CUED - Engineering Tripos Part IIA 2020-2021 **Module Laboratory Report**

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Feedback to the student

☐ **See also comments in the text**

		Very good	**Good**	Needs improvement
CONTENT	**Completeness, quantity of content:** Has the report covered all aspects of the lab? Has the analysis been carried out thoroughly?	✓		
	Correctness, quality of content Is the data correct? Is the analysis of the data correct? Are the conclusions correct?		✓	
	Depth of understanding, quality of discussion Does the report show a good technical understanding? Have all the relevant conclusions been drawn?	✓		
	Comments: This is a good report. most of calculations are correct. The discussion on local scour around a cylinder is insightful. There are system errors in our experiment. First, the flume is short and thus the flow may not be uniform. Second, sediment is not circulated (only water is circulated). The lack of sediment input from the upstream end may mean that sediment transport is not in equilibrium.			
PRESENTATION	**Attention to detail, typesetting and typographical errors** Is the report free of typographical errors? Are the figures/tables/references presented professionally?		✓	
	Comments: The report has a good structure. Need to number the figures and tables. Some numbers in the tables contain too many decimal places.			

Raw report mark	4.5 / **5**
Penalty for lateness	

The weighting of comments is not intended to be equal, and the relative importance of criteria may vary between modules. A good report should attract 4 marks.

1 mark / week or part week.
Please use allowance forms to inform the teaching office about mitigating circumstances.

Marker: Jun Ma

Date: 2020.12.13

3D5 Hydraulics Laboratory: Sediment Movement Experiment Report

Louis Zeng (lz406)
Fitzwilliam College; 4th December 2020

Summary

The aims of our experiment are to study the threshold flow conditions under which sediments motion start happening over an immobile bed, and to investigate the relationship between water flow conditions and the resulted bedforms. Also, we qualitatively observed the formation of local scouring phenomenon around a cylinder. Finally, we discuss the reason of local scour occurrence, and mitigation method that might be adapted.

Results and Discussion

(a)

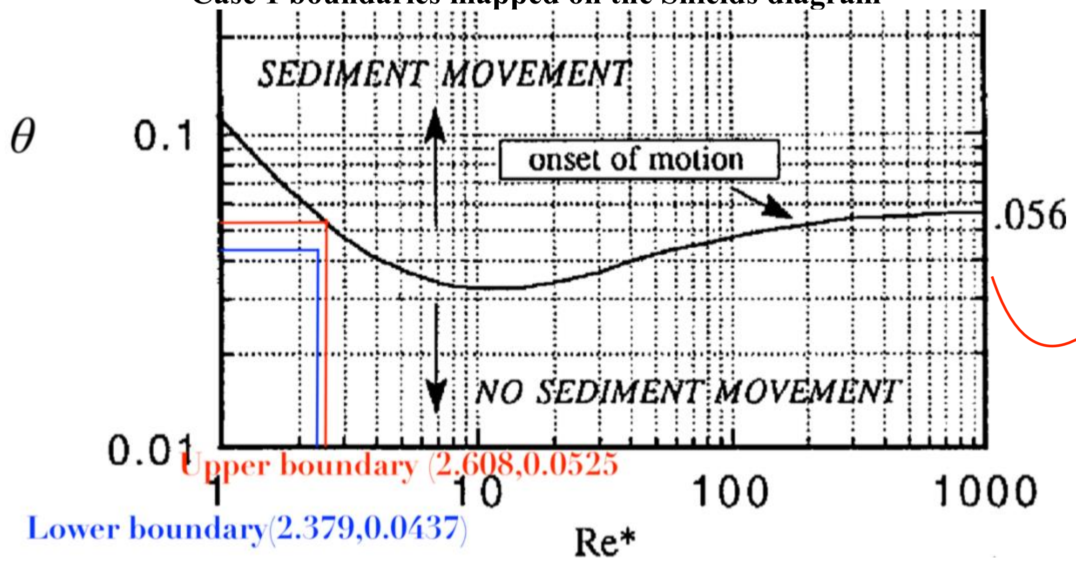
Case 1. Pump speed setting 3, Q=0.2 L/s

onset of particle motion	C	$\tau_b\ (Pa)$	$u^*\ (m/s)$	θ	Re^*
lower boundary ($S_b = 0$, h=1.3cm)	51.942	0.141	0.0119	0.0437	2.379
upper boundary ($S_b = 0.003$, h=1.2cm)	51.318	0.170	0.0130	0.0525	2.608

