HYDRAULICS RESEARCH DIVISION

Technical Note

DATE: November 1979 **REPORT NO:** 79-20

TITLE: "Experimental Program to Test the Hydrographic Method"

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REASON FOR REPORT:

To provide information in response to a request from Water Survey of Canada to extend tests on the Hydrographic Method for measuring bed-load transport.

CORRESPONDENCE FILE NO:

2242-1 (H79 012)

1.0 INTRODUCTION

The Hydrographic Method to compute bed load uses spatial and temporal data of migrating dunes. The development and preliminary tests of the equations have been reported by Engel, Wiebe (1979) and Engel, Lau (1979). The method was compared with limited flume data and showed good agreement. In order to further test the Hydrographic Method, Water Survey of Canada (Campbell, 1978) has requested that additional flume experiments be made. In particular, it was requested to conduct tests (a) with flow conditions for which the Froude number is in the range of 0.1 to 0.25 and (b) using different grain sizes representative of the bed material of the lower Fraser River in British Columbia.

In this report, the extent to which such an experimental program can be usefully taken is examined, and a testing plan is presented. The work is part of the Environmental Hydraulics program at the National Water Research Institute identified as Study No. H79-012.

2.0 ANALYTICAL CONSIDERATIONS

When considering a two-dimensional, normal, tranquil (Froude number <1), open-channel flow, with no external sources of sediment, the parameters dependent on the two-phase flow (sediment-water) can be expressed by seven independent variables (Yalin, 1977). In order to conduct flume tests for the Hydrographic Method which are representative of the conditions likely to be encountered on the lower Fraser River, one must be able to model: (a) the rate of bed load transport q_s, the dune speed U_w and the dune length Λ as the prime dependent variables. These three dependent variables can be expressed in terms of the seven independent variables by the functional relationships:

$$q_s = f_g \left[V_*, h, \rho, \mu, D_{50}, \rho_s, \gamma_s \right] \quad (1)$$

$$U_w = f_{Uw} \left[V_*, h, \rho, \mu, D_{50}, \rho_s, \gamma_s \right] \quad (2)$$

$$\Lambda = f_\Lambda \left[V_*, h, \rho, \mu, D_{50}, \rho_s, \gamma_s \right] \quad (3)$$

where: q_s=volumetric bed load discharge per unit width including the voids, U_w=dune speed, Λ=dune length (crest to crest), f denotes a function, V_*=shear velocity ($V_*=\sqrt{ghS}$, g=gravitational acceleration, S=water surface slope in uniform flow), h=depth of flow, ρ=density of water, μ=viscosity of water, D_{50}=median grain size, ρ_s=density of sediment, γ_s=submerged unit weight of the sediment.

From dimensional analysis one obtains

$$\frac{q_s}{\rho V_*^3} = f'_{qs} \left[X, Y, Z, W \right] \quad (4)$$

$$\frac{U_w}{V_*} = f'_{Uw} \left[X, Y, Z, W \right] \quad (5)$$

$$\frac{\Lambda}{D_{50}} = f'_\Lambda \left[X, Y, Z, W \right] \quad (6)$$

where: $X=V_* D_{50}\rho/\mu$, $Y=\rho V_*^2/\gamma_s D_{50}$, $Z=h/D_{50}$, $W=\rho_s/\rho$. For sediment transport (i.e. sand-water) W≈constant and its effect is negligible and thus W may be ignored. For bed load, since it travels in the vicinity of the bed, Z is not an important parameter and if X is large enough to make viscosity effects negligible, then bed-load transport q_s depends only on Y. In the case of Λ/D_{50} and consequently U_w/V_* (since $U_w=\Lambda/t_*$, t_*=time for one dune to pass a given point), it has been shown that when X≥40, $\Lambda/D_{50}\approx 2\pi h/D_{50}\approx 2\pi Z$ (Yalin, 1977). Therefore, to model Λ and consequently U_w, one must be able to model Y and Z. These conditions can be expressed by

$$\frac{q_s}{\rho V_*^3} = f''_{qs}\left[Y\right] \qquad (7)$$

$$\left.\begin{aligned} \frac{U_w}{V_*} &= f''_{Uw}\left[Y, Z\right] \qquad (8) \\ \frac{\Lambda}{D_{50}} &= f''_{\Lambda}\left[Y, Z\right] \qquad (9) \end{aligned}\right\} X>40$$

Therefore, for the experiments to test the Hydrographic Method, in order to have conditions similar to those of the lower Fraser River, one must have similitude for Y and Z. This can be expressed as

$$\lambda_Y = 1 \qquad (10)$$

and

$$\lambda_Z = 1 \qquad (11)$$

where λ denotes the model to prototype ratio of the given parameters Y and Z.

