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Uniform Water Flows within Rectangular Open Channels of Composite Roughness

*Demetriou J. **Retsinis E.

*, ** Civil Engineers, National Technical University of Athens, Greece

ABSTRACT

In this experimental study the Manning's n roughness coefficient is investigated in uniform-turbulent-steady water flows, within sloped (J_o) rectangular open channels of composite roughness. The channel's bed always remains smooth, but both walls' roughness is varying, through adhesive rubber vertical strips (κxκ, where, κ=4mm) at various distances, λ. Thus, a number of ratios λ=12.5-25-50-100 and ∞ (entirely smooth channel, κ=0) are examined in an effort to fully understand the flow's hydraulic behavior in such open channels of composite roughness. A large number of experimental measurements were performed in the hydraulics laboratory and the results appear to be systematic. The present study is aiming at helping the hydraulic engineer in his practical water flow problems.

Keywords: Open Channels. Composite Roughness

1. INTRODUCTION

In this experimental study the water uniform-turbulent-steady flow within a rectangular open channel (water depth z_n and width b) is investigated, analyzed and discussed. The channel bed is smooth while both vertical walls are rough, i.e. covered by symmetrical vertical rubber strips of square cross section (κ=4 mm) and at various distances λ, Fig. 1. λ distances were 5-10-20-40 cm, and thus the ratios λ/κ were 12.5-25-50-100, while for κ=0, λ/κ=∞ (smooth channel-bed/walls). The longitudinal channel's slope was J_o=0.0012 (=constant), the discharges were Q, the cross-sectional velocities are, $V=Q/(z_n \cdot b)$, and the Reynolds numbers are $Re=V \cdot 4 \cdot R/v$, where $R=(z_n \cdot b)/(b+2 \cdot z_n)$=hydraulic radius and v=water kinematic viscosity. The well known empirical Manning's formula

$$Q=(1/n)\cdot(z_n \cdot b)\cdot R^{2/3}\cdot,$$

was used, and the roughness coefficient (n for rough channel and n_s for smooth channel) was investigated where z_n, b, R, Q, in the metric system and n in ($s \cdot m^{-1/3}$).

The other most important parameters are: the Reynolds number, $Re=V \cdot 4 \cdot R/v$, where v=water's kinematic viscosity and the Froude number, $Fr=V \cdot (g \cdot z_n)^{-1/2}$, where $n \sim Re^{2/3}$ or n~Fr. Although Re is mainly used in closed systems (pipes, etc) and Fr in open channels, the Reynolds numbers are used here, simply because they show the turbulence level. Both Re and Fr are interconnected and when Re is used, then Fr is also known.

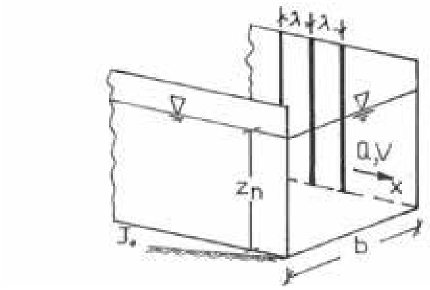

Figure 1. Flow geometry.

In general the Manning's formula does not deal with channels of severe differences in roughness (walls-bed), but since this method is the only in use, the present study has to be compared with it.

Table 1 presents the summary of all laboratory measurements (clear b=24 cm).

Table 1. Laboratory measurements.

Series	z_n (cm)	Q (l/sec)	V (cm/sec)	Re	λ/κ	n
1	4.97 to 25.28	4.71 to 41.83	39.48 to 49.40	49,674 to 158,428	12.5	0.00941 to 0.01632
2	4.70 to 35.53	3.84 to 41.83	34.07 to 49.05	41,206 to 108,590	25	0.01062 to 0.01604
3	3.13 to 35.45	3.84 to 39.56	34.07 to 49.05	45,472 to 149,313	50	0.00577 to 0.01589
4	4.92 to 34.30	5.43 to 45.79	46.05 to 55.62	57,528 to 177,110	100	0.00803 to 0.01524
5	4.62 to 36.25	3.84 to 52.08	34.68 to 59.87	41,413 to 125,685	∞	0.01035 to 0.01411
Number of measurements						
-	80	80	80	80	80	-

