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Velocity distribution and Dip phenomenon in a large amplitude meandering channel

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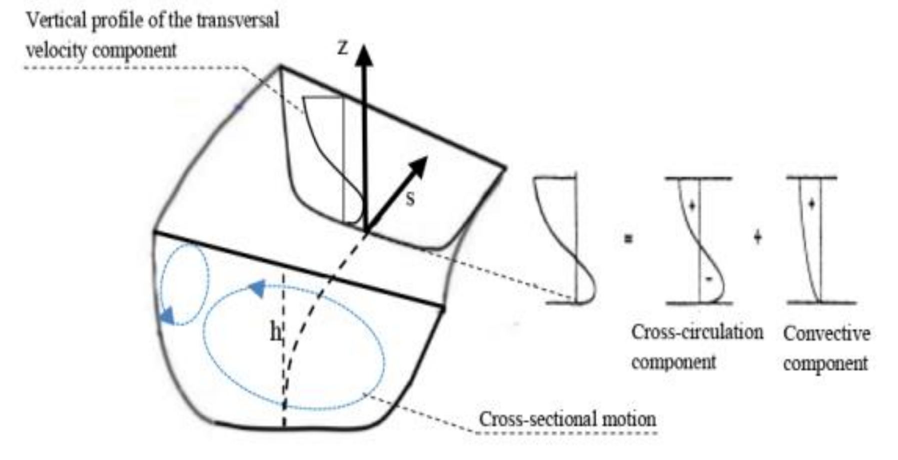
BACKGROUND

A natural meandering stream represents one of the most complex flow situations.
Accurate predictions of velocity distribution along the meander wave is important to analyze problems related to river restoration, water quality and water management.

When the flow enters a bend the so-called helical motion, given by the combination of the transversal cross-sectional motion with the longitudinal motion, is produced.



The cross-sectional motion can be considered as the composition of the cross-circulation component and the convective component (among others Yalin 1992).

In a meandering bend, which is characterized by a continuously changing curvature in the downstream direction, the cross-sectional motion varies from cross-section to cross-section (Termini and Piraino 2011)

BACKGROUND

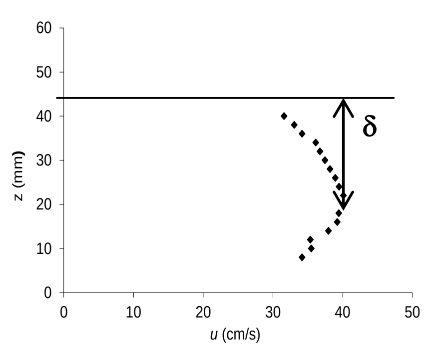
The cross-sectional motion exerts an important role in the redistribution of the stream-wise velocity along the bend.

This effect is important especially in high-curvature bends where the channel's curvature is more accentuated.

Although several works have been conducted to analyze the flow velocity pattern in meandering bends (among others Whiting and Dietrich 1993, Blanckaert and Graf 2004; da Silva et al. 2006; Termini 2009)**, several aspects related to the influence of the cross-sectional motion on the velocity and fluid mass distributions are still poorly understood.**

BACKGROUND

Studies conducted in straight channels highlighted **a deviation of the velocity profile from the logarithm behavior and the occurrence of the phenomenon known as "dip-phenomenon" due to the position of the maximum velocity below the water surface.**



Most of these studies (among others Cardoso et al., 1989; Nezu and Nakagawa, 1993) **suggested to relate the dip-phenomenon to the secondary flow which transports low momentum fluid from the near bank region to the center and high momentum fluid from the free surface to the bed.**

The position of the velocity-dip could depend both on the distance from the sidewalls and on the aspect ratio (Yan et al., 2011)

Several simple dip-modified log-wake-laws (Coles 1956; Finley et al. 1966; Kironoto and Graf 1994; Song and Graf 1996; Guo and Juliean 2008) **can be found in literature but they are not universal and are unable to predict the velocity-dip location in flows with high secondary currents effects.**

No systematic research has been conducted to identify the localization of the velocity-dip and the maximum velocity along a bend

