Because of the small number of data points for *n*, two and three, no curve was drawn through them. However, looking at the data points for n = 2, the same form of function relating π_* and ϕ_*' is expected to be followed.

As not all possible combinations of parameter were considered in our experiments, by increasing the data points in the dimensionless diagram presented by Fig. 6, it should be possible to estimate either the riprap layer thickness corresponding to a maximum admissible rate of base erosion, or to know the base erosion rate for a given riprap layer thickness.

Acknowledgements The research support by the Fundação de Amparo a Pesquisa do Estado de São Paulo (FAPESP) and by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), is gratefully acknowledged.

REFERENCES

Anderson, A. G., Paintal, A. S. & Davenport, J. T. (1970) Tentative design procedure for riprap-lined channels. *Report no. 108, National Cooperative Highway Research Program, St Antony Falls Hydraulic Laboratory, Minnesota Univ., USA.*

Graf, W. H. (1971) *Hydraulics of Sediment Transport.* McGraw-Hill, New York.

Knight, D. W. (1981) Boundary shear in smooth and rough channels. *J. Hydraul. Div ASCE* **107** (HY7), 839-851.

Paintal, A. S. (1971) Concept of critical shear stress in loose boundary open channels. *J. Hydraul. Res.* **9** (1), 91-113.

Simons, D. G. & Sentürk, F. (1976) *Sediment Transport Technology.* Water Resources Publication, Fort Collins, Colorado.

Wang, S. & Shen, H. W. (1985) Incipient sediment motion and riprap design. *J. Hidraul. Engng* **111** (3), 520-538.

Sediment Budgets (Proceedings of the Porto Alegre Symposium, December 1988). IAHS Publ. no. 174, 1988.

Analytical evaluation of bed load transport in a river subject to backwater effect: the case of the River Trombetas

L. C. VEIGA PIRES, LUCIA O. RIBEIRO

ENGE-RIO, Engenharia e Consultoria S/A, Departamento Engenharia Civil, Divisão de Hidrotecnia, Rua México 3, 9º andar, Centro RJ/RJ CEP: 20031, Brazil

A. R. S. R. COIMBRA

ELETRONORTE, Centrais Elétricas do Norte do Brasil S/A, Departamento de Projetos, Divisão de Engenharia Civil, Setor Comercial Norte, Quadra 6, Conj. A, Super Center Venâncio 3000, Sala 60l, B1.A, Brasília/DF, CEP: 70710, Brazil

Abstract The calculation of bed load transport in a river is a problem that is difficult to solve. There are many formulae, based on tractive force, that estimate bed load discharge. These values are overestimated and generally inconsistent among themselves; in addition, this methodology does not take account of the velocities near the bottom. To overcome these problems, we recommend the application of impact forces theory in the calculation of bed load transport. The basic difference between these two methodologies is that, while in the first one the critical velocity is unique, the second one yields an interval throughout which velocity is critical, and in which movement can occur according to a probability distribution. The utilization of these two methodologies allows the technician to have available an interval whose lower limit is the result obtained by the impact forces method, while the upper limit is given by the formulae based on tractive force.

Evaluation analytique du transport solide par charriage dans un fleuve sujet à remous: le cas du Trombetas

Résumé Le calcul du transport solide par charriage dans un fleuve est un problème difficile à resoudre. Bien qu'existent plusieurs formules basées sur la force tractive pour déterminer le transport solide par charriage, les valeurs obtenues sont surestimées et incohérentes entre elles. De plus, ces valeurs ne considèrent pas les vitesses près du fond. Pour minimiser ces problèmes, la théorie des forces d'impact a été utilisée dans le calcul du débit solide de charriage. Cette théorie admet une bande de vitesse où le mouvement est imminent. La différence fondamentale entre les deux méthodes est due à ce que la première considère une vitesse critique, alors que la deuxième admet une bande où la vitesse est critique et associe le mouvement à son degré de probabilité. L'utilisation de ces deux méthodes permet de disposer d'une gamme de vitesses dont la limite inférieure est obtenue par la méthode des forces d'impact, tandis que la limite supérieure est donnée par les formules basées sur les forces tractives.

INTRODUCTION

The analytical evaluation of bed load transport is a problem that is difficult to solve, and the several existing formulae based on tractive forces theory usually overestimate the true values. They sometimes yield values which cannot possibly occur in a water course.

This problem does not occur with the method developed by Stelczer (1980) based on impact forces theory. Its results are very reasonable, and it used field data in its formulation.

This paper presents both methodologies, as well as the comparison between the results obtained at the application of these formulae.

CONSIDERATIONS ON THE METHODS

Tractive forces theory

The formulae based on tractive forces theory were originated in the studies developed by Du Boys (1879). In this first formulation, Du Boys assumed that bed load material moves in layers and that the average mean velocity of the successive layers grows linearly (Fig. 1). The tractive stress that the streamflow exerts over the river bed is the main factor for the occurrence of this movement.

