EXPERIMENTAL VERIFICATION OF DISCHARGE SEDIMENT MODEL AT INCIPIENT MOTION

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ABSTRACT:

Preliminary study on gravel sedimentation was conducted in a recirculating flume. A $53^0 8'$ V-notch was used in the experiment. This paper describes the results obtained by this flow-measuring device and compares it with that of the incorporated flow meter of the flume. The results showed only minimal deviations from the measured values. Also for the flow over gravel floors a formula was established relating discharge at incipient motion to the size of the gravel.

NOTATION

Q = volumetric flow rate of discharge
q_c = discharge at incipient motion
C_W = weir discharge coefficient
K = particle size in general
d = gravel size
τ = boundary shear stress
H = head over weir
H = head measure from water surface over weir
ξ = constant of proportionality
u = velocity
R = hydraulic radius
S = hydraulic gradient
θ = vertex angle of V-notch = $53^0 8'$
y = depth of gravel floor
$u_* = \frac{\sqrt{\tau}}{\rho}$ shear velocity
τ_C = critical bedload shear stress
u_{*c} = critical shear velocity at incipient motion
ρ = mass density of water
g = acceleration of gravity
γ = specific weight of water
γ_s = specific weight of sediment, gravel
L = length of gravel floor or bed
b = breadth of flume = O.3m = constant
S_O = flume slope, kept constant at 16 x 10-3
R = particle Reynolds number
ν = kinematic viscosity of water
x = elevation head
ℓ = mixing length
η = a constant of proportionality
K = constant for turbulent flow

1. INTRODUCTION

The main objective of the gravel sedimentation study is to illustrate the formation of pavement under mobile - bed conditions and to ascertain if bed-load obeys the relationship found to hold for natural paved gravel-bed streams. Secondly it is desired to observe the transition of a mobile-bed pavement to a static armour on cessation of sediment - feed. The study is being conducted in a laboratory flume because the required tests for the necessary hydraulic quantities like discharge can be scaled down avoiding the necessity for large capital for equipment and personnel that would have been the case in the field. Thus, if the model can be shown to obey the same lows as govern field phenomena as tested against available field data, it can be used with some certainty to reproduce events that have not yet occurred. For example, if the model reproduces the field situation for a certain stream with given ambient fines content or flood statistics, the effect of catastrophic floods can be evaluated in the model a€ a means of avoiding it in the field. In this preliminary study therefore, flume calibration for discharge using a miniature flow-measuring device is conducted to establish flow rate depth changes and incipient motion parameters of the sediments chosen, for the purpose of this study, as river gravel of varied sizes.

2. THEORITICAL BACKGROUND

(i) Discharge: The basic equation for discharge over a V-notch is

Q =

$$\int_o^H \sqrt{2gh}\ (H-h)2\tan\left(\frac{\theta}{2}\right) dh \qquad (1)$$

for which, in the case of 53^0 8-V-notch a discharge coefficient Cw = 0.58 has to be applied according to BS 3680 part 4A 1964 (11).

Equation (1) then reads

$$Q = 0.685\ H^{\frac{5}{2}} \text{ in SI units … (2)}$$

With the V-notch fixed in position over the gravel-bedded flume,

Equation (2) is of the form $Q_c = 0.685 yc$ ………….. (3)

where Q_c is the discharge at incipient motion and Y_c depth at incipient motion, over the weir

(ii) hydraulic gradient S: the value of S may be obtained from the expression according to Henderson (2) and Fig. 2 as

$$S = S_O + \frac{y_1 - y_2}{L} + \frac{U_1^2 - U_2^2}{2gL} \text{ ....(4)}$$

where the subscripts 1 and 2 refer to any two sections along the flume in the direction of flow.

