring the Point Velocities

The data for point velocities were collected at different stage of flow for the flood plain width of 0.20 m (B/b = 9), 0.14 m (B/b = 6.6) and 0.09 m (B/b = 4.6) across the section of the channel. The points to take the velocities across the channel are as shown in Figures 8, 9 and 10 for the three different sections with different B/b ratios.

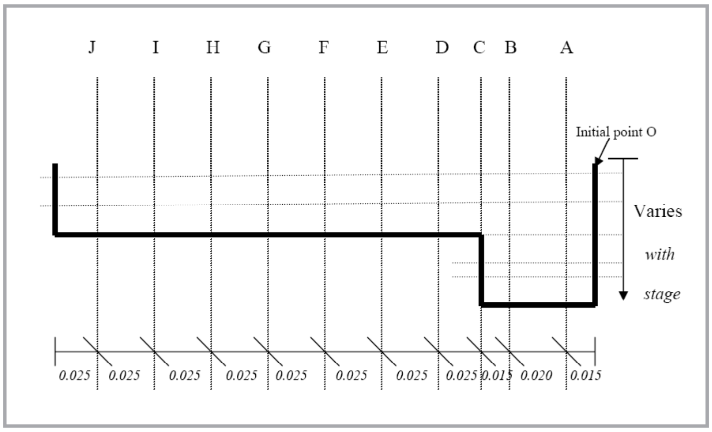


Figure 8: Point velocities locations (intersection of the dotted vertical and horizontal lines) for B/b = 9; for the number of vertical points, it varies with the stage of water (not to scale, all unit in m)

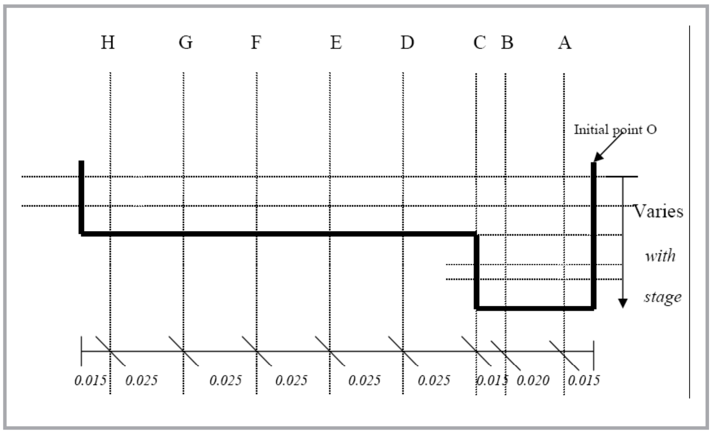


Figure 9: Point velocities locations (intersection of the dotted vertical and horizontal lines) for B/b = 6; for the number of vertical points, it varies with the stage of water (not to scale, all unit in m)

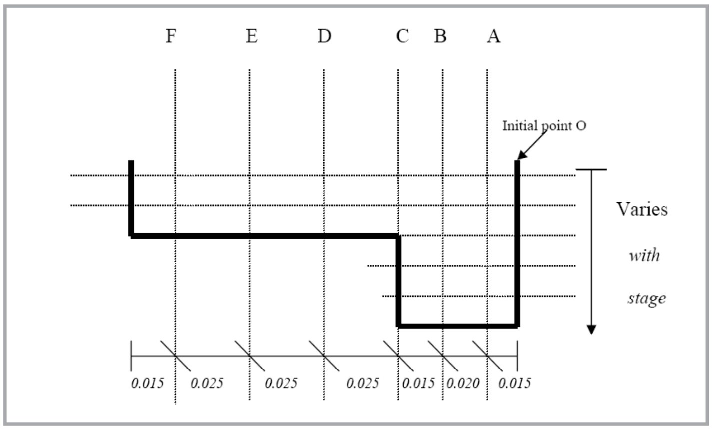


Figure 10: Point velocities locations (intersection of the dotted vertical and horizontal lines) for B/b = 4.6; for the number of vertical points, it varies with the stage of water (not to scale, all unit in m)

