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UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN

OF

THE PINE VIEW SPILLWAY

By J. B. DRISKO, ASSISTANT ENGINEER

AND

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Under direction of

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TECHNICAL MEMORANDUM NO. 333

Denver, Colorado

Aug. 23, 1934

(PRICE $5.00)

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Summary

Model tests of the spillway of the Pine View Dam showed that the preliminary design was unsatisfactory on two counts: the flow down the steep chute was too irregular to be satisfactory, and the stilling pool was not adequate for the maximum discharge of 10,000 c.f.s. A new design was drawn up and a new model constructed; extensive tests were made on it and on several variations. As a result of the tests, a design was recommended which incorporated the following features: a head-gate and transition section which produces smooth flow down the chute by the formation of an hydraulic jump just below the gates, at all flows; a large, steep-sided stilling pool; a slight break in the slope of the chute just before it enters the pool; and a dentated sill on the pool floor at the downstream end.

PROJECT:

The Pine View dam is an earth fill dam on the Ogden River project, and is located some three miles west of Huntsville, near Ogden, Utah, (Fig. 1). The spillway for this dam will be a steep chute at the northwest end of the earth dam (Fig. 2), terminating in a stilling pool excavated in the river-bank below the dam, and a lead-off channel which returns the flow to the river. The maximum predicted flow in the spillway is 10,000 c.f.s.; the discharge is controlled by gates at the upper end. The proposed spillway is flat through the gate section, dips slightly through a transition section,

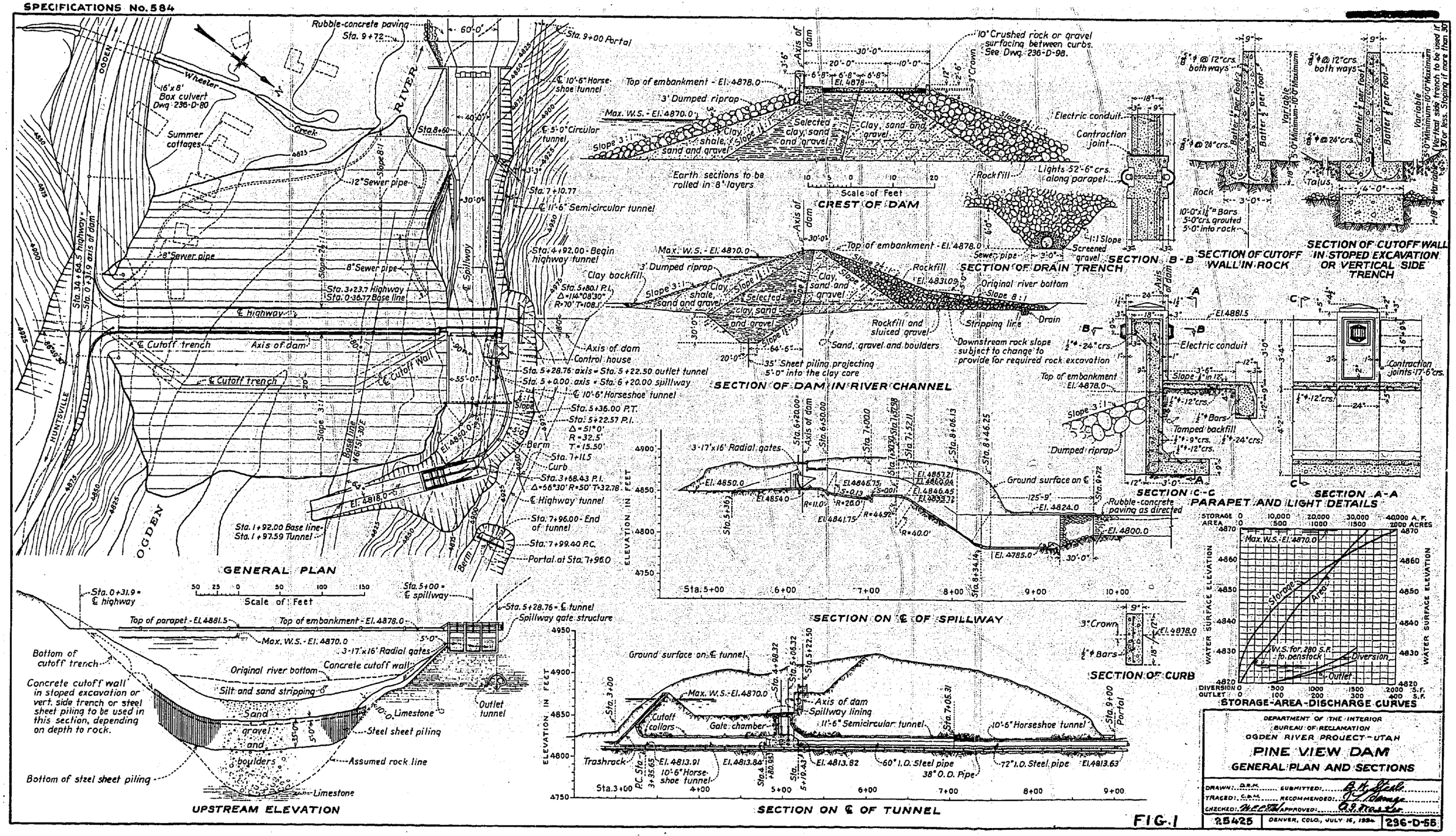
GENERAL PLAN
Scale of Feet
Rubble-concrete paving
Sta. 9+72
Sta. 9+00 Portal
16'x8' Box culvert Dwg. 236-D-80
Summer cottages
Wheeler Creek
RIVER
OGDEN
HUNTSVILLE
12" Sewer pipe
8" Sewer pipe
Sta. 3+23.7 Highway
Sta. 0+36.77 Base line
℄ Highway
℄ Cutoff trench
Axis of dam
℄ Cutoff Wall
℄ Spillway
Sta. 4+92.00 - Begin highway tunnel
Sta. 7+10.77
℄ 11'-6" Semi-circular tunnel
℄ 10'-6" Horse-shoe tunnel
℄ 5'-0" Circular tunnel
Sta. 34+64.5 highway = Sta. 0+31.9 axis of dam
Sta. 5+28.76 axis = Sta. 5+22.50 outlet tunnel
Sta. 5+0.00 axis = Sta. 6+20.00 spillway
℄ 10'-6" Horseshoe tunnel
Sta. 5+36.00 P.T.
Sta. 5+22.57 P.I.
Δ = 51°0'
R = 32.5'
T = 15.50'
Sta. 7+11.5
Sta. 3+68.43 P.I.
Δ = 56°30' R = 50' T = 32.78'
℄ Highway tunnel
Sta. 7+96.00 - End of tunnel
Sta. 7+99.40 P.C.
Portal at Sta. 7+96.0
Sta. 1+92.00 Base line
Sta. 1+97.59 Tunnel
Berm
Curb
Control house
CREST OF DAM
Top of embankment - El. 4878.0
3' Dumped riprap
Max. W.S. - El. 4870.0
Selected clay, sand and gravel
Clay, sand and gravel
Clay, shale, sand and gravel
Earth sections to be rolled in 8" layers
10" Crushed rock or gravel surfacing between curbs. See Dwg. 236-D-98.
Electric conduit
Contraction joint
Lights 52'-6" crs. along parapet
Rockfill
Screened gravel
SECTION OF DRAIN TRENCH
SECTION B-B
SECTION OF CUTOFF WALL IN ROCK
SECTION OF CUTOFF WALL IN STOPED EXCAVATION OR VERTICAL SIDE TRENCH
Rock
Talus
Clay backfill
Sta. 5+80.1 P.I.
Δ = 114°08'30"
R = 70' T = 108.1'
Original river bottom
Rockfill and sluiced gravel
Sand, gravel and boulders
Stripping line
Drain
Downstream rock slope subject to change to provide for required rock excavation
35' Sheet piling projecting 5'-0" into the clay core
SECTION OF DAM IN RIVER CHANNEL
Top of embankment El. 4878.0
Electric conduit
Tamped backfill
Dumped riprap
SECTION C-C
SECTION A-A
PARAPET AND LIGHT DETAILS
Contraction joints 17'-6" crs.
3-17'x16' Radial gates
Ground surface on ℄
Rubble-concrete paving as directed
SECTION ON ℄ OF SPILLWAY
ELEVATION IN FEET
Sta. 5+00
6+00
7+00
8+00
9+00
10+00
SECTION OF CURB
STORAGE-AREA-DISCHARGE CURVES
WATER SURFACE ELEVATION
Max. W.S. - El. 4870.0
Storage
Area
W.S. for 280 S.F. to penstock
Diversion
Outlet
Sta. 0+31.9 = ℄ highway
Sta. 5+00 = ℄ spillway
Sta. 5+28.76 = ℄ tunnel
Spillway gate structure
Top of parapet - El. 4881.5
Top of embankment - El. 4878.0
Max. W.S. - El. 4870.0
3-17'x16' Radial gates
Bottom of cutoff trench
Concrete cutoff wall
Original river bottom
Concrete cutoff wall in stoped excavation or vert. side trench or steel sheet piling to be used in this section, depending on depth to rock.
Silt and sand stripping
Sand gravel and boulders
Limestone
Outlet tunnel
Steel sheet piling
Assumed rock line
Bottom of steel sheet piling
UPSTREAM ELEVATION
Ground surface on ℄ tunnel
Max. W.S. - El. 4870.0
Axis of dam
Spillway lining
Cutoff collars
Gate chamber
11'-6" Semicircular tunnel
10'-6" Horseshoe tunnel
Trashrack
El. 4813.91
10'-6" Horse-shoe tunnel
El. 4813.84
El. 4813.82
60" I.D. Steel pipe
38" O.D. Pipe
72" I.D. Steel pipe
El. 4813.63
Portal
SECTION ON ℄ OF TUNNEL
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT - UTAH
PINE VIEW DAM
GENERAL PLAN AND SECTIONS
DRAWN: D.R.M.
SUBMITTED:
TRACED: C.B.M.
RECOMMENDED:
CHECKED:
APPROVED:
25425
DENVER, COLO., JULY 16, 1934
236-D-55

