SUMMARY

The instrument developed for measuring scour depth in the field has been used for a period of over a year with only routine servicing. The data obtained have provided the necessary and sufficient prototype information for comparison with a model study as described in the following paper in these Proceedings. The servicing procedure established includes routine maintenance of the recording portion of the instrument and check measurements of the water surface elevation and the stream bed elevation between the piers and in the scour hole. Personnel of the Iowa State Highway Commission laboratories—without special training—have capably handled the field operation. Probably any engineer and most engineering aides would be equally competent.

Now that a tried instrument is available, the field measurement program should be expanded. The measurement of scour at sites of simple geometry should eventually serve to establish the needed model-prototype relationship. The measurement of scour at sites of more complex geometry, both typical and extreme, should provide the factual data to guide the designer in his estimate.

Model-Prototype Comparison of Bridge-Pier Scour

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QUALITATIVELY, the patterns of scour around bridge piers and abutments obtained in the laboratory have also been observed in the field. Moreover, certain apparent anomalies of field scour have been rationalized on the basis of the concept of scour formulated during the laboratory study. The first quantitative comparison of scour in model and prototype has been the laboratory study of a 1:12 model of the Skunk River pier described in the companion paper. Although the results of this study indicate that as a first approximation the depths of scour in model and prototype might be related simply by the geometric ratio, the single site investigated does not supply sufficient evidence for a general conclusion. Field measurement of scour at other sites of simple geometry is therefore needed.

● BECAUSE the purpose of the laboratory investigation of scour around bridge piers and abutments, being conducted by the Iowa Institute[1], is to find a means whereby scour in the field can be predicted, the establishment of the model-prototype relationship has always been considered a part of the general program. The measurement of scour in the field described in the preceding paper in these Proceedings made possible a study of model-prototype conformity. This study, plus qualitative model-prototype comparisons plus certain conclusions drawn from the laboratory investigation, is very encouraging in that the model-prototype relationship indicated is simple. However, other aspects of the laboratory investigations and the fact that only one quantitative model-prototype conformity study has been made suggest that caution should be exercised in drawing any general conclusions at this time. More field measurements at sites of simple geometry are needed. Simple sites are desirable because of the ease of modeling and of interpreting the results. The Skunk River bridge is a good example of a desirable site. There should be other sites scattered throughout the country where the needed field data can be obtained.

[1] A project sponsored jointly by the Iowa State Highway Commission and the Bureau of Public Roads.

Figure 1. Scour pattern around a single round shaft.

QUALITATIVE MODEL-PROTOTYPE COMPARISON

The first phase of the laboratory investigation, the effect of pier and abutment geometry, has been reported previously [1]. Typical scour patterns obtained in that part of the study are shown for a single round shaft (Fig. 1) and for a webbed pier which is not aligned with the flow (Fig. 2). The upstream portion of these scour holes approximates an inverted cone wrapped around the forepart of the pier and having side slopes of the angle of repose of the bed material. The downstream portion of the scour hole consists of two shallow tails separated by a dune in the wake of the pier. This same pattern is apparent in the pictures of a scour hole around a pier of the Julien Dubuque Bridge over the Mississippi River at Dubuque, Iowa (Fig. 3).

Many other examples of field scour which provide qualitative checks on the laboratory findings have been presented by D. E. Schneible in a recent publication [2]. Although such checks on the similarity of scour patterns in the laboratory and in the field do not lead to a quantitative rule for model-prototype conformity, they do indicate that the same mechanism of scour is acting and, therefore, that gross distortion is unlikely.

INFERENCES FROM LABORATORY OBSERVATIONS

The second phase of the laboratory project was concerned with the effect of stream and sediment characteristics on scour [3, 4]. Several conclusions drawn from this phase of the study are of interest in formulating a model-prototype relationship. After an active period of scouring, an equilibrium depth of scour is established as a temporal mean. This equilibrium depth appears to be independent of the velocity of flow and the sediment size, varying only with the form and size of pier and the depth of flow. The rate of scour during the active period, however, is dependent on the velocity of flow and the sediment size as well as the pier characteristics and the flow depth. In the laboratory it was found that