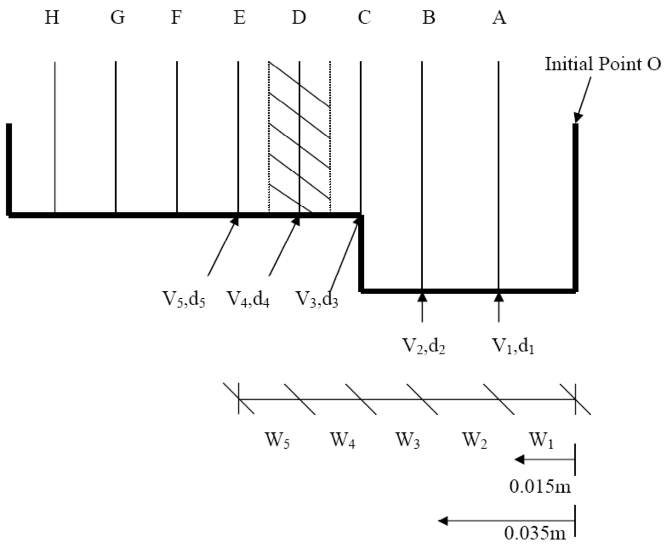
Point velocities of the section were measured by using a miniature propeller/current meter. The reading recorded by the recorder is in Hertz (Hz) and is transferred into the m/s unit using the formula provided by the manufacturer:

$$V(m/s) = 0.0056R + 0.0337 \qquad (5)$$

where R is the reading in Hertz (Hz) from the recorder.

3.2.3 Determining the Discharge

By using the point velocities data, the discharge of the whole channel as well as the discharge and velocity of the flood plain and main channel were determined by using the midsection method. In this method, it was assumed that the velocity at each vertical represents a mean velocity for a section that extends half the distance into the preceding and following segments. An example of subsection in the midsection method for the channel use in this project is as shown in Figure 11.



$$\text{Area for subsection D} = \frac{W_4 + W_5}{2} \times d_4$$

$$\text{Discharge through subsection D} = V_4 \times \frac{W_4 + W_5}{2} \times d_4$$

$$\text{Discharge through subsection x} = V_x \times \frac{W_{x-1} + W_x}{2} \times d_x$$

Figure 11: Subsection in the midsection method for the model channel (not to scale)

The data for discharge calculated using the recorded point velocities data by midsection method was assumed as the "observed data". This calculation was repeated three times for the B/b ratios of 9, 6 and 4.6. The data for smooth flood plain with smooth main channel was also been collected using the same non-symmetrical compound channel model for comparison.

4. RESULT AND DISCUSSION

In doing this experimental project, the observed data collected from running the model non-symmetrical compound channel was used for three purposes as follow:

(a) To understand the discharge characteristics of non-symmetrical compound channel.
(b) To do a comparison of the different methods for predicting the discharge and velocity.
(c) To check which method produces the closest results to the observed data by using the weighted divided channel method (WDCM).

4.1 Discharge Characteristics of Non-Symmetrical Compound Channel

In order to study the discharge characteristics of a non-symmetrical compound channel, the graphs of discharge-stage are as shown in Figure 12 for channel with both smooth main channel and flood plain and in Figure 13 for channel with smooth main channel but rough flood plain. These graphs were plotted from data observed during the experiment of this project.

For the discharge-stage plots, all three different B/b ratios used in this experiment had shown the same characteristics. From the plot, the most notable feature of these relationships is the discontinuity/break point at bankfull depth (in this case, approximate of 0.05 m), where the slope of the graph is steeper after the bankfull stage. However, from both Figures 12 and 13, the breakpoint at stage 0.05 m might not be clear due to the limitations in the experiment where the equipment used cannot take the reading of point velocities near the 0.05 m stage. From the observation of discharge-stage relationship, it was concluded that flood plain contributes a lot to the overall discharge of the channel and a change in the flood plain would cause the overall discharge of the channel to also change.

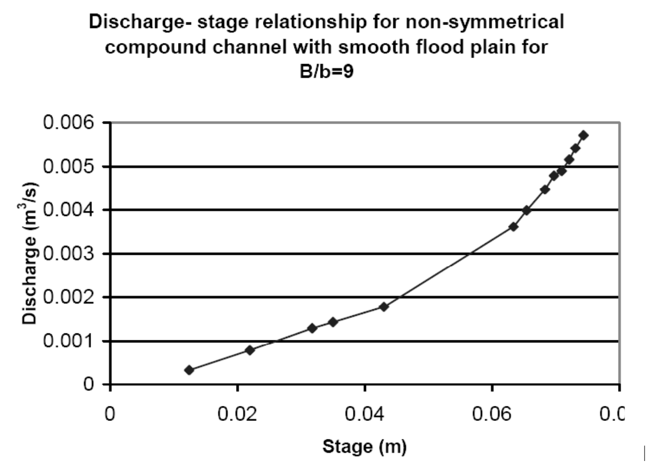


Figure 12: Discharge-stage relationship for non-symmetrical compound channel with both smooth main channel and flood plain for B/b = 9

