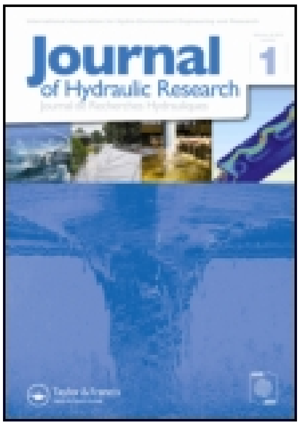

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Apparent friction coefficient in straight compound channels

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Discussion

Apparent friction coefficient in straight compound channels

BY *PEDRO J.M. MORETA and JUAN PEDRO MARTIN-VIDE, Journal of Hydraulic Research Vol. 48, No. 2 (2010), pp. 169–177*

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The discussers congratulate the authors for their valuable study of the apparent shear stress in compound channel flows. The authors summarized a large amount of data allowing for the development of two new formulas for small- and large-scale channels with a wider applicability than most of the available equations (Knight 2001). Their analysis is based on the dependence of the apparent friction coefficient C_{fa} on geometric parameters and on the roughness ratio between the floodplain and the main channel. This discussion is focused on: (1) influence of side slope of the main channel on C_{fa}, (2) effect of inlet supply on C_{fa}, and (3) dependence of C_{fa} on roughness ratio.

(1) The authors mentioned the influence of side slope of the main channel but this parameter is not included in Eq. (4) and the subsequent equations. The replacement of the main channel bottom width b in Eq. (5) by the main channel top width b_c in Eq. (6) does not account for this effect. For that purpose b, b_c, and h would have to be included in Eq. (6). Regarding the side slope issue, Holden and James (1989) found a decrease in the interaction between floodplain and main channel as the side slope reduces, although for very low flow depths the intensity was larger for a steeply-sloping bank than for vertical or milder slopes. The trapezoidal main channel data of tests PT-A1,A2 (63° side angle) shown in Fig. 4(a) seem to follow a different trend from the other data which is supported by Holden and James (1989). For the FCF data (Fig. 4b), the side slope seems to have no influence, since the FCF-s8 data for the rectangular main channel behave similar to the other trapezoidal main channel data. This can be linked to the cross-sectional area increase, reducing the side slope effect. The inclusion of side slope is therefore important to clarify the scatter of the small-scale flume data.

(2) It is unclear what geometrical parameter was used to differentiate between 'small-scale' and 'large-scale' flumes. Although the authors used such a criterion to fit Eqs (6) and (7) to the data, it is not evident that, for the range of widths studied, there is a geometrical limitation on the underlying physical processes. Maintaining the same range in the relevant geometrical non-dimensional parameters (Table 1), one would expect similar physical processes and order of magnitudes in both 'large-scale' and 'small-scale' experiments. As a result, the data may be fitted by a single equation, where the apparent friction coefficient is a function of relevant geometrical parameters, including the main channel side slope.

The discussers conducted experiments in a 10 m long and 2 m wide compound channel, which was symmetric and had two 0.7 m wide lateral floodplains. The main channel was 0.4 m wide and 0.1 m high, with a side bank slope of 1:1. Its longitudinal slope was 0.0011 m/m and the bottom was made of polished concrete ($n = 0.00935\ \mathrm{s/m^{1/3}}$). The non-dimensional parameters were $B/b = 5$ and $h/b = 0.25$, respectively, i.e. within the ranges of Table 1 and Fig. 2. The flume was slightly wider than the small-scale flumes used in the calibration process, but considerably smaller than FCF. Figure D1 shows the apparent

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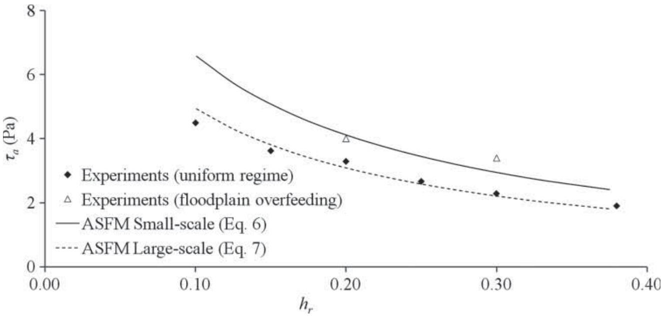

Figure D1 Apparent shear stress versus relative depth for (__), small-scale; (- - -), large-scale flumes

shear stress from Eqs (6) and (7) and the discussers' measured values for six different relative depths under uniform regime. The measurement of the apparent shear stress involved the momentum balance with the boundary shear stress obtained with a Preston tube. The experimental results under uniform regime agree remarkably with Eq. (7) for the large-scale flume.