FIG. 1

SPECIFICATIONS No. 584

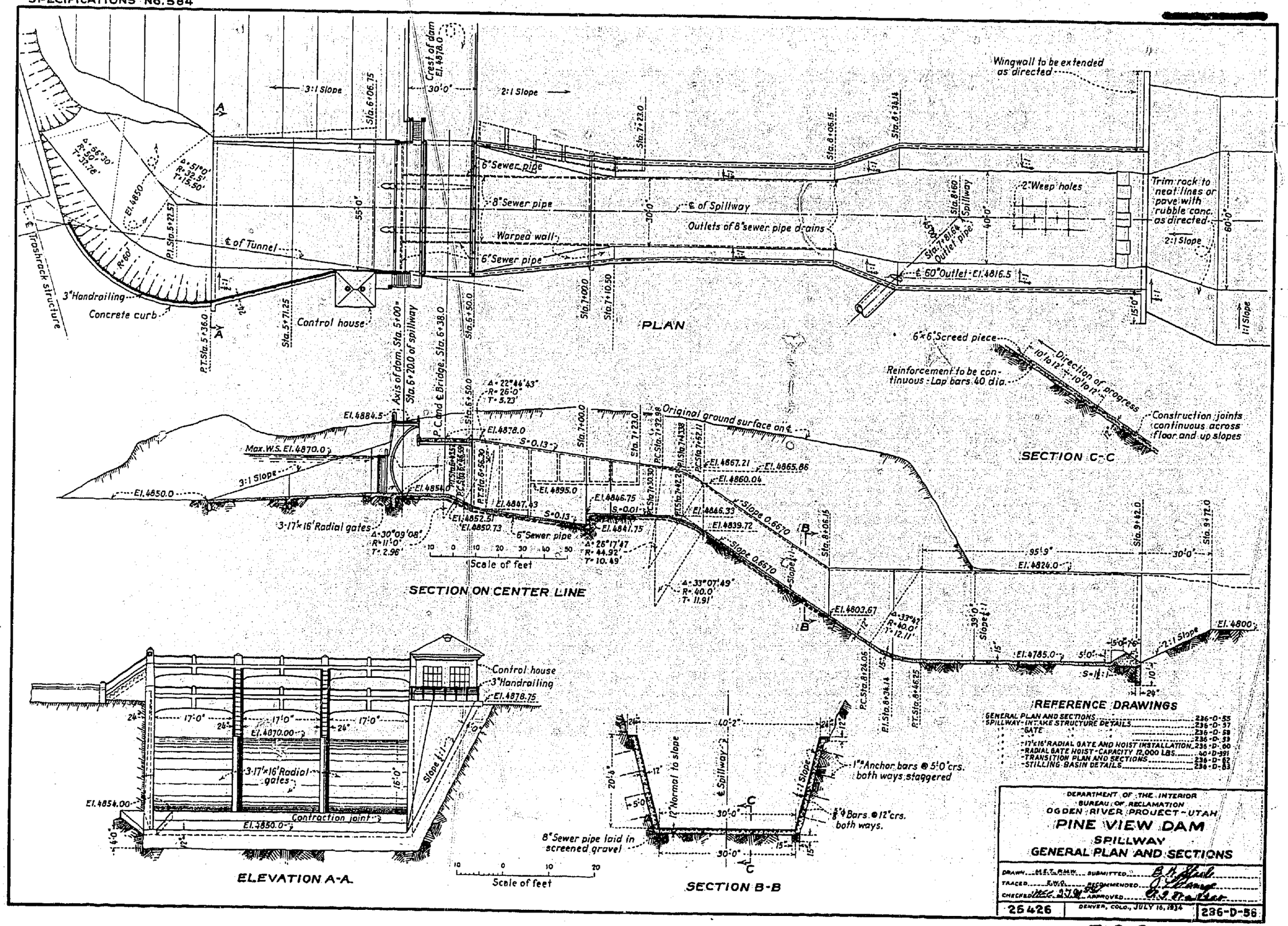

FIG. 2

and drops abruptly to the pool (Fig. 2). The total drop from reservoir surface to the tailwater is 53 feet.

During the first five months of 1934, model studies of the entire spillway were carried on in the Denver Hydraulic laboratory of the Bureau, to insure a safe and economical design.

Laboratory

The hydraulic laboratory of the Bureau is in the basement of the Old Custom House, 16th and Arapahoe Streets, Denver, (Fig. 3). The water supply system, which recirculates the same water, includes a weir tank with a 90° V-notch weir and a pump sump, set somewhat below the floor level, a 6" centrifugal pump with a discharge of up to 3.5 sec. ft., and a twin head tank for water supply to the models. The discharge from the models is carried back to the weir tank in a sheet metal return flume on the laboratory floor.

The graphic picture of the spillway and stilling-pool action which the model provided was very convincing to members of the design staff, who were frequent visitors during the model testing.

The model work was carried on by two test crews working in two shifts, each crew made up of one junior engineer and two laborers.

Model

The Pine View Model was built with linear dimensions one-thirtieth those of the prototype, and included the complete spillway from entrance down to the lead-off below the stilling pool. The maximum discharge through the model was 2.03 c.f.s. corresponding to 10,000 c.f.s. in the prototype. The model scale chosen was the

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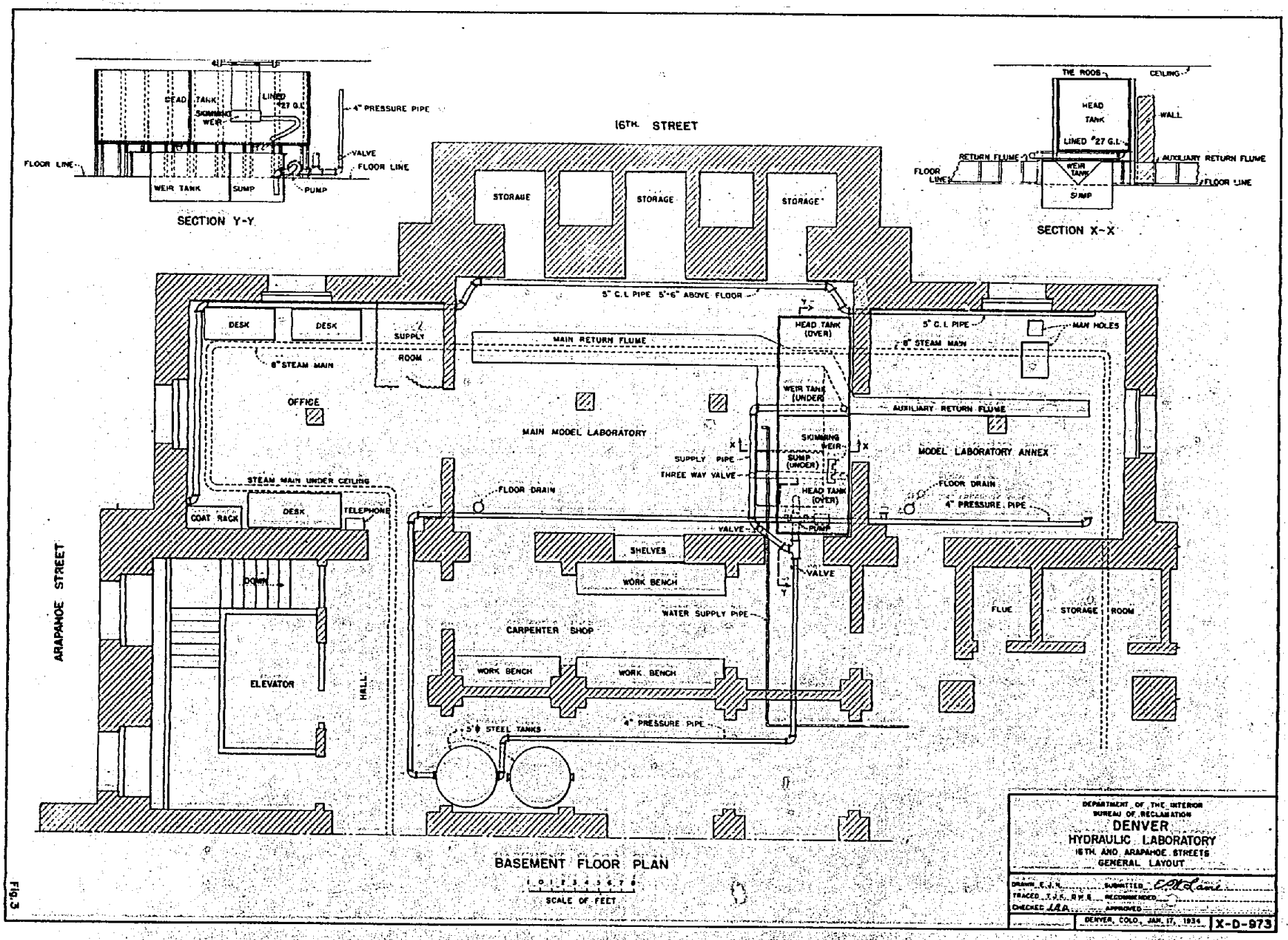

SECTION Y-Y
HEAD TANK
LINED #27 G.I.
SKIMMING WEIR
4" PRESSURE PIPE
VALVE
FLOOR LINE
WEIR TANK
SUMP
PUMP
16TH. STREET
SECTION X-X
TIE ROOD
CEILING
WALL
RETURN FLUME
AUXILIARY RETURN FLUME
STORAGE
5" C.I. PIPE 5'-6" ABOVE FLOOR
DESK
SUPPLY ROOM
MAIN RETURN FLUME
HEAD TANK (OVER)
5" C.I. PIPE
MAN HOLES
8" STEAM MAIN
WEIR TANK (UNDER)
OFFICE
MAIN MODEL LABORATORY
SKIMMING WEIR
SUPPLY PIPE
SUMP (UNDER)
THREE WAY VALVE
MODEL LABORATORY ANNEX
STEAM MAIN UNDER CEILING
FLOOR DRAIN
COAT RACK
TELEPHONE
4" PRESSURE PIPE
SHELVES
WORK BENCH
WATER SUPPLY PIPE
CARPENTER SHOP
FLUE
STORAGE ROOM
ARAPAHOE STREET
DOWN
ELEVATOR
HALL
5' ϕ STEEL TANKS
BASEMENT FLOOR PLAN
SCALE OF FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER
HYDRAULIC LABORATORY
16TH AND ARAPAHOE STREETS
GENERAL LAYOUT
DENVER, COLO., JAN. 17, 1936
X-D-973

