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EFFECT OF BED ROUGHNESS ON HYDRAULIC JUMP CHARACTERISTICS

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تأثير خشونة القاع على خصائص القفزة الهيدروليكية

تم قياس خواص القفزة الهيدروليكية فى ترعة أفقية ذات جوانب ملساء رأسية، وقاع ذات أنواع مختلفة من الخشونة تم عمل قاع خشن باستخدام نماذج أسطوانية بارتفاع ٨,٧ مم وقطر ٦ مم وقد وضعت متوازية أو في صورة متداخلة – وكذلك باستخدام نماذج على شكل شرائح بعرض القاع.

ومن النتائج التى تم الحصول عليها وجد أن القاع الخشن يقلل من العمق النهائى (Y_2) وطول القفزة الهيدروليكية – وكذلك وجد أن النقص فى العمق المتعاقب او المتتابع أو التالى (Y_2) وطول القفزة المائية يتوقف على رقم فراود وخشونة القاع .

ABSTRACT

Hydraulic jump characteristics were measured over various types of artificially roughened test beds in a horizontal flume 5 cm bed width and smooth vertical side walls. Roughness was created using 8.7 mm high cylindrical pins of 6 mm diameter. The patterns of roughness were staggered or parallel and also using strip and spotted roughness test bed, which provided the range of bed friction from 0.042 to 0.16 5.

It was observed that the bed roughness reduces the sequent depth and length of hydraulic jump; the observed reductions were related to the Froude number and the bed roughness.

INTRODUCTION

The hydraulic engineers have been facing for a long time the problem of dissipating surplus kinetic energy of water flowing over spillways, weirs, canal drops and also through under sluices and tunnels etc. The object has been to dissipate the surplus energy as much as possible within smallest distance from hydraulic structures which overwise causes damage of the downstream bed and bank of the channel by process of continuous erosion and degradation.

There has been considerable research to study the effectiveness of various devices for dissipation of surplus energy of flowing water. One of these devices consists of using hydraulic jump for energy dissipation, which is usually confined partly of entirely to a channel reach known as stilling basin. The entire bed of the

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basin is completely paved to resist scouring. Practically the stilling basin is seldom designed to confine the entire length of hydraulic jump on the paved apron because such a basin would be too expensive. Consequently, accessories to control the jump are usually installed in the basin. The main purpose of such control is to shorten the range within which the jump will take place and thus to reduce the size and cost of the basin.

The phenomenon of hydraulic jump has been studied extensively but past investigators have only concentrated on establishing the flow characteristics of hydraulic jump on smooth bed. Very little information is available about the hydraulic jump characteristics over rough bed surface. Some remarkable study on hydraulic jump over rough beds was done by Hughes and flank, J.E. [5]. They used a smooth test bed, two strip roughness and three densely packed gravel test beds which provided a relative roughness ranges up to 0.9

Observations showed that boundary roughness reduces both the sequent depth and the length of hydraulic jump. Further study on the flow characteristics of hydraulic jump over bed surface was carried by Senger [9] and Govil [3].

EXPERIMENTAL SET UP AND PROCEDURE

The experimental set up consisted of an open channel rectangular flume with 5.0 cm × 17cm cross section and 5.0m long. The side walls of the flume were made of transparent prespex sheet. The outlet of the flume was fitted with a storage tank of size 1.55m × 0.70 m × 0.30 m which was further connected to a measuring tank. The inlet of the flume was made with a pipe of diameter 2.54 cm connected from a storage tank. Water was pumped from a storage tank to the inlet of the flume by centrifugal pump with capacity of 1 hp. A discharge regulating mechanism was also provided to regulate the flow. A sluice gate was provided upstream and a plain vertical gate was used downstream for the formation of the hydraulic jump in the middle of the flume.

ROUGHNESS ELEMENTS

Following types of the roughness elements were used.

Spotted Roughnes Elements :

(a) A series of circular staggered elements 1 mm and height 1.4 5mm.

