[redacted]ry Observations of Scour at Bridge Abutments

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The importance of being able to accurately predict the magnitude of scour at bridge abutments and piers cannot be overemphasized. Bridge design demands a knowledge of the scour phenomenon in order to insure a safe, economic structure. In the past, bridge designers have been forced to rely upon personal experience, judgment, and similar designs in determining the depth of the bridge foundations. Consequently, due to the limited amount of information on scour available to the designer, bridges are destroyed due to foundation failures each year during peak runoff periods.

Both laboratory and field studies are needed to increase the knowledge for determining the scour depth. This report is based upon a laboratory investigation of scour at abutments, currently being undertaken in the Hydraulics Laboratory of the Colorado State University. The project is sponsored by the Bureau of Public Roads.

CLASSIFICATION OF THE SCOUR PROBLEM

THE PROBLEM of scour at bridge abutments is similar to the problem at any obstruction in an alluvial channel; for example, embankments, jetties, and piers. In any case the flow in the process of moving past the obstruction must undergo a certain change in direction with consequent increasing turbulence and eddy action. This action becomes evident in the erosion or scouring at the abutments and piers.

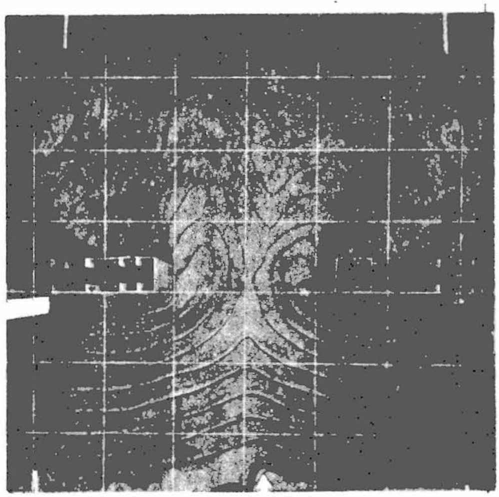
The depth of the scouring action, according to which the foundations must be designed, depends upon the flow conditions, shape of the obstruction, alignment and spacing of abutments or piers, bed material and sediment supply. Flow conditions involve the interrelated variables of slope, depth of flow, bed roughness, velocity, and discharge. The shape and alignment of the abutment or pier is obviously also important in determining the eddies that are produced in the flow—a more streamlined shape producing less disturbance and a reduction in scour. The spacing of abutments must also be considered as shown in Figures 1a and 1b. Closely spaced abutments may allow the localized scour areas at each abutment to interfere and cause a general lowering of the bed in the constriction. The properties of the bed material, such as size, gradation, and cohesiveness must be taken into consideration. As indicated in Figure 2, the presence of appreciable bed-load movement from upstream eventually produces an equilibrium scour depth. The scour rate in the absence of bed-load movement shown in Figure 2, appears to continue indefinitely.

The scour problem at best is quite complicated and requires investigation of many variables in order to understand the process and develop a workable criterion for the extent of the action.

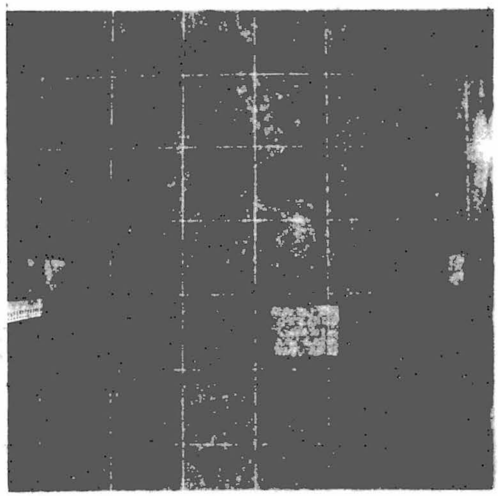
PREVIOUS INVESTIGATIONS

Field Studies

Although numerous bridges have failed because of scour, information on such failures is very limited. The depth of scour observed after a flood usually does not re resent the maximum scour since the scour hole is often partially refilled during the time of the receding flood. Unless some type of continual depth sounding device is used to indicate the complete history of the scour depth, the maximum scour depth often remains unknown. The Indian engineers have determined maximum scour depths by noticing the depth to which rip rap has been buried beneath the river bed. Although such depths of scour may have been affected by the presence of the rip rap, it does give some indication of the maximum depth of scour that occurred during flood stage. Some records of scour depths at certain bridges are available but the data are quite limited.



