TURBULENCE FLUME TO MEASURE BED LOAD

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In planning water-control works involving canals, it is of utmost importance that consideration be given to the sediment load which is to be carried by the canal. This load should be considered in relation to the capacity of the canal for carrying sediment and the load which is being carried by the stream or other body of water from which the canal derives its supply. Mute evidence of the importance of the sediment problem may be seen in the unfortunate number of irrigation and power systems which have failed because of the inability to control the deposition of sediment in the canals which carry the water to the project from the source of supply.

Prior to the construction of a diversion works on the Middle Loup River for an irrigation project in the sand-hill region of North-Central Nebraska, joint action was taken by the Quality of Water Branch of the United States Geological Survey and the United States Bureau of Reclamation to determine as accurately as possible the bed load and suspended load of sediment in the Middle Loup River at Dunning, Nebraska. Through Mr. P. C. Benedict, Regional Engineer of the Quality of Water Branch of the Geological Survey in the Missouri River Basin a contract was negotiated with the Research Foundation of Colorado Agricultural and Mechanical College to design and test by models in the laboratory a structure which would make possible the measurement of the total sediment load in the stream. The highway bridge at Dunning was chosen as the site for the structure.

Although the size of the watershed upstream from the proposed structure is approximately 1850 square miles as determined from topographic maps, the area actually contributing to surface runoff is estimated at only 93 square miles. The entire watershed is in sand-hill country so that most of the stream flow comes from ground water. As a result, the maximum instantaneous runoff on record is only 821 cfs while the minimum is 220 cfs. Visual observation indicates that most of the sediment load and the bed material originates from caving of the banks of the stream. The mean size of the bed material was determined to be 0.35 mm. Specifications for the design of the structure were that a measurement of 2000 ppm of total sediment load be made possible.

Although standard equipment is now available for measuring the suspended load in a relatively simple manner (1), measurement of the bed load in a stream has not been possible except by means of rather elaborate structures for trapping the sediment moving along the stream bed. In order to simplify the structure, have a continously operating process, and permit exclusive use of the standard suspended-load sampling equipment, a design which would force the entire sediment load into suspension was selected. For the stream to carry all of the load in suspension, its carrying capacity must be increased by increasing the turbulent-energy content. The additional energy may be supplied either by utilizing the energy of the stream itself or from some external source such as an electric motor or a gasoline engine. Because of the requirement of a continous process so that equilibrium conditions would prevail at all times, however, the external-energy possibilities were dropped from consideration as being uneconomical.

In order to create additional turbulence near the bottom of the stream where it is needed to pick up the bed load, it was decided to use roughnesses placed on the stream bed. The first attempt was to use continous baffles placed across the flow with a longitudinal spacing such that the greatest loss in total energy would be obtained -- this condition logically being the one which would create the greatest turbulence. Powell (2) and Johnson (3) found that the longitudinal spacing which created the greatest resistance was approximately 12 times the height of the baffle. However, when continous baffles were used in the model tests, each baffle was slowly but surely covered by the sediment as it moved downstream. To remedy this situation, baffle plates with open spaces between them were installed to permit movement of that part of the bed load which had not yet been forced into suspension. Experimentation proved the effectiveness of this design and each additional row of baffles added to the turbulence until the entire bed load was in suspension.

Each laboratory test was made with the Froude Number the same for the model as for the prototype. To make the similitude as nearly complete as possible, an attempt also was made to keep the velocity ratio W/V the same for the model and prototype for any particular flow (4), (5) and (6). In this ratio, W is the mean fall velocity of the sediment and V is the velocity of flow in the stream. Maintaining similarity with regard to the velocity ratio, however, was difficult because of the small size of sediment required for the model. The following table shows the velocity ratios for the model and prototype:

Ratio W/V of the Mean Fall Velocity of the Sediment to the Velocity of Flow in the River

Discharge in cfs	Prototype	Model
200	0.098	0.16
400	0.072	0.12
800	0.051	0.084
1200	0.042	0.070

As may be seen in the table, the sand used in the model was always larger than necessary for similarity. This deviation, however, is in the direction of safety because if it is possible to force in suspension sand of a given fall velocity it will certainly be possible to force in suspension the same concentration of a smaller sand having a lower fall velocity.

