The effect of bedform on increasing the flow depth

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ABSTRACT

Through sediment transport in alluvial channels, regular and alternating triangular-shaped patterns known as bedforms develop on the riverbed. Depending on the flow characteristics and regime, the geometric dimensions of these bedforms evolve, significantly influencing bed roughness and, consequently, increasing flow depth—particularly under ripple and dune conditions. Predicting flow depth based on bed roughness is therefore a critical aspect of hydraulic modeling and the design of hydraulic structures. In movable-bed channels, estimating flow resistance and its corresponding depth poses a major challenge due to the inherent uncertainty associated with the formation and transformation of bedforms. As such, developing a reliable, straightforward, and practical relationship to estimate the maximum flow stage in the presence of bedforms is both important and necessary. This study presents a simple and practical linear relationship for predicting flow stage under lower flow regime conditions, based on 292 recorded experimental cases from four reputable research sources. From this relationship, a coefficient of 1.25—referred to as the Tabriz University coefficient—is introduced, which significantly simplifies calculations of flow depth in the presence of ripple and dune bedforms without requiring detailed geometric information of the bedforms. The accuracy of this coefficient in estimating flow depth was found to be acceptable. Furthermore, a corresponding relationship for estimating the Manning roughness coefficient based on the flat-bed Manning coefficient was derived using this special coefficient. The performance of the proposed relationship for Manning's coefficient was validated under controlled laboratory conditions in rectangular flumes. however, its application to natural channels remains outside the scope of this study and is suggested for future research.

KEYWORDS

Dune bed form, ripple, flow resistance, Manning coefficient, Tabriz University coefficient

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Introduction

The formation of dune and ripple bedforms in alluvial rivers markedly increases bed roughness, which appears as a discontinuity in stage–discharge rating curves due to enhanced flow resistance. Research on this topic has generally followed two approaches: evaluating total bed roughness and isolating bedform-induced roughness. Based on laboratory and field data, several empirical relations have been proposed. Einstein and Barbarossa [1] related relative shear velocity $\left(v/u_*''\right)$ to particle size, hydraulic radius and density. Engelund [2] expressed energy slope as a function of flow depth and Froud number. Van Rijn [3] linked roughness to grain size and bedform geometry. Liu et al. [4] proposed a relation for Manning's coefficient as a function of Froude number and relative flow depth.

2. Methodology

A comprehensive review of previous investigations on flow resistance in alluvial rivers reveals that flow resistance is governed by hydraulic parameters, sediment properties, channel geometry, and the geometric characteristics of bedforms. Among these factors, the geometry of bedforms is a dependent variable that is determined by the interaction of the other parameters. Accordingly flow resistance can be expressed as a function of three independent variables: hydraulic, sediment, and channel geometry parameters. It can thus be anticipated that the flow depth in the presence of bedforms is proportional to the flow depth over a flat bed. To validate this hypothesis and establish the corresponding relationship, laboratory datasets from the studies of Guy et al. [5], Barton and Lin [6], Wang and White [7], and Williams [8] were employed (Table 1). Based on the hydraulic conditions, sediment characteristics, and flume geometry, the hypothetical flow depth for a flat bed (y_0) was first calculated. The computed depth was then compared with the measured flow depth in the presence of bedforms (d) (Figure 1).

The comparison between these two depths revealed a regression relationship (Eq. 1). According to this relationship, the formation of bedforms under lower flow regime conditions results in an approximate 24% increase in the flow stage, in addition to an increment of 14 millimeters.

(1) $$d = 1.2445 y_0 + 0.0139$$

3. Results and Discussion

Eq. (1) demonstrates an acceptable level of accuracy. Moreover, its application is straightforward, allowing for the direct estimation of flow stage over mobile beds without the need for iterative procedures or trial-and-error adjustments. Eq. (1) reflects the influence of dune and ripple bedforms on increasing the bed roughness and the corresponding equivalent flow depth. With reasonable approximation, this relationship can be rewritten in the simplified form of Eq. (2).

(2) $$d \approx 1.25 y_0$$

The coefficient of 1.25, which provides a simple representation of the relationship between the flow depth over a flat bed and that over bedforms, is referred to as the Tabriz University coefficient. To evaluate the accuracy of Eq. (1) and (2), the flow depth was also estimated using the methods proposed by Simons and Richardson [9], van Rijn [3], and Karim [10]. The results of these Methods were compared with the performance of Eq. (1) and (2), as presented in Table 2. For this comparison, the statistical indices of the correlation coefficient (R), coefficient of determination (DC), and root mean square error (RMSE) were employed.

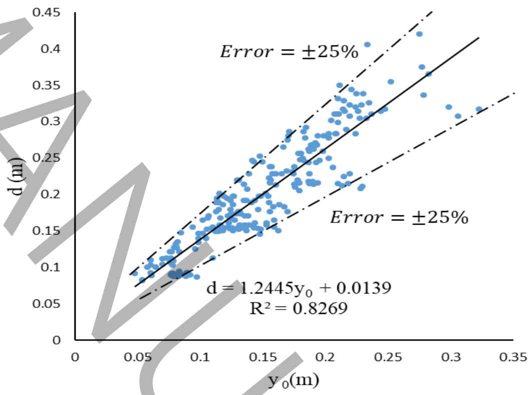

Figure 1. Effect of ripple and dune bed form on change of flow depth

4. Conclusion

- The newly developed linear relationship (Eq. 1) for estimating flow depth over mobile bed does not require any information regarding bedform dimensions. Furthermore, since the maximum flow resistance typically occurs under dune and ripple formation conditions, the proposed relationship can be utilized for estimating the maximum flow stage

Table 1. Experimental data used in this study

Source	Run	D_{50} mm	S ×1000	Flume width m	d cm	Q L/s	Number of runs with Dune or Ripple
Guy [**5**]	228	0.19-0.93	0.07-13.6	2.438	9-40	56.6-639	158
Barton and Lin [**6**]	25	0.18	0.44-2.1	1.219	9-23.7	25.5-229	19
Wang and White [**7**]	108	0.076-0.76	0.01-10.73	1.2	6.2-36.5	225-409.9	40
Williams [**8**]	177	1.35	0.6-36.7	0.075-1.19	2.4-22.5	10.2-315.8	75

Table 2. Verification and evaluation of the accuracy of Eq. (1) and (2) in estimating the flow depth and comparing it with the methods of other researchers

Methods	**Percentages of data lying within different error bands (%)**				**Statistical Parameters**		
	±10	±20	±25	±30	R	DC	RMSE
Simons and Richardson [9]	29	57	71	76	0.863	0.782	0.0022
Van Rijin [3]	49	82	86	93	0.938	0.844	0.0016
Karim [10]	43	86	94	98	0.917	0.918	0.0008
Eq. (1)-Linear Relation	45	75	82	88	0.929	0.927	0.0007
Eq. (2)-Tabriz University Specific Coefficient	39	78	90	94	0.929	0.921	0.0008

during design discharge occurs, even in the absence of detailed information about the bed morphology. Validation of the proposed linear equation indicates that it exhibits an error of less than 20% in approximately 75% of the cases, demonstrating its acceptable level of accuracy and reliability.

- According to the proposed linear relationship, the ratio of flow depth in the presence of bedforms to that over a flat bed is equal to 1.25. Validation of this coefficient demonstrates satisfactory accuracy, with computational errors of less than 20% observed in approximately 78% of the cases.
- Since the newly developed relationship was derived based on laboratory data obtained from rectangular flumes, it is recommended that future studies evaluate the performance of this approach using field data collected from natural alluvial channels.

4. References

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