THE CHARACTERISTICS OF ALLUVIAL CHANNELS

Technical Training School
Quality of Water Branch

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The various important characteristics of alluvial channels and their influence on channel geometry, resistance to flow, and sediment transport are discussed in the following sections.

I - Regimes of Flow

Two regimes of flow are generally recognized:

a - Tranquil flow -- $F_r < 1$

b - Rapid flow -- $F_r > 1$

These two regimes of flow are also defined by the specific energy diagram. Flow is tranquil when normal depth is larger than critical depth, and flow is rapid when normal depth is less than critical depth. When flow is tranquil the undulations on the bed are out of phase with the undulations of the water surface. When flow is rapid the bed and water surface undulations are in phase. This is true for both alluvial and rigid boundary conditions as illustrated in Fig.1.

Within the tranquil regime of flow the following forms of bed roughness occur in alluvial channels:

1. Plane bed -- no sediment movement
2. Ripples
3. Ripples superposed on dunes
4. Dunes
5. Transition from dunes to plane bed or rapid flow
6. Plane bed if $d < 0.4$ mm

Within the rapid flow regime the forms of bed roughness are:

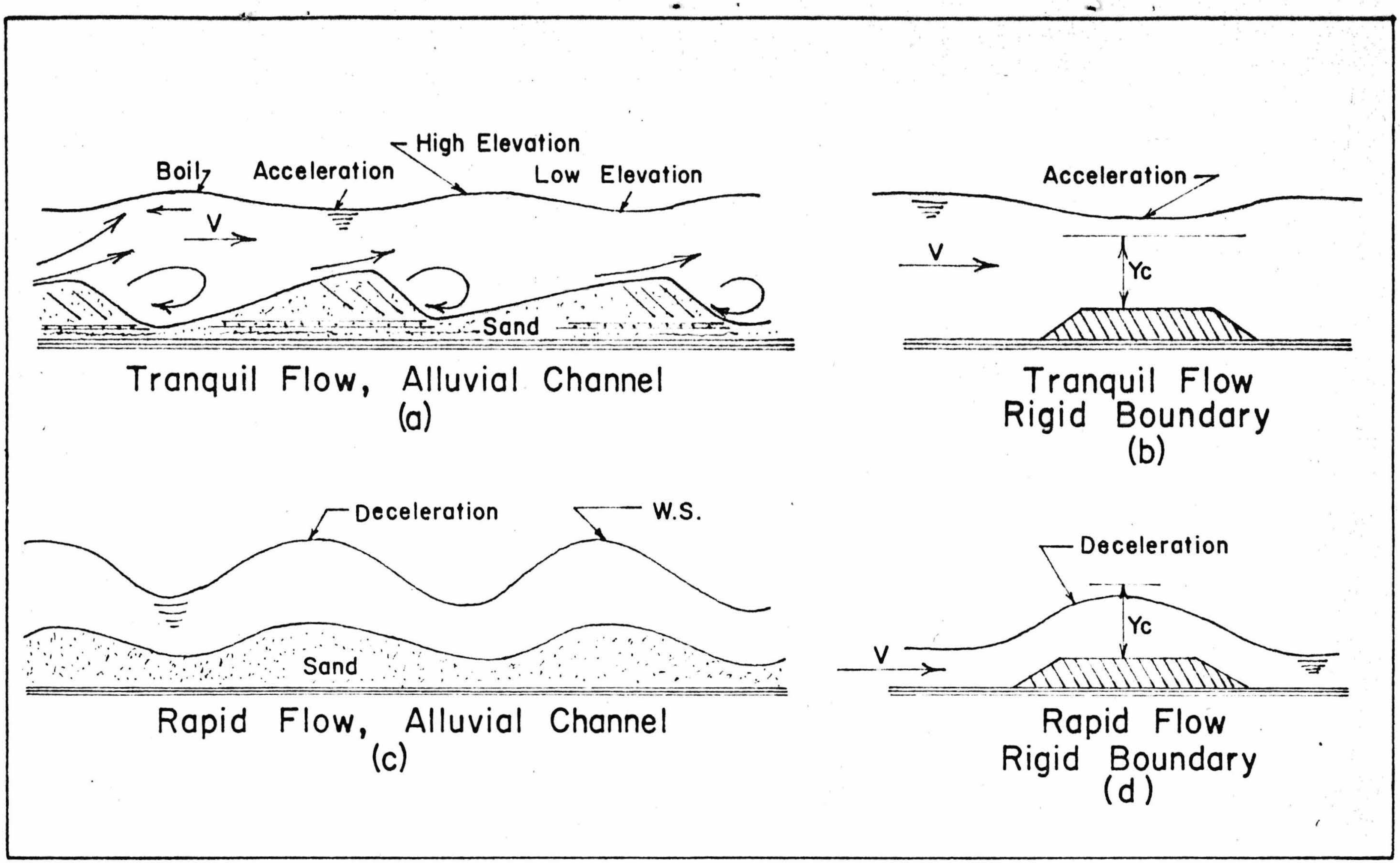

Fig. 1 Relation Between Water Surface and Bed Configuration in the Tranquil Flow and Rapid Flow Regimes.