A physical explanation on why the discussers' flume data under uniform regime fit well the authors' large-scale Eq. (7) follows. The apparent shear stress concept of Myers (1978) is based on a streamwise momentum balance for a subsection (floodplain or main channel) assuming uniform flow. Then, the relevant processes in transverse momentum exchange are (i) large-scale horizontal coherent structures (e.g. Sellin 1964, Prooijen and Uijttewaal 2002); (ii) bottom turbulence (e.g. Prooijen *et al*. 2005), and (iii) secondary flow (e.g. Shiono and Knight 1991, Prooijen *et al*. 2005). From the overall dimensions of the flume cross-sections, one would expect that the general Eq. (2) would adjust all data provided that the influence of those processes is accounted for by the apparent friction coefficient. As it is not the case, the need to divide the data into two sub-data sets to adjust Eq. (2) can be linked to the establishment of uniform flow. Bousmar *et al.* (2005) addressed this issue on the basis of the total head concept and concluded that, for a classical inlet (i.e. unique water supply for both main channel and floodplain), the floodplain discharge in the upstream section exceeds the discharge corresponding to uniform flow and a mass transfer necessarily develops from the floodplain towards the main channel. They also verified that then a much longer distance is needed to balance the discharge distribution between subsections than the distance required for boundary-layer development. For that purpose, they suggested a minimum-channel-length-to-floodplain-width ratio of 35. Although the authors did not present their longitudinal position of the measuring station, only the FCF and some of the small-scale flumes respect that criterion. Assuming that most of the 'small-scale' data were obtained in short flumes with a single inlet, it is possible that the data relate to non-uniform flow, with a mass transfer between subsections. The discussers' flume does not meet that criterion either but, since the inlets to the main channel and the floodplains were separated, there was no overfeeding problem (Bousmar *et al.* 2005).

Experimental evidence of the presence of this term, increasing the apparent shear stress, are found for non-uniform flow in straight compound channels (Proust *et al.* 2010) or even stronger in compound skewed flows (Elliott and Sellin 1990, Proust *et al.* 2010). The increase in the apparent shear stress due to mass transfer helps to interpret the different coefficients of Eqs (6) ($K_{fa} = 0.004$ for small-scale flumes) and (7) ($K_{fa} = 0.003$ for large-scale flumes). It also explains the small-scale flume data spread, since the magnitude of mass transfer can differ for each experiment. The effect of mass transfer on the apparent shear stress coefficient could be accounted for in Eq. (4) by including a non-dimensional parameter related to the magnitude of that mass transfer. The discussers conducted two experiments to evaluate the effect of floodplain over-feeding on the apparent shear stress by increasing the floodplain discharge by 20% when compared with uniform regime discharge and by decreasing the same absolute value in the main channel discharge. The results for relative depths $h_r = 0.2$ and 0.3 are shown in Fig. D1, indicating an increase in the apparent shear stress for non-uniform flows, with values close to Eq. (6) proposed for small-scale flumes.

(3) The inclusion of relative roughness, n_r, in Eq. (6) would better be based on multivariate regression to obtain the exponents using

$$C_{fa} = K_{fa}\left(\frac{B}{b}\right)^{\alpha}\left(\frac{h}{b}\right)^{\beta}\left(\frac{H-h}{H}\right)^{\chi}(n_r)^{\delta} \tag{D1}$$

instead of an additional term in Eq. (8). The reduction of that coefficient due to the increase of floodplain roughness seems physically sound. For a shallow mixing layer, Booij and Tukker (2001) state that bottom friction reduces its growth by suppressing the large-scale horizontal coherent structures. As for the upstream floodplain overfeeding, an increase in floodplain roughness provokes a faster decrease in the initial velocity and, consequently, a smaller length would be needed to establish uniform flow conditions. This would imply equality between Eqs (9a) and (9b) using $K_{fa} = 0.003$ in Eq. (9a) for small-scale flumes (as discussed above). A data reanalysis and the inclusion of more results are needed to confirm this hypothesis.

