STUDY OF FLOW CHARACTERISTICS IN A NON-SYMMETRICAL COMPOUND CHANNEL : SMOOTH FLOOD PLAIN

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STUDY OF FLOW CHARACTERISTICS IN A NON-SYMMETRICAL COMPOUND CHANNEL : SMOOTH FLOOD PLAIN

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Tesis Dikemukakan Kepada
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ABSTRAK

Pada beberapa tahun kebelakangan ini, kajian tentang aliran air dalam sungai yang mempunyai dataran banjir adalah subjek yang selalu dipertimbangkan. Akan tetapi, masih terdapat kesusahan untuk mengira isipadu aliran dalam sungai yang mempunyai dataran banjir. Kaedah yang biasa digunakan untuk mengira isipadu aliran di sungai yang berbentuk mudah adalah kurang tepat apabila aliran air melebihi tebing sungai. Ini adalah sangat merbahaya jika isipadu aliran air kurang dikira. Jika isipadu aliran air lebih dikira, maka rekabentuk yang terhasil adalah terlebih juga. Dalam kajian ini, ciri-ciri aliran air di dalam sungai yang berdataran banjir dan berbentuk tidak simetri telah dikaji melalui eksperimen yang dijalankan. Satu saluran yang diperbuat daripada kayu dan mempunyai nisbah lebar, B/b = 9 telah dibina. Hasil kajian menunjukkan kaedah yang biasa digunakan seperti Kaedah satu saluran, Kaedah pembahagian saluran menegak dan Kaedah pembahagian saluran melintang yang tidak menimbangkan kesan interaksi momentum adalah kurang sesuai untuk mengira isipadu aliran air. Kaedah ubahsuai pembahagian saluran didapati adalah kaedah yang paling sesuai untuk mengira isipadu aliran air dalam sungai yang berbentuk mudah. Kesan interaksi momentum di antara dataran banjir dan saluran utama akan menyebabkan kehilangan tenaga keupayaan aliran dan mengurangkan isipadu aliran sebanyak 4% hingga 20%.

ABSTRACT

The study of flow in compound channel sections has been the subject of considerable research in recent years. There is still difficulty in estimating discharge capacity for rivers with compound cross-sectional shape. Method appropriate to simple cross-sectional shapes are less accurate when applied to overbank flows and may lead either to under-estimation of discharge capacity, which is dangerous, or to over-estimation of discharge capacity which leads to over design. In this study, the flow characteristics of non-symmetrical compound channel with smooth flood plain were studied by experimental investigations. A wooden compound channel with with width ratio, B/b = 9 was built purposes. The results show that conventional methods such as Single channel method, Vertical divided channel method and Horizontal divided channel method which do not consider the momentum interaction effect are less accurate to predict the discharge. The Weighted divided channel method was found to be the best method to predict discharge for simple compound channel. The momentum interaction between flood plain flows and main channel flows increases head losses and reduce the discharge capacity of 4% - 20%.

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A	=	Area
ARF	=	Aspect ratio factor
B	=	Flood plain width to centre of main channel
b	=	Half width of main channel
COH	=	Coherence
DISADF	=	Adjustment factor, measured discharge / basic calculation
DISDEFBF	=	Discharge deficit as a proportion of bankfull flow
fa	=	Apparent friction factor
FP	=	Flood plain
H	=	Flow depth
h	=	Depth of main channel
MC	=	Main channel
n	=	Manning's n
P	=	Wetted perimeter
Q	=	Discharge
R	=	Hydraulic radius
Re	=	Reynolds number
R^2	=	Correlation
s	=	Channel's bed slope
Tm	=	Average shear stress
V	=	Velocity
w	=	Semi top width of main channel
Y	=	Stage
ξ	=	Epsilon value
ρ	=	Fluid density

CHAPTER 1

INTRODUCTION

1.0 Introduction

Rivers represent one of mankind's most important environmental assets. River flows are often affected by man's activities and therefore require careful management for water supply, waste disposal, flood alleviation and power generation as well as amenity uses. River engineering design must ensure the optimum use of a valuable resource and flood protection.