(iii) Resistance Equation for flow in rigid boundary Channels: the expression

$$\tau = \left(\frac{\delta u}{\delta t}\right) + \rho 1 \left(\frac{\delta u}{\delta t}\right)^2 \text{.................(5)}$$

due to Prandtl (5) yields

$$\frac{U}{U_*} = C + \frac{1}{K}\lambda n\ \frac{Y}{K} \text{....................(6)}$$

which after conversion to logarithm of bass 10 and putting K - 0.4 becomes

$$\frac{U}{U*} = C + 5.75 \log\frac{Y}{d}$$ where the constant C = 8.5 as found by Koulegan (8)

(iv) Shields criterion for incipient motion is

$$\frac{\tau_C}{\left(\gamma_\rho - \gamma\right)d} = \frac{U*d}{\nu} = f(R*) \text{ ....(7)}$$

where $R_* = \tau_*$ = constant determined by Shields as 0.06. The value of R_* for the range of values in this e experiment is greater than 70. Equation (7) may be expressed for a wholly rough boundary as

$$\tau_C = C \text{ ....} \qquad (8)$$

According to Little & Mayer's (9) statistical relationship of the data collected from various other investigators in this area,

$$U_{*C} = \sqrt{\frac{C}{\rho}}\ d^{\frac{1}{2}} = \xi d^{\frac{1}{2}} = 0.74 d^{\frac{1}{2}} \text{ ....(9)}$$

By squaring and equating (9) to the square of U_{*c} one obtain

$$\frac{yc}{d} = \frac{0.056}{S} \qquad (10)$$

so that by equations (3,4) and writing

$s = n^S o$ the discharge - sediment equation at incipient motion is

$$q_c\ \frac{Q_c}{0.3} = 0.0018(\eta^S o)^{-2.5} \text{in SI unit} \qquad (11)$$

3. EXPERIMENTAL EQUIPMENT AND PROCEDURE

3.1 Equipment:

The major test apparatus for the study is a recirculating flume 6m long, 0.3m wide and 0.5m deep. The flume is located in the basement of the Department of Geology of the University of Glasgow.

It was selected because its clear plastic walls allow for visibility of the moving sediment (gravel) layer from the sides. Water is drawn by a pump from a sump underneath the floor of the laboratory and flows into a stilling tank with baffles at the upstream end of the flume before entering the flume proper.

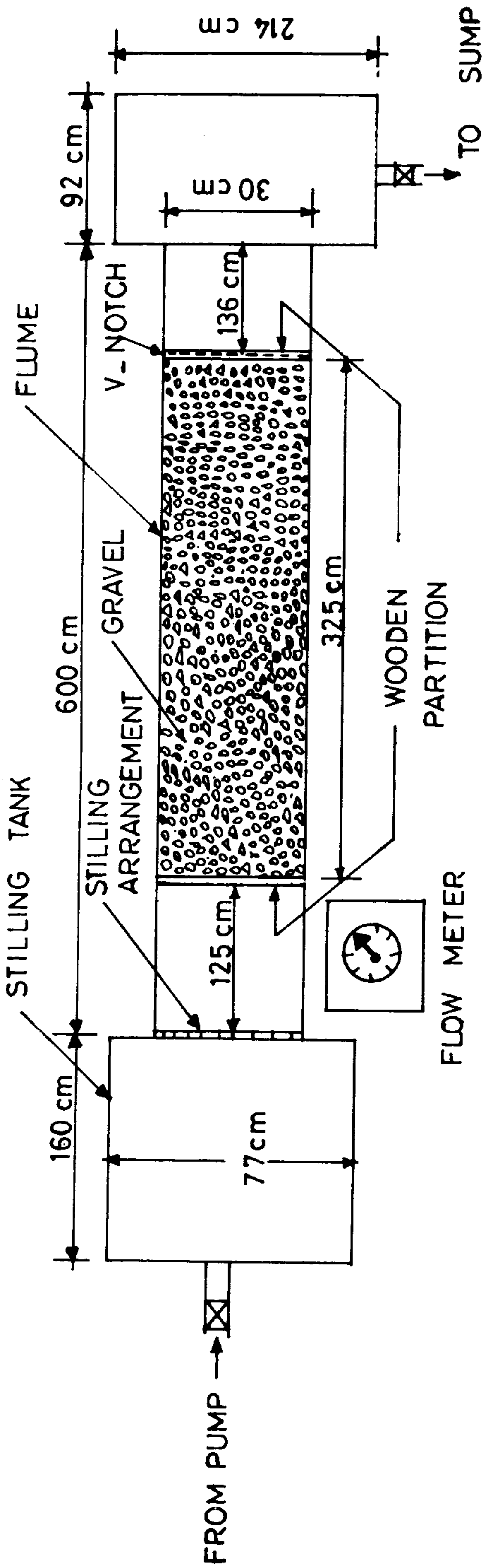
TABIE 1: DISCHARGE OVEP WEIR FOR CALIBRATION