a. Interference of local scour



b. No interference of local scour

Figure 1. Contour view of local scour.

Laboratory Studies

Scour data from laboratory investigations are also quite scarce. Those studies that have been made are generally confined to conditions of no sediment supply. In the case of no sediment supply, as shown in Figure 2, the depths increase indefinitely with time. In the interest of determining the best shape of piers to reduce scour, Keutner (9) carried out an investigation early in 1934. This same approach was used by Ishihara (8). Tison (23, 24) studied the mechanics of scour at bridge piers. His study was also qualitative in nature. Although Straub (19) did not study the problem of local scour at piers or abutments, his analysis on the equilibrium condition of a contracted section is considered to be valuable in the general understanding of scour problems. He expressed the regime depth in the contracted section as a function of the approaching flow depth and the degree of contraction. Inglis (7) compared the depth of local scour with the regime depth in the contracted section based upon Lacy's regime theory. Inglis's analysis was based upon field data obtained in India. From the data, Inglis was able to draw the conclusion that the depth of local scour depends upon the discharge per foot of width adjacent to the extremity of the constriction and the size of the bed material. His approach was followed by Blench (5) and Ahmad (2).

In the United States, Laursen has done considerable work on the problem of scour at bridge piers and abutments. He studied the problem of scour both with and without sediment supply in the approaching flow. In the case where the flow is uniformly distributed across the channel, he concluded that the depth of scour for a given geometry of the obstruction, depends only on the width of the obstruction and on the depth of flow, provided that the sediment supply is appreciable.

The following publications should also be mentioned. The paper by Lane and Borland (10) on the depths of scour in a contracted section during flood; Posey's (17) investigation of scour around a circular cylinder; and Ahmad's (3) analysis of the model law concerning the scour at piers and abutments is included in the references.

MODEL LAW OF LOCAL SCOUR

Considerable progress has been made in the past several decades on the technique of model study for hydraulic structures. Model studies of various types of hydraulic structures have provided many fruitful results.

Strictly speaking, an exact model should have complete similarity with the prototype, that is: (a) geometric similarity, (b) kinematic similarity, and (c) dynamic similarity. However, such a complete similarity is usually not obtainable. The model is usually chosen so that it retains the similarity of major factors. For example, for flow through a contraction, the Froude similarity is used and the Reynolds similarity is neglected. The geometric similarity is generally maintained except in some cases—for example, the sediment size relative to the flow depth and the width of the flood plain relative to the flow depth. If the size of the sand is to be modeled in the laboratory according to the same scale as the flow depth, the sand size has to be reduced so small that the dynamic similarity cannot be studied without encountering difficulties. If the model is reduced in size to include the entire flood plain, the flow depth will be reduced so small that both viscosity and surface tension become important in the study. Such a reduction should be avoided, and under such circumstances, a distorted model is normally employed.

Laboratory model studies can be divided into two categories: (a) a study for a specific engineering project, and (b) a general investigation of the mechanics of a certain phenomenon. In the specific model study the topographical conditions in the vicinity of the structure are also made similar in the model. Quantitative design information can be obtained through this type model study by using the technique of model verification. That is to say, if the past events in the prototype can be reproduced in the model, the results obtained from the model can be used as a guide in the design and construction of the prototype structure.

The second category of model study would apply to scour investigations. Each of the various variables, geometry, flow conditions, sediment supply, etc., needs to be studied independently to evaluate its effect and relative importance on the general over-all scour phenomenon. It is hoped that after such an understanding is achieved, a design criterion can be formulated.