Fig. 3

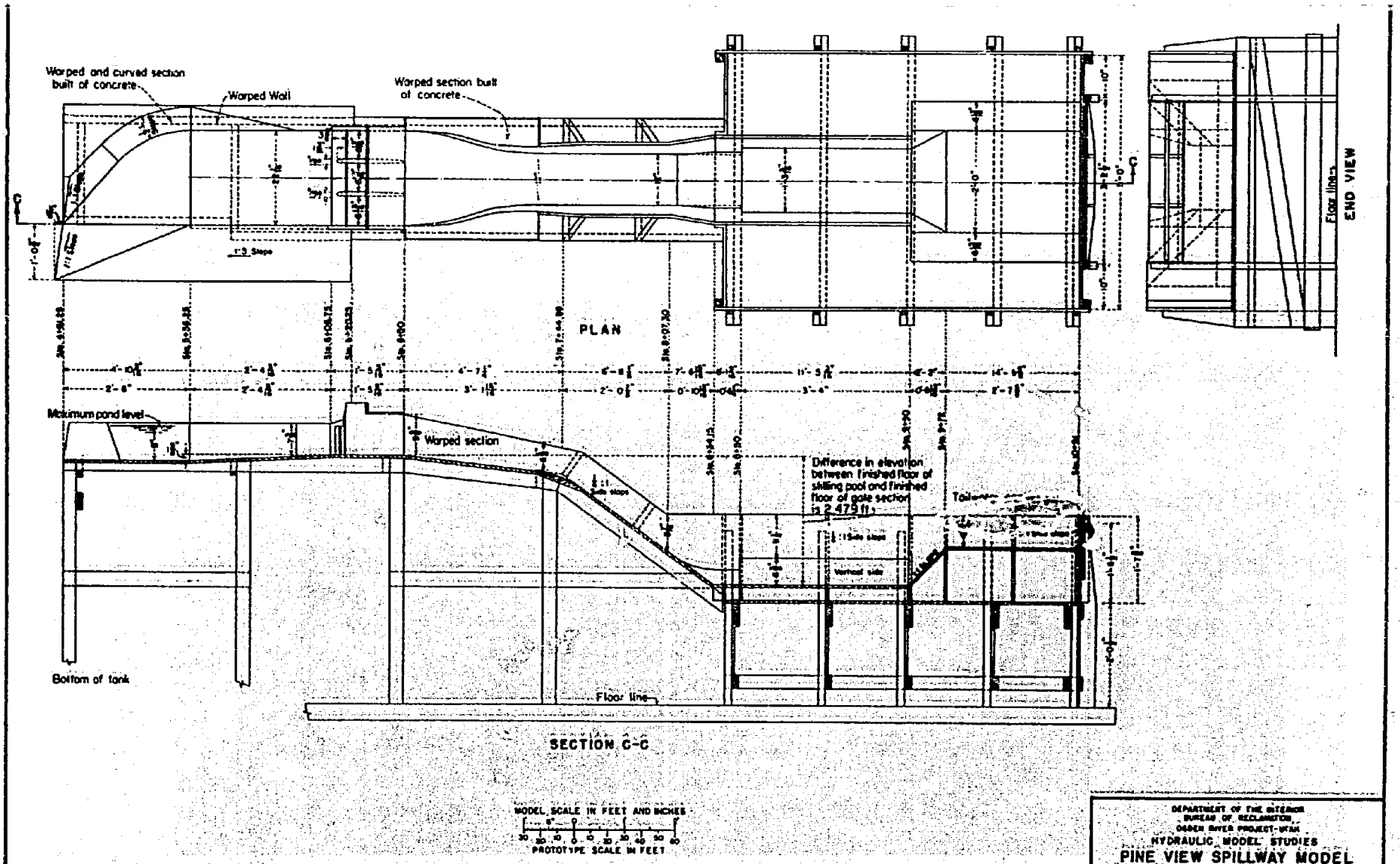
largest permitted by the available laboratory space.

The model was constructed of wood; the stilling pool and the chute floor were lined with sheet metal, and the rest was unlined wood, in the original model (Plate I). In the revised model, (Fig. 4) the transition below the head gates was made of concrete, shellacked, and the rest of the model was lined with sheet metal, except the gate section and piers, which were made of redwood. The gates were of sheet metal, sliding in grooves in the piers. A sand bin below the stilling pool made it possible to study the erosion which would occur in the leadoff channel.

The slope of the model was increased slightly over that of the prototype to insure corresponding velocities at entrance to the pool. The prototype slope was divided into friction slope and excess or acceleration slope. The friction slope computed for the model was then added to the excess slope (same for model and prototype) to give the total model slope. Measurements in the model showed these velocities to be within a very few percent of the calculated velocities for the prototype. The value of Kutter's "n" used for the prototype was n = .014 for the transition and n = .010 for the chute. A uniform value of n = .010 was used in the model.

Comparative tests on the various layouts were made at the maximum expected discharge of 10,000 c.f.s. in nature, and occasionally at lesser flows. The final design was tested at 5 different discharges from 2,000 c.f.s. up to 10,000 c.f.s.

Each test included measurement of the discharge through the



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT-UTAH
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY MODEL
GENERAL PLAN AND SECTION POOL B-1

DRAWN T.J.R. CHK. SUBMITTED John B. Drake
TRACED J.D.R. RECOMMENDED
CHECKED J.E.D. APPROVED

DENVER, COLO. JUNE 2, 1934 | 236-D-127

FIG. 4

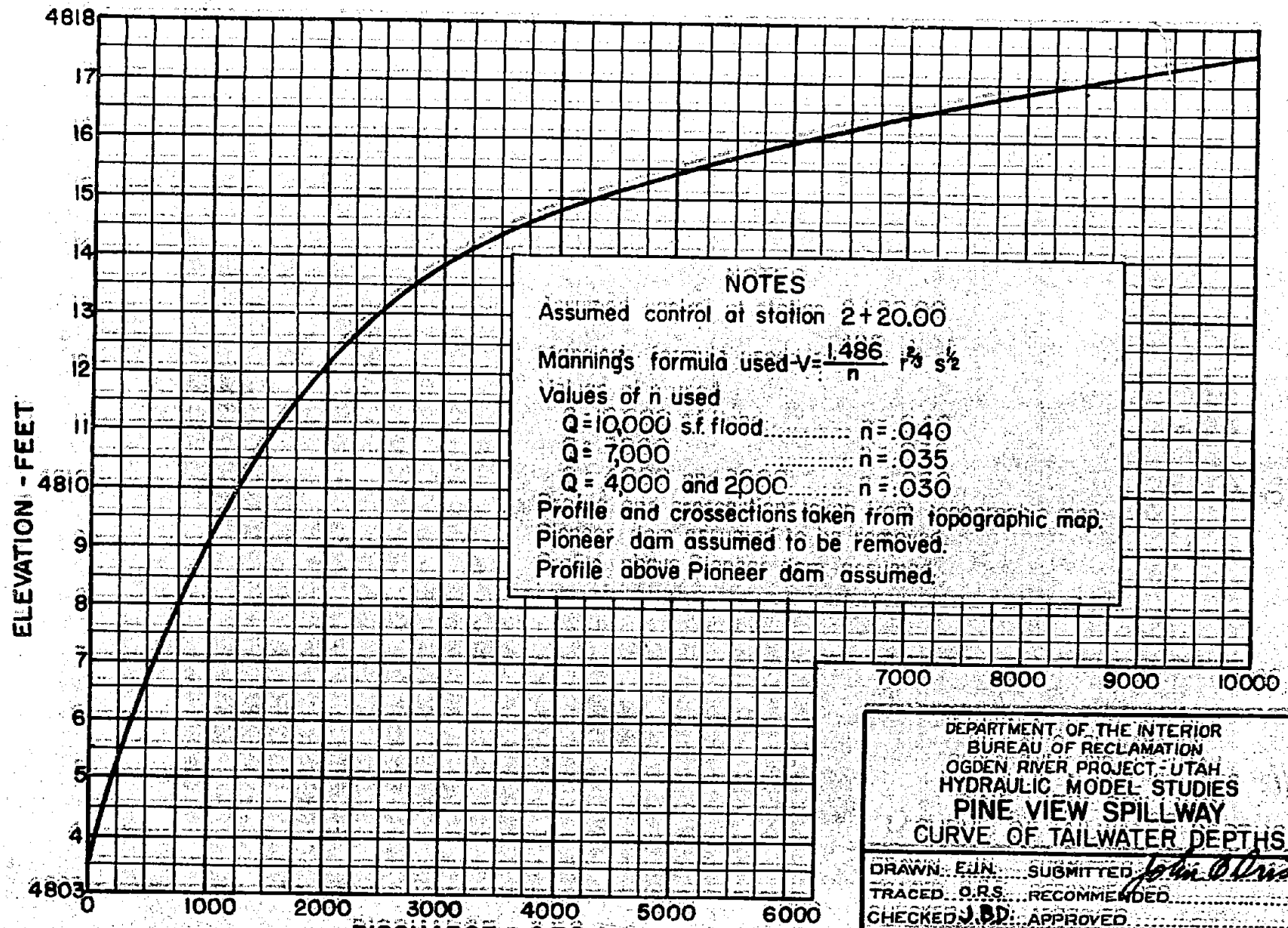
model, the water depths in the pool and lead-off channel, the head on the gates, and, for the runs made with an erodible lead-off channel, the erosion which occurred. The height of the splash along the stilling pool walls was also measured for the final design.

Original Data; Tailwater Depth

At the start of the model studies, the available data regarding tailwater conditions was very meagre. Nothing was known about the river into which the stilling pool emptied, except that an old dam somewhat downstream would probably act as control to maintain the tailwater depth in the stilling pool. Investigation showed that this dam was an earth structure and would probably wash out at something less than maximum flood flow, and the river channel would have to act as control, thus lowering the tailwater elevation. Calculations were made to determine the tailwater elevation at four discharges, assuming the dam to be washed out and the channel itself to act as a control. From these values a curve of tailwater elevation against discharge was drawn (Fig. 5). Plate VIII shows the pool action when the tailwater depth is insufficient, and shows the resulting river bed scour.