Head H,cm	Q_V Litre/See	Q_F Litre/See	Error $Q_V - Q_F$	Error %
5	0.38	0.43	-0.05	5.0
6	0.60	0.650	-0.050	5.0
7	0.89	0.965	-0.075	7.5
8	1.20	1.25	-0.05	5.0
9	1.67	1. 77	-0.10	10.0
10	2.17	2.245	-0.075	7.5
11	2.75	2.850	-0.10	10.0
12	3.40	3.50	-0.10	10.0
13	4.20	4.325	-0.125	12.5
14	5.0	5.10	-0.10	10.0

The Mean error = 8.25%
The standard deviation = 2.45

TABLE 2: SEDIMENT DISCHARGE DATA S_O = 0.016

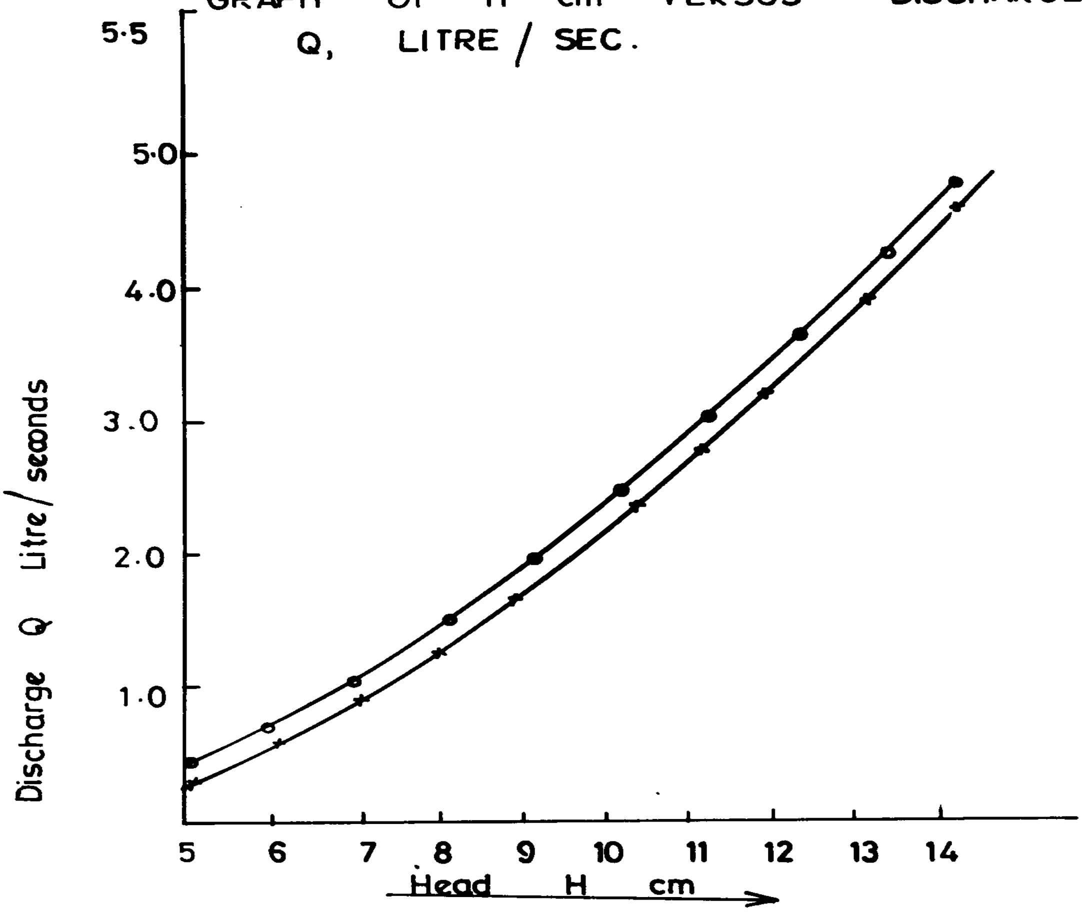
Gravel size d, mm	Coefficient $\eta = \frac{0.056}{S_O}\frac{d}{y_c} = \frac{35d}{y_c}$	Hydraulic Gradient S S = ηSo	Depth at Incipient Y_c , mm	Shear Velocity U* $\frac{m}{Sec}$	Particle Reynolds Number R* R* = $\frac{U*d}{\nu}$	Average Velocity U $\frac{m}{Sec}$	Discharge at incipient motion per unit width of flume qc $\frac{m}{Sec}$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
5	1.320	.00215	13.25	0.0167	83.50	0.1026	0.044
8	1.240	.00199	22.58	0.0209	167.20	0.231~	0.182
11	1.050	.00170	35.32	0.0243	267.30	0.2773	0.582
15	0.875	.00140	42.85	0.0240	360.00	0.3005	2.118
22	0.660	.00105	65.62	0.0259	569.80	0.2908	11.472
30	0.584	.00093	84.77	0.0473	819.00	0.2971	33.809
42	0.501	.00080	99.32	0.279	1171.00	0.2661	113.841