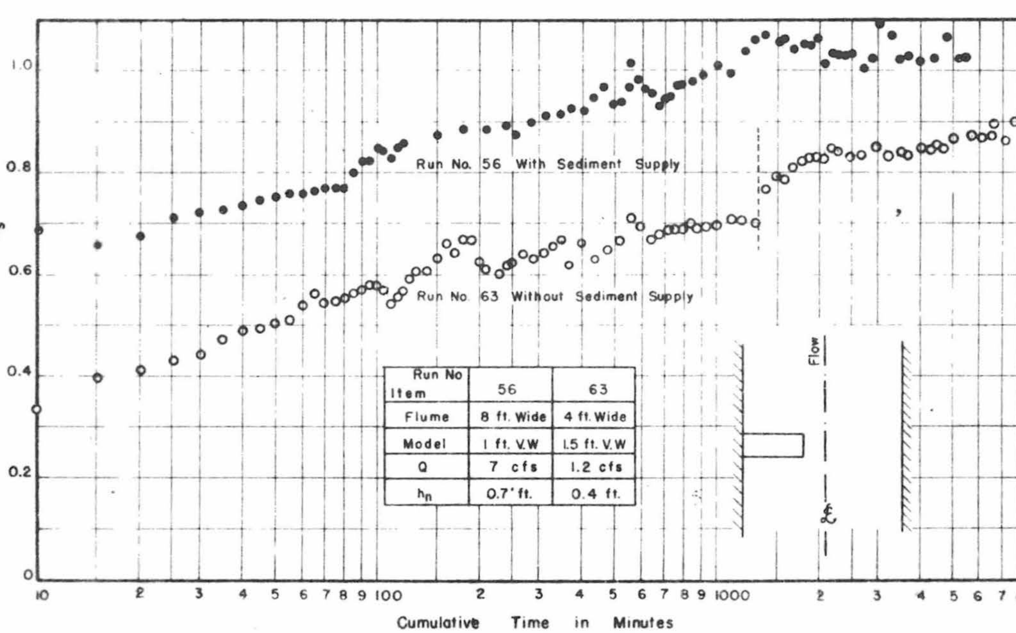


Figure 2. Scour rate curve.

LABORATORY EQUIPMENT

Two flumes were used in the tests. One was 8 ft wide, 160 ft long, and 2 ft deep. The slope of the rails on top of the flume wall and the slope of the flume were adjustable. A recess section located near the mid-point of the length of the flume allowed scour depths up to 5 ft deep. After enough water had been drawn from a sump located beneath the floor, it was recirculated along with sediment in a closed system. The bed material was regular pit run sand with a gradation as shown in Figure 3. A point gage attached to a wheeled carriage which traveled on top of the rails was used to measure the water surface, the bed surface, and the depth of scour. Discharge was measured by use of an offset orifice inserted in the pipe system.

A second flume used for the testing was 4 ft wide, 90 ft long and 2 ft deep. The facilities on this flume were similar to the 8-ft flume with the exception that sediment was not recirculated. A filter sand was used for bed material in this flume with the gradation as shown in Figure 3.

To provide a continuous history of the scour depth, an instrument called the Sonic Depth Sounder (Fig. 4) was utilized. In this instrument, high frequency or ultrasonic sound waves, produced by an electrically pulsed piezoelectric crystal, were used to measure the distance from the transducer to the sand bed. The crystal on being electrically pulsed vibrates at its natural frequency for a short period (a few cycles) resulting in a short burst of energy which travels through the water to the sand bed. Most of the wave is immediately reflected back to the transducer. The time interval between the start of the energy from the transducer and the return of the echo from the sand bed is proportional to the distance between the transducer face and the sand bed. The Sonic Depth Sounder measures the time interval and converts it to a voltage which varies linearly with time. This voltage is then used to operate a strip chart recorder. The piezoelectric element on the face of the transducer is concave in order to focus the energy waves. Depending on the distance to the original bed surface from the transducer face and the range of scour depths anticipated, the correct size and shape of piezoelectric element may be properly chosen. Figure 5 shows an actual recording produced by the instrument.