(b) A series of circular elements of diameter 5 mm and height 1.85 mm placed at equal distance along the direction of the flow.

Right angled strip element

Right angled strip elements of height 5 mm with sloping side in the upstream direction and clear spacing of 2 cm, 1 cm and 0.5 cm.

Cylindrical Roughness:

Solid cylindrical pins of 6mm diameter and 8.7 mm height made of plastic were to produce roughness on the bed of the channel on the downstream of the gate. The pins were so arranged on the bed as to produce staggered as well as parallel roughness elements.In all cases the strip as well as cylindrical roughness elements were inserted on the rubber ped at the downstream of the gate up to a considerable length of flume Fig.1.

Four quantities were measured to describe each hydraulic jump.

(a) The flume discharge, Q varied between 0.454 l/s and 3.0 l/s.

(b) The initial depth Y_1 was determined from point gauge measurements just upstream from the leading edge of the surface roller. It varied between 0.945 cm and 2.40 cm.

(c) Sequent depth Y_2 was determined from point gauge measurements, which varied from 3.16 cm. to 7.42 cm.

(d) Jump length Lj was measured from the leading edge of the jump to a point just downstream from the top roller of the jump. The length of the hydraulic jump varied from 6 cm to 20 cm.

The range of Reynolds number and that of Froude number were between 1.49×10^4 to 6.9×10^4 and 2.15 to 5.73, respectively.

ANALYSIS OF DATA

The Darcy – Weisbach bed friction factor f_b can be related to Manning 's coefficient of bed roughness n_b for bed only as.

$$n_b = 8g / (R^{1/6} / n_b)^2 \qquad (1)$$

The coefficient of roughness for bed only was calculated from the estimated readings of hydraulic radius for bed R_b and channel longitudinal slope S using Einstein – Barbarossa method (Appendix B) separating the effects of side and bed roughness. Thus a series of values for f_b were obtained for different conditions of flow. The ratio between the sequent depth and the initial depth (Y_2 / Y_1) was plotted for corresponding values of Froude number (F_1) with f_b as third parameter, Fig.2. A distinct trend in the relationship was observed. The slope of the best fit line between (Y_2 / Y_1) and F_1 that is m, was plotted against corresphonding values of f_b Fig.3, which provided the relationship

$$m = 1.297 - 2.407 f_b \qquad (2)$$

Using the above mentioned expression for m, a relationship between Y_2/Y_1 and F_1 is obtained as follows.

$$Y_2 / Y_1 = (1.297 - 2.407 f_b)F_1 + 4.814 f_b - 0.224 \qquad (3)$$

Equation 3 can be used to determine the values of Y_2/Y_1 for any bed friction factor f_b at given Froude number, F_1. Considering no bed friction (i.e. $f_b = 0$) , Eqn. 3 reduces to.

$$Y_2/Y_1 = 1.297 F_1 - 0.224 \qquad (4)$$

This equation does not match with the theoretically derived Belenger's equation.

$$Y_2/Y_1 = \frac{1}{2}\left(\sqrt{1 + 8 F_1^{\,2}} - 1\right)$$

Which can be approximated to

$$Y_2/Y_1 = 1.404\ F_1 - 0.500 \qquad (5)$$

This equation was derived considering no bed friction, however in an experimental work, there will always be some friction at the bed. The maximum deviation of Eqn.4 with Belenger's equation is + 6 % only.

The fact that the resistance to the flow increases in channels with increase of Froude number has been studied by earlier investigators [10]. The trend is verified in the present paper also.

