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Flow estimation by using interface plane methods in compound channel

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ABSTRACT
This paper evaluates the accuracy of flow estimation for different materials of compound channel such as smooth concrete, perspex and floodplain rod roughened. Previous laboratory data set with ideal conditions such as steady and uniform flow were used for flow estimation. The flow were estimated by using the Manning's equation in combinations with traditional interface plane methods such as Horizontal Divided Method (HDM), Vertical Divided Method (VDM), Inward Diagonal Method (IDM) and Weighted Hydraulic Radius Method (WHRM). Each interface plane method will be divided into subsection zone accordingly with the different arrangement of imaginary interface plane in compound channel. Four interface methods for estimating discharge in compound channels were compared with varies of geometrical shapes, hydraulic slopes and Manning coefficients in compound channel. The flow estimation errors are found can be as large as 12.86%, 44.25%, and 27.03% for smooth concrete, Perspex and rod roughened floodplain compound channel respectively, depending on the particular interface method used. Further study must be carried out in order to estimate the flow accurately for compound channel.

Keywords: Flow estimation; compound channel; interface plane methods; Manning's equation.

1 Introduction

Flow estimation is essential in term of regulation, development, and management of river system. However, during overbank flow, the estimation of flow is complex because of the variability in compound channel shape and surface conditions. Various methods as well as empirical formulas have also been proposed for discharge calculation from the previous studies. However, for previous studies, methods for flow estimation during overbank condition are not so accurate. The main reason for this is due to the idealized condition assumed in laboratory investigations by previous researchers such as uniform channel cross-section, surface roughness and bed slope (Myers & Brennan, 1991; Lambert & Sellin, 2000; Mc Gahey et al., 2008).

In river engineering, it is difficult to estimate discharge for overbank compound channel due to some factors. In such case, the turbulence flow occur at the interface between main channel and floodplain flow, form momentum transfer which may retard the velocity, causes more uncertainty parameters on floodplain affect the discharge estimation accuracy.

The methods that will be discussed in this paper are based on traditional flow estimation methods which known as Divided Channel Method (DCM), without consider the momentum transfer between main channel and floodplain. DCM divides a compound section into hydraulically homogeneous sub sections generally by vertical, inclined or horizontal division lines that lead to an averaged flow velocity for each sub section. (Chow, 1959). These methods have been extensively used because of its simplicity and they are the primary tools used by engineers.

The objective of this paper is to determine the interface plane arrangement towards the flow estimation for different geometrical shapes and materials of compound channel by using data from previous studies.

2 Literature Reviews

Generally, uniform flow formula such as Manning equation widely used in analyzing the flow through open channel with regular sectional shape. However, this can lead to considerable errors due to the irregularity of compound channel. Sudden change of depth at transition between main channel and floodplain might occur, especially for a compound channel which consists of a deep main channel with shallow floodplain.

Zheleznyakov (1965, 1971) was the first investigator who demonstrated that at shallow floodplain depths ($d/D<0.3$), where as d is floodplain water depth (m) and D is total water depth for compound channel. The flow velocities for the interaction between main channel and floodplain were significantly decreased by lateral momentum transfer (LMT). At larger floodplain depths (*d/D*>0.3) condition, the flow in these mixing regions indicated of weak LMT. This perception where then agreed by Myers (1978), Chatila and Townsend (1996). Up to date, there are no common generally applicable methods for estimate the flow of compound channel with different geometric shapes and boundary conditions.

The influence of cross-sectional geometry particularly the width ratio of floodplain to main channel, and the aspect ratios of floodplain and main channel to the flow has long been recognized as important. However, no systematic investigation of its effect on channel capacity has been carried out to date due to many variations involved.

