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PHYSICAL SIMULATION OF FLOW IN PERIODIC PATTERN CHANNELS

SIMULATION PHYSIQUE DE L'ECOULEMENT DANS LES CANAUX A MOTIF PERIODIQUE

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ABSTACT

Numerous studies have been and are still being carried out on flows in periodic pattern channels. However, if these continue to multiply, it is because the phenomena involved are very complex and there are still a large number of poorly described points. The main objective of this work is to simulate physically the flow in periodic pattern channels. Given the complexity of these flows, scale models remain a privileged tool. We have carried out a series of experiments on several models of low and high slope macro-roughness channels. Our observations and experimental results have enabled us to propose empirical formulae for studying the flows in these channels.

Keywords: Periodic pattern channel, Empirical, Macro-roughness, Model, Slope.

RESUME

De nombreuses études ont porté et portent encore sur les écoulements dans les canaux à motif périodique. Or si celles-ci continuent à se multiplier c'est que les phénomènes intervenant sont très complexes et qu'il reste un grand nombre de points mal décrits. L'objectif principal qu'on s'est assigné dans ce travail est de simuler physiquement l'écoulement dans les canaux à motif périodique. Devant la complexité de ces écoulements, les modèles réduits restent un outil privilégié. Nous avons fait des séries d'expérimentations sur plusieurs maquettes de canaux à macro-rugosité à faible et à forte pentes. Nos observations et nos résultats expérimentaux nous ont permis de proposer des formules empiriques permettant d'étudier les écoulements dans ces canaux.

Mots clés : Canal à motif périodique, Empirique, Macro-rugosité, Maquette, Pente

INTRODUCTION

Unlike conventional stormwater drainage systems with smooth profiles, stepped channels consist of a steps series' arranged along the channel. They are designed to carry large flows of water over structures while helping to dissipate a considerable amount of flow energy. The stepped channels concept origin can be traced back in history distant eras. Throughout this history, different civilizations have contributed to the development of the building dam's art and stepped spillways (Chanson, 1994).

The flow on the stepped spillway is not easy because of the different flow regimes, but in a very important way because of the strong aeration of the flow, the very strong turbulence and the interaction between entrained air and turbulence.

To show the interest of studying these flows, we have carried out a series of experiments on several models of stepped canals. We present only the results on two models. Our observations and experimental results have enabled us to propose empirical formulae for the design and dimensioning (side walls) of stepped canals with low and high slopes.

EXPERIMENTAL INSTALLATION

The experimental installation is shown in Figure 1 below. It was carried out at the Hydraulics Laboratory of the National Polytechnic School of Algiers. The steps dimensions are given in the relevant sections for each case studied.

Figure 1: Experimental installation

EXPERIMENTAL STUDY OF LOW-SLOPE CHANNEL FLOWS WITH PERIODIC PATTERNS

The study of the flow in a stepped channel set in a horizontal or low-slope position corresponds to the study of the flow over triangular elements fixed on the channel bottom. In 1970, Raju and Garde classified this type of flow into three categories: *"isolated roughness"* flow, *"wake interference"* flow, and *"quasi-smooth"* flow.

In order to visualize the existing hydrodynamic phenomena in flows crossing channels with complex geometry and low slope, experiments were carried out on a variable slope glazed channel, made up of thirteen periodic patterns: 8 cm x 8 cm x 25 cm.

Average height variation

During the tests, two main measurements were carried out consisting of flow rates and water heights measurement. Three slopes were considered: tg α = 4.25%, tg α = 3%, and tg α = 1.6%.

During the tests, for low flow rates the water line took the channel shape: it is a quasi-smooth flow. But as we increased the flow discharge the water line tended to flatten.

In order to propose a discharge relationship governing the water movement over triangular elements fixed on the channel bottom, we attempted anamorphoses based on the classical representation of hydraulic phenomena in open channels.

Our underlying idea is that if we have an anamorphoses that gives a linear representation without too much dispersion, the errors probability decreases and therefore there is like a measurements confirmation by each other. Different anamorphoses were tried in particular: $y = f(Q^{1/2})$ and $y = f(Q^{1/3})$,which finally led us to plot $h_*^{5/3}$ as a function of the flow discharge and this for each slope.

Figures 2, 3, and 4 show the variation of $h*^{5/3}$ as a function of the flow discharge for each slope. Figure 5 shows the variation of $h*^{5/3}$ as a function of $(tg\ \alpha)^{1/2}$.