CONCLUSIONS

1. The slope of the trend line using test data was obtained as 1.297 which is close to the slope vaule as obtained by theoretical equation given by Belanger.
2. The graphical representation of the data collected by using different roughness test beds shows that the effect of change of concentration (spacing between two elements) is more on the bed roughness than the change in pattern (parallel or staggered) of fixing the roughness elements.
3. The data for rough bed lie close to the line for smooth bed as the Froude number decreases. Theoretically there is a jump formation when F_1 is greater than 1. But practically it is not possible to predict the jump formation for F_1 less than 2 because jump is very weak Hence in the graphical representation, the lines for different roughness test bed and smooth bed appear to be meeting at $F_1 = 2$.
4. Comparison of the data trends from one curve to the next shows that the reduction in ratio of sequent to initial depth becomes very pronounced as bed roughness increases. As the bed roughness increases the trend line falls progressively further below the smooth boundary curve. The observed reduction was found to be the related to both the initial Froude number and bed roughness.
5. The length of jump, is reduced as the bed roughness increases, for all Froude number. The relationship between the slope of trend lines (m) and bed friction factor f_b could be represented by .
   $m = 1.297 - 2.407\ f_b$
6. The relationship between Y_2 / Y_1 , F_1 and f_b is found as
   $$Y_2 / Y_1 = (1.297 - 2.407\ f_b)\ F_1 + 4.814\ f_b - 0.224$$
7. The line representing the relationship between Y_2 / Y_1 and F_1 for 5mm high right

angles strip roughness element with clear spacing of 0.5 cm overlaps the line representing the relationship between Y_2 / Y_1 and F_1 for 8.7 mm high pins.

@ 2.0 cm C/C (staggered) It shows that the roughness produced by 5mm high right angled strip roughness element is equivalent to the roughness produced by 8.7 mm high pins @ 2cm C/C (staggered).

8. **Field data are not available to the outhor to verify their experimental results.**

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APPENDIX – A

Bed friction factor f_b for height angled strip roughness test bed with clear spacing of 1.0 cm.

The following values for this case are given as follows:

Composite roughness ,n = 0.0162

Depth flow ,y = 2.30×10^{-2} m

Hydraulic radius ,R_h = 1.425×10^{-2} m

Side wall roughness ,n_w = 1.010

Using the Einsten and Barbarossa's method,

$$R_w = (n_w R_h^{2/3} / n)^{2/3}$$

Substituting the previous values, into the foregoing egn:

$R_w =[0.1 \times (1.425 \times 10^{-2})^{2/3} / 0.0162]^{3/2}$
$= 6.94 \times 10^{-3}$ m
But, $A_w = R_w \times 2y = 3.19 X 10^{-4} m^2$
Therefore, $_b = A - A_w = 1.405 \times 10^{-3} m^2$
Hence, $R_b = A_b / B = 0.0187$ m

Now using the relation,

$n_b = n_w (R_b / R_w)^{2/3} =$

$0.010 (0.0187 / 6.94 \times 10^{-3})^{2/3} = 0.0193$

But, $C_b = R_b^{1/6} / n_b = 26.62$

Hence, $f_b = 8g / C^2_b = 0.110$

APPENDIX – B

To check the type of boundary surface, the following data are chosen for this purpose.

Flow rate, $Q = 0.054 \times 10^{-3} m^3 / sec.$

Flow velocity, $V = 26.3 \times 10^{-2}$ m/sec.

Longitudinal slope, $S = 5.235 \times 10^{-3}$

Hydraulic radius, $R_h = 1.425 \times 10^{-2}$m

Shear velocity, $u_* = \sqrt{g. R_h. S}$

$= \sqrt{9.81 X 1.425 X 10^{-2} X 5.235 X 10^{-3}} = 0.0270$

Thickness of laminar sublayer

$$\delta = \frac{11.6 \gamma}{u *} = \frac{11.6 X 10^{-6}}{0.0270} = 4.2962 \times 10^{-4} \text{ m}$$

Bed friction factor, $f_b = 0.110$ from Appedix A .