1. Symetrical sand and water waves

2. Antidunes

3. Violent antidunes

The foregoing major forms of bed roughness are illustrated in Fig. 2.

The most usual forms of bed roughness are ripples, dunes, and plane bed; although standing wave and antidune forms of bed roughness are not uncommon.

The form of bed roughness can be related to size of bed material (see Fig. 3) which relates $\frac{V_*}{\omega}$ to $V_* d/\nu$ (Albertson, Simons and Richardson, 1958)

II Variation of Resistance to Flow with Form of Bed Roughness

The magnitude of resistance to flow varies with form of bed roughness. The magnitude of variation of Manning n with form of bed roughness is indicated at least qualitatively in Table 1.

TABLE 1

Form of Bed Roughness	Range in Manning n
Plain bed bed before motion	0.015
Ripples	0.016 - 0.022
Dunes	0.018 - 0.035
Plane bed and symetrical sand and water waves	0.010 - 0.018
Antidunes	0.012 - 0.020

The foregoing values of n are based upon ideal conditions and one size of bed material. In the field those values would be larger because of such factors as sinuosity of channel and vegetation. Note the discontinuity of n values as the form of bed roughness changed from dunes to plane bed or standing waves.

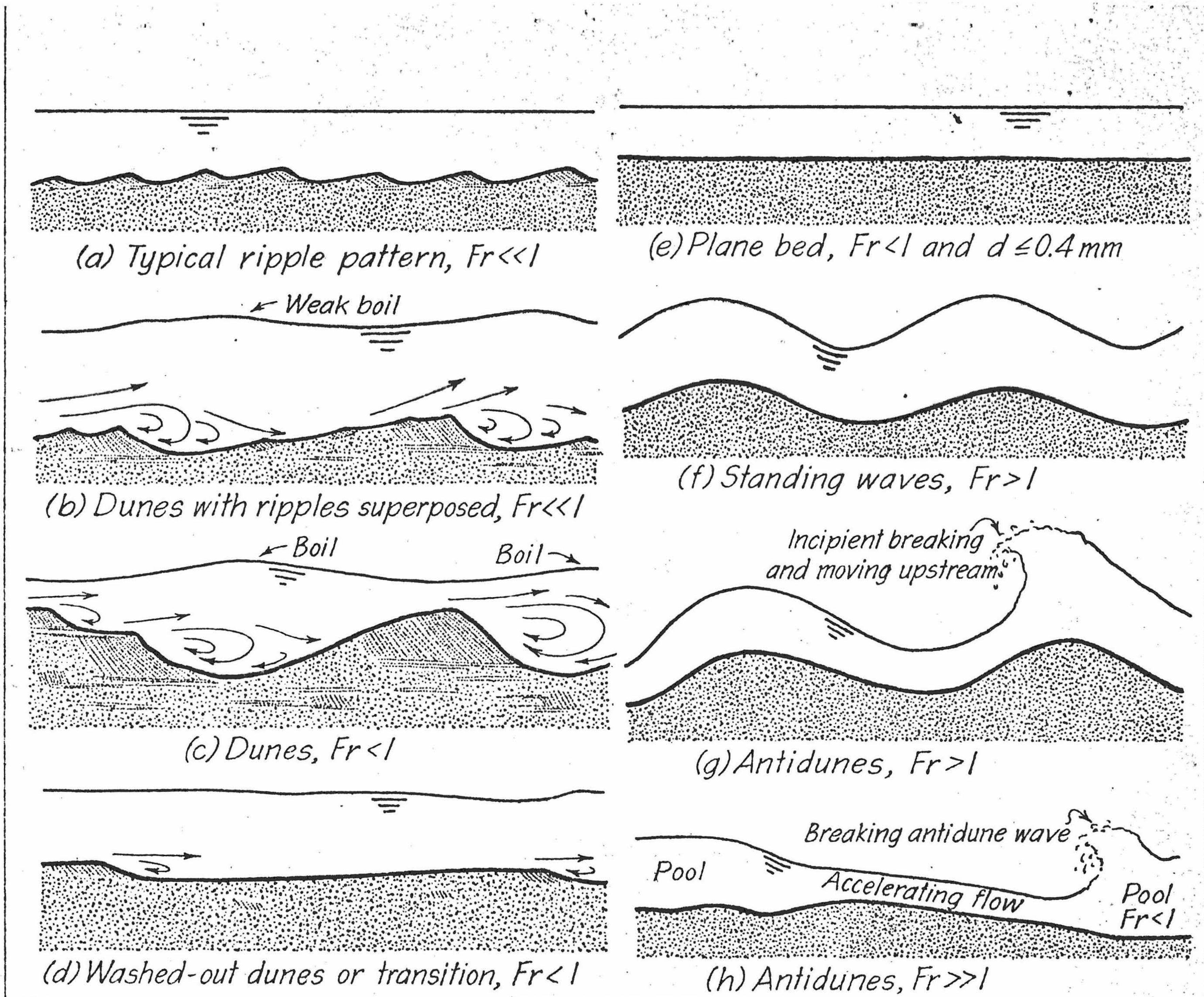

Fig. 2 Forms of Bed Roughness in Alluvial Channels

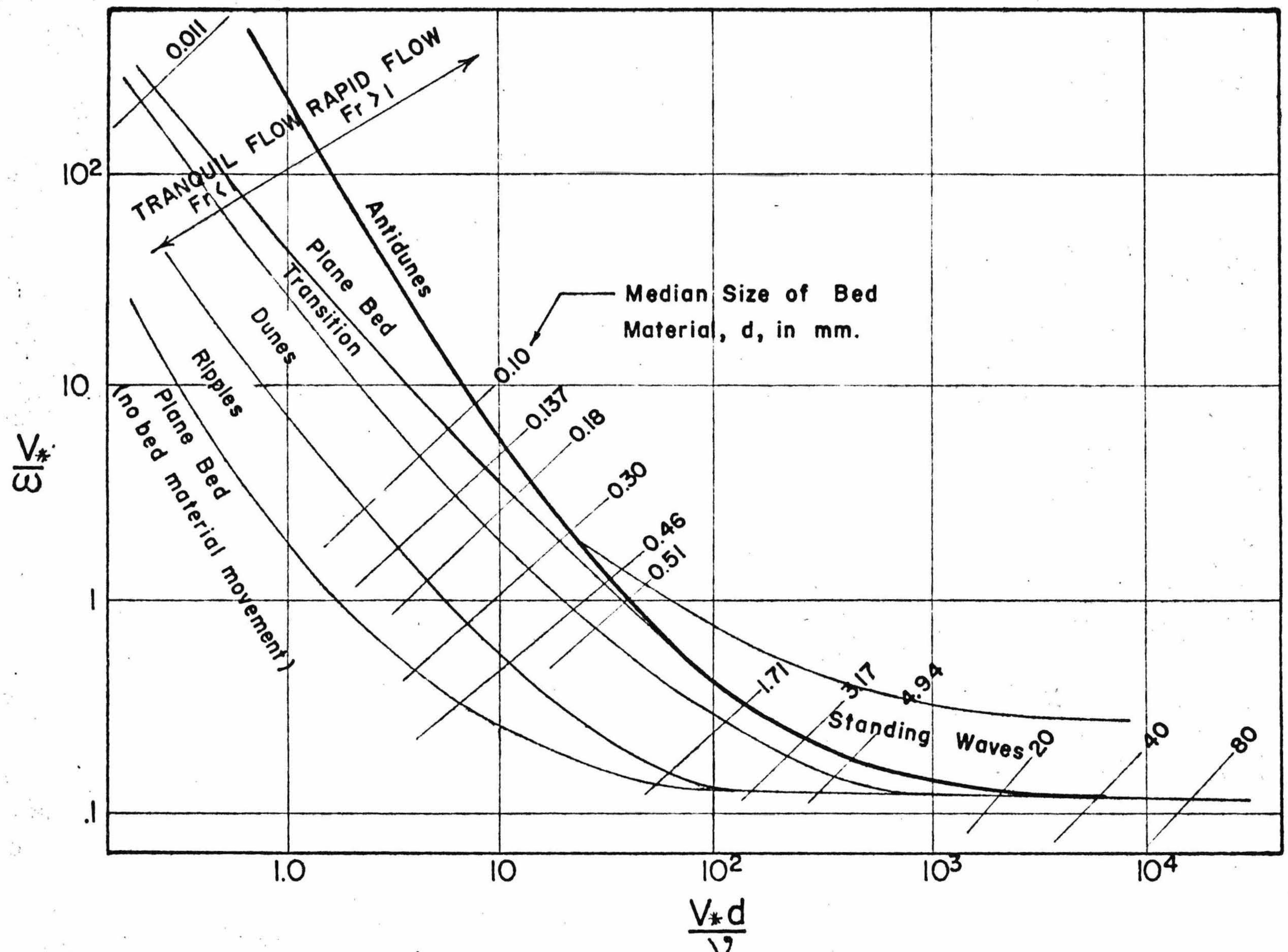

Fig. 3 Qualitative Concept of Regimes of Flow and Forms of Bed Roughness in Alluvial Channels.

The effects of changes in bed roughness on stage or depth discharge relations are illustrated in Fig 4. Before the discontinuity in the curve of Fig. 4a the form of bed roughness is dunes. After the discontinuity, the form of bed roughness is plane bed or standing waves.

III Variation of Total Sediment Load with Form of Bed Roughness

A qualitative relationship between form of bed roughness and total sand-silt sediment transport is indicated in Table 2

TABLE 2

Form of Bed Roughness	Variation in Total Load, ppm
Ripples	0 - 75
Dunes	75 - 500
Transition - dunes to rapid flow	500 - 1000
Standing Waves	1000 - 4000
Antidunes	6000 and more

These data are based on flume experiments using a sand with a median diameter of 0.46 mm and a standard deviation equal to 1.60.

