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GEOMETRICAL RELATIONSHIP FOR FLOW ESTIMATION IN OPEN CHANNEL

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ABSTRACT
This paper describes the geometrical relationship for open channel under overbank flow conditions. Hydraulic depth, D is one of the important geometrical parameter according to Darcy-Weisbach equation, which characterizes the properties of cross section in order to determine the flow in open channel. Previous studies assumed D = 4R for open channel in discharge estimation using Darcy-Weisbach equation. However, the result of this study proves that D is not equal to 4R due to geometrical effects and irregular shape of the compound channel. In compound channel, the shapes are irregular, and the flow is usually turbulent with a considerable mixing. When the flow in compound channel is just overbank, sudden increment in wetted perimeter will decrease the value of R which is essential for discharge estimation during flood condition. Hence, a new relationship for hydraulic depth, D has to be developed for compound channel with different geometrical shapes and boundary conditions.

Keywords*: *geometrical relationship, overbank flow, compound channel.

INTRODUCTION
Geometrical parameters such as width, water depth and bed slope are very important to estimate the discharge for open channel. However, during overbank flow, the estimation of geometrical effect is complex because of the variability in natural river shape and surface conditions. For previous studies, methods for flow estimation during overbank condition are not very accurate. The main reason for this is because most of the previous researches are based on laboratory investigations, with certain idealized conditions, for example uniform channel cross-section, surface roughness and bed slope [1, 2, 3]. Under such conditions, the equations derived will be specific for a certain channel type, and it is not generally applicable for rivers with different geometrical shapes and boundary conditions.

In literature, Acker presented that the ratio of flood plain width to main channel width is an important factor [4]. Apart from this, the influence of geometry on channel capacity by comparing rectangular and compound shapes had been illustrated. Narrow flood plain tends to show better interference effect than wide floodplain. High velocities in the main channel of such deep central cross section to low velocities on the flood plains leads to the formation of a momentum transfer mechanism, in the form of a bank of vortices along the interface between the two zones of flow. Best fit lines were determined on each geometry parameter and used to calculate the parameter for particular values of cross sectional area in order to compare the carrying capacity of each shape at equal values of cross sectional area [5]. From these studies, it shows the danger of neglecting shape effects in open channels and it underlines the need for a systematic investigation on cross sectional shape in order to determine the discharge capacity of open channels. The objective of this paper is to determine the geometrical effect towards the flow estimation during overbank condition for compound channel by using data collected from previous studies.

THEORY CONSIDERATIONS
The flow in pipes and ducts has been extensively studied in the fluid mechanics discipline. From the time of Prandtl (1875-1953) and Von Karman (1881-1963), research by many expert investigators has enabled considerable understanding of flow and associated useful practical application. The studies on pipe flow have lead to derivation of various flow and resistant equation such as the well known Darcy-Weisbach, Manning

equation, and Colebrook-White equation. A combination of Darcy-Weisbach equation and Colebrook equation can be used to determine the geometrical relationship at a given channel cross-section during overbank flow. From Darcy-Weisbach equation,

$$v = \sqrt{\frac{2gDS_o}{f}} \tag{1}$$

where v velocity (m/s)
g gravitational acceleration (m/s^2)
D hydraulic depth (m), $D = \frac{A}{B}$
f friction factor
S_o hydraulic slope

Colebrook-White equation is described as follow:

$$\frac{1}{\sqrt{f}} = -2\log\left[\frac{k_s}{3.7D} + \frac{2.51}{\mathrm{Re}\sqrt{f}}\right] \tag{2}$$

where ks sand coefficient roughness
Re Reynolds Number

Colebrook-White equation is valid at turbulent flow condition in partially-full of fluid in duct, pipe, or tube surface [6]. As Reynold number and relative roughness increase, Equation (2) becomes similar in format to the Prandtl Von Karman equation with a slightly different coefficient which can be written as:

$$\frac{1}{\sqrt{f}} = 2\log\left[\frac{3.7D}{k_s}\right] \tag{3}$$

Various equations for calculating k_s in different conditions had been studied. Strickler equation has been chosen because it is a generally accepted technique for measuring this property geometrically [7].

Equation (4) shows the relation between sand roughness coefficient and manning roughness coefficient (n). It is usually known as Manning-Strickler form of Manning-n [8]. This relationship is deceptively simple but it also contains important information. Even for large increment in sand roughness coefficient, Manning-n does not change much.

$$k_s = (29.24n)^6 \tag{4}$$

METHODOLOGY

For an open channel, it is usually considered to be a conduit cut into two where hydraulic diameter (D) is defined to be equal to 4 times hydraulic radius (R) [9]. However, D is seldom equal to $4R$ ($D \neq 4R$) for open channel in particular those with compound cross section [10]. Hence, the Darcy-Weisbach Equation needs to be modified.