The study of flow in compound channel sections has been the subject of considerable research in recent years. Two-stage or compound river geometry (Fig.1) ensure of reasonable depth at low flows and flood plains provide conveyance for floods. The term 'compound' covers channel cross-sections having berms or flood plains that come into action at high flows but normally are dry.

There is however difficulty in estimating discharge capacity in rivers of a compound cross-sectional shape. Method appropriate to simple cross-sectional shapes are less accurate when applied to overbank flows and may lead either to under-estimation of discharge capacity, which is dangerous, or to over-estimation of discharge capacity which leads to over design and wastage of resources.

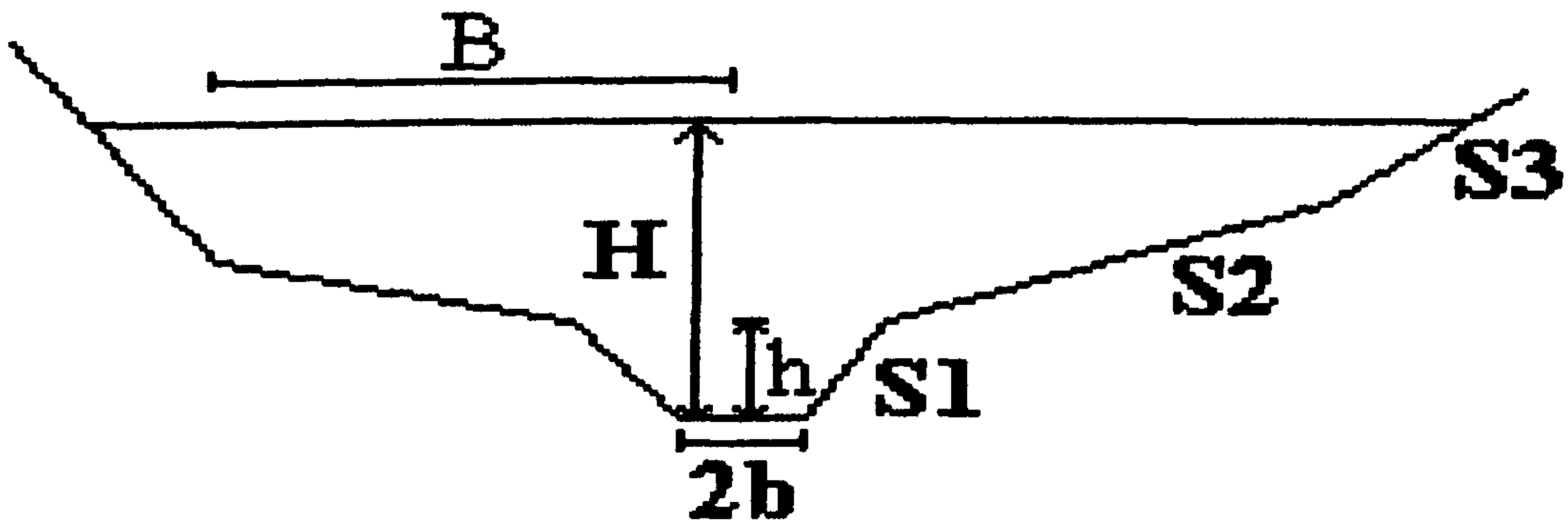

Fig. 1 : Compound channel geometry.

1.1 Objective

The main objective of this project is to study the flow characteristics in a non-symmetrical compound channel with smooth flood plain.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

The apparently simple problem of determine the discharge capacity of a compound channel under uniform flow conditions has proved to be difficult, especially in a non-symmetrical channel. Sellin (1964), first identified the modification of the velocity distribution and the resulting changes in the discharge capacity caused by the turbulent interaction between the main channel and the floodplain. Since that time, work has proceed on methods to quantify the momentum exchange process.