Using well known Colebrook and White equation Raju [6]

$$\frac{1}{\sqrt{f}} = 1.14 - 2 \log \left(\frac{ks}{4R_h} + \frac{21.25}{Re^{0.90}}\right)$$

$Re = V \times 4 \times R_h / \nu$

$= (26.3 \times 10^{-2} \times 4 \times 1.425 \times 10^{-2} / 1 X 10^{-6}) = 1.94 \times 10^4$

or $\frac{1}{\sqrt{0.110}} = 1.14 - 2 \log \frac{ks}{4 X 1.25 X 10^{-2}}$

$+ 21.25 (1.49 \times 10^4) -^{9}]$

or $ks = 6.369 \times 10^{-3}$ m

Now, $\frac{ks}{\delta'} = \frac{6.369 X 10^{-3}}{4.2962 X 10^{-4}} = 14.824 > 6$

Hence, the surface is ydrodynamically rough. Alternatively,

$$\frac{u * X ks}{\nu} = \frac{0.0270 \times 6.369 X 10^{-3}}{1 \times 10^{-6}}$$

$= 171.963 > 100$

(hydrodynamically rough)

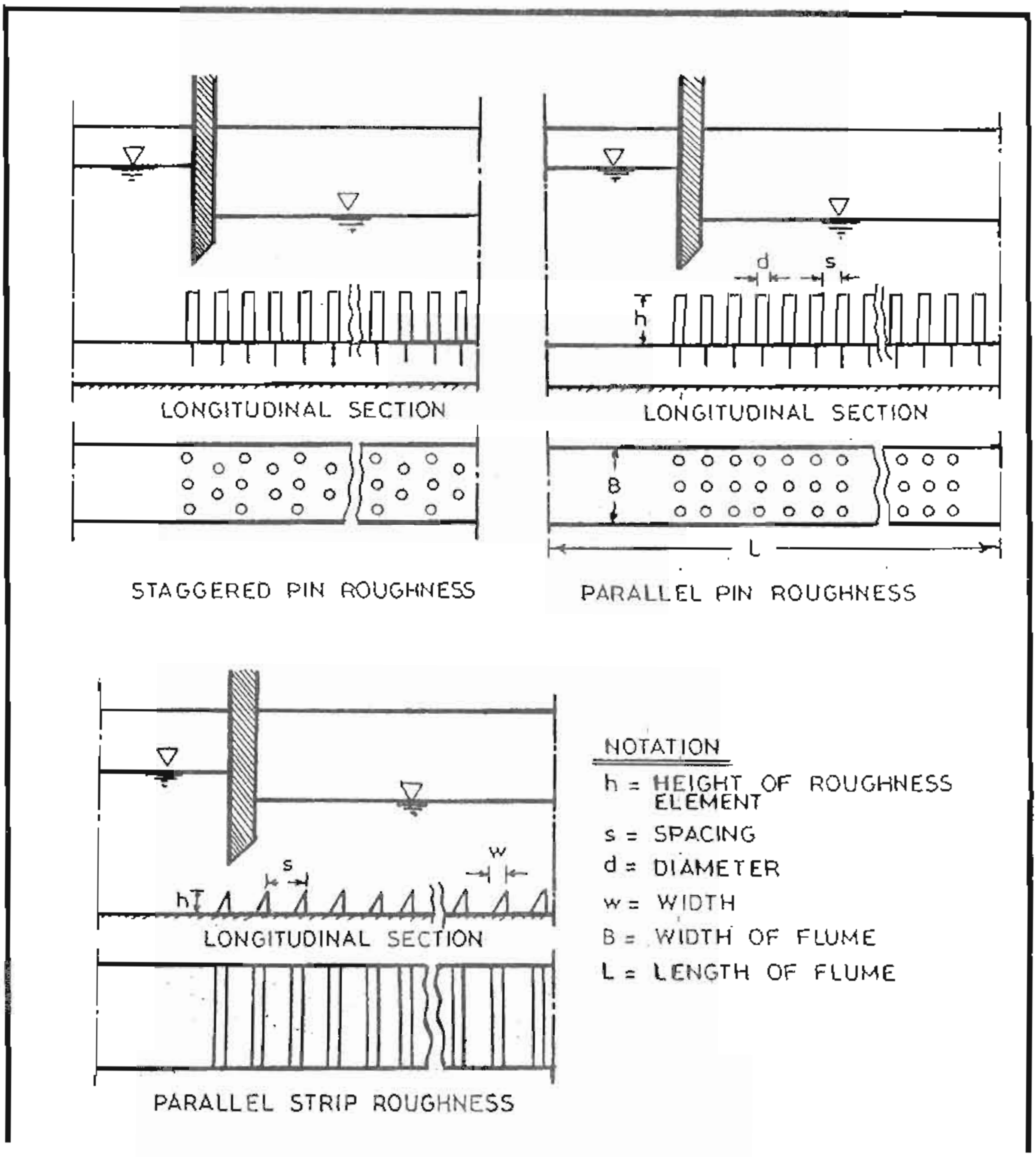

FIG.1 – ARRANGEMENT OF ROUGHNESS ELEMENTS

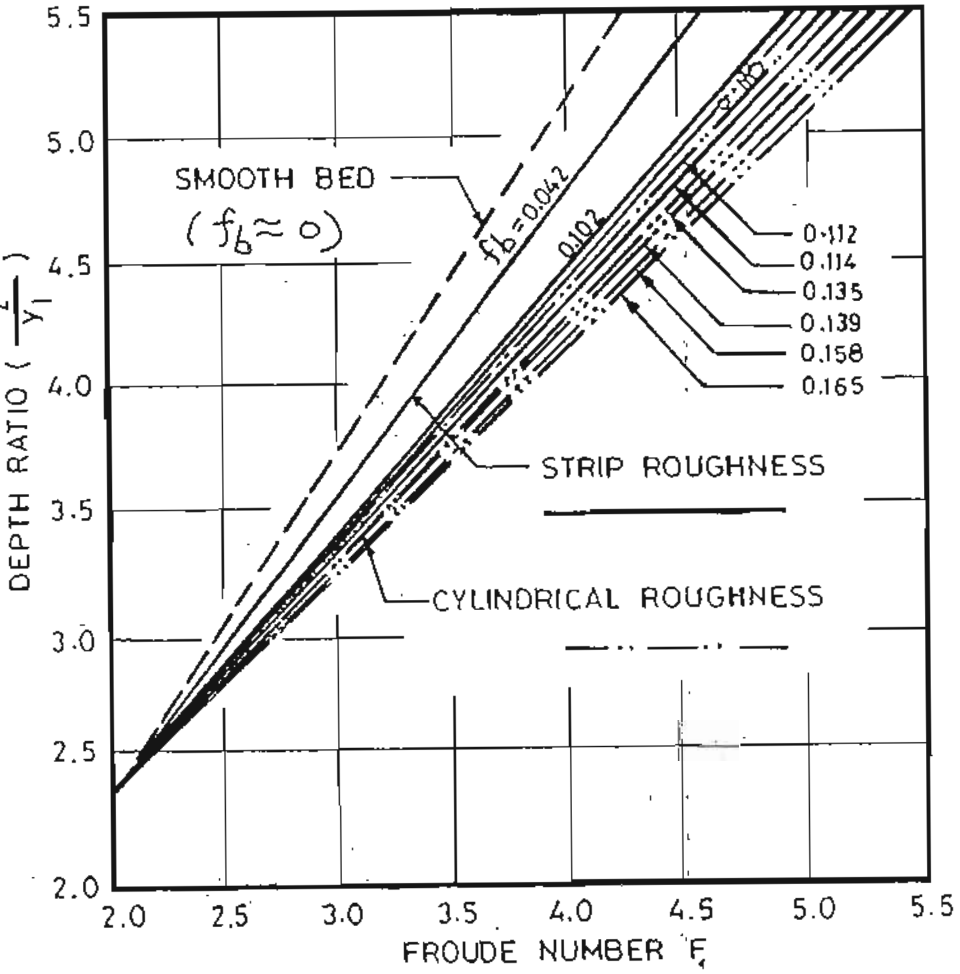

FIG.2 PLOT SHOWING THE RELATIONSHIP BETWEEN THE DEPTH RATIO (y_2/y_1) AND FROUDE NUMBER (F1) FOR DIFFERENT TYPES OF DEB ROUGHNESS