IV The Influence of Fine Material on Channel Roughness and Sediment Transport

Recent investigations conducted by the U.S.G.S. at Ft. Collins, Colorado, indicate that:

a. The addition of fine material (sometimes called wash load) to the flow has little effect on resistance to flow when in concentrations less than 2000 - 3000 ppm.

b. The addition of large quantities of fine material (in excess of 10,000 ppm) in the ripple and dune range of bed roughness reduces the resistance to flow as much as 40 percent.

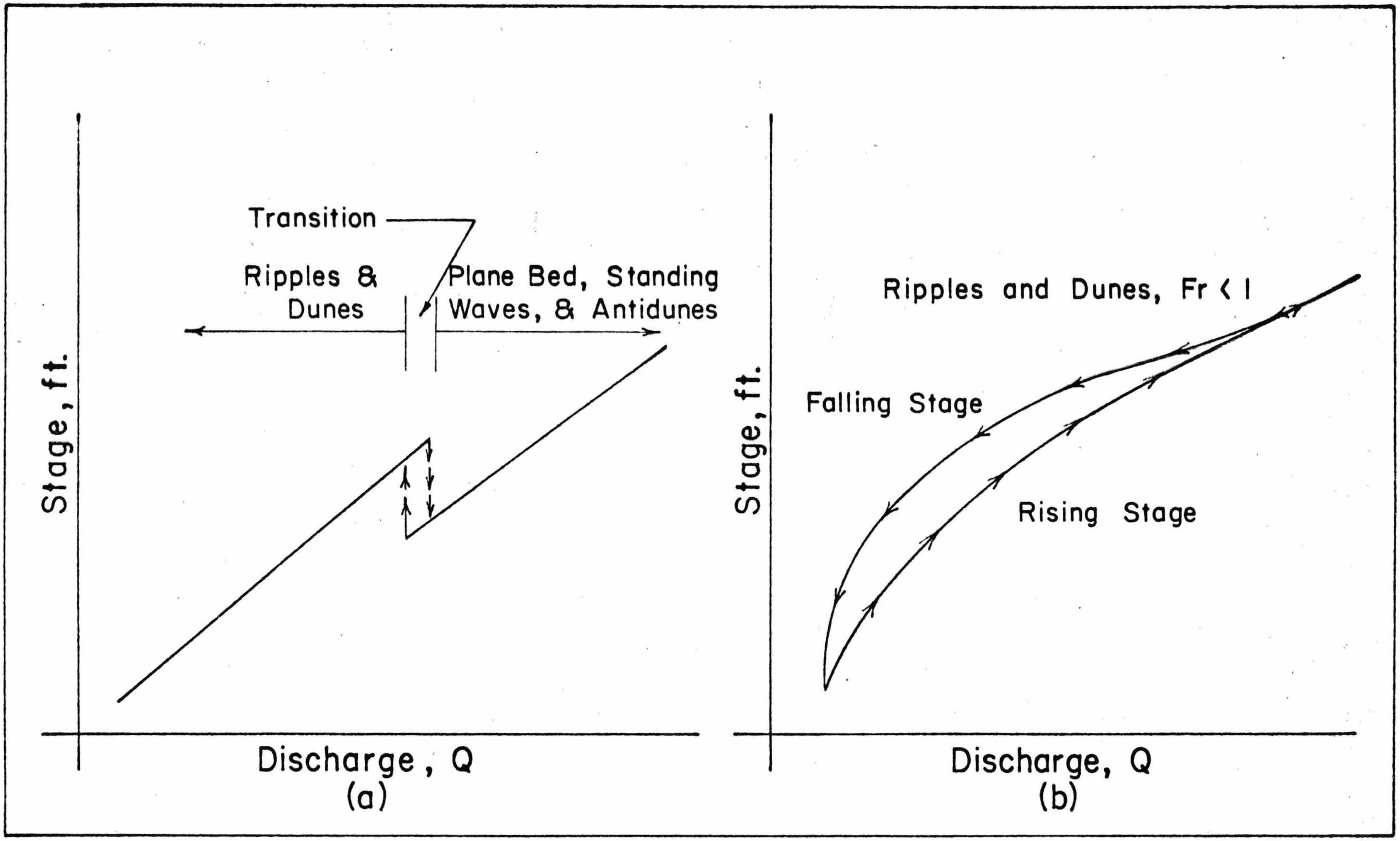

Fig. 4 Typical Qualitative Stage-Discharge Curves for Alluvial Channels.

c. The addition of fine material with dunes (in excess of 30,000 ppm) increases the magnitude of the silt-sand sediment load as much as 100 percent.

d. The influence of the fine material, even in relatively small quantities, (100 - 500 ppm) evidently plays an important roll in channel geometry under certain field conditions. Reductions of channel width equal 0 - 39 ft due to the presence of fine material in the flowing water have been observed. This action is called berming.

In the preceding statements the fine material referred to is sufficiently small (clay) that it is not found in appreciable quantities in the shifting portions of the alluvial bed.