Original Design

The original design for the spillway proposed a warped transition on a steep slope, immediately below the gates; the chute then continued at the same slope to the stilling pool, which was of trapezoidal cross-section (Fig. 6 and plate I). Tests of this setup



NOTES

Assumed control at station 2+20.00

Mannings formula used $V=\frac{1.486}{n} r^{2/3} s^{1/2}$

Values of n used

Q = 10,000 s.f. flood ..... n = .040

Q = 7,000 ..... n = .035

Q = 4,000 and 2000 ..... n = .030

Profile and crossections taken from topographic map.

Pioneer dam assumed to be removed.

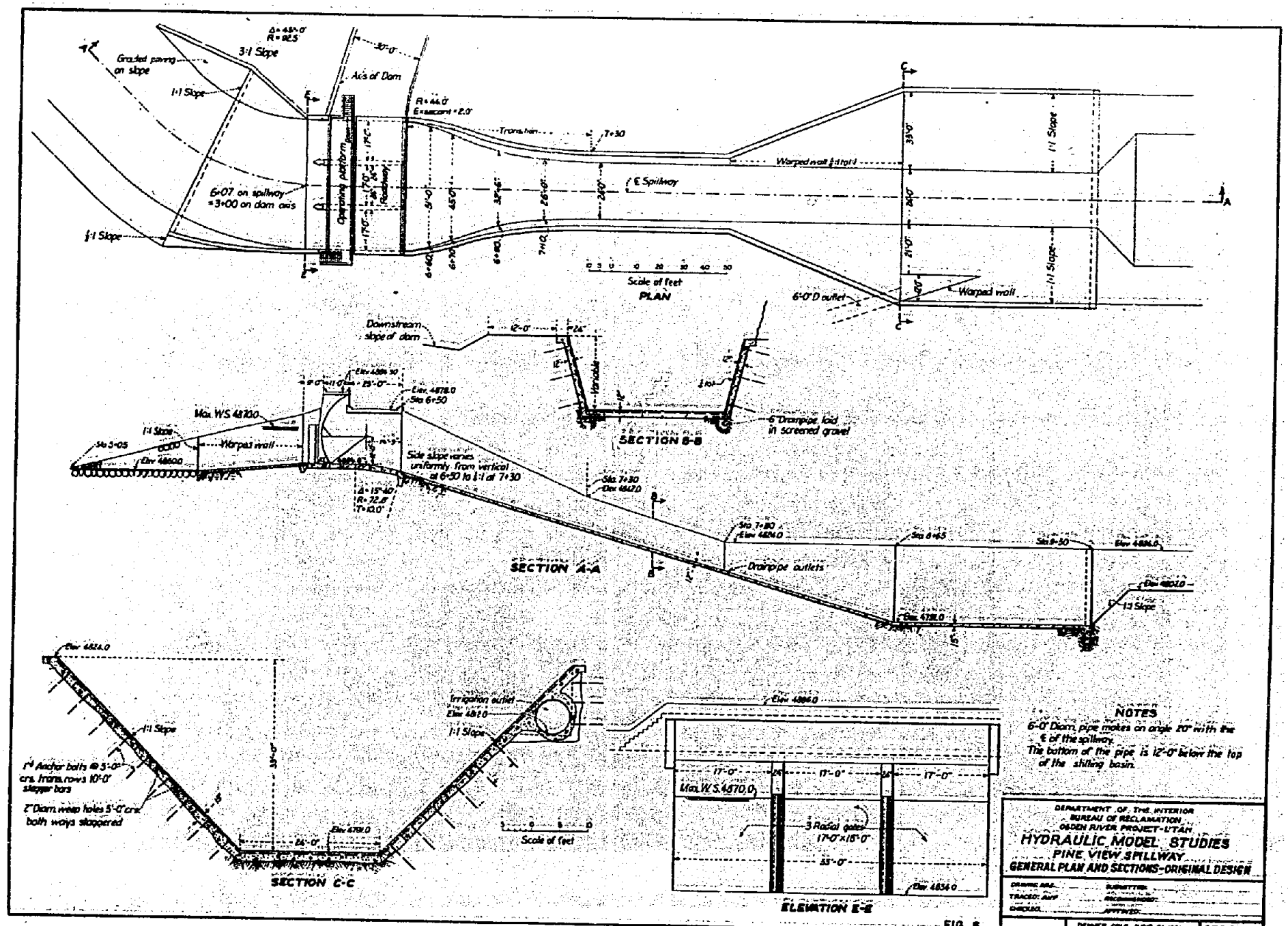
Profile above Pioneer dam assumed.

FIG. 5

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT - UTAH
HYDRAULIC MODEL STUDIES
PINE VIEW SPILLWAY
CURVE OF TAILWATER DEPTHS

DRAWN: E.J.N. SUBMITTED: John A. Dricks
TRACED: O.R.S. RECOMMENDED:
CHECKED: J.B.D. APPROVED:

DENVER, COLO., 6-13-34 236-D-128

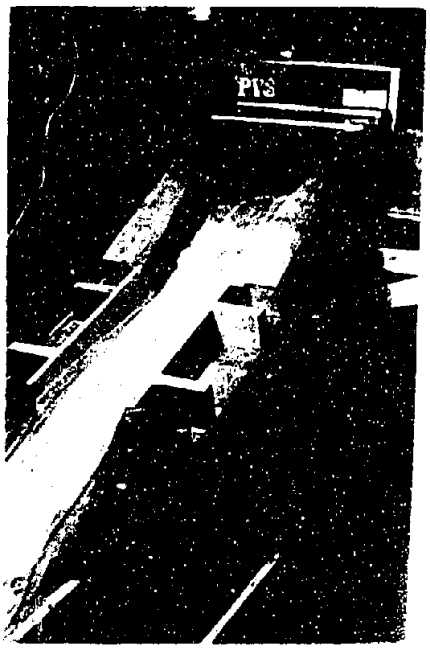


Graded paving on slope
3:1 Slope
1:1 Slope
Axis of Dam
Operating platform
Roadway
6+07 on spillway
=3+00 on dam axis
Transition
7+30
Warped wall
℄ Spillway
6'-0" D outlet
Warped wall
Scale of feet
PLAN
Downstream slope of dam
6" Drainpipe laid in screened gravel
SECTION B-B
Max. W.S. 4870.0
Warped wall
Side slope varies uniformly from vertical at 6+50 to 1:1 at 7+30
Drainpipe outlets
SECTION A-A
1:1 Slope
1" Anchor bolts @ 5'-0" crs. trans. rows 10'-0" stagger bars
2" Diam. weep holes 5'-0" crs. both ways staggered
SECTION C-C
Irrigation outlet
Scale of feet
Max. W.S. 4870.0
3 Radial gates 17'-0" x 15'-0"
ELEVATION E-E
NOTES
6'-0" Diam. pipe makes an angle 20° with the ℄ of the spillway.
The bottom of the pipe is 12'-0" below the top of the stilling basin.
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT-UTAH
HYDRAULIC MODEL STUDIES
PINE VIEW SPILLWAY
GENERAL PLAN AND SECTIONS-ORIGINAL DESIGN
DENVER, COLO. JUNE 21, 1934
236-D-129

FIG. 6

A-Pool and Chute

B-Headgates and Transition



C-Flow Down Chute

D-Flow Down Chute

ORIGINAL DESIGN

PLATE I

showed the flow through the transition and down the chute to be very irregular. The transition caused the fast-traveling water coming from the gates to ride up in the center of the flume and form a high fin (Plate II). At entrance to the pool, the condition was reversed; the water rode up the sides of the flume, and was shallow in the center. The trapezoidal pool was too small to contain an hydraulic jump and the water shot through the pool and jumped into the air to a height of about 15 inches or 38 ft. in the prototype (Plate II).

Alterations

The spillway was then redesigned; the approach to the gates was changed, the slope of the chute was broken, placing the transition on a flatter slope, and the pool was made with nearly vertical walls. The prototype pool will be largely in rock cut, and so this was entirely feasible.

The flow through the revised chute was much improved (Plate II); the water surface was tolerably flat and the water did not splash up on the sides. The water did not approach the gate section smoothly from the reservoir, due to the cross flow which tumbled over the low side of the entrance channel (Plate III). Various modifications of the intake design were investigated, and much better conditions were obtained by blocking off the side flow. The difficulties of construction of these modifications were such that they were not adopted.

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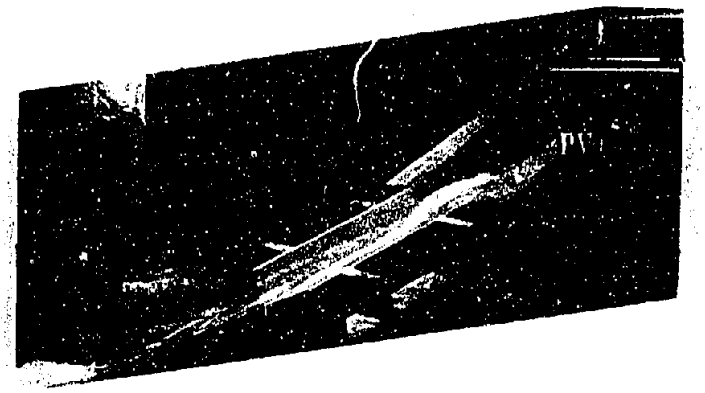


A–Flow Down Chute–Original Design

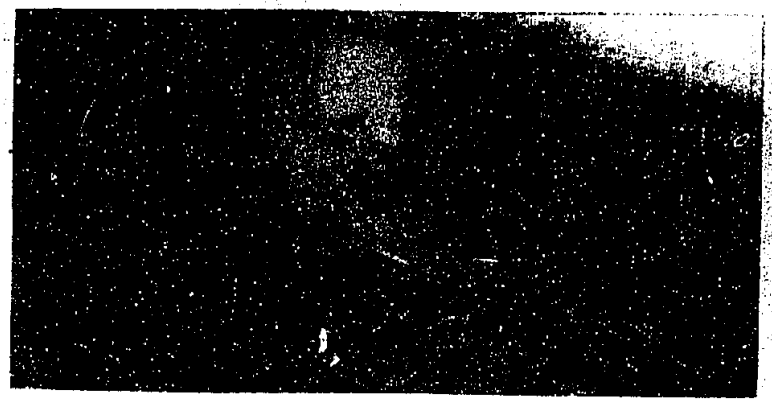
B–Stilling Pool–Original Design

C–Flow Through Revised Transition

D–Revised Transition at Partial Flow, Center Gate Closed.