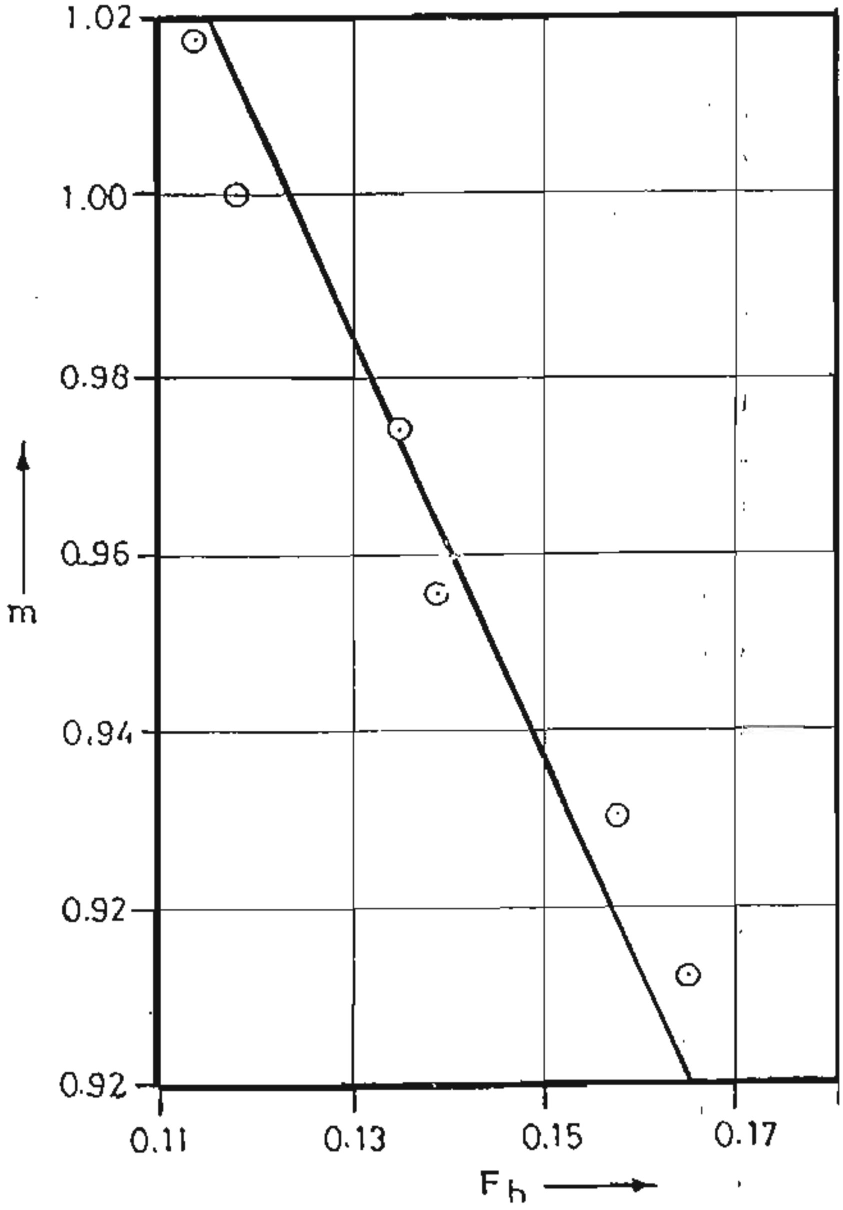

FIG.3 PLOT SHOWING THE RELATIONSHIP BETWEEN SLOPE OF TREND LINE (m) AND DEB FRICTION FACTOR (F_b)