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Influence of the Entropic Parameter on the Flow Geometry and Morphology

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***Abstract*—**The necessity of updating the numerical models inputs, because of geometrical and resistive variations in rivers subject to solid transport phenomena, requires detailed control and monitoring activities. The human employment and financial resources of these activities moves the research towards the development of expeditive methodologies, able to evaluate the outflows through the measurement of more easily acquirable sizes. Recent studies highlighted the dependence of the entropic parameter on the kinematical and geometrical flow conditions. They showed a meaningful variability according to the section shape, dimension and slope. Such dependences, even if not yet well defined, could reduce the difficulties during the field activities, and also the data elaboration time. On the basis of such evidences, the relationships between the entropic parameter and the geometrical and resistive sizes, obtained through a large and detailed laboratory experience on steady free surface flows in conditions of macro and intermediate homogeneous roughness, are analyzed and discussed.

***Keywords*—**Froude number, entropic parameter, roughness, water discharge.

I. INTRODUCTION

THE increasing need to operate on the rivers with an appropriate plan of defense and protection, besides the need of correct procedures for the flood risk forecast, requires a suitable knowledge of the flow regime in extreme conditions. Currently, the use of numeric modeling, consistently increased in the last few years both at a forecasting and controlling stage, represents one of the most valuable tools in the planning and designing activity. This tool has, though, the need of up-to-date and reliable data and information, which require field activities, both on site and in remote, not always possible due to the relative time and costs involved.

For this reason, the aim of the present paper is to develop tools which could enable the evaluation of outflows in an expeditive way and with less expensive and time-consuming measurement campaigns.

Recent studies on regular flows have shown the possibility to attain a model formulation, derived from the application of maximization theories of the informational entropy ([1]-[8]), able to reconstruct the flow field and assess the water discharge in an expeditive way.

Such model presents a very simple analytical structure based on the evaluation of a single parameter, which globally takes into account the influence of the cross section geometry and roughness, to be calculated by the ratio between the mean and maximum flow velocities in the considered section.

The extension of such law to natural flows ([8]-[13]) seems to drive a sufficient reliability even in conditions of geometric irregularity.

Some river observations produce a possible linear dependence between the mean and maximum cross section velocities, with a reduced variability of the ratio between the two velocities, generally depending on local morphology.

In particular, the studies produced by [9] on the Mississippi river, in several cross sections located both in rectilinear and curvilinear riverbed stretches, have underlined a perfect linear dependence between the maximum and the mean velocity, showing a value of the parameter constant and increasing as the ratio bend radius/section width increases.

The studies of the other Authors underline, instead, a large variability of the entropic parameter for the natural flows, depending on the different morphology of the investigated sections.

In the last years, the studies on different cross sections of Italian rivers (Central and Southern Italy) and Algerian ones ([14], [15]) have shown the dependence between the entropic parameter, M, and the morphologic characterization of the river stretches, even if qualitative, based on the Rosgen classification [16]. In particular, they showed how the river stretches belonging to the same river shape present the same value of parameter M, while differentiating among the reaches with different morphologic characteristics. Therefore, the research of a dependence between the entropic parameter and the geometric and roughness quantities, which characterize the fluvial morphology, could be a useful support to control and monitoring the surface water resources, especially with respect to the surveying activities.

However, it is important to point out that the analytical relation between the entropic parameter and the "sizes", which define the local morphology of stretch, like for example the shape of the section, the roughness, the plani-altimetrical configuration, the slope of the bed, has not yet been well defined.

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Therefore, in the present paper we analyze the dependences between the entropic parameter and the geometry and roughness of the section through measurements in laboratory on a steady free surface flow in conditions of macro and intermediate homogeneous roughness.

II. Experimental Details

The experimental tests have been carried out in the Hydraulics Laboratory of Basilicata University, on a tilting channel 9m long and characterized by a rectangular cross section of 0.5m in width (Fig. 1).