V River Regime

The stability of a river can be upset in a number of ways such by varying the slope, the discharge, the sediment load or the size of sediment. Lane, 1955, discussed this aspect of fluvial morphology in considerable detail. He presented a very simple expression which is useful to qualitatively analyze the many problems of stream morphology

$$Q_s d \sim QS \qquad \text{- - - - - - - - - -} (1)$$

where

Q_s = the quantity of sediment being transported as bed load

d = the median size of the sediment

Q = the water discharge

S = the slope of the stream

This equation is an expression of equilibrium. If any variable in the equation is altered it indicates the change or changes in the other variables necessary to restore equilibrium. For example, if the sediment load in a regime stream is reduced (perhaps by construction of a dam) equilibrium can be restored if Q and/or S are decreased sufficiently or if the diameter of the sediment is decreased an adequate amount.

The changes which take place in a stream as a result of altering one or more of the variables in Eq 1 can usually be related to:

1. Decreasing Q by diverting clear water for one purpose or another. Thus, Q changes without changing Q_s and d. This condition causes the channel to aggrade.
2. Reducing the normal sediment load. This usually results from the construction of a dam across the river channel which traps the sediment load. This causes degradation below the dam.
3. Raising the water level at one point. This usually is due to the construction of a dam, or the damming of a river by landslides, mud flows, lava flows, or a glacier. The net result is an aggrading river upstream of the point of rise.
4. Dropping the water level at a point. This condition is usually the result of lowering the water surface in a reservoir from one level to another. The effect is a degrading stream. This situation is illustrated by Whitewater river which flows into the Salton Sea. Originally the water level in the Salton Sea was 40 ft above sea level. This body of water has since been cut off

from the ocean and its level has been lowered by evaporation to 250 ft below sea level. The river is slowly adjusting itself to this new base level.

5-6. Changing the length of the stream by moving the base level upstream or downstream without change of elevation.

In the foregoing cases only vertical movements of streams have been discussed. Horizontal changes accompany the vertical ones. These changes are discussed in the following paragraphs.

VI The Meandering Stream

Every channel with erodible sides has a tendency to meander. If a straight channel is constructed in the laboratory flume, it is inevitable that with time a stream shape very much like a horizontal sine curve will develop. These simple sinusoidal curves can be observed in natural streams in many instances. However, because of the many conditions which influence the behavior of a natural stream such as violently varying water discharge and sediment loads, varying sediment sizes, nonuniform bank material, land slides, ice jams, etc., most rivers can not meander in a strictly sinusoidal manner. Most rivers exhibit a wide variety of flow patterns. Despite the variation in meander patterns, meandering is still recognizable without difficulty.

Meandering is usually accompanied by cutoffs. A cutoff occurs as a result of the development and advancement of the meander bends. A cutoff is simply an alternate flow path which provides a means of short-circuiting the flow past a meander. In effect this shortens the channel and increases the channel slope. A meander pattern with cutoff is illustrated in Fig. 5.

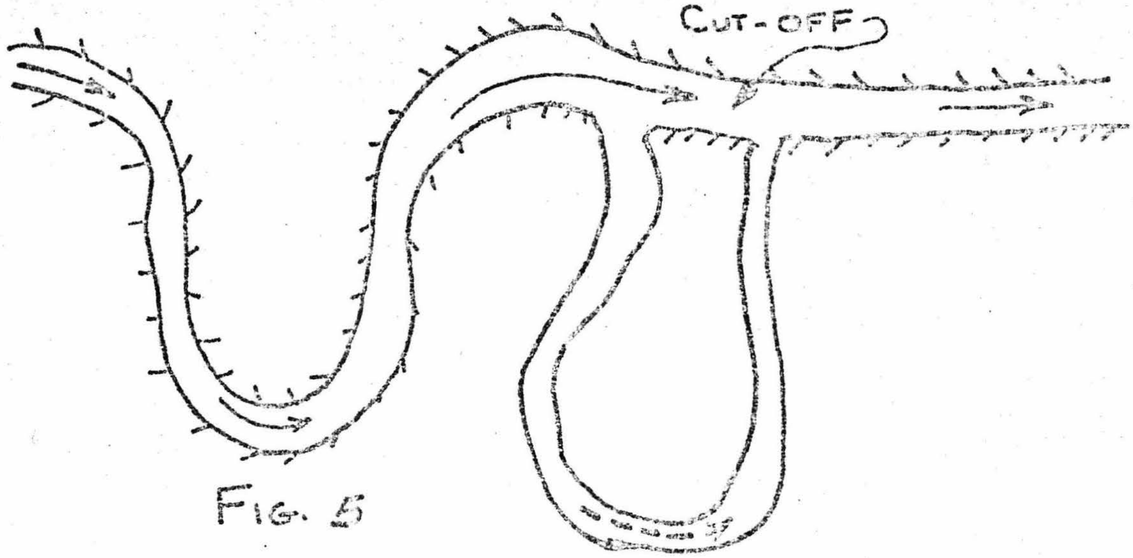

FIG. 5

VII The Braided Stream

A certain degree of stability is exhibited by a meandering stream. Its banks, in the relatively straight reaches, are fairly stable. The principle regions of erosion are confined to regions of maximum channel curvature. If rate of discharge, sediment discharge, and slope are changing frequently, either simultaneously or individually, the degree of instability may be so large that it is impossible for a clear cut meander pattern to develop at all. The net result is usually a braided stream with an aggrading bed. In this case there is no incised channel and flooding occurs at high discharges. A braided channel is illustrated in Fig. 6.