All measurements were performed in the hydraulics laboratory of the Nat. Technical Univ. of Athens (Greece). The channel's length was 12 m, the discharges were measured through a Venturi tube and suitable manometer, the depths were mean values from a number of measurements from upstream 4 gauges. These gauges were put in proper places in order that the measured depths were ensuring the uniformity of flows, while all these flows were regulated through a tale gate.

The initial bed and walls of the channel were smooth (perspex), the bed has steadily been a smooth one, while the walls were alternating (with vertical rubber strips) from rough (λ/κ=100) to more rough (λ/κ=12.5). In this way a composite channel's roughness was succeeded, for a long variety of discharges and corresponding V, Re, λ/κ and n.

In this paper, as most interesting previous papers, the following investigations have been selected: By Chow, (1959), [1], Ramesh et al, (2000), [8], Pyle, (1981), [7], Robertson et al, (1973), [9], Rosso et al, (1990), [10], Ghosh, (1972), [2], Demetriou, (2003), [6], Demetriou et al, (1999), [3], Demetriou, (2000), [4], and finally Demetriou et al, (2001), [5].

2. RESULTS/DISCUSSION

All measurements' series present a peak in n, around Re≈85,000 although z_n, Q, R, etc are continuously increasing.

Fig. 2 shows the results of the relationship between n(=n_s) vs Re for the completely smooth channel case. n_s-Re line presents a peak (≈0.0135) around Re≈85,000, while for larger Re the pertinent curve is falling (n_s≈0.01175 for Re≈195,000).

Since no part of the above line is a straight line but a curved one, the repeated application of the Manning formula for various discharges Q in the same open channel, gives a curved relationship between n, Re and any particular λ/κ ratio (in Fig. 2, λ/κ=∞).

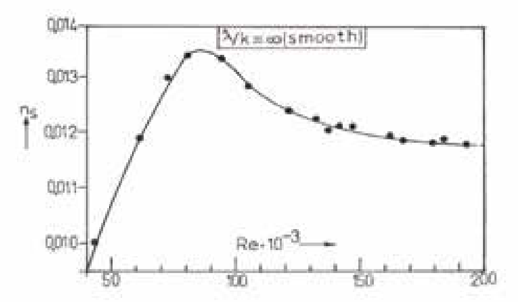

Figure 2. n for λ/κ=∞ (smooth case) vs Re.

Figs. 3, 4, 5, 6, present similar results of n vs Re, for λ/κ=100-50-25-12.5, where all curves show a similar behaviour like the curve of the smooth case (Fig. 2).

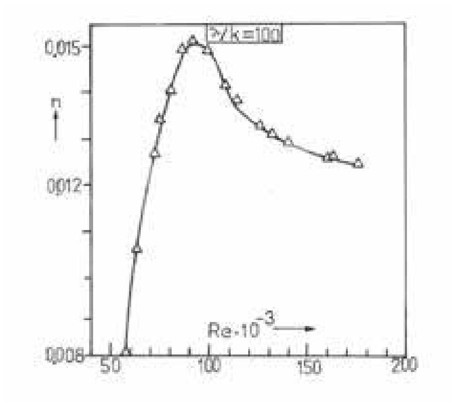

Figure 3. n vs Re for λ/κ=100.

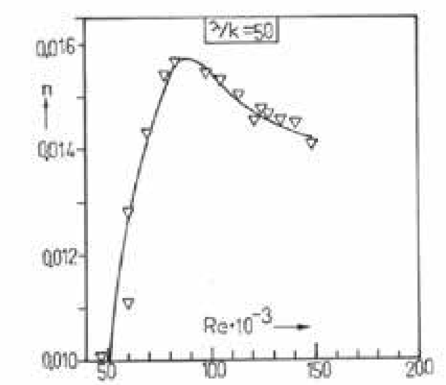

Figure 4. n vs Re for λ/κ=50.