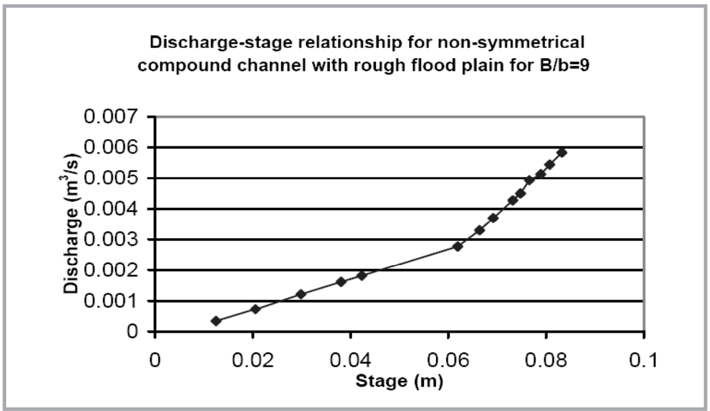


Figure 13: Discharge-stage relationship for non-symmetrical compound channel with rough flood plain but smooth main channel for B/b = 9

In order to study the effect of flood plain roughness, a plot of overall discharges for the non-symmetrical compound channel for both smooth and rough flood plain was plotted in the same graph. Figure 14 shows the plot for comparison of discharges for both smooth and rough flood plain for the ratio of B/b = 9. Whereas for the other two cases (B/b = 6.6 and B/b = 4.6), the plots also show the same characteristics as the plot for B/b = 9 where after bankfull stage, by comparing for the same stage, the channel with smooth flood plain had higher discharge than the channel with rough flood plain. This is because the extra roughness on the rough flood plain reduces the velocity of flow on the floodplain, thus reducing the overall discharge capacity of the channel. With this, it was concluded that extra roughness on the flood plain tends to retard the overall discharge capacity of the channel.

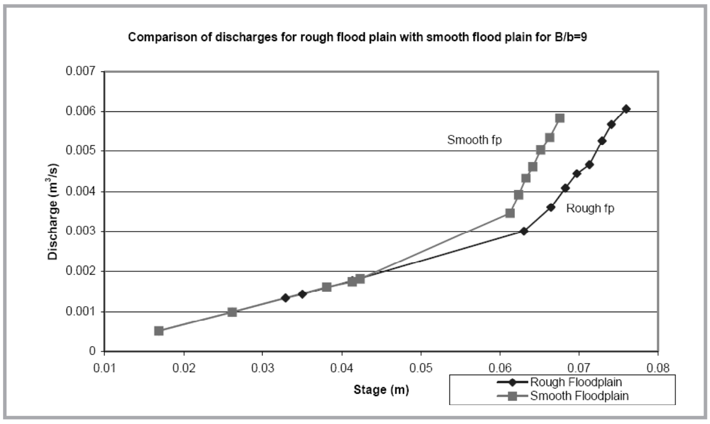


Figure 14: Comparison of discharges between rough and smooth flood plain for B/b = 9

To study the effect of relative depth of the flood plain flow to the main channel, a graph of relative depth (H-h/H) versus Qfp/Q and Qmc/Q for all the three cases of B/b ratio is plotted (see Figure 15). H is the total depth of the water measured from the bottom of main channel, h is the depth of water on top of flood plain, Qfp is the observed discharge for the flood plain, Qmc is the observed discharge for the main channel and Q is the overall average discharge of the channel. The graph showed that as the depth rises, the differences between main channel and flood plain discharges as well as the velocities will become less. There would come a point where the main channel and flood plain are roughly equal in carrying capacity as the depth further increases. This means that as the depth of water further increases above the flood plain, the effect of interaction between the slower moving flood plain flow and the main channel flow that causes head losses become less.

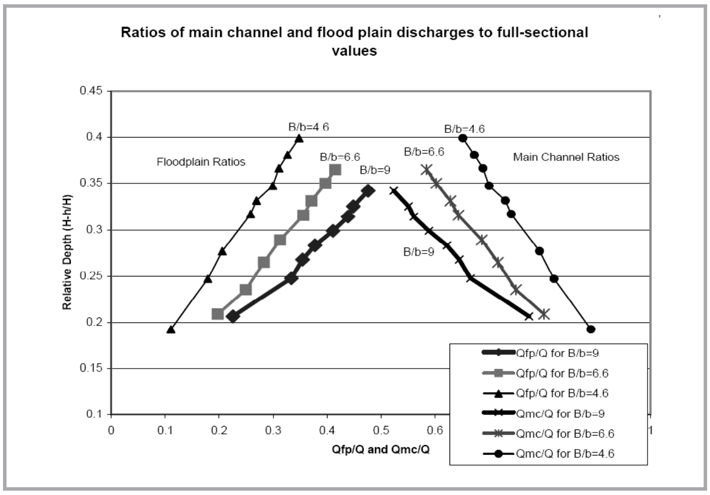


Figure 15: Ratios of main channel and flood plain discharges to full cross-sectional values

