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Computer-based predictors for sediment discharges and friction factors of alluvial streams

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CHAPTER VI

SUMMARY AND CONCLUSIONS

A. Summary

Two predictive models for flow in alluvial streams were developed. These consist of relations for sediment discharge by size fraction, and friction factor or velocity. It was concluded from an examination of laboratory and field data (Chapter I) that friction factor (f) or velocity (U) cannot be uniquely determined from flow depth (d) and slope (S) (or S and water discharge Q or q = Ud) unless sediment discharge (Q_t or its unit value q_t) or some other sediment-discharge parameter (e.g., mean concentration $\overline{C}$, or near-bed concentration C_b) is also specified. Therefore, the friction-factor relations developed in this study include q_t or C_b as independent variables. These models are outlined in the following sections.

1. Suspended- and Bed-Load Transport Model (SBTM). The suspended- and Bed-Load Transport Model (SBTM) yields estimates of both the suspended- and bed-load discharges. SBTM treats the sediment transport as occurring in two distinct zones: the bed-layer zone, whose thickness depends on mean sediment size and shear velocity, and in which sediment concentration, C_b, is constant; and the upper zone, where sediment is transported in suspension as described by the convection-diffusion equation. The value of C_b for each flow of a data base consisting of 15 data sets comprised of a total of 615 field and laboratory flows in all

bed regimes (ripple, dune, plane and antidune) was calculated by requiring the measured total concentration to be equal to the computed total concentration obtained by integration of the product of the power-law velocity distribution and the calculated sediment-concentration distribution over the depth of flow, using C_b as the reference concentration. Predictors for C_b, (50), were developed by expressing computed values of C_b as functions of various dimensionless independent variables representing the characteristics of the flow, sediment, and fluid. Quantitative predictors were derived by means of multiple linear-regression analysis. Standard statistical criteria, including multiple correlation coefficient (R), standard error of estimate (S_e), and F-statistic, were used as measures of goodness of fit. The friction-factor predictor, (51) or (52), was developed in a similar way, using the particle Froude number, $U/\sqrt{g(s-1)D_{50}}$, as the dependent variable, and C_b(or q_t) as one of the independent variables. An iterative computation scheme (Section II.C.9) was developed for solving the sediment-discharge and friction-factor predictors simultaneously to obtain C_b and f, from which bed-load and suspended-load discharges are obtained by integration over the depth of flow.

In the formulation of SBTM, the power-law velocity distribution was used, in which the exponent is expressed as a function of f and Karman's constant, κ. A relationship for κ for sediment-laden flow, (16), was developed by hypothesizing that the decrease in κ is related to the rate of dissipation of energy by inter-particle friction in the bed-layer, which, in turn, is assumed to be a function of C_b, the bed-layer particle velocity, u_b, bed-layer thickness, y_b, and a dynamic friction coefficient;

κ was expressed as a function this energy-dissipation rate normalized by the total energy-dissipation rate of the flow.

2. Total-Load Transport Model (TLTM). The Total-Load Transport Model (TLTM) is a simplified friction-factor and sediment-transport model, and is especially suited for application to the mathematical modelling of alluvial river processes over long prototype reaches and extended time-periods, which requires large amounts of computer time. The concept of mutual dependence between the sediment discharge and friction factor was incorporated in TLTM, as in the case of SBTM, and the same data base was utilized for its development. Multiple regression analysis was used to formulate the sediment-discharge relation, (55), and the friction-factor relation, (56), which are solved simultaneously using the iteration scheme described in Section III.B.5, to calculate q_t and f for given values of Q, S, D_{50}, and specified fluid properties.

3. Sediment discharge by size fraction. The heuristic model developed for sediment discharge by size fraction [(56), (57),(58) and (60)] express the size distribution of the transported sediment as a function of D_{50}, the representative diameter of each size fraction, D_i, and the fraction of material of the size D_i in bed material, P_i. The method is applicable to either SBTM or TLTM.

4. Verification of the models. The two friction-factor and sediment-transport models, SBTM and the TLTM, were applied to 24 different data sets which include a total of 947 flows, of which 339 occurred in

rivers and 608 in laboratory flumes. The accuracy of prediction was measured by the mean normalized error (MNE), which is defined as the weighted mean of the absolute difference between measured and computed values, expressed as percents of the measured values. The details of the sediment-discharge and friction-factor results computed by SBTM and TLTM are presented in Tables 17 through 29, and in Tables 30 through 32, respectively. The MNE's obtained with SBTM (Method I) for 947 points are 45.2% and 29.9% for sediment-discharge and friction-factor predictions, respectively. The corresponding MNE's for TLTM are 44.8% and 28.5%, respectively. In view of the inaccuracies inherent in data on sediment-transporting flows, the prediction accuracies of both SBTM and TLTM are judged to be about as good as the parent data permit.

The sediment-discharge predictions obtained from SBTM and TLTM were compared with those calculated using the methods developed by Ackers-White (1972) and Engelund-Fredsøe (1976). The Ackers-White method was found by its authors to give better prediction accuracies than several other existing relationships, including those of Engelund-Hansen, Einstein, Toffaletti and Meyer-Peter-Mueller. The MNE's for the same 947 data points for sediment-discharge predictions by the Ackers-White and Engelund-Fredsøe methods are 58.0% and 112.7% respectively. The friction-factor predictions by the present methods were compared with those by the White-Paris-Bettess (1979) method, which was found by its authors to give better prediction than several other relationships, including those of Einstein-Barabarossa and Engelund. The MNE's of the friction-factor predictions by the White-Paris-Bettess method were calculated, for the same 947 data points, to be 54.1%.

Both SBTM and TLTM give comparable accuracies in prediction of the total sediment discharge and friction factor. However, SBTM gives a more complete description of the transport, including the sediment concentration in the bed-layer, C_b; the thickness of bed-layer, y_b; and suspended-load and bed-load discharges separately.

The accuracy of the proposed relation for prediction of sediment discharge by size fraction was demonstrated by plots, Figures 15 through 34, of the cumulative distribution function, F(D), of the measured and the computed size distributions of several sediment discharges. The proposed relation gives good agreement with the measured values for flows with predominantly suspended-load discharges, but remains to be verified for flows transporting significant amounts of bed-load discharge.

B. Conclusions and Recommendations

The principal conclusions derived from this investigation may be summarized as follows:

1. The mutual dependence between the sediment discharge and friction factor must be considered in order to formulate a complete description of the characteristics of alluvial-channel flows.
2. A comprehensive formulation of the friction factor and sediment-transport process in alluvial channels has been achieved on the basis of the concept set forth in the preceeding item and the presently available knowledge on the mechanics of sediment transport, by utilizing the computational power of modern electronic computers. However, adequate knowledge of many component parts of the transport process is not yet available. The present model,