Variations in roughness predictions (flume experiments)

D. Noordam¹, A. Blom¹, H. van der Klis² & S.J.M.H. Hulscher¹
¹Department of Water Engineering and Management, Faculty of Engineering Technology, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands; d.noordam@ctw.utwente.nl
²WL | Delft Hydraulics, P.O. Box 177, 2600 MH Delft, The Netherlands.

Abstract
Data of flume experiments with bed forms are used to analyze and compare different roughness predictors. In this study, the hydraulic roughness consists of grain roughness and form roughness. We predict the grain roughness by means of the size of the sediment. The form roughness is predicted by three approaches: Van Rijn (1984), Vanoni & Hwang (1967) and Engelund (1966). The total roughness values (friction factors) are compared with the roughness values according to the Darcy-Weisbach equation. Results show that the different methods predict different friction factors. In future research uncertainties in the hydraulic roughness will be taken into account to determine their influence on the computed water levels.

Introduction
In the Netherlands, the heights and strengths of dikes and other flood defense systems are based on computed water levels which occur during a certain extreme discharge, i.e. the design discharge. The uncertainty in the hydraulic roughness of the river bed is one of the main sources of uncertainty in these computed water levels (Van der Klis, 2003). The purpose of the present research is to compare different state-of-the-art roughness predictors and examine the influence of the roughness predictor on water levels. We use the same approach as Julien et al. (2002). The overall aim of this study is to gain knowledge on the size and type of uncertainties in the hydraulic roughness and their influence on computed water levels.

Material and methods
Flume experiments were conducted by Blom et al. (2003) in the sand flume facility at WL|Delft Hydraulics in the Netherlands (1997-2000). The experiments were performed under steady uniform flow conditions and sediment from the Waal River (near the Pannerdensch Kop) was used. The experiments were aimed at conditions with bed forms. Their heights (Δ) and lengths (Λ) were measured, as well as the hydraulic radius (R), flow depth (h), flow velocity (u) and the energy slope (i). We derive the friction factors by means of two different methods. The first method gives the reference values. It uses flow data and the Darcy-Weisbach equation:

\[ f = \frac{8gRi}{u^2} \]  

The second method for calculating the roughness is using a roughness predictor. In these experiments the only sources of roughness are grain roughness \( f' \) (caused by the protrusion of grains from the bed into the flow) and form roughness \( f'' \) (created by the pressure differences over bed forms). The sum of grain and form roughness gives the total roughness. To calculate the grain roughness we distinguish between a roughness height \( k'_{s} \) of \( d_{90} \) and \( 3d_{90} \). The value of the roughness height can be converted to a value for \( f' \) with the following relation (Van Rijn, 1993):

\[ f' = 0.24 \log \left( \frac{12R}{k'_{s}} \right)^{2} \]  

For calculating the form roughness we study three models. For the Van Rijn (1984) approach (3), a value for \( f''_{v} \) is obtained by applying equation (2) (using \( k''_{s} \) instead of \( k'_{s} \)).

\[ k''_{s} = 1.1 \left( 1 - e^{-\frac{2s\Delta}{k'_{s}}} \right) \]  

The other two models are the Vanoni & Hwang (1967) approach:

\[ f''_{vh} = \left( 3.3 \log \left( \frac{\Delta R}{\Delta - 2.3} \right) \right)^2 \]  

and the Engelund (1966) approach:

\[ f''_{e} = 10 \left( \frac{\Delta^{2}}{RA} \right) e^{-\frac{2s\Delta}{h}} \]

Results and preliminary conclusions
Figure 1 shows some results of the calculations. The experiments T5, T7, T9 and T10 were conducted under different flow conditions, i.e. different discharges, velocities and slopes. All roughness predictors yield a larger friction factor than the Darcy-Weisbach reference value. From other calculations it
appears that a difference of 0.05 in the friction factor (f) can lead to a 20 cm change in hydraulic radius (R), and thus a significant change in water levels. The results give a first impression of the uncertain hydraulic roughness and show that variations in friction factors influence calculated water levels.

**Further research**

Plans for future research are first to choose the most appropriate roughness predictor (based on the flume experiments). Then, we want to include uncertainties and perform a Monte Carlo analysis to examine the influence of the uncertain hydraulic roughness on water levels. Furthermore, we will examine what the results of the flume experiments mean for field situations.

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**References**


