

# OBSERVATIONS ON THE NATURE OF SCOUR

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## FUNDAMENTAL CHARACTERISTICS OF SCOUR

Within the framework of our knowledge of physical phenomena, certain general characteristics of the process of scour can be formulated. Since in many areas the framework exists only in broad outline, our insight into the more detailed features of scour must depend on experimentation. These details, however, must be consistent with the general characteristics; and the formulation of general characteristics, therefore, establishes an outline for the interpretation of experimental observations.

Scour can be defined as the enlargement of a flow section by the removal of material composing the boundary through the action of the fluid in motion. Implicit in this definition is the fact that the moving fluid exerts forces on the particles composing the boundary, causing their movement. The amount of material which the fluid can move or transport, in unit time, is termed the capacity of the flow.

If the principle of conservation of matter is accepted, the local rate of scour is equal to the difference between the rate of removal and the rate of supply. Moreover, since no distinction is made between the material supplied and the material scoured, the rate of removal must equal the local capacity of the flow. Application of this concept to the more detailed characteristics of the scour process is possible if certain assumptions regarding the flow conditions at the boundary are made.

Even if the bulk flow is constant with time, the change in the boundary configuration because of scour results in unsteady flow conditions along the boundary. In general, the enlargement of the flow section will result in a reduction of velocity along the boundary and, therefore, a reduction in capacity for transport. The rate of scour must then decrease as the difference between the capacity and the rate of supply decreases. Implicit in the foregoing statement is

the notion of a limiting extent of scour. The rate of scour will equal zero when the capacity is exactly equal to the supply. That a limit exists, for which the rate of scour is equal to zero, can be deduced with the aid of two further assumptions.

The premise that the velocity decreases as the flow section enlarges can be expanded to require that the velocity becomes zero when the boundary extends to infinity. If the rate of flow is finite this assumption is assuredly acceptable, and is sufficient to prove that a limit exists for the case in which material is supplied to the scoured area. If the capacity decreases with the velocity then there must be some finite boundary position for which the capacity equals the supply. This position will be the limit to the extent of scour. For the case in which there is no supply to the scour hole an additional assumption is needed — that below some critical velocity the capacity is zero. There must then be some finite boundary position for which the velocity decreases to this critical value and the rate of scour becomes zero. For the case of no supply, this position satisfies the notion of limit.

Establishing the existence of a limit to the extent of scour gives no indication as to the time necessary to attain the limit. That the limit must be approached asymptotically can be shown. If the limit were to be reached in finite time, the scour must continue beyond the limit, or deposition (negative scour) must occur after the limit is reached, or the scour process must be described by two functions, one before and one after the limit. None of these possibilities is admissible. Deposition would require a two-valued relation between the capacity and the difference between the actual and the limiting boundary. Continued scour is not compatible with the concept of limit. Unless some new force is added there is no reason why the scour function should change at the limit. If the limit is approached asymptotically, however, no matter how small the difference between the actual and limiting boundary, there is always a small rate of scour so that the limiting position is approached more closely. Not until the limit is reached at infinite time does the rate of scour become zero. This process is orderly and continuous.

To recapitulate, the following general characteristics which should be basic to any detailed analysis of local scour have been deduced:

1. The rate of scour will equal the difference between the capacity for transport out of the scoured area and the rate of supply of material to that area.

2. The rate of scour will decrease as the flow section is enlarged.
3. There will be a limiting extent of scour.
4. This limit will be approached asymptotically.

The premises necessary to form these characteristics are a definition of scour, the principle of conservation of matter, and two restrictive assumptions that describe the kind of process the scour phenomenon is expected to be. The two assumptions, which are not overly restrictive but rather credible in the light of general knowledge of fluid mechanics and sediment transportation, are:

1. The movement of the fluid along the boundary ceases when the boundary extends laterally to infinity.
2. The capacity of the flow decreases in a single-valued continuous relation as the flow section is enlarged, and decreases to zero before the movement of the fluid ceases.

Nothing has been said or need be said, at this stage, about the mechanism of transport or the method of supply. It should be kept in mind, however, that only conditions at the boundary are under consideration.

#### APPLICATION OF FUNDAMENTAL PRINCIPLES

By using symbolic terms the first general characteristic can be written as an equation of scour,

$$\frac{d}{dt}[f(B)] = g(B) - S \quad (1)$$

where  $B$  is a mathematical description of the boundary, so that

$\frac{d}{dt}[f(B)]$  is the rate of scour,

$g(B)$  is the capacity of the flow as a function of the boundary position, and

$S$  is the rate of supply.

To apply this equation to a specific situation, the rate of supply and the capacity of the flow (as it varies with the boundary position) must be known. If the relation between capacity and the velocity distribution near a boundary were known exactly and if methods were available to specify the flow pattern for any boundary condition, the equation of scour could be used to solve any scour problem. For most instances such a relation and such methods are not available and recourse must be had to approximations and experimentation.