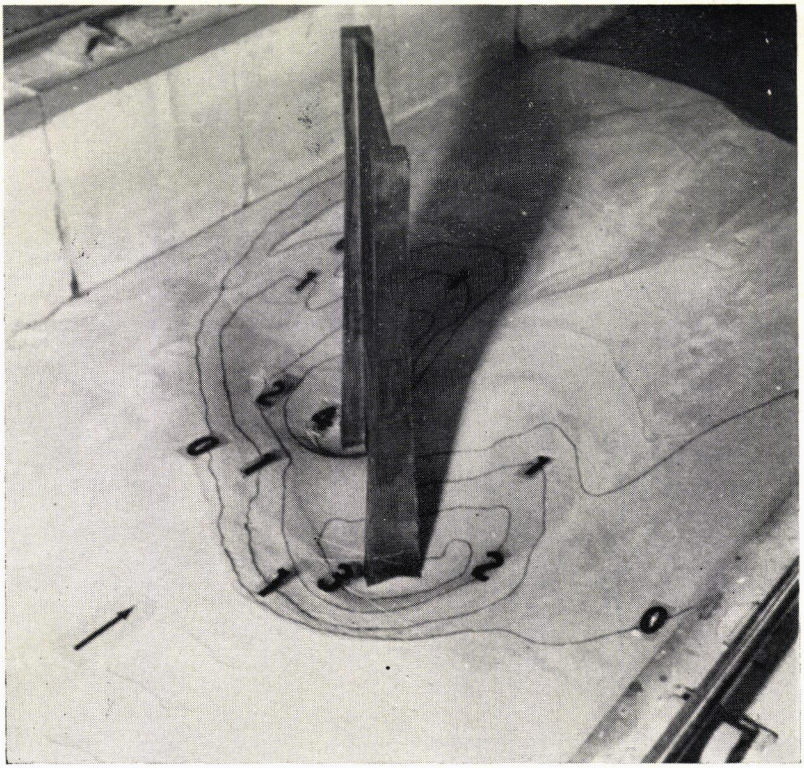

Figure 2. Scour pattern around a webbed pier.

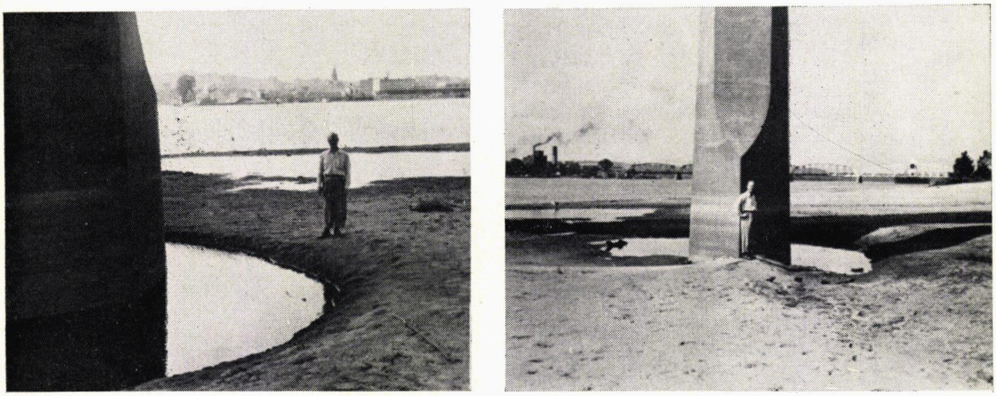

Figure 3. An example of scour in the field—Julien Dubuque Bridge. (Courtesy D. E. Schneible, BPR)

during the active period depths of scour in excess of the final equilibrium depth could occur.

Thus the results of the laboratory study indicated that, although the scour process is unquestionably dynamic, geometry alone determined the final equilibrium depth of scour. The questions remain, however, whether the rising stages of floods are sufficiently slow to insure the equilibrium state as the important condition of scour in the field, and whether excess depths of scour can occur in the field as they did in the laboratory.

