INTERIM REPORT

HYDRAULIC MODEL STUDIES

DEL RIO SITE STREAM GAGING CONTROL STRUCTURE

RIO GRANDE RIVER

Phase 1

Two-Dimensional Studies

For

International Boundary and Water Commission,

United States Section

By

S. S. Karaki

Colorado State University
Research Foundation

November, 1960

CER60SSK62

 To Files

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The model study was conducted with participation and consultation by the members of the field investigating team: S. Karaki, Dr. A. R. Chamberlain, Dr. D. B. Simons, Dr. M. L. Albertson and A. R. Robinson. The report was reviewed also by this team. There was also active participation in the model investigations by Dr. J. D. Lawson, Hydraulics Engineering Department, University of Melbourne, Australia, who attended Colorado State University for a six-month period under a Fulbright grant.

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SUMMARY

This is an interim report on the two-dimensional model study of the Del Rio flow control and measurement structure. The model study was conducted for the purpose of obtaining hydraulic data on which to base the design of the structure. The objectives of the study were to establish the structure cross-section and to determine the effects of sediment deposition upstream of the structure on flow measurement accuracy and control. The results of the study indicated that the structure shapes of Weirs D, E and F were all hydraulically satisfactory. Weir F was functionally superior, however, in that sediment did not accumulate on the crest of the structure. The normal broad-crested weir, Weir A, was found to be greatly affected by sediment deposition upstream of the structure.

determining the feasibility of designing a structure that would result in a stable stage-discharge curve, and if so to

INTRODUCTION

Under the water treaty of 1944 between the United States and Mexico, National Ownership of waters of the Rio Grande from Fort Quitman to the Gulf of Mexico is determined from stream flow records on the main river and on its principal tributaries in both countries. In order to improve the accuracy of the basic stream gaging records which is subject to ... shifting channel controls and to ~~Accurate and precise water accounting is required if there is to be equitable water distribution, but this has not been possible because of basic inaccuracies of flow data. The principal reasons for these inaccuracies have been shifts in channel alignment and~~ deposition of sediment at or near the gaging ~~sections~~ sections. ~~For these reasons~~ the United States Section of the International Boundary and Water Commission had tentatively concluded that artificial controls in the river were necessary ~~in order to obtain more reliable stream flow records~~. This decision was concurred in an investigation by a team of engineers from Colorado State University, Fort Collins, Colorado. The results and conclusions of the field investigation of gaging station sites by the group from Colorado State University is embodied in a report to the Boundary Commission entitled, "Locating and Designing Structures to Improve Stream Gauging Accuracy in the Rio Grande River Basin", CER60SSK34, dated June, 1960.

The field investigation report also includes recommendations for the type and locations of the artificial controls to be constructed in the Rio Grande and Pecos Rivers. Because of many hydraulic factors which were unknown to the team at the time of the field investigation, it was recommended that a model study be conducted for a specific gaging station for the purpose of determining the feasibility of eliminating the problem of shifting controls; and of obtaining basic data on which to base the design of the control structures.

The Del Rio site was suggested and subsequently chosen for initial modeling. It was contended that because of the similarities at many of the proposed and existing gaging station sites on the Rio Grande, a model study of this specific site would also provide valuable information for design of the other controls.

The model study was planned in two phases. First, reported herein, a two-dimensional study of a generalized structure was made to determine several basic factors which would aid in the study of the Del Rio model. Second will be a three-dimensional model of the Del Rio gaging station site to establish the location and fundamental dimensions of the structure to assure adequate hydraulic performance.

The immediate objectives of interest in the first [this] phase were:

1. To determine the general shape of the structure cross-section consistent with efficient hydraulic performance. Primary considerations in establishing structure shape included: (a) Flow velocities over the structure to be subcritical to permit current meter measurements on the crest; (b) A sufficient width of the crest to permit measurement by wading or from a cable. [vehicular traffic at low-water stage.]

2. To observe the effects of sediment deposition near the structure on the hydraulic performance of the structure as a flow measurement section.