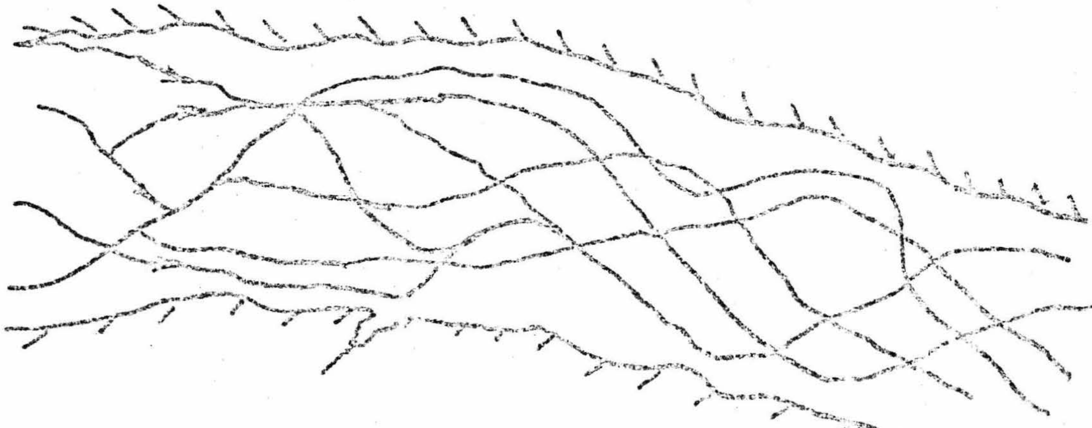

FIG 6 - BRAIDED CHANNEL

In a recent study by Leopold and Wolman (1957) channel slope was related to bankful discharge for straight channels, meandering channels, and braided channels, see Fig. 7.

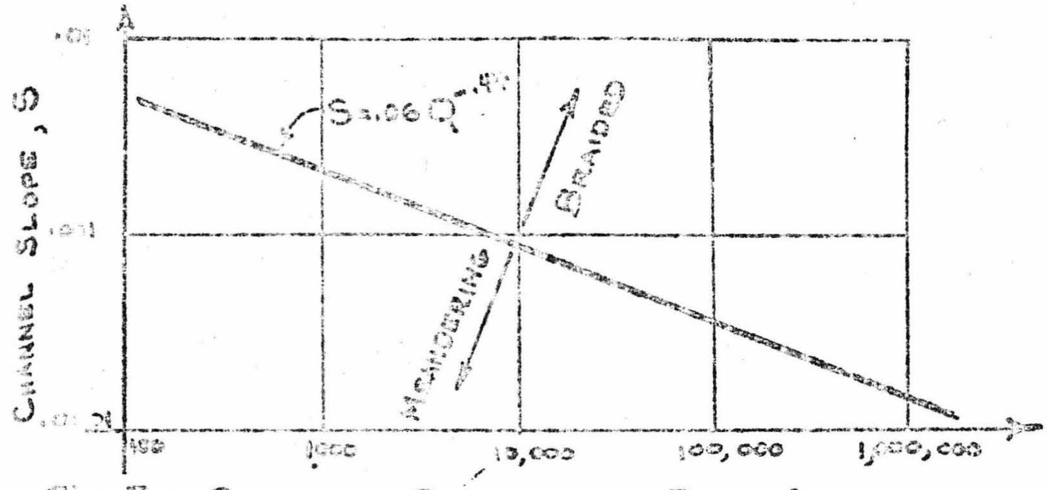

Fig 7 - BANKFULL DISCHARGE Q, cfs

This relationship separates meandering channels from braided channels in a rather effective manner. The equation of the line dividing the two types of channels is

$$S = 0.06\, Q^{-0.44} \qquad \text{------------- (2)}$$

where

S = channel slope

Q = bankful discharge in cfs.

That is, if the actual slope exceeds the slope indicated by Eq 2 for a given Q the channel will probably braid, and if the slope indicated by Eq 2 for a given Q is larger than the measured slope, the channel is probably a meandering channel.

It may be worthwhile to relate braided and meandering streams to the Froude number. Based on field studies it seems that when $F_r > 0.3^{\pm}$ the banks in the straight reaches, as well as the bends, are unstable. The unsymetrical excessive erosion and consequent variation of the channel may yield an aggrading braided stream. On the other hand, if Fr < 0.3$^{\pm}$ the bends are probably unstable and the straight reaches connecting the bends are reasonably stable, yielding a meandering stream.