Assume

$$D = \in R \tag{5}$$

where $\in$ coefficient of hydraulic radius

and from Equation (1) and Equation (3), Darcy-Weisbach can be rearrange and written as:

$$\frac{1}{\sqrt{f}} = \frac{v}{\sqrt{2g(\in R)S_o}} \tag{6}$$

Prandtl Von Karman Equation can be written as:

$$\frac{1}{\sqrt{f}} = 2\log\left[\frac{3.7(\in R)}{k_s}\right] \tag{7}$$

The combination of equation (6) and (7) gives:

$$\frac{v}{\sqrt{2g(\in R)S_o}} = 2\log\left[\frac{3.7(\in R)}{k_s}\right] \tag{8}$$

By solving equation (8), the value of $\in$ can be obtained, and hence the relationship of D and R can be determined. Extensive data have been collected from various sources as shown in Table 1. All of the collected data from previous studies were used for current analysis and the effect of geometrical parameters towards the value of D is drawn.

Table 1: Data for Compound Channels (b=bottom width, B=top width, B/b=width ratio, h=bank full depth of main channel, S_0 =hydraulic slope, S_1=side bank slope of main channel, S2=lateral bed slope of flood plain, S_3=side bank slope of flood plain, MC=Main channel, FP=Flood Plain, SC=Smooth Concrete, PP=Perspex.) [1, 11, 12]

Source	Dimension				Slope				Bed Material	
	b(m)	*B(m)*	*B/b*	*h(m)*	S_0	S_1	S_2	S_3	*MC*	*FP*
Lambert & Myers, 1998; Myers & Brennan., 1991	0.750	1.650	2.20	0.150	0.00100	1	0	1	SC	SC
Myers et al., 2001	0.750	3.000	4.20	0.150	0.00100	1	0	1	SC	SC
Lambert & Myers, 1998	0.300	0.080	4.75	0.080	0.00191 0.00109 0.00061 0.00037	∞	0	∞	PP	PP
	0.180	0.080	3.25	0.080	0.00127 0.00097 0.00032	∞	0	∞	PP	PP
	0.300	0.080	4.75	0.120	0.00178 0.00145 0.00105	∞	0	∞	PP	PP

RESULTS AND DISCUSSIONS

The effects of value $\in$calculated under overbank flow with different geometrical conditions are investigated. The geometrical parameters used in this study includes of width ratio, bank full depth and hydraulic slope are plotted as shown in Figure 1, 2, 3 and 4.

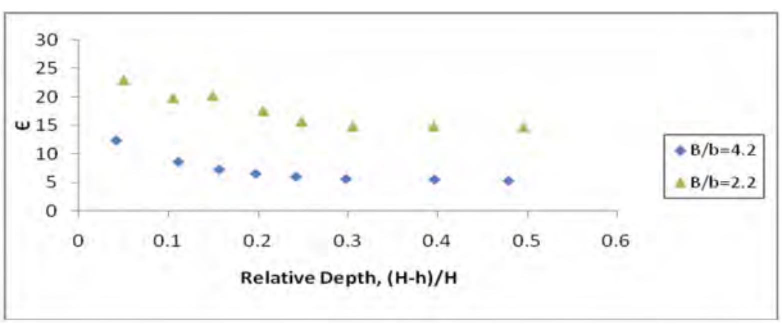

Figure 1: Comparison of width ratio from FCF, U.K

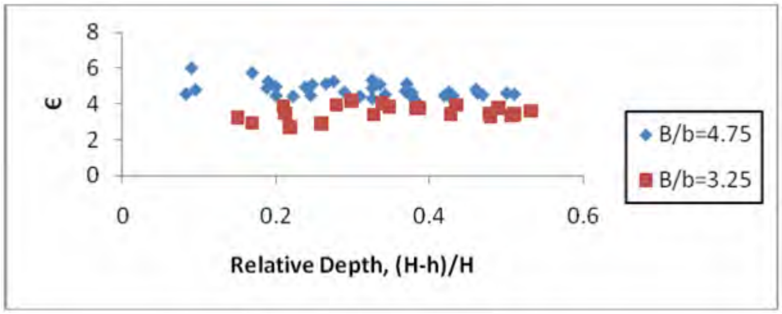

Figure 2: Comparison of width ratio from laboratory flume with perspex.

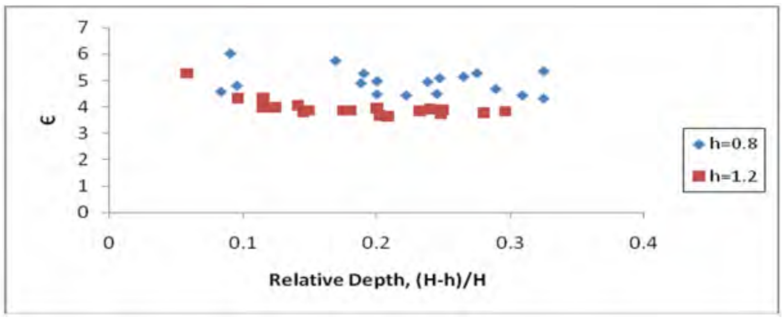

Figure 3: Comparison of bankfull depth of main channel from laboratory flume with perspex.