3. To observe local scour effects at the toe of the structure.

4. To determine an approximate rating curve, or more comprehensively to study the discharge coefficients for the recommended structure, To determine the stability of the stage discharge relationship for the cross section with

particular regard to the moving upstream bed and different levels of sediment deposition.

5. To consider the feasibility or desirability of permeable or semi-permeable structures in lieu of an impermeable structure.

6. To determine the type and size of sediment to be used in the three-dimensional model.

7. To make a study of the problems to be expected in a distorted three-dimensional movable bed model.

MODEL SCALE CONSIDERATIONS

An undistorted model scale was chosen for the two-dimensional study. The scale chosen was 1:5, model to prototype, and based on the physical dimensions of the available laboratory flume, and discharge. The discharge problem was not the inability to obtain the maximum as is the usual case, but to obtain a discharge small enough to represent 10,000 cfs of the prototype and at the same time to develop velocities to move the sediment in the flume.

It was assumed that sediment movement was probably not significant in the Rio Grande, particularly at the Del Rio Station, for discharges less than 10,000 cfs. This assumption was based on observations made during field investigations and comments made by the staff of the International Boundary and Water Commission.

Using the Froude criterion for model similitude and the model scale, the following relationships hold:

$$L_r = \frac{L_p}{L_m} = 5$$

$$q_r = \frac{q_p}{q_m} = (L_r)^{5/2} = 55.9$$

$$V_r = \frac{V_p}{V_m} = (L_r)^{1/2} = 2.24$$

EXPERIMENTAL EQUIPMENT

The Flume

The flume used for the two-dimensional study was a tilting flume 60 feet long, 2 feet wide and 2.5 feet deep. A schematic diagram of the equipment is shown in Fig. 1. The flume walls were constructed of plexiglass and the floor of stainless steel. Both water and sediment were recirculated through a 12-inch centrifugal pump. Discharge was controlled by a gate valve and measured by a calibrated orifice in the discharge line. The water level in the flume was controlled by a slotted gate at the downstream end.

The Sediment

Two types of sediment were used. The first was silica sand, having 0.28 mm median (d_{50}) fall diameter, analyzed with the visual accummulation tube, and with specific gravity of 2.65. Standard deviation of this material was 1.54. Movement of particles for this size of sediment would begin at about an average flow velocity of 0.90 fps. The second type was light-weight aggregate, commercially used for making concrete, obtained from an aggregate plant in Laramie, Wyoming. The median fall diameter for this material was 0.37 mm, the specific gravity was 1.78 and the standard deviation was 1.61. Use of the second material indicated bed movement and greater rate of transport at lower flume velocities and thus, while a fundamental sediment scale, model to prototype was not determined, the second material was used throughout the majority of the two-dimensional tests.

The Model Weirs

There were six weir models tested in the flume. The dimensions of these weirs are given in Figures 2-7.

Weir A -

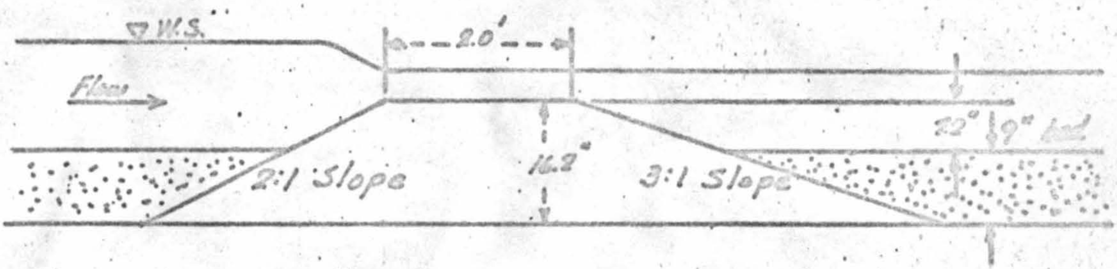

Fig. 2.