Reynolds Number was not considered to enter the problem because of the turbulence in the flume which no doubt destroyed the laminar sublayer thereby making the viscous forces unimportant compared with the forces of inertia.

Following the preliminary tests which were made with a model-prototype scale ratio of 1:8, the final investigations were made on a sectional model having a scale ratio of 1:4. These experiments revealed that nine rows of baffle plates placed 6 ft on centers across the flow and 2 ft apart in the direction of flow were adequate to force 2000 ppm into suspension provided the baffles were 2 ft long and one ft high. When the baffles were only 6 in. high, however, the sand dunes moved downstream to cover the baffles almost completely.

When the baffles were one ft high, a sand dune would almost cover an upstream baffle as the crest of the dune reached it, but the baffle would be completely uncovered when the trough of the dune was passing. By the time the dune reached the downstream end of the structure, however, the sand passed the measuring sill entirely in suspension.

As a result of the laboratory tests, the final recommendations were to have the baffle plates a minimum of one ft in height and placed so that each baffle was centered downstream from the 4 ft space between the baffles in the row immediately upstream. In order to help equalize the influence of the baffle plates, it was recommended that a continuous 6 in. baffle be placed 2 ft downstream from the last row of baffles and 2 ft upstream from a measuring sill. The measuring sill was 6 in. high by 18 in. wide so that the flow would be moving nearly parallel to the sill as it entered the sampler. It was planned that the sampler would be lowered past the downstream edge of the sill when measurements were being taken.

The structure has been built and operated by the Geological Survey since the summer of 1949 and inspections made by the writer, of the flow and sediment pattern in the prototype, showed it to be working satisfactorily. With 1-ft baffles, all sediment small enough to be measured by the sampler, was forced into suspension. Furthermore, the patterns and the movement of the sand dunes upstream from and through the structure were found to be almost identical quantitatively with what was found by the model studies.

So far as the writer knows, this is the first time that a bed-load measurement structure has been built which operates continously and permits the entire sediment load of the stream to be measured with a suspended-load sampler. The model-prototype comparison demonstrates rather conclusively the possibility of making quantitative measurements of the movement of sediment in a model provided the viscous effects, as reflected in the laminar sub-layer, are eliminated in both the model and prototype.

The design of the structure and the model tests were made in the Hydraulics Laboratory at the College and were under the direction of the writer. Reports (7) were prepared which completely describe the theory of design and the model studies.

REFERENCES

1. Field practice and equipment used in sampling suspended sediment, Interagency Report No. 1 on Measurement and analysis of sediment loads in streams. August 1940.

