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BEDFORM FEATURES WITH GROINS IN SERIES

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1. Introduction

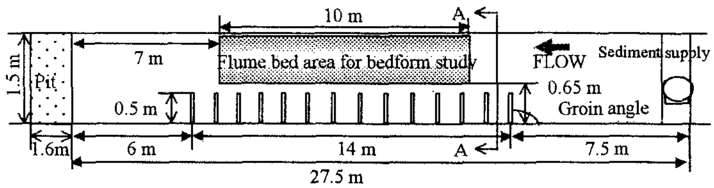

Fig. 1 Experimental setup of groin experiment

Riverbed formations have been studied for a long time without considering the effects of hydraulic structure except for local scour. Fukuoka et al.[1)] studied the bed topography around submersible and impermeable groins in series but not the bedform far from the groin head. Hino[2)] defined minus 3 power law for sand wave spectrum with proportional constant $2.8x10^{-4}$. For ocean waves[3)], the area under the spectral density function is related with the second power of significant wave height. The present study investigates the variation of bedforms and roughness due to the presence of hydraulic structures like submersible permeable and impermeable groins. Similar to ocean waves, a functional relationship is derived for power spectrum of bed profile and bedform height by auto-correlation function and experimental results.

2. Experimental procedure

The flume of the mobile bed shown in **Figure 1** had re-circulation of water and a continuous sediment supply in the upstream. The hydraulic structures used for the experiments were submersible impermeable and permeable groins in series. Hydraulic conditions of one no groin experiment and all other groin experiments were same except changing the arrangement of groins (Table 1). We did another no hydraulic structure experiment with different hydraulic conditions (Table 1). The initial bed was flat with sediment size of 0.80mm and slope in the range of 0.0018 to 0.0016. The protruded height of the groin from the initial bed was considered as groin height. The groins in each experiment were arranged along the left bank (**Fig.1**) at a distance of 6m from the downstream end to 20m upstream with same interval, angle and height (Table 1). Their length and width were 0.5m and 0.05m respectively. We took eight longitudinal profiles, measured along the lines from 65cm to 135cm apart from the left bank of the flume. For bedform measurements the effective flume length was from chainage 7m to 17m. We measured the bed elevation Y, as a function of longitudinal distance x, with an ultra-sonic bed profile indicator where each profile had 71 numbers of bed elevation data.

3. Comparative study of bedform under the effect of hydraulic structure

This analysis shows that bedform varied due to arrangement of groins. Groin height is an important factor influencing the bedform geometry. Case 4 and Case 6 impermeable groin had same arrangement except different groin heights of 3cm and 2cm respectively. Case 6 groin bedform was not only smallest of all other impermeable groin bedform, but also very close to no groin bedform (**Table 1**). Bedform was also function of permeability of groin. Case 7 permeable groin had 3cm of groin height, but its bedform was smaller than impermeable groin having 3cm of groin

Table 1. Experimental conditions and results

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	No groin	No hydr. str.
Permeability	Imper.	Imper.	Imper.	Imper.	Imper.	Imper.	Perm.	Perm.		
Groin angle	105^0	105^0	90^0	90^0	75^0	90^0	90^0	90^0		
Groin interval	1.0m	0.75m	0.75m	1.0m	1.0m	1.0m	1.0m	1.0m		
Groin height, Hg	3cm	3cm	3cm	3cm	3cm	2cm	3cm	5cm		
Water discharge (l/s)	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	36.4	90
Sediment supply (l/s)	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.014
Water surface slope	0.0021	0.0019	0.002	0.002	0.0018	0.0017	0.0017	0.0016	0.0017	0.0021
Final bed slope	0.0028	0.002	0.0019	0.0022	0.0026	0.0018	0.0023	0.0029	0.0014	0.0016
Main flow depth, h (cm)	10.5	8.08	8.58	7.8	8.3	7	7.3	8.2	6.47	14.4
Bed shear vel. u_*(cm/sec)	4.7	3.87	3.81	3.85	3.4	3.5	3.5	3.63	3.32	5.6
Bedform height, H (cm)	2.63	1.85	2.26	1.7	2.16	1.4	1.56	1.9	1.45	4.7
Bedform length, L (cm)	78.4	83.1	78.5	81.4	83.3	114.3	93.5	82.4	118.2	99.8
Significant height, $H_{1/3}$ (cm)	3.84	2.7	3.4	2.6	3.2	2.1	2.2	2.83	2.3	7
Stan. dev. of bed elev. (cm)	1.3	1	1.1	0.9	0.9	0.8	0.8	1.2	0.7	2.7
Equi. roughness Ks (cm)	3	0.98	1.44	1.5	1.58	0.96	0.83	1.08	0.77	8.1

