UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF REPUBLIC DIVERSION DAM, HEADWORKS AND SLUICEWAY STRUCTURES--PROGRESS REPORT NO. 2 ON GENERAL STUDIES OF HEADWORKS AND SLUICEWAY STRUCTURES

Hydraulic Laboratory Report No. Hyd-316

ENGINEERING LABORATORIES

OFFICE OF THE ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

January 29, 1954

FOREWORD

The Hydraulic model studies covered by this report are a continuation of the studies reported in Hydraulic Laboratory Report No. Hyd-275, March 22, 1950. The studies were carried on in the Hydraulic Laboratory, Office of the Assistant Commissioner and Chief Engineer, Bureau of Reclamation, during 1950.

The Republic Diversion Dam is a part of the Bostwick Division, Kansas River District, Missouri River Basin Project. As shown in Figure 1, the proposed dam site is on the Republican River near the town of Hardy, Nebraska.

The designs and studies were made in cooperation with the Diversion Dams Section, Canals Branch.

The studies were made by Messrs. O. S. Hanson, L. B. Quello, J. J. Hillner, and L. J. Keyser under the supervision of Mr. E. J. Carlson. Mr. E. W. Lane, Consulting Hydraulic Engineer, provided advice throughout the testing program.

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FIGURES

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Office of Assistant Commissioner
and Chief Engineer
Engineering Laboratories
Denver, Colorado
January 29, 1954

Laboratory Report No. Hyd-316
Hydraulic Laboratory
Compiled by: O. S. Hanson and
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Reviewed by: E. J. Carlson

Subject: Hydraulic model studies of Republic Diversion Dam, headworks and sluiceway structures--Progress Report No. 2 on general studies of headworks and sluiceway structures

SUMMARY

The Hydraulic model studies of the Republic Diversion Dam and appurtenant works were a continuation of the program undertaken to improve the design of canal headworks and sluiceways in connection with the control of sedimentation in canals. Previous work was covered by Hydraulic Laboratory Report No. Hyd-275 "Hydraulic model studies of Superior-Courtland Diversion Dam, Headworks and Sluiceway Structures--Progress Report No. 1 on General Studies of Headworks and Sluiceway Structures."

Comparisons of the various designs were made by using the ratios of sediment concentration in the sluiceway to sediment concentration in the headworks, C_s/C_h, for each design. All concentrations are expressed in terms of parts of sand per million parts of water by weight.

The various designs tested are shown in Figure 8. The preliminary design gave a C_s/C_h of 1.26 with a prototype discharge of 120 cfs in the headworks and 60 cfs in the sluiceway. Several arrangements were tested in which two curved guide walls confined the flow in a channel as it approached the headworks and sluiceway. Both a 20-foot and a 10-foot channel were tested. These arrangements are shown in Figure 8 as Changes 2, 3, and 4. The concentration ratios C_s/C_h for these three changes were lower than the concentration ratio for the preliminary design. Compared to the average velocities obtained in the Courtland headworks model study*, the average velocities

*Hydraulic Laboratory Report Hyd-275, Hydraulic Model Studies of Superior-Courtland Diversion Dam, Headworks, and Sluiceway structures--Progress Report No. 1 on General Studies of Headworks and Sluiceway Structures.

in the approach channel between the guide walls of Republic headworks was approximately one-third for similar arrangements.

Change 5, Figure 8, shows the lay-out of the Republic headworks model with a 12-inch by 15-inch elliptical vortex tube installed upstream of the headworks gate. The design recommended for Republic Diversion Dam utilizes the vortex tube with an actuating vane over it. Figure 12 shows the recommended design for the Republic headworks and sluiceway based on tests made.

The Hardy Canal headworks, on the opposite side of the dam from Republic headworks, is similar in entrance conditions except the discharge is less. The results of the tests made for Republic headworks and sluiceway were used in determining the design recommended for Hardy headworks and sluiceway. The recommended design for Hardy headworks and sluiceway is shown in Figure 13.

INTRODUCTION

The study of the problem of control and removal of coarse sediment carried into canals by water diverted from heavily sediment-laden streams is a continuing project under general sedimentation investigations. The first work was done using the Superior-Courtland Diversion Dam as the test structure. The Superior-Courtland tests were completed in June 1949, and results were covered by Hydraulic Laboratory Report No. Hyd-275. The Republic Diversion Dam, a part of the Bostwick Division, Kansas River District, Missouri River Basin Project, was investigated next. The proposed dam site, as shown in Figure 1, is near Hardy, Nebraska, on the Republican River. A vicinity map is shown in Figure 2.

The Republic Diversion Dam, as shown in Figure 3, was similar in plan to the Superior-Courtland Diversion Dam with only minor differences in the overflow weir, headworks, and some differences in the upstream conditions. The Superior-Courtland model was modified, and a 1:15 undistorted model incorporating one-half of the Republic diversion weir and the Republic headworks and sluiceway was built into the testing box.

Further studies of a general nature are being made on this problem as time permits.

DESCRIPTION OF MODEL

Upon completion of the Superior-Courtland tests the existing model was modified to represent the Republic Diversion Dam and Republic Canal headworks. A new headworks structure was installed and some changes were made in the upstream lay-out. The overflow weir and sluiceway were left unchanged with the exception of relocating the sluiceway gate. Figure 4 shows the general lay-out of the model.

The sand used for the movable bed was the same as previously used in other sediment studies. It was obtained from a loosely cemented sandstone which had been broken down in a hammer mill, producing a sand with a median diameter of 0.2 mm with 90 percent between the 40- and 100-mesh United States Standard Sieves (0.42 mm to 0.15 mm). Figure 5 shows photomicrographs of the model sand and washed Republican River sand. Size comparison can be made from the 1 mm rectangular grid shown on the photographs.

Water was supplied to the model by a portable pump mounted over the supply channel. Flow into the model was measured with a venturi orifice meter and controlled by means of a valve. Division of flow through the sluiceway and headworks was controlled by gate settings, and a V-notch weir was placed in the end of the return channel from the headworks to measure the amount of water diverted through the headworks.

Two vibrating pan feeders were mounted over the head end of the model. They were set to give a uniform sand feed at the rate required by the model study. These feeders were hopper fed and controlled by means of rheostats. Figure 7A shows the sand-feeder arrangement.

Samples of the sand-water mixture flowing through the sluiceway and headworks were taken at intervals by-passing a collecting trough through the nappe, Figure 6A. The samples were collected in tanks, Figure 6B, calibrated to read the amount of water in liters. The sand settled into glass funnels mounted at the bottom of the tanks. The funnels were graduated to give grams of dry sand, deposited under water, so the amount of sand could be read directly and the concentration computed without further conversion of the data. The upstream pool water surface, read on a staff gage, was maintained at the normal water surface elevation 1522.57 for all tests.

METHOD OF OPERATION

Experience with earlier studies of a similar nature indicated that the most satisfactory method of operating a movable bed model was to choose a fixed discharge for all runs, thus reducing the number of variables to be considered. To maintain comparable flow conditions to those used on the Superior-Courtland tests, a total discharge of 180 cfs, divided with 120 cfs through the headworks and 60 cfs through the sluiceway, was chosen and all runs were made at these settings.