How the solution for a specific instance of scour could be obtained

within this general framework can be seen by an examination of a paper by Straub [1]. The specific situation was the equilibrium depth obtaining in long channel contractions. The procedure was

equivalent to setting  $\frac{d}{dt} [f(B)] = 0$  and solving for the limiting

condition of scour. At the limit the capacity for transport in the contracted, scoured section must equal the rate of supply — which is equal to the capacity for transport in the uncontracted section. The contraction was sufficiently long that essentially uniform flow was established.

The flow was described by Manning's formula with the same value of  $n$  in the contracted and uncontracted sections,

$$Q = \frac{1.49}{n} W_1 d_1^{2/3} S_1^{1/2} = \frac{1.49}{n} W_2 d_2^{2/3} S_2^{1/2} \quad (2)$$

and the capacity was described by a sediment transport formula of the DuBoys type with coefficients experimentally determined,

$$g(B) = W_1 \psi \gamma d_1 S_1 (\gamma d_1 S_1 - \tau_c) = W_2 \psi \gamma d_2 S_2 (\gamma d_2 S_2 - \tau_c) = S \quad (3)$$

Upon combining Eqs. (2) and (3), an equation for depth of flow in the contracted portion is formed,

$$d_2 = \left( \frac{d_1}{(1-\beta)^{3/7}} \right) \left\{ \frac{-\tau_c + \left[ \left( \frac{\tau_c}{\gamma S_1} \right)^2 + \frac{4d_1 \left( d_1 - \frac{\tau_c}{\gamma S_1} \right)}{1-\beta} \right]^{1/2}}{2 \left( d_1 - \frac{\tau_c}{\gamma S_1} \right)} \right\}^{3/7} \quad (4)$$

In these and the following equations,

$Q$  and  $Q_s$  are the rates of flow of water and sediment

$\psi$  and  $\tau_c$  are constants

$S_1$  and  $S_2$  are the slopes in uncontracted and contracted sections,

$\beta$  is the contraction so that  $W_2 = (1 - \beta) W_1$ , and

$d_1$  and  $d_2$  are the depths in uncontracted and contracted sections.

Experiments in the laboratory confirmed this relationship very closely. Such confirmation could be expected since the coefficients in the transport equation were determined under similar conditions. Whether Eq. (4) will apply to field conditions depends not on Eq. (1), which must be valid, but on Eq. (2) and especially Eq. (3), which are approximate. Equation (4), with  $\tau_c$  equal to zero, is very

nearly Griffith's equation [2], which is based on field observations,

$$d_2 = d_1 \left( \frac{W_1}{W_2} \right)^{0.637} \quad (5)$$

This agreement between analysis, laboratory, and field indicates that even approximate knowledge of transport and flow conditions can lead to useful results.

#### SCOUR BY A SUBMERGED JET

Under the sponsorship of the Office of Naval Research, the Iowa Institute is conducting an investigation of the effect of sediment characteristics on the scour process. A submerged jet is being used as the active scouring agent, and the flow as well as the sediment characteristics is being varied. For uniform sands it has been found possible to analyze this scour process by means of Eq. (1) and the necessary empirically determined relationships.

The experimental boundary conditions are shown schematically in Fig. 1. It was found necessary to restrict the pendulation of the jet by the lip shown at the upper edge of the slot. The sand profile was obtained by photographing with back lighting, and the time of observation was recorded by the including of a clock in the photograph. A typical series of profiles is superposed on Fig. 1. Sands having the characteristic curves designated as M, A, and B in Fig. 2 were used.

Similarity of scour profiles was established by plotting the dimensionless coordinates of the profiles; the horizontal distance from the slot to the crest of the dune was used as the repeating variable (Fig.

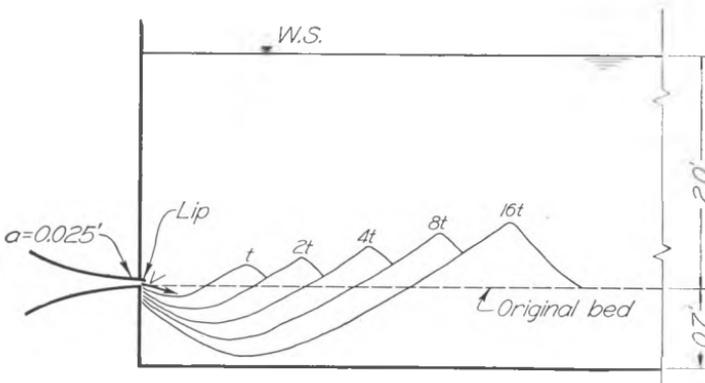


FIG. 1. SCHEMATIC OF EXPERIMENTAL EQUIPMENT FOR SCOUR BY SUBMERGED JET.