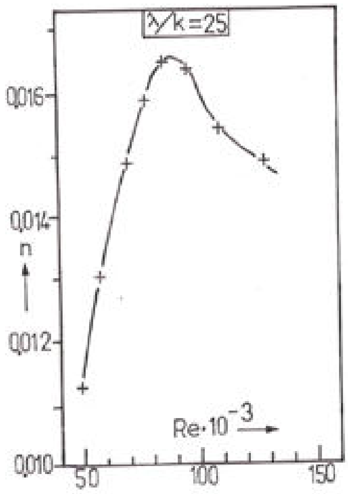

Figure 5. n vs Re for λ/κ=25.

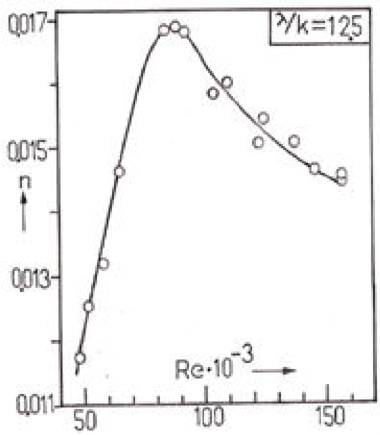

Figure 6. n vs Re for λ/κ=12.5.

Fig. 7 shows together all curves, where the total of curves are systematic, while some parts of them are under the smooth cases's curve. All curves present a peak around Re≈90,000 to 100,000, while beyond those values they are coming down-for larger Re.

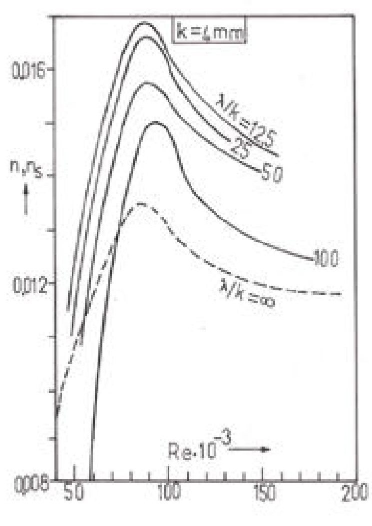

Figure 7. n (or n_s) vs Re for λ/κ=∞, 100, 50, 25, 12.5.

Figs. 8, 9, 10, 11, show the ratios n/n_s vs Re, for λ/κ=100-50-25-12.5, where all curves show a similar behaviour: All curves present a peak between Re≈90,000 and Re≈110,000.

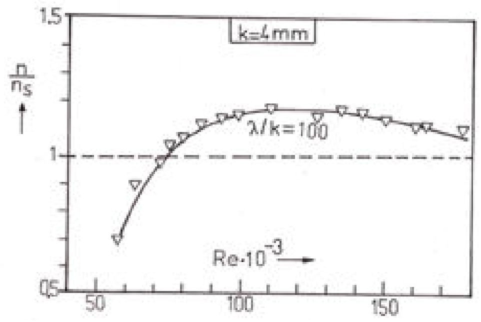

Figure 8. n/n_s vs Re, for λ/κ=100.

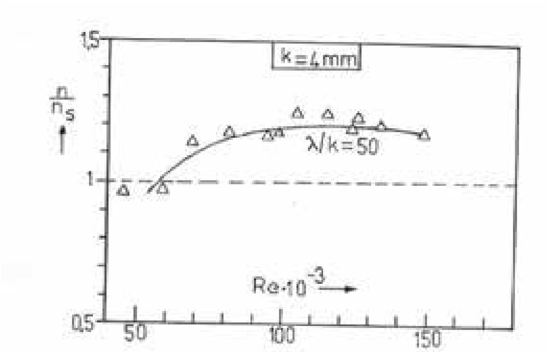

Figure 9. n/n_s vs Re, for λ/κ=50.