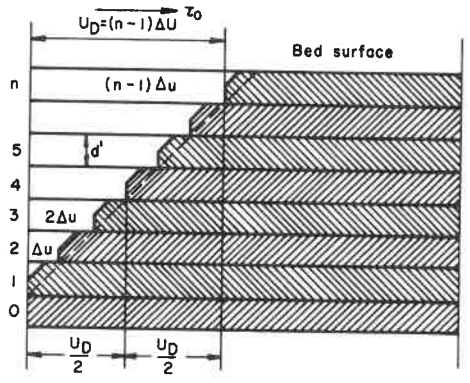

Fig. 1 Du Boys' model for bed load transport.

Among the equations originated from this theory, we can mention the formulae of Du Boys (1879), Schoklitsch (1914), Shields (1936), Meyer-Peter & Müller (1948), Einstein (1950).

From the analysis of these formulae we can observe that the discharge of a material with specific physical properties and specific weight, in a condition of unidirectional streamflow, can be defined as a function of bottom shear stress (τ). The shear stress varies directly according to streamflow slope. The importance of this slope in the quantification of bed load transport creates problems when we study a river subject to backwater effect. However, it is important to mention that, even when we are dealing with this kind of river, the application of these formulae throws up inconsistent results; therefore, we recommend the use of several formulae and the use of good sense to establish the values to be adopted. Of these formulae, the most used are the Meyer-Peter & Müller and Einstein formulae.

Impact forces theory

The main characteristic of this theory is that the dominating factor for motion occurrence is bottom velocity. So, this theory turns out to be very appropriate in the quantification of bed load transport in rivers subject to backwater effect, considering that slope parameter would not be used in this quantification. Based on this theory, Stelczer (1980) developed a methodology in which, from bottom velocity, we obtain bed load discharge

According to this methodology, we consider the following measurable physical parameters: (a) river velocity near the bottom; (b) characteristic diameter of river bed; (c) streamflow depth; (d) river bed condition. The existence of non-measurable parameters, such as the shielding effect of larger particles, wedging and locking of the particles, changes in the geometry of natural stream channels, etc., is also admitted. The effect of these parameters on bed load transport is purely random in character and impossible to determine quantitatively.

This theory establishes that bed load transport is characterized and practically controlled by intermittent motion. The critical condition (incipient motion) is characterized by a range (interval) of velocities, rather than by a single velocity. The critical velocity is the mean value of the range bounded by the lowest and highest velocities. Thus the critical bottom velocity is essentially a mean velocity value and indicates the velocity at which a bed load particle is set into motion with the greatest probability. The approach to the critical condition as to a random phenomenon implies that the velocity range characterizing the critical condition should be described by some distribution function, rather than by stating simply the mean and/or extreme values (lowest, highest).

Through the studies developed for the River Danube, Stelczer concluded that the critical condition is characterized in a high degree of confidence by the normal distribution $N(m,\sigma)$, with constant σ equal to 0.06.

The calculation of bed load discharge is made through the following expression:

$$Q_B = \alpha A \bar{V}_{hv}$$

where α is a density factor, A is the cross-sectional area through which the bed load moves (m^2) and V_{hv} is the mean virtual travel rate of the bed load ($m\ s^{-1}$).

For actual calculation the cross section of the river bed should be subdivided into parts by verticals, just as in the area-velocity method of streamflow calculation.

The bed load discharge Q_B should be calculated for each vertical and the total bed load discharge in the cross section is obtained as ΣQ_B (Fig. 2).

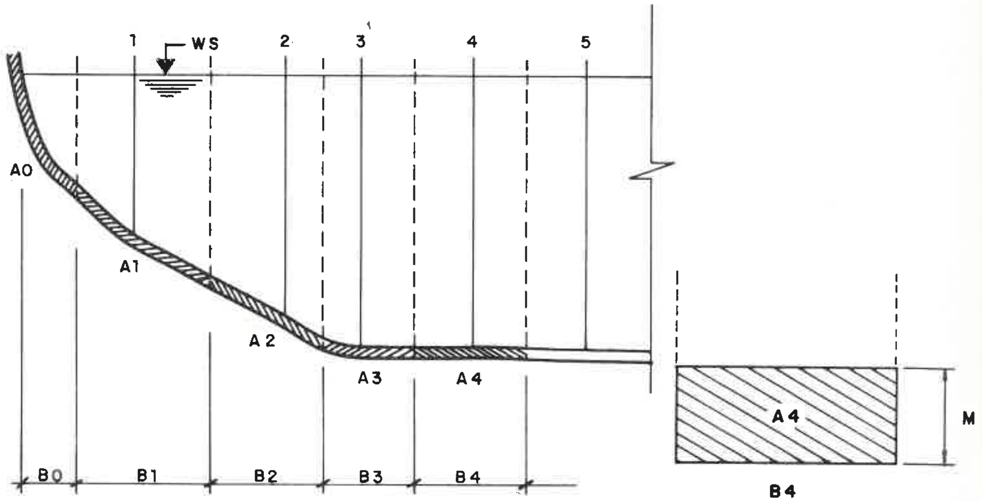

Fig. 2 Schematic representation of bed load discharge calculation by Stelczer.