The flow law we propose for quasi-smooth flows over triangular elements fixed on the channel bottom is:

$$Q = 1{,}84\ h_*^{\frac{5}{3}} \sqrt{2g}\ \sqrt{tg\alpha} \qquad (1)$$

where $h*$ corresponds to the average depth in meters.

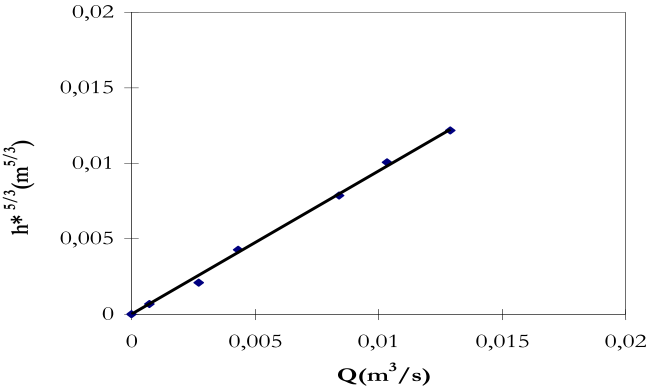

Figure 2: Variation of h*$^{5/3}$ as a function of flow discharge for tg α = 1,6%

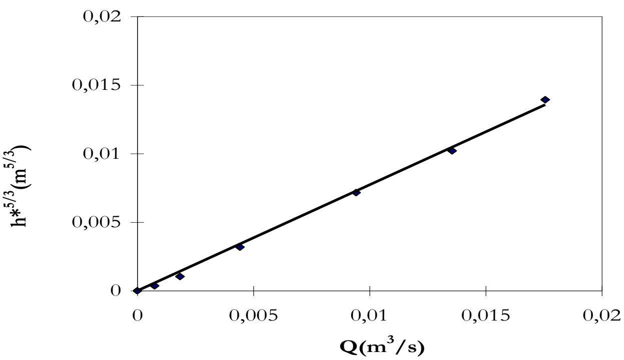

Figure 3: Variation of h*$^{5/3}$ as a function of flow discharge for tg α = 3%

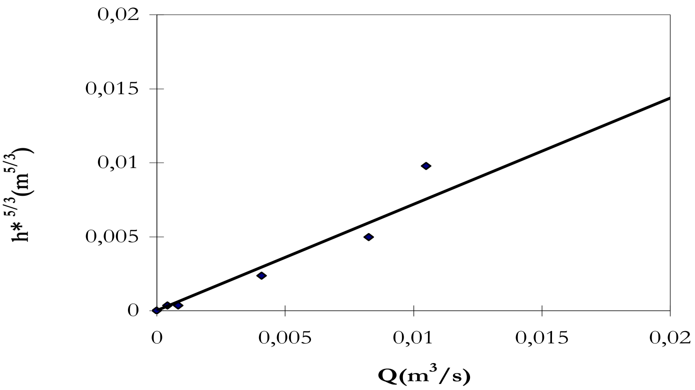

Figure 4: Variation of h*$^{5/3}$ as a function of flow discharge for tg α = 4,25%

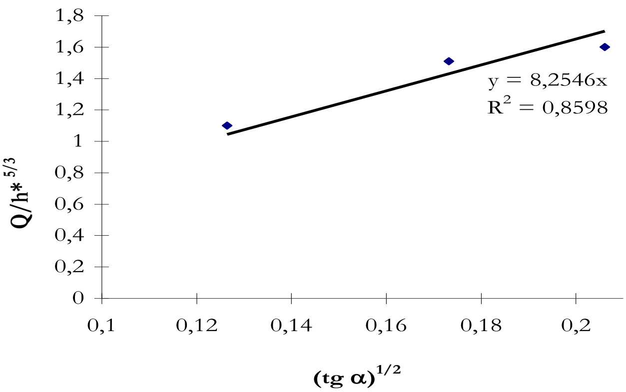

Figure 5: Variation of h*$^{5/3}$ as a function of flow discharge for (tg α)$^{1/2}$

Hydraulic slope variation

Figures 6, 7 and 8 show the variation of the Q^2/J ratio as a function of the flow depth over the various obstacles and for each slope. A certain dispersion of the points, especially for the channel last step, is observed.

