THE INFLUENCE OF SUBMERSIBLE GROINS IN SERIES ON BED GEOMETRY

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Longitudinal bed profiles and sedimentary bed-forms, one experiment without any groin and five with impermeable submersible groins in series experiments, were investigated in a 27.5m long straight channel in different arrangements of groins. Spectrum analysis of longitudinal profiles near and even very far from groin head showed large amplitude spectral peaks in the region of higher wave numbers. This indicated the groin bed's more irregular sand waves and non-equilibrium sediment transport than no groin bed having same the hydraulic conditions. The bed-form height and bed-form length followed a separate distribution function. The former fitted Rayleigh distribution well and the latter had Normal distribution. The van Rijn empirical formulae for bed-form height and bed-form steepness were modified, and bed-form height and length of groin bed might be estimated from the modified equations.

Key Words: *Submersible groin, bed-form height, bed-form length, bed-form steepness, spectrum analysis, probability distribution, significant sand waves.*

1. INTRODUCTION

River bed formations have been studied for a long time, as they are objects of an interesting morphological phenomenon and river engineering work. To understand the mechanism of sedimentary bedform, researchers have approached to the problem along different lines of inquiry such as statistical and geometrical method. Van Rijn[1)] developed one of the most practically-oriented methods based on flume and some river data for the analysis of alluvial channel bed geometry, and assumed the plane-bed at the Shields parameter or transport stage parameter $T = 0$ and $T > 25$. Later Julien et al[2)] showed non-applicability of the method for large rivers; the van Rijn[1)] method underestimates bed-form height and steepness of large rivers.

Most of the bedform researchers have conducted their studies without considering the effects of hydraulic structure on bed formation except for local scour. Fukuoka et al.[3)] studied the bed topography around submersible and impermeable groins in series but not the bed formation far from the groin head. In the present paper, we investigate longitudinal bed profiles by spectrum analysis and the distribution of bed-form height and length by fitting different distribution functions to find the influence of groin arrangement on bed geometry. In addition to statistical analysis, the variation of bed-form in response to the arrangements of groin is also studied. As the van Rijn[1)] methods underestimated bed-form height and steepness, and had deficiencies in application to large rivers, we attempt to modify them with the view to estimating groin bedform.

2. EXPERIMENTAL DESCRIPTION

The laboratory flume of the mobile bed was 27.5m long and 1.5m wide. It had re-circulation of water and a continuous sediment supply with an instrument carriage moving across the channel in the upstream of the channel. We carried out one experiment without any groin and five groin series experiments with different angles from the left bank of the flume and intervals between two neighboring groins (Fukuoka et al.)[3)]. The angles were 75, 90, and 105 degrees from left bank in anti-clock wise direction (**Fig.1**). The intervals between two neighboring groins were 1m or 0.75m. The submersible groins were 3cm exposed from the initial bed, and their length and width were 0.5m and 0.05m respectively. The groins in each experiment had the