The mean virtual rate of travel ($\bar{V}_{hv}$) of bed load is found as

$$\bar{V}_{hv} = b(V_f - V_{fc})$$

where V_f is bottom velocity; V_{fc} is the mean critical bottom velocity; b is a constant equal to 0.004 35 if the bed material is "soft"; and equal to 0.015 70 if the bed material is "hard".

The cross-sectional area through which the bed load moves is $A = B\ M$. The width B (m) is the spacing of the verticals, whereas the height M (m) of the cross-sectional area is:

$M = 4\ d_{80}$ if the bed material is "soft"
$M = 2\ d_{80}$ if the bed material is "hard"

where d_{80} is the particle diameter corresponding to 80% passing. The density factor is obtained from the utilization of the normal distribution function considering that the standard deviation of the velocities is invariable and equal to 0.06.

CASE STUDY

These two methodologies were used at the determination of bed load discharge in River Trombetas. This river, a left-bank tributary of River Amazon, has at its lower part a series of alternate bars where the Amazon terrapin (*Podocnemis expansa)* lays its eggs and nidify. This study of bed load transport in this river aims at the evaluation of river bed degradation and the conservation of the alternate bars after the construction of a hydroelectric power plant upstream of these beaches, at a place called Cachoeira Porteira.

A very important aspect is the fact that, downstream of Cachoeira Porteira, River Trombetas is permanently subject to a backwater effect caused by River Amazon. Due to this fact, the calculation of bed load discharge through the tractive forces method is not very appropriate for, according to this method, the slope has a direct influence in motion quantification.

The Meyer-Peter & Müller and Einstein formulae were selected for the calculation of bed load transport in this river according to tractive forces

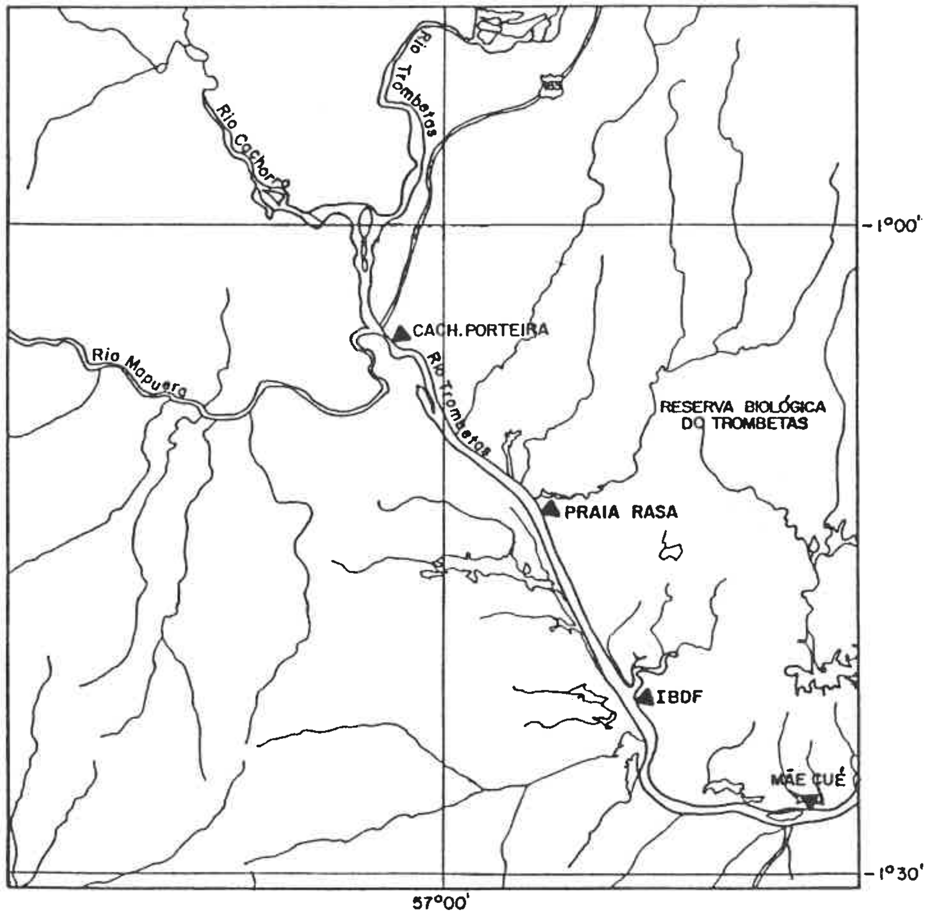

Fig. 3 Location of the streamgauges.

theory, and to compare this movement with the results obtained through the impact forces method. This was done at the streamgauges situated at the river segment being studied, that is: Cachoeira Porteira, Praia Rasa, IBDF and Mãe Cué. The alternate bars at issue are located near IBDF streamgauge.

