LABORATORY STUDIES OF THE ROUGHNESS AND SUSPENDED LOAD OF ALLUVIAL STREAMS

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DECEMBER 1957

SECOND PRINTING OCT. 1972

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Pasadena, California

in cooperation
with

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CORPS OF ENGINEERS
OMAHA, NEBRASKA

M.R.D. Sediment Series No. 11

I. INTRODUCTION

This report describes some sediment transportation studies made in two laboratory flumes charged with fine sand. The sediment was fine enough to be transported primarily as suspended load, with the bed being movable so that under certain conditions dunes and bars appeared. The research was carried out under Contract No. DA-25-075-eng-3866 with the U. S. Army Corps of Engineers, Missouri River Division, Omaha, Nebraska, and this report is the final one for the sponsor.

A. The Problems

In natural alluvial streams with loose beds of sand there are two major unsolved problems facing river engineers: how can the channel roughness be predicted inasmuch as it varies with the bed configuration and the amount of sediment load; and how can the rate of sediment transport be predicted from the flow conditions? While it may be said that for any given stream these quantities can be measured, nevertheless it is vital for engineers to be able to solve these problems when man-made changes in the stream regimen are being planned, such as for flood control, power, navigation and water supply. The research conducted in the laboratory flumes was directed at these two problems. Because of the extreme complexity of them, the problems are still by no means solved, but the results reported herein should increase the engineer's general understanding of the processes involved.

The resistance to flow of clear water in a channel with fixed boundaries has been studied extensively and can be predicted with a satisfactory degree of certainty. Values of friction factors to be used in the flow equations such as the Manning or Darcy-Weisbach formulas have been determined and are given in reference works on hydraulics as a function of the texture or roughness of the channel walls and the Reynolds number.

However, when a stream has a movable bed, and sediment is being transported, the problem of determining the resistance is much more complicated than in the simple case of clear water flowing in a channel with fixed walls. Observations have shown that the friction factors for such sediment-bearing or alluvial streams vary over appreciable ranges.

However, the problem has not been studied sufficiently to enable hydraulic engineers to predict a friction factor for given conditions.

The fact that the friction factors for alluvial streams vary has been known for a long time. Despite this, the problem is not discussed at any length in the literature, and textbooks are particularly silent on this point. This leaves all but the expert in this field with the erroneous impression that the friction factor of streams is constant and can be determined once for all time. The lack of discussion in the literature of the resistance of alluvial streams may be explained by the fact that the problem is not well understood, and information on it is often conflicting. For instance, some evidence presented shows that the friction factor of a stream increases as the sediment load increases, while other evidence supports the opposite conclusion.

The variation of roughness of sediment-laden streams is caused by two distinct processes: (1) appearance of dunes and bars which may increase the roughness several fold because of the additional form resistance of the bed; and (2) the damping effect of the suspended sediment on the turbulence in the stream tending to reduce the hydraulic roughness. Because of these two opposing processes, there has often been confusion about the effect of sediment load on roughness. Indeed, it is very difficult to separate the two effects because, for streams in which a significant amount of bed material is carried in suspension, the two processes are always acting together, but with differing relative effects. For example, in a sediment-laden stream flowing at high velocity over a flat bed of sand, the friction factor or roughness coefficient will probably be lower than that for a clear flow over a fixed bed of comparable grain roughness because of the damping effect of the suspended load. On the other hand, at a lower velocity with light suspended load, dunes may grow, and the net result will appear to be an increase in the friction factor over that for a fixed flat bed of the same sand roughness.

To investigate these two processes two kinds of experiments were made; these will be designated hereinafter as "General Studies" and "Special Studies". In the General Studies the beds of the flumes were covered with sand, and the water was circulated, allowing the sediment to be transported and the bed configuration to become adjusted to the flows.

In other words, in the General Studies the flume was allowed to behave as much as possible like a stream (except for fixed walls and straight channel), and the hydraulic roughness was affected by both the processes described above.

In the Special Studies an effort was made to separate the two processes in order to determine qualitatively their relative order of magnitude. To accomplish this, runs were made with suspended load and a movable bed, and then with clear water but with no change in the bed configuration. This necessitated the development of a procedure for solidifying a natural bed configuration in place so that the clear water could be made to flow over exactly the same bed as the sediment-laden flow. A comparison of friction factors then showed directly the damping effect of the sediment separately from the effect of changing bed configuration.

The problem of determining the law of transportation of suspended sediment cannot be solved independently of the roughness problem. On any stream the depth, velocity and shear for any discharge are determined by the roughness, which itself depends on the sediment load. But, on the other hand, the sediment discharge is intimately related to the depth and velocity; thus it is seen that the two problems are closely interlocked and that they should, therefore, be attacked simultaneously. This, in fact, was the case for all the experiments described under "General Studies".

B. Organization of the Report

Although the report deals with two distinct investigations, it has been organized together as a single report to avoid duplication of text and figures which apply equally well to both the General and Special Studies.

In Chapter II previous investigations of the resistance of alluvial streams will be briefly reviewed. Following that, Chapters III and IV will describe the laboratory apparatus and procedure common to both sets of experiments. The experimental results of the General Studies appear in Chapter V, and discussion of them is in Chapter VI. Presented in Chapter VII are the results of the Special Studies, as well as special items of procedure; discussion follows in Chapter VIII. The conclusions are summarized in Chapter IX. Acknowledgments, appendices, and a list of references may be found at the very end of the report.