In order to study the effect of flood plain width to main channel ratio for a non-symmetrical compound channel, the observed discharges for the flood plain width to main channel width ratio of B/b = 9, B/b = 6.6 and B/b = 4.6 were compared with the estimated discharges as predicted by the vertical divided channel method (V-DCM). To show this effect clearly, a graph of relative depth versus (Qest – Qobs)/Qobs is plotted as in Figure 16. Qest is the discharge estimated using the vertical divided channel method while Qobs is the observed overall average discharge for the channel.

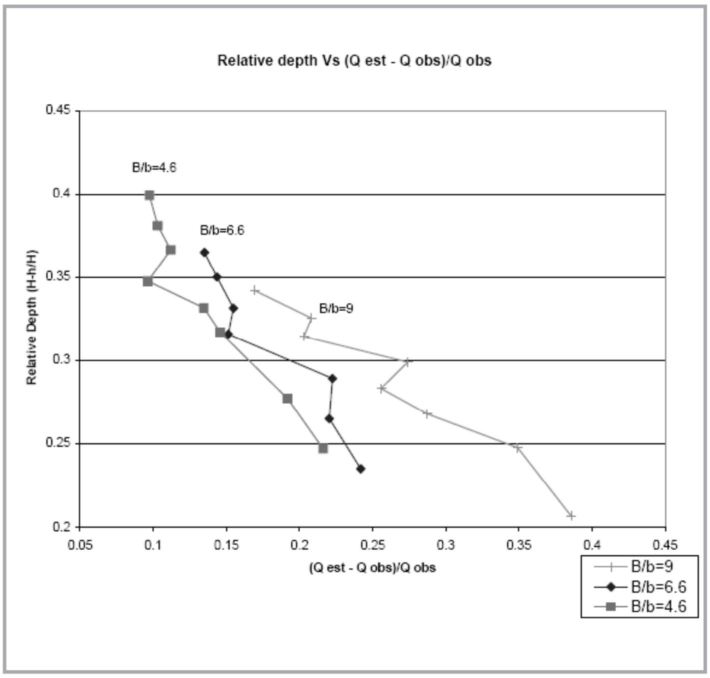


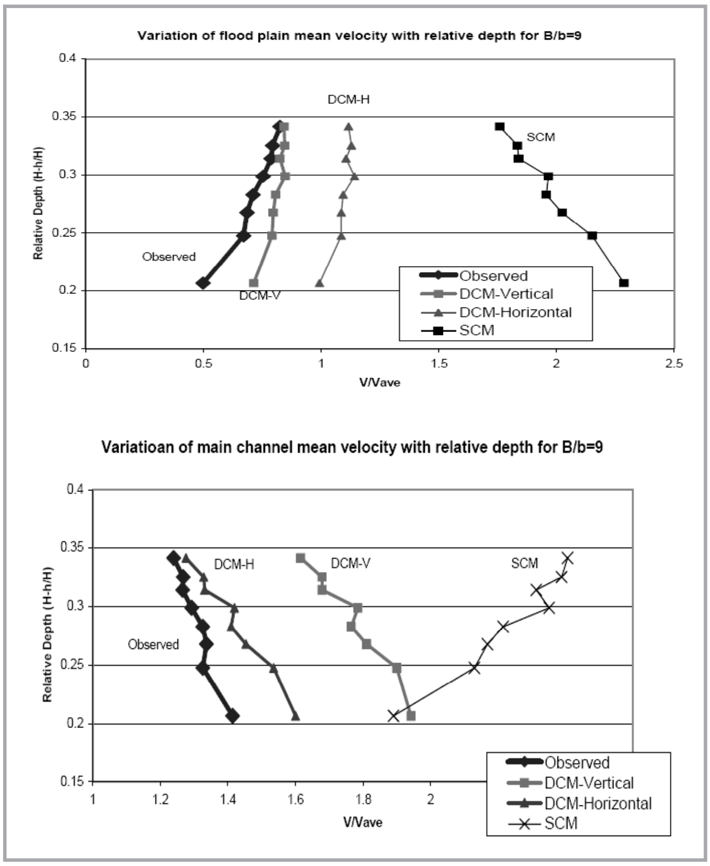
Figure 16: Relative depth versus (Qest – Qobs)/Qobs for different B/b ratio