Results of sediment investigations in the Kansas River Basin, November 1, 1942, to September 30, 1946, by the Corps of Engineers, Department of the Army, showed the Republican River near Bloomington, Nebraska, carried a bed load of approximately 0.165 percent by weight of the water discharge. At the standard discharge in the model this required a rate of sand feed of 1.28 pounds per minute. Some difficulty was encountered adjusting the feeders to this low rate but by

careful control this rate was obtained within reasonable limits. By utilizing the vibrating feeders a fairly uniform, continuous addition of sand was obtained. In a previous model study cyclic fluctuation of concentrations was encountered at the headworks and sluiceway, due to the sand being fed at intervals.

All test runs were made at the standard water and sand discharges with samples of both the headworks and sluiceway discharges taken at regular intervals. The runs were continued until all concentrations, as shown by the samples, became reasonably constant, thus indicating an equilibrium condition in the model. The equilibrium condition was checked by plotting concentrations in ppm against time. A minimum run of 24 hours, and in a few cases over 100 hours, was found necessary to obtain satisfactory averages.

TEST RUNS

Preliminary Design

The initial run was made with the headworks and sluiceway arranged according to the preliminary design as shown on Drawing No. 271-D-241, Figure 3. During the first several hours of the run the bed built up until it had established a slope and depth of flow, normal for the water and sand discharges. As it approached this condition, the flow was unstable with continually changing channels throughout the bed area which resulted in a variation in concentrations in the samples collected. A total run of 109 hours was sufficient to obtain an average concentration ratio. This ratio, C_s/C_h, for the preliminary design was 1.26. Figure 7B shows the bed at the end of this run.

Upstream Guide Wall

A guide wall 37.5 feet long, extending from the upstream edge of the headworks to a point 24 feet upstream from the overflow weir, Change No. 1, Figure 8, was installed in the model. The guide wall directed the water across the sluiceway entrance as the water approached the headworks. For this arrangement there was considerable turbulence around the end of the guide wall and the pier, resulting in much of the sediment being entrained into suspension. Although a slightly higher concentration ratio was achieved it appeared that the turbulence and change of direction of the water approaching the headworks and sluiceway was too great. The average concentration ratio for the test of Change 1, after 39 hours of operation, was $C_s/C_h = 2.63$. Observations indicated that much more bed sediment was thrown into suspension for this set-up than for the other arrangements tested. Figure 9 shows a general and close-up view of the bed after completion of the test.

Curved Approach Channel

Several tests were made in which curved guide walls leading to the headworks and sluiceway were installed. Curved guide walls were used to take advantage of the natural tendency for movable bed sediment to go to the inside (convex side) of an open channel curve. It was found that for the Republic headworks set-up, the discharge and consequently the velocity were lower than in the Superior-Courtland tests (Hyd-275), and the action for moving bed sediment to the inside of the curve and toward the sluiceway was not so great. The curved channels tested are shown as Changes 2, 3, and 4, Figure 8. The greatest improvement in which guide walls for controlling sediment were used included a 10-foot sluice gate moved upstream 6 feet 10 inches from its position in the preliminary design, with the guide walls parallel giving a channel 10 feet wide. The concentration ratio for this test was, C_s/C_h, = 1.55. Moving the sluice gate upstream lowered the elevation of the sediment bed just upstream from the sluice gate and immediately in front of the headworks. Figure 10 shows typical bed conditions at the conclusion of the tests utilizing curved guide walls alone.

Vortex Tube at 90° Angle with Headworks Channel

With the curved guide walls in place, the headworks structure was rebuilt to include a 12-inch by 15-inch elliptical vortex tube. This tube was placed at 90° to the flow immediately upstream from the head gate and discharged through a 15-inch pipe which emptied into the sluiceway downstream from the sluice gate. Change No. 5, Figure 8, shows the lay-out of this design.

The first run with this lay-out showed only a slight improvement over the guide walls alone. The tube would occasionally fill up over part of its length, and the amount of sand withdrawn was rather small. The velocities existing through the headworks above the gate were too low to produce a strong vortex in the tube, thus reducing its effectiveness.

A horizontal vane, tapered in profile, was then installed above the vortex tube to increase the velocity directly over the tube, Figure 8. This system of increasing the efficiency of a vortex tube was developed in a larger scale sectional model in the Hydraulic Laboratory. Three positions of the vane, as shown in Figure 8, were tested with that shown as Position 2, 15 inches above the floor elevation, proving to be the most effective. Some of this series of runs were made with the curved guide walls removed to separate the improvement resulting from the vortex tube from that due to the guide walls.

During these tests it was noted that a portion of the sand passing through the headworks was being thrown into suspension by turbulence created at the headworks sill. To reduce the turbulence a sloping face was built upstream from the sill. Figure 11A shows the bed conditions in front of the headworks at the end of the run which included the sloping face in front of the headworks sill, a 90° vortex tube with actuating vane over it, but no guide walls. Although only a straight sloping face, Change 6, Figure 8, upstream from the headworks sill was tested in the model, a rounded face, Figures 12 and 13, is recommended for the prototype. The rounded face will reduce the turbulence at the headworks entrance, and reduce the amount of sediment thrown into suspension.

Vortex Tube at 65° Angle with Headworks Channel

From the results of tests made by other investigators*, it was known that a vortex tube operated most efficiently at an angle with the line of flow. A new tube was built and installed at 65° with the line of flow. This was the smallest angle practicable in the model with the clearance available in the preliminary design.

A test of 99 hours was made with this tube installed with no baffle or guide walls. This test gave a C_s/C_h ratio of 1.47, indicating a definite improvement over the operation of the 90° tube. With the addition of a horizontal vane placed 15 inches above the lip of the tube the C_s/C_h ratio was increased to 2.37. The 90° tube under the same conditions gave a C_s/C_h ratio of 1.31. Figure 11B shows the condition of the bed at the conclusion of this run.

As shown in Figure 8, the model tests with a vortex tube were made with the floor downstream from the tube 0.17 foot lower than the floor upstream from the tube. Other investigators had indicated this arrangement gave better action in the vortex tube. Later experiments in a sectional model study in the Hydraulic Laboratory have shown the vortex action to be just as good with the floor at the same level upstream and downstream from the tube as shown in Figures 12 and 13. The level floor gives easier construction and better hydraulic conditions, therefore it is recommended for the prototype.

RECOMMENDED DESIGN

Based on the results of the model studies, it is recommended that a vortex tube with an actuating vane built over it, as shown in Figure 12, be built into the Republic headworks. It is recommended that the headworks structure be lengthened enough that the vortex tube and vane can be built at an angle of 60° with the center line of the headworks.

*Ralph L. Parshall "Model and Prototype Studies of Sand Traps," ASCE Transactions Volume 117, pp 204-214.

The underside of the actuating vane should be 15 inches above the top of the vortex tube. The upstream face of the headworks sill should be sloped as shown in Figure 12.