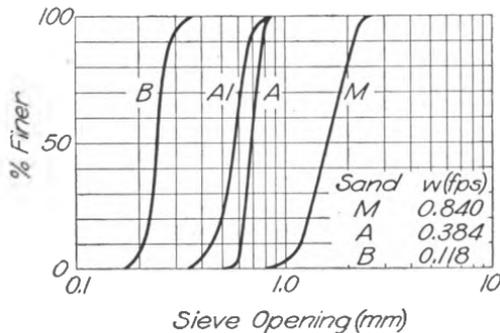


FIG. 2. SAND CHARACTERISTICS.

3). Except for the profiles representative of an initial transitory stage of scour, all the profiles of a run superpose if plotted in this manner. Moreover, the profile forms for all runs of any one sand were almost identical and the forms for the various sands differed only slightly.

At the beginning of each run the sand was moved as bed load. During this transitory stage, the vertical dimensions of scour hole and dune increased faster than the horizontal dimensions. When the upstream face of the dune reached the natural angle of repose, the mechanism of transport changed to suspension. The sand was then entrained by the flow, largely at the point of impingement, and was lifted in suspension by the upward currents of the flow. Some of the sediment was returned to the scour hole by the large counter-clockwise eddy shown in Fig. 4. The greater part of the sediment was deposited on the upstream face of the dune and slumped back into the scour hole. The sand removed from the scour hole was con-

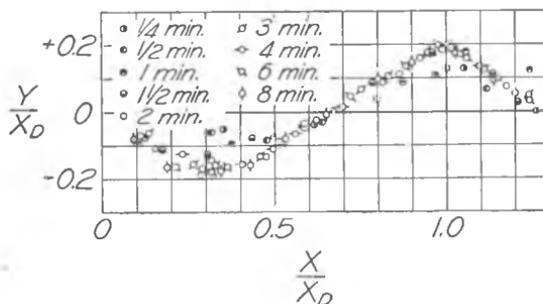


FIG. 3. SIMILARITY OF SCOUR PROFILES.

fined to that portion which deposited downstream from the crest of the dune.

Having established similarity of profiles it was sufficient to examine one typical dimension in the investigation of the variation of the extent of scour with time. The variation of the extent of scour with time is plotted in Fig. 5, the distance  $x_D$  (see Fig. 4)

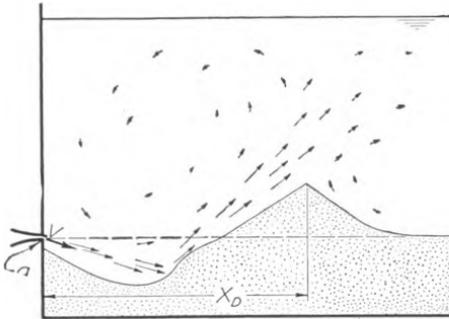


FIG. 4. FLOW PATTERN OF SUBMERGED JET.

having been chosen as a typical length. After the transitory stage it can be seen that the plotted points scatter around the straight lines with the logarithm of a time parameter as abscissa. This would seem to indicate that the extent of scour would become infinite as time became infinite — in contradiction to characteristic No. 3 of the first section, that there must be a limit to the extent of scour.

By reducing the velocity of flow after a scour hole had developed, conditions could be imposed so that the sand particles rarely moved at the point of impingement, and movement of any particle over the crest was hardly conceivable. An increase in velocity would increase the amount of movement. The limiting velocity for any given size of scour hole was arbitrarily defined as the velocity which appeared to carry particles to, but not over, the crest, during a period of observation of several minutes. The points in Fig. 6 were thus obtained. To provide a distinguishing notation,  $x_D$  at the limit has been called  $x_L$ . A limit such as indicated in Fig. 6 and a relationship between extent of scour and time as indicated in Fig. 5 can both exist only if the true function is approximately logarithmic over a considerable range and yet approaches a finite limit. That such a function can describe the phenomenon will be shown.