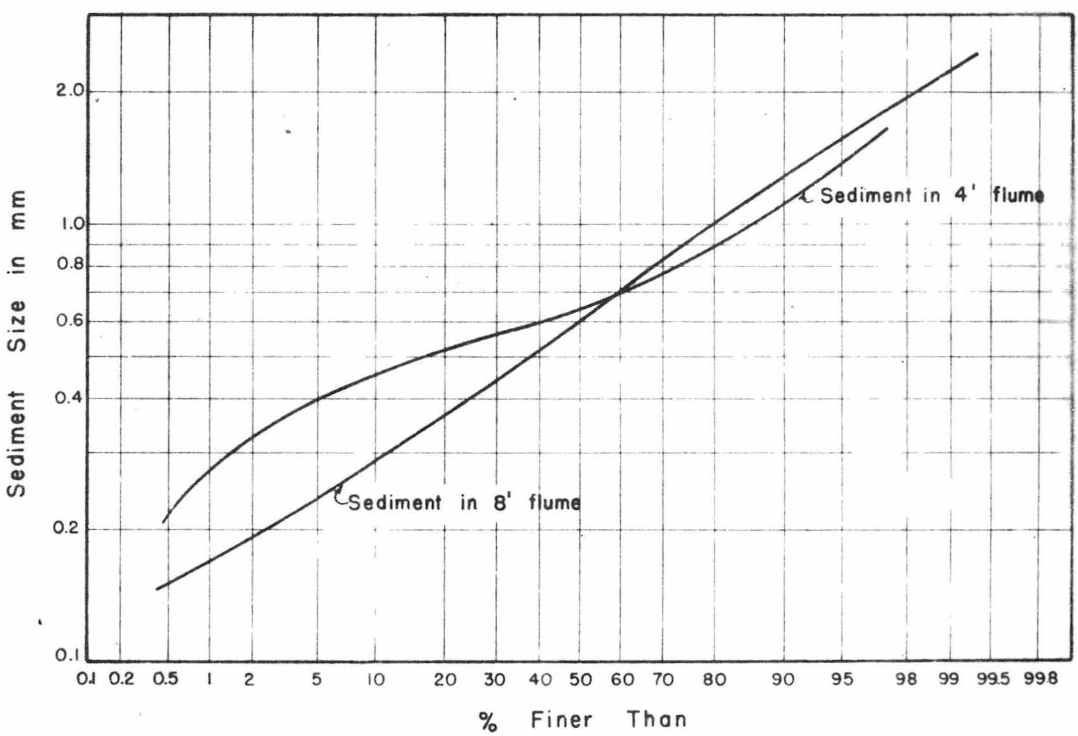


Figure 3. Sediment size analysis curve.

TESTING PROCEDURE

Before installing a model abutment, normal flow conditions were established in the flume. At this time, water surface, bed surface, discharge and depths were recorded. In the case of the 8-ft flume with sediment supply, the bed was normally in the ripple or dune regime depending upon the conditions of flow. In the 4-ft flume where no sediment was recirculated the bed was planed off with a screed and flow conditions established to just produce incipient bed movement. In both cases the datum for the scour depths was taken as the average elevation of the normal bed surface.

After normal flow conditions had been established, the abutment model was installed and readings started. Where sediment was being recirculated, equilibrium scour depths were usually obtained in two or three days. Since equilibrium scour depths could not be reached under conditions of no sediment supply, the 4-ft flume runs were of a comparative nature based on a five hour duration.

The backwater and also the drop of water surface across the embankment were measured. However, due to the movement of sand waves on the bed and also the rapid

Figure 4. View of the 8-ft flume, 4-ft flume and the sonic depth sounder.