Soulsby and Whitehouse's equation for threshold condition

Critical Shields parameter θ_c	0.04772
Dimensionless particle size d_*	5.0592

Case 1 boundaries mapped on the Shields diagram



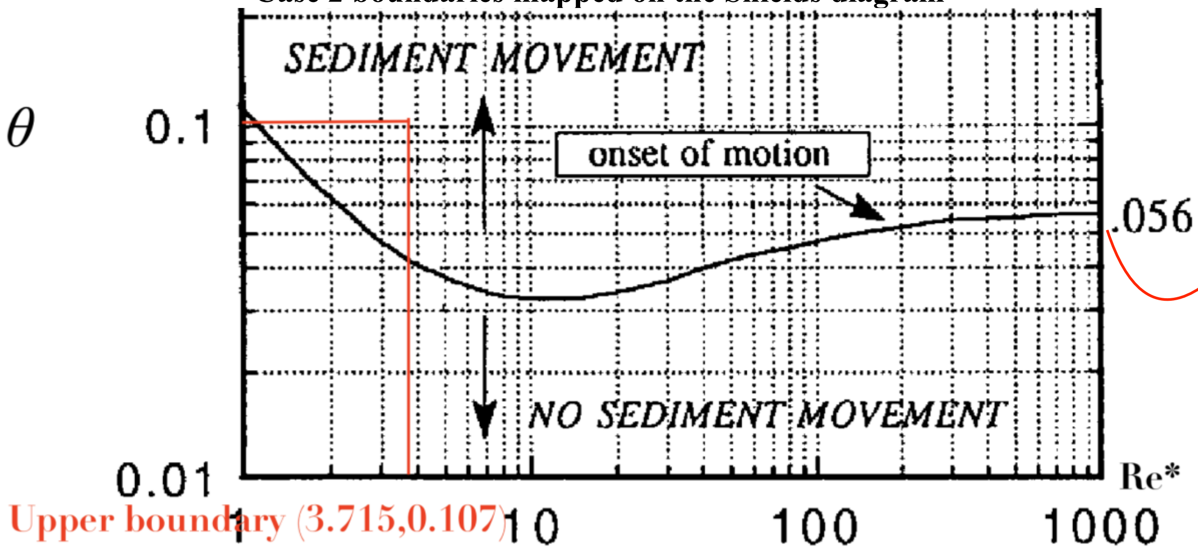
As shown on the graph, when compared with Shields diagram, Case 1 estimation gives a reasonable indication to the threshold of particle motions.

Case 2. Pump speed setting 2, Q=0.6 L/s

onset of particle motion	C	$\tau_b\ (Pa)$	$u^*\ (m/s)$	θ	Re^*
Cannot determine lower boundary	N/A	N/A	N/A	N/A	N/A
upper boundary ($S_b = 0$, h=2.3cm)	56.393	0.345	0.0186	0.107	3.715

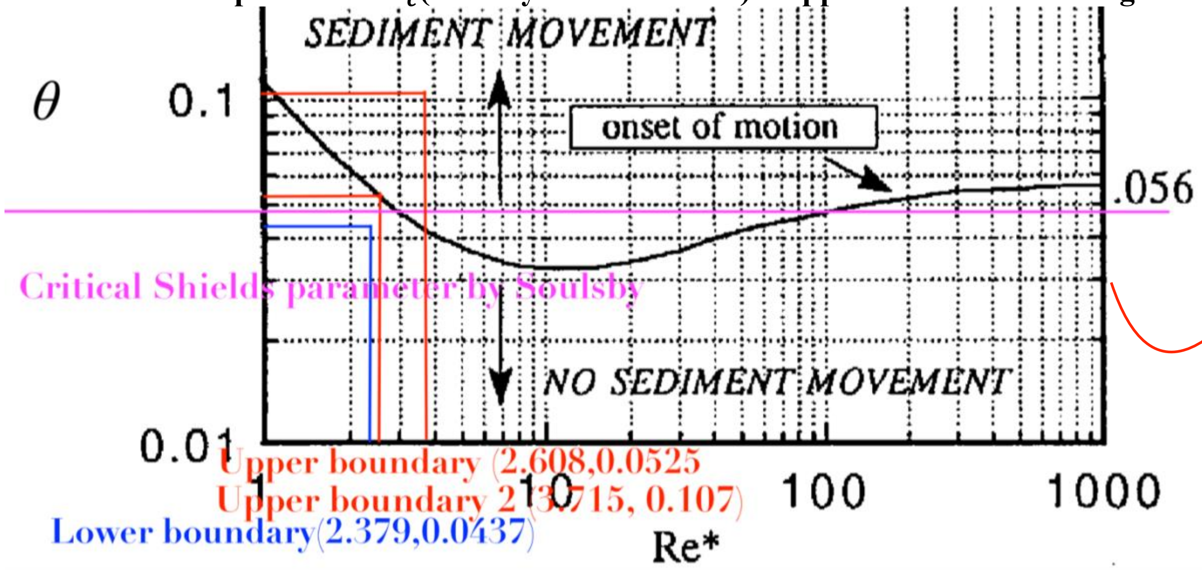
Sediment motion is observed even at the lowest flume slope setting when Q=0.6L/s, therefore no lower boundary of particle motion threshold can be estimated and using $S_b = 0$, h=2.3cm as threshold upper boundary estimation can be inaccurate in this case.