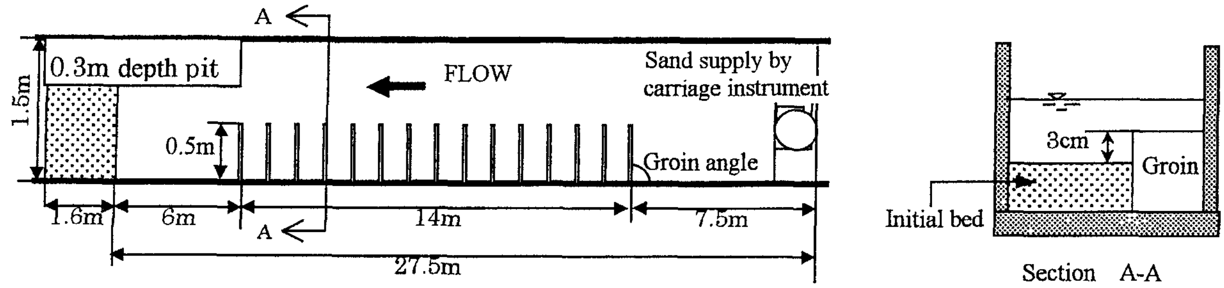

Fig.1 Experimental setup

Table 1 Experimental conditions and results

	Case 1 groin	Case 2 groin	Case 3 groin	Case 4 groin	Case 5 groin	No Groin
Groin angle from left bank	105^0	105^0	90^0	90^0	75^0	
Groin interval	1.0m	0.75m	0.75m	1.0m	1.0m	
Water discharge (l/s)	36.4	36.4	36.4	36.4	36.4	36.4
Sediment supply (l/s)	0.004	0.004	0.004	0.004	0.004	0.004
Water surface slope	0.0021	0.0018	0.0017	0.002	0.0018	0.0017
Final bed slope	0.0028	0.0021	0.0019	0.0022	0.0026	0.0014
Avg. water depth (cm)	10.0	7.9	8.1	8.2	8.3	6.4
Bed shear velocity u_*, (cm/s)	4.5	3.8	3.7	4.0	3.8	3.3
Avg. bedform height (cm)	2.6	1.9	2.3	1.7	2.3	1.5
Avg. bedform length (cm)	78.3	83.1	78.5	81.3	83.3	118.0
Stan. dev. of bed elevation (cm)	1.3	1.0	1.1	0.9	0.9	0.7
Stan. dev. of bedform length (cm)	27.3	34.0	25.5	41.7	34.7	44.6

same interval and angle along the left bank. These groins were placed at a distance of 6m from the downstream end to 20m upstream. The bed consisting of nearly uniform non-cohesive granular sediment with the size of 0.80mm was initially flat, having a slope in the range of 0.0018 to 0.0016. Hydraulic conditions (**Table 1**) were the same for all experiments, except changing the placement of the groins. As the groins were arranged along the left bank of the channel, we took eight longitudinal profiles, measured along the lines from 65cm to 135cm apart from the left bank of the flume. For spectrum analysis, we used 71 numbers of bed elevation data along each longitudinal profile of every experiment.

3. STATISTICAL ANALYSIS

The objective of the spectrum analysis by FFT is to find out the impact of the groins on the mechanism of sedimentary bed-form and longitudinal bed profiles. It can provide information about the geometric properties of irregular sand waves. For the analysis, we measured the bed elevation Y, as a function of longitudinal distance X, with a ultra-sonic bed profile indicator. The spectrum of no groin bed (**Fig. 2**) had a similar slope to the minus three power law' but the proportionality of $2x10^{-6}$ was different from the value stated by Hino[4]. Two spectral peaks experimentally observed by Jain and Kennedy[5] were supposed to describe the physical and geometrical mechanisms of two distinct types of sand waves. The first peak[6] might be related to the bed-form of large wavelength at a lower wave number and the second peak at higher wave number related to the instability of an interaction between the erodible bed and the turbulent flow. Groin bed spectra (**Fig. 4** and **Fig. 5** of groin Case 3 and Case 1, respectively) showed more than two spectral peaks at lower as well as higher wave number, while irregularities of sand waves increased and more groups of smaller wavelength were present compared to no groin bed. Both groin beds longitudinal profiles had a larger bed-form of dune superimposed by small bed-form. At high wave number, sand waves would migrate faster, so smaller sand waves of groin beds will move faster than no groin bed. The proportional constant of '-3 power low' for the groin beds increased by a factor of 10 along with bed shear stress with respect to no groin bed. The difference among these spectra figures **Fig. (2-7)** shows that groin beds experienced more non-equilibrium sediment transport than no groin bed even very far from the groin head. The no groin bed spectrum had peak at lower wave-number and then gradually decreased with the increase of wave-number. The spectrum along the longitudinal line near the head of the groins (**Fig. 6** and **7**) where local scour occurred, had two peaks at a high wave-number. A comparison of all the spectrum figures Fig.(2-7) showed that rough turbulent flow caused groin beds much more disturbance than no groin bed.