There are several traditional hydraulic methods to predict the discharge capacity for a straight compound channel as below:

a) Single channel method (SCM)

b) Vertical divided channel method (DCM-V)

c) Horizontal divided channel method (DCM-H)

All the methods mentioned above assumed that there is no interaction between floodplain and main channel. The discharge capacity predicted will not accurate when applied to overbank flows and may lead either to under-estimation of discharge capacity, which is dangerous, or to over-estimation of discharge capacity.

Many experimental studies have been carried out addressing various aspects of the problem, ranging from the boundary shear distribution to the structure of turbulence in compound section and various methods as well as empirical formulas have been proposed for discharge calculation as below:

a) Apparent friction factor method
b) Coherence method (COH)
c) Weighted divided channel method (WDCM)

2.1 Single channel method (SCM)

This method is counting for whole channel without considering the interaction between floodplain and main channel. Area and the wetted perimeter for the compound cross section will be calculated without divided it into small parts.

2.2 Divided channel method (DCM)

Compound channels have traditionally been analysed by dividing the compound cross-section into relatively large homogeneous sub-area which are easier to analyse. This approach will be termed the divided channel method (DCM).

Compound channel divided into three zones: main channel, left floodplain and right floodplain as shown in Fig.2(a). Typically, these divisions are made by drawing straight vertical lines at the edges of the main channel which are assumed to be shear-free and as a result , not included in the wetted perimeter. This treatment of a compound channel assumed that there is no interaction between the subdivided area despite the existence of mean velocity discontinuities at the assumed internal boundaries. The ratio of the observed discharge in the main channel, Q_{obs}, to the calculated discharge, Q_{calc} assuming that there is no interaction , is plotted against relative depth. When temporary floodwalls are present, a ratio near unity is obtained for the trapezoidal channel. The presence of floodplains next to the edges of the main channel dramatically reduces the main channel discharge.

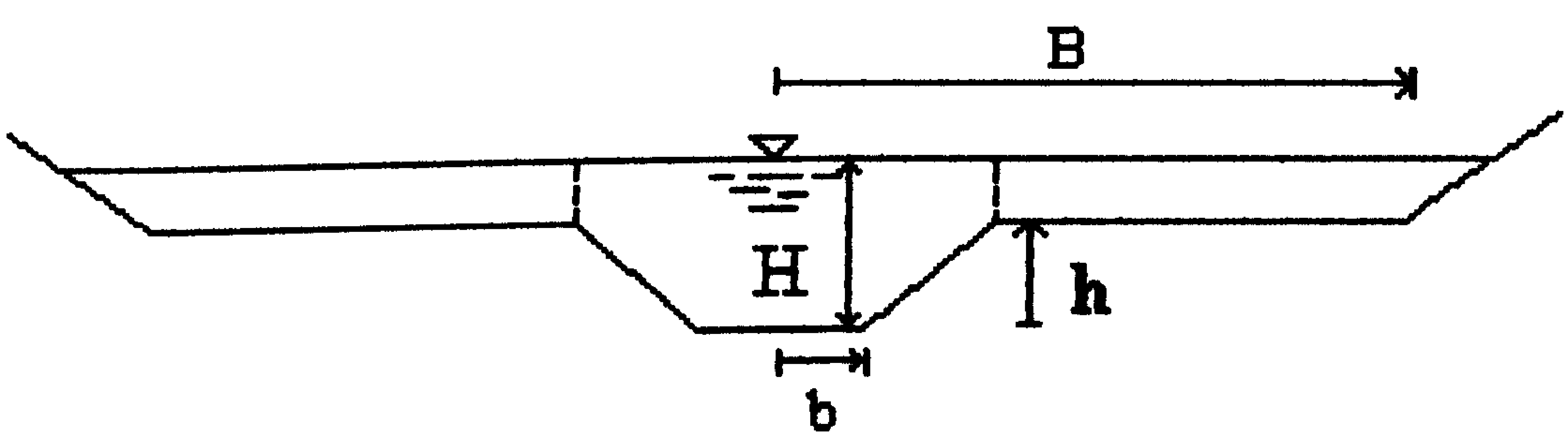

Fig 2(a) : Vertical divisions of a compound channel.