PLATE II

A-Entrance to Gates — Revised design



B-Flow Approaching Gates — Revised design

C-Improved Conditions;
Side Flow Blocked Off

PLATE III

The action in the steep sided pool was much better, although still not satisfactory. The length of the pool seemed short and there was considerable turbulence in the lead-off channel.

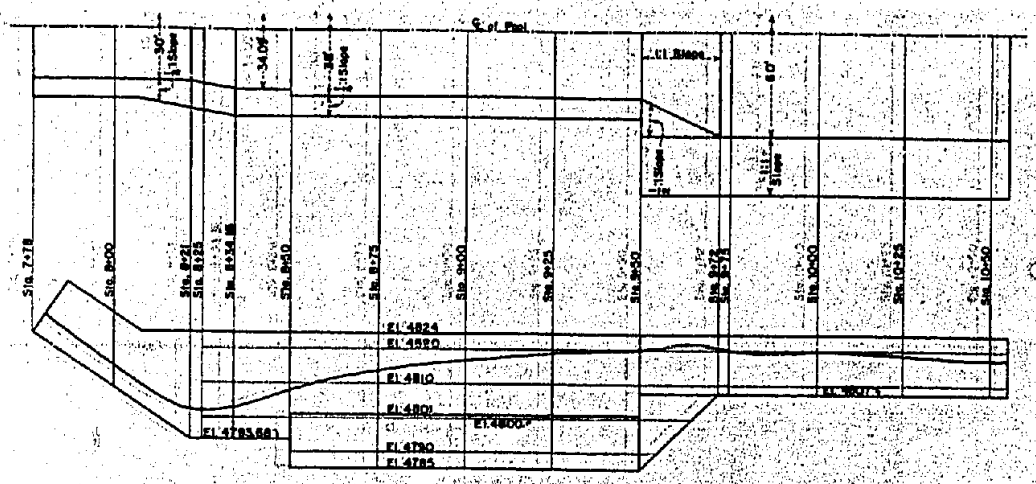
The pool was subsequently revised several times and finally a sand bin was built downstream from the pool to investigate the erosion of the river bed where the spillway enters it.

Pool B-1

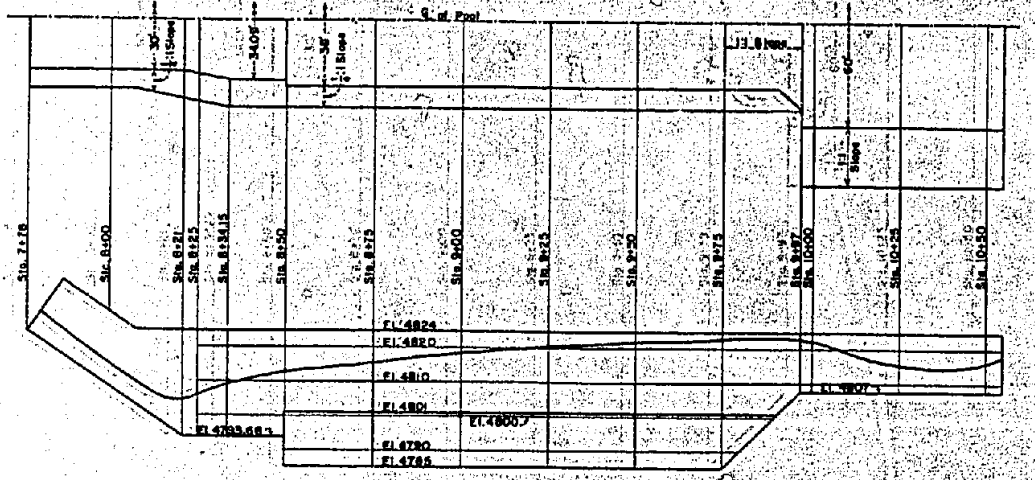
This pool was 116 foot long and had side slopes of 1/4 : 1 (Fig. 7 and Plate IV). At the downstream end of the pool, the floor was inclined upward on a 1:1 slope, and flared out to the width of the lead-off channel. The jump action in this pool was only fair; an 8½-foot high apron at the pool entrance, as in Fig. 7, improved the pool action considerably, (see also Fig. 8). In every case, the B-1 design produced irregular conditions in the lead-off channel; either there was excessive bubbling and boiling, or a standing wave with velocities which would endanger an unprotected tail-way. The source of the trouble seemed to be an insufficient length of pool; the jump did not have opportunity to form completely and there was a large amount of kinetic energy left in the outflowing water.

Pool B-2

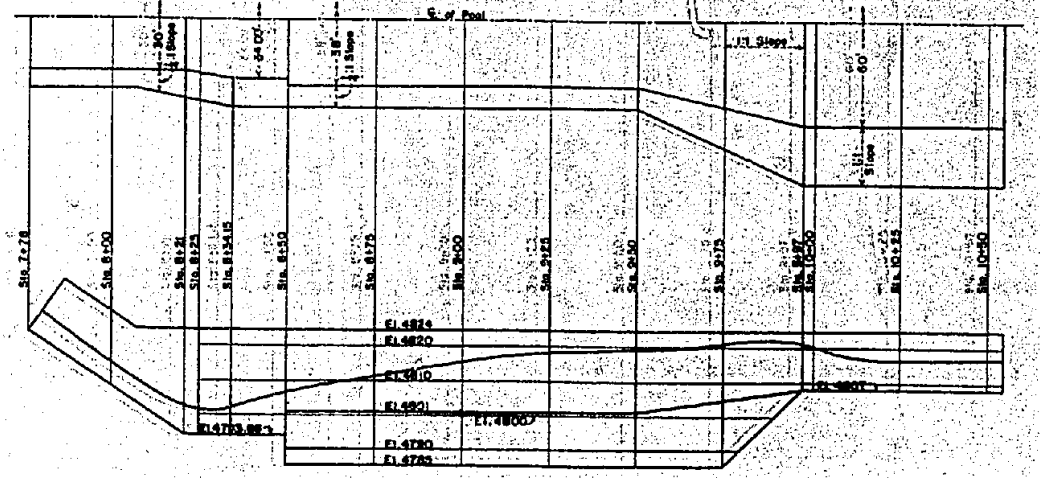
Pool B-2 was similar to B-1, but longer (141 ft.) and there was no flaring transition from pool to tailrace (Plate V and Fig. 7). The abrupt change without a gradual transition caused a very undesirable standing wave, and, after two tests, transitions were built



POOL B-1 – TEST 16-PV-1 – Q=9950 C.F.S.



POOL B-2 – TEST 19-PV-1 – Q = 9990 C.F.S.



POOL B-3 – TEST 20-PV-1 – Q=9990 C.F.S.

PROTOTYPE SCALE IN FEET

10 0 10 20 30 40 50 60

0 6 12 18 24

MODEL SCALE IN INCHES

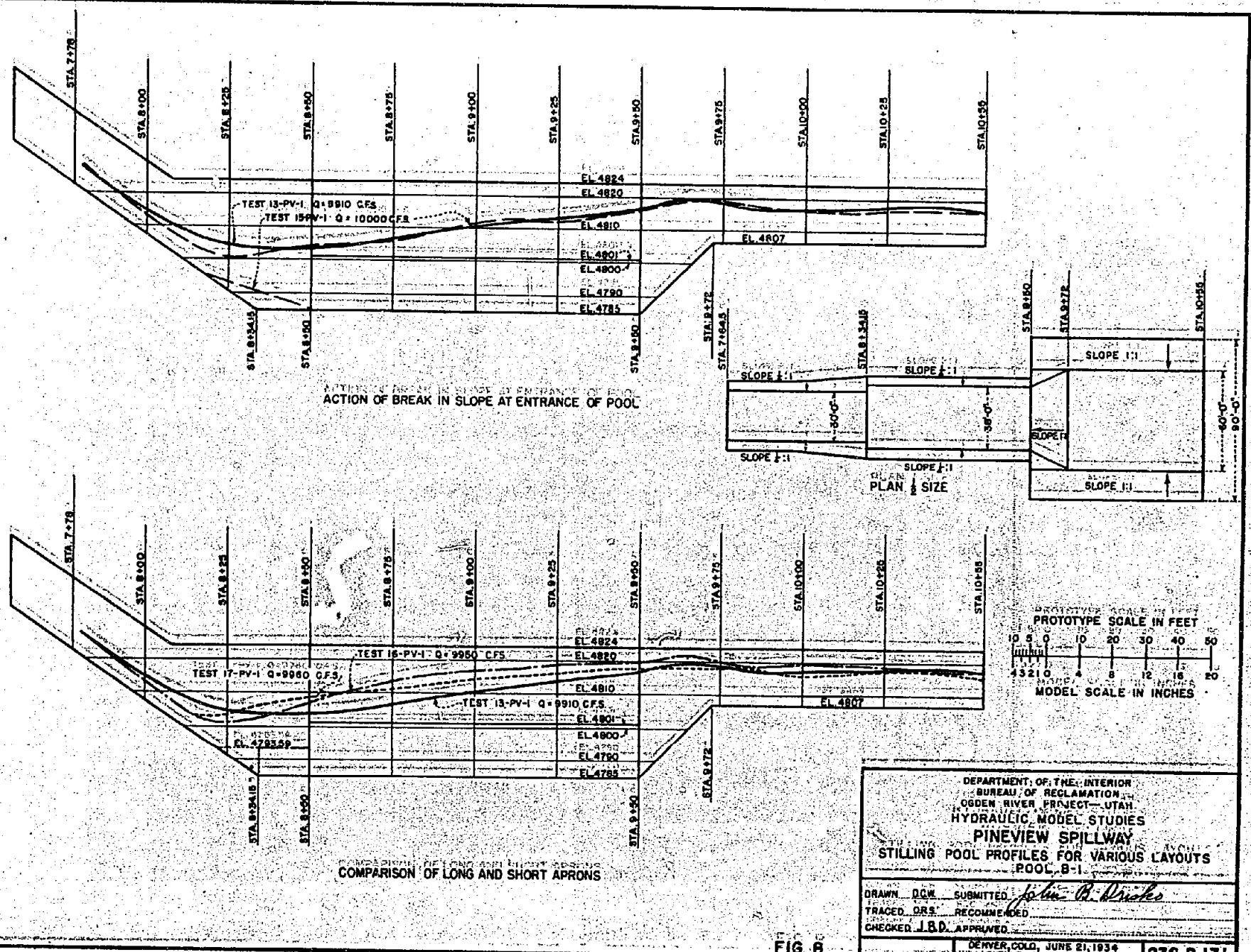
U. S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
GREEN RIVER PROJECT - UTAH
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY

STILLING POOLS B-1, B-2, AND B-3 WITH WATER SURFACE PROFILES.

