2006

Reply to comment by M. Bayani Cardenas and John L. Wilson on "Flow resistance and bed form geometry in a wide alluvial channel"

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Abstract

The authors would like to thank Cardenas and Wilson [2006] for their valuable comments and interesting discussions.

Keywords

bed, resistance, flow, form, alluvial, geometry, wide, reply, l, john, cardenas, bayani, m, channel, comment, wilson

Disciplines

Engineering | Science and Technology Studies

Publication Details

Yang, S., Tan, S. & Lim, S. (2006). Reply to comment by M. Bayani Cardenas and John L. Wilson on "Flow resistance and bed form geometry in a wide alluvial channel". Water Resources Research, 42 (6), 1-3.

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Received 19 January 2006; revised 7 March 2006; accepted 14 April 2006; published 8 June 2006.

Citation: Yang, S.-Q., S.-K. Tan, and S.-Y. Lim (2006), Reply to comment by M. Bayani Cardenas and John L. Wilson on ''Flow resistance and bed form geometry in a wide alluvial channel,'' *Water Resour. Res.*, *42*, W06602, doi:10.1029/2006WR004915.

[1] The authors would like to thank *Cardenas and Wilson* [2006] for their valuable comments and interesting discussions. The main points raised by the commenters are summarized as follows.

[2] 1. Cardenas and Wilson's main interest lies in the estimation of the characteristic length (L'') of the separation zone behind the bed form.

[3] 2. Equation (28a) of *Yang et al.* [2005] suggests that α may vary from 12 to 45, while *Engel* [1981] and *Karahan and Peterson* [1980] suggested that α has a value in the range of 4–6; thus it appears that equation (28a) overestimates the value of α by as much as 300% or more. The commenters concluded that the errors in α propagates into the analysis for the energy slope.

[4] 3. The commenters were not clear on the values of α used for the calculation of S_c, and how Figure 4 of the Yang et al. was derived. The commenters assumed that the authors had used a value of $\alpha = 16$ in the computation of energy slope S and found that the value of α was not constant.

[5] The authors would like to stress that the objective of the paper is to develop a method to estimate the energy slope using easily obtainable data from the field or laboratory, such as the discharge, channel width, flow depth and sediment size. We will show that the different conclusions drawn by the commenters and the writers are attributable to the different research objectives.

[6] First, the authors' purpose is to evaluate the energy slope S which is expressed as follows (equation (6) of Yang et al.)

$$S = S'\frac{L'}{L} + S''\frac{L''}{L} \tag{1}$$

It can be seen that $S''L''$ is lumped together in the second term on the right-hand side of RE (1) (hereinafter RE will be used to indicate an equation is from this reply to distinguish between equations from this paper and those of the original article by *Yang et al.* [2005]). For any given value of $S''L''$, suppose the eddy length L'' is underestimated (or overestimated), S'' will be overestimated (or underestimated) correspondingly and the product $S''L''$ would remain the same and is unaffected. This means that the errors due to the eddy length value will not be "propagated" into the analysis. In other words, if equation (28a) overestimates α or L'' by, say as much as 300% or more, the calibration of the measured data will correspondently underestimate S'' by the same percentage, and S calculated using RE (1) would be valid. Obviously, if the intermediate variable α is used to compare with the measured data in the manner described by the commenters, the results would be unacceptable.

[7] Second, the authors would like to take this opportunity to explain how α is determined in order to calculate S_c (S_c is used by the commenters which is equivalent to S of Yang et al.), and how Figure 4 of Yang et al. is obtained. Determination of α begins with equation (3) of Yang et al. and presented by the Cardenas and Wilson as follows:

$$\alpha = \frac{u_*^2 - u_*'^2}{u_*''^2 - u_*'^2}\frac{L_a}{\delta_a} \tag{2}$$

where the subscript a refers to actual experimental values as defined by the commenters. RE (2) shows that α (or L'') is a function of u_*'' which is in turn dependent on S'' or k_s'' as can be seen from the following equations,

$$u_*^2 = gR_aS_a \tag{3}$$

$$u_*' = \frac{V_a}{2.5\ln\frac{11R_a}{2d_{50}}} \tag{4}$$

$$u_*'' = \frac{V_a}{2.5\ln\frac{11R_a}{k_s''}} = \sqrt{gRS''} \tag{5}$$

$$k_s'' = \delta_a\left(\frac{\delta_a}{L_a}\right)^p \tag{6}$$

where *p* is an empirical exponent.