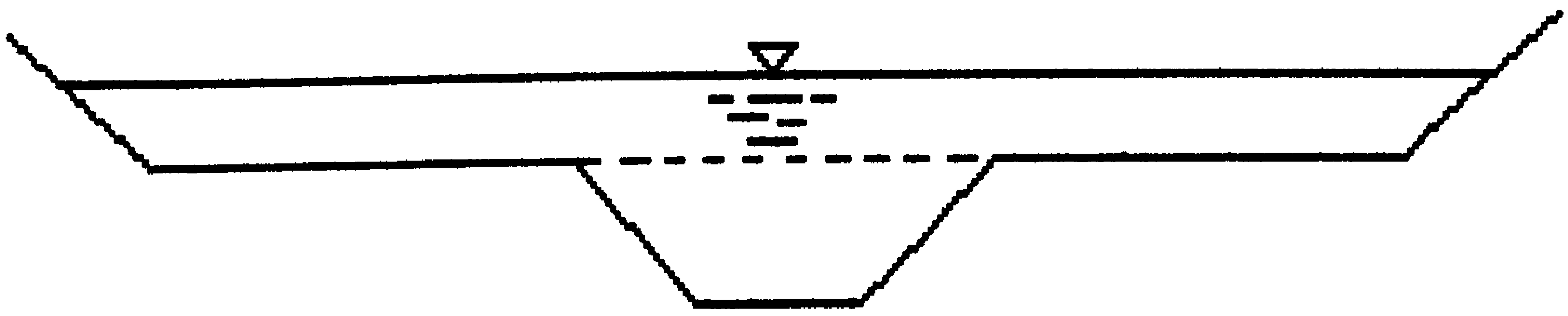

Fig 2 (b) : Horizontal divisions of a compound channel.

2.3 Apparent friction factor method

Myers (1978), questioned the use of shear-free vertical divisions and showed, using boundary shear stress measurement, that an apparent shear force must be present at these boundary to produce a balance between the gravitational and boundary resistance forces. This approach has been expanded by Wormleaton et al.(1982), Knight et al.(1982), Baird and Ervine (1984), and Wormleaton and Merrett (1990), who have developed various empirical relationships expressing the apparent shear stress as a function of various geometry and flow variables.

The apparent shear stress on the imaginary vertical interface between main channel and flood plain may expressed as

$$T_a = 1/2\ \rho c_{fa} \Delta V^2 = 1/8\ \rho fa \Delta V^2 \qquad (1)$$

Where ρ is the fluid density

ΔV is the difference of mean velocity in the two subsections

fa is an apparent friction factor analogous to the familiar Darcy-Weisbach friction factor ($fa = 4c_{fa}$)

Assuming uniform flow and considering the balance of forces along the flow direction in the main channel leads to :

$$T_a . 2y + T_m P_m = \rho g S_o A_m \qquad (2)$$

Where S_o is the bottom slope

A_m , P_m are the area and wetted perimeter (excluding the interface) of the main channel, respectively

T_m is the average shear stress on the main channel boundary

If T_a can be estimated, Eq. (2) may used to evaluate the main channel discharge for a given flow depth, whereas the flood plain discharge could also be obtained by a similar procedure (Radojkovic and Djordjevic, 1985; and Wormleaton and Merrett, 1990).

The apparent friction factor fa should in principle depend on the geometry of the cross section and on some Reynolds number(s) as well as on the boundary roughness(es). For a smooth typical section, dimensional considerations lead to an expression of the form

$$f_a = \varphi \text{ (} B/b, y/h, b/h, Sm, Sf, Re_m, Re_f \text{)} \qquad (3)$$

Where Re_m and Re_f are the main channel and flood plain Reynolds numbers, respectively as :

$$Re_m = 4\, R_m V_m\ \rho/\mu \qquad Re_f = 4\, R_f V_m\ \rho/\mu$$

Where R_m and R_f are the respective hydraulic radii.

