Introductory Remarks on Bed Forms

Prepared for

The Sediment Seminar of the IAHR Meeting
in Montreal, Canada, August 1959

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by

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Bed forms of alluvial channels have been long recognized as closely related to the mechanics of sediment transport, rate of sediment transport, and roughness of alluvial bed. One of the difficulties in model studies of alluvial channels, is the non-transferability of the bed form from model to prototype. Unless the formation of various bed forms is well understood, such a hazard of model study will continue. Bed load generally moves in the form of sediment waves, and suspended load is a function of flow turbulence which depends upon bed form and boundary roughness. It is obvious therefore until the mechanics of bed forms is thoroughly studied, the phenominon of sediment transport will not be well comprehended.

Classification of bed forms

One of the difficulties in studying bed forms is the lack of standardization of terminologies appearing in the literature of sediment transport, such as plane bed, ripples, riffles, dunes, sand waves, sand bars, smooth bed, transition, flat bed, undulation, and antidunes. Classification of bed forms cannot be made satisfactorily unless these terminologies are clearly defined.

There exists two different opinions on the beginning of ripples: (a) beginning of sediment motion is the necessary and sufficient condition for ripple formation (1) (b) beginning of sediment motion is a necessary but not sufficient condition for ripple formation (2).

It can be shown mathematically that once sediment waves appear on the bed, they tend to become asymmetric (3). The writer (4) is of the opinion that sediment waves are one type of interfacial waves; and the formation of sediment waves is a result of instability of the interfacial zone in which there exists a high velocity gradient. Hence most sediment waves can be considered as interfacial sediment waves. The mechanics of interfacial sediment waves is a very inviting subject.

Although there are many factors which may affect and modify interfacial sediment waves, the writer's analysis of data has shown that the two parameters $\frac{V_*}{w}$, $\frac{V_* d}{\nu}$ can be used satisfactorily to define the initiation of interfacial sediment waves. Extending the writer's analysis, Albertson and others (5) by use of laboratory data have proposed criteria for beginning of dunes, transition and antidunes. Although their criterion for dunes are applicable for prototype condition, their criteria for trans-ition and antidune are not applicable for prototype con-dition. The discrepancy may be attributed to factors such as relative depth and Froude number.

Except those obtained by Gilbert (6), data on tran-sition and antidunes are very scarce. A related research work on bed forms sponsored by the U.S. Geological Survey has been underway for two years in the Hydraulics Labo-ratory of Colorado State University. The object of the research is to study the effect of bed forms on bed roughness.

Garde and Albertson (7) proposed recently new criteria for transition and anti-dunes by use of two parameters $\frac{\tau_b}{\Delta\gamma_s d}$ and Fr. Their method remains to be verified.

Prototype data on bed forms are difficult to obtain. Recent publication by Carey and Keller (8) on sand waves in the Mississippi River is very valuable information. In case of small alluvial streams, it has been found recently by engineers of the U.S. Geological Survey and by those of the U.S. Agricultural Research Service that during flood period the transition stage between dunes and antidunes is very common. The transition stage shows up in the rating curve as an abrupt change of dis-charge-stage-relationship.

Mechanics of Ripple Formation

There are many factors which affect the formation of ripples and other types of sediment waves. Consequently, many proposals have been made to explain the formation of sediment waves. Exner (3) proposed that sediment waves are caused by the periodic variation of the velocity near the bottom. Anderson (9) has shown that surface waves may modify the characteristics of sand waves. Velikanove (10) showed that turbulence can cause the variation of bed elevation. Tison (11) has found that ripples and dunes are associated with turbulent flow. Inglis (12) is of the opinion that ripple formation is caused by non-uniform deposition and erosion of sediment particles. The writer is of the opinion that instability of the zone of velocity gradient near the bed is responsible for the formation of interfacial sediment waves. The physical concept of the instability hypothesis is related to the concepts of vortex layer and boundary layer. Matsunashi (13) has employed the method of small oscillation to analyze mathematically such an instability problem. All the hypotheses and explanations on ripple formation cannot be proved or disproved by experiments at the present time, mainly because it is difficult experimentally to separate the various factors which affect sediment waves.

Effect of Bed Forms on Other Problems of Sediment Transport

(a) On velocity of flow.

The formation of sand waves can affect the velocity distribution, and cause a considerable change of the resistance coefficient. Einstein and Barbarossa (14) porposed a method of estimating the mean flow velocity by separating the grain roughness from the roughness of bed forms. Recently Liu and Hwang (15) have proposed a velocity equation.

$$V = C_a R_b^x S^y$$

in which V is the mean velocity

R_b is the hydraulic radius pertaining to the bed

S is the energy gradient

C_a is a discharge coefficient

X, y are dimensionless numbers

The discharge coefficient C_a and exponents X and y depend upon the bed configurations and the mean bed-material size.

(b) On rate of sediment transport

The mode of sediment transport is related to the bed forms. For example, in the wake of sand dunes vorticis are generated; consequently, fine particles may thus be thrown into suspension and carried downstream. In case the bed is in the form of dunes, the total amount of bed load can be determined satisfactorily by use of the continuity principle of wave motion (16). It has been found that the speed of sediment wavesis generally small and proportional to some power of the mean velocity of flow (17).

On the mechanics of the bed load transport, Meyer-Peter, and others (18), considered the uneven shape of the bed as a factor hindering bed-load transport, and assumed that the bed-load transport depends only on the energy converted into swirl at the bed particle.

(c) On model with movable bed.

In general, the result of model with movable bed, cannot be transferred quantitatively to prototype condition. This is largely due to the unpredictable nature of various bed forms (19) Bogardi;(20) has proposed a modification of similarity laws of distorted river model with movable bed previously recommended by Einstein and Chien (21).

(d) On boundary shear.

Based upon his flume study, Brooks (22) has indicated that the rate of sediment transport is not a single function of boundary shear.

River Forms

Discussion on bed forms will not be complete without mentioning the river forms. It is possible that some meanders may be resulted from bed irregularities. Leopold and Wolman (23) found that a braided river is caused by deposition of course material in the channel proper. The formation of meanders is a very complex problem itself, and there are many factors contributing to such a phenomena.

Conclusion

The writer is thoroughly convinced that in order to understand the mechanics of sediment transport, it is necessary to study the bed forms.

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