In order to obtain an independent measure of the capacity func-

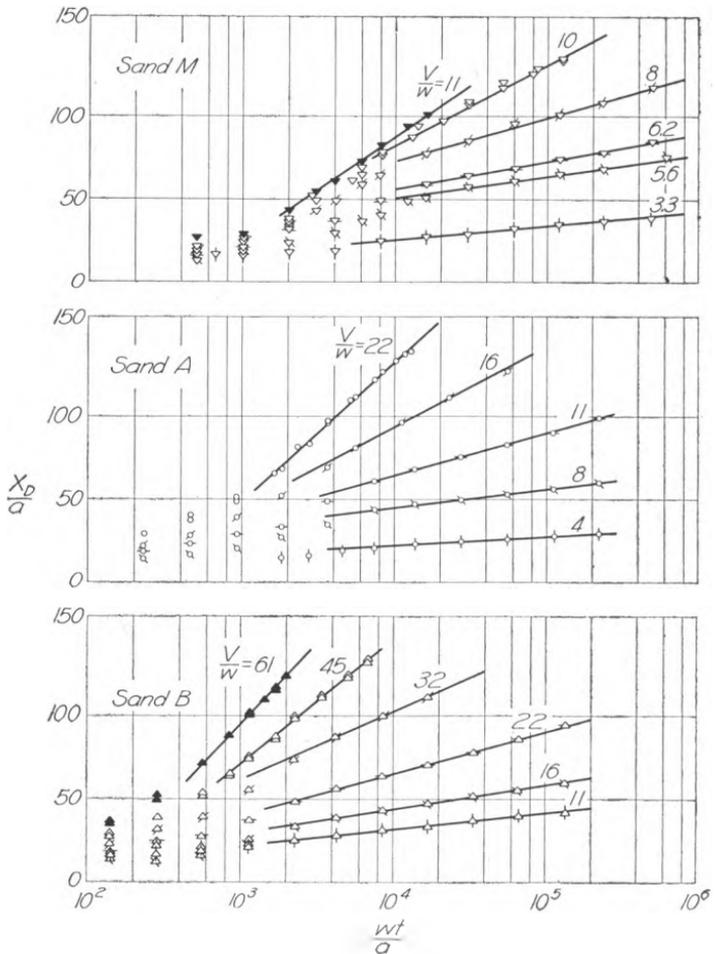


FIG. 5. VARIATION OF EXTENT OF SCOUR WITH TIME.

tion, a sand hopper was added to the experimental equipment. The same experimental procedure was used as before, except that, above the slot, sand was supplied at a measured rate. A scour hole and dune formed as before and the pattern was essentially the same as without the sand feed. The dune advanced downstream until the rate of removal of sand from the scour hole equaled the sediment supply. The position of the upstream face of the dune then moved upstream. The effect of the boundary configuration on the capacity of the flow was determined by relating each rate of sediment sup-

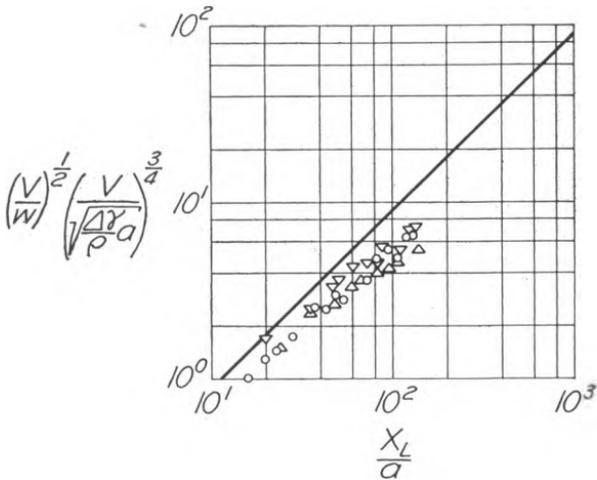


FIG. 6. LIMITING EXTENT OF SCOUR.

ply to the position of the crest of the dune when the upstream face was at its maximum distance from the slot. By varying the velocity and by using a second sand the composite plot of Fig. 7 was obtained, thereby determining a capacity function,

$$\frac{Q_s}{b} = \frac{K_c V^{6.5}}{w^2 x_D^4} \tag{6}$$

in which  $b$  is the width of the channel,  $K_c$  is a dimensional constant, and  $w$  is the fall velocity of the sediment.

Since the similarity of shape had been established, the rate of

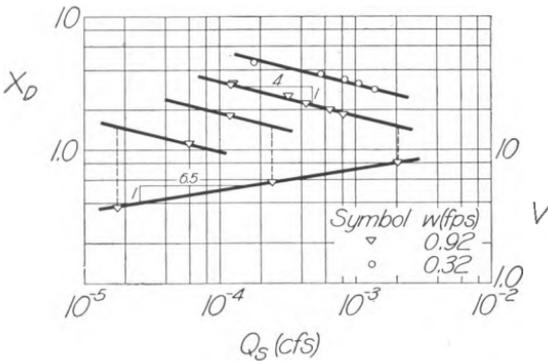


FIG. 7. CAPACITY OF SUBMERGED JET.

scour per unit width could be written as :

$$\frac{d}{dt}[f(B)] = \frac{dA}{dt} = K_s \frac{d(x_D^2)}{dt} \tag{7}$$

in which the coefficient  $K_s$  for the different sands is 0.14 for sands M and A, and 0.15 for sand B. These coefficients were determined from similarity plots such as Fig. 3. By modifying the capacity function to include a limit  $x_L$  for which capacity would be zero, and inserting Eqs. (6) and (7) in Eq. (1) a differential equation of scour was obtained,

$$K_s \frac{d(x_D^2)}{dt} = \frac{K_c V^{6.5}}{w^2} \left( \frac{1}{x_D^4} - \frac{1}{x_L^4} \right) \tag{8}$$

This equation can be integrated to give,

$$f\left(\frac{x_D}{x_L}\right) = -\left(\frac{x_D}{x_L}\right)^2 + \frac{1}{2} \ln \left[ \frac{1 + (x_D/x_L)^2}{1 - (x_D/x_L)^2} \right] = \frac{K_c V^{6.5}}{K_s w^2 x_L^6} t \tag{9}$$

As is seen from Fig. 8, the function  $f(x_D/x_L)$  has the desired characteristics of approximating, over a considerable range, a straight line with semi-logarithmic plotting and also being asymptotic to a limit.