DRAWN C.R.H. SUBMITTED John C. Hinaka
TRACED A.P.K. RECOMMENDED
CHECKED J.R.D. APPROVED
DENVER, COLO. MAY 17, 1954 — 23S-D-130

FIG. 7

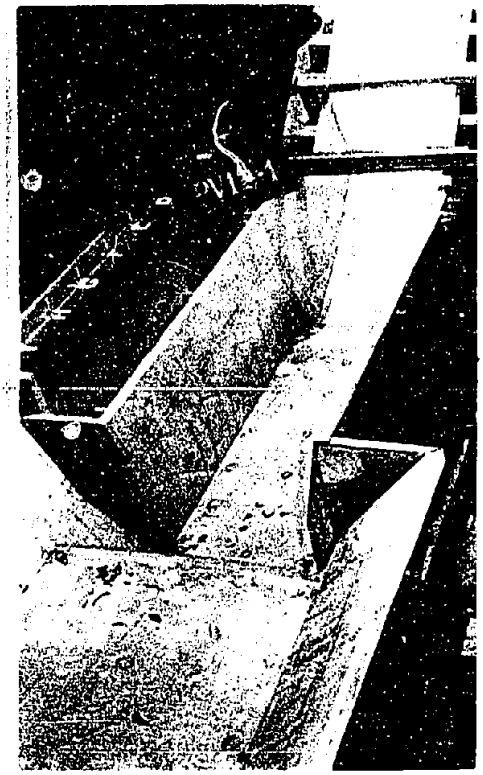


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT—UTAH
HYDRAULIC MODEL STUDIES
PINEVIEW SPILLWAY
STILLING POOL PROFILES FOR VARIOUS LAYOUTS
POOL B-1

DRAWN D.C.W. SUBMITTED John R. Drake
TRACED D.R.S. RECOMMENDED
CHECKED J.B.D. APPROVED

DENVER, COLO., JUNE 21, 1934 | 236-D-131

FIG. 8



A

B
Q = 9940

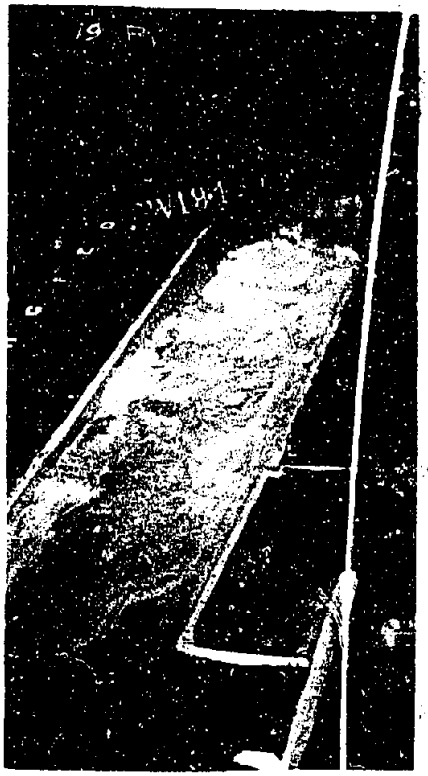
C-Pool with Apron

D
Q = 9970

POOL B-1

PLATE IV

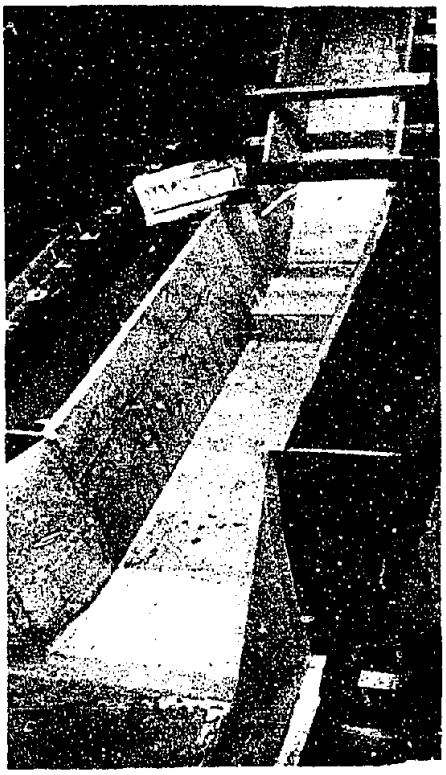
A



B

Q = 9990

POOL B-2



C

D

Q = 9980

POOL B-3

PLATE V

A
Q = 5780

B
Q = 7200

C
Q = 8400

POOL B-3

PLATE VI

into the model.

Pool B-3

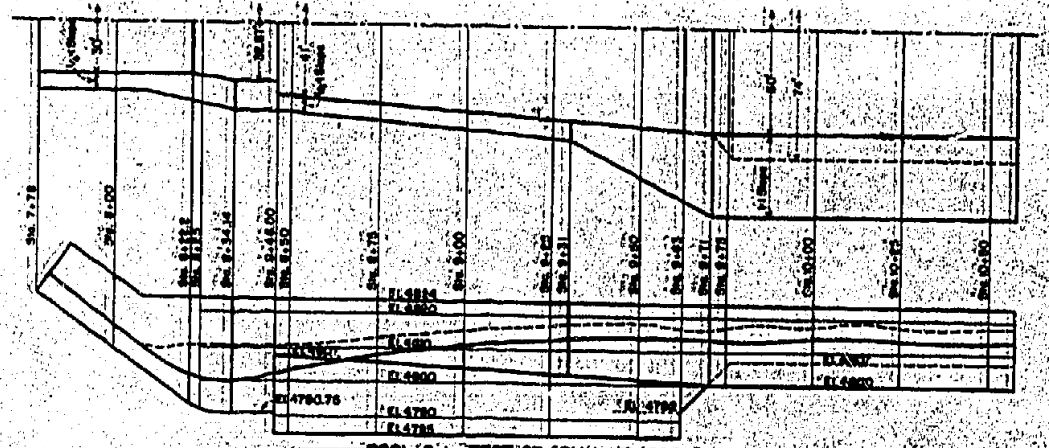
A flaring transition was added to Pool B-2 between pool and tailway. (Fig. 7 and Plate V). The standing wave in the tailway persisted, although not as pronounced as before. Again, of the various setups tried, an apron showed the best results. A high ($8\frac{1}{2}$ ft.) apron was found to produce unstable conditions in the pool. At certain flows less than maximum, the entering stream of water rode the surface of the pool and rose to a very great height (Plate V and VI). Undoubtedly a large roller formed beneath and forced the stream upward. Because of this liability to erratic action, the use of an apron was not deemed advisable.

Pool C-1

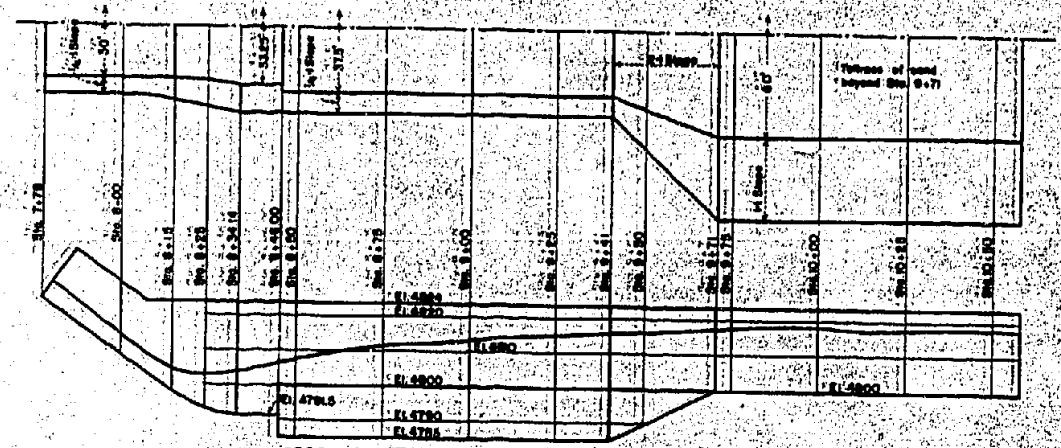
This revision differed in that the sides of the pool gradually diverged and the floor of the lead-off channel was dropped 7 feet, to elevation 4800 (Fig. 9 and Plate VII). The action in this pool was not satisfactory; the eddying was more pronounced and the pool surface was much more turbulent and unstable. The larger lead-off channel did not confine the pool sufficiently to form a deep jump. The water in the pool was shallow and very turbulent.