Equations 10 and 11 specify the relationships

$$\frac{hm\ Sm}{\gamma_{sm}\ D_{50m}} = \frac{hp\ Sp}{\gamma_{sp}\ D_{50p}} \qquad (12)$$

and

$$\frac{hm}{D_{50m}} = \frac{hp}{D_{50p}} \qquad (13)$$

where subscripts m and P denote model and prototype respectively.

By rearranging, one obtains the equations in terms of scale ratios as

$$\frac{\lambda_h \lambda_s}{\lambda_s \lambda_{D50}} = 1 \qquad (14)$$

and

$$\frac{\lambda_h}{\lambda_{D50}} = 1 \tag{15}$$

In considering the condition of equation 14, if sand is used as the test material, then γ_s is the same for the flume and river and $\lambda_{\gamma_s}=1$. Using $\lambda_{\gamma_s}=1$, one must have $\lambda_h \lambda_s/\lambda_{D50}=1$. On the one hand, this condition can be readily met in the flume by adjusting the water surface slope (i.e. steeper slope in the model and in river). On the other hand, the condition in equation 15, clearly cannot be satisfied when the prototype (river bed) material is of small grain size since hm <<hp and $D_{50m} \sim D_{50p}$. In other words, the grain size in the flume cannot be sufficiently reduced to be compatible with λ_h. Apart from this difficulty in using fine material, there would be mechanical problems in that cohesional forces become significant which would render the results to be unrepresentative of the prototype where cohesion is negligible. In addition, the very small grain size would result in values of $X=V_* D_{50}\rho/\mu$ in the flume which are so small as to place the sand waves from dune into the ripple regime. Therefore, since both conditions given by $\lambda_y=1$ and $\lambda_z=1$ cannot be met, we cannot model the river conditions exactly. This condition cannot be improved by using materials lighter than sand. For such materials, it can be shown that $D_{50m} > D_{50p}$ and this will not remedy the problem imposed by the constraint $\lambda_Z=1$, and consequently $\lambda_\Lambda=1$.

The implications of the above analysis are that the conditions for the tests set out by the Water Survey of Canada cannot be met. This can also be graphically demonstrated as follows.

From dimensional analysis it can be shown that

$$\frac{U}{\sqrt{gh}} = \sqrt{W-1}\;\phi\left[X, Y, Z, W\right] \tag{16}$$

Once again, for sand and large enough values of X to eliminate viscous effects, and taking account of only those flows for which there is sediment motion, equation 16 can be reduced to

$$\frac{U}{\sqrt{gh}} = \phi_1\left[\frac{Y}{Y_{cr}}, Z\right] \tag{17}$$

where: Y_{cr} is the critical value of Y and can be obtained from the Shield's curve. The parameter $U/\sqrt{gh}$ is the Froude number of the flow. Equation 17 is plotted as $U/\sqrt{gh}$ versus Z with Y/Y_{cr} as a parameter in Figure 1 using data from Williams (1970) and Engel (1977). The plots give a family of curves, each curve revealing a decrease in Froude number as h/D_{50} increases for a given value of Y/Y_{cr}. The curves are for values of Y/Y_{cr} up to 5, but values of Y/Y_{cr} for the Fraser River are of the order of 30. It becomes clear from Figure 1 that conditions of $Y/Y_{cr} \approx 30$ and $F \approx .25$ will be in a range of $Z \gg 300$ and this cannot be achieved in the lab.

The above results indicate that in order to test the Hydrographic Method for flows with a Froude number from 0.1 to 0.25, measurements must be conducted in the field. This may be possible once reliable calibrations for bed load samplers have been produced. However, this does not mean that meaningful tests cannot be conducted in the flume. A proposed work plan for such tests is given in the next section.