3 Interface plane methods

Four interface plane methods (Figure 1) with different imaginary interface plan arrangement to artificially sub divide the compound flow field into homogeneous zones. These methods were then compared the flow computed in compound channel. The methods used for discharge calculation are:-

a) Horizontal Divided Method (HDM),
- horizontal interface at the bankfull depth to separate the floodplain and main channel flows respectively.

b) Vertical Divided Method (VDM),
- vertical interfaces to separate the main channel and floodplain flows respectively

c) Inward Diagonal Method (IDM), and
- this method studied by Yen and Overton (1973). This interface extends from the junctions between the floodplains and main channel to the center point (c) in Figure 1 of the main channel at the water surface.

d) Weighted Hydraulic Radius Method (WHRM).
- this method studied by French (1985). This method has the same interface plane arrangement as c), but the hydraulic radius, *R* computed for subsections as follow:-

$$R_w = \frac{\frac{A_{lf}^{\,2}}{P_{lf}} + \frac{A_{mc}^{\,2}}{P_{mc}} + \frac{A_{rf}^{\,2}}{P_{rf}}}{A_{lf} + A_{mc} + A_{rf}} \qquad (1)$$

where R_w is weighted hydraulic radius (m), A_{lf}, A_{mc}, A_{rf}, P_{lf}, P_{mc} and P_{rf} are the subdivided areas and wetted perimeters of the left floodplain, main channel, and the right floodplain respectively.

All methods will be compared in different condition of compound channels. The overall evaluations carried out for each of estimation obtained are as shown in Figure 2.

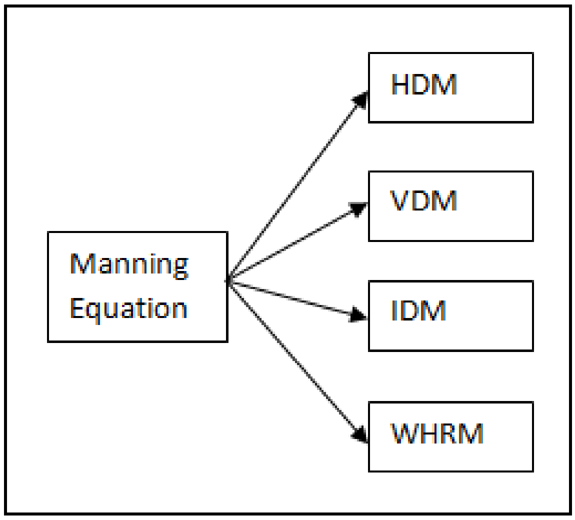


Figure 2 Methods used for discharge estimation in compound channel

Table 1 shows previous laboratory data which represent a wide range of compound channels with different cross section, hydraulic slopes, and roughness.Compound channel is subdivided and the flow of each subsection is calculated using Manning's equation:

$$Q = \frac{A}{n} R^{2/3} S^{1/2} \qquad (2)$$

where Q= Cross sectional flow (m^3/s), n= Manning coefficient (s/$m^{1/3}$) , A= Cross section area, R=Hydraulic radius (m) and S=Hydraulic slope

Table 1 Geometrical and Roughness Parameters (Lai, 2006)

Source	Dimension	
	B/b	*h*(m)
Knight & Demetrious (1983)	2.00	0.076
	3.00	0.076
	4.00	0.076
Lambert & Myers (1998)	4.75	0.080
	3.25	0.080
	4.75	0.120
Myers et al. (2001)	4.20	0.150

The total flow of the cross sectional compound channel is the sum of the sub section flows. The flow were measured and estimated in the range of $0 < (H-h)/H < 0.52$, where H is the total depth of compound channel and h is the main channel depth.

The roughness of wetted perimeter for floodplains and main channel may be different in compound channel. Chow (1959) stated that in order to estimate the flow, an equivalent n value needs to be computed depends on the geometrical shape of channel.