[8] RE (2) to RE (6) show that once the measured velocity V_a, hydraulic radius R_a, energy slope S_a, sediment size d_{50}, bed form geometry δ_a and L_a are known, the values of α can be determined. Yang et al. used data sets from *Guy et al.* [1966] and *Williams* [1970] to calculate α and plotted against δ/h as shown in Figure 4. Equations (28a) and (28b) were obtained based on the trend lines of the data in Figure 4. and

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0043-1397/06/2006WR004915

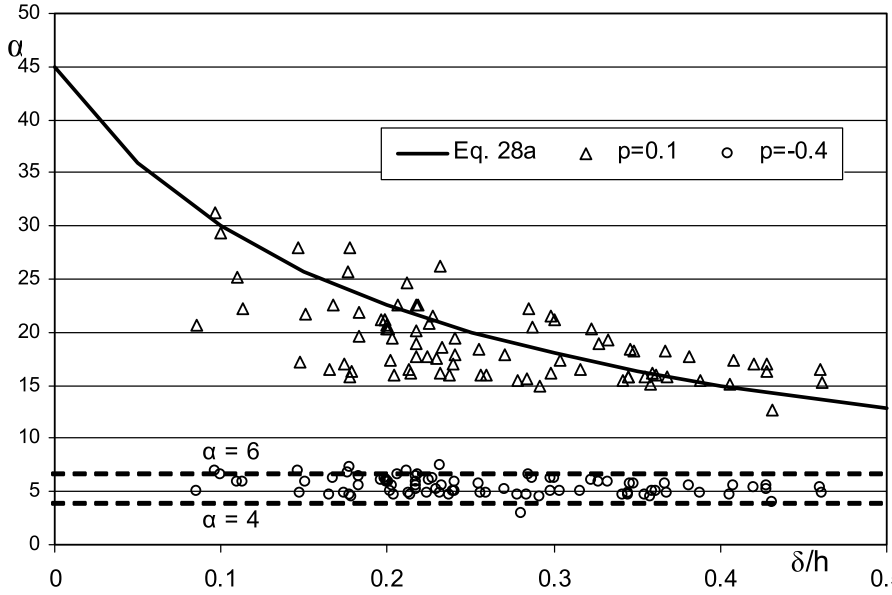

Figure 1. Variation of α versus δ/h based on experimental data of *Guy et al.* [1966].

the calibrated α was used to calculate S_c (= S) using equation (12b) of Yang et al.. Hence no prior assumption on the value of α had been made and we did not use a fix α = 16 in the computation of the energy slope S, as stated in the discussion.

[9] Third, we are not aware of any readily available analytical formula for the estimation of S''. In this regards, we used an empirical equation similar to *van Rijn*'s [1984] with *p* = 0.1 in RE (6).

[10] In order to show how α is affected by the bed form roughness k_s'' or S'', the value of *p* in RE (6) is adjusted based on the experimental data from *Guy et al.* [1966], and the results, based on the data points in the dune regime, are shown in Figure 1. Figure 1 shows how the values of α vary with the bed form roughness k_s'' or S'' for two different p values in RE (6). Using the definition of *van Rijn* [1984], based on the data set of *Guy et al.* [1966], leads to equation (28a) with p = 0.1. However, using Engel's observation that α is to be within the range of 4–6 as pointed out by the discussion paper, then the exponent p would have to assume a value of p = −0.4, and the k_s'' or S'' would be different from that shown by Yang et al. We agree that further experimental works are needed to verify the parameter p in RE (6) to obtain the correct α in the dune regime. We acknowledge that using van Rijn's definition of bed form roughness lead to overestimation of the eddy length as the commenters correctly noted.

[11] It remains to address whether the total energy slope S_c was also overestimated or underestimated if the eddy length was overestimated. RE (1) indicates that one should correctly estimate $S'L'/L$ and $S''L''/L$ to obtain the correct S_c. The former, $S'L'/L$, can be determined and has been verified (see Figures 2 and 3 of Yang et al.). The latter involves the bed form roughness and eddy length. The good agreement between the measured and predicted energy slopes S (see Figures 5 and 6) indicate that $S''L''/L$ had been reasonably modeled in the present study. In other words, the errors caused by inappropriate α or L'' are compensated by the bed form roughness through the product term $S''L''$. The good agreement in Figures 5 and 6 also supports that the errors in α or L'' would not have propagated into the analysis for the energy slope.

[12] On the other hand, if we used the average of α ≈ 5 when p = −0.4 for the dune regime where δ/L ≈ 0.06, then the following relationship is obtained,

$$S = S' + 0.3(S'' - S') \quad (7)$$

Therefore, if one adopts the equation of the bed form roughness developed by *van Rijn* [1982], then equation (12a) would be valid. However, if Engel's observations could be extended to mobile bed, then RE (7) would be valid. Obviously further experimental works are required to justify these two observations.

[13] Finally, the authors would like to clarify that the data set of *Guy et al* [1966] were not used to compute the energy slope S_c, but to calibrate the parameter α. It is not appropriate to use these data as is done in Table 2 of the discussion paper. The data points within the dotted ellipse in Figure 1 of Cardenas and Wilson had been excluded in the formulation of equation (28a) (Figure 4 of Yang et al.).

[14] In summary, the eddy length L'' or α of the bed form of Yang et al. was derived from measured data using an improved formula developed by van Rijn. Errors for the estimation of L'' or α are unavoidable. However, as an empirical formula of α was obtained independently, and $L''S''$ was determined as a lumped parameter, the errors in L'' or S'' would not affect the estimation of energy slope S. It is concluded that the energy slope S or the flow resistance in a mobile bed can be reasonably modeled using the suggested method shown by Yang et al.

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