VIII The Flood Hydrograph and Channel Behavior

When observing and studying flood flow phenomenon there are several factors that are worthy of consideration. One of the most interesting is the variation of resistance to flow with flood stage. At least three distinctly different situations can exist, as follows:

a. A flood passing through a channel with sufficiently flat slope that the regime of flow remains tranquil. That is, the form of bed roughness is always ripples or dunes. In this case the bed roughness may be ripples at low stage, and as the magnitude of flow increases the bed becomes rougher (that is, it changes from ripples to small dunes to larger dunes). In this instance the development of roughness lags the increase in discharge on the rising stage. The reverse is true on the falling stage. That is, the reduction in roughness lags the decrease in discharge.

b. A flood passing through a sufficiently steep channel that the flow is always in the rapid flow regime. In this case there is very little change in bed roughness as the flood stage develops and then recedes, and total sediment transport increases with increasing Froude number.

c. A flood passing through a channel with such a slope that flow is tranquil at low stage and rapid at high stage. In this instance there is a discontinuity in the stage discharge relation, see Fig. 4. A typical depth discharge relationship for a flood of type c is presented in Fig. 8.

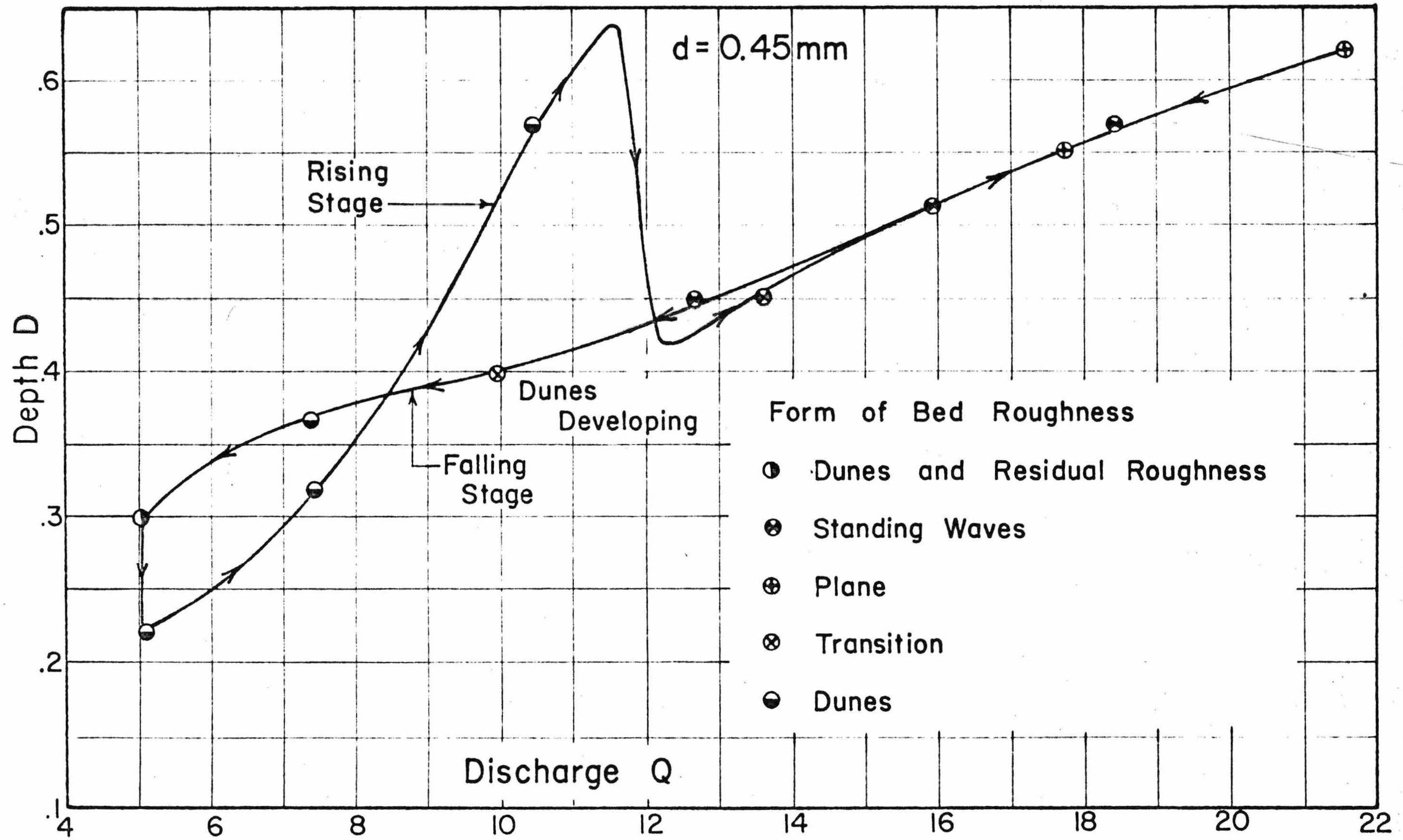

Fig. 8 Rapid and Tranquil Flow Depth-Discharge Relation, Slope Varying with Discharge

IX Sediment Sampling Problems in Alluvial Channels

The accuracy with which sediment load can be measured is a function of such factors as:

a. Type of sampling equipment

b. Type of channel geometry, that is, braided or meandering

c. Location of sampling station

d. Frequency of sampling

e. Number of samples taken.