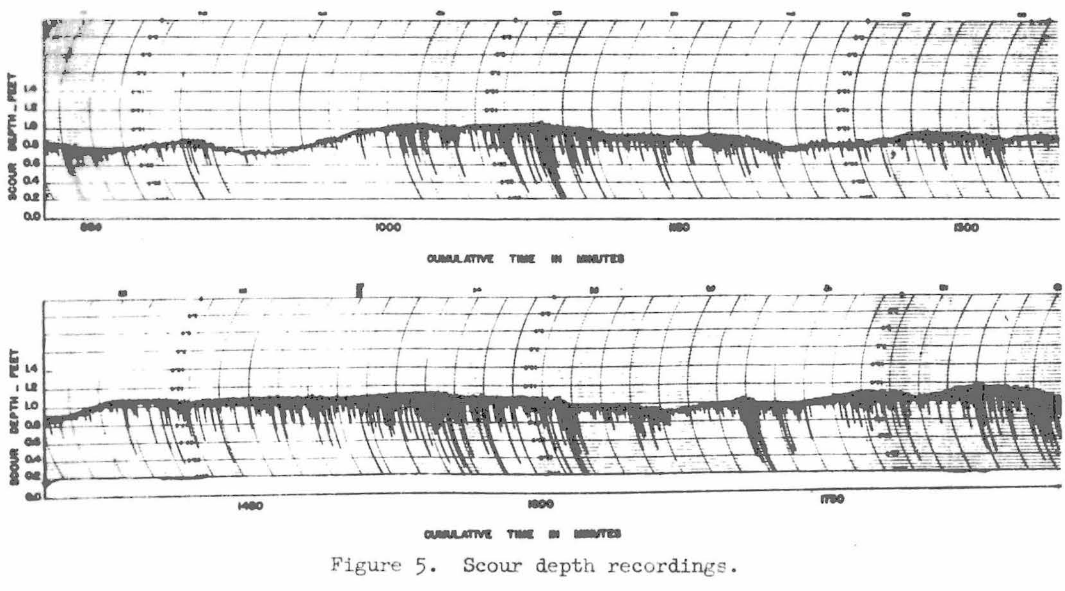


Figure 5. Scour depth recordings.

enlargement of the scour hole, many of the backwater measurements on the 8-ft flume were inconsistent. Better backwater measurements were obtained in the 4-ft flume studies.

After the flow was shut off the scour hole was contoured and a photograph was taken. Various types of abutments as depicted in Figure 6 were investigated for various degrees of contraction.

LABORATORY OBSERVATIONS OF SCOUR AT ABUTMENTS

Data obtained from the research up to the time of this writing are not sufficient to draw any definite conclusions, but some interesting observations have been made.

Geometry

Streamlining of the abutments reduces the extent of the scour depth. Figure 7 shows a comparison of scouring action for different abutment shapes under similar flow conditions; the more streamlined shapes produce the least scour while the vertical wall produces the most scour. As might be expected, a certain amount of properly placed rip rap material reduces the scouring action. On the other hand, the rip rap introduced considerable roughness on the bed in the constriction increasing the backwater upstream.

However, scour may eventually be inhibited by armor plating where the coarser fraction of the bed material is separated out by turbulence and eddies in the scour hole and deposited on the bottom of the hole in the form of a protective coating.

Sediment Supply and Bed Material

As pointed out earlier, the absence of sediment supply to the scour hole from upstream allows the scour depths to increase indefinitely. However, scour may eventually be inhibited by armor plating action. (The coarser fraction of the bed material becomes separated by the turbulence and eddies in the scour hole and then deposits in the form of a protective coating over the bottom of the hole.) Cohesive bed materials have not been investigated so the effect of the cohesion variable is still undetermined.