LAYOUT OF EXPERIMENTAL SET-UP

FIG. 1

FIG. 3
GRAPH OF H cm VERSUS DISCHARGE Q, LITRE / SEC.



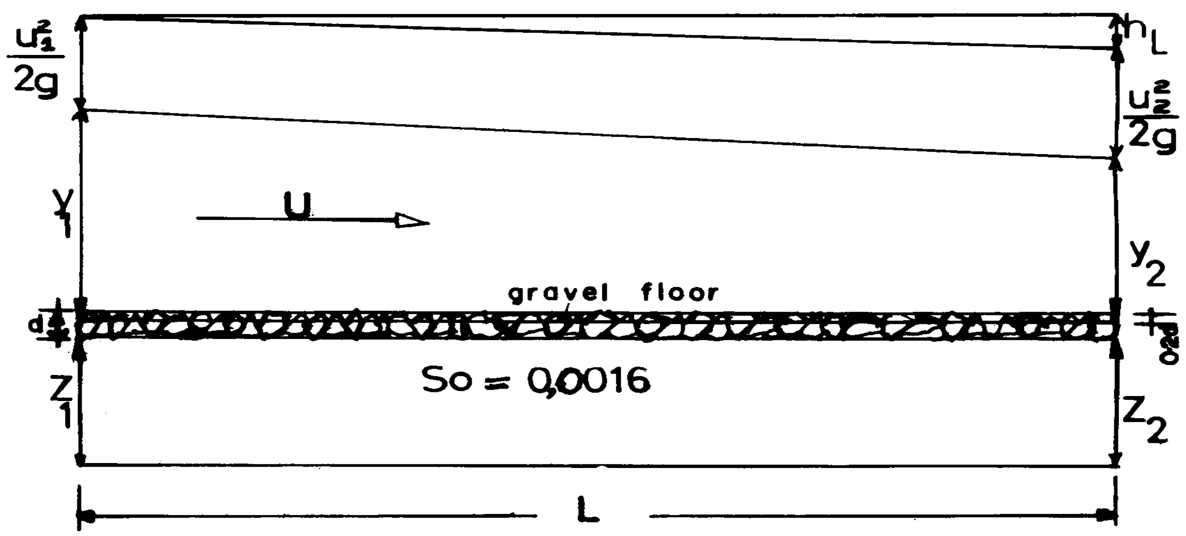


FIG 2 — Definition Sketch For FLow over gravel

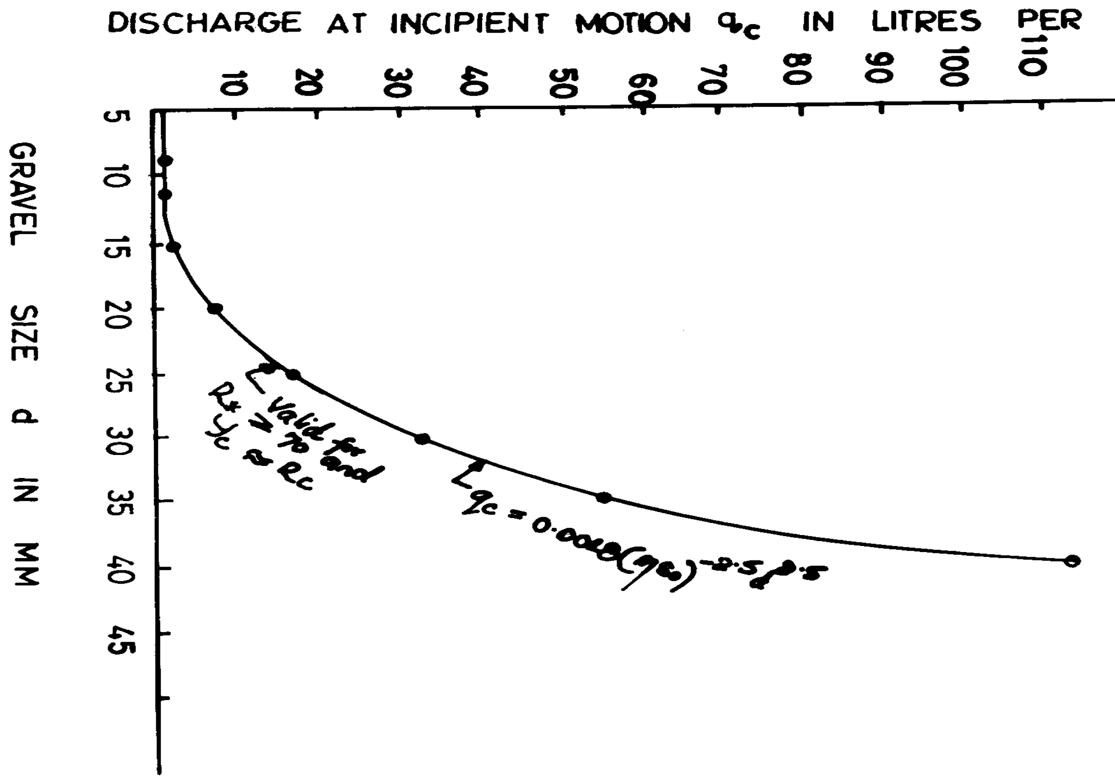


FIG. 5 - **Discharge- Grain Size** Relationship

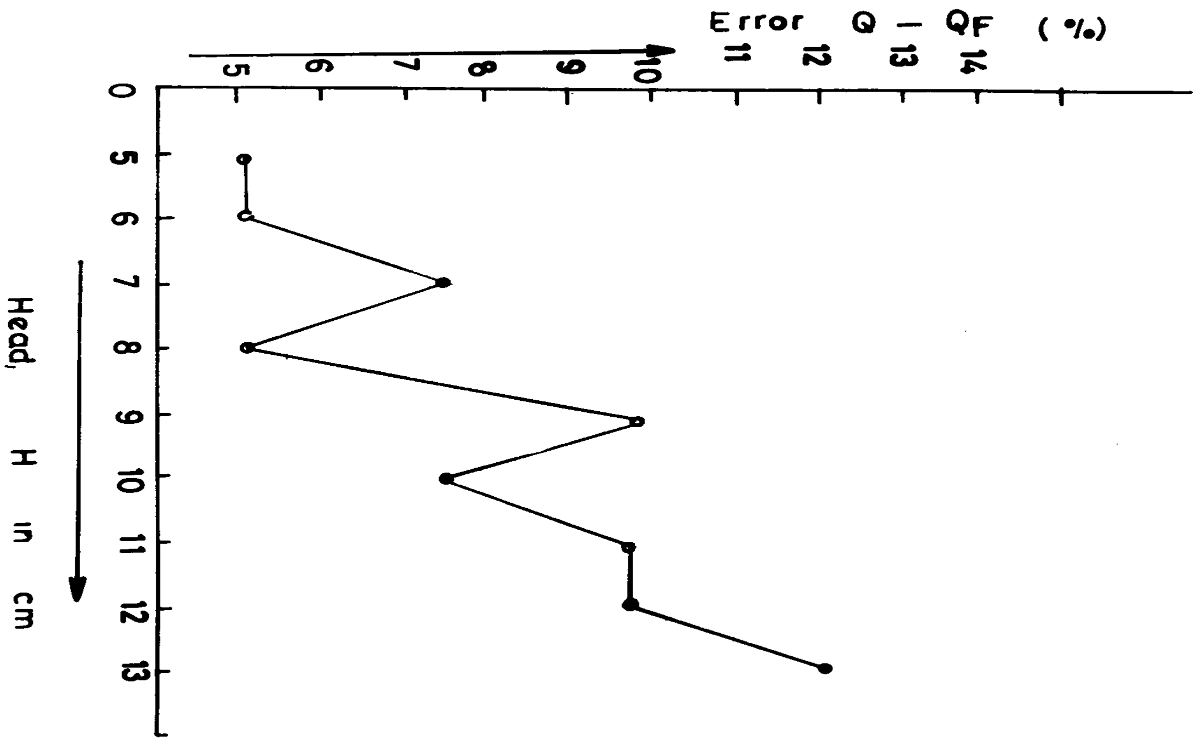


FIG. 4 GRAPH OF ERROR VS HEAD

The experimental weir was fixed in the flume by means of a wooden frame at a length of 4.5m from the tank. The head over the weir was measured with a point guage with small divisions of O.lmm.

The movable bed portion of the flume or gravel floor reach is delineated by two wooden partitions, the first near the stilling tank and the second located 3.25m downstream, from the first. This portion is filled with the respective gravel sizes under investigation and is screeded level at the beginning of each mobile-bed run. The manometer tubes used to read deflections were attached to a bank inclined at 58^0 to the vertical to improve accuracy. Flume slope was set at 0.016 