The design recommended for the Hardy headworks and sluiceway is similar to that recommended for Republic headworks and sluiceway and is shown in Figure 13.

FUTURE STUDIES RECOMMENDED

In the past a wide variety of designs have been used for diversion works, both in this country and abroad. Many have proven to be excellent designs and others have operated unsatisfactorily. Even in cases where the same general design has been used, the operating efficiency has varied greatly due to different conditions at the diversion site.

A program of testing and evaluating these designs should be undertaken. Each design should be investigated, and conditions of discharge, sediment load, river form, etc., should be determined for the most satisfactory operation of each type. Much work has already been done by other investigators which will be helpful in selecting and eliminating designs to fit the specific conditions. Some further laboratory work will be necessary to determine the factors governing proper operation of the various designs.

OPERATING SUGGESTIONS FOR PROTOTYPE

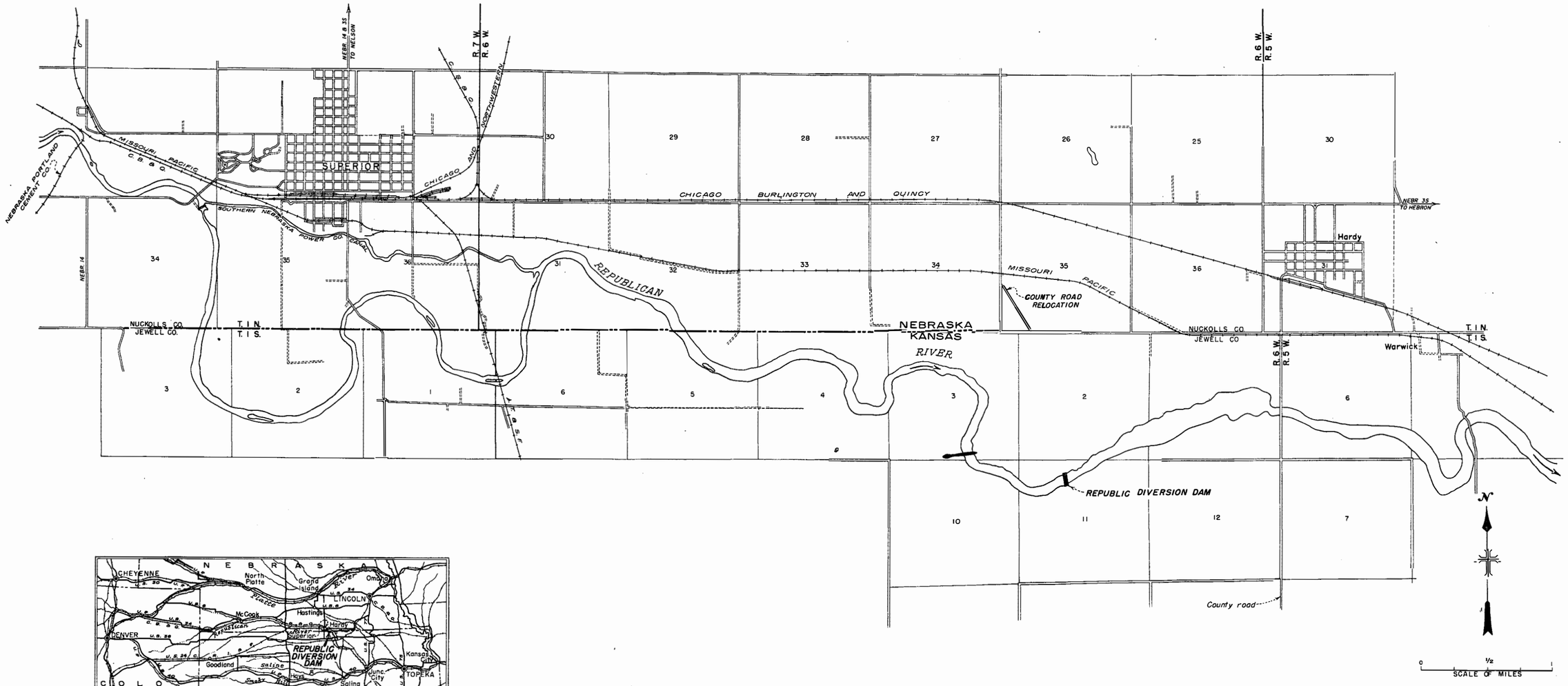
The following operating suggestions, based on the hydraulic model studies, are recommended as a guide to operating personnel in order to obtain the best results from the operation of the Republic Diversion as well as other Diversions from a sediment control standpoint. Actual observations on the completed prototype may indicate some modifications in these procedures. To best determine these changes, records of the amount of sediment deposited in the canal, sediment load in the river upstream from the diversion, and operating procedure followed should be kept for the first several years the project is in operation.

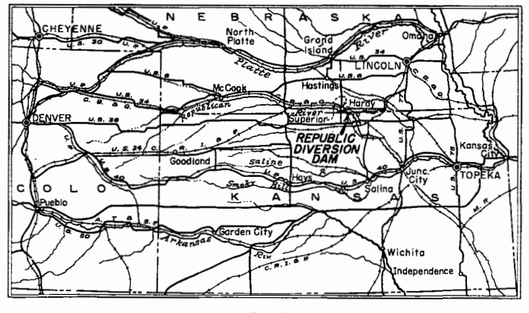
Intermittent sluicing--periodically opening the sluiceway gate full open--gives the most favorable sediment distribution as indicated by previous model studies. Whenever irrigation and canal conditions permit, intermittent type of sluicing operation should be used. When the sluice gate is opened, the headworks gates should be closed and the entire discharge of the river allowed to flow through the sluice gate until the pool elevation has dropped to a minimum. The sluicing period should be alternated between the Hardy and Republic headworks, with only one side being sluiced at a time so a maximum discharge may be used for each sluicing operation. The division of sluicing water

between sluiceways should be made in the prototype on the basis of the amount of sediment being drawn into the canals and not on the basis of quantity of water diverted. The division of flow will have to be carefully watched during the recession of flood flows and the non-irrigation season in order to keep the channels to each headworks open.

Another factor governing the formation of the sediment deposits behind the diversion works is the water-surface elevation in the pool. The lower this elevation can be carried the lower the sediment deposit near the headworks and sluiceway will be. It would be desirable to set the headworks and sluice gates so as to maintain a pool elevation just sufficient to obtain the proper canal discharge.

The quantity of water diverted should be held as low as possible and still satisfy irrigation demands. Any surplus water diverted and returned to the river through wasteways will tend to aggravate the sediment problem by carrying additional sediment into the canals. The majority of this sediment will be deposited in the upper reaches of the canal, and any sluicing action caused by flow through the wasteways will not offset this additional deposition.