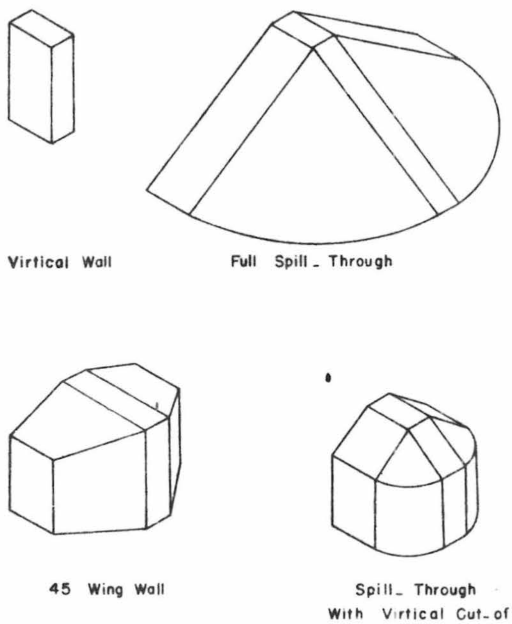


Figure 6. Abutment models.

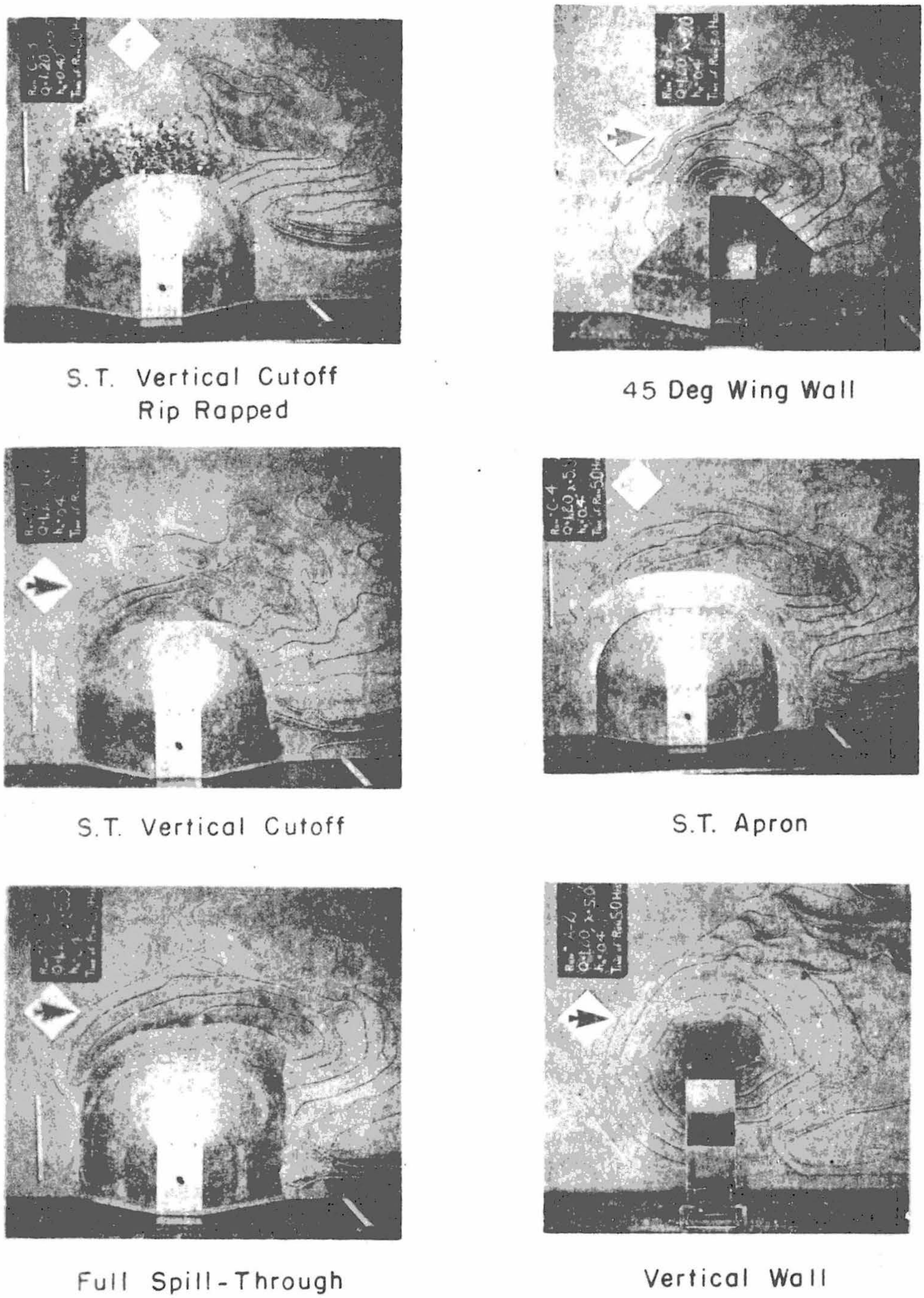


Figure 7. Comparison of scour for various models.

Development of the Scour Hole

The process of scour hole development and the accompanying flow patterns have been noted to be similar for the various models tested. Vertical wall and wing wall models develop the maximum scour depth at the upstream nose. The maximum scour for spill-through models occurs some distance downstream of the nose. In each case the maximum scour hole occurs at the point of flow separation.

The scoured material is transported from the scour hole in the form of suspended and bed load. Most of the scoured material is deposited in the vicinity of the downstream side of the abutment.

The pattern of flow in the scour hole is depicted in Figure 8. As flow approaches the abutment from upstream, a portion of the upper layer near the stream side of the abutment sweeps immediately around the nose while the other portion of the upper layer may circulate towards the bank and produce a stagnant pool. The lower layer of the approaching flow also tends to divide as it approaches the abutment with the portion of the stream