The broad-crested weir of Fig. 2 had the basic shape recommended in the Field Investigation Report. The upstream face was sloped at 2:1 and the downstream face at 3:1. The height 16.2 inches was based on sand depth of 9 inches in the flume and the crest 7.2 inches (or 3 ft prototype) above the channel bed. The crest width of 2 feet in the model represented 10 feet in the prototype.

Weir B -

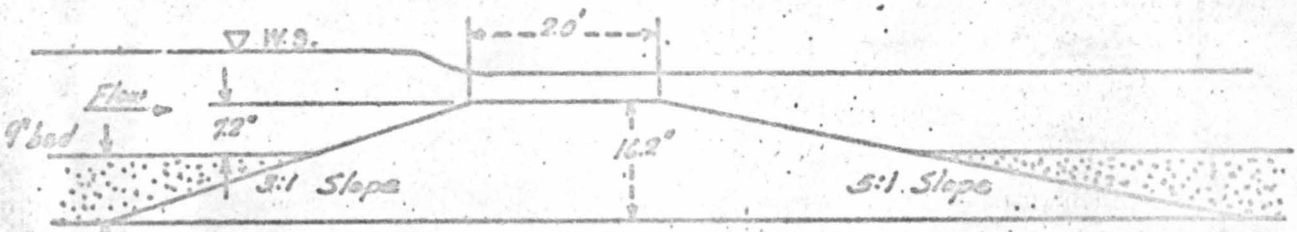

Fig. 3.

The upstream and downstream slopes of Weir B was changed to 3:1 and 5:1 respectively. Other dimensions were the same as for Weir A.

<u>Weir C</u> -

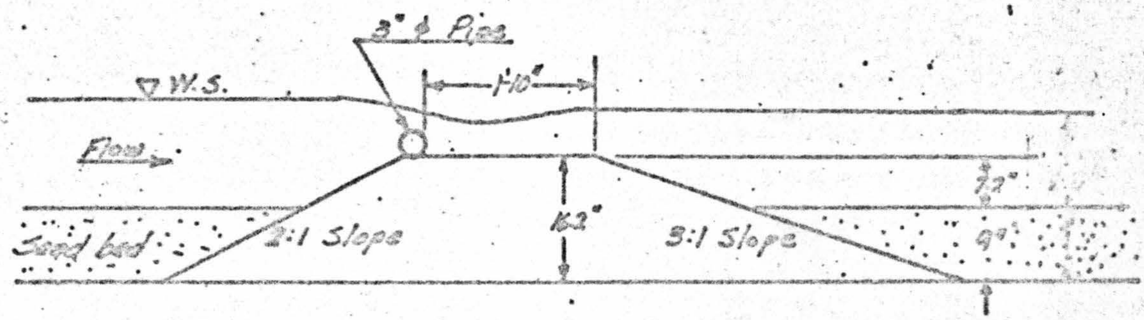

Fig. 4.

A circular crest made of 3 inch pipe was placed at the upstream limit of the crest of Weir A.

<u>Weir D</u> -

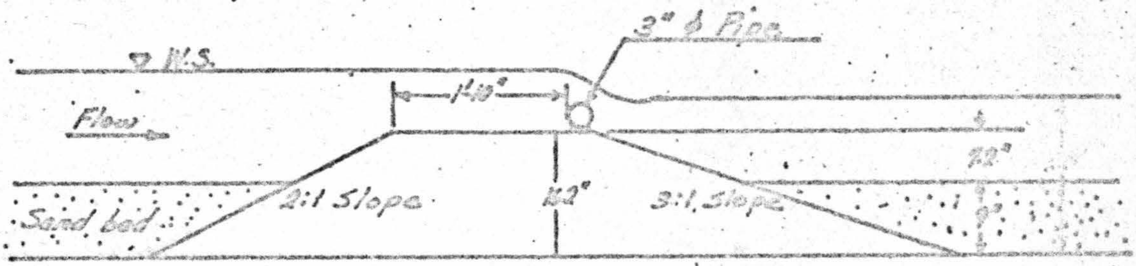

Fig. 5.

The circular crest was placed at the downstream limit of the crest of Weir A.