with the aid of a surveyor's level before beginning the experiments. This value was not altered subsequently. Four bucketfuls of supplied river gravel was sieved yielding principal sizes of 42mm, 3Omm, 15mm, 11mm, 8mm and 5mm leaving fines of 2mm and less that would later be used to fill up the interstices between the gravels in the future major experiments .

3.2 General Procedure:

The pump was started and 10 runs of water were passed for the V-notch in position.

By means of the point guage the depths were read and discharge computed from Equation (l). At each run the flowmeter value of discharge was noted. The temperature of the water remained at or near 18°c throughout the experiment. For easy deciphering of the manometer deflection a very small solution of potassium permanganate was injected into the manometer tubes.

The gravels were then positioned on the bed of the flume in the provided section 3.25m long beginning with the 42mm size. For each size gravel water was run and recirculated in the flume at varying flowrates. Whenever a depth was reached at which gravel began to move, the pump was stopped and that depth noted, by having the flume photographed to scales, attached to the side of the flume.

CONCLUSIONS:

From the results obtained from this investigation, the following conclusion may be drawn:-

(i) The incorporated flowmeter of the flume performs accurately enough compared with the precalibrated triangular weir with an average error of 8.25%.

(ii) The measurement with the weir positioned across the gravel- bed yielded an empirical equation relating discharge at incipient motion to the gravel size, of the form,

Equation (ll),

$q_c = 0.0018\ (n^S o)\ -2.5\ d\ 2.5$ where the coefficient

$$\eta = \frac{0.056}{S_O}\frac{d}{y_c}$$

for given Slope So and gravel size, d. The depth at incipient motion Y_c may be assumed approximately equal to the hydraulic radius R_e for

$$\frac{\text{flume width}}{\text{flow depth}}\ \text{i e}\ \frac{b}{y} >> 1.$$

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