Case 2 boundaries mapped on the Shields diagram



As shown on the graph, when compared with Shields diagram, Case 2 prediction largely overestimated the onset of particle motion, which is to say in Case 2 sediment motion would first be observed for a S_b value smaller than 0.

Critical Shields parameter θ_c(Soulsby & Whitehouse) mapped on the Shields diagram



As shown in the graph above, Soulsby and Whitehouse's formula is close to the estimations given by Case 1,2; and is therefore seem to be a good representation of real critical Shields parameter in our experiment set up.

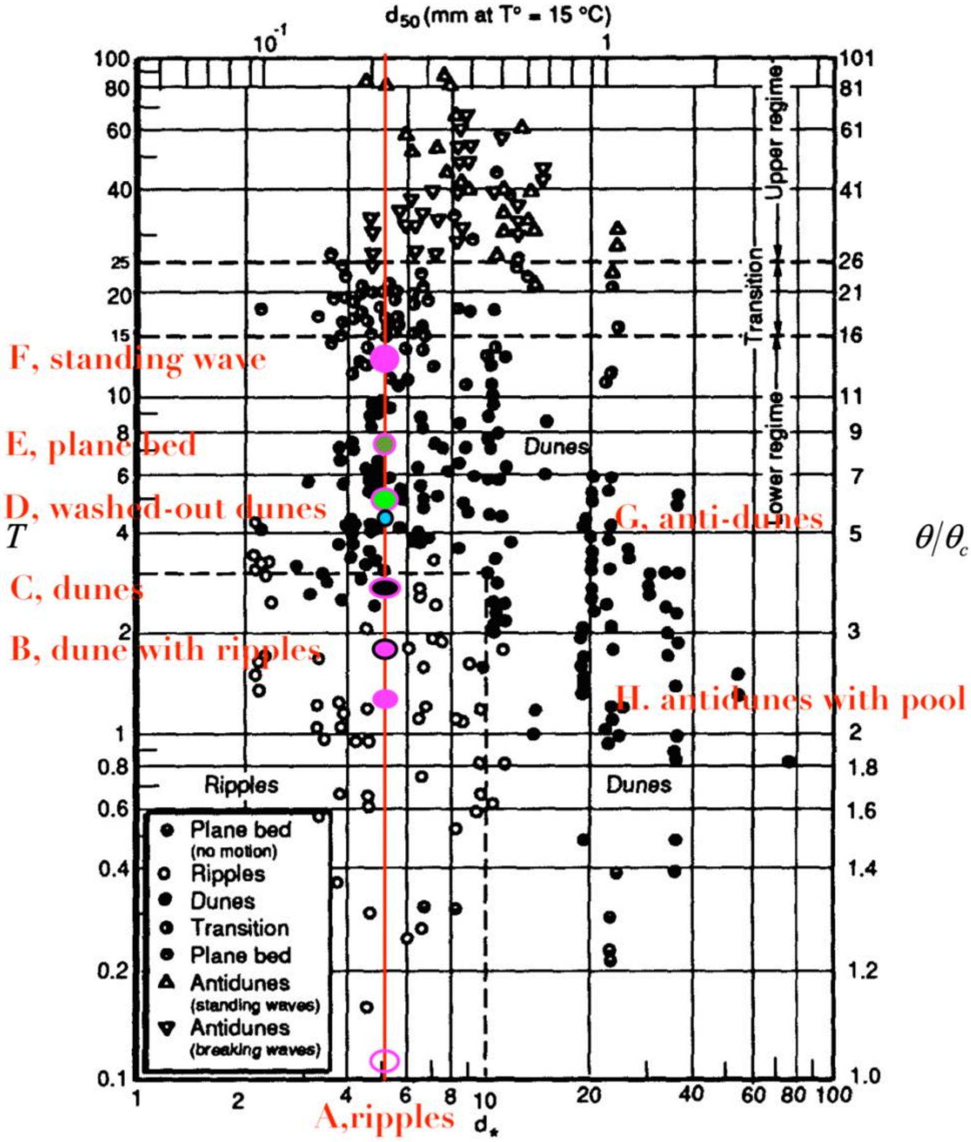
In conclusion, estimating the threshold condition could only give reasonable results when multiple readings are available above and below the threshold condition. (i.e., when Q is small)