INDEX MAP

UNITED STATES
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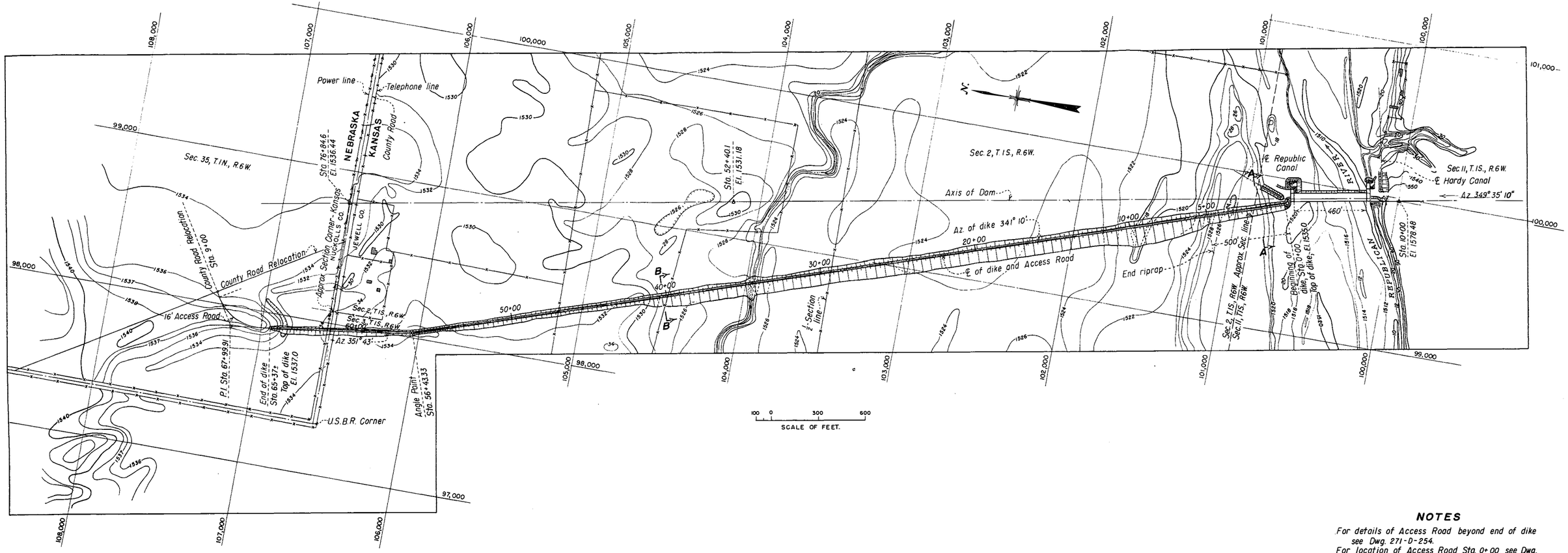
MISSOURI RIVER BASIN PROJECT
BOSTWICK DIVISION – NEBRASKA – KANSAS

REPUBLIC DIVERSION DAM

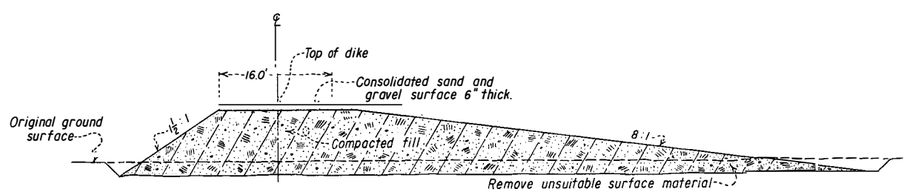
LOCATION MAP

DRAWN H.C.C.	SUBMITTED		
TRACED E.J.H.	RECOMMENDED		
CHECKED	APPROVED	CHIEF ENGINEER	
	DENVER, COLORADO DEC. 23, 1948		271-D-237

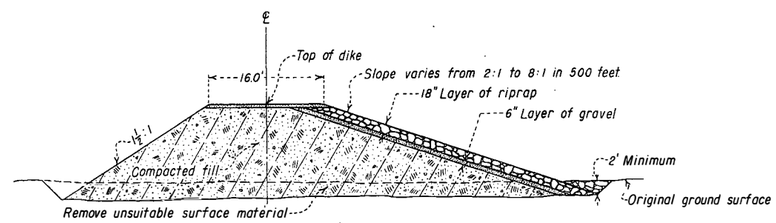


NOTES

For details of Access Road beyond end of dike see Dwg. 271-D-254.
For location of Access Road Sta. 0+00, see Dwg. 271-D-251.



DIKE SECTION B-B



DIKE SECTION A-A

10 0 10 20 30
SCALE OF FEET.

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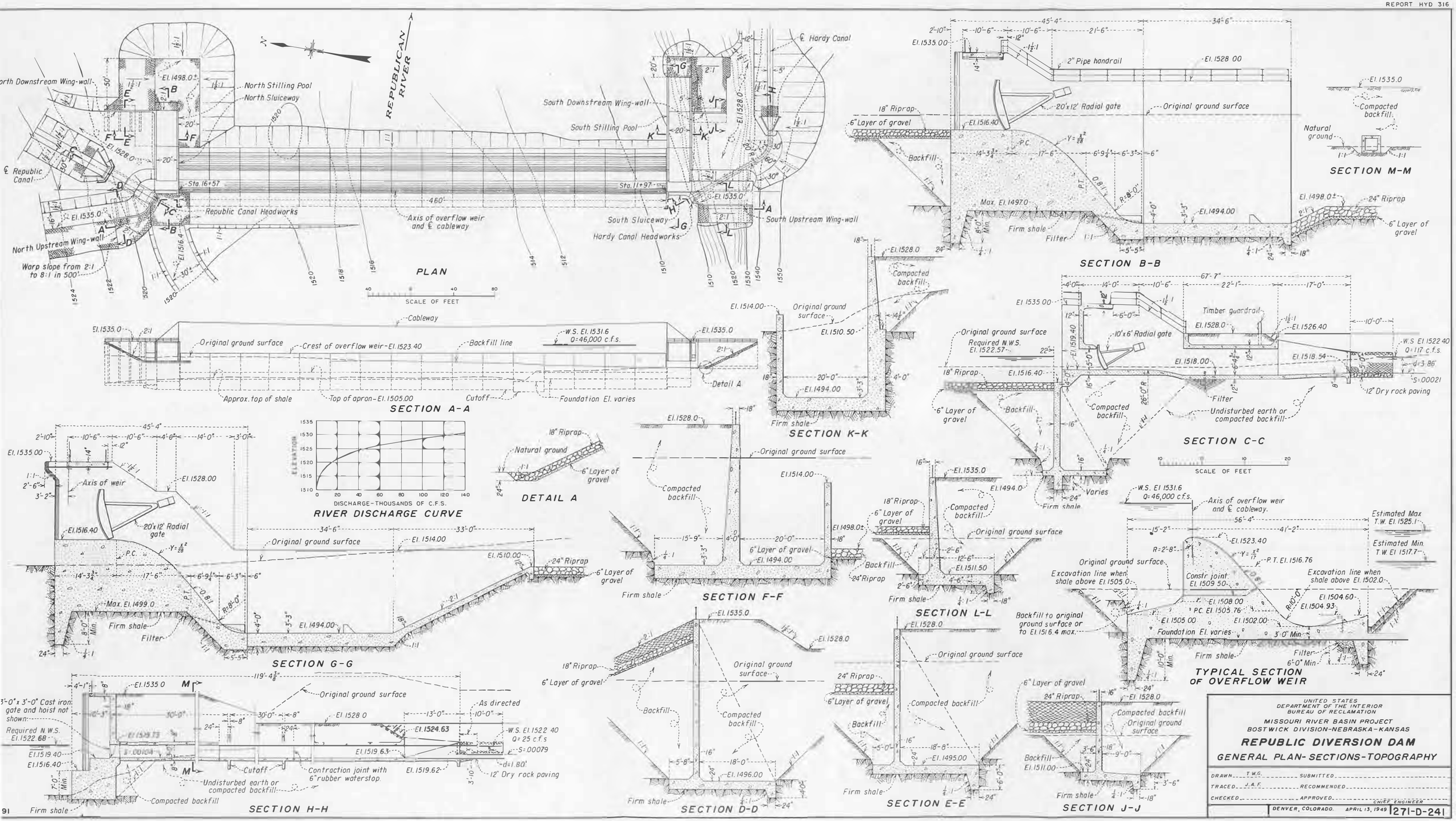
BOSTWICK DIVISION - NEBRASKA - KANSAS