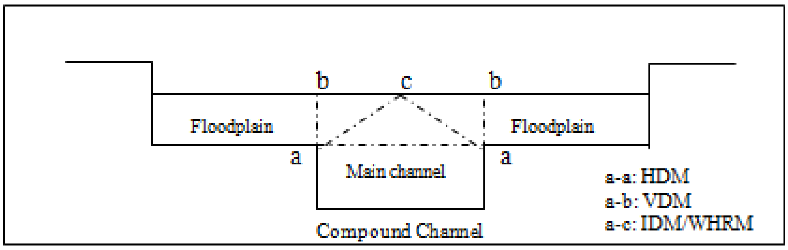


Figure 1 Different interface plane arrangement in compound channel

4 Results

Flow calculated by using various interface estimation methods with different types of compound channel material accordingly to the Manning coefficient and depth ratio of water level. A sample of flow calculated is represented in Table 2.

All the data are then illustrated in Figure 3 to Figure 5. In Figure 3, all interface plane methods seems to be accurate with measured flow under different shape of channels and width ratio for smooth concrete main channel and floodplain, except for VDM method slightly over estimate. This result shown in Figure 3 was agreed with Myers (1978) which shown that the effect of over estimate and under estimate is due to the turbulent interaction between the fluid stream in the main channel and on the floodplain.

In Figure 4, all the methods tend to under estimate when the depth ratio increases in smooth concrete main channel and floodplain rod roughened except VDM method which shows excellent relationship between flow and depth ratio. This figure clearly shows the influence of floodplain roughness to the flow capacity in compound channel. When the flow is overbank, the flows were found to increase with depth ratio. At the same time, the increment of roughness caused by apparent shear which tends to slows down the flow in overall channel.

Table 2 A sample of calculated flow using various estimation methods with different compound materials

(a) Perspex

n	*(H-h)/H*	*Q measured*	*Q HDM*	*Q VDM*	*Q IDM*	*Q WHRM*
0.001	0.108	0.005	0.005	0.006	0.005	0.005
0.001	0.197	0.006	0.006	0.007	0.007	0.007
0.001	0.242	0.007	0.007	0.008	0.008	0.008
0.001	0.330	0.009	0.010	0.011	0.010	0.010
0.001	0.396	0.012	0.013	0.013	0.012	0.012
0.001	0.493	0.017	0.018	0.018	0.017	0.017