Agreement between the above theory and experiment was realized when values of  $x_L$  from the straight line on Fig. 6 were used in Eq. (9). That the  $x_L$  values to be used in Eq. (9) are smaller than those determined by experiment might be expected, because Eq. (6) is a simple approximation of the capacity function. The effect of turbulence is not fully included therein — especially at the limit for

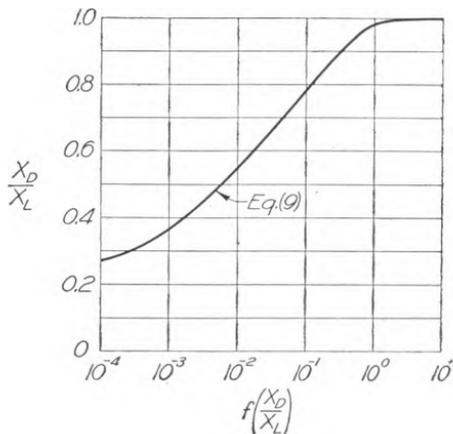


FIG. 8. GRAPHICAL REPRESENTATION OF EQ. (9).

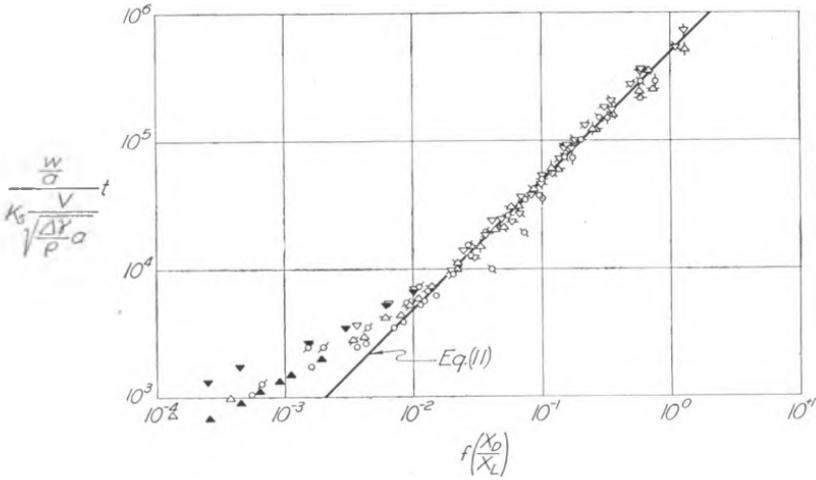


FIG. 9. VERIFICATION OF EQ. (11).

which occasional turbulent velocities, but not the mean velocity, can be sufficient to enlarge the scour hole. If the equivalent expression for  $x_L$ ,

$$x_L = c_1 a \left( \frac{V}{w} \right)^{1/2} \left( \sqrt{\frac{V}{\Delta\gamma/\rho}} a \right)^{3/4} \tag{10}$$

is substituted in Eq. (9), a new set of parameters for the coefficient of  $t$  is obtained, and Eq. (9) takes the form :

$$\begin{aligned} f\left(\frac{x_D}{x_L}\right) &= \frac{K_o (\Delta\gamma/\rho)^{7/4}}{c_1^6 a^{13/4}} \cdot \frac{w/a}{K_s V/\sqrt{a\Delta\gamma/\rho}} t \\ &= c_2 \frac{w/a}{K_s V/\sqrt{a\Delta\gamma/\rho}} t \end{aligned} \tag{11}$$

This equation is a mean line through the points in Fig. 9. The points off the lower end of the line are from high-velocity runs of short duration. Subtraction of a time for flow establishment would bring these points closer to the theoretical curve. A combination of Figs. 8 and 9 results in Fig. 10, wherein the extent of scour, instead of a function of the extent, is plotted against time.

SCOUR AROUND BRIDGE PIERS AND ABUTMENTS

Under the sponsorship of the Iowa State Highway Commission and the Bureau of Public Roads, the Iowa Institute is conducting