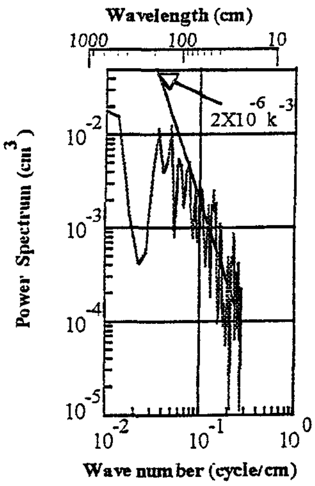

Fig.2 Spectrumof no groin

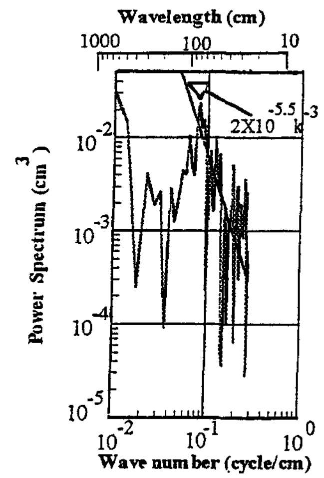

Fig.3 Spectrum of Case 2 groin along long. line 105cmfromleft bank

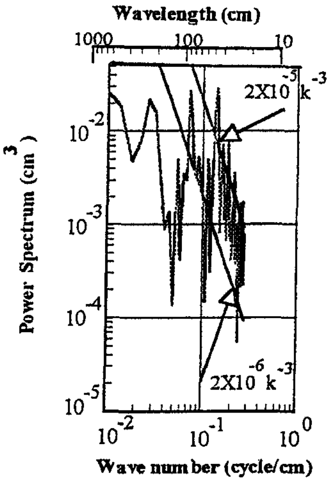

Fig.4 Spectrum of Case 3 groin along long. line 95cmfromleft bank

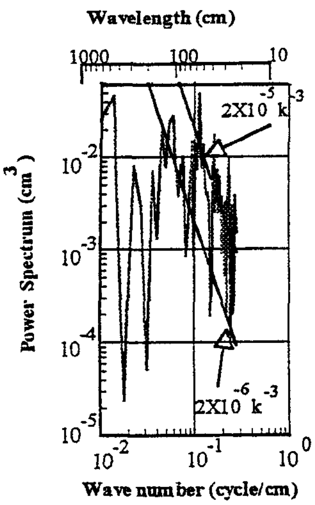

Fig.5 Spectrum of Case 1 groin along long. line 95cmfromleft bank

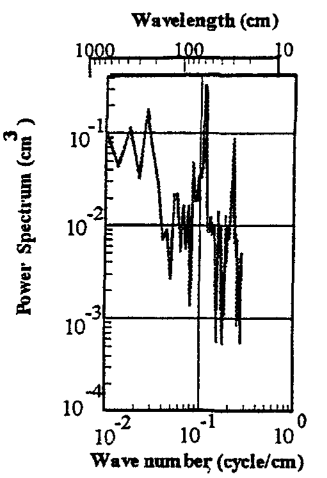

Fig.6 Spectrum of Case 1 groin along long. line 55cmfromleft bank

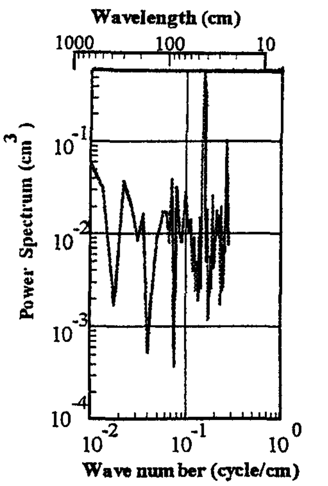

Fig.7 Spectrum of Case 2 groin along long. line 55cmfromleft bank

Ashida and Tanaka[7] approached the probability distribution of dimensionless bed-form height and bed-form length to describe the irregularity of sand waves where experimental results of both bed-form features in the lower regime fitted Rayleigh distribution well. The bed-form height of the present four experiments agreed with Rayleigh distribution (**Fig. 8**), but bed-form length deviated from that distribution (**Fig. 9**), especially for larger and smaller wavelengths. The bed-form height distribution had deviation from one experiment to another with respect to maximum likelihood estimated parameter mode θ of respective bed-form height. The standard deviation of bed elevation σ of each experiment had a relation with the mode $\theta = 1.5\sigma$ (**Fig. 11**). On the other hand, straight and dotted lines of **Fig. 10** indicated that the bed-form length better fitted Normal distribution, where the parameters, mean and standard deviation were estimated from experimental data.

