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The Gravel-Bed River Reach Properties Estimation in Bank Slope Modelling

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1. Introduction

Church and Kellerhals [2] point out the difficulty of adequately characterizing a gravel bed by a single grain size distribution for a relatively long river reach. Bray [1] indicated that the initiation of motion calculations gave as a result in which the gravel bed is immobile or at least not highly mobile at flows by flooding boundary layers. The basic data for each gravel-bed river reach are directly applied to a specified equation to compute the average velocity.

The knowledge about the hydraulic geometric parameters, width, depth and area of the river at the bankful discharge are required for solving a variety of problems related to river training, location of river constructions and navigation. To predict the average velocity of flow, the resistance offered to the flow by the boundary and air-water interface needs to be known. In methods for the prediction of width, depth, area and the flow velocity or resistance coefficient the results of the analysis of the available gravel-bed river data will be given.

2. Method

The resistance characteristics and the study of hydraulic geometry for gravel-bed rivers is the main method for finding all the hydraulic characteristics. The hydraulic geometry refers to the geometrical characteristics of the cross-section such as the average width w , average depth h and area $A (=wh)$ at the bankful discharge Q .

The basic data for each gravel-bed river reach are directly applied to a specified equation to compute the average velocity. Then for each reach the percent deviation (PDEV) of the computed average velocity from the “observed” average velocity is computed. The distribu-

tion of the percent deviations associated with a specified equation is then determined for the different gravel-bed rivers reaches. A summary of the parameters to describe the distribution of the percent deviations for each of the specified equations is given in Table. 1.

Equation (1)	Mean (2)	Standard Deviation (3)	Minimum Value (4)	Median Value (5)	Maximum Value (6)
Manning's Eq.	-3.3	29.6	-50.0	-7.0	83.2
n by modified Cowan n by Strickler	44.9	43.7	-18.6	31.8	181.9
$n=0.41 D_{50}^{1/6}$	37.5	40.9	-23.1	25.0	156.9
$n = 0.038 D_{90}^{1/6}$ n by Limerinos	2.5	28.8	-41.8	-3.1	74.4
Keulegan's Eq.	54.2	46.1	-12.7	40.4	195.3
$k_3 = D_{50}$	47.0	42.7	-17.3	35.2	169.2
$k_3 = D_{65}$	32.9	38.3	-23.9	23.0	136.4
$k_4 = D_{90}$ Lacey's Eq.	8.6	29.4	-26.6	-0.7	116.1

Table 1. Statistics for Gravel-bed River Reaches [1]

Some of the characteristics which differentiate gravel-bed rivers from the alluvial rivers are:

- a. much steeper slope (0.001 – 0.02)
- b. resistance is higher than the alluvial rivers

There is scope of using all the available gravel-bed river data and develop non dimensional relationships for the hydraulic geometry. In the analysis of river and channel problems it must be given a relationship between the average velocity U , the depth h or the hydraulic radius R , channel slope S and some coefficient which is related to the channel boundary. This is known as the resistance relationship [3]. The work of Lacey [4] about the sand-bed rivers has shown that for such rivers depth h or hydraulic radius $R \sim (Q/f_1)^{1/3}$, width W or wetted perimeter $P \sim Q^{0.50}$, Area $A \sim Q^{5/6} / f_1^{1/3}$ where f_1 is Lacey's silt factor and is given by $f_1 = 1,76 (d)^{0.5}$, d being the median size of bed material in mm. As regards the gravel-bed rivers Kellerhals and Bray [5] have related W , h , A to Q and sediment size d as

$$W = 2.08 Q^{0.528} d^{-0.70} \quad (1)$$

$$h = 0.256 Q^{0.331} d^{-0.25} \quad (2)$$

All such equations are based on the analysis of limited amount of data and are not dimensionally homogeneous. Only the dimensionless parameters W/d , h/d and $U/(\Delta\gamma_s d/Q_f)^{0/5}$ and related them to the dimensionless discharge $Q/d^2 (\Delta\gamma_s d/Q_f)^{0/5}$ are given [3]. Hence $\Delta\gamma_s$ is the difference in specific weights of sediment and water and Q_f is the mass density of water. Hence there is scope of using all the available gravel-bed river data and develop non-dimensional relationships for the hydraulic geometry. In the analysis of river and channel problems we need also a relationship between the average velocity U , the depth h or the hydraulic radius R , channel slope S and some coefficient which is related to the channel boundary. This is known as the resistance relationship [3]. The resistance relationship is expressed in dimensionless form as [3],