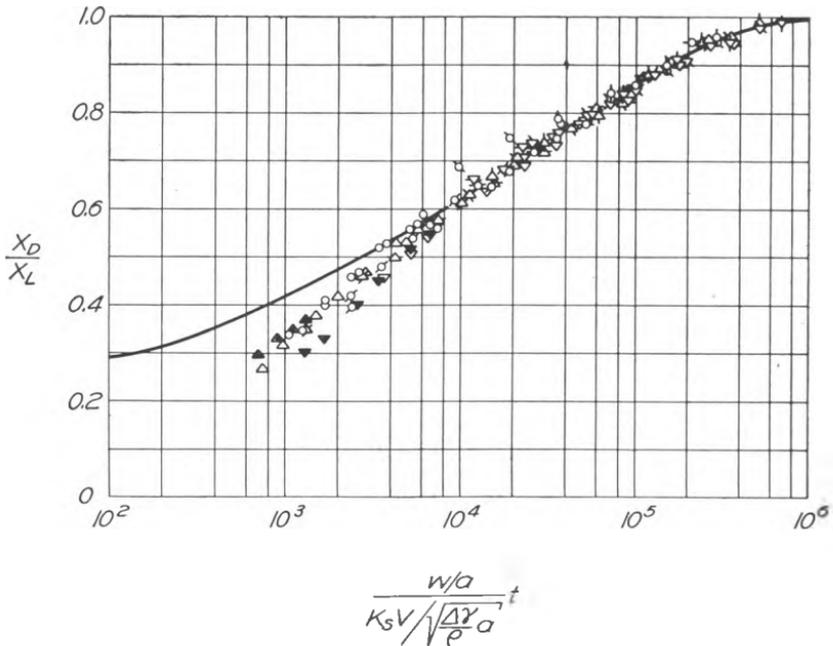


FIG. 10. EXTENT OF SCOUR RELATIVE TO LIMITING EXTENT AS A FUNCTION OF TIME.

a comprehensive study of the bridge-pier scour problem. The results of the first two phases of this study have been reported in detail elsewhere [3, 4] and only those results pertinent to the general scour problem will be stressed here.

If an obstruction, such as a bridge pier, is placed in a natural sediment-bearing stream, the flow pattern in the immediate vicinity of the obstruction is greatly modified. Since the capacity for sediment transport is dependent largely upon the velocity at the level of the particles in motion on the bed, the transport capacity at points near the obstruction will also be modified. As a result of the variation in capacity in the vicinity of the pier, scour will occur where capacity exceeds supply. The enlargement of the boundary caused by the scour will further modify the flow pattern — and in turn the scouring action — continually approaching a limiting, or equilibrium, flow and boundary condition.

For the study of the effects of velocity, depth of flow, and sediment size, a transport flume, with a trap for determining the rate

of sediment transport and an elevator for adding sand at that rate, was used. A typical pier with a web set at an angle of  $30^\circ$  to the flow has been used in all these experiments to date. The range of tests has included depths of flow from 0.2 to 0.9 foot and velocities from 1.0 to 2.25 fps. The lower limit on the velocity was the requirement of appreciable bed-load movement; the upper limit was imposed either by an approach to critical flow in the flume or by sand jumping the trap. The variation of velocity and depth resulted in a fifty-fold variation in the rate of sediment transport. Sands A-1 and M of Fig. 2 have been tested.

The relation between equilibrium depth of scour and the velocity, depth of flow, and sediment size is indicated in Fig. 11. The effect, if any, of velocity and sediment size is so small as to be within the precision of the measuring instrument. The effect of depth of flow is considerable, although the relationship is not one of direct proportionality.

These experimental results can be rationalized in the light of the general characteristics of the scour process. For the velocity to have no effect on the equilibrium depth of scour, the capacity for transport of the spiral roller at that scour depth must always equal the rate of sediment supply as furnished by the bed-load movement in the flume. This can be true only if the capacity of the roller and the capacity in the flume bear the same relation to the mean velocity of flow. In the scour hole, the velocity at the grain level is a function

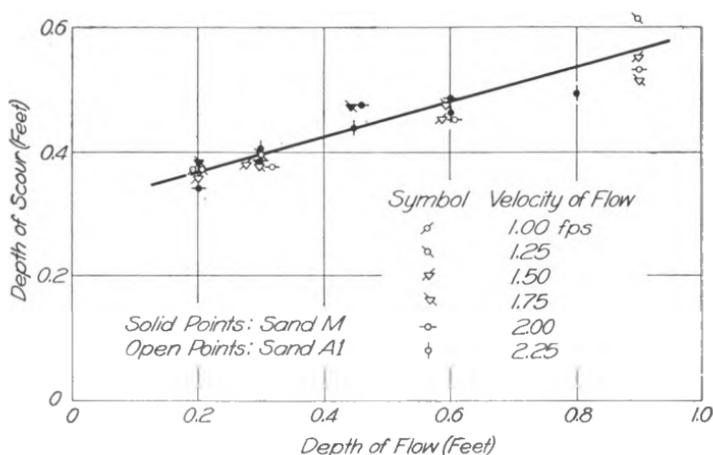


FIG. 11. TRANSPORT BALANCE AT EQUILIBRIUM DEPTH OF SCOUR.

of the velocity of the roller; in the flume, it is a function of the mean velocity. The velocity of the roller, as a first approximation, could be expected to bear a constant ratio to the mean velocity of flow. Therefore, the velocity at the level of the moving grains in the scour hole and in the flume should result in balanced capacities no matter what the absolute magnitude of the mean velocity. Essentially the same argument will explain the lack of change of scour depth with a change in the size of the uniform sand.