4. VARIATION IN BED-FORM

Even though the groin experiments had same hydraulic conditions as on groin experiment, the former had a larger number of bed-form than the latter. Among them, Case 1 groin bed had the largest number of sand waves with the highest bed-form height and smallest bed-form length, whereas no groin bed was just the opposite. All the groin beds had larger bed roughness than no groin bed. Groin bed-forms converted into smaller wavelength and higher amplitude superimposed by very small bed-form features. Average bed-form height and wavelength (**Table 1**) were measured by neglecting those small bed-forms of each longitudinal line. The distance from the trough of a sand wave to the next downstream sand wave trough was considered as the bed-form length. The difference between the elevations of the sand wave peak and the next downstream trough was estimated as the bed-form height. Nordin and Algert[8] showed that the significant sand wave height $H_{1/3}$ that means average of one-third highest bed-form height was equal to 3 times of the standard deviation of bed elevation. We

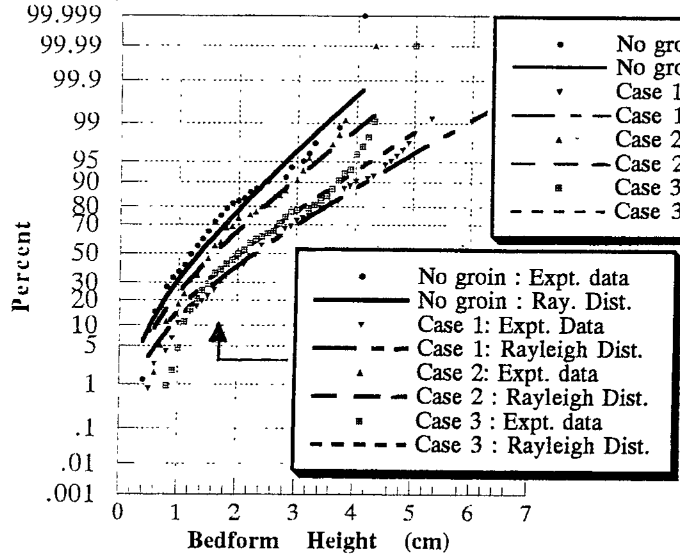

Fig. 8 Distribution of bedform height

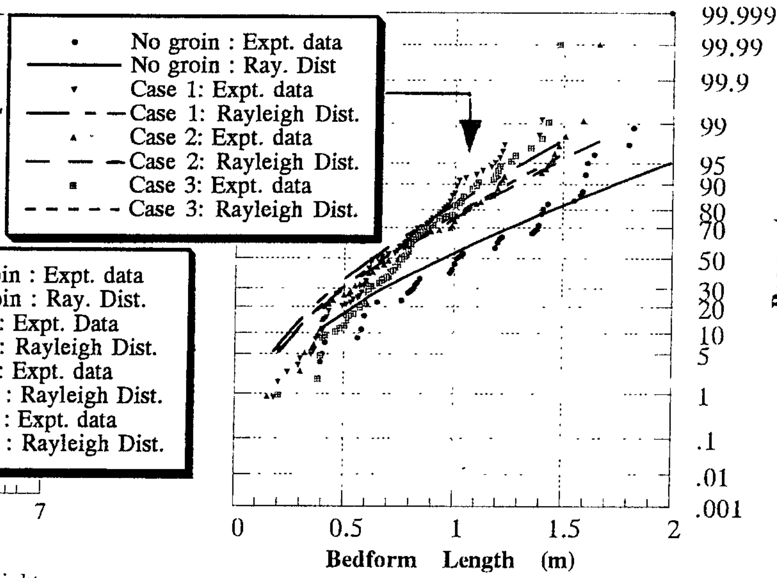

Fig. 9 Distribution of bedform length

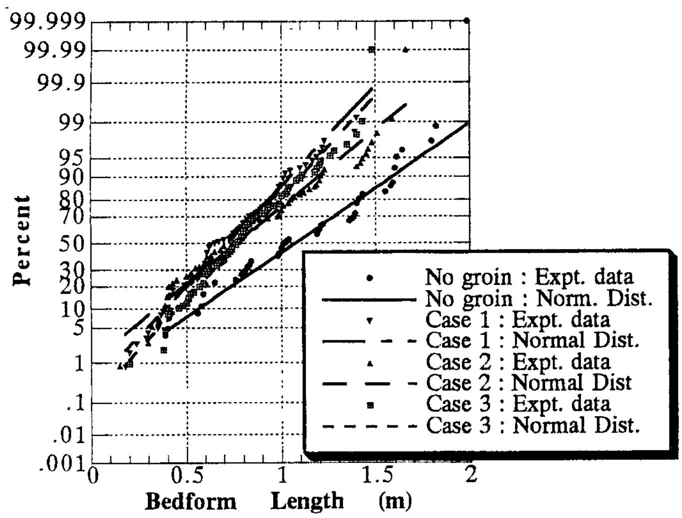

Fig. 10 Distribution of bedform length

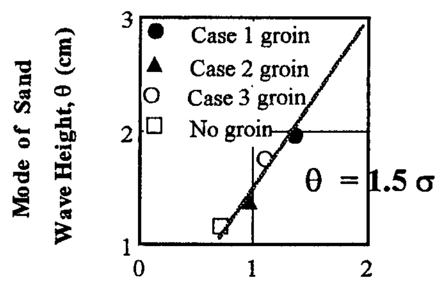

Fig. 11 Relation between mode of sand wave height and standard deviation ofbed elevation

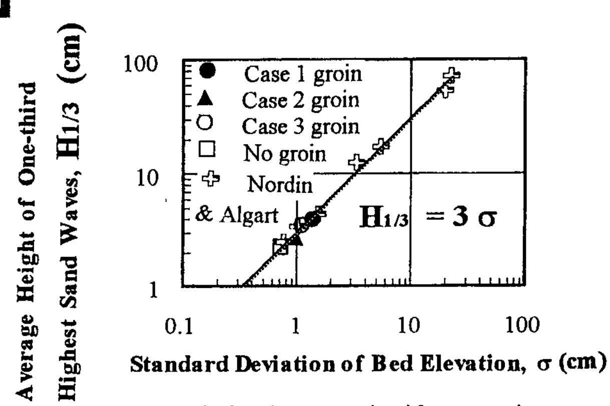

Fig. 12 Relation between significant sand waves and standard deviation ofbed elevation