REPUBLIC DIVERSION DAM
VICINITY MAP

DRAWN H.C.C. SUBMITTED
TRACED C.S.M. RECOMMENDED
CHECKED OAM APPROVED CHIEF ENGINEER
DENVER, COLORADO, DEC. 17, 1948 271-D-240


PLAN
SCALE OF FEET
REPUBLICAN RIVER
North Downstream Wing-wall
North Stilling Pool
North Sluiceway
Republic Canal
Sta. 16+57
Republic Canal Headworks
Axis of overflow weir and ℄ cableway
North Upstream Wing-wall
Warp slope from 2:1 to 8:1 in 500'
South Downstream Wing-wall
South Stilling Pool
Hardy Canal
Sta. 11+97
South Sluiceway
Hardy Canal Headworks
South Upstream Wing-wall
SECTION A-A
Cableway
Original ground surface
Crest of overflow weir-El. 1523.40
Backfill line
W.S. El. 1531.6 Q=46,000 c.f.s.
Approx. top of shale
Top of apron-El. 1505.00
Cutoff
Foundation El. varies
Detail A
SECTION B-B
2" Pipe handrail
20'x12' Radial gate
18" Riprap
6" Layer of gravel
Backfill
Firm shale
Filter
24" Riprap
SECTION M-M
Compacted backfill
Natural ground
SECTION K-K
Compacted backfill
Firm shale
SECTION C-C
Timber guardrail
10'x6' Radial gate
Required N.W.S. El. 1522.57
W.S. El 1522.40 Q=117 c.f.s.
12" Dry rock paving
Undisturbed earth or compacted backfill
SCALE OF FEET
SECTION G-G
Axis of weir
20'x12' Radial gate
Original ground surface
Max. El. 1499.0
Firm shale
Filter
RIVER DISCHARGE CURVE
DISCHARGE-THOUSANDS OF C.F.S.
ELEVATION
DETAIL A
Natural ground
SECTION F-F
Compacted backfill
6" Layer of gravel
Firm shale
SECTION L-L
Compacted backfill
Original ground surface
Firm shale
TYPICAL SECTION OF OVERFLOW WEIR
W.S. El 1531.6 Q=46,000 c.f.s.
Axis of overflow weir and ℄ cableway.
Estimated Max T.W. El. 1525.1
Estimated Min T.W. El 1517.7
Excavation line when shale above El. 1505.0
Excavation line when shale above El. 1502.0
Backfill to original ground surface or to El. 1516.4 max.
Foundation El. varies
Firm shale
Filter
SECTION H-H
3'-0"x 3'-0" Cast iron gate and hoist not shown
Required N.W.S. El. 1522.68
Original ground surface
As directed
W.S. El 1522.40 Q=25 c.f.s
12" Dry rock paving
Undisturbed earth or compacted backfill
Contraction joint with 6" rubber waterstop.
Compacted backfill
Firm shale
SECTION D-D
Backfill
Compacted backfill
Firm shale
SECTION E-E
Compacted backfill
Backfill
Firm shale
SECTION J-J
Compacted backfill
Original ground surface
Backfill
Firm shale
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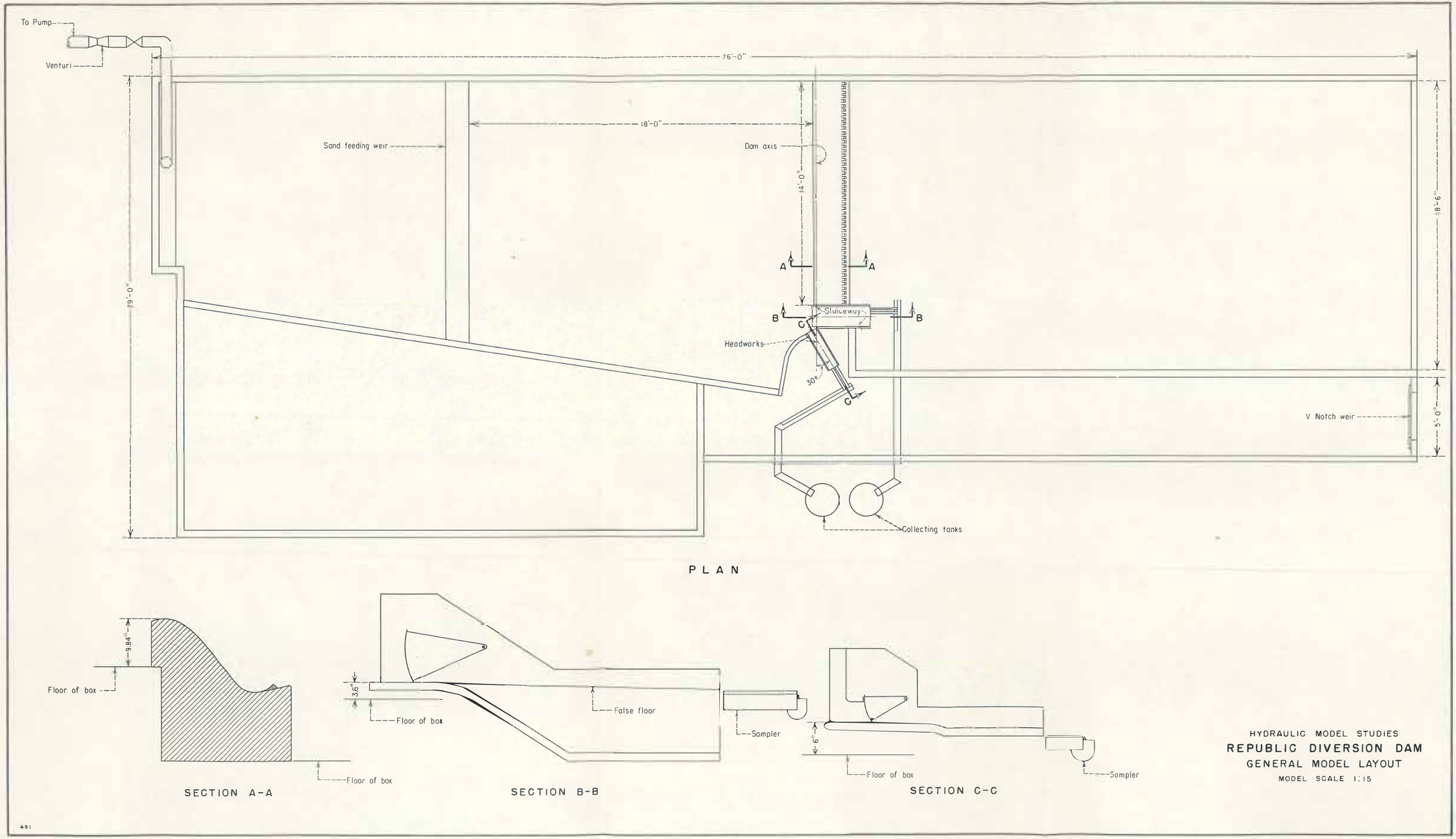
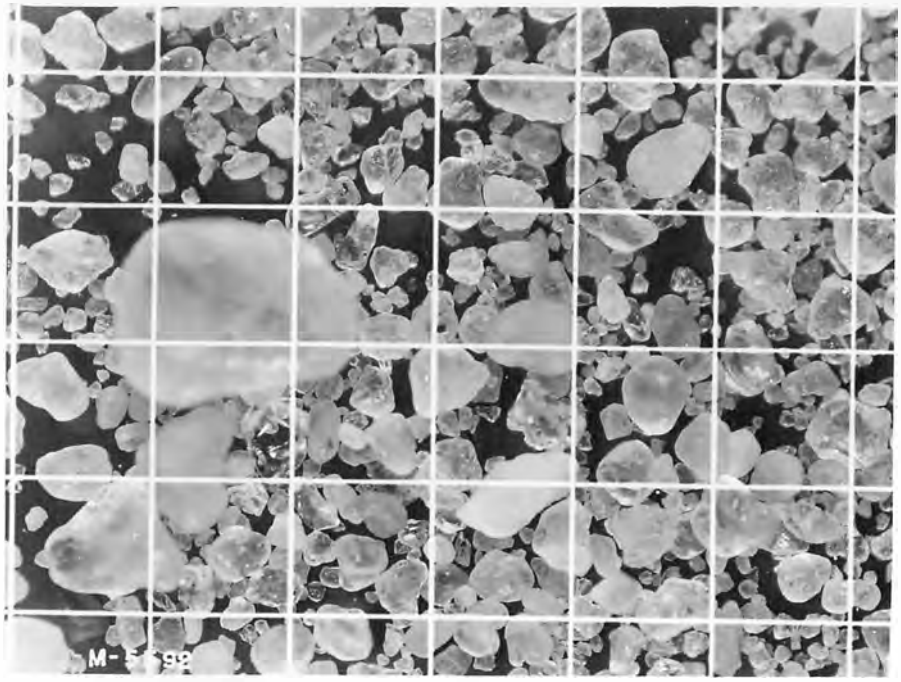
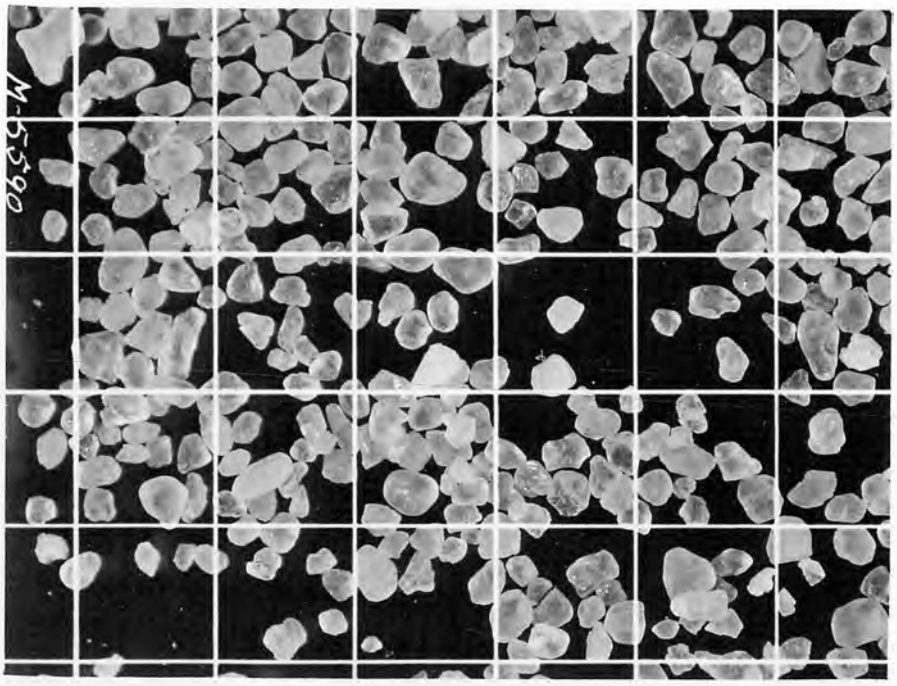
MISSOURI RIVER BASIN PROJECT
BOSTWICK DIVISION-NEBRASKA-KANSAS
REPUBLIC DIVERSION DAM
GENERAL PLAN-SECTIONS-TOPOGRAPHY
DRAWN T.W.G.
TRACED J.A.F.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
CHIEF ENGINEER
DENVER, COLORADO. APRIL 13, 1949
271-D-241


To Pump
Venturi
76'-0"
18'-0"
Sand feeding weir
Dam axis
14'-0"
8'-6"
19'-0"
A
A
B
B
C
C
Sluiceway
Headworks
30°
V Notch weir
5'-0"
Collecting tanks
PLAN
9.84"
Floor of box
Floor of box
SECTION A-A
3.6"
Floor of box
False floor
Sampler
SECTION B-B
6"
Floor of box
Sampler
SECTION C-C
HYDRAULIC MODEL STUDIES
REPUBLIC DIVERSION DAM
GENERAL MODEL LAYOUT
MODEL SCALE 1:15
491