GOAL

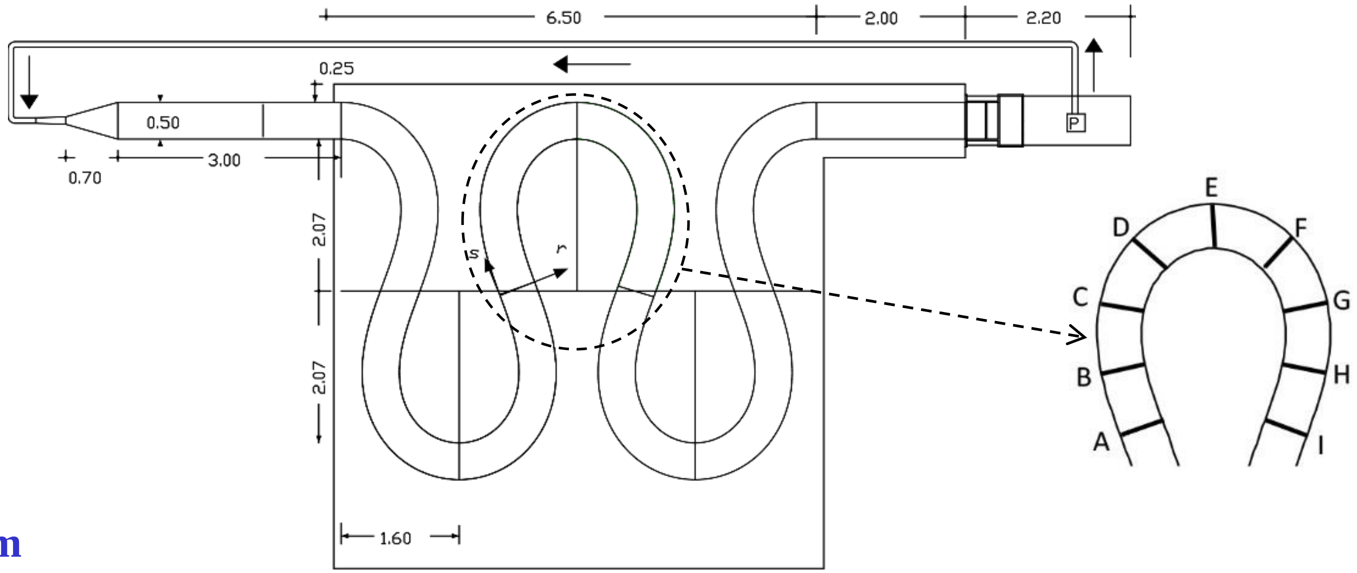
The present study aims to gain some insights on the evolution of the dip-phenomenon along a high-amplitude meandering bend.

The main objectives of the present study are:

to explore the location of the maximum velocity based on available experimental data along the bend for two values of the width-to-depth ratio;

to investigate the relationship between the velocity-dip, the channel’s curvature parameters and the aspect ratio.

EXPERIMENTAL DATA



θ_o=110°
B=0.50 m

Run1: Q=0.019 m^3/s; channel-averaged flow depth h_{av}=5.5 cm; aspect ratio B/h_{av}=9.09<10

Run2: Q=0.007 m^3/s; channel-averaged flow depth h_{av}=3.0 cm; aspect ratio B/h_{av}=16.67>10

The instantaneous local longitudinal and transversal velocity components were measured along the verticals of nine transverse abscissas symmetrically to the channel axis by using a 2D side-looking Acoustic Doppler Velocimeter (ADV) manufactured by SonTek Inc

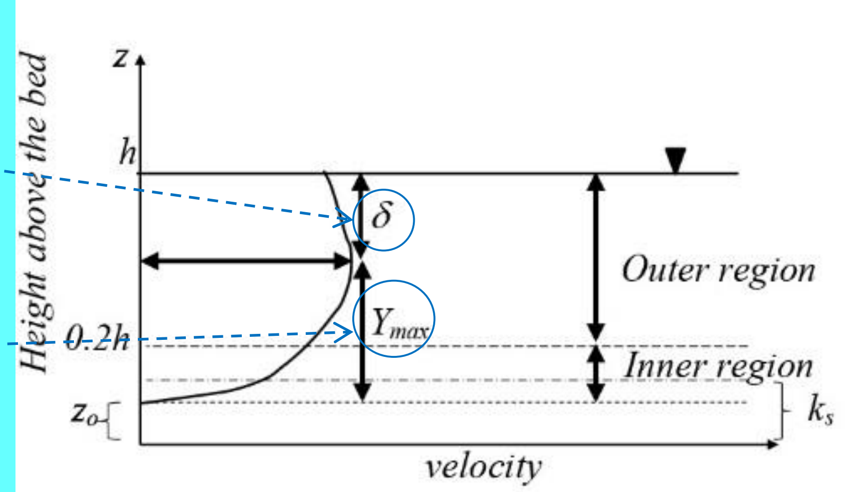
THEORETICAL CONSIDERATIONS

Two regions can be distinguished in the vertical velocity profile of fully turbulent flows:

the outer region - the inner region.