The main structure of the channel is totally in steel; while the lateral walls are in transparent glass and the floor of the channel is in Plexiglas. A mechanism of slope variation positioned under channel allows to obtain different values of slope, from 0 up to 2%.

The flow inside the channel is derived by a close circuit supply which comprises a pumping plant, an accumulating and supplying tank, an adducing system constituted by conduits and recycling and an outflow system. An inlet valve regulates the in-flow rate which is measured by a diaphragm, which has an estimated uncertainty below 1%.

Fig. 1 View of the free surface open channel

Measurements have been referred to a control volume composed by roughness elements which simulate a natural roughness arrangement. These elements are disposed on three plywood plates for a total length of 3m (1m each plate), having 0.01m of thickness and 0.5m of width, and positioned in the middle part of the channel in order to reduce the disturbances of the flow induced by the inlet and outlet conditions of the tanks. To obtain a homogeneous roughness condition, the used elements were all wood spheres of 3.5cm in diameter (*d*), positioned according to a regularly spaced stripe pattern (Fig. 2). The spacing between two following transverse rows was equal to 6cm; while the distance between the 5 spheres stripes in the longitudinal direction was of 10cm. The roughness concentration on the channel floor was calculated according to Schlichting's definition [17] as the ratio of the sum of upstream projected areas (*a*) of the roughness elements to the floor area (*A*) on which these are positioned:

$$\lambda = \frac{a}{A} n = 0.15 \tag{1}$$

where n is the number of elements on the floor area A. The choice of such configuration is not casual, but according to [18] for regular pattern of macro-roughness disposition, the maximum flow resistance is achieved when macro-roughness spatial density is between 0.15-0.20. As pointed out by [19] for flow in closed conduits, the presence of a maximum in flow resistance can be explained in terms of different behaviour of flow motion relating to the spacing (or to spatial density) of macro-roughness stripes. For high spacing values, when macro-roughness stripes are "isolated", motion might be regarded as a "non wake interfering", while for low spacing values, the vortex generation and dissipation associated with a stripe is not complete before the flow meets the next stripe.

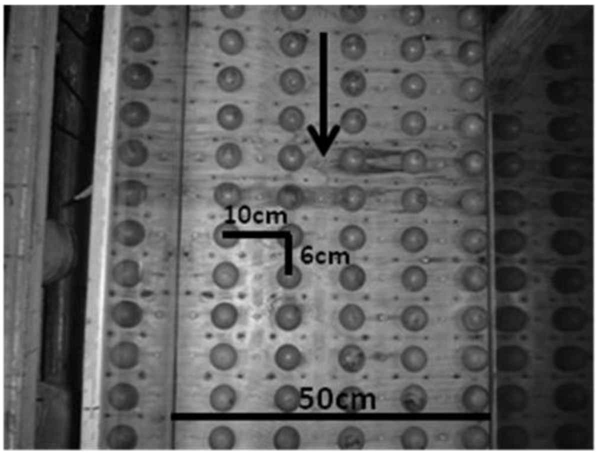

Fig. 2 High view of the spheres set-up inside the channel

The experiments have been carried out in a steady free surface flow with different discharges ranging from 7 to 76l/s and for slopes in between 0.1% - 1% in order to simulate the behaviour of rivers located in the middle valley and near the delta. The evaluation of water discharge has been performed according to the velocity-area method [20], which requires to divide the cross section areas into several verticals and a further subdivision of each vertical into discrete points, in order to evaluate the mean velocity of the flow along each vertical. The number of measurement points on each vertical has been chosen in order to have a good reconstruction of the flow field. In fact in the followed approach, the difference in velocity between two consecutive points must be less than 20% compared to the higher measured value and that the points found close to the floor of the channel and to the water surface must be fixed according to the sizes of the used instrument. In this case the instrument has been the micro-current meter having a characteristic dimension of 1cm.

