Theoretical Determination of Partition of Suspended to Total Sediment Discharge

Chun-Yao Yang[1] and Pierre Y. Julien[1]

[1]Colorado State University

January 17, 2018

Abstract

The analytical solution of Einstein's suspended load function provides us insight to the partition of suspended and total sediment discharge as well as the partition of measured and total sediment discharge. Both of the ratios can be reduced to a function of the ratio of shear velocity to the fall velocity of suspended material u_*/ω, flow depth h, the median grain size of bed material d_{50}. When the suspended material is fine (such as silt or clay), the ratio of suspended to total load is further reduced to a function of the ratio of flow depth to bed material size, and the ratio of measured to total load is reduced to a function of flow depth. Under this condition, at least 80% of sediment load is in suspended when $h/d_s > 10$, and 90% of sediment load can be measured when $h > 1$ m. The measurements of 35 watersheds in South Korea are used to demonstrate the proposed analysis. Furthermore, we found that for the sand bed rivers in South Korea, sediment is predominantly transported in suspension. The ratio of bedload increases when the grain size increases. When the discharge is larger than mean discharge, at least 90% of sediment is transported in suspension for gravel and sand bed rivers.

1. Introduction

The quantification of total sediment transport rate from the combination of suspended and bed loads is still one of the difficult topics in river engineering. Bedload is naturally difficult to measure and the total sediment load is often not available(Turowski et al., 2010; Wohl et al., 2015). Einstein (1950) proposed a bedload function to calculate bed material load in sand bed rivers. The method was a breakthrough in the study of sediment transport. Several methods to calculate the total sediment load were developed from it, e.g. (Colby and Hembree, 1955) and (Toffaleti, 1977). In this study we will focus on (Colby and Hembree, 1955) and its derivatives. (Colby and Hembree, 1955) compared the total sediment load computed by Einstein Procedure to the sediment measurement in Niobraba river and found that the computed size distributions of sediment discharge compared poorly to the measurement. The Einstein Procedure is not designed to apply to single cross-sections either. They modified the Einstein Procedure to compute the total sediment load based on the depth-integrated samples. The method is known as Modified Einstein Procedure (MEP). The MEP is generally applicable to different streams because depth integrating samplers measure much of the sediment discharge. However, the MEP has been subjected to several empirical adjustments over time. (Colby and Hubbell, 1961) introduced four nomographs to simplify the computation of MEP. (Lara, 1966) pointed out that the following assumption by Colby and Hembree was not valid: the theoretical exponent for vertical distribution of sediment ("Z" value) is not always 0.7. Lara suggested Z values determined based on the power relationship between Z and fall velocity $Z = \alpha\omega ^\beta$ for the size frictions having significant percentage quantities in both suspended and bed sediment materials. Two major revisions of MEP were proposed by (Burkham and Dawdy, 1980): 1) they replaced the effective roughness k_s from d_{65} to $5.5d_{65}$; 2) they developed a procedure to compute the bedload transport intensity ϕ_* from shear intensity ψ_* instead of arbitrarily dividing ϕ_* by 2. The method by Burkham and

Dawdy is known as the Revised Modified Einstein procedure. (Shen and Hung, 1983) reaffirmed the use of least squares fit of the power relationship between Z and ω. In addition, they proposed an optimization procedure for the calculation of suspended sediment discharge.

Computer programs have been developed to ease the MEP calculations \cite[]{Burkham1980,Stevens1985,Holmquist-Johnson2006}. The latest development is the Bureau of Reclamation Automated Modified Einstein Procedure (BORAMEP)\cite[]{Holmquist-Johnson2006}. (Shah-Fairbank, 2006) did a thorough testing on BORAMEP.

In 2009, she proposed the Series Expansion of the Modified Einstein Procedure (SEMEP) to obtain the total sediment transport rate for depth-integrating and point samplers \cite[]{Shah-Fairbank2009,Shah-Fairbank2011,Shah-Fairbank2015}. The SEMEP assumes a Z value evaluated by the Rouse's equation \cite[]{Rouse1937}, so there is no need for a minimum of two overlapping size fractions for both the bed material and suspended material. In addition, the bedload is calculated directly from measured load, so there is no need to arbitrarily divide the bedload transport intensity by two. Lastly, unlike MEP, the calculated total sediment discharge is always larger than the suspended sediment discharge \cite[]{Julien2010}.

The objective of this study is to derive the ratio of measured to the total sediment discharge as well as the ratio of suspended to the total sediment load as functions of water depth and grain size. A case study of South Korea were be present and compared with the BORAMEP.

References

D.E. Burkham and David R. Dawdy. *General study of the modified Einstein method of computing total sediment discharge*. Water Supply Paper 2066. U.S. Geological Survey, 1980. Retrieved from https://pubs.er.usgs.gov/publication/wsp2066.

Bruce Ronald Colby and C.H. Hembree. *Computations of total sediment discharge, Niobrara River near Cody, Nebraska*. Water Supply Paper 1357. U.S. Geological Survey, Washington, DC, 1955.

Bruce Ronald Colby and D. W. Hubbell. *Simplified Methods for Computing Total Sediment Discharge with the Modified Einstein Procedure*. Water Supply Paper 1593. U.S. Geological Survey, Washington, DC, 1961.

H A Einstein. *The bed-load function for sediment transportation in open channel flows*. Technical Bulletin No.. 1026. U.S. Department of Agriculture, Washington, DC, 1950.

Joseph Martin Lara. *Computation of Z's for Use in the Modified Einstein Procedure*. Department of the Interior, Bureau of Reclamation, Division of Project Investigations, Hydrology Branch, Sedimentation Section, 1966.

Seema C. Shah-Fairbank. Variability in Total Sediment Load Using BORAMEP on the Rio Grande Low Flow Conveyance Channel. Master's thesis, Colorado State University, Fort Collins, CO, 2006.

Hsieh W. Shen and Cary S. Hung. Remodified Einstein Procedure for Sediment Load. *Journal of Hydraulic Engineering*, 109(4):565–578, apr 1983. ISSN 0733-9429. doi: 10.1061/(ASCE)0733-9429(1983)109:4(565).

F B Toffaleti. *A procedure for computation of the total river sand discharge and detailed distribution bed to surface*. Technical report - Committee on Channel Stabilization, Corps of Engineers, U. S. Army ; no. 5. 1977. Retrieved from https://hdl.handle.net/2027/coo.31924004484808.

Jens M. Turowski, Dieter Rickenmann, and Simon J. Dadson. The partitioning of the total sediment load of a river into suspended load and bedload: A review of empirical data. *Sedimentology*, 57(4):1126–1146, feb 2010. doi: 10.1111/j.1365-3091.2009.01140.x.

Ellen Wohl, Stuart N. Lane, and Andrew C. Wilcox. The science and practice of river restoration. *Water Resources Research*, 51(8):5974–5997, aug 2015. ISSN 00431397. doi: 10.1002/2014WR016874.