The maximum velocity occurs below the free surface **(velocity-dip δ)**

At a distance from the bed indicated as Y_{max}



THEORETICAL CONSIDERATIONS

The log-law can be written as follows (Yalin 1992):

$$\frac{u}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z}{k_s}\right) + B_s$$

$$\longrightarrow \quad B_s = \frac{1}{\kappa} ln \frac{u_* z}{\nu} + 5.5 \quad \longrightarrow \quad \text{for} \quad Re_* = \frac{u_* k_s}{\nu} < 5$$

$$\longrightarrow \quad B_s = 8.5 \quad \longrightarrow \quad for \quad Re_* = \frac{u_* k_s}{\nu} > 70$$

u_* =shear flow velocity

κ =universal Von Karman's constant

ν = water viscosity

k_s = representative roughness height

$Re_* = \frac{u_* k_s}{\nu}$ = roughness Reynolds number.

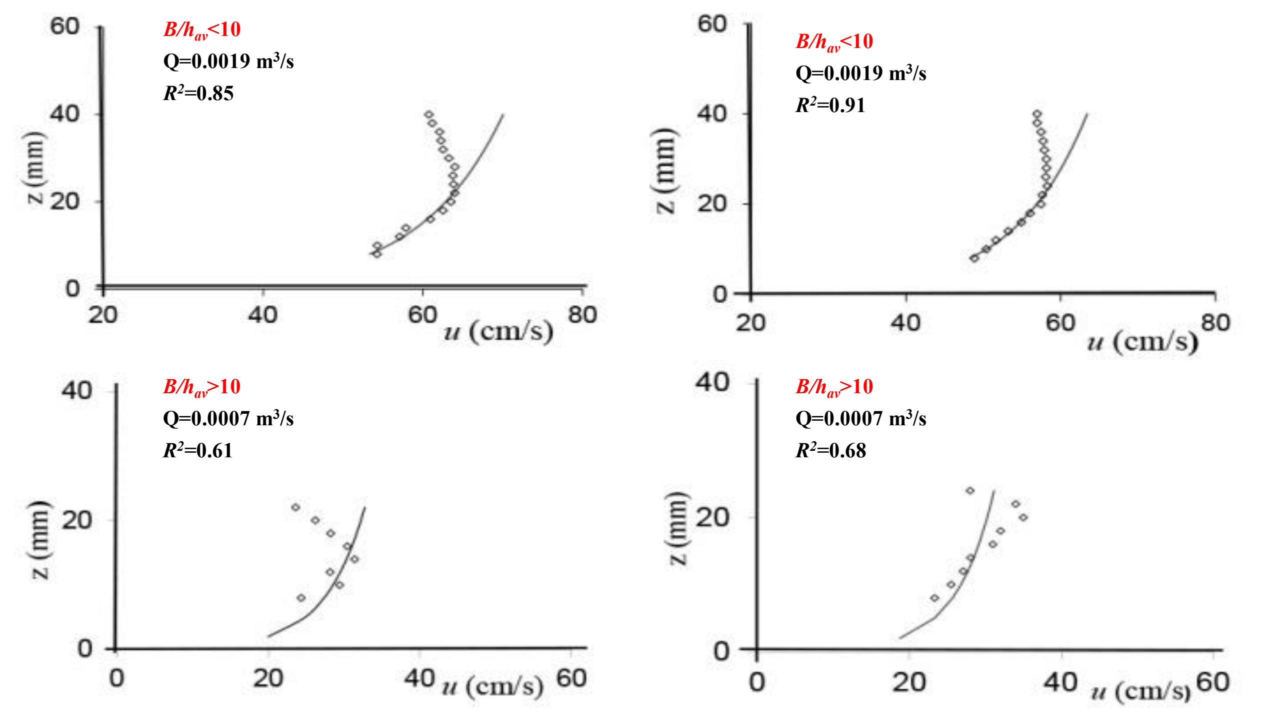
The log-law could approximate the vertical profiles in the inner region but in the outer region it deviates from the experimental profile.

In a meandering bend u* varies from one location to another and thus it cannot be assumed constant along the bend.