Depending on the velocity measure points, the mean velocity has been calculated. Once evaluated the mean velocity for each vertical, the water discharge was calculated by the way of the mean-section method. In this method, the partial discharge is computed by multiplying the average value of mean velocities of two adjacent verticals for the area included in the respective verticals. This is repeated for each segment and the total discharge is obtained by adding the partial discharge of each segment. The range of considered relative submergences, y/d, (in which y represent the maximum water current height) was between 1.9 and 6.4, which represent conditions of macro and intermediate roughness.

In Table I are reported the details of the effected experimental measures; while in the Fig. 3 is represented a scheme on the choice of measurement points for the verticals considered in the cross section.

TABLE I
RANGE OF CONSIDERED CHARACTERISTIC PARAMETERS

i (%)	*Q (l/s)*	*y/d*	u_{mean} *(m/s)*	u_{max} *(m/s)*
0.1 - 1	7 - 76	1.9 - 6.4	0.20 - 0.80	0.34 - 1.08

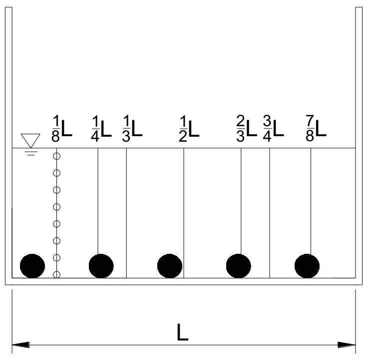

Fig. 3 Scheme of measurement points for the verticals considered in the section

III. DATA ANALYSIS

The aim of the paper leads in the proposition of a expeditive method for water discharge assessment based on the entropy theory firstly derived by Chiu [1]. Thus, the experimental measures, previously described, have been used in order to try a simplification of the water discharge evaluation, by the way of parameter M. In fact, considering the formulation based on the entropy concept, the cross section mean velocity, u_{mean}, can be expressed as function of the maximum velocity, u_{max}:

$$\frac{u_{mean}}{u_{max}} = \frac{e^M}{e^M - 1} - \frac{1}{M} \tag{2}$$

where M is the well known dimensionless entropy parameter.

For each value of the water discharge the maximum velocity and its precise localization inside the current, have been estimated. However, it is necessary to point out that u_{max} is unknown, but it can be considered as the maximum value in the data set of velocity points sampled during the measurements.

Knowing the water discharge, Q, and the cross section, Ω, it has been possible to verify the cross section mean flow, $u_{mean}=Q/\Omega$, and thus calculate the entropic parameter, M.

The evaluation of different entropic parameters is useful to study the dependence of this parameter on the geometric and morphological characteristics of the flow. In particular, in this paper the relationship between M and the relative submergence and the Froude number has been analyzed.

In fact, Fig. 4 reports M versus the relative submergence, y/d, in which y is the maximum water current depth for the different considered slopes.

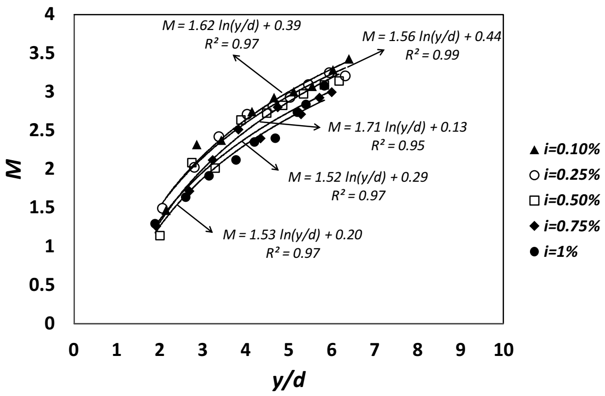

Fig. 4 M in function of the relative submergence y/d, at fixed slopes i

The formula which best interpolates the observed data is the logarithmic one:

$$M = A_{y/d} \ln(y/d) + B_{y/d} \tag{3}$$

where the values of the coefficients $A_{y/d}$ and $B_{y/d}$ and of the correlation coefficient for each slope are reported in Table II. As it is possible to observe, for all investigated slopes a strong correlation exists between M and the relative submergence with the R^2 greater than 0.95 generally.