The location of these streamgauges can be seen in Fig. 3.

The utilization of the three formulae resulted in the values of annual mean total bed load discharge shown in Table 1.

Table 1 *Annual mean total bed load discharge (10^3 t year^{-1}) estimated by various methods*

Method	*Cachoeira Porteira*	*Praia Rasa*	*IBDF*	*Mãe Cué*
Meyer-Peter & Müller	*5056*	*2460*	*2983*	*3153*
Einstein	*7658*	*1791*	*3211*	*1446*
Impact Forces	*138*	*3*	*153*	*249*

The results obtained lead to the conclusion that the bed load discharges obtained through the impact forces method are plausible. The suspended load, found to be near 1 300 000 t year^{-1} leads to the conclusion that Meyer-Peter & Müller's and Einstein's formulae overestimated bed load transport. But, through the impact forces method, the bed load found is very coherent, the proportion bed load/suspended load usually found, i.e. 10 to 30%, being maintained.

REFERENCES

Du Boys, M. P. (1879) Etudes du régime et de l'action exercée par les eaux sur un lit à fond de graviers indefiniment affouillable. *Ann. des Ponts et Chaussées,* ser. 5 **18**, 141-195.

Einstein, H. A. (1950) The bed load function for sediment transportation in open channel flows. Washington, US Department of Agriculture, *Technical Bulletin no. 1026,* 1-68.

Meyer-Peter, E. & Müller, R. (1948) Formulas for bed load transport. *Proc. II Congress IAHR* (Stockholm), 39-64.

Schoklitsch, A. (1914) *Uber Schleppkraft und Geschiebebewegung* (on shear stress and bed load movement). Engelmann, Leipzig.

Shields, A. (1936) Anwendung der Ahnlichkeitsmechanik und Turbulenzforschung auf die Geschiebebewegung (Application of similarity principles and turbulence research to bed load movement). *Mitt. der Preuss. Versuchanstalt für Wasserbau und schiffbau, Berlin, no. 26.*

Stelczer, K. (1980) *Bed Load Transport: Theory and Practice.* Water Resources Publications, Littleton. Colorado.

Sediment Budgets (Proceedings of the Porto Alegre Symposium, December 1988). IAHS Publ. no. 174, 1988.

The cropping pattern and its role in determining erosion risk: experimental plot results from the Mugello valley (central Italy)

C. ZANCHI

Department of Agronomy and Herbaceous Productions, Agricultural Faculty, University of Florence, P. delle Cascine 18, 50144 Florence, Italy

Abstract The evaluation of soil loss related to different crops is of primary importance, since biological measures are often the only applicable conservation practices on hilly lands. Runoff and soil loss data collected since 1979 to 1987 from nine experimental plots (20 m length, 5 m width, 14% slope) with three different crops (wheat, corn, pasture) are reported. The results put in evidence the remarkable efficacy of pasture in reducing runoff and soil loss in comparison with that recorded from corn and wheat plots. The experimental values of the cover and management factor are in accordance with those derived from Wischmeier & Smith's tables. The results also indicate that, in some Italian environments, it may be possible to utilize the Universal Soil Loss Equation which provides a useful tool for planning agricultural systems to conserve the soil fertility.

Les cultures et leur rôle dans la détermination des risques érosifs: résultats sur parcelles dans la vallée de Mugello (Italie centrale)

Résumé L'évaluation des pertes en sol relatives à différentes cultures revêt une grande importance si l'on considére que les mesures biologiques de conservation sont en général les seules pratiques de conservation qui peuvent être appliquées en milieux de collines. Les résultats du ruissellement et des pertes en sol presentés dans cette communication, ont été obtenues de 1979 à 1987 sur neuf parcelles expérimentales (longues de 20 m, larges de 5 m, avec une pente de 14%) avec trois cultures différentes (blé, maïs, prairie). Les résultats mettent en évidence combien la prairie facilite la réduction du ruissellement et des pertes en sol par rapport aux parcelles de maïs et de blé. Les valeurs expérimentales du facteur cultural ont été identiques aux valeurs déduites des tables de Wischmeier & Smith. Les résultats indiquent qu'il est possible d'utiliser, même dans certains milieux italiens, l'Equation Universelle des Pertes de