RESULTS

Longitudinal velocity profile and log-law

Section A **Section B**



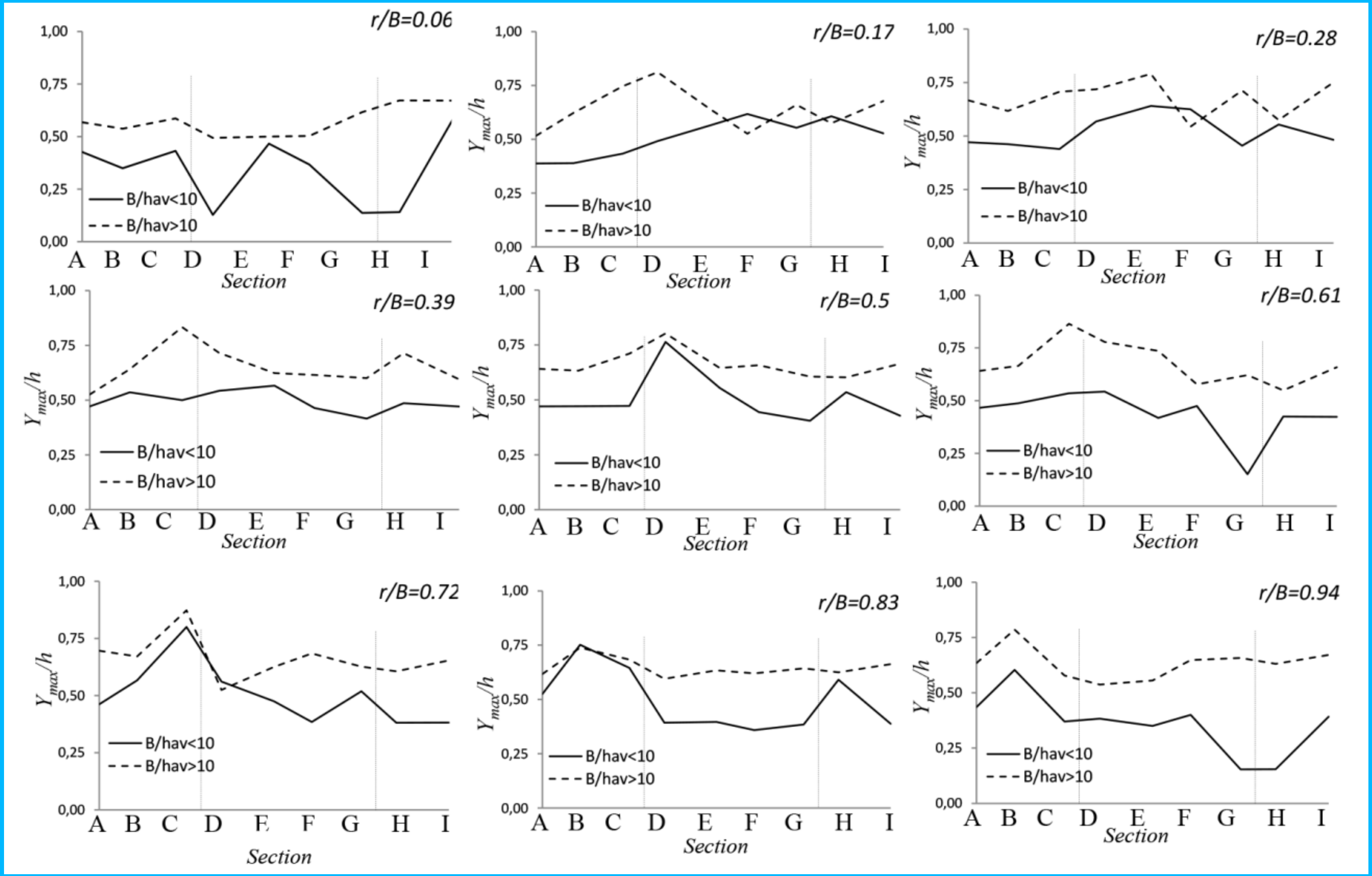
RESULTS

Estimated Y_{max}/h along the bend

Outer region

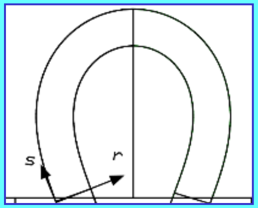
Central region

Inner region



RESULTS

The velocity-dip



The main parameters are:

- the channel’s curvature, parameterized by the deflection angle θ of each considered section
- distance from the outer bank, parameterized by the ratio *r/B*
- the aspect ratio *B/hav*

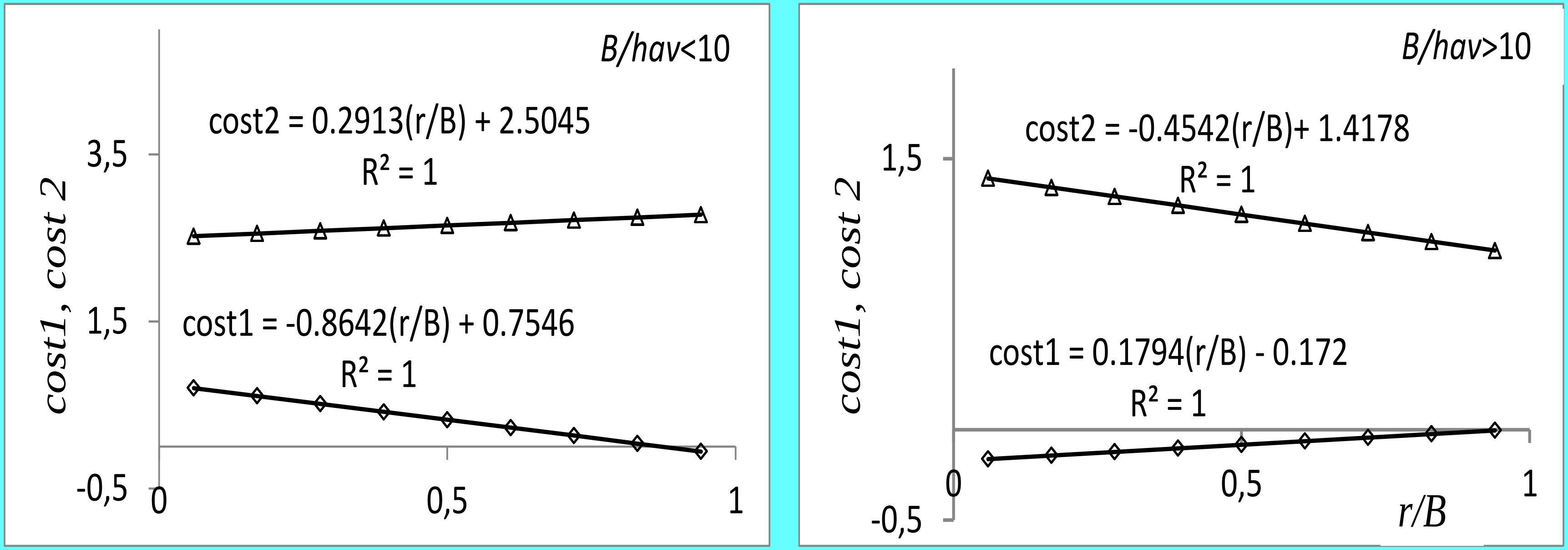
The regression analysis of the δ-values by considering *r/B* and θ as independent variables has yielded the following expression:

$$\boxed{\delta = cost1\left(\frac{r}{B}\right)\sin\theta + cost2\left(\frac{r}{B}\right)}$$

where *cost*1(*r/B*) and *cost*2(*r/B*) are the linear functions of the distance *r/B*

RESULTS

The velocity-dip



Relation between *cost*1(*r/B*) and *cost*2(*r/B* and the distance *r/B*

RESULTS

The velocity-dip

By relating the obtained values of *cost*1 and *cost*2 to the independent variable B/h_{av} the following equation has been obtained:

$$\boxed{\delta = \left(a\frac{B}{h_{av}} + b \right) \sin\theta + \left(c\frac{B}{h_{av}} + d \right)}$$