A similar analysis will show that the depth of scour should increase with the depth of flow. As a result of the vertical velocity distribution, the velocity at the level of the moving sand grains in the flume will decrease as the depth of flow increases. Since this velocity is the active agent of transport, the rate of sediment transport in the flume will also decrease. For an equilibrium depth of scour to obtain, the capacity of the roller must similarly decrease. The vertical velocity distribution has only a secondary influence on the roller velocity. The roller must, therefore, increase in size to be reduced sufficiently in velocity, and thereby in capacity — resulting in a greater depth of scour for greater depths of flow.

The rationalization in respect to the effect of velocity on the equilibrium depth of scour was confirmed by a series of tests on rate of scour. For this series the sand bed of the flume was replaced by bricks except in the vicinity of the pier. Transport into the hole was thus minimized. The rate of scour as a function of the depth of scour is shown in Fig. 12. The scour rate at small depths of scour should be disregarded because of the unsteadiness of flow during establishment, and at depths approaching the equilibrium because transport into the hole becomes significant. If the middle portion of each rate-of-scour curve is extrapolated, the capacity of the roller at the equilibrium depth is found to be equal to the transport into the hole under normal transport conditions.

Two qualifications, implicit heretofore, limit this analysis of bridge-pier scour. The lower limit is expressed by the requirement for general bed-load movement. As flow conditions approach the critical for sediment movement, the turbulence structure assumes greater importance. The upper limit is expressed by the requirement for sub-critical flow ( $F < 1$ ). The flow patterns for Froude numbers greater and less than unity will be markedly different.

Large scale experiments are needed to explore fully the effect of depth of flow on the equilibrium depth of scour. The depth of flow

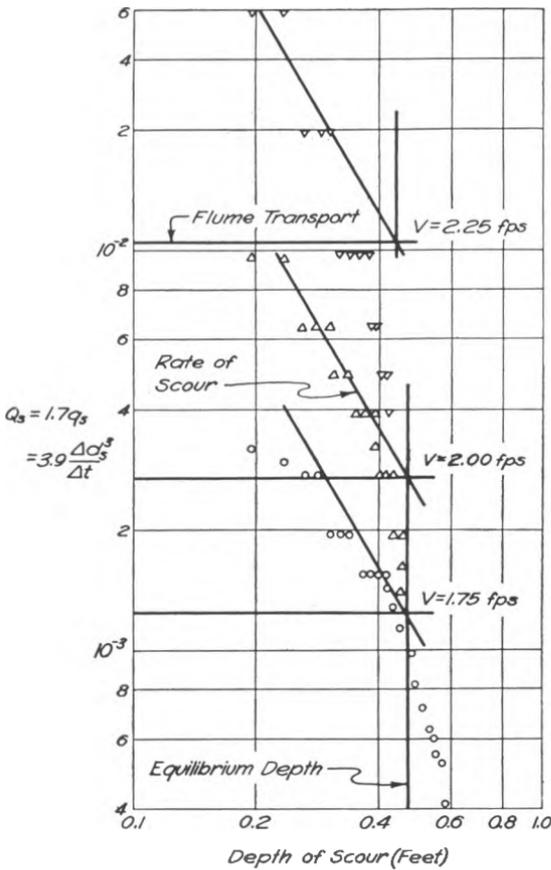


FIG. 12. DEPTH OF SCOUR AS A FUNCTION OF VELOCITY, DEPTH OF FLOW AND SEDIMENT SIZE.

should not be considered merely a geometric length variable. Indeed, its influence does not appear to be direct, but indirect through its influence on the relationship between the transport capacity in the unobstructed stream and in the scour hole. The dynamics of the flow and the state of the bed may, therefore, have secondary influences implicit in the effect of the depth of flow. However, if the qualifications mentioned above are met, the velocity of flow and sediment size, insofar as they determine the absolute rate of transport, should not affect the equilibrium depth of scour no matter what the scale. It is this simplification which gives promise that a correlation between field and laboratory may be possible.

## CONCLUSIONS

By reasoning from a few premises, several general characteristics of scour were demonstrated — that the rate of scour is equal to the difference between the capacity of flow and the rate of supply, that the rate of scour decreases as the extent of scour increases, and that there is a finite limit to the extent of scour which is approached asymptotically. The first of these characteristics must be true of all scour phenomena. The others are true if the flow pattern complies with the restrictive assumptions made. For most cases of scour, the assumptions are credible. Other assumptions, of course, might be adopted to describe the flow pattern in some special circumstances. The deduction of similar characteristics should then follow.

The re-examination of Straub's solution for the depth of flow in a long contraction showed the assumed characteristics to be in accord with a particular case of scour for which laboratory and field measurements were already available.