(b)

Results of each Bedform for van Sijin's diagram

Bedform	h	C	$\tau_b\ (Pa)$	θ	T
A (ripple)	1.2	51.318	0.170	0.0525	0.101
B (dunes with ripples)	0.8	48.156	0.435	0.134	1.813
C (dunes)	0.7	47.114	0.593	0.183	2.839
D (washed-out dunes)	1.5	53.059	0.916	0.283	4.932
E (plane bed)	0.5	44.490	1.303	0.403	7.437
F (standing waves)	0.4	42.749	2.206	0.681	13.279
G (anti-dunes)	0.6	45.912	0.850	0.263	4.502
H (anti-dunes with pools)	2.2	56.046	0.382	0.118	1.472

T, d* results for each bedform plotted on van Rijin's diagram



(Above) d*−T results plotted on van Rijn's diagram

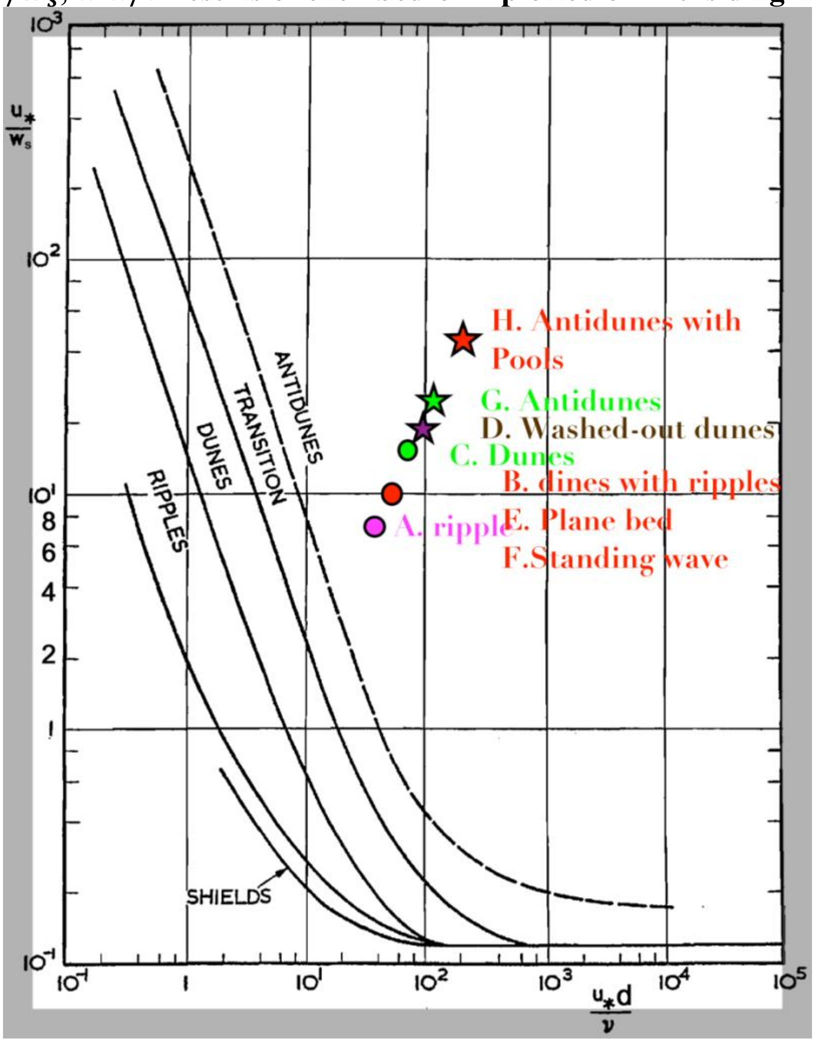
It can be shown that T results for G (antidunes with incipient breaking waves), H (antidunes with breaking wave and pools) are significantly below (<4.5, about 1 magnitude smaller than) the values given by the van Rijn's diagram (>20).
With badforms A(ripples) to F(standing waves), d*−T results from the experiment in general agree with the van Rijn's diagram (for A to F, T results from the experiment are mapped onto the lower band of each bedform groups).