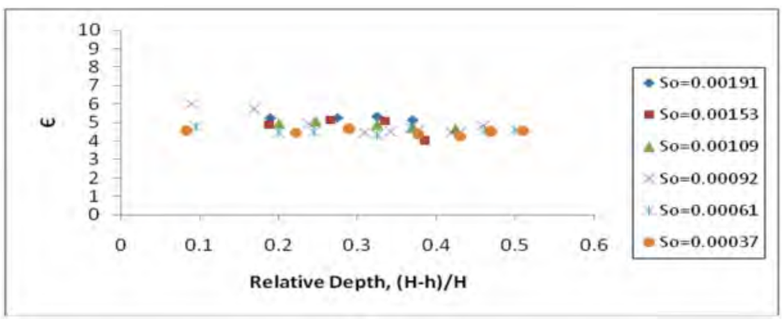

Figure 4: Comparison under various hydraulic slope.

Figure 1 and Figure 2 compare two different width ratios respectively. The $\in$ value for smaller width ratio is higher than the $\in$ value for larger width ratio with corresponding relative depth due to the width of floodplain channel is narrower. Figure 3 shows that for higher value of bank full depth, the $\in$ value is found to be smaller. These graphs show that increment in relative depth will decrease the $\in$ value. For Figure 1, the $\in$ value will be constant after a specific relative depth is reached. Figure 4 shows that the hydraulic slope is not very significant in influencing the $\in$ value. Hence, the geometrical effect of hydraulic slope can be neglected.

CONCLUSIONS

In conclusion, the $\in$ value is influenced by relative depth, with ratio, and bank full depth. Hydraulic slope can be neglected in determining the $\in$ value as it is the least significant parameter which influencing the value of $\in$. According to this conclusion, D is not equal to $4R$ and a regression analysis is required to describe the relationship between the geometrical parameters with the value of $\in$. Further study on the regression analysis will be carried out to develop a general equation for accurately computing the $\in$ value under different geometrical conditions.

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REFERENCES

[1] Myers W.R.C. and Brennan E.K. (1991) Flow resistance in compound channel. Journal of Hydraulic Research, V28, No2, 141-155.
[2] Lambert M.F. and Sellin R.H.J. (2000) Estimating the discharge capacity of doubly sinuos compound channels. Proceedings of the Institution of Civil Engineers. Water, Maritime and Energy, 103-112.
[3] 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.
[4] Ackers P. (1993). Flow formulae for straight two-stage channels. Journal of Hydraulic Research, 31 No.4. 509-531.
[5] Robert W. and Myers W.R.C. (1991) Influence of geometry on discharge capacity of open channels. Journal of Hydraulic Engineering, Vol. 117, No. 5, 676-680.
[6] Colebrook C.F. and White C.M. (1937) Experiments with fluid-friction roughened pipes. Proc. R. Soc. Ser. A 161, p. 367.
[7] Limerinos, J.T. (1970) Determination of the Manning coefficient for measured bed roughness in natural channels. Water Supply paper 1898-B, U.S. Geological Survey, Washington D.C.
[8] Bruschin, J. (1985) Discussion on Brownlie (1983): Flow Depth in Sand-bed Channels. Journal Hydraulic Engineering ASCE, Vol. 111: pp. 736-739.
[9] Chow V.T. (1959) Open channel hydraulics, 1st Edition. McGraw-Hill Book Co.,New York, N.Y.
[10] Lai S.H., Bessaih N., Law P.L., Abd. Ghani A., Zakaria N.A. and Mah Y.S. (2007) Discharge estimation for equatorial natural rivers with overbank flow. International Journal of River Basin Management, IAHR, INBO & IAHS.
[11] Lambert M.F. and Myers W.R.C. (1998) Estimating the discharge capacity in straight compound channels. Proceedings of the Institution of Civil Engineers. Water, Maritime and Energy, 84-94.
[12] Myers W.R.C., 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.

NOMENCLATURE

v	velocity (m/s)
g	gravitational acceleration (m/s^2)
D	hydraulic depth (m), $D = \frac{A}{B}$
f	friction factor
R	hydraulic radius (m), $R = \frac{A}{P}$
A	cross section (m^2)
P	wetted perimeter (m)
B	top width (m)
b	bottom width(m)
H	total depth (m)
h	bank full depth of main channel (m)
n	Manning roughness coefficient
S_o	hydraulic slope
$\in$	coefficient of hydraulic radius
ks	sand coefficient roughness (mm)
Re	Reynolds Number
S_1	side bank slope of main channel
S_2	lateral bed slope of flood plain
S_3	side bank slope of flood plain
MC	main channel
FP	flood plain
SC	smooth concrete
PP	Perspex
FCF	Flood Channel Facility