The effectiveness of these principles in an original analysis was then demonstrated for the case of scour by a submerged jet. By using an approximate experimental capacity function the differential equation of scour was integrated to give a relationship between the extent of scour and time. Experimental data confirmed the analysis.

The usefulness of the general concepts in interpreting experimental results was illustrated for the case of scour around bridge piers and abutments. The experimental observations that velocity of flow and sediment size had no measurable effect on the equilibrium depth of scour were rationalized from the premise that the transport capacities in the unobstructed flume and in the scour hole have the same relationship to the mean velocity of flow. The equilibrium then does not depend on the absolute rate of transport, but only on a balance between the two capacities. The same reasoning was used in explaining why the depth of flow had an influence on the equilibrium depth of scour. Although this influence cannot even be approximately expressed from the limited range of the experiments, large-scale experimentation should provide data for such an expression. The simplification of the problem that has been obtained indicates that correlation between field and laboratory should be possible since the absolute rate of transport does not need to be scaled.

In essence, the formulation of the general characteristics trans-

forms the scour problem into the problems of the determination of flow patterns and of the relation between the flow pattern and the transport capacity of the flow. Although these two problems usually depend upon experimental determination, the general concepts provide a guide for interpretation and analysis.

#### DISCUSSION

Mr. Parsons said that Mr. Laursen has employed straightforward reasoning in the analysis of the scour problem. A logical concept of the overall process of scour has been used as the basis for the testing program and for orderly determination of the associations of variables that enter into the mechanics of the scour process. The first assumption or deduced characteristic that the rate of scour is equal to the capacity of the flow at the spot under consideration less the rate of supply appears to be rather a definition of capacity.

He called attention to a tacit assumption made in the analysis which is undoubtedly correct for the conditions of the experiments. This assumption is that the fall velocity is the correct representation of the effect of qualities of the bed material. This is correct so long as the mode of transport is by suspension and that suspension is due to vertical components of the flow. He felt that if transport is occurring in close proximity to the bed, investigators should seek a more realistic expression of the pertinent qualities of the material being transported. However, even here the fall velocity may be a sufficiently close approximation.

Mr. Parsons believed that Mr. Laursen had deduced in a convincing manner that there is a finite limit to the extent of scour. Furthermore, he had devised and performed ingenious tests to prove it and to measure the scour at the limit.

Mr. Rouse wished to emphasize the point that neither the velocity of flow nor the size of sediment affects the scour around bridge piers. This significant conclusion, which results from the interrelated dependence on mean velocity of the transport both on the stream bed and in the scour hole, leads to a marked simplification of a complex problem.

Mr. Jetter expressed his interest in the work of Yarnell and Nagler in determining bridge coefficients. He once asked Yarnell what would be the effect of debris caught against the bridge piers on the discharge coefficients. Future studies could be made along the line

of the effect of debris on scour and on the design of piers to minimize debris catchment.

Mr. Izzard said that practicing engineers are aware of the drift, or debris, problem, but feel that the general problem must be attacked one factor at a time. There are a number of variables which affect the problem; as some are understood, others will be added. The relationship of the bridge opening to the total flood plain is a geometric variable that may be important. The work which Kindsvater is doing for the U. S. Geological Survey indicates the importance of this part of the general problem even though his work is confined to a fixed bed. There is some indication that the amount of backwater caused by a bridge opening is not changed by piers in the opening. The losses from constriction at the bridge seem to be much more important than the pier losses studied by Yarnell.

Mr. John Dawson said that research performed under his supervision indicated an appreciable movement in the sand two inches below a sand bed in movable beds.

Mr. Albertson reported on a study in his laboratory of the scour resulting from solid and hollow jets directed vertically downward onto a bed of erodible material. With low tailwater elevations the scour hole was small. It increased as the tailwater increased, reaching a maximum and then decreasing. This was contrary to his expectations, but he believed that it was due to changes in secondary circulation.

Mr. Laursen said in conclusion that considerable experimentation remains before the questions raised by the discussors can be answered. As Mr. Rouse pointed out, the absence of effects of velocity and sediment size on the equilibrium depth of scour around bridge piers is a big step in predicting scour in the field from model studies. However, the effect of depth of flow is very probably not a simple geometric effect but may be related to the boundary layer. Furthermore, the sorting that can occur with natural non-uniform sediments may have a great importance in the field. Mr. Izzard has mentioned another important consideration of the bridge scour problem — the constriction effect. This is likely to be especially important if the floodplain carries a high percentage of the flow but not an equivalent sediment load. Scour may also be a factor in the discharge relationship which Kindsvater is studying. Mr. Jetter's question as to the effect of debris cannot be answered at this time.

Debris would certainly change the geometry of the pier. This effect will be studied as the program continues.

Movement as deep as reported by Mr. Dawson has not been noted. In the case of the bridge pier, the shifting moving sand was only a few grain diameters in thickness. In the case of the submerged jet the layer of moving sand was thicker where the jet impinged.

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