That the flow in the laboratory tests was

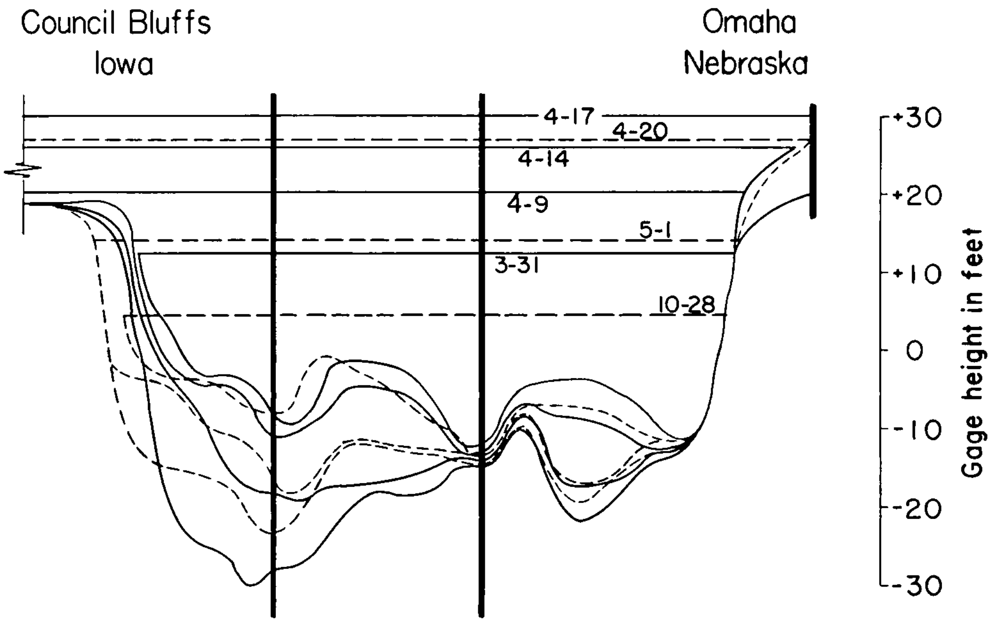

Figure 4. Cross-sections of Missouri River at Ak-Sar-Ben Bridge during 1952 flood. (Courtesy USGS)

always subcritical and the tractive force was well above the minimum for movement of the sediment are qualifications that are probably also met in the field. A more important qualification is that in the laboratory study the sediment moved entirely as bed load. Sediment movement in the field may occur by suspension as well, and for this reason the comparatively simple relations indicated by the model studies may not be entirely applicable at larger scale.

A CONCEPT OF SCOUR

The observation in the second phase of the laboratory study that neither velocity of flow nor sediment size affected the equilibrium depth of scour was rationalized by the concept of scour as an imbalance between the capacity for sediment movement in an area and the rate at which sediment is supplied to that area. If the capacity exceeds the supply, active scour will occur; if the capacity equals the supply, an equilibrium bed configuration will obtain. The rate of sediment supply to a scour hole is dependent on the mean velocity of flow, the depth of flow, and the sediment size; the capacity for sediment movement in a scour hole is dependent on the angular velocity of the spiral eddy in the scour hole, the size of the hole, and the sediment size. As a first approximation the ratio of the velocity of the spiral eddy to the mean velocity will be constant for a given geometry —i.e., pier size and shape and depth of flow. If, then, the capacities for transport in the stream and in the scour hole bear the same relation to the respective velocities, a change in either mean velocity or sediment size will change the absolute rate of sediment movement, but not the balance between capacity and supply.

The balance concept of scour can also be useful in interpreting field observations. In Fig. 4 the scour occurring at the Ak-Sar-Ben Bridge over the Missouri River between Council Bluffs and Omaha during the record 1952 flood is shown. The cross sections were obtained from USGS stream-gaging records and at high stage are therefore only approximate in the vicinity of the piers. General scour at the crossing is evident, especially on the Iowa side; this is the result of a contraction in the levee system in this area. The local scour hole at the pier on the Iowa side increases in size on the rising stage and fills on the falling stage. At the pier on the Nebraska side the scour hole increases slightly to a limiting size; as the flood stage continues to

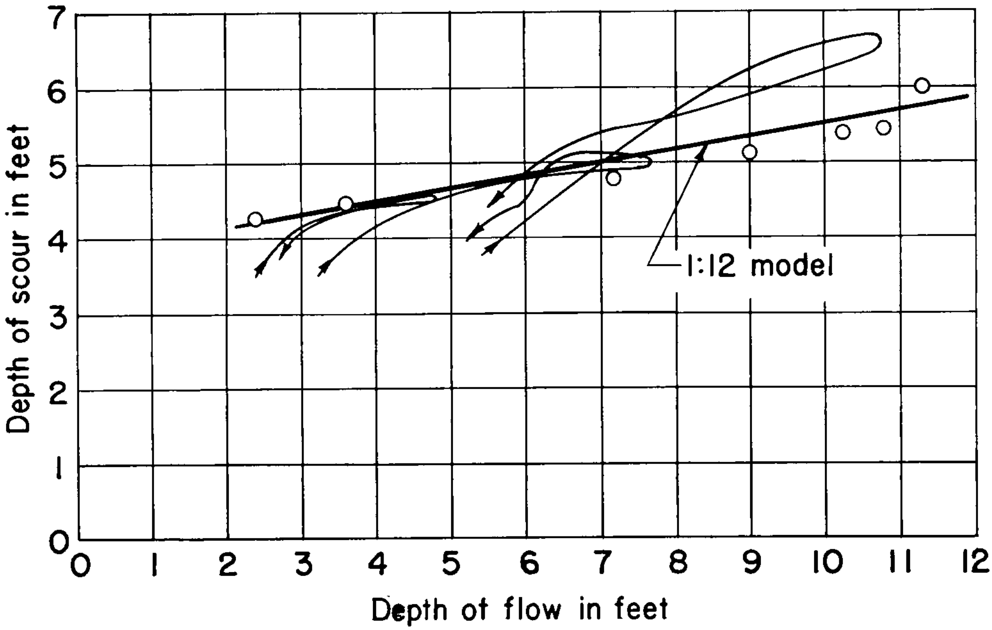

Figure 5. Quantitative model-prototype comparison, Skunk River Bridge near Ames, Iowa