Key Words: Submersible groin, bedform height, bedform length, steepness, spectrum density function.
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height. Bedform steepness indicates geometric properties of sand wave and it is function of transport stage parameter or the Shields parameter $T = (u_*/u_{*c})^2 - 1$. Here, u_* is the bed shear velocity; and u_{*c} is the critical bed shear velocity. **Figure 2** shows the bedform steepness of experimental beds along with Nordin and Algert[4] data. For Nordin and Algert[4] data average bedform height was estimated from significant dune height divided by factor of 1.5 obtained from our experimental results. Groin bedform steepness increased with increase of transport stage parameter. Steepness of no hydraulic structure bed was higher than groin beds, but less than Nordin and Algert data and maximum steepness given by Yalin[5] Bedform steepness for Case 6 bed was almost close to no groin bed. Groin bedform steepness will further increase with increase of tractive force.

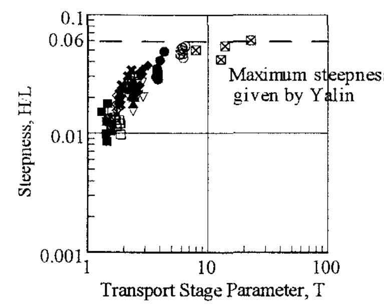

Fig. 2 Bedform steepness

4. Roughness of the experimental beds

Equivalent roughness of the experimental beds was computed by the resistance equation of hydraulic rough flow. **Table 1** shows that the presence of hydraulic structures effected the equivalent roughness. The relative roughness of experimental beds which is function of bedform height and steepness is plotted along with the methods predicted by the investigators[6] (**Fig. 3**). It shows that bedform of groin bed is similar to no groin bed.

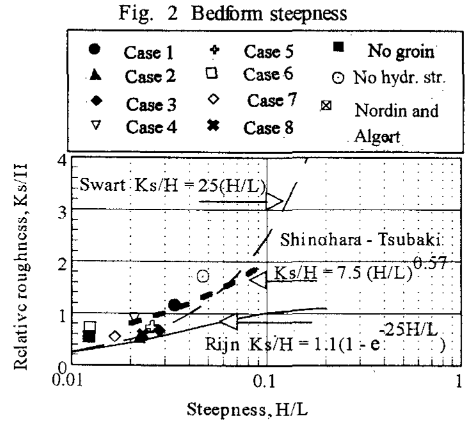

Fig. 3 Comparison of bedform roughness

5. Power spectrum as function of bedform height

The proportional factor of '-3 power law' for the groin beds[7] varied along with bed shear stress. Similar to ocean waves, a relationship between power spectrum and bedform height is derived from auto-correlation function for bed elevation Y(x) with lag distance $\tau = 0$, where Y is bed elevation and x is longitudinal distance. Jain and Kennedy[8] assumed a certain range of wave numbers k_1 to k_n for fully developed bed profiles over which the mean square value of bed elevation might remain unchanged. Assuming that the mean square of dune bed elevation Y is proportional to square of the average bedform height H, the area under the spectrum density function for equilibrium sub-range of wave number k_1 to k_n of the bed profile could be given by

$$\sum_{k_1}^{k_n} S(k_i)\Delta k = cH^2 \tag{1}$$

Here S(k) = power spectrum density (PSD) function, k = Wave number cycle/cm and c = proportional factor. The relation (1) gives the validity to the interpretation of wave number PSD function S(k) of longitudinal bed profile as energy spectrum. The **Figure 4** shows similar relation as equation (1) with 1.5×10^{-4} proportional factor.

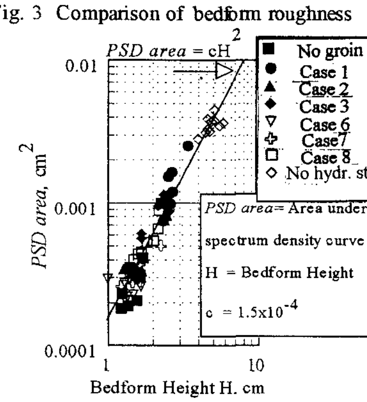

Fig. 4 Spectrum as a function of bedform height

6. Conclusions

Groin bedforms are similar to no groin bedform for relatively low groin height and tractive force. Bedform steepness of groin beds might further increase with increase of tractive force. Bedforms might show different result for higher groin height and larger tractive force. Similar to significant ocean waves, area under the PSD function of sand wave is related to the second power of average bedform height.

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