3.0 WORK PLAN FOR FLUME TESTS

The existing data used by Engel, Wiebe (1979) and Engel, Lau (1979) to test the Hydrographic Method is given in Tables 1 and 2. The data shows ten runs with basically two average values of h/D_{50}, namely 145 and 122. All the data were obtained with sand for one grain size specified by D_{50}=1.1 mm. The range of Y/Y_{cr} was from 1.85 to 5.74. Values of h/D_{50} can be increased by increasing depth of flow and reducing the grain size. Values of Y/Y_{cr} can be increased apart from increasing depth and reducing grain size by increasing the water surface slope (uniform flow). The suggested work plan indicating a minimum of 16 tests is shown in Table 3. More tests can be done depending on the assessment of results from these tests.

Although the conditions in the flume are not representative of large river conditions, the tests should indicate what one might expect from the Hydrographic Method as a survey tool. The above objectives can be most conveniently achieved by using a single depth of flow. This will make it possible to attribute any changes in dependent variables for a change in h/D_{50} to the change in the grain size D_{50}. The depth of 20 cm was chosen to maximize the effective working length of the flume. It is known that, when $V_* D_{50} \rho/\mu > 40$, $\Lambda = 2\pi h$. Therefore, by choosing a small depth, a shorter value of dune length Λ is obtained, thereby increasing the number of dunes in the working section. This consideration is advantageous from a statistical point of view.

The methodology used in these tests will be the same as described by Engel (1977). The total length of time for the tests will average out to about one test/week, for a total of 16 weeks. Further testing requirements can then be assessed after the data from the proposed tests has been analyzed.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conditions of bed load transport for flows with a Froude number of 0.1 to 0.25 cannot be achieved in the laboratory flumes at NWRI.

4.2 Since it is impossible to simulate the river conditions exactly, the test schedule is designed to achieve the following objectives:

a) To assess how the accuracy of the Hydrographic Method might vary with Y/Y_{cr} for a given grain size.

b) To see how the method is affected when part of the sediment load travels as suspended load as Y/Y_{cr} becomes larger, up to maximum attainable.

c) To attempt to establish a relationship between number of profiles taken and accuracy of computing the bed load, as a function of Y/Y_{cr} for a given value of h/D_{50}.

d) To see if the accuracy of the method is dependent on h/D_{50}.

4.3 The flume tests must be complemented by field tests. The proposed flume tests will be of great help in planning the field tests, particularly regarding the probable number of profiles required for a particular traverse in the river section.

4.4 Field tests should be planned after the flume tests, and as soon as reliable sampler calibration curves are produced.

REFERENCES

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TABLE 1 EXPERIMENTAL DATA (ENGEL, 1977)

Run	Depth m	Slope	q m^2/s	U m/s
1	.1606	.00184	.0875	.545
3	.1665	.00237	.0875	.526
4	.1498	.00171	.0750	.501
5	.1544	.00227	.0855	.554
6	.1664	.00313	.1015	.610
7	.1626	.00103	.0820	.504
8	.1417	.00196	.0800	.565
13	.1270	.00206	.0605	.476
14	.1287	.00208	.0620	.482
15	.1358	.00231	.0690	.508
D_{50} = 1.1 mm				

TABLE 2 DIMENSIONLESS PARAMETERS

Run	$U/\sqrt{gh}$	Y/Y_{cr}	h/D_{50}	
1	.434	3.25	146	
3	.412	4.35	151	
4	.413	2.82	136	
5	.450	3.86	140	
6	.477	5.74	151	
7	.399	1.85	148	
8	.479	3.06	129	
13	.427	2.88	116	
14	.429	2.95	117	
15	.440	3.46	124	
D_{50}=1.1 mm				

TABLE 3 PROPOSED TESTS OF HYDROGRAPHIC METHOD

OCTOBER 1979		WORK PLAN FOR FLUME TESTS								
Study No. H79-012		Depth of Flow h = 20 cm								No. of Tests**
		Y/Y_{cr}	h/D_{50}	Y/Y_{cr}	h/D_{50}	Y/Y_{cr}	h/D_{50}	Y/Y_{cr}	h/D_{50}	
Grain Size (Sand) D_{50} in mm	1.1	3	182	4	182	5	182	6	182	4
	1.1	8	182	10	182	12	182	max*	182	4
	0.4	3	333	4	333	5	333	6	333	4
	0.4	8	333	10	333	12	333	max*	333	4