Finally, the discussers would like to underline the collection of all data related to apparent shear stress as well as the authors

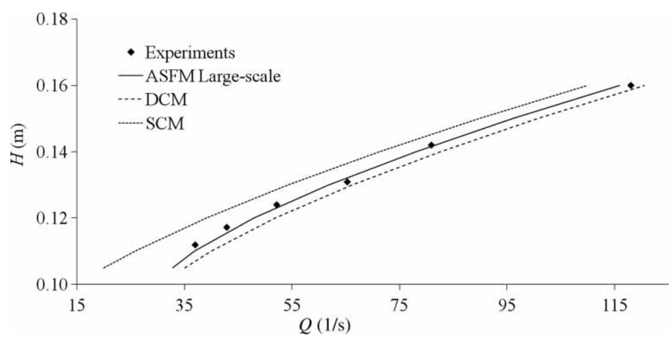

Figure D2 Stage-discharge curve: (__), large-scale Eq. (6); (- - -), DCM; (· · ·), SCM analysis. Despite the aspects presented in this discussion, the authors' Eq. (7) results in a significant improvement of discharge estimation in a compound channel (Fig. D2), where experimental data of the discussers and those obtained with the divided channel method (DCM) and the single channel method (SCM) are presented.

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Reply by the Authors

The authors would like to thank the discussers for their interesting comments and analysis. The discussion is well-founded and clear. In this reply, the authors will try to better elaborate the points of the discussion.

(1) The discussers suggest to include the side slope into the formulation. The authors think this is a nice refinement that was not followed in the research because of two reasons. First and foremost, the authors found that it is difficult to distinguish a general trend for the effect of the side slope on C_{fa}, with the currently data available; more data are needed for this aim. The second reason is that, as shown in Fig. 5.11 by Knight and Shiono (1996) this effect is small, especially if it is compared with that of other parameters. It is true, as stated by the discussers, that the trend of the errors in PT data is different to other small-scale data, but the authors consider that the reason cannot be the difference in the side slope as both PT series have different side slopes but the same trend.

(2) The authors did not try to use any geometrical parameter to divide the small-scale and the FCF data, but after looking at Fig. 2(b), it is concluded that FCF data should be treated separately. Besides, they are assumed to be the best valuable data in compound channels to date, which is a strong reason to separate the analysis of the FCF to the small-scale.

The discussers state an interesting explanation for the difference between the FCF and the small-scale channels formulae of C_{fa}, based on the discharge distribution at the inlet. A certain length from the inlet is needed to avoid mass transfer from floodplains to the main channel for a unique water supply for the whole section. The experimental tests carried out by the discussers seem to confirm this explanation.

What the authors would like to put forward, though, is the following point of discussion and further research. The channel-length-to-floodplain-width ratio in the FCF experiments (non-dimensional length, L/B as Bousmar *et al.*, 2005) is above the limit $L/B > 35$, corresponding to uniform flow conditions in the discharge distribution. The authors present Table 2 as a comparison between the different channels in terms of non-dimensional length. This indicates that most of the small-scale experiments meet the criteria suggested by Bousmar *et al.* (2005). On the contrary, two of the three FCF series and the discussers' experiments, without the inlet separation, are below. Looking at the best value of the coefficient K_{fa} for each data series (Table R1), it seems difficult to find a relationship between this coefficient and non-dimensional length. In conclusion, the explanation of the discussers is theoretically and physically consistent, but the authors think that the comparison with the FCF and the other small-scale experiments disagrees with the conclusions of Bousmar *et al.* (2005). The authors therefore suggest that the non-dimensional length criteria be revisited before establishing a separation limit due to non-uniformity conditions.