plotted the authors' data along with Nordin and Algert data in **Fig. 12**. Even in the case of groin beds, the significant sand wave height $H_{1/3}$ was equal to 3 times the standard deviation of bed elevation.

Van Rijn[1] first defined the functional relations of bed-form height H and bed-form length L with average water depth h, bed sand particle diameter D_{50} (50% passing by weight), and the Shields parameter or transport stage parameter $T = (u_*/u_{*c})^2 - 1$. In this paper, we investigated the above relations to compare the variation of bed-form of the groin experiments. Here, u_* is the bed shear velocity; and u_{*c} is the critical bed shear velocity. Van Rijn, who mostly dealt with the flume and some river data, pointed out plane-bed at $T = 0$ and $T > 25$. Julien et al.[2] later investigated the applicability of the van Rijn method during flood condition of large rivers of different countries and showed that an upper-regime plane-bed did not obviously occur at $T = 25$ and the bed-form height parameter $(H/h)(h/D_{50})^{0.3}$ and the bed-form steepness parameter $(H/L)(h/D_{50})^{0.3}$ of the Mississippi River remained constant, even at $T = 47$.

The dune bed-forms[9] may move to transition of plane-bed at a large value of transport stage parameter. And Julien et al.[2] pointed out that during floods some rivers reach plane-bed. We modified the van Rijn empirical formula to apply for laboratory bed as well as for rivers. Combining the data of van Rijn[1], Julien et al.[2], and Yalin[9] each collected from different sources and the authors, the bed-form