(c)

Results of each Bedform for Liu's diagram

Bedform	$New\ \tau_b\ (Pa)$	$u^*\ (m/s)$	u^*/w_s (Y-axis)	u^*d/v (X-axis)
A (ripple)	35.316	0.188	7.181	37.585
B (dunes with ripples)	62.784	0.251	9.575	50.113
C (dunes)	137.340	0.371	14.162	74.119
D (washed-out dunes)	220.725	0.470	17.953	93.963
E (plane bed)	147.150	0.384	14.659	76.720
F (standing waves)	156.960	0.396	15.139	79.236
G (anti-dunes)	294.300	0.542	20.730	108.499
H (anti-dunes with pools)	1079.100	1.039	39.696	207.759

u^*/w_s, u^*d/v results of each bedform plotted on Liu's diagram



As show in the plot that the u^*/w_s, u^*d/v results for each bedform from the experiment does not overlap with the underlying curves However, from the overall distribution of the points on the graph, similar $u^*/w_s - u^*d/v$ curves for each bedform might exist but located more towards upper-right on the graph and with closer gaps between neighbouring curves than the given curves on Liu's diagram.

(d)

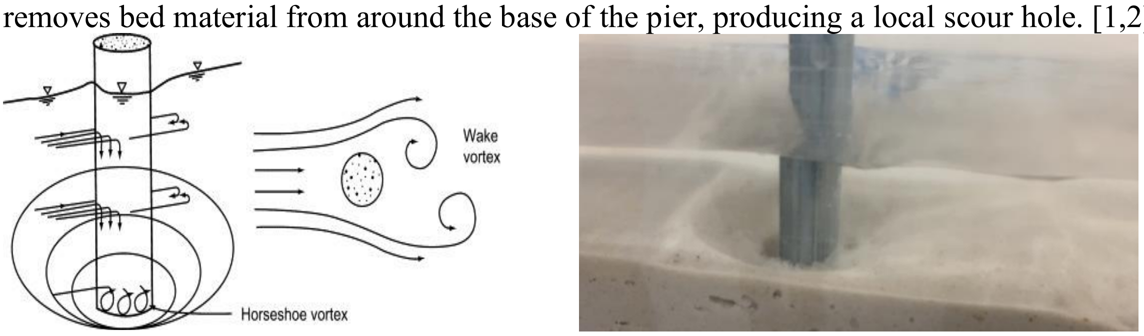
From the results of (b) and (c), we can conclude that qualitatively determine bedform type through comparing bedform diagrams is challenging in practice and yielded results can be reliable to certain extent but hardly accurate.
With the most apparent problem being the bedform downstream along the flume transforms quicker and more apparent than the sand bed upstream, such discrepancy results difficulties in determine the boundaries of bedforms transformations.

(e)

Potential errors/improvements in the experiment are:
1.Flow accelerates along the flume because of its slope, increasing flow velocity will cause bedform downstream more obvious and transform faster than bedform upstream.
2. The nature of quick transforming bedform makes accurate Mean Water Depth h challenging to achieve.
3. Shields diagram should be plotted with a wide band of onset of motion θ- Re* values, rather than a single lined curve. As in reality, there are no absolutely clear boundaries at which sediment motion initiates.