* max denotes maximum attainable Y/Y_{cr} in the flume

** one test takes about four working days to complete

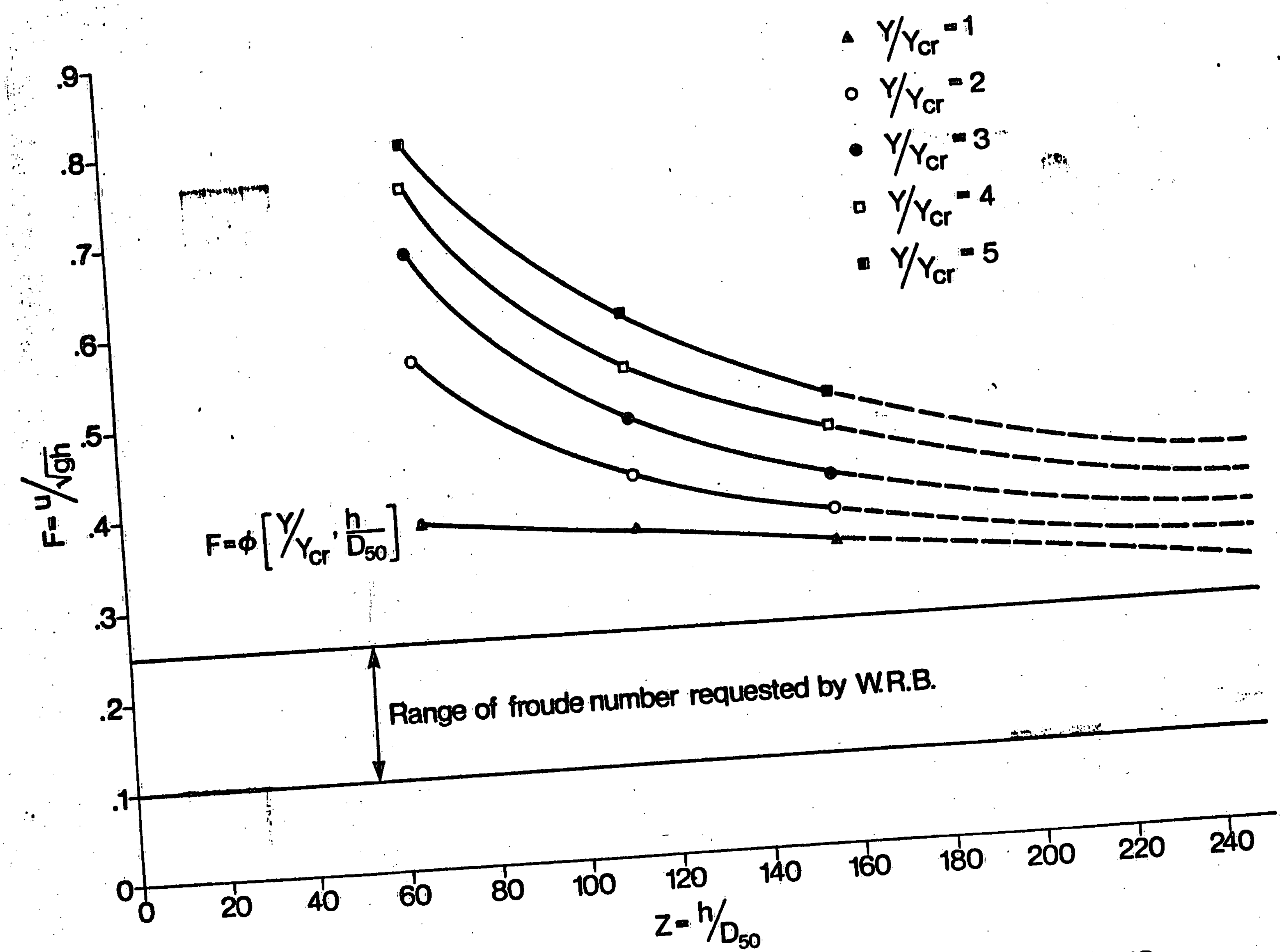

Figure 1 RELATIONSHIP BETWEEN FROUDE NUMBER AND FLOW CONDITIONS (data from Williams, 1970)

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