rise, the bed away from the pier scours to an elevation below the bed near the pier. On the falling stage the stream fills until eventually the usual configuration is again established The apparent anomaly of the history of this scour hole can be explained by the balance concept of scour only by assuming that at the limiting elevation there exists a layer of large-size sediment—i.e., approximately the largest size the stream can carry. Even if there were an excess capacity for scour, the rate of scour would be very small because of the large particle size in this layer. The "paving" layer, therefore, might not be removed from the scour hole in the duration of the flood. Conversations with USGS engineers familiar with the location revealed that a smelter upstream dumped slag in the river and that chunks of slag could be observed in the dune downstream from the pier at low-water stages. The prediction of a layer of large-size material was therefore confirmed.

QUANTITATIVE MODEL-PROTOTYPE COMPARISON

The field measurements presented by P. G Hubbard in the preceding paper indicate that for the Skunk River site the equilibrium condition is sensibly attained, and little, if any, excess scour occurs (Fig. 5). In general, if the equilibrium depth of scour is not yet attained by the time a flood crests, the scour should continue to increase on the falling hydrograph, giving a counterclockwise loop. If excess depths of scour occur, the depth of scour on the falling stage may be either greater or less than the depth of scour on the rising stage, and the loop may be either clockwise or counterclockwise.

The two smaller floods in Fig. 5 have small counterclockwise loops at the crest of the flood; the largest flood has a somewhat larger clockwise loop at the crest. All loops are of a size that is comparable to the precision of the instrument, and the depths of scour on the rising and falling stages appear to be approximately the same. The rate of rise of the largest flood was 5 feet in 12 hours and that of the intermediate flood 4 feet in 10 hours. This rate of rise appears to be sufficiently slow to insure the establishment of the equilibrium condition.

To obtain a quantitative model-prototype comparison, the pier of the Skunk River bridge was modeled at 1:12 scale. The simple geometry of the field site permitted the simulation of the river by the laboratory flume used for the study of the effect of stream and sediment characteristics. No attempt was made to model the sediment size or the velocity of flow. An available sand of 0.58-mm mean diameter and an arbitrarily chosen mean velocity of 1.75 fps was used for all the runs. This convenient technique was justified by the observation previously made that neither velocity of flow nor sediment size affected the equilibrium depth of scour. The depth of flow was varied by making several runs each with a different depth.

In Fig. 5, the equilibrium scour depth as determined in the model is superposed on the field measurements by multiplying by the scale factor of 12. Although this relationship between model and prototype is suggested by the previous observation in the laboratory that the equilibrium depth of scour is determined by geometry alone, such a simple relationship must be considered optimistic speculation at this time. However, the comparison between model and prototype on this basis is good, particularly for the smaller depths, although the model indicates a depth of scour about 15 percent low for the larger depths of flow.

It is of interest to note that the Skunk River is clear at low stages and carries a light suspended load at high stages. The suspended load is primarily bed material and the concentration of the order of 1000 ppm. The low indication of the model conceivably could be caused by this difference in the mode of sediment movement in model and prototype. However, the discrepancy between model and prototype could also be the result of some other factor not yet fully appreciated.

Considering the difficulties inevitably attendant upon a first field installation, the correlation between model and prototype is very encouraging—even though not perfect. Even if perfect, correlation in a single instance does not substantiate a relationship. The necessity for more field measurements and more model-prototype studies should be evident.

CONCLUSIONS

Qualitative comparisons of scour around bridge piers and abutments have indicated that the same patterns of scour can be expected in the field as in the laboratory. The presumption may therefore be safely made that the general mechanism of scour is similar. However, the details of the scour mechanism may differ between field and laboratory because of the large difference in scale.

Two considerations especially may determine whether the quantitative model-prototype relationship is simple or complex: (1) laboratory studies are usually restricted to bed-load movement, whereas in the field suspended sediment may also be important; (2) the rate of sediment movement is unimportant only in respect to the equilibrium depth of scour, whereas the unsteady character of floods may not always permit the establishment of equilibrium conditions.

The model-prototype study described indicates that the scaling relationship may be simple. However, the correlation obtained at this single site does not constitute sufficient evidence on which to base a general conclusion as to the model-prototype relationship. The fact that the model scour depths in this instance were approximately related to the prototype scour depths by the geometric scale ratio is encouraging, but it may be happenstance. More field measurements at sites of simple geometry which can be modeled in the laboratory are urgently needed.

REFERENCES

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