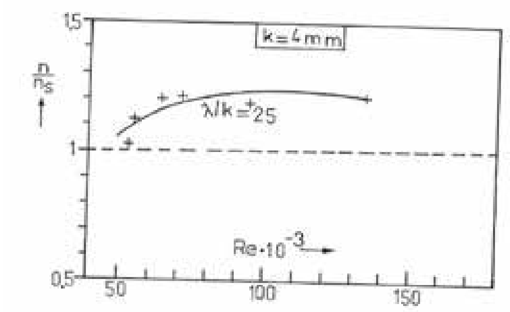

Figure 10. n/n_s vs Re, for λ/κ=25.

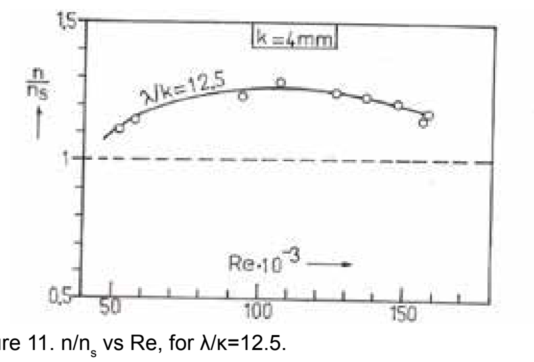

Figure 11. n/n_s vs Re, for λ/κ=12.5.

Finally, Fig. 12 presents all curves together, from Figs. 8 to 11, for comparison reasons. All curves are systematic, and any curve for a rougher wall (for example for λ/κ=50) lies over the preceding less rough wall (for example λ/κ=100). This is natural, in view of the n/n_s sequence, and are considered as reasonable.

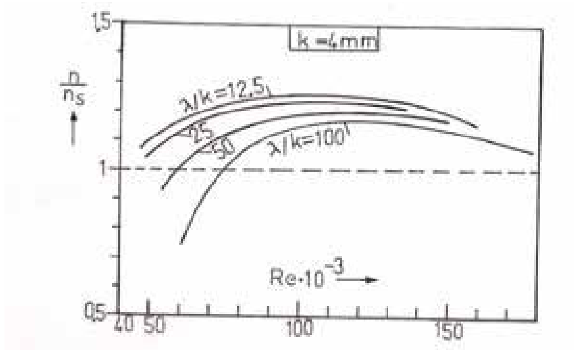

Figure 12. n/n_s vs Re for λ/κ=100-50-25-12.5.

3. CONCLUSIONS

In this experimental study the Manning's roughness coefficient, n, is investigated in uniform-turbulent-steady water flows, within sloped (J_o) rectangular open channels of composite roughness. The channel's bed always remains smooth, but both walls' symmetrical roughness is varying, through adhesive vertical rubber strips (κxκ, where κ=4mm) at various λ distances. Thus, a number of ratios λ/κ=12.5-25-50-100 and ∞ (completely smooth channel, κ=0) are examined. The main conclusions are: (1). The curve n_s-Re, corresponding to the smooth case, is rising from Re≈40,000 to 85,000, and then it falls beyond Re are approaching the value of 100,000. (2). A similar behaviour show the corresponding curves for λ/κ=100-50-25-12.5. (3). The respective curves n-Re-λ/κ are systematic in the sense that each one of them is at higher position-from smooth's case curve, and are rising higher and higher according to theirs roughness' ratios, λ/κ=100-50-25-12.5. (4). The relative n/n_s ratios were also examined, for κ=4 mm and according to λ/κ=100-50-25-12.5 increasing roughness. (5). Each curve n/n_s vs λ/κ ratio and Re is systematically lying over the others, according to increasing λ/κ ratios, and all curves are over the smooth channel's curve case. (6). Although, some n/n_s vs Re and λ/κ curves have parts under the n/n_s=1 value. The present study is aiming at helping the hydraulic engineer in his practical water flow problems.

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