From Figure 16, it can be seen that with higher B/b ratio, the percentage of error or the (Qest – Qobs)/Qobs ratio is also higher. It also can be seen that as the water depth above the flood plain increases, the (Qest – Qobs)/Qobs ratio seems to be decreasing. From this it was concluded that:

(a) When the water stage is just above the bankfull stage and inundated the flood plain, there exist interaction between the slower moving flood plain flow and the main channel flow. This interaction increases head losses significantly, so the discharge as estimated using the vertical divided channel method overestimated the true channel capacity.
(b) As the flood plain width become wider (higher B/b ratio), the effect of this interaction also increases causing significant head losses. That is why the (Qest – Qobs)/Qobs ratio is much higher for wider flood plain. This shows that the differences between the discharges estimated by the vertical divided channel method and the observed discharges become bigger as the flood plain width increases.
(c) However, as the relative depth or the water stage above the flood plain increases further, the interaction effect becomes less because there is likely to be less difference between main channel and flood plain velocities. This is true for all the three cases of B/b = 9, B/b = 6.6 and B/b = 4.6 in the experiment.

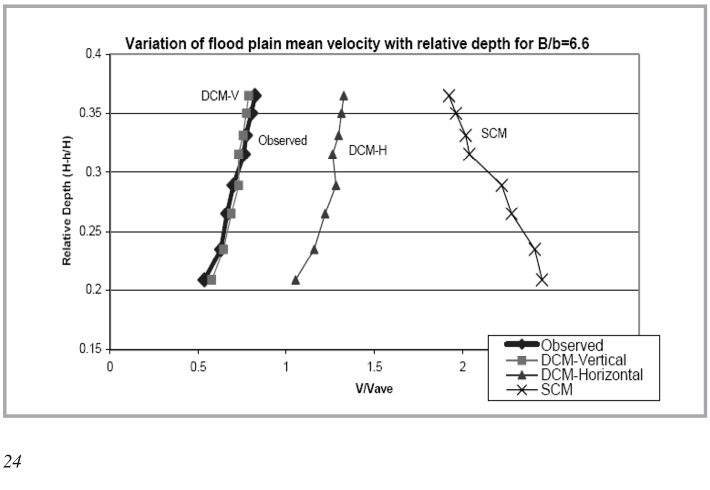
4.2 Comparison of Different Methods for Predicting Velocities

The usual approach to design compound channels found in hydraulic textbooks which is the divided channel methods, either by the vertical or horizontal division did not take into account the interaction between the slower moving berm flows and the main channel flow which increases head losses significantly [6]. Due to this, the discharges and velocities predicted by these methods are less accurate and corrections are needed to allow for the interzone interactions. So, in order to compare the velocities predicted by these different methods (horizontal division, vertical division and single channel method), the graphs of relative depth versus V/Vave are plotted for both the flood plain and main channel for all the different B/b ratios (Figures 17, 18 and 19). V is the velocity calculated using either the vertical division, horizontal division or the single channel method while Vave is the average observed velocity.


Variation of flood plain mean velocity with relative depth for B/b=9

Variatioan of main channel mean velocity with relative depth for B/b=9

Figure 17: Variation of flood plain and main channel mean velocity with relative depth for B/b = 9