Weir E -

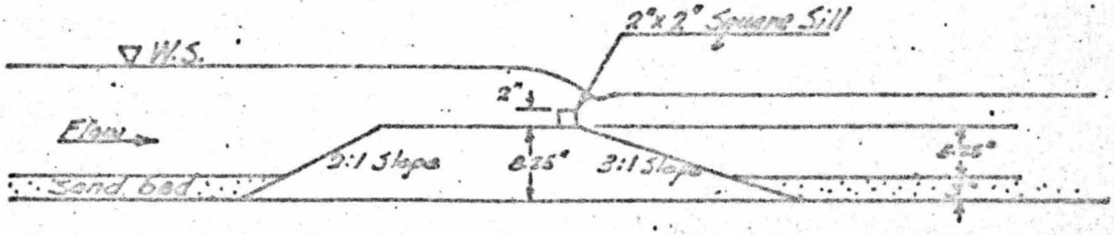

Fig. 6.

The circular crest of Weir D was replaced by a square sill 2" x 2". The overall height of the structure was reduced to 10.25" to allow greater depths of flow in the flume. Sand was removed from the flume to give an average depth of 3 inches.

Weir F -

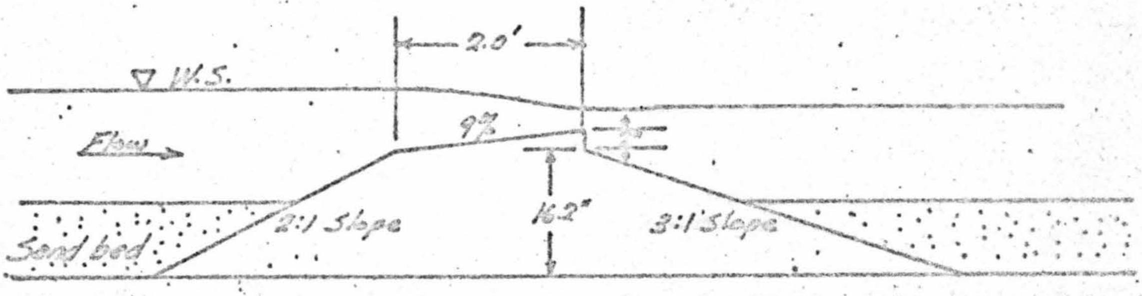

Fig. 7.

Structure F was designed to keep the structure free of sediment at all discharges. The top of the structure was sloped upward at 9 per cent to the high point of the crest.

EXPERIMENTAL PROCEDURE

The slope of the flume was varied during preliminary tests to determine its effect on the experimental study. It was found that if a structure was placed in the flume, flow depth, water surface slopes and eventually through equilibrium conditions, the bed slopes were controlled by the structure, discharge and movement of the sediment. (Changes in channel bed form caused variations in roughness. The variations of depth due to changing roughness patterns were small in the distance from the crest to the points of water surface measurements.) Thus the slope of the flume was maintained constant for the remainder of the tests.

To establish a test run, water was introduced into the flume from the city water main and allowed to pond. When a sufficient ponding depth was developed the pump was started and the water was recirculated. By this procedure it was possible to avoid excessive and unrealistic movement of sediment during the initial starting stage. Once recirculation was started, downstream flow depth was controlled and varied by a slotted gate at the end of the flume. Water surface elevations were measured with a point gage on a travelling carriage. Flume slope was determined by level measurements.

EXPERIMENTAL RESULTS AND DISCUSSION

Weirs A and B

The results of studies with Weirs A and B showed no effect on hydraulic performance due to changes in slope of the upstream and downstream faces of the weir. The results are shown in Fig. 8 with coefficient of discharge, C , as a function of unit model discharge. The coefficient C was calculated from

$$Q = CLH^{3/2}_{e} .$$

This may be reduced to

$$q = CH^{3/2}$$

when

$$q = \frac{Q}{L}$$

The value of H was corrected for the velocity of approach.

