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Influence of bed discordance on head losses in an open channel confluence

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ABSTRACT

The objective of this contribution is to study with Large Eddy Simulations the influence on head losses and recirculation zone dimensions of a bed elevation discordance between the main and tributary channel in a 90° angled open channel confluence.

1 INTRODUCTION

An important feature of a right-angled, schematized, open channel confluence (Figure 1) is the separation of the tributary flow from the downstream corner of the confluence. The ensuing zone of recirculating flow (RZ) influences the head losses in the confluence hydrodynamics zone (CHZ), and as a consequence, the backwater effects of the confluence.

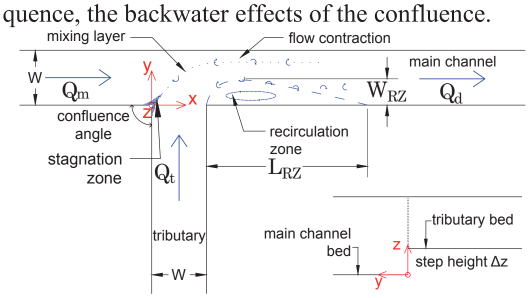

Figure 1. Schematization of the flow in a right-angled, open channel confluence with bed elevation discordance

It is well-known (Best & Reid, 1984) that the dimensions of the RZ in a 90° angled confluence of concordant bed channels with rectangular cross-sections of equal width W, depend on the flow ratio:

$$q = Q_m/Q_d = Q_m/(Q_m + Q_t) \quad (1)$$

and the tailwater Froude number Fr_d. In case of a bed elevation discordance between the main and tributary channel, the step height Δz is also known to influence the RZ dimensions, based upon simulations with a Reynolds-Averaged Navier-Stokes (RANS) solver (Đorđević, 2013).

In this contribution, the aim is to further study the influence of the step height onto the recirculation zone dimensions and the head losses in the confluence, by means of Large Eddy Simulations (LES).

2 METHODOLOGY

Similar to the earlier modelling work of Schindfessel et al. (2015), simulations are performed with the OpenFOAM toolbox, using LES with a standard Smagorinski subgrid-scale model and adopting a horizontal rigid lid approach for the free surface, a wall model for the channel walls, zero-gradient boundary conditions at the outlet and precursor channels are preceeding the channel inlets in order to ensure turbulent inflow.

Four simulations are performed: one concordant bed (CB) case, for reference purposes, and three cases with a discordant bed (DB).

The CB case is based on the experiment by Weber et al. (2001) with W=0.914 m, q=0.582 and tailwater conditions (at x/W=24) reading h_d=0.296 m, Q_d=0.170 m³/s, U_d=0.628 m/s and Fr_d=0.37. The computational domain has shorter channels than in the experiment and extends from the channel inlets at x/W = -2 and y/W= -2 to the outlet at x/W= 8 and from the bed at z=0 to the rigid lid at z_{lid}=0.308 m. The grid consists of ca. 4 million cells, which is sufficient to resolve the (large) turbulent scales.

The DB cases maintain the discharges (hence the flow ratio) and most of the computational domain dimensions of the CB case. Only the bed elevation in the tributary changes (hence the domain height and the inlet velocity in the tributary). The bed discordance ratio of the different cases, and their abbreviation, are indicated in Table 1.

Table 1. Bed discordance ratio

Case	CB	DB10	DB25	DB50
$\Delta z/h_d$	0	0.10	0.25	0.50

3 RESULTS

Water depth profiles are calculated, based on predicted (time-average) pressure values on the rigid lid:

$$h\,(x,y) \;=\; z_{lid} + P(x,y,z_{lid})/(\rho g) \qquad (2)$$

Figure 2 shows the water depth profiles in the centreline of the main channel. For the CB case, the predicted profile agrees well with the experimental data by Weber et al. (2001). Note that the water level depression in the flow contraction zone and the backwater effect decrease in function of the bed discordance ratio.

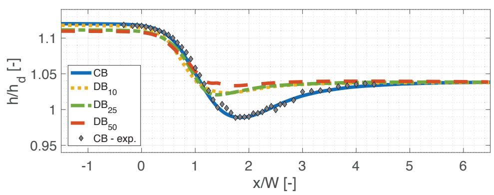

Figure 2. Water depth profiles along y/W=0.5

Figure 3 shows the RZ dimensions (length and width), determined by means of the line of zero longitudinal velocity. This line indicates the zone of reverse flow, which is slightly less extensive than the actual separation zone. Note that, in accordance with previous findings (Đorđević, 2013), the RZ dimensions decrease with increasing bed discordance ratio.

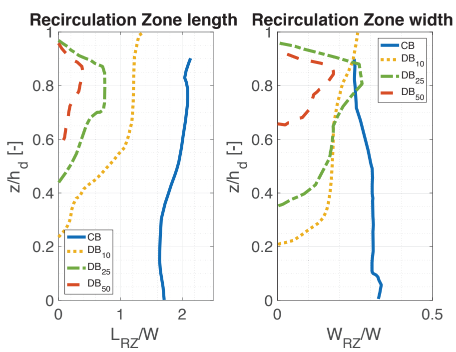

Figure 3. Variation across domain height of RZ dimensions

Head losses are defined here as the difference between the (average) heads H_1 in a section 1 and H_2 in a section 2. The corresponding head loss coefficients are based on the average velocity U_2 in section 2:

$$\xi = \frac{H_1 - H_2}{U_2^2/2g} \qquad (3)$$

For the main channel loss coefficient ξ_m (resp. the tributary loss coefficient ξ_t) section 1 is at x/W= -2 (resp. y/W= -2), while section 2 is at x/W= 6. From Table 2 follows that ξ_t strongly increases in function of the bed discordance ratio, which is related to the associated increase of the (inlet) velocity U_t in the tributary. Due to the reduction of the RZ dimensions, however, ξ_m decreases with bed discordance. Therefore, Table 2 also presents the depth-averaged length $\overline{L}_{RZ}$ and width $\overline{W}_{RZ}$ of the recirculation zone, as well as the Borda-Carnot head loss coefficient ξ_{BC}, expressing the expansion losses between the most contracted section (with a width $W - \overline{W}_{RZ}$) and the section at x/W= 6 (with a width W):

$$\xi_{BC} = \left[\frac{W}{W - \overline{W}_{RZ}} - 1\right]^2 \qquad (4)$$

Though, as mentioned before, the RZ width (hence the expansion loss) is somewhat underestimated, ξ_{BC} also shows a decrease in function of the bed discordance ratio.

Table 2. Depth-averaged recirculation zone dimensions and head loss coefficients

Case	$\overline{L}_{RZ}/W$	$\overline{W}_{RZ}/W$	ξ_{BC}	ξ_m	U_t/U_d	ξ_t
CB	1.871	0.298	0.180	0.369	0.402	0.005
DB_{10}	0.698	0.150	0.031	0.340	0.447	0.169
DB_{25}	0.421	0.133	0.024	0.237	0.536	0.268
DB_{50}	0.198	0.095	0.011	0.075	0.805	0.681

4 CONCLUSIONS

In this contribution, it was shown, based upon Large Eddy Simulations (LES), that the recirculation zone dimensions strongly depend on the bed elevation discordance between the tributary and the main channel in a right-angled confluence. As a consequence, also the head losses, hence the backwater effects, decrease with the bed discordance ratio.

ACKNOWLEDGEMENTS

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