2. Powell, R. W., Flow in a channel of definite roughness, Trans. ASCE, vol. 111, 1946.

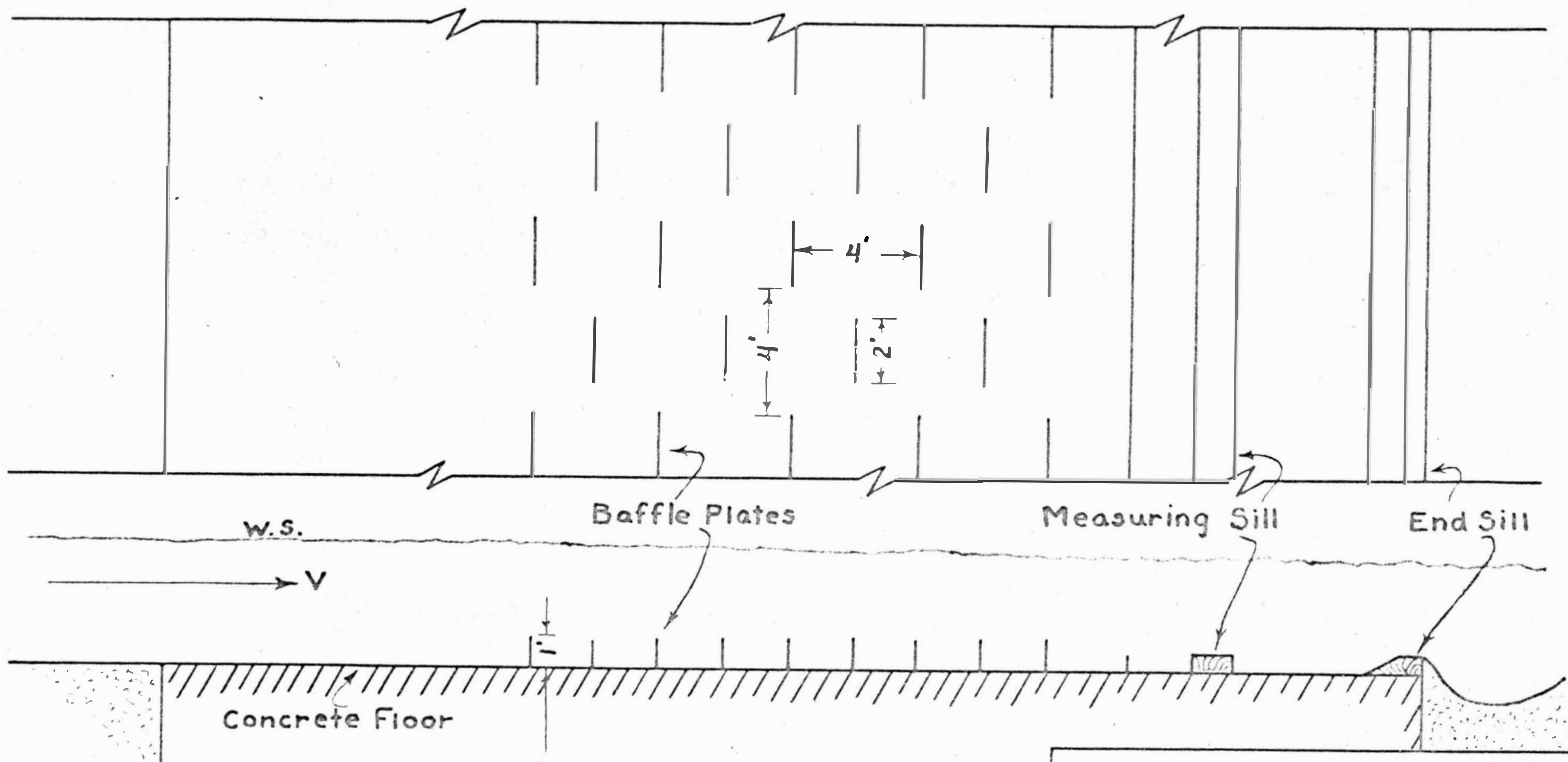
3. Johnson, J. W., Rectangular artificial roughness in open channels, Trans. American Geophysical Union, Section Hydrology, 1944.

4. Krumbein, W. C., Settling velocities and flume behavior of nonspherical particles. American Geophysical Union, Trans. 1942.

5. Rouse, Hunter, Criteria for similarity in transportation of sediment, Proceedings of Iowa Hydraulics Conference, 1939. State University of Iowa Studies in Engineering Bulletin No. 20.

6. Doddiah, Doddiah, Comparison of scour caused by hollow and solid jets of water. Thesis for Master of Science in Irrigation Engineering. Colorado Agricultural and Mechanical College. December, 1949.

7. Albertson, M. L. Design of the Loup River bed-load measurement structure. Final Report. Colorado Agricultural and Mechanical College. July, 1948.



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Designed and Tested
at
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MLA