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EXTENDED ABSTRACT

Analytical Model of Hydraulic Geometry Functions in Meander River

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Introduction

Regime and hydraulic geometry are two of the most important proposed models over the past century in the related disciplines of river engineering and fluvial geomorphology. Therefore, the hydraulic geometry is of prime importance in planning, design, and management of river engineering and training works (Huang, 1996). The first systematic analysis was conducted on canal systems in India by Kennedy (1895) who exhibited a relation between velocity and depth. Downstream hydraulic geometry relationships describe the shape of bank-full alluvial channels in terms of bank-full width, average flow depth, average flow velocity and channel bed slope. Although some concepts of hydraulic geometry were proposed toward the end of the nineteenth century, the real impetus toward formulating a theory of hydraulic geometry was provided by the work of Leopold and Maddock (1953). Leopold and Maddock (1953) adapted the ideas from regime relations for canals to the description of natural stream channels. Generally, there are two experimental and analytical methods to obtain the hydraulic geometry relations in order to determine the stable geometric dimensions of the rivers. Different researchers have studied hydraulic geometry relations for straight rivers without considering the effect of the secondary flow. The main focus of this study is to analytically derive the hydraulic geometry equations considering the concept of secondary flow in meandering channels.

Methodology

Hydraulic geometry relationships are theoretically developed by using four governing equations: continuity , flow resistance, bed load equations and secondary flow.

The fourth equation considers the effect of secondary flow and is as the ratio of the radial shear stress to the longitudinal shear stress. Radial shear stress is a vital parameter in investigating the secondary flow in meanders. Most of the radial shear stress equations are obtained from the momentum equation in the radial direction. A particle starts to move when its shear stress is higher than critical bed shear stress. Two shear stresses influence sediment particles in a meander, i. e. radial stress and longitudinal shear stress. Therefore, the angle between the resultant shear stress and the longitudinal shear stress is of great significance . By increasing the angle, the radial shear stress will increase and a stronger secondary flow would form. Therefore, the sediment particle will move from the outer bend to the inner bend and there is a sharper bend. By decreasing the angle, the longitudinal shear stress will increase and the bend becomes milder. Therefore, to consider the effect of the secondary flow in the equations, the radial shear stress to the longitudinal shear stress ratio could be used. Using the four aforementioned equations, hydraulic geometry relations are obtained.

Because of the importance of independent and dependent variables, they should be selected carefully. The independent variables of equation are: flow discharge, mean sediment size and bed-load sediment while the dependent variables of equation are: the mean depth, width, mean flow velocity and channel slope.
Hydraulic geometry relationships can also be shown as follows:

$$D = C_1 Q^{x1} D_{50}^{y1} Q_s^{z1} \quad (1\text{-a})$$

$$W = C_2 Q^{x2} D_{50}^{y2} Q_s^{z2} \quad (1\text{-b})$$

$$V = C_3 Q^{x3} D_{50}^{y3} Q_s^{z3} \quad (1\text{-c})$$

$$S = C_4 Q^{x4} D_{50}^{y4} Q_s^{z4} \quad (1\text{-d})$$

In these equations C_i is a constant, Q is discharge D is the average flow depth, $D_{50}$is sediment size, Q_s is sediment discharge, W is width, V is the average velocity, S is the longitudinal bed slope, τ_* is Shields function and xi, yi and zi are constants.

Results and Discussion

Upon achieving the hydraulic geometry relations, four variables of depth, width, velocity and longitudinal slope of bed were obtained using these relations and data from Hey and Thorne (1986). A reasonable agreement between observed and calculated values are obtained partially in model calibration. However, some discrepancies were also observed in the results which may be due to the assumptions made in the model. Then, sensitivity analysis is conducted to figure out the parameter to which the model is most sensitive. According to the sensitivity analysis, the model was not sensitive to discharge and shields function so that the error changes were insignificant. The model is sensitive to bed sediments size so that dependent variables were calculated with a higher error rate.

Finally, width, depth and longitudinal slope of bed values for rivers were obtained and compared using the hydraulic geometry relations of the present study and relations by England and Hanson (1968). The calculation errors of depth, width and longitudinal slope of bed were less in the present study.

Conclusions

A reasonable agreement between observed and calculated values are obtained partially in model calibration. The model is sensitive to bed sediments size, In addition, calculated error of the longitudinal slope of the bed was higher than other dependent variables which the direct relationship between the longitudinal bed slope and sediment size. Then, derived hydraulic geometry relations were compared with other researches. Calculation errors of depth, width and longitudinal slope of bed were less in the present study, which indicates the influence of the secondary flow on improvement of the hydraulic geometry relations of meanders for estimating hydraulic parameters of the channels.

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