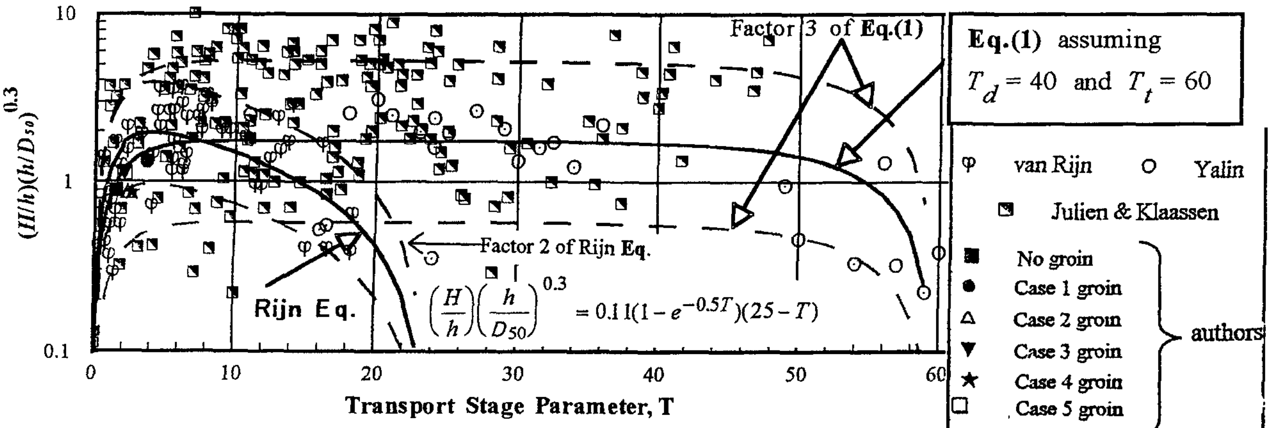

Fig.13 Bedform height

$$\left(\frac{H}{h}\right)\left(\frac{h}{D_{50}}\right)^{0.3} = 0.03(1-e^{-0.5T})(T_t-T)+0.03T-0.065e^{(T-T_d)/6} \tag{1}$$

$$\left(\frac{H}{L}\right)\left(\frac{h}{D_{50}}\right)^{0.3} = 0.006(1-e^{-0.5T})(T_t-T)+0.006T-0.013e^{(T-T_d)/6} \tag{2}$$

$$L = 5h \tag{3}$$

height and the bed-form steepness parameter were plotted as a function of the transport stage parameter in **Fig. 13** and **15.** The best representations were given by **Eq.(1)** and **Eq.(2)** modification of van Rijn method by the authors, where T_d = transport stage parameter at dune height starting to decrease towards transition; T_t = transport stage parameter at transition of upper plane-bed. Both equations had a factor of 3 to describe almost all data. Yalin[10] have shown a family of curves of sand wave steepness depending on h, sand diameter D and T. One of these curves indicates sharp decrease of steepness at T_d =40 and the advanced stage plane-bed after T_t =60. Other curves might have smaller values of T_d and T_t. In **Fig. 13** to **16**, we assumed T_d =40 and T_t=60 for the modified equations. The modified equations might be applied for rivers during flood assuming larger values T_d and T_t, as Julien et al.[2] argued that the bed-form height and bed-form steepness might remain constant at a large value of T for rivers. The dune bed-form steepness will remain constant[11] even at a large value of T until all of the sediment moves as bed load that depends on the size of sand particle. Fredsoe showed two families of curve of bed-form steepness at higher values of T, one for coarse, the other for fine sediment. In both **Eq.(1)** and **Eq.(2)**, bed-form height and steepness parameters initially increase and then remain constant up to T_d, this prediction coincides with the Fredsoe analysis. Similarly van Rijn[1] and Yalin[9] viewed that for $u_* \gg u_{*c}$ bed material will go into suspension and bed form will be converted into plane-bed. Therefore, the value

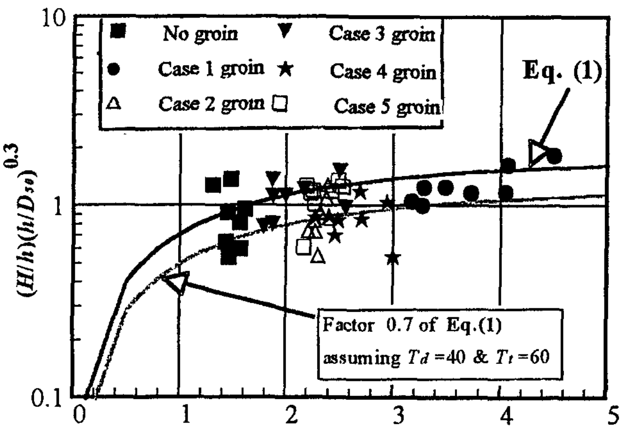

Fig.14 Groin bedform height

of T_d and T_t might depend on sediment particles going into suspension along with other parameters to decrease dune bed-form height and washed it out. The equations can be applied to higher as well as lower values of transport stage parameter at transition by selecting two parameters T_d and T_t and overcoming the under estimation of bed-form height and bed-form steepness of the van Rijn method. The value of T_d and T_t are still not well defined for a river, even the flume flow becomes critical of the upper plane-bed at T = 25, and that requires further study. Equation **(3)** is the expression for bed-form length derived from **Eq.(1)** and **Eq.(2)** which is the same as the data experimentally obtained by Yalin[12]. The modified equations can be used to estimate bed-form height and bed-form length of the groin beds. Average bed-form height and bed-form length parameters of eight longitudinal profiles of each experiment were plotted against transport stage parameter in **Fig. 14** and **Fig. 16**. **Eq.(1)** and **Eq.(2)**