Observations made during the tests indicated no discernable difference in aggradation of the upstream bed or scour downstream from the structure due to the change in geometry of Weir B from Weir A. It was noted that as material was added upstream from the weir gradual aggradation of the stream bed occurred, however, the crest of the structure was free from sediment deposit at all discharges.

Were weirs effects entirely submerged at max. flows? What was shape of upstream bed profile?

Simulated step-wise hydrographs were run in the flume to investigate the effects of rising and falling river stages on the hydraulic performance of weirs A and B. Figs. 9 and 10 show the results. Fig. 9 in particular shows that the discharge coefficient changes with aggradation in the river. No attempt is made here to relate this simulated hydrograph with what might occur in the Rio Grande River. It should be noted that sediment movement in the flume is probably very large in comparison to the prototype river, as indicated by the rates of aggradation in both of the studies by the rapid decrease in the value p, the crest height above the upstream bed.

In view of the gradual deposition of sediment in the stream channel upstream from the structure, a study was made to determine the effect of the rising stream bed level on the hydraulic performance of the structure. The effect could best be represented by plotting the coefficients of discharge for the various stream bed levels. The results, shown in Fig. 11 indicate that essentially no variation was noted in the value of C for q greater than about 1.3 cfs/ft. There was, however, noticeable variations for smaller discharges.

When the bed was level with the crest, C remained virtually constant for all discharges. Converting the model discharge to prototype according to the chosen model scale, 1.3 cfs/ft represents 71.3 cfs/ft of the prototype. From selected cross sections of the Del Rio reach, the prototype crest length of the structure would be about 380 ft for this discharge. Assuming then, uniform flow over the crest, the total flow represented in the river would be about 27,000 cfs. Thus for discharges up to 27,000 cfs in the river, variations in the stage-discharge curve can be expected depending upon the degree of aggradation of the stream upstream from the structure. Inasmuch as this is an undesirable condition, and does not improve the present situation of stream gaging on the Rio Grande River, different shapes of structures were investigated to give more constant values of C with discharge.

Weir C

Weir C was tested in an attempt to provide a more stable discharge coefficient. As is shown in Fig. 12, larger and more constant coefficients of discharge for Weir C were observed than for structures A and B. While a more stable coefficient was obtained, the undesirable feature of this weir was that high velocities were created on the level portion of the structure because the flow depth would pass through critical at the crest. The high velocities would make it difficult to obtain current meter measurements on the structure. This undesirable feature from the standpoint of field practice, was also common to structures A and B. Furthermore, at certain tailwater conditions, a hydraulic jump could form on the level portion of structure C, thus making current meter measurements difficult or impossible.

Weirs D and E

Weir D and its alternate Weir E were tested to overcome the undesirable features of Weir C. For structure D, the pipe crest was moved to the downstream point of the level surface of the structure. The location of the control at this point creates sub-critical velocities on the portion of the structure which is level. Weir E, simply substitutes the pipe crest with a sill. As Fig. 13 indicates, the discharge coefficients for the two structures although numerically different because of the lack of stream lining in Weir E, are constant as for Weir C. Observations made during the testing of these structures indicated that although the upstream bed aggraded to the level of the crest, the structure was not buried by the sediment, so long as the downstream bed did not also aggrade. The unit discharges for Weir E greater than 1.3 developed considerable sediment movement in the flume. It appears necessary for the crest of the structure to be elevated from the normal stream bed, its height to be consistent with prevailing slope of the river reach and with consideration given to the amount of sediment flow in the river.

At low discharges, sediment may deposit on the level section of structures D and E when the stream bed was aggraded, but at high discharges, the local acceleration was sufficient to keep the top of the structures free from sediment deposition. Because of this observation and with a view to providing a section for current meter measurements on the structure, Weir F was tested as a possible atlernative to Weir E.

Weir F

This structure provided a gradual upstream slope (9 per cent) to the control sill at the top of the structure. The test results, plotted in Fig. 14 show a relatively constant coefficient with unit discharge. Observations indicated that little deposition of sediment occurred on the structure. There is a greater zone of accelerated flow for this weir than was prevalent for structures D and E because of the slope leading to the high point of the crest, making the drop in water surface profile of the structure somewhat comparable to structures A and B.