$$\text{in Manning's Equation : } \frac{U}{\sqrt{ghS}} = \frac{h^{1/6}}{n\sqrt{g}} \quad (3)$$

$$\text{in Chezy's Equation : } \frac{U}{\sqrt{ghS}} = \frac{C}{\sqrt{g}} \quad (4)$$

$$\text{in Darcy-Weisbach Equation: } \frac{U}{\sqrt{ghS}} = \sqrt{\frac{8}{f}} \quad (5)$$

$$\frac{U}{\sqrt{ghS}} = F\left(\frac{h}{d}\right) \quad (6)$$

In the above equations n is Manning's roughness coefficient, C is Chezy's discharge coefficient, f is Darcy-Weisbach resistance coefficient and F is a function. These coefficients depend on the resistance, offered to the flow by the channel boundary and air-water interface [3]. The available data in Turkey at East Black Sea Basin have been analysed in a unified manner to obtain dimensionally homogeneous relationships for W , h , A and U .

3. Data

A summary of data were classified as bankful discharge and variable discharge. The bankful discharge data were used to study the hydraulic geometry. The variable discharge data pertain to discharges other than the bankful in any stream. In order to study the effect of bed condition, each set of data were further subdivided into those with mobile bed, and those with paved bed. There is no need to subdivide the data, because both sets of data behaved in similar manner.

4. Analysis of hydraulic geometry

The dependent variables can be any two of the four variables average width W , average depth h , area of flow $A = Wh$ and the average velocity U . The independent variable related to the flow is bankful discharge Q . The sediment representing the bed and the banks will be described by the median size of the bed material d , its geometric standard deviation σ_g and the difference in the specific weights of sediment and water $\Delta\gamma_s$ [3]. It is known that for a given stream the channel slope is related to the bankful discharge Q , the slope decreases as Q increases in the downstream direction [3]. If we deal with the data from different basins, S and Q will not be related and hence S should be taken as an independent variable. If we ignore Q_B , because the gravel-bed rivers carry a small amount of sediment load, we can analyse as [3],

$$W, h, A, U = F(Q, d, \sigma_g, \Delta\gamma_s, \rho_f, \mu, S) \quad (7)$$

With simplifications Garde [3] gave the dimensionless relationship for hydraulic geometry of different river basins as,

$$\frac{W}{d}, \frac{h}{d}, \frac{A}{d^2}, \frac{U}{\sqrt{\frac{\Delta\gamma_s}{\rho_f} d}} = F \left[\frac{Q}{d^2 \sqrt{\frac{\Delta\gamma_s}{\rho_f} d}}, S \right] \quad (8)$$

If studied regime types of relations, we must plot W , h , and A against Q on log-log scale which yielded straight lines giving equations by [3],

$$W = 4.547 Q^{0.507} \quad (9)$$

$$h = 0.293 Q^{0.332} \quad (10)$$

$$A = 1.330 Q^{0.839} \quad (11)$$

By comparing this equations, also the North Anatolian River Reaches will be investigated. The exponents of Q obtained in Eqs. [9], [10], [11] are very close to those obtained by Lacey [4]. Similar investigation was carried out using W/d , h/d and A/d^2 and determining their variation

with $\frac{W}{d}, \frac{h}{d}, \frac{A}{d^2} = F \left[\frac{Q}{d^2 \sqrt{\frac{\Delta\gamma_s}{\rho_f} d}} \right]$ by plotting on log-log scales [3].