A. Republican River sand



B. Model Sand

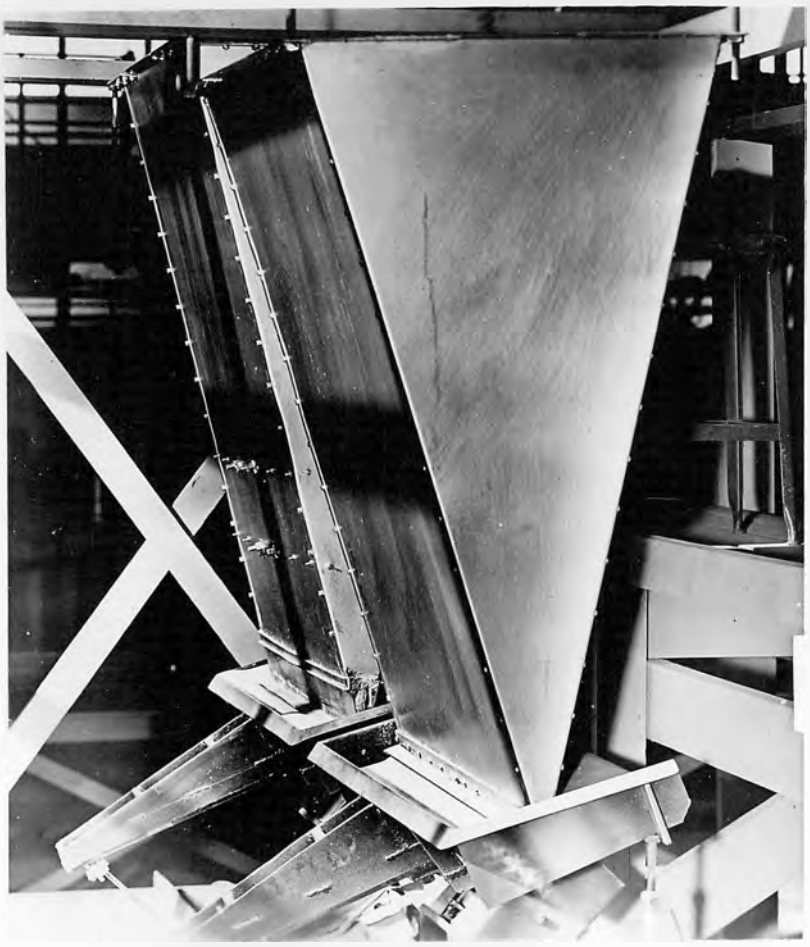
PHOTOMICROGRAPHS OF MODEL AND PROTOTYPE SANDS
GRID SPACING 1 mm.