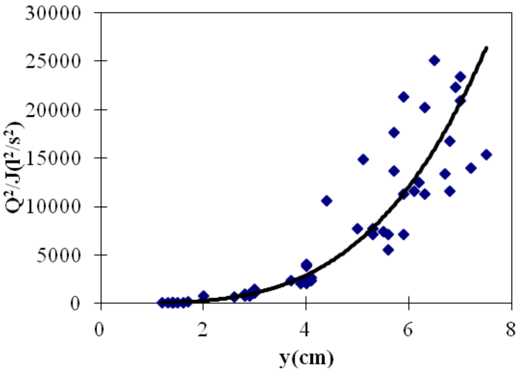

Figure 6: Variation of Q^2/J ratio as a function of water height for tg α =1,6%

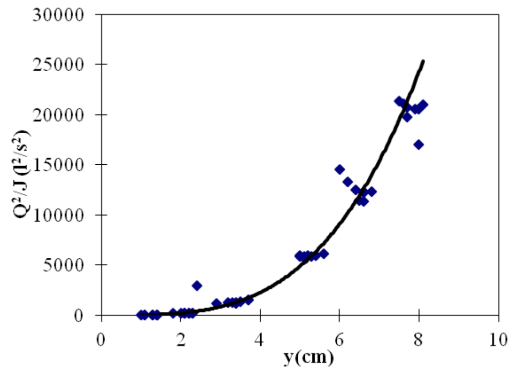

Figure 7: Variation of Q^2/J ratio as a function of water height for tg α = 3%

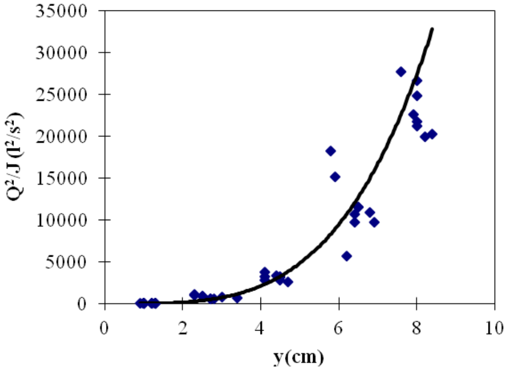

Figure 8: Variation of Q^2/J ratio as a function of water height for tg α = 4,25%

Following the obtained experimental results, the pressure loss law we propose is:

$$Q = 0{,}55\, y^{7/4} \sqrt{2g}\, (sin\, \alpha)^{0{,}6} \sqrt{J} \qquad (2)$$

where J is the slope of the water line and y represents the spatial variable.

EXPERIMENTAL STUDY OF FLOWS IN STEEPLY SLOPING PERIODICAL PATTERN CANALS

The flows on a stepped channel have been the subject of much work that has led to their classifications, particularly according to the flow regime. Thus, three types of flow have been identified: the nappe flow regime, the transitional regime and the turbulent *"skimming flow"* regime (Benmamar, 2006; Kisi *et al.*, 2008).

The nappe flow is characterized by a succession of water nappes falling on each step. Depending on the flow discharge the water nappe strikes, partially or totally, the step horizontal part (Figure 9). The jet impact causes energy dissipation and can also cause a hydraulic jump.

In contrast to the nappe flow where the nappe shape approximately follows the steps profile, in a turbulent regime the water flows in a strong, coherent and turbulent current over the steps; the overflowing water nappe is no longer visible and the steps are completely submerged.

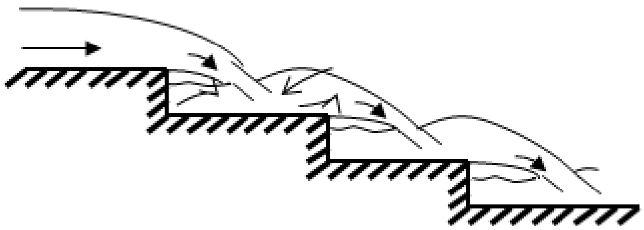

Figure 9: Nappe flow regime

According to Stephenson (1991) and Chanson (2001), Esserey and Horner (1978) studies indicated that in the case of extremely turbulent flow the water flows over the steps face as a regular stream and the steps represent an internal friction form causing the slow down flow. The extreme edges of the steps thus form a pseudo-base under which recirculating rollers develop occupying the hollow space between the steps and the current (Figure 10). These recirculation rollers are maintained by the transmission of fluid shear stresses.