Pool C-2

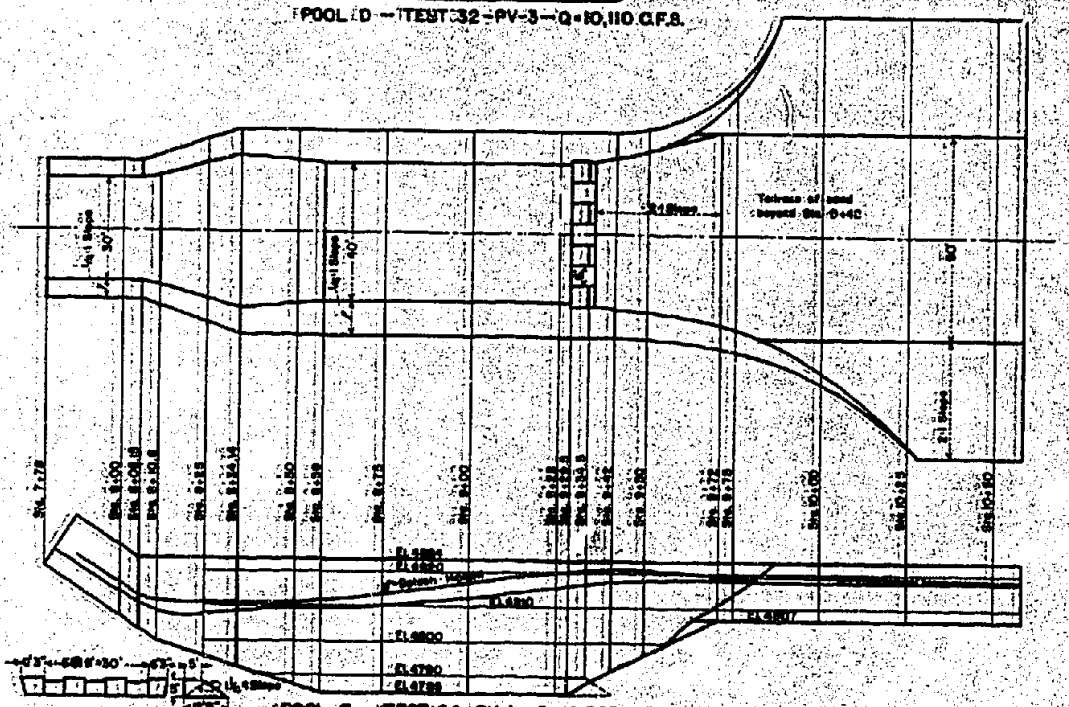
Two tests were made with a smaller lead-off channel, with only fair results (Plate VIII). The pool was deeper, but still very



POOL C-1 — TEST 27 - PV-1 — Q=9920 C.F.S.
POOL C-2 — TEST 30 - PV-1 — Q=9960 C.F.S.



POOL D — TEST 32 - PV-3 — Q=10,110 C.F.S.



POOL E — TEST 34 - PV-1 — Q=10,020 C.F.S.

FINAL DESIGN

PROTOTYPE SCALE IN FEET
0 10 20 30 40 50 60
0 6 12 18 24 30 36
MODEL SCALE IN INCHES

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLORADO RIVER PROJECT-UCRSP
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY

STILLING POOLS C-1, C-2, D AND E
WITH WATER SURFACE PROFILES

DRAWN: S.T.H. SUBMITTED: [signature]
TRACED: P.P.V., M.R.B. RECOMMENDED:
CHECKED: J.R.D. APPROVED:
DENV. R. COLO., OCT. 4, 1954

FIG. 9

A

B
Q = 9930

POOL C-1

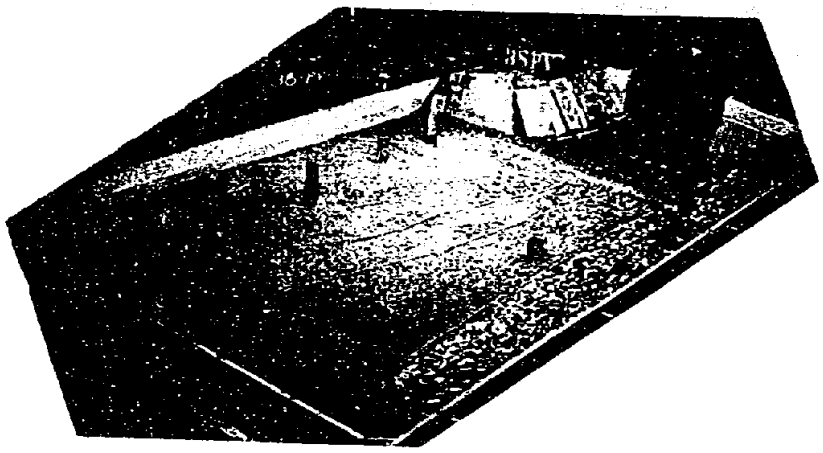
A

B
Q = 9930

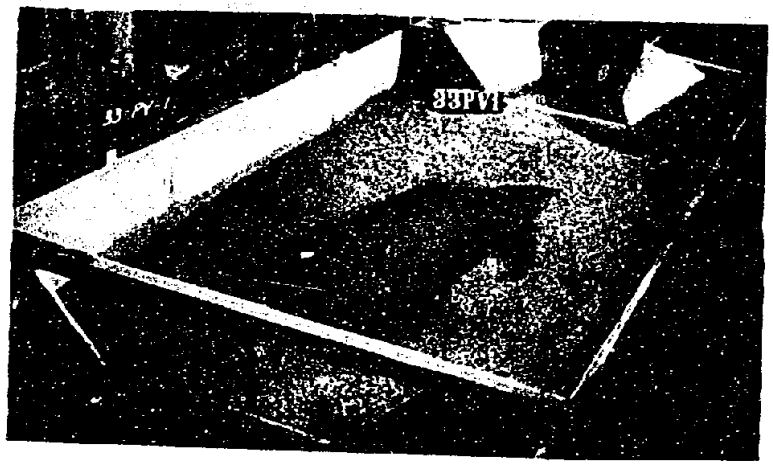
POOL C-2

PLATE VII

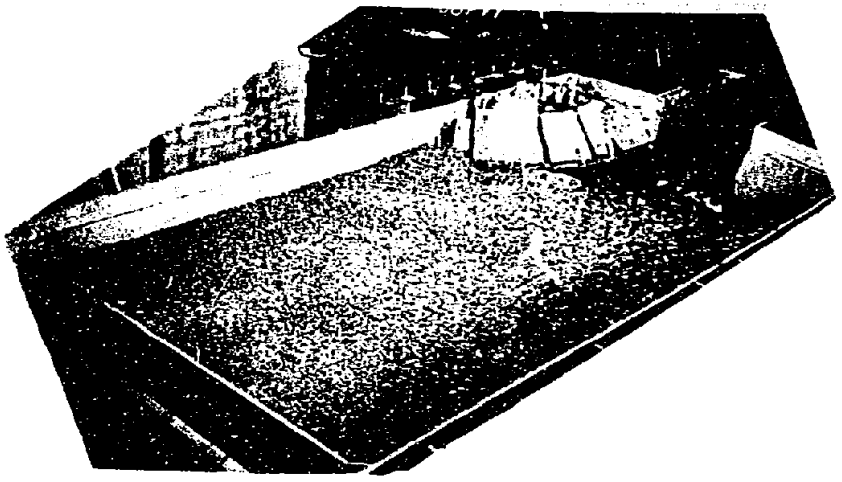
A-Jump Washed Out
Q = 10,000



C-Sand Shaped Like
Existing River Bed



B-Erosion of Sand Bed



D-After Test

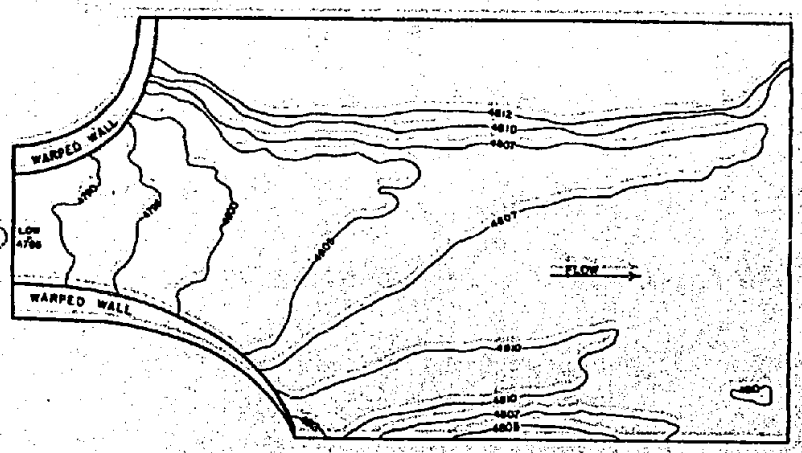
POOL D

PLATE VIII

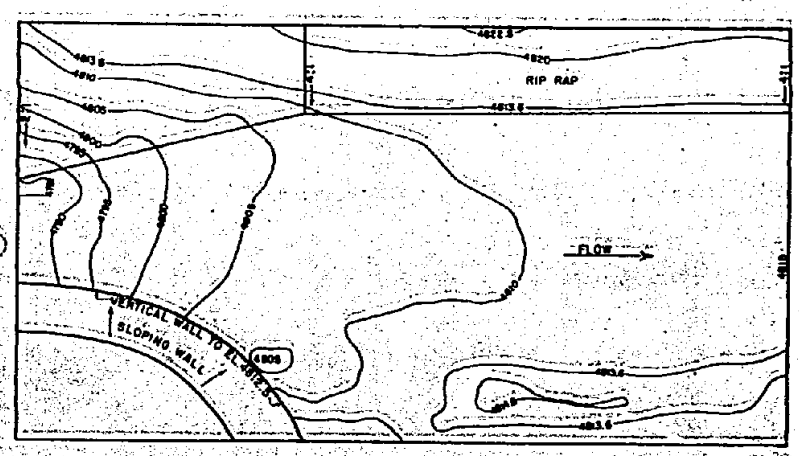
turbulent. Because of the consistently poor tail-race conditions, (high velocities, standing waves, turbulence) with the load-off channel bottom at elevation 4807, it was decided to make future runs with a deeper tailrace (bottom at elevation 4800). Subsequent model tests were made with a load-off channel formed in sand, in order to study the erosion likely to occur. The sand particles varied in size from .1 mm. to 8 or 10 mm. diameter, with a mean value of 3.2 mm. It should be noted that the sand-bin tests do not yield quantitative results, but give only an indication of the nature of the erosion to be expected. Observation of the erosion in the model was facilitated by the use of a large pantograph. With still water in the sand bin and pool, set at a chosen elevation, the edge of the water indicated a contour line. These lines were traced with the pantograph pointer, and a reduced contour map was drawn by the pantograph pencil. In some cases, the contour lines along the sand were also marked with white string and photographed, as in Plate VIII. Pantograph maps are shown in Figure 10.