side diving diagonally down around the nose and carrying with it quantities of bed material at this point. The bank side of the lower layer strikes the upstream face of the abutment and dives directly downward to the bottom of the scour hole and picks up material at this point. This diving jet produces a somewhat generally stable roller in the hole which deposits the scoured material on the sloping face on the upstream side of the scour hole. The material on the sloping upstream side of the scour hole tends to conform roughly to the angle of repose of the material. This portion of the material moves out of the scour hole mainly in the form of bed load.

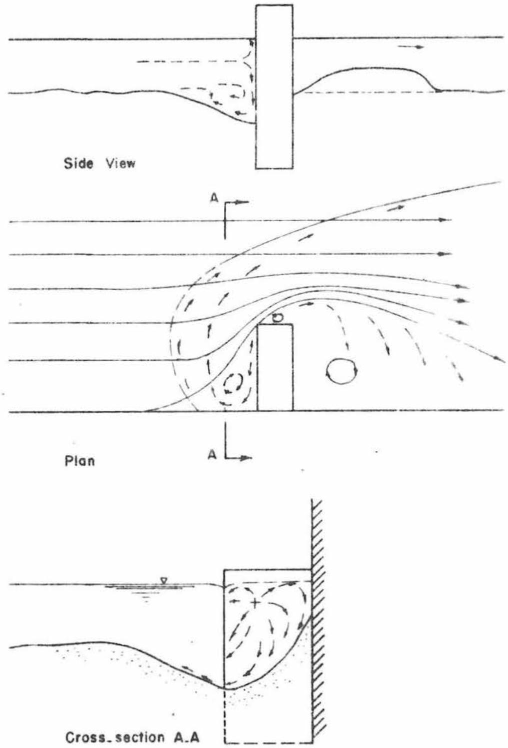


Figure 8. Flow patterns in the vicinity of the scour hole.

CONCLUSIONS

The laboratory study on scour around bridge abutments described here makes possible a much better understanding of the scour phenomenon. As to quantitative results, more time and testing will be required. Also satisfactory verification of model results with similar structures and conditions in the field are requisite before the information can be released for design purposes.

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