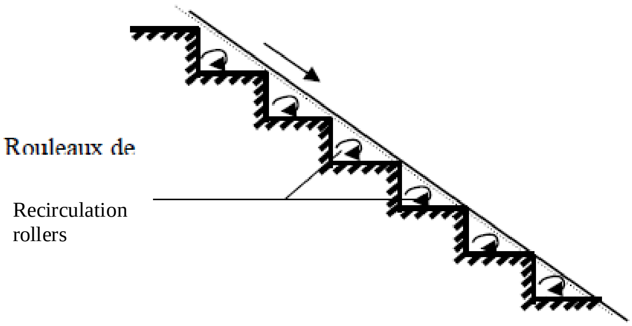

Figure 10: Extremely turbulent flow regime

There is a range of flow discharge between nappe flow and turbulent flow regimes for which a third flow type called transitional flow is observed (Kisi *et al.*, 2008). This flow regime is difficult to observe experimentally due to temporal hydrodynamic fluctuations that can induce undesirable vibrations in the experimental device structure (Chanson, 1996).

In order to determine the beginning of each flow type, a second experiments series was conducted on a second model consisting of a channel comprising fifteen (15) steps with constant dimensions: 6.0 cm x 4.0 cm x 4.0 cm.

The tests allowed us to make the following observations:

1. In the case of low flows, the nappe thickness is much reduced, the flow adheres to the steps thus characterising nappe flows with the formation of small fully developed hydraulic jumps. As we increase the flow discharge a formation of partially developed hydraulic jumps is noticed.
2. In the case of large flows and steep slopes, very turbulent flows are generated, characterized by air entrainment (Boes and Hager, 2003). The water would turn white and rollers could be seen trapped in the steps hollows.

The occurrence of different flow regimes depends mainly on the shape ratio of steps and water flow rate. Figure 11 shows the variation in the ratio of the critical height d_c to the step height h as a function of the channel slope.

This figure shows the different flow regimes limits in the stepped channels. The highly turbulent flow regime appears at a flow rate above the critical value deduced as follows:

$$\frac{d_c}{h} = -0{,}5\,\frac{h}{l} + 1{,}1 \quad (3)$$

Nappe flows with a fully developed hydraulic jump occur at flow rates lower than the critical value defined by:

$$\frac{d_c}{h} = 0{,}12\left(\frac{h}{l}\right)^{-1{,}12} \qquad (4)$$

where, h and l are respectively the step height and width.

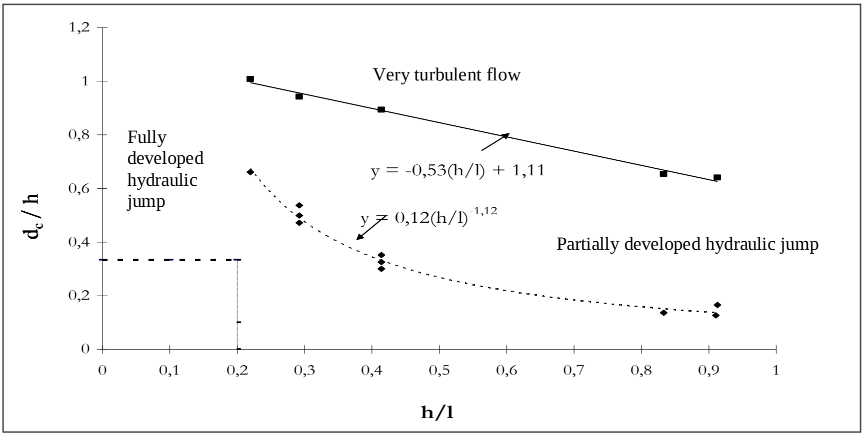

Figure 11: Limits of different flow regimes in stepped channels

CONCLUSIONS

Faced with the water flow complexity on steps, scale models remain a privileged tool. We have therefore carried out an experiment on scale models in order to observe the water flow in periodic patterns canals.

Our observations and experimental results have allowed us to propose empirical laws for designing and dimensioning of low and high slope macro-roughness channels.

The work carried out has shown that this subject offers many experimental perspectives. It would be interesting to measure the flow velocity along the stepped channel using a lateral ADV probe and to determine the forces exerted by the water on the steps by means of a pressure sensor.

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