Besides, from the Fig. 4, it is possible to note how the curves are translated slightly toward the top as the slope decreases, and even due to increasing ratio u_{mean}/u_{max} as slope decreases. The small amplitude of the $A_{y/d}$ and $B_{y/d}$ range underlines how the differences between the curves are not so significant, because of the small changes of slope that we analyzed.

Therefore a single logarithmic curve, reported in Fig. 5, can be considered representative of all data and this is also stated by the high correlation value (R^2=0.93), and by the values of $A_{y/d}$ and $B_{y/d}$ coefficients ($A_{y/d}$ =1.62 and $B_{y/d}$ =0.25) which range in between of observed values in Table II.

TABLE II
COEFFICIENTS OF THE CURVES OF M IN FIG. 4

i (%)	$A_{y/d}$	$B_{y/d}$	R^2
0.10	1.62	0.39	0.97
0.25	1.56	0.44	0.99
0.50	1.71	0.13	0.95
0.75	1.52	0.29	0.97
1.00	1.53	0.20	0.97

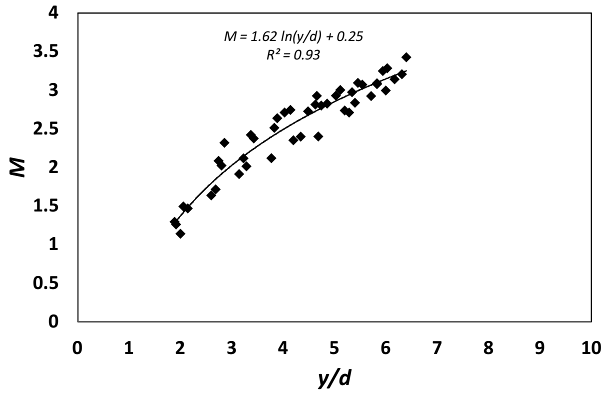

Fig. 5 M in function of the relative submergence y/d, for all data

A further contribution to the results has been obtained by the error analysis[1] between the measured entropic parameters (M_m) and those calculated (M_c) by the logarithmic equation of Fig. 5. In both the cases, the error was very low, less than 20%, and in most of experiences it was around 10%. Obviously, on the basis of the previous results, a less accuracy has been observed for the equation of Fig. 5.

Therefore, in Fig. 6 it is just reported the error analysis for the parameter M in the case of Fig. 5, as function of the measured discharge ratio Q_m^*. In order to compare better the results, the data have been formulated in terms of dimensionless quantities, and, in fact, the measured and computed water discharges ratio, Q_m^* and Q_c^* respectively, have been obtained by the ratio between the observed / calculated values and the estimated maximum ones, Q_{max}. As it is possible to note in Fig 6, for all measured discharge ratios, Q_m^*, the error remains very low, with only some values upper to 10%.

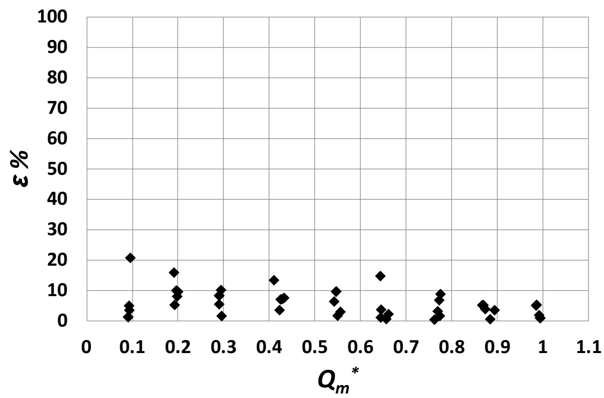

Fig. 6 Error of M in function of the measured discharge ratio Q_m^*, for all data