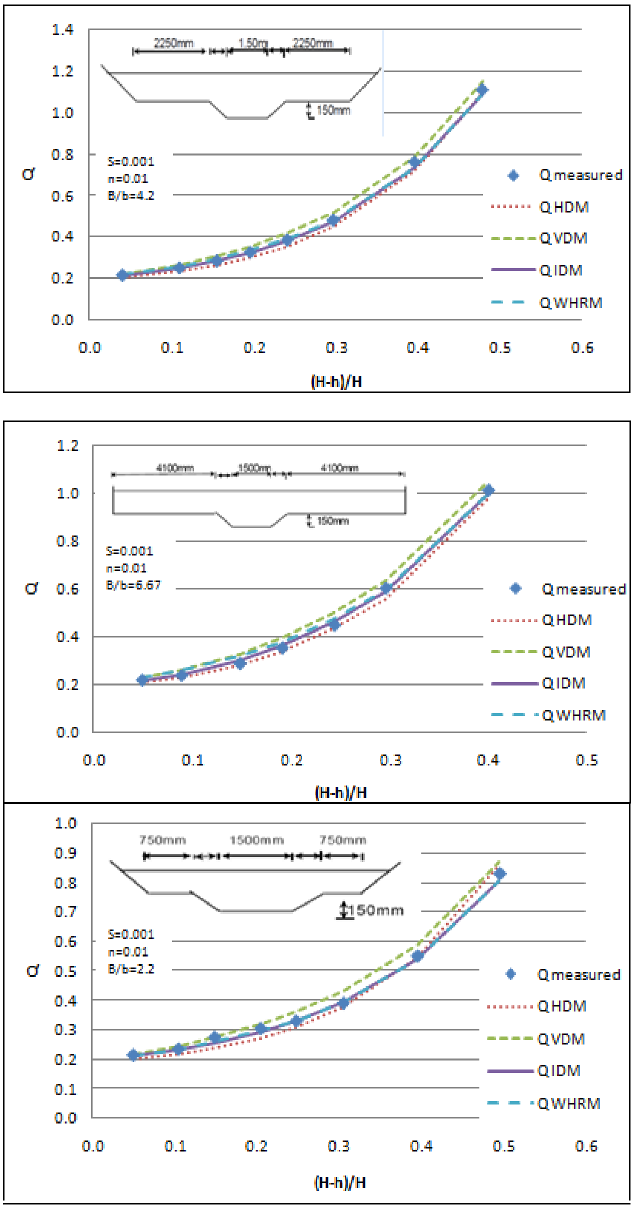
(b)Smooth

n	*(H-h)/H*	*Q measured*	*Q HDM*	*Q VDM*	*Q IDM*	*Q WHRM*
0.001	0.042	0.212	0.205	0.219	0.212	0.218
0.001	0.111	0.248	0.232	0.265	0.248	0.258
0.001	0.156	0.282	0.263	0.307	0.283	0.294
0.001	0.197	0.324	0.300	0.354	0.324	0.334
0.001	0.242	0.383	0.356	0.418	0.382	0.391
0.001	0.298	0.480	0.450	0.520	0.476	0.484
0.001	0.397	0.763	0.717	0.789	0.734	0.738
0.001	0.479	1.114	1.101	1.157	1.094	1.095

(c)Rod Roughened

n_{mc}	n_{fp}	*(H-h)/H*	*Q measured*	*Q HDM*	*Q VDM*	*Q IDM*
0.0101	0.0125	0.0378	0.216	0.201289	0.2140	0.208
0.0118	0.0155	0.1501	0.254	0.206748	0.2483	0.226
0.0123	0.0187	0.1931	0.272	0.213958	0.2684	0.239
0.0133	0.0210	0.2481	0.300	0.228609	0.2955	0.259
0.0144	0.0251	0.3144	0.343	0.252075	0.3376	0.289
0.0153	0.0295	0.3995	0.424	0.309251	0.4269	0.357
0.0191	0.0342	0.5041	0.543	0.415173	0.5425	0.460

*n_{mc} = Manning coefficient for Main channel, n_{fp} = Manning coefficient for Floodplain



*B/b = width ratio

Figure 3 Comparison of calculated and measured flow under different depth ratio condition (Smooth Concrete Main Channel and Floodplain)

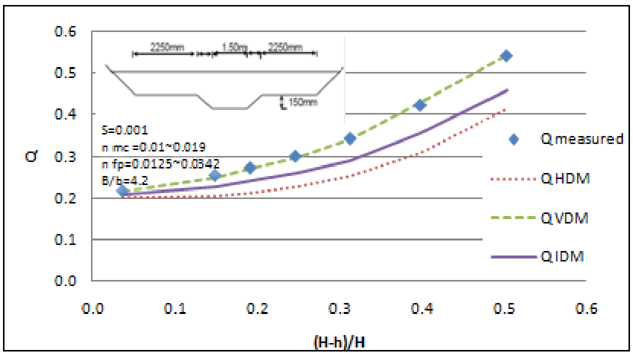


Figure 4 Comparison of calculated and measured flow under different depth ratio condition (Smooth Concrete Main Channel and Rod Roughened Floodplain)