A. Headworks Collecting Trough

B. Measuring Tanks

SAMPLING APPARATUS

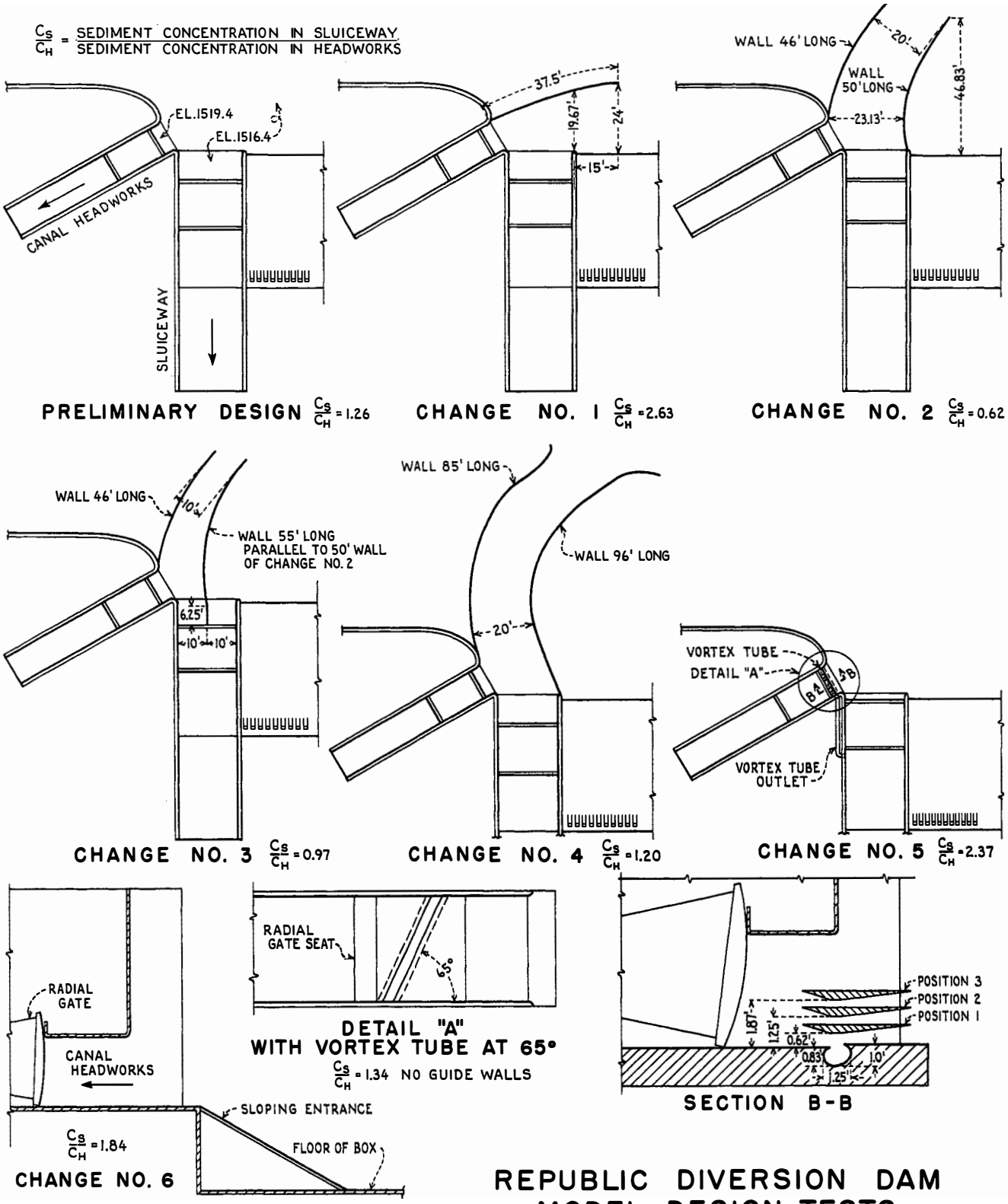
Figure 7



A. Sand Feeding Apparatus

B. Model Bed at Completion of Test Run
Preliminary Design

SAND FEEDING APPARATUS AND SCOUR PATTERN PRELIMINARY RUN



REPUBLIC DIVERSION DAM MODEL DESIGN TESTS

A. Closeup of Headworks at End of Test Run

B. Model Bed at End of Test Run

REPUBLIC HEADWORKS, CHANGE NO. 1

A. Ten-Foot Channel--Sluice Gate In Preliminary Downstream Position

B. Twenty-Foot Channel--Sluice Gate Moved Upstream 6 Ft. 10 In.

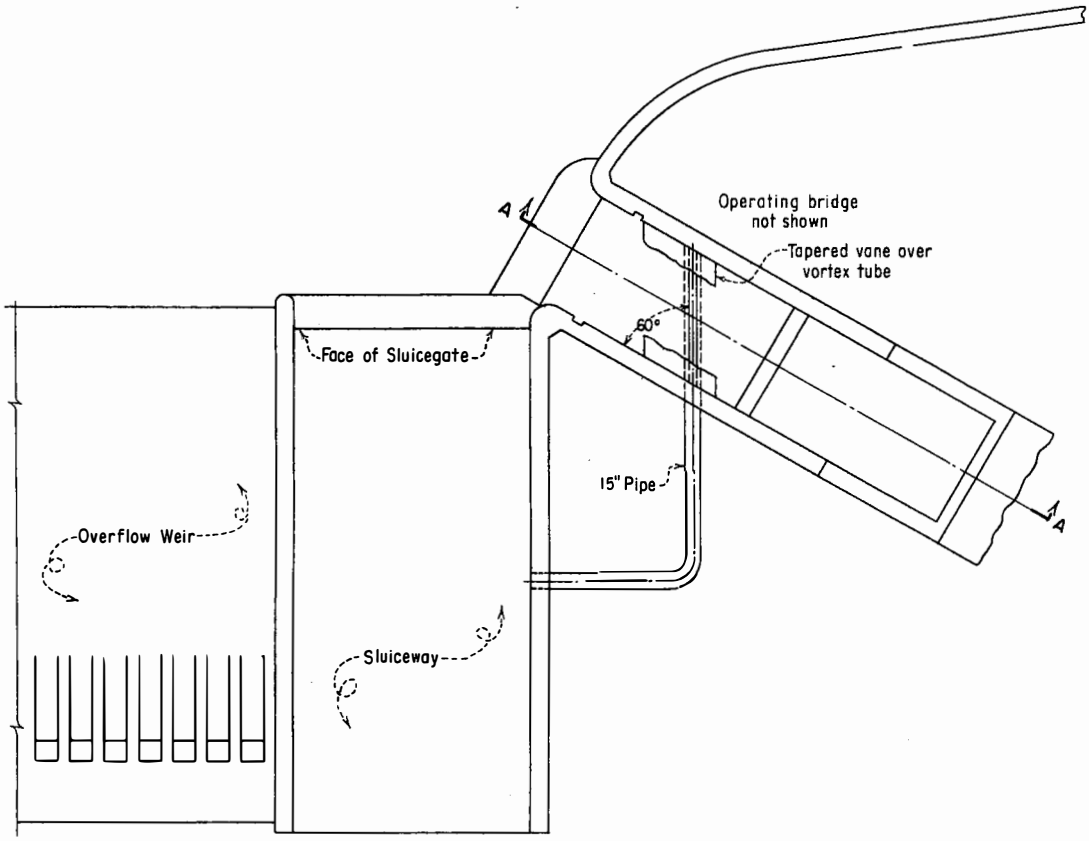