To explore the dependence of f_a on the parameters shown in Eq. (3) the experimental results from series 1,2,3,7,8,10 conducted at the facility were analysed (HR.Wallingford, 1992). The boundaries were smooth in all cases expect for the flood plains in series 7. In addition, and in order to detect in particular the Reynolds number dependence, data of small-scale experiments presented by Knight and Demetriou (1983) were also considered. The analysis was based on the reported value of T_a on the vertical interface, calculated from the measured data; the velocity difference between subsection was obtained not from the measured value but from the velocities estimated by the Manning formula for each subsection, assuming n=0.010 for the smooth boundary (in accordance with the single channel value reported by Myers and Brennan, 1990) and n=0.020 for the rough boundary. This approach was preferred to allow the evaluation of f_a in a predictive sense, i.e. without the need for measuring the velocities of the subsections.

Fig 3 shows the dependence of f_a on the relative depth for various width ratios and section geometries. It is seen that f_a remains nearly constant for $0.3 < y/h < 1.0$, its value depending clearly on B/b, as noted earlier by Christodoulou (1992). Remarkably, the results of series 2 and 7 essentially coincide despite the different roughness, implying that the effect of roughness can be successfully incorporated in the value of the mean velocities estimated by

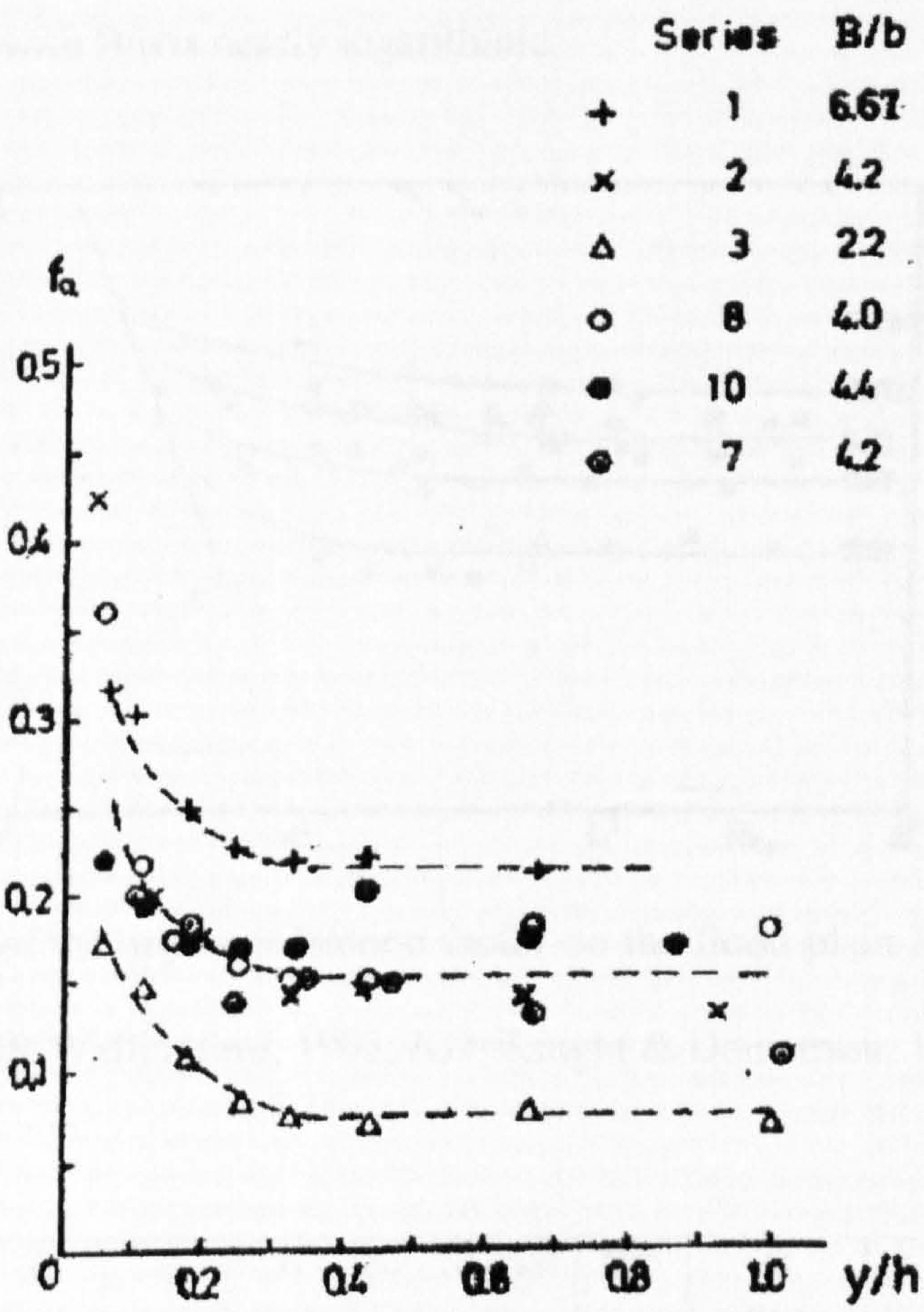

Fig 3 : Variation of apparent friction factor with relative depth and width ratio in the Flood Channel Facility experiments.

proper selection of Manning's n. It is also seen that for small y/h the apparent friction factor increases appreciably in all cases suggesting a Reynolds number influence for low overbank flows. After several trials it was found that f_a can be best correlated to the flood plain Reynolds number Re_f, as shown in Fig 4. This figure includes data from both large scale (HR Wallingford, 1992) and small scale (Knight and Demetriou, 1983) experiments. Despite the inevitable experimental scatter, it is clear that f_a tends to a constant value depending on B/b for large Re_f and increases for lower towards a limiting line on the (Re_f, f_a) plane independent of B/b is seen to play the role of the relative roughness K_s/d of pipe flow; even the variation of the ultimate value of f_a (for large Re_f) with B/b is nearly logarithmic.