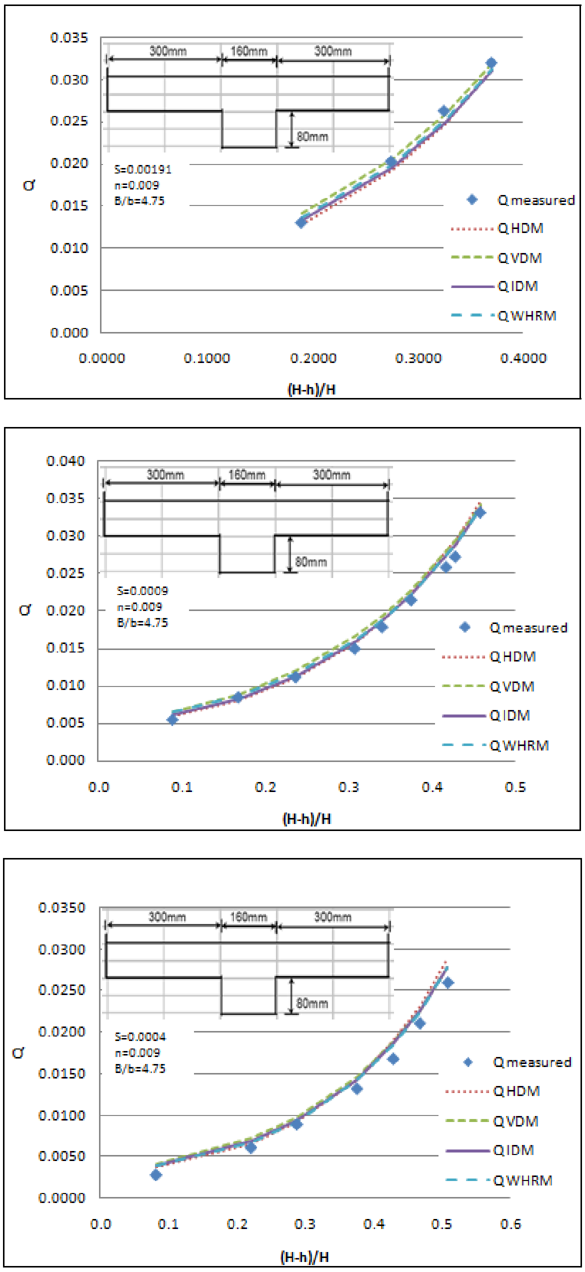


Figure 5 Comparison of calculated and measured flow under different depth ratio and hydraulic slope condition (Perspex with floodplain width 300mm)

Figure 5 shows the comparison of calculated and measured flow under different depth ratio and hydraulic condition in Perspex channel, with the floodplain width 300mm. From the Figure 5, the decreases in hydraulic slope will tend to increase in the significance of over-predicted flow.

From Table 3, for smooth concrete compound channel, the flow estimated for VDM and WHRM were found error with overestimation of 12.66% and 10.41%, followed by IDM and HDM were underestimated with an error of 6.73% and 12.86% respectively. IDM was found be able to produce a better estimation with and averaged error of 0.69% and RMSE = 0.01 only. For compound channel with rod roughened floodplain, the flow estimated for VDM, IDM and HDM were found error with underestimation of 2.23%, 15.71% and 27.03% respectively. It is also found that the flow in compound channel with rod roughened floodplain can be estimated more accurately using the VDM, with an averaged error of 0.97 and RMSE = 0.004. Meanwhile, the flow estimation for HDM, VDM, IDM and WHRM were found seriously errors with overestimation of 32.39%, 44.25%, 38.07% and 42.92 respectively. This time, IDM was found to be better estimation method for Perspex compound channel which has a moderate averaged error, 7.35% and smallest RMSE = 0.0013 among all the methods.

Table 3 Maximum Error, Average Error and RMSE for various estimation methods accordingly with different compound material

Type of Channel	HDM	VDM	IDM	WHRM
Maximum Error				
Smooth Concrete	-12.86	12.66	-6.73	10.41
Rod Roughened Floodplain	-27.03	-2.23	-15.71	-
Perspex	32.39	44.25	38.07	42.92
Average Error				
Type of Channel	HDM	VDM	IDM	WHRM
Smooth Concrete	-4.93	6.75	-0.69	1.64
Rod Roughened Floodplain	-21.08	-0.97	-12.48	-
Perspex	7.35	11.03	7.82	8.70
RMSE				
Type of Channel	HDM	VDM	IDM	WHRM
Smooth Concrete	0.02397	0.03065	0.01221	0.01501
Rod Roughened Floodplain	0.08338	0.00386	0.05057	-
Perspex	0.00157	0.00154	0.00130	0.00133

*RMSE = Root Mean Square Error

5 Conclusion

It can be seen that the complexity of flow in compound channel and the errors encountered by interface plane methods in flow estimation in either smooth concrete, rod roughened floodplain or Perspex compound channel.