Approximate water surface profiles over this structure for different discharges are plotted on Fig. 15. The tail water rating curve used to establish these profiles (Fig. 16) was calculated on the basis of cross-section data of the Del Rio reach furnished by the International Boundary and Water Commission. The rating curve was calculated on the assumption that normal depth existed in the reach for all discharges. Engineers of the Boundary Commission Staff indicated that no well defined control was believed to exist in the river downstream from the Del Rio Reach.

The profiles show that at 10,000 cfs and larger the structure is practically totally submerged. For discharges of about 5,000 cfs or less, however, the crest would flow free since the normal depth is about equal to the height of the structure. Results of additional studies conducted to determine the effect of submergence on the discharge coefficient of structure F, are summarized in graphical form on Fig. 17. It shows that the coefficient is unaffected by submergence up to approximately 70 per cent but that a decrease in discharge coefficient is evident for a greater degree of submergence.

This does not appear consistent with other charts see 11-12-13 which indicate weir not submerged with >7,000 cfs. — J.B.

11/30 different set of conditions — J.B.

CONCLUSIONS

The following conclusions can be drawn from the results of two-dimensional study.

1. The General Shape of Structure Cross-Section

Upstream and downstream slopes flatter than 2:1 and 3:1 respectively do not hydraulically improve performance of the control structure with a broad crest. It is imperative in a river transporting sediment that the crest of the structure be higher than the average bed level to allow aggradation of the river bed upstream without burying the structure with sediment. It is also necessary that the control structure take the general shape of Weirs D, E or F in order to develop sufficiently low velocities over the structure to permit current meter measurements, and at extremely low discharges allow vehicular travel over the length of the weir. Weir F may be slightly more advantageous than Weirs D or E in that a sediment-free crest should exist for the lower discharges at such time as the stream channel may have completely filled upstream.

2. Effect of Sediment Movement

The crest of the structure must be sufficiently elevated to permit aggradation in the river upstream without eventually covering the structure. At the same time, the structure must not be so high that energy dissipation becomes a major problem. River aggradation affected the hydraulic performance of structures A and B but did not noticeably affect the other structures tested.

3. Rating Curve

An approximate rating curve of the flow over the control structure, Weir F, is shown in Fig. 15. The study indicated that except for the effect of submergence the discharge coefficient was stable; hence, the rating curve would not be subject to fluctuation due to gradual aggradation of the upstream river bed. This structure would thus permit more accurate measurements of discharge in the Rio Grande River than structure A or B. Structures D and E would perform equally well hydraulically.

4. Type of Structure

Permeable or semi-permeable structures were considered undesirable because the flow through the structure cannot be measured satisfactorily. They were therefore not considered functionally adequate and were not studied in this phase.

5. Sediment Type and Size

The sediment material to be used in the three-dimensional model must be sufficiently small in size or in weight to be moved at low velocities. While there is no essential purpose in this study for attempting to dynamically simulate the movement of individual particles, it is important that the effects of general or local deposition and scour be reproduced in the model. From observations made during this study it is concluded that the light weight aggregate should be used with the three-dimensional model.

6. <u>Three-Dimensional Model</u>

In reviewing the application of the above conclusions in the light of the Del Rio Site, a three-dimensional model should be studied to:

(a) Assure that the height of the structure will be satisfactory in all regards hydraulically.

(b) Make a definitive location for the structure as affected by channel slope and alignment.

(c) Determine areas of local scour and recommend possible rip-rapping or other river control.

(d) Study possible need to drop structure to low point at center to adequately measure low discharges.

(e) Consider notching the weir to concentrate low flows.

(f) Study the Del Rio Site sufficiently in hope of circumventing need for any individual study of Langtry and other sites on the Rio Grande.

(g) Study local aggradation, particularly upstream, on the flow distribution and effects on the stage-discharge relationship.