Pool D

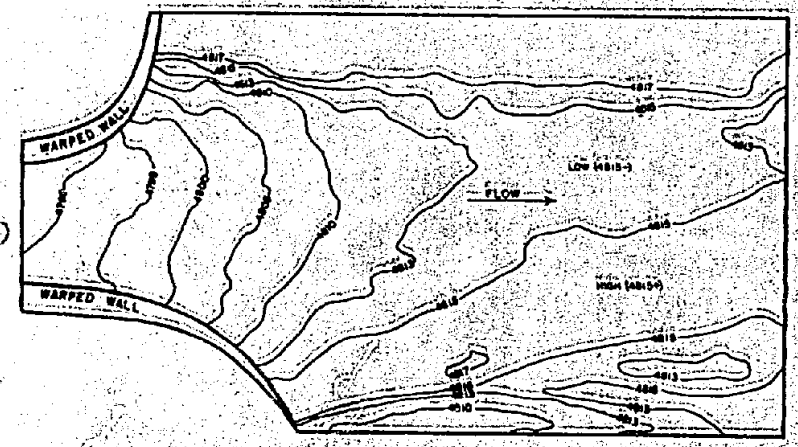
Pool D, (Fig. 9) was very similar to pool B-3 except that it was shorter and the tailway was set at a lower elevation. Several variations of this pool were tested. In practically all of the tests of Pool D, a dentated sill or some variation of it was placed at the downstream end of the pool to minimize the erosion of the sand load-off channel.



TEST 54-PV-1 TIME RUN-2HR. 12 MIN.

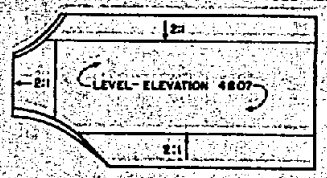


TEST 38-PV-1 TIME RUN-2 HR.

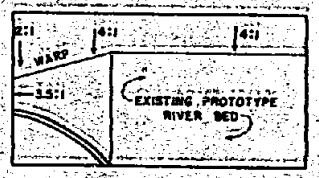


TEST 58-PV-1 TIME RUN-2 HR. 12 MIN.

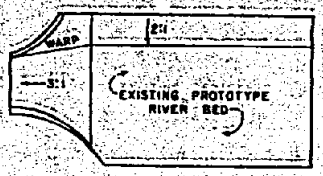
SKETCHES OF TAILWAYS
BEFORE TESTS
SEE ALSO PLATES 8, 9, AND 10



54-PV-1



38-PV-1



58-PV-1

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OWYHEE RIVER PROJECT—UTAH
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY

CONTOURS OF TAILWAYS AFTER TESTS 54, 58, AND 38; TAKEN FROM PANTOGRAPH SHEETS

DRAWN E.C.R. Jr. SUBMITTED
TRACED J.O.K. RECOMMENDED
CHECKED S.B.D. APPROVED

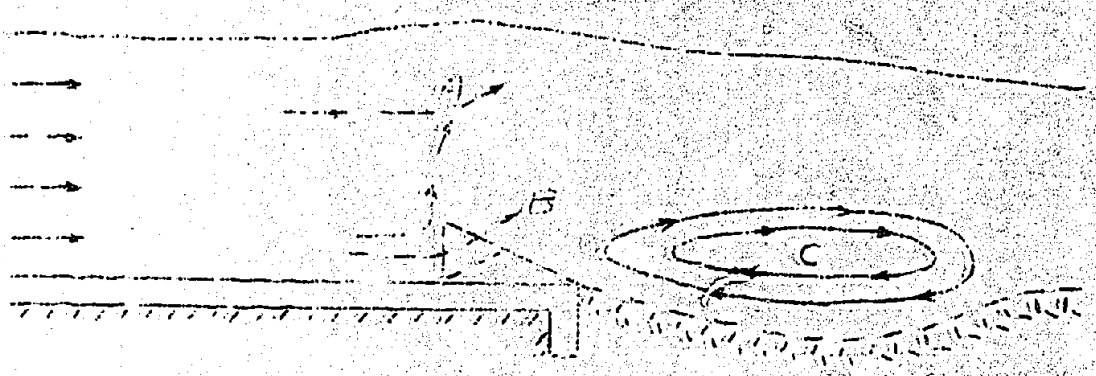
DENVER, COLO. AUG. 4, 1934 | 236-D-133

FIG. 10

Apron. An apron at the upper end of the pool produced a fairly good pool but the erosion below the pool was excessive. No dentated sill was used in this test.

Lead-off Channel. Several tests were made with a deepened lead-off channel immediately below the pool. These layouts were generally satisfactory, but required extra excavation and were therefore abandoned.

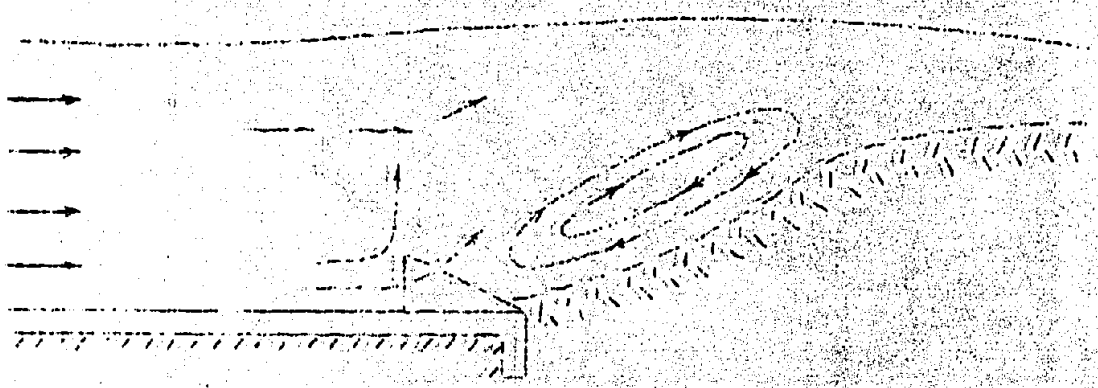
Dentated Sill. Some form of sill is necessary to reduce the dangerous erosion at the end of the stilling pool. One of the commonest forms is the dentated sill devised by Rehbock. This sill is composed of alternate teeth and semi-openings. Its action may best be explained with the help of the following sketch.



The flow near the surface is "lifted" by the water rising from the tooth, as at A, and the flow which goes through the half-openings is deflected upward, as at B. The net effect is to force the most of the downstream velocity up toward the surface of the tailrace and permit or cause the formation of a submerged roller, as C, which

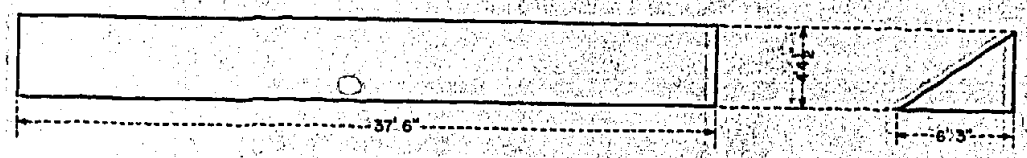
greatly decreases the erosion downstream from the sill. If there is not sufficient space for the roller C to form, the bed will erode, if possible, until enough space for the roller is provided.

If the tailway is higher than the pool floor, as in the case of the Pine View spillway, the condition is slightly different. The space available for a roller is less, and once the flow is

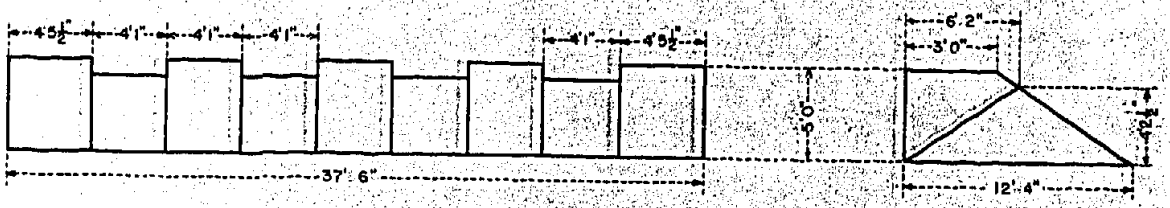


"lifted" to the top of the tailwater, it has to stay there because of the physical layout. In this situation the advantage of the Rehbock sill over other sills of more simple design is not as pronounced as in the case of a horizontal floor. The Rehbock sill was recommended for use in the Pine View pool because of the eventual possibility of a material lowering of the river bed below the spillway.

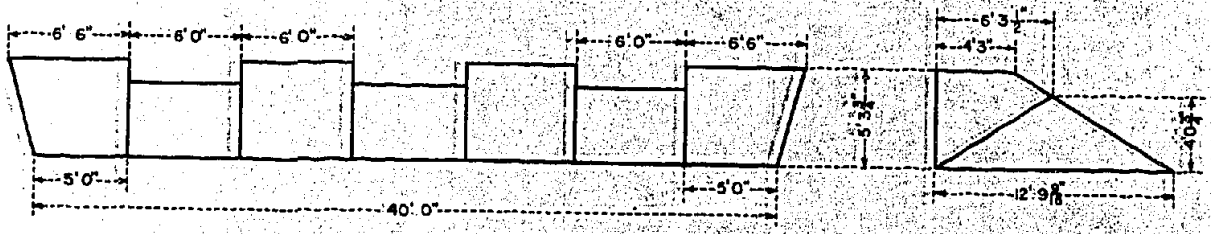
Comparative tests of a Rehbock sill, a diffusion sill, and a modified diffusion sill (Fig. 11) showed very similar erosion in the tailway. The action of all three in minimizing erosion is apparently very much the same. The Rehbock sill was recommended



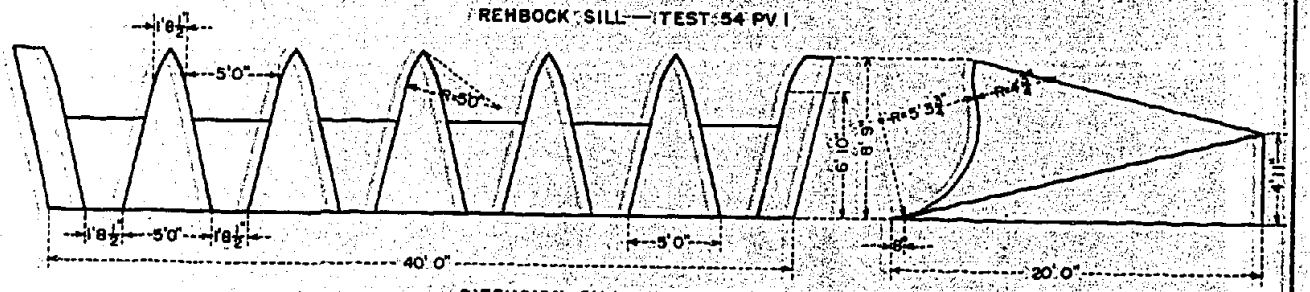
TRIANGULAR SILL — TEST 34 PV I