Some conclusions have been made based on the result above :-

1. The accuracy of flow estimation for interface plane methods are depend on hydraulic slope, Manning coefficient, width ratio and depth ratio from the results of different floodplain widths and main channel depths for previous laboratory data (7 sets of data, from Lai, 2006).
2. IDM is proposed for flow estimation method in smooth concrete and Perspex compound channel, meanwhile the VDM is the most suitable for flow estimation method in rod roughened floodplain compound channel method.

More laboratory and field data need to be collected for further studies in understanding the flow estimation in either symmetrical or non symmetrical compound channel.

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References

1. Chatila, J.G. and Townsend, R.D. (1996). "*Discharge estimation methods for steady compound channel flows*". Canadian Water Resources Journal, 21, No. 2, 131-137.
2. Lai, S.H. (2006). "*Determination of composite friction factor and Manning roughness coefficient for discharge estimation in natural compound channels*". PhD Dissertation, University Malaysia Sarawak, Malaysia.
3. Lambert, M.F. and Myers, W.R. (1998). "*Estimating the discharge capacity in straight compound channels*". Proceedings of the Institution of Civil Engineering, Water, Maritime and Energy, 130. 84-94.
4. Lambert, M.F. and Sellin, R.H.J. (1996). "*Velocity distribution in a large-scale model of a doubly meandering compound channel*". Proceedings of the Institution of Civil Engineers, Water, Maritime and Energy, 118, No.1, 10-20.
5. Myers, W.R., Lyness, J.F. and Cassells, J. (2001). "*Influence of boundary on velocity and discharge in compound channels*". Journal of Hydraulic Research, Vol. 39, No. 3, 311-319.
6. Myers, W.R. and Brennan, E.K. (1990). "*Flow resistance in compound channel*". Journal of Hydraulic Research, V28, No2, 141-155.
7. Knight D.D. and Demetriou, J.D. (1983). "*Flood plain and main channel flow interaction*". Journal of Hydraulic Engineering, ASCE, 109, No.8, August, 1073-1092.
8. Mc Gahey, C., Samuels, P.G., Knight, D.W. and O'Hare, M.T. (2008), "*Estimating river flow capacity in practice*". Journal of Flood Risk Management 1, 23-33.

9. Chow V.T. (1959), "*Open channel hydraulics*", 1st Edition. McGraw-Hill Book Co.,New York, N.Y.
10. Zheleznyakov, G.V. (1965). "*Relative deficit of mean velocity of instable river flow*; *kinematic effect in river beds with floodplains*". Proceedings of the Eleventh International Conference of the International Association for Hydraulic Research, Leningard, U.S.S.R.
11. Zheleznyakov, G.V. (1971). "*Interaction of channel and floodplain streams*". Proceedings, Fourteenth International Conference of the International Association for Hydraulic Research, Paris, France.
12. Myers, W.R. (1978). "*Momentum transfer in a compound channel*". Journal of Hydraulic Research, 16, No.2, 139-150.
13. Ackers, P. (1993). "*Flow foemulae for straight two-stage channels*". Journal of Hydraulic Research, 31, No. 4, 509-531.
14. Robert, W. and Myers, W.R. (1991). "*Influece of geometry on discharge capacity of open channels*". Journal of Hydraulic Engineering, 117, No. 5, 676-680.
15. Sturm, T.W. and Aftab S. (1996). "*Water Surface Profiles in Compound Channel with Multiple Critical Depths*." Journal of Hydraulic Engineering, ASCE, 122, No 12, 703-709.
16. Yen, C.L. and Overton, D.E. (1973). "*Shape Effects on Resistance in Flood Plain Channels*." Journal of the Hydraulics Division, ASCE, 99, No 1, 219-238.