When sampling stations are located in contracted reaches, for example at bridges, the samples taken on the rising stage will contain an excessive amount of sediment because of local scour. On the falling stage the samples taken will indicate a small rate of sediment transport because of local aggradation. It can be argued, however, that these two opposing tendencies cancel one another with time. However, this is doubtful and should be studied further.

A similar situation exists when sampling stations are located in bends of channels. There is excessive scour under almost all circumstances at such locations and the fluid turbulence is such that part of this local excessive scour is measured. The channel shape is also continuously changing more rapidly in the bends than in the connecting straight reaches of channel.

Sampling time is very intimately related to the accuracy with which daily sediment load can be measured. A detailed study of variation of total load with time based upon ideal laboratory conditions is indicated in Fig. 9. An analysis of this figure indicates that samples must be taken continuously over a period of about 2 hours and averaged in order to estimate total load accurately under steady flow conditions. A comparison of individual samples shows a variation in total load of as much as [illegible] percent.

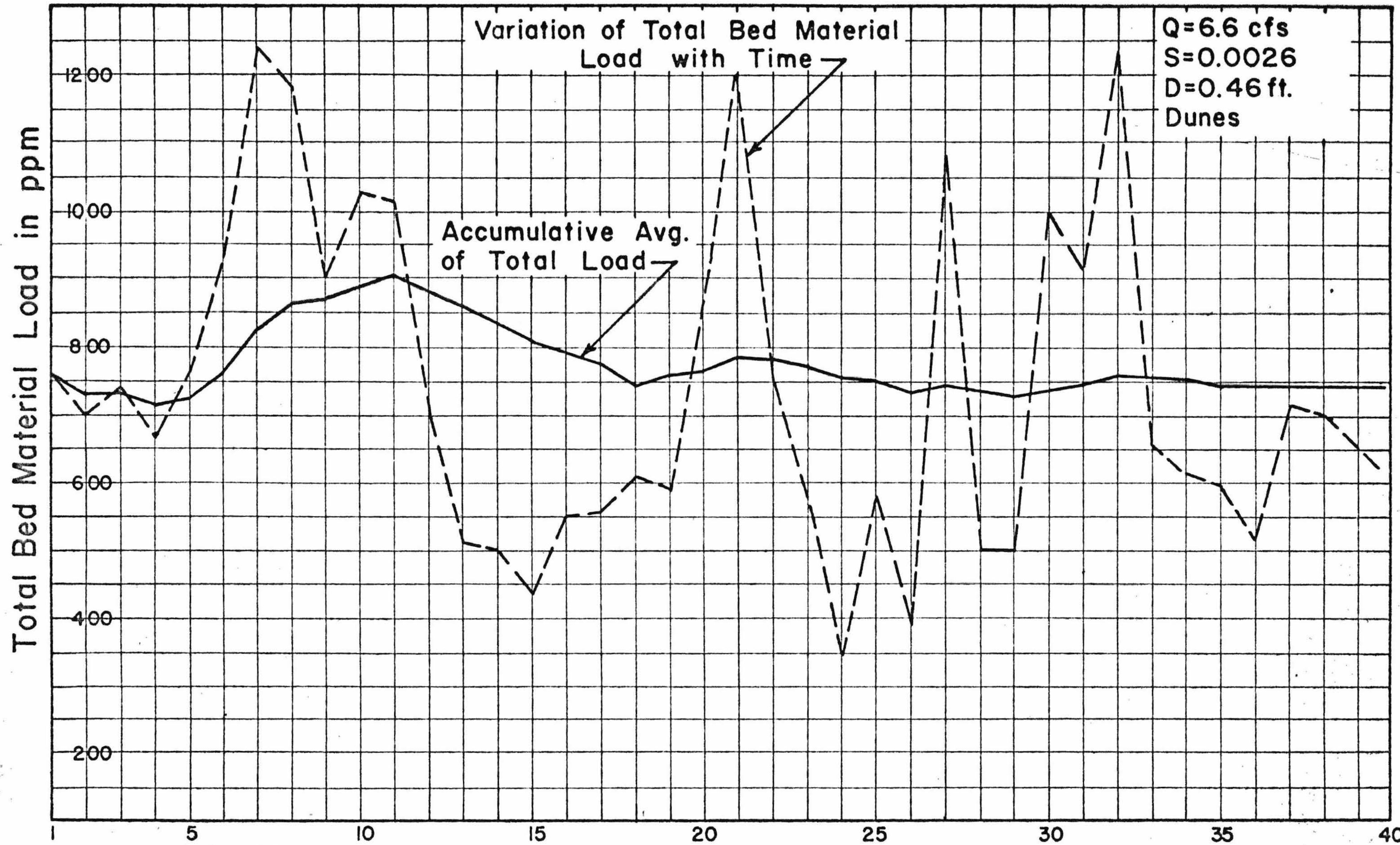

FIG 9 Number of Total Load Samples Taken
(One sample taken every five minutes)

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