The relationships given by Garde [3] are,

$$W/h = 7.675 Q^{0.448} \quad (12)$$

$$h/d = 0.504 Q^{0.373} \quad (13)$$

$$A/d^2 = 3.872 Q^{0.821} \quad (14)$$

5. Method

From www.terrasol.com the program for landslides can be estimated by TALREN 4 which is ideal for checking the stability of natural slopes, cut or fill slopes, earth dams and dikes. It takes into account various types of reinforcements, such as: anchors and soil nails, piles and micropiles, geotextiles and geogrids, steel and polymer strips. There is another new user-friendly graphical interface with:

- a. In the program, definition of the profile using a mouse, rulers and a grid. Other features include pop up menus and choice of soil colours.
- b. Ability to load background drawings (.jpg and .gif formats) and adjust to scale.
- c. Several construction stages and calculation alternatives can be handled in the same file.
- d. Tables illustrating main soil, load and reinforcement data.
- e. Various output options for graphical display and tables (shadings, forces in reinforcements, detailed results for each failure surface, etc.)
- f. Wizards and databases to help produce the best model and choice of input data (partial safety factors).

New calculation functionalities:

- a. Automatic search option for circular failure surfaces (no need to define a manual grid).
- b. No limit on the number of elements you can define (points, layers, reinforcements, hydraulic mesh, etc.)
- c. Future upgrade option for TALREN 4 users: calculation method based on limit analysis theory.
- d. TALREN still benefits from extensively used methods as limit equilibrium calculation along potential failure surfaces using the Fellenius, Bishop or perturbations methods.
- e. Ability to take into account hydraulic conditions.

- f. Seismic loads are taken into account by the pseudostatic method.

6. Data uncertainties

For estimation of landslides condition we require precipitation, streamflow, evapotranspiration and watershed morphology. The effects of data uncertainties must be considered in different ways:

1. whether the model parameters are determined from calibration or from physical measurements and principles,
2. whether the model is used to estimate real events (landslide forecasting), or to estimate synthetic events (design storms and generation of synthetic flows which reasoned the landslides. These issues are considered separately.

In Turkey the landslides can be seen in the Karst environment. Karst is a term applied to topography fdmed in regions of limestone or dolomite bedrock by the vigorous solution work of groundwater. One recognizes karst topography by the presence of large numbers of sinkholes, solution valleys, disappearing streams, and landslides. The development of karst topography is enhanced by the presence of well-jointed carbonates or evaporites near the surface. It is also enhanced by rainfall. And sufficient relief to insure continuous movement of groundwater that will carry away dissolved matter. The term karst comes from a limestone plateau in Yugoslavia where solution features are well developed. Similar topography can be found in Turkey, Kentucky, Tennessee, Indiana, northern Florida, and Puerto Rico. Types of mass wasting Earth materials on slopes shows the movement where it shows as the result of landslides.

	Rate of Movement	Amount of Water Present
Flow (movement distributed throughout material)		
Creep	Slow	Water not necessary
Rock glacier, rock, stream	Slow	Water not necessary
Solifluction	Fast	Water-saturated
Mudflow, debris flow	Slow or fast	Much water
Earthflow	Slow or fast	Much water
Slide (movement as one Mass on a slip surface)		
Debris avalanche	Fast	Wet or dry
Slump	Fast	Wet or dry
Landslide, rockslide	Fast	Wet or dry
Fall (free fall of rock or soil)		

Table 2. Types of mass movement (Levin, 1986)

Creep is a small form of land movement where the amount of water is not necessary and its measure is only a few centimeters in one year (Watkins et al., 1975). Creep can decrease if we can follow it through the earth surface and is a form of small earth flow. There are two types of creep, soil and rock creep which can be observed.

Landslide prevention

Simple engineering techniques have been used to prevent the landslide, for example, by flattening the cut-slope angle the landslide movement of erosion can improve in an easy way by construction of infrastructure (Levin, 1986). Meandering environment shows us another way of landslides as an example, polygonal ground on the flood plain of the Kogosukruk River, Alaska. Scale of air photograph 1: 20.000 (Courtesy of U.S. Geological Survey)

7. Relation for meander tortuosity

The relationship between the tortuosity ratio and other parameters can be expressed as,

$$LR/LV = f(W, D, S, m) \quad (15)$$

This can be reduced to the dimensionless equation,

$$LR/LV = f(W/D, S, m/D) \quad (16)$$

If mean velocity and discharge per length of channel width are assumed as two more relevant parameters, Eq.(3) can further be modified as,

$$LR/LV = f(W/D, S, m/D, R, F) \quad (17)$$

in which $R = q/v$ = the Reynolds number; $F = V / (gD)^{1/2}$ = the Froude number; q = discharge per unit length width; v = kinematic viscosity; V = mean velocity; and g = gravitational acceleration.