(f)

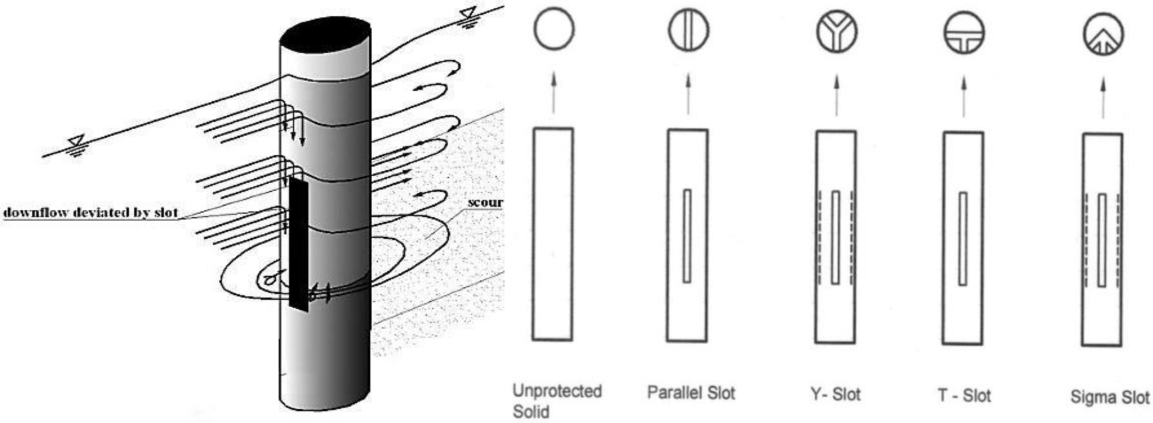
Local scour at bridge piers is caused by horseshoe vortices formed at the base of the pier. Obstruction of flow by a pier results in a stagnation line on the front of the pier. As we recall from basic fluid dynamics, the stagnation pressure is larger than the hydrostatic pressure by an amount equal to the dynamic pressure. The dynamic pressure is proportional to the square of the local velocity and is lower near the bed. Therefore, a downward hydraulic gradient develops in front of the pier that causes downflow directed towards the bed, as shown on the left graph.
We also recall from fluid dynamics that flow past a body separates from the body, and wake vortices form in the separation zone. The boundary layer separation combined with downflow produces the horseshoe vortex wrapped around the base of the pier. This system of vortices removes bed material from around the base of the pier, producing a local scour hole. [1,2]



(Left) Schematic view of vortexes around a pier; (Right) scour around the vertical cylinder.

For safe and economical designs, scour holes around bridge piers are required to be controlled. Reduction of scouring can be achieved by using a horizontal slot through the bridge pier. Such slots help to pass most of the flow through it (because of a favourable pressure gradient), and therefore to cause a much-reduced scour damage.

As shown in the graph, the slot divers the downflow away from the bed, and reduces horseshoe vortex. [3]



(Left) Schematic view of slotted pier and vortices around it; (Right) Possible types of slots.

Conclution

From our experiment results above, it is clear that predicting the flow strength at which sediment movements first begins through graphical method (Shields diagram) cannot give accurate results; and neither van Rijin's diagram nor Liu's diagram give a reliable prediction between bedform types and flow conditions/bed sediment properties they associated with.

Reference

[1] https://www.researchgate.net/figure/Schematic-view-of-vortexes-around-a-pier_fig1_322132029
[2] https://www.sciencedirect.com/topics/engineering/local-scour
[3] http://www.ijeijournal.com/papers/v2i7/B02070715.pdf

Appendix

Table 1. Pump speed at setting 3 and valve closed (Q = 0.2 litre/s)

Flume Slope S_b	Mean Water Depth h (cm)	Sediment Motion Or Not	Bedform
0	1.3	No.	No bedform
0.003	1.2 slight motion	Yes.	ripple.
0.005	0.9	Yes	B. (with ripple up stream)
0.008	0.8	Yes	B. (Deeper dunes)
0.01	0.7	Yes.	B.
0.015	0.8	Yes	C. (Not very obvious)
0.02	0.7	Yes.	C (obvious)
0.025	0.6.	Yes	D
0.03	0.5	Obvious.	E.
0.04	0.4	Fast	F
0.05	0.6.	Fast	G

Table 2. Pump speed at setting 2 and valve open (Q = 0.6 litre/s)

Flume Slope S_b	Mean Water Depth h (cm)	Sediment Motion Or Not	Bedform
0	2.3	Yes	ripple.
0.003	2.2.	Yes.	B
0.005	2	Yes	C.
0.008	1.8	Yes.	C.
0.01	1.6	Yes	D
0.015	1.5.	Yes	D
0.02	1.5	Yes	E
0.025	1.3	Yes	F (take time to form)
0.03	1.6	Yes	F
0.04	2.1	Yes	G
0.05	2.2	Yes	H