Another important analyzed dependence is relative to the relationship between the parameter M and the Froude number, Fr, here calculated with the following equation:

$$Fr = \frac{u_{mean}}{\sqrt{gy}} \tag{4}$$

where g is the gravity acceleration. As for the previous parametric relation, different logarithmic curves have been evaluated for each considered slope which represent very well the data (Fig. 7), and underline better the fundamental influence of the ratio u_{mean}/u_{max} in changing of the entropic parameter, M.

$$M = A_{Fr} \ln(Fr) + B_{Fr} \tag{5}$$

In fact, as already observed in Fig. 4, the curves are translated to the top as slope decreases, due to the increasing ratio u_{mean}/u_{max}. In the Table III the coefficients A_{Fr} and B_{Fr} have been reported; while in Fig. 8 the function representing all data has been evaluated. In this case the correlation coefficient of the logarithmic curve is less than the previous (R^2=0.66). In fact, the error was very low, less than 20% in all measures considering the curves at different slope, instead, in the case related to curve of Fig. 8, the estimated error was up to 40%.

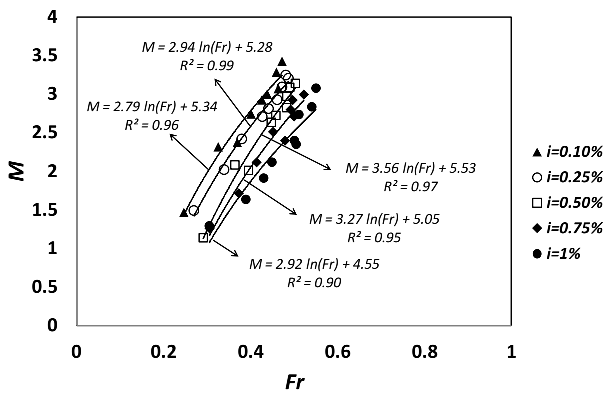

Fig. 7 M in function of the Froude number Fr, at fixed slopes i

TABLE III
COEFFICIENTS OF THE CURVES OF M IN FIG. 7

i (%)	A_{Fr}	B_{Fr}	R^2
0.10	2.79	5.34	0.96
0.25	2.94	5.28	0.99
0.50	3.56	5.53	0.97
0.75	3.27	5.05	0.95
1.00	2.92	4.55	0.90

[1] The error has been evaluated as $\varepsilon\% = (M_m - M_c)/M_m \cdot 100$.

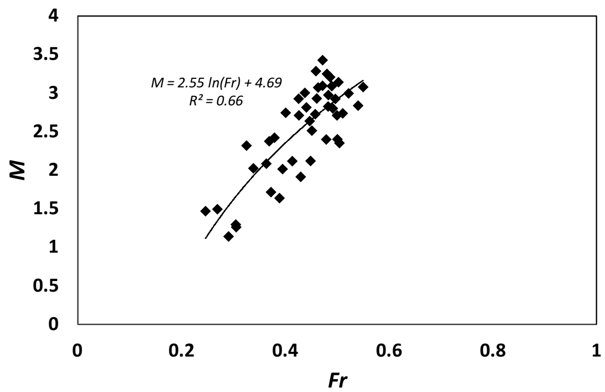

Fig. 8 M in function of the Froude number Fr, for all data

On the basis of the results obtained by the previous relationships, it has been proposed the comparison between the measured discharges ratio Q_m^* and those calculated Q_c^* considering u_{mean} estimated by the entropic parameter M derived by the logarithmic formulas of Fig. 5 and 8. In detail, a perfect correspondence between the measured and calculated discharges is evident in both Fig. 9 and 10. This good correspondence is confirmed also by the estimated error analysis, which is widely under the 10% for all the cases.

In particular, an interesting result is shown in Fig. 11 about the error analysis of the discharge[2] estimated using the parameter M deriving by the relation in Fig. 8. In fact, it is possible to note a good data agreement, with a maximum error of about 7% , notwithstanding the greater dispersion of M in function of Fr observed in Fig. 8. This indicates that the Froude number represents a indicative parameter for the water discharge evaluation.