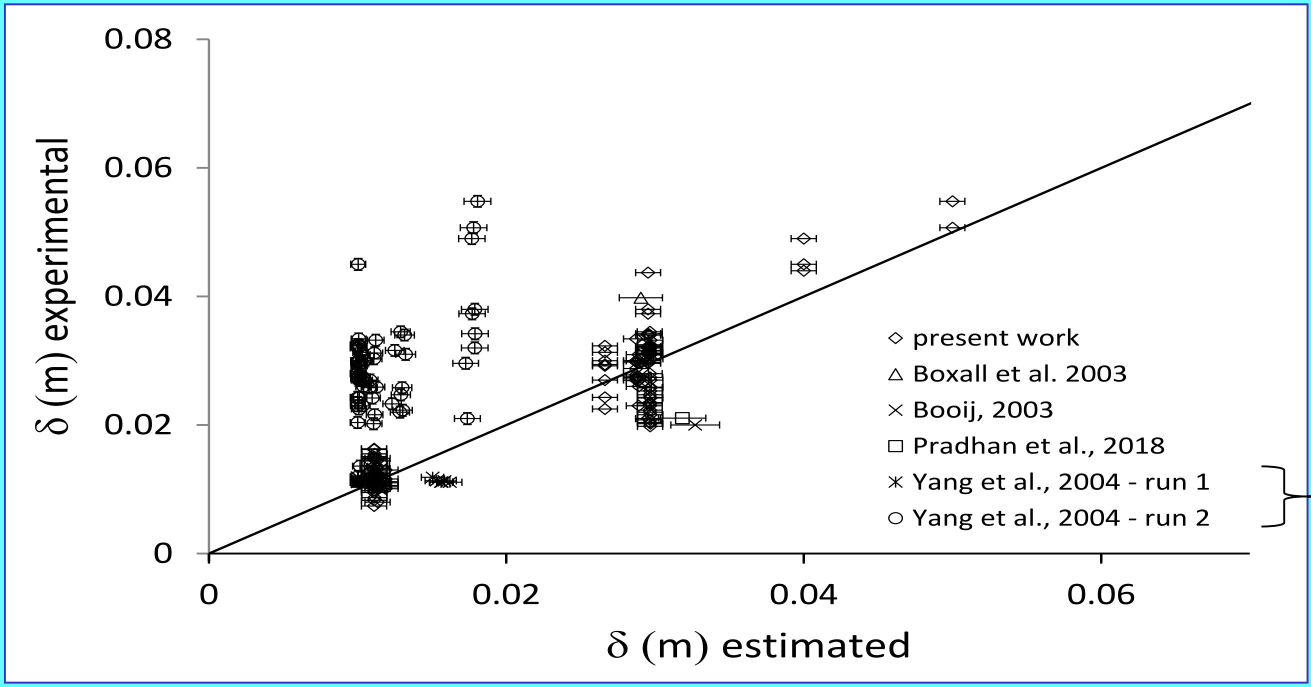
with a regression coefficient $R^2=0.8$.

The coefficients *a*, *b*, *c*, *d* have to be determined by using experimental data;
for the considered case the following values of the coefficients have been obtained: $a=-0.0536$, $b=0.8104$, $c=-0.1925$, $d=4.4003$.

Unlike other literature expressions, this equation directly relates the velocity-dip to the local channel's curvature and the width-to-depth ratio B/h_{av}.

RESULTS

The velocity-dip: validation



$$\boxed{\delta = 1 + 1.3 e^{-r/h}}$$

Reference	Channel's Planform	Section considered
Boxall et al. 2003		
(see also Boxall and Guyner 2001)	Sine-generated q=60°	apex
Booij 2003	180° constant middle curved	Section at 135°
Pradhan et al.2018	Sine-generated q=110°	apex

CONCLUSION

The results obtained in the present work have demonstrated that:

-the distance of the maximum velocity from the bed, Y_{max}, varies along the bend as a function of the distance from the outer bank, $\boldsymbol{r/B}$, the local channel's curvature (parameterized by the deflection angle $\boldsymbol{\theta}$), and the width-to-depth ratio, $\boldsymbol{B/h_{av}}$.

- **close to the outer-bank** a different behavior between the case of $B/h_{av}>10$ and the case of $B/h_{av}<10$ has been observed.
  Such a different behavior could be due both to the fact that the convective behavior of flow is more significant for $B/h_{av}>10$ than that for $B/h_{av}<10$ and to the fact that a protective counter-rotating circulation cell forms close to the outer bank for $B/h_{av}<10$, as described in Termini and Piraino (2011).

- **in the central and in the inner-bank regions**, for both the width-to-depth ratios, the relative distance Y_{max}/h assumes a high peak value at the bend entrance and a second lower peak value close to the bend exit.

An expression which directly relates the velocity-dip to the parameters θ and B/h_{av} has been presented.

The values of velocity-dip estimated by this equation are in good agreement with the experimental dip-values both considered in the present work and taken from literature in curved channels.

THANK YOU FOR YOUR ATTENTION

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