(3) The discussers suggest to include the roughness ratio as a multiplicative factor instead of a new addition term. The authors evaluated the type of formula suggested by the discussers but due to length constraints, this was not included in the final version. The results were as follows:
- A regression analysis can be applied to obtain K_{fa}, and the exponents in Eqs (9a) and (9b). For small-scale flumes, the correlations r between C_{fa} and each independent variable B/b_c, $(H-h)/H$ and h/b_c are 0.813, −0.057 and −0.051, respectively. For FCF, these are 0.722, −0.507 and 0.057, respectively, indicating that C_{fa} strongly depends on the

Table R1 Geometrical parameters of flume channels used in this work

Authors	Series ref.	Relative water depth $(H - h)/H$	Flume length L [m] (L_m [m])	Floodplain width B_f [m]	Non-dimensional length L/B (L_m/B)	K_{fa}
Wormleaton *et al.* (1982)	W-A	0.11–0.37	11 (-)	0.46	22	0.0047
Notsopoulos and Hadjipanos (1983)	NH-A1	0.19–0.46	15 (-)	0.425	33	0.0047
	NH-A2	0.29–0.47	15 (-)	0.325	**43**	0.0061
	NH-A4	0.25–0.48	15 (-)	0.225	**55**	0.0038
Knight and Demetriou (1983)	KD-s3	0.11–0.51	15 (12)	0.229	**66** (52)	0.0042
	KD-s2	0.13–0.49	15 (12)	0.152	**99** (79)	0.0048
	KD-s1	0.11–0.49	15 (12)	0.076	**197** (158)	0.0037
Prinos and Townsend (1984)	PT-A1	0.09–0.33	11 (-)	0.203	**54**	0.0040
	PT-A2	0.09–0.33	11 (-)	0.305	**36**	0.0041
Atabay *et al.* (2004)	A-sr	0.07–0.49	18 (-)	0.407	**44**	0.0041
Fernandes *et al.* (2010)-discussers	CVC	0.10–0.38	10 (-)	0.6	17	0.0030
Wormleaton and Merret (1990)	FCF-s1	0.06–0.40	56 (-)	4.10	14	0.0027
	FCF-s2	0.04–0.48	56 (-)	2.25	25	0.0030
	FCF-s3	0.05–0.5	56 (-)	0.75	**75**	0.0026

Notes: Non-dimensional lengths in bold are >35. L_m is length at measuring station.

Table R2 Results of multiple regression analysis

	K_{fa}	χ	β	α	r^2
Eq. (6)	0.004	$-1/3$	$-1/3$	1	0.941
Eq. (6): multiple regression	0.004	-0.18	-0.27	1.29	0.957
Eq. (7)	0.003	$-1/3$	$-1/3$	1	0.786
Eq. (7): multiple regression	0.003	-0.42	-0.31	0.90	0.896

width ratio and moderately on the other variables. The values obtained for (K_{fa}, χ, β, α) by the regression of Eq. (D1) are given in Table R2.

- The squared multiple correlation coefficients r^2 are only slightly better than these obtained with Eqs (6) and (7). However, these formulae are preferable for the individual analysis of each exponent, varying the parameter studied while the rest remains constant.
- The same analysis was carried out for a formula of the type of Eq. (D1) for roughened floodplains. The values of the exponent δ in Eq. (D1), assuming identical coefficients and exponents than for the smooth floodplains, are -0.75 and -0.20 for small-scale and for the FCF, respectively. The correlations between C_{fa} and n_f/n_c are -0.156 and 0.981 for the small-scale flumes and the FCF, justifying the difference in the roughness ratio exponent. The coefficients r^2 obtained from the multiple regression analysis are 0.839 and 0.938 for small-scale and FCF, respectively, similar to those obtained with Eqs (9a) and (9b). However, the mean errors are larger, with 25% for small-scale and 12.7% for the FCF. In the latter, the mean error is almost twice indicating that the summing term gives the most accurate results.

The discussers also propose that if the floodplains are roughened, the same coefficient should be used in both the FCF and the small-scale formulae, as a consequence of item (2). The authors agree with this argument. However, a data reanalysis using this coefficient and the new calibrated exponents results in a mean average error of 23.5%, higher than when using Eq. (9a) with an error of 19.3%. As the discussers, it is concluded that new experimental data are needed, with different types of roughness and the same other flow and geometrical conditions.

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