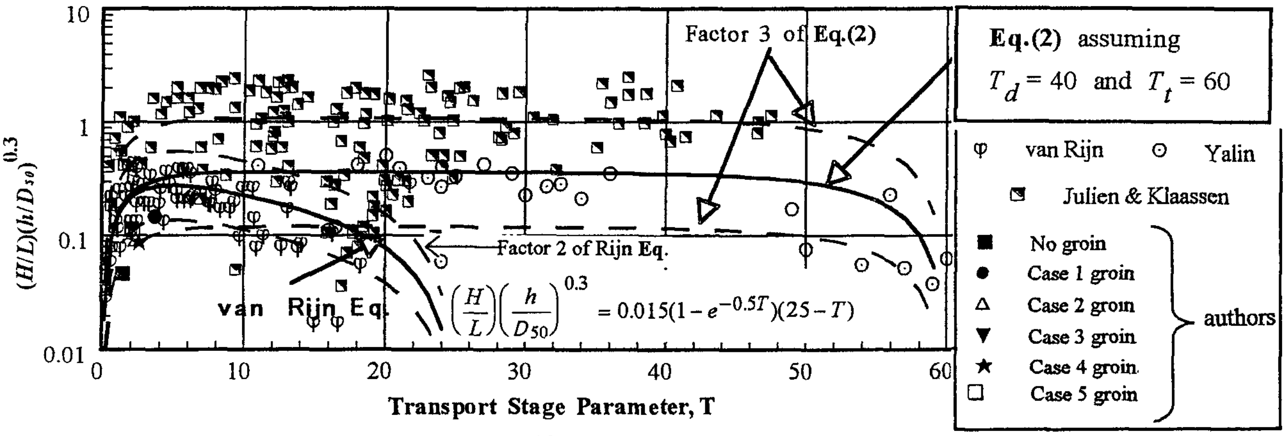

Fig.15 Bedform steepness

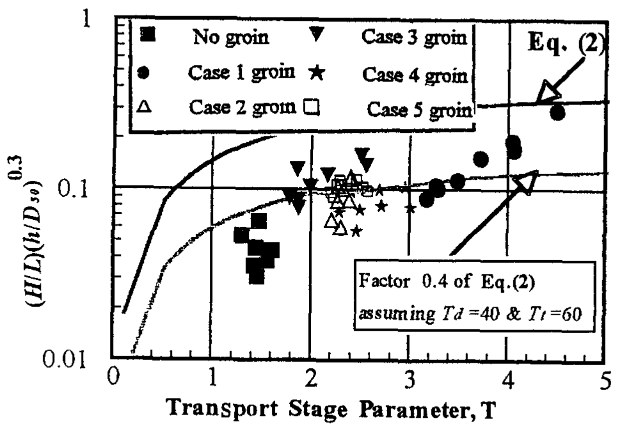

Fig.16 Groin bedform steepness

had factors of 0.70 and 0.4 for the groin bed-form height and bed-form steepness, respectively.

5. CONCLUSION

Spectrum analysis showed that the groin beds had more instability and non-equilibrium sediment transport than no groin bed. As a result, the groin bed converted into higher bed-form height and a smaller wavelength. The proportional constant of '-3 power low' for the groin bed spectrum increased with respect to no groin bed with the increase of water depth and transport stage parameter. Distribution of bed-form height and bed-form length followed the separate probability function. The former fitted the Rayleigh distribution well, but the latter had Normal distribution. The mode of bed-form height was equal to 1.5 times of standard deviation of bed elevation. The groin beds had larger bed roughness than no groin bed. The modified **Eq.(1)** and **Eq.(2)** overcome the deficiencies of the van Rijn method and those might be applied for the laboratory as well as river by selecting two appropriate parameters T_d and T_t. Groin bed-form height and bed-form length can be calculated using these modified empirical equations.

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