Variation of flood plain mean velocity with relative depth for B/b=6.6

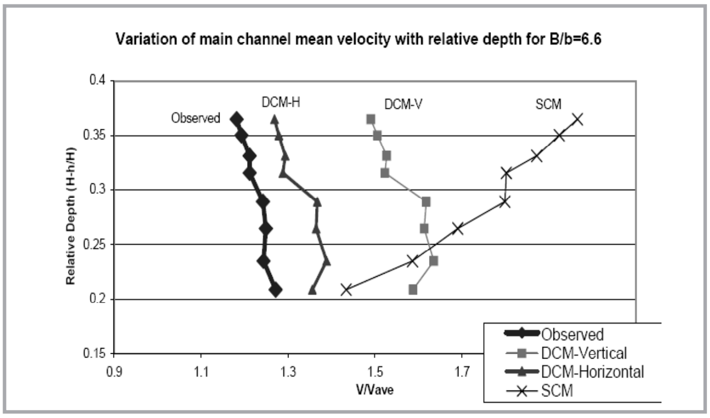
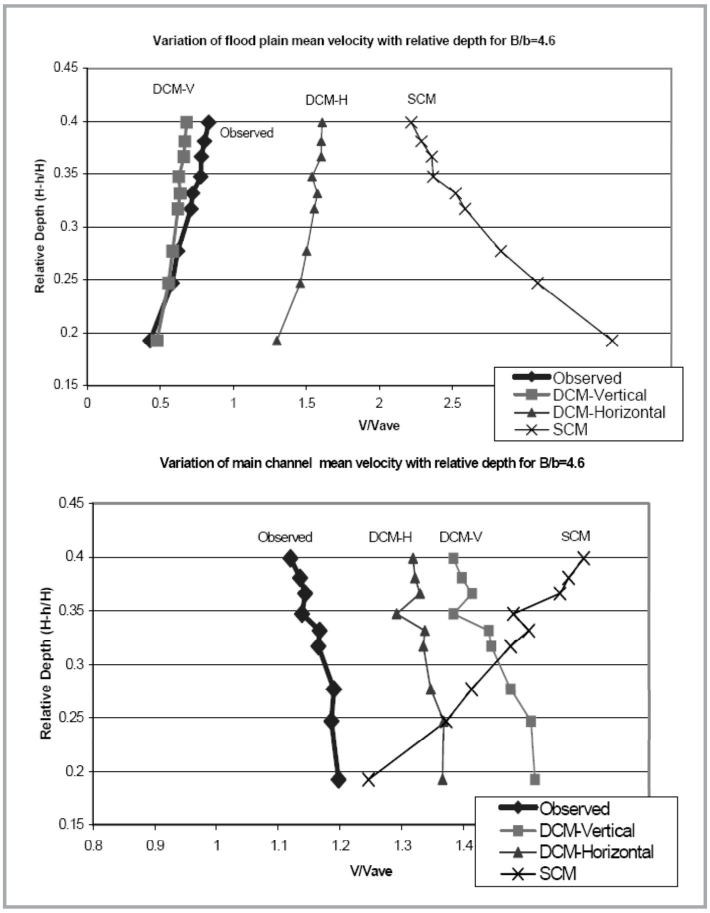

Variation of main channel mean velocity with relative depth for B/b=6.6

Figure 18: Variation of flood plain and main channel mean velocity with relative depth for B/b = 6.6


Variation of flood plain mean velocity with relative depth for B/b=4.6

Variation of main channel mean velocity with relative depth for B/b=4.6

Figure 19: Variation of flood plain and main channel mean velocity with relative depth for B/b = 4.6

From Figures 17, 18 and 19, for all the three cases of B/b ratio, vertical division method (DCM-Vertical) tends to under-predict the magnitude of flood plain mean velocity as the relative depth increases; however, the values are closest to the observed data if compare with other method. As for the case of main channel, the vertical division methods tend to over-predict the magnitude of main channel velocity. One can also observe that horizontal division method (DCM-Horizontal) and single channel method (SCM) tend to over-predict the mean velocities in flood plain and main channel for all the three cases of B/b ratio. From this, it was concluded that a more reliable methods of predicting the discharge and velocities for non-symmetrical compound channel is needed.

4.3 The Weighted Divided Channel Method (WDCM) and ξ Value

In the weighted divided channel method (WDCM) [5], weight is applied to both the main channel and the flood plain areas to give improved mean velocity estimates for these areas (see Sections 2.4). The new velocity estimates are then used to determine the overall discharge. In this experimental work project, the weighting coefficient ξ is assumed to be the same value for both flood plain and main channel ($\xi mc = \xi fp$); however, it is not necessary that they be kept the same [5].

By using trial and error, the value for ξ from 0 to 1 is substitute into Equation (3) in Section 2.4 to find the mean velocity (Vmean WDCM). A graph of Vmean WDCM versus mean observed velocity (Vmean observed) is plotted for each of the trial ξ value and the graph with the best linear regression, R^2 value is the best fit. The ξ value for that graph is chosen as the weighting value. The summary of the trial ξ values with R^2 values is as shown in Table 1 while Figures 20, 21 and 22 shows the graphs for the best R^2 value for each of the different B/b ratio.

Table 1: Summary of the trial ξ value with R^2

B/b = 9		B/b = 6.6		B/b = 4.6	
Trial ξ	R^2	Trial ξ	R^2	Trial ξ	R^2
0	0.9542	0	0.9057	0	0.9668
0.1	0.9539	0.1	0.9057	0.1	0.9671
0.2	0.9536	0.2	0.9058	0.2	0.9674
0.3	0.9533	0.3	0.9058	0.3	0.9677
0.4	0.9530	0.4	0.9059	0.4	0.9680
0.5	0.9527	0.5	0.9059	0.5	0.9684
0.6	0.9524	0.6	0.9060	0.6	0.9693
0.7	0.9521	0.7	0.9061	0.7	0.9688
0.8	0.9518	0.8	0.9061	0.8	0.9698
0.9	0.9515	0.9	0.9062	0.9	0.9703
1.0	0.9512	1.0	0.9062	1.0	0.9708