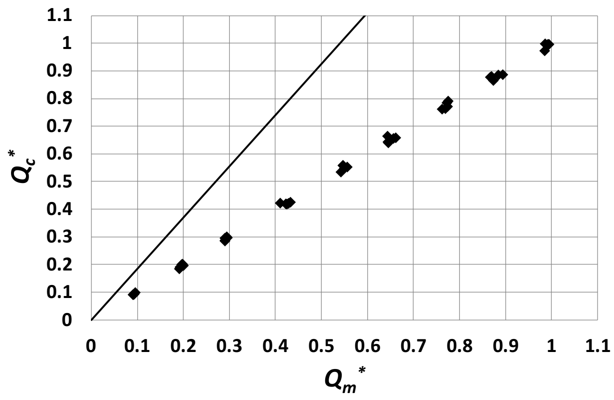

Fig. 9 Comparison between Q_m^* and Q_c^* calculated using M derived by y/d, for all data

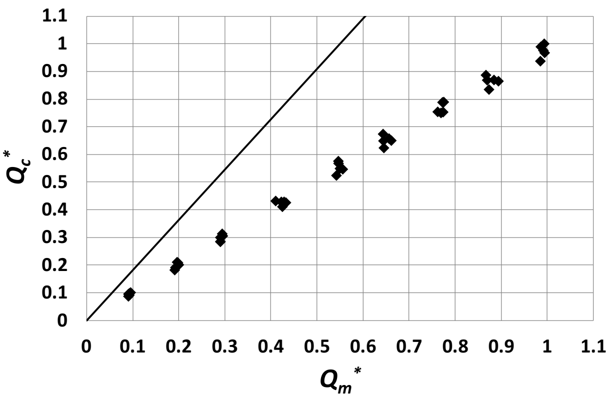

Fig. 10 Comparison between Q_m^* and Q_c^* calculated using M derived by Fr, for all data

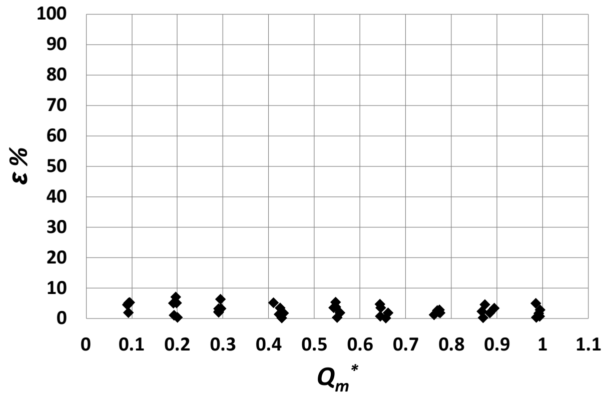

Fig. 11 Error between Q_m and Q_c calculated using M derived by Fr, in function of Q_m^*, for all data

IV. Conclusion

A detailed laboratory activity has been realized in order to research an expeditive methodology able to evaluate the water discharges through the measurement of more easily acquirable parameters. Experiments have been carried out in a steady free surface flow in conditions of macro and intermediate homogeneous roughness, with different values of discharges and for slopes less than 1%, in order to simulate the behaviour of rivers located in middle valley and near the delta.

The obtained results show a good correlation, represented by logarithmic formulas, between the entropic parameter and the relative submergence on one hand, and the Froude number on the other, both sizes characterizing the geometry and morphology of the flow.

Besides, on the basis of these relationships the comparison between the measured discharges and those calculated through the entropic parameter has been performed. Such analysis has underlined a strong correspondence between the two water discharges with maximum error less than 10%.

Finally, because of the positive results obtained, it would be advisable to extend the measurements activities to higher slopes in future.

[2] The error has been evaluated as $\varepsilon\% = (Q_m - Q_c)/Q_m \cdot 100$.

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