Bedforms and roughness of compound and meandering channel flows

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1. Introduction

Previous researchers studied sedimentary bedform and alluvial roughness for straight single section channels and rivers. A great deal of progress has been made for estimation of bedform parameters and river-bed roughness. Natural rivers not only possess straight single section reaches, but in fact the rivers also in many cases have compound and meandering reaches. So far, bedforms of compound and meandering channels has not been studied yet. This paper investigates bedform features and roughness of compound and meandering channel, and compares them to those of straight single section channel. Additionally, it also studies the statistical properties of bedform.

2. Experiment and field measurement

In this paper, we are analyzing five experimental data of a laboratory straight compound flume and three meandering irrigation channel data of the Japanese Hii River. The laboratory flume had 0.9m wide main channel with movable bed and 0.3m wide flood channels with fixed bed on each side of the banks. The bed of the main channel was initially flat consisting of uniform non-cohesive sediment with the D_{50} size of 0.80mm. Among the five experiments, two had bankfull flow and other three had compound channel flow with different relative depth, water discharge and sediment supply. Detail hydraulic conditions of the experiments are shown in Table 1. For the bedform analysis of compound meandering flow, we also used data from Okada et al. (2000). We collected field data of 5.0m wide irrigation channel of the Japanese Hii River for bedform analysis. It is a single section meandering channel. We measured bed profile and water level along two alternate bends. The angles of curvature of two bends were 26.5^0 and 11^0. The length of curvature of the measured channel was 41.5m. Its bed was consisting of uniform sand of D_{50} 1.80mm.

3. Bedform analysis

We measured bedform features by alternate slope change method and alternate zero-crossing method. Both the methods are defined in our previous study (2000). It is observed from this analysis that the bedform height H and bedform length L of straight compound channel (Case 2, Case 3, Case 5) had different characteristics from those of single section (Case 6 and Case 7) and bankfull flow (Case 1, Case 4, Case 11 and Case 12). Compound flow causes larger bedform height and shorter bedform length compared to bedforms of single section flow. Zero-crossing bedform height H_0 and bedform length L_0 varies from the bedform height and length measured by slope change method, especially for the cases of meandering flow. Bedform height ratio H_0/H for meandering channel flow varies from 1.06 to 1.41. On the other hand, bedform length ratio L_0/L is significantly large value for compound and meandering flow (1.24 to 1.30). For the cases of meandering channel flow, both the bedform height and length ratios show larger value compared to single section and bankfull flow. Hii River irrigation channel bedform measurements show different ratio of bedform length to water depth with respect to single section flow. The latter has higher ratio of bedform length to water depth then that of the former.

Table 1: Hydraulic conditions and bedform results

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	**Case 6**	**Case 7**	**Case 8**	**Case 9**	**Case 10**	**Case 11**	**Case 12**
	Straight channel							Meandering channel				
Flow section	Bankfull	Compound		Bankfull	Comp.	Single section					Bankfull	
Relative depth		0.33	0.45		0.4							
Water discharge, l/s	27.5	42.5	58.4	8.3	23.8	36.4	90	2.7×10^6	2.6×10^6	2.4×10^6	14.4	14.4
Sediment supply, l/s	0.011	0.017	0.022	0	0.008	0.004	0.014				0.1	0.2
Water surface slope	0.0026	0.0026	0.0035	0.00245	0.0027	0.0017	0.0021	0.0013	0.0007	0.0007	0.0019	0.0019
Bed slope	0.0026	0.0036	0.0044	0.0029	0.0031	0.0014	0.0016	0.006	0.002	0.005	0.0027	0.0032
Flow depth, cm	5.95	8.62	11	2.77	5.51	6.47	14.4	61.2	71	65	4.97	6.4
u_*, cm/s	3.89	4.5	5.9	2.58	3.5	3.3	5.6	8.83	7.3	6.9	3	3.4
Bedform H, cm	1.75	2.9	3.74	1	1.8	1.45	4.7	8.5	7.75	6.8	5	3.9
Bedform L, cm	135	90	85	210	87	118	99.8	238	205	195	276	256
Bedform H_0 cm	1.84	2.94	3.94	1.1	1.96	1.47	4.98	12	9.2	8.14	5.3	5
Bedform L_0 cm	155	112	110.6	272	113	130	123	297	254	248	297	425
$H_{1/3}$, cm	2.44	3.95	5.3	1.42	2.57	2.3	7	12.4	12	9.8	6.9	6.5
σ, cm	0.71	1.28	1.8	0.7	0.67	0.7	2.7	10.7	12.72	10.5	2.9	2.7
Ks cm	0.33	1.6	3.4	0.31	0.53	0.77	8.1	14.2	12.8	9.8	0.5	1.7

Key Words: Bedform, bed roughness, significant sand wave height, distribution of bedform features
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4. Statistical analysis of bedform

Ashida et al. (1967) showed that dimensionless bedform heights and lengths fitted the Rayleigh distribution. Later, it had been noted (Bahar & Fukuoka, 1999) that groin bedform heights agreed with the Rayleigh distribution but the bedform length deviated from that distribution, especially for larger and smaller wavelengths. The distribution of bedform lengths rather fitted Normal distribution. This study observes that bedform heights of straight compound channel do not follow Rayleigh distribution. Rather, both the bedform features of this channel agree with (Figure 1) Normal distribution. Because of the different geometrical characteristics of bedform for a compound channel, its distribution varies from that of single section bedform.