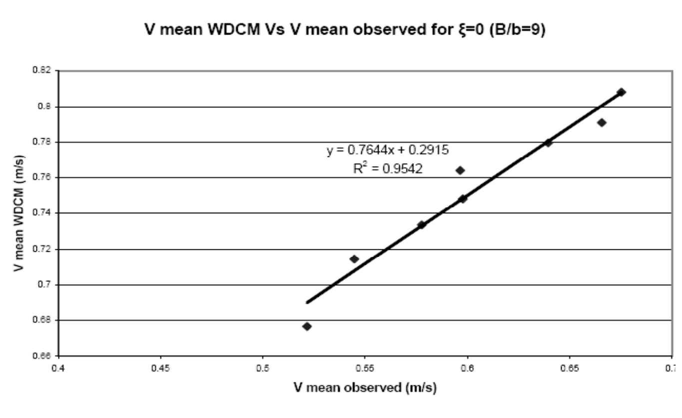


Figure 20: Vmean WDCM VS Vmean observed for ξ = 0 (B/b = 9)

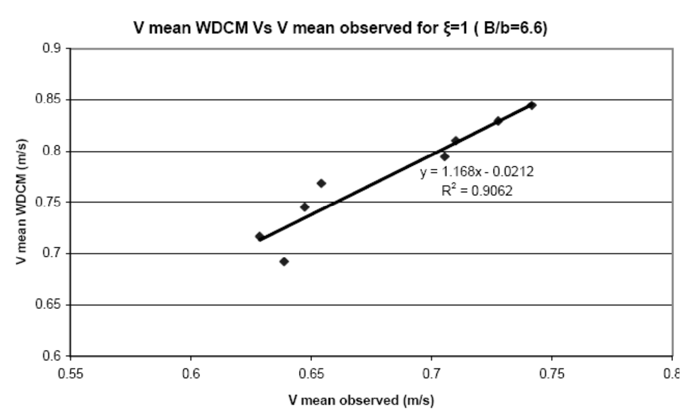


Figure 21: Vmean WDCM VS Vmean observed for ξ = 1 (B/b = 6.6)

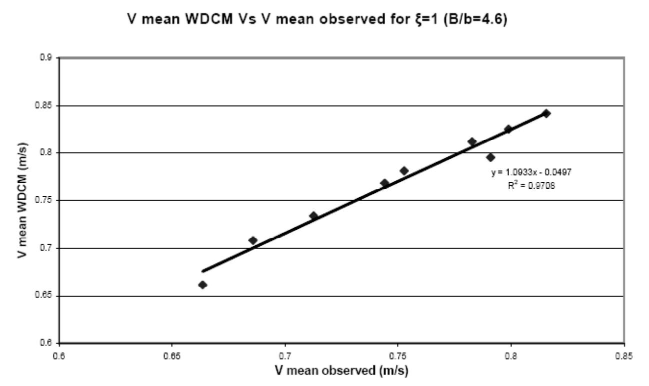


Figure 22: Vmean WDCM VS Vmean observed for ξ = 1 (B/b = 4.6)

From Table 1 and Figures 20 to 22, the best estimated ξ values for B/b = 9 is 0, B/b = 6.6 is 1 and B/b = 4.6 is also 1. From equation (3) for weighted divided channel method (WDCM); it was observed that if the ξ value is closer to 0, the horizontal division channel method (DCM-H) is suitable to be used in predicting the discharge. If the ξ value is closer to 1, then, the vertical division channel method (DCM-V) can be used to predict the discharge. From the results of this project, it can be seen that when the B/b ratio is big (wide flood plain), such as in the case for B/b=9, the horizontal division channel method (DCM-H) could be used best to predict the discharge of the non-symmetrical channel with rough flood plain. This seems to conform to what is observed by Lambert and Myers [5] where they found that a value of ξ = 0.2 (tending towards the DCM-H method) was appropriate for describing the mean velocity for flood plains that are substantially rougher than main channel. However, also from the results of this project, as the B/b ratio getting smaller, just as in the case for B/b=6.6 and B/b=4.6, the value of ξ is 1, which means that the vertical division channel method (DCM-V) is suitable to predict the discharge.

The reason why the horizontal division method is suitable for compound channel with wide flood plain is because with the increase of width, the interaction effect between the slower moving flood plain flow and the main channel flow also increases. One way to conceptualise this effect of interaction is to extend the influence of the flood plain wetted perimeter into the main channel past the point defined by the vertical division line. However, for smaller flood plain width, the effect of this interaction is small; thus, the vertical division method is suitable to predict the discharge.