REPUBLIC HEADWORKS, CURVED GUIDE WALLS INSTALLED

Figure 10

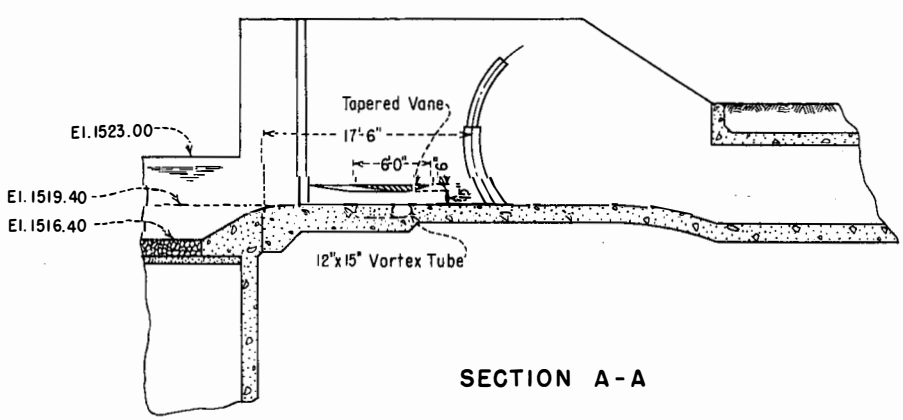
A. Tube at 90 Degree Angle with ℄ of Channel

B. Tube at 65 Degree Angle with ℄ of Channel

REPUBLIC HEADWORKS, VORTEX TUBES WITH ACTUATING VANE INSTALLED



PLAN



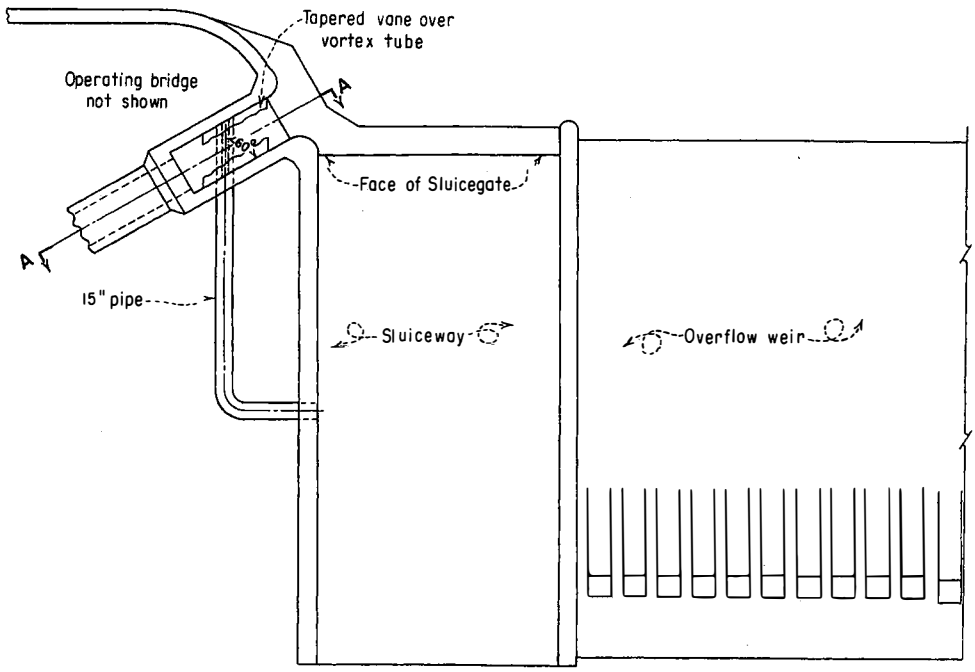
SECTION A-A

HYDRAULIC MODEL STUDIES

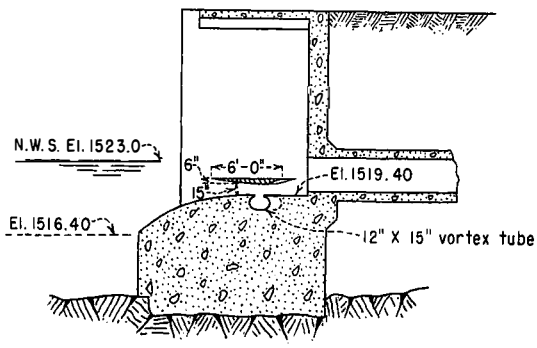
REPUBLIC DIVERSION DAM

RECOMMENDED DESIGN-REPUBLIC HEADWORKS

MODEL SCALE 1:15



PLAN



SECTION A-A

HYDRAULIC MODEL STUDIES

REPUBLIC DIVERSION DAM

RECOMMENDED DESIGN-HARDY HEADWORKS

MODEL SCALE 1:15