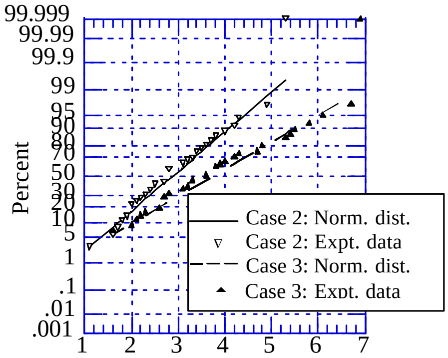

Figure 1: Distribution of bedform height

The significant sand wave height $H_{1/3}$ of a straight channel, even in the presence of groins (1999) in series, was equal to 3 times the standard deviation of bed. The present analysis shows (Figure 2) that this relationship exist for straight compound channel excepting in the case of meandering irrigation channel of the Hii River.

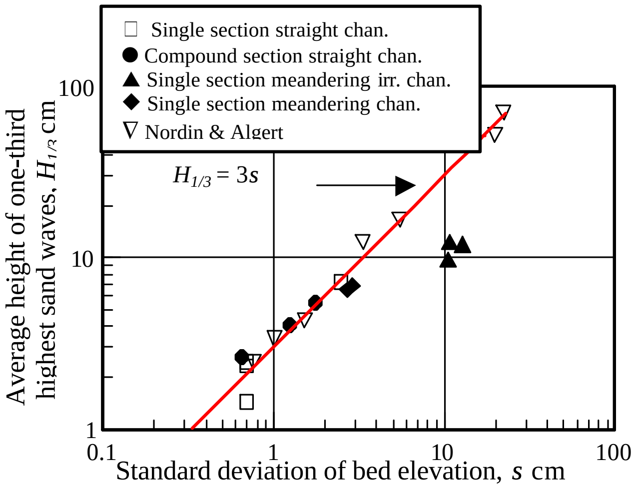

Figure 2: Significant sand wave height

5. Bed roughness

We used resistance equation of hydraulic rough flow to estimate equivalent roughness of the beds. For the compound channel beds, Einstein's formula was used to calculate hydraulic radius of main channel in order to eliminate the effects of side wall. Bed shear velocity u* of these beds was obtained through estimation of Manning's roughness coefficient for sand waves. Thereafter, the hydraulic radius and the bed shear velocity were used to calculate equivalent roughness Ks for the compound channel flow. In Figure 3, relative roughness, Ks/H ratio, of the beds is plotted along with bedform roughness equations given by Shinohara et al. (1959) and Rijn (1982). Rijn's expression was based on straight flume and field data of dune bed from different sources. Shinohara et al. used the Hii river without any irregularities and straight irrigation channel data. Because of momentum transfer from main channel to flood channel and shear stress acting along main channel/flood channel interface, flow behavior in the compound straight channel is complicated and different compared to single straight channel flow. Therefore, bedform steepness of the former channel is much larger than that of the later channel. As the bedform roughness is related with sand wave steepness, the compound single channel bed provides larger resistance to flow compared to the single straight channel bed. The present analysis shows that the bedform steepness and relative roughness of compound straight channel increases with increase of tractive force. Even though the bedform roughness relations of Rijn and Shinohara & Tsubaki were based on single section flume and field data, bedform steepness and relative roughness of the compound straight channel, single meandering channel and single straight channel are shown in Figure 3. The meandering irrigation channel data, which had larger sediment size than the experimental channels, is in far and upper limit of Rijn's equation. It seems to follow a line along with single straight channel data close to the expression of Shinohara & Tsubaki. For the compound straight beds, the relative roughness increases with bedform steepness and crosses the Rijn's expression. As natural streams are neither two-dimensional nor straight, it is important to go through further study of bedform roughness for compound and meandering channel flows.

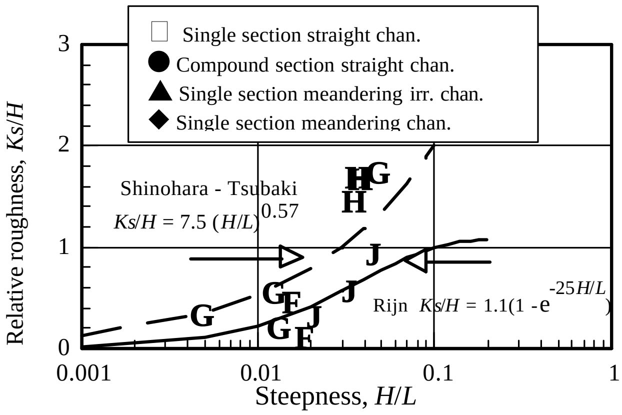

Figure 3: Relative roughness.

6. Conclusions

The compound straight channel flow causes different characteristic of bedform compared to the bedform of single straight channel flow. Zero-crossing bedform height and length of the single meandering channel was significantly larger than those of slope change method. Bedform heights of straight compound flow do not follow Rayleigh distribution, rather they fit Normal distribution well. The relationship between significant sand wave height and standard deviation of bed elevation, as stated by Nordin et al., does not hold for the meandering irrigation channel. Because of complex flow behavior in the compound straight channel compared to single straight channel, larger bedform steepness of the former causes higher bedform roughness than that of the latter.