In short, the weighted divided channel method (WDCM) could be used to check the validity of the horizontal division method and the vertical division method in predicting discharge. For a small scale non-symmetrical compound channel with rough flood plain like the one used in this project, for wide flood plain, the horizontal division method was found appropriate; while for narrower flood plain, the vertical division method was appropriate in predicting the discharge.

5. CONCLUSIONS

From the data and results of this project on a non-symmetrical compound channel with rough flood plain model, it was concluded that:

(a) A change in the flood plain would cause the overall discharge of the channel to also change; for example, extra roughness on the flood plain tends to retard the overall discharge capacity of the channel.

(b) As the depth of water further increases above the flood plain, the effect of interaction between the slower moving flood plain flow and the main channel flow that causes head losses will becomes less.

(c) As the flood plain width become wider (higher B/b ratio), the effect of interaction between the slower moving flood plain flow and the main channel flow also increases causing significant head losses.

(d) The vertical division (DCM-Vertical), horizontal division (DCM-Horizontal) and single channel method (SCM) do not take into account the interaction between the flow in the flood plain and main channel; thus, a more reliable method is needed.

(e) The weighted divided channel method (WDCM) could be used to check the validity of the vertical division method and horizontal division method in predicting discharge. For this project, the estimated weighting coefficient ξ value for B/b = 9 is 0; B/b = 6.6 is 1 and B/b = 4.6 is also 1.

(f) For a compound channel like the one used in this project, horizontal division method is suitable for wide flood plain while the vertical division method is suitable for narrow flood plain in predicting the channel discharge.

For further studies in understanding the flow characteristics in a compound channel, it is suggested to study to what extend or limit of B/b ratio where the flood plain can be considered as wide and the horizontal division method will be more suitable than the vertical division method. Study can also be done on the effect of side slope of main channel and flood plain to the overall flow of the non-symmetrical compound channel.

ACKNOWLEDGEMENT

The authors would like to thank Assoc. Prof. Dr Nabil Bessaih for his guidance in this project. Special thanks are also due to Prof. F.J. Putuhena for peer-reviewing this paper. ■

REFERENCES

[1] Sellin R.H.J. (1964). "A Laboratory Investigation into the Interaction between the Flow in the Channel of a River and that over its Flood Plain". La Houille Blanche, 110: pp689-789.

[2] Myers W.R.C. (1978). "Momentum Transfer in a Compound Channel". Journal of Hydraulic Research, 16(2): pp139-150.

[3] Shiono K. and Knight D.W. (1989). "Two Dimensional Analytical Solution for a Compound Channel". Proceedings of the 3rd International Symposium on Refined Flow Modelling and Turbulence Measurements, Tokyo, July 1989: pp503-510.

[4] Wormleaton P.R. and Merrett D.J. (1990). "An Improved Method of Calculation for Steady Uniform Flow in Prismatic Main Channel/Flood Plain Sections". Journal of Hydraulic Research, 28(2): pp157-174.

[5] Lambert M.F. and Myers W.R. (1998). "Estimating the Discharge Capacity in Straight Compound Channels". Proceedings of the Institution of Civil Engineers, Water, Maritime and Energy, 130: pp84-94.

[6] Ackers P. (1992). "Hydraulic Design of Two-Stage Channels". Proceedings of the Institution of Civil Engineers, Water, Maritime & Energy, 96: pp247-257.

[7] Christodoulou G.C. and Myers W.R.C. (1999). "Apparent Friction Factor on the Flood Plain-Main Channel Interface of Compound Channel Sections". Proceedings of 28th Congress of the International Association for Hydraulic Research, Graz, Austria, SE3, A 379.

PROFILES

Engr. Charles Bong Hin Joo

Engr. Charles Bong Hin Joo, Grad. IEM is currently a lecturer attached to the Civil Engineering Department, Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS). He obtained his M.Eng (Civil–Hydraulic & Hydrology) from Universiti Teknologi Malaysia (UTM) in 2006. Previously, he obtained his B.Eng. (Hons) in Civil Engineering from UNIMAS in 2003 and Dip. Civil Eng. from Politeknik Kuching, Sarawak in 1999. His research interests are mainly in the fields of surface water hydrology and water resources management.

Engr. Darrien Mah Yau Seng

Engr. Darrien Mah Yau Seng, Grad. IEM is currently a Ph.D. candidate in the field of Water and Environmental Engineering, attached to Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS). He received his Master of Engineering in Hydrology and Water Resources Engineering from UNIMAS in 2006. Previously, he was conferred B. Eng. (Hons) (Civil) from UNIMAS in 2003 and Dip. Civil Eng. from Politeknik Ungku Omar, Ipoh in 1999.