To investigate the actual relationship and its validity, river data or laboratory data for meandering flumes were needed for all the parameters involved. The study of the effect of parameters W/D , S and m/D individually on meander tortuosity, plots of LR/LV against these three parameters indicate that channels with low tortuosity ratio, i.e., more or less straight channels, have wide and shallow cross sections, steeper slopes, and relatively coarser bed material. A value of LR/LV equal to one indicates straight channels. With gradual reduction in the value of all three parameters W/D , S , and m/D , the tortuosity ratio increases, indicating that meanders become more and more acute.

Flow curvature creates superelevation and transverse flow across the section of a channel bend. The strength of the transverse current depends on boundary friction. In wide and shallow

channels the ratio of roughness elements to flow depth is higher than in deep channels because of coarser bed material as well as shallower depth, the higher roughness ratio results in more frictional resistance and hence weaker transverse flow than in narrow and deep channels. In considering river patterns, channels can logically be divided into two main groups, single channel streams and multichannel streams, with a transition range between the two. Single channel streams can be further subdivided into meandering channels and straight channels with a transition between them. Meanders can be classified as regular or irregular, simple or compound, acute or flat, and sine, parabolic, circular or sine-generated curves.

Meandering channels are formed if the flow dynamics corresponds with the channel morphology. Braided channels occur if flow dynamics and channel morphology are incompatible. Alluvial channels are unstable because the stability criteria for the channel bed and for the channel banks are different.

Meander flow takes place in one single channel which oscillates more or less regularly with meandering river amplitudes that tend to increase with time. Meanders are found in beds of fine sediment with gentle slopes.

x/L (Distance)	Elevation from bottom(mm)	Run.1 ($\tau_{\max}=100\text{mN/m}^2$)	Run. 2($\tau_{\max}=239\text{mN/m}^2$)	Run. 3($\tau_{\max}=300\text{mN/m}^2$)	Run. 4($\tau_{\max}=390\text{mN/m}^2$)
0	-5.00	0.63	1.06	1.27	1.5
0.05	-4.00	0.64	1.17	1.32	1.58
0.1	-3.00	0.655	1.30	1.40	1.77
0.15	-2.00	0.84	1.40	1.50	1.89
0.20	-1.00	0.92	1.5	1.67	1.96
0.25	0.00	0.97	1.58	1.78	2.06
0.30	1.00	1.09	1.70	1.93	2.2
0.35	2.00	1.19	1.80	2.00	2.3
0.40	3.00	1.25	1.85	2.08	2.3
0.45	4.00	1.25	1.92	2.1	2.4
0.50	5.00	1.27	1.94	2.1	2.4
0.55	4.00	1.27	1.95	2.1	2.4
0.60	3.00	1.14	1.87	2.0	2.4
0.65	2.00	1.00	1.76	2.0	2.36
0.70	1.00	0.79	1.67	1.97	2.29
0.75	0.00	0.71	1.50	1.87	2.2
0.80	-1.00	1.0	1.58	1.80	2.1
0.85	-2.00	1.0	1.40	1.58	1.9
0.90	-3.00	0.72	1.25	1.48	1.7
0.95	-4.00	0.62	1.10	1.20	1.5
1.00	-5.00	0.556	1.10	1.19	1.4

Table 3. Shear Stress Distribution by landslides at mendering channels experimental set-up

8. Model application

The results of model applications were carried out for the same situations as the mathematical model at the Technical University of Berlin, Institute Wasserbau and Wasserwirtschaft (Yilmaz, 1990), started with flat bed, continued until $\partial z / \partial t = 0$. Then the beds were solidified, and precise measurements of the bed configuration and the velocity were performed. Plan geometries of runs consist of a sine-generated curve and an asymmetrical meander loop, respectively. The latter is derived by a Fourier series analysis on several typical bends. The meso-scale bed configuration in alluvial streams is highly dependent on the width-depth ratio of the channel. The velocity measurements were made with small mechanical current meters fixed to a 1m high frame that rested on the bottom while measuring the lower points on the profile. The frame was suspended at different levels above the bottom to collect the data represented by the higher points. Velocity profiles are plotted semi-logarithmically with the dots representing field data and the smooth lines showing model predictions. The mean velocity was calculated from a fit to the entire data set, not for each profile. Smaller dunes (0.50 m high, 2 m long) were superimposed on the large sand wave. Smith and McLean (1977) estimated the roughness parameter for both the skin friction and the form drag due to the smaller dunes to be 0.141 cm^3 . Three different perturbations are recognized:

1. **Alternating bars:** The bed configuration reached an equilibrium state after one hour, and the quantitative and qualitative agreements are given. Sensitivity analyses of each term in Eqs. 2 and 3 into the development of alternating bars were also carried out. The term in the Eq. (3) $\partial v / \partial s$ was found to play the most important role in developing alternating bars.
2. **Braided bars :** The calculated velocity vectors and bed configurations were given after one hour. Divergence and convergence of flow streamlines in a wide straight channel and the meso-scale bed configuration of braided bars can be clearly seen.
3. **No bars:** The calculated velocity vector and bed configuration were given after one hour. The velocity distributions are almost uniform and the bed configuration is two-dimensional with less scour and fill than in the case of alternating bars and braided bars.

Numerical calculations are performed using the hydraulic conditions as listed in Table.4.

9. Observations

If the sediment transport behaves as bed load, the sediment surface at meandering channels will deform into transverse waves. These bed forms can have a variety of scales ranging from ripples through small dunes to fully developed dunes or sand waves. Smith (1970) gave that, under pure bed load transport, a flat sand bed is unstable at all wavelengths to small perturbations in boundary topography so that with sufficient time all infinitesimal undulations will grow in height. His analysis predicts that, for bed features of finite wave number, a fastest growing wave exists only when there is a lag between the boundary shear stress and the

Run Number (1)	Width Of Channel B(m) (2)	Size of Bed Material Dx10 ⁻² (3)	Average Bed Slope (4)	Flow rate Q x 10 ³ (m ³ /s) (5)	Average Water Depth h (m) (6)	Froude number (7)
10	0.50	0.30	1/75	1.00	0.70	">1
8	0.50	0.30	1/100	1.25	0.80	"
5	0.50	0.30	1/120	1.15	0.69	"
9	0.50	0.30	1/60	1.20	0.75	"
7	0.50	0.30	1/80	1.00	0.70	"
9	0.50	0.30	1/90	1.10	0.73	"
11	0.50	0.30	1/110	1.20	0.75	"
5	0.50	0.30	1/70	1.00	0.70	"
8	0.50	0.30	1/50	1.10	0.74	"

Table 4. Experimental Condition for Alternating Bars

sediment transport rate; this is the ripple instability. The tendency for larger bed forms to have a seemingly discrete wavelength distribution, and a wavelength associated with fastest growth, is not explained by such a primitive stability model, so Smith (1970) suggested that wake effects also had to be taken into account.

It was showed that once perturbations are of finite amplitude, the larger stresses at the crests cause the crests to propagate faster than the troughs, thus imparting asymmetrical shapes to the waves. When the asymmetry is strong enough, the flow will separate, which creates a momentum deficit downstream of the wave crest much like that found in the wake of a circular cylinder. At the point of reattachment, the near-bottom velocity and stress are both zero. Downstream from this point, an internal boundary layer must develop beneath the momentum defect, or wake, region. The internal boundary layer adjusts to the velocity of the wake region above it, which increases downstream due to the flux of momentum into the wake from the interior. This produces two competing processes that are critical to determination of the boundary shear stress. They are : accelerating effect of an outward diffusing velocity defect; and the decelerating effect of a thickening boundary layer. In the near-field, spatial acceleration of the fluid in the wake dominates the decelerative effects of the internal boundary layer, but in the mid-field the opposite is true, and the net result is a decrease in the near-bed velocity in this region. In the far-field the boundary layer ultimately engulfs the wake entirely, and the boundary shear stress asymptotically approaches equilibrium. The essential features of this response to separation are preserved over an upsloping surface such as the stoss side of a bed form. Consequently, the resulting maximum in the stress profile has important consequences for both bed deformation and bed-form growth.

10. Conclusions

The flow resistance in a meander bend is considerably increased due to the form resistance of the patterns about which much is not known. It depends on a number of factors including grain friction, form resistance of two- and three dimensional patterns, skin friction of the non-separated oscillatory component and the sediment transport rate.

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