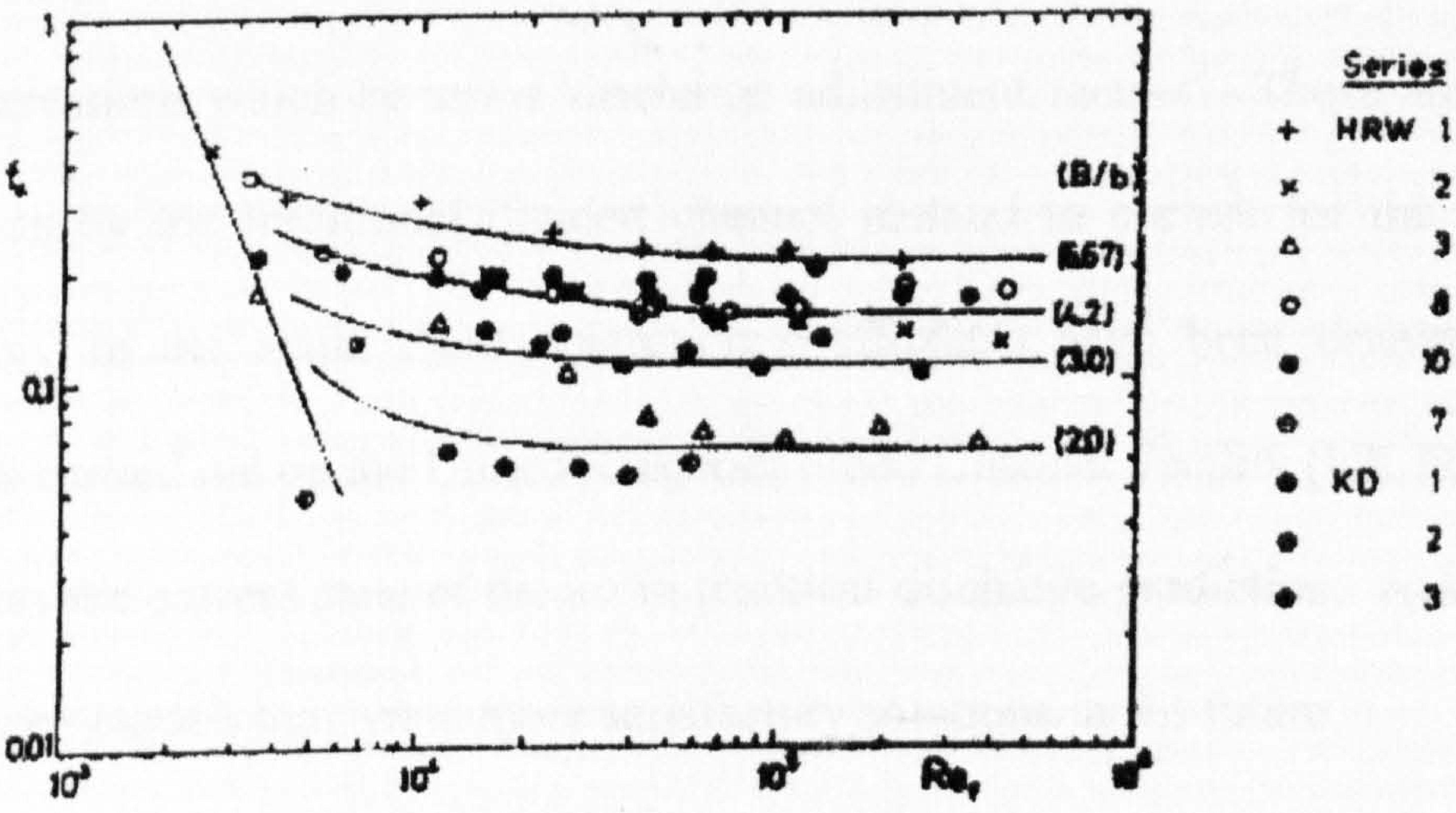

Fig 4 : Dependence of the apparent friction factor on the flood plain Reynolds number and the width ratio (HRW=HR Wallingford, 1992; KD=Knight & Demetriou, 1983; see Table 1)

Reference	B (m)	b (m)	h (m)	S_m	S_f	b/h	B/b	Q (l/s)	y/h	Re (10^4)	$Re_f(10^4)$
Hr Wallingford (1992)											
Series 1	10	1.50	0.15	1	0	10	6.67	208-1014	0.060-0.67	6.8-32.6	0.41-22
Series 2	6.3	1.50	0.15	1	1	10	4.2	212-1114	0.043-0.92	11.8-63.4	0.26-42
Series 3	3.3	1.50	0.15	1	1	10	2.2	225-835	0.053-1.0	22.9-75.6	0.34-36.6
Series 7	6.3	1.50	0.15	1	1	10	4.2	216-543	0.04-1.01	12.7-31.5	0.12-25
Series 8	6.0	1.50	0.15	0	1	10	4.0	185-1103	0.053-1.0	9.5-57.4	0.32-43
Series 10	6.6	1.50	0.15	2	1	10	4.4	237-1092	0.053-0.86	12-54.7	0.35-33.8
Knight & Demetriou (1983)											
Series 1	0.608	0.152	0.076	0	0	2	4	4.9-29.4	0.12-1.02	2.5-12.7	0.53-10.7
Series 2	0.456	0.152	0.076	0	0	2	3	5.0-23.4	0.15-0.96	3.1-12.3	0.68-9.0
Series 3	0.304	0.152	0.076	0	0	2	2	5.2-17.1	0.12-0.97	4.3-11.2	0.49-5.7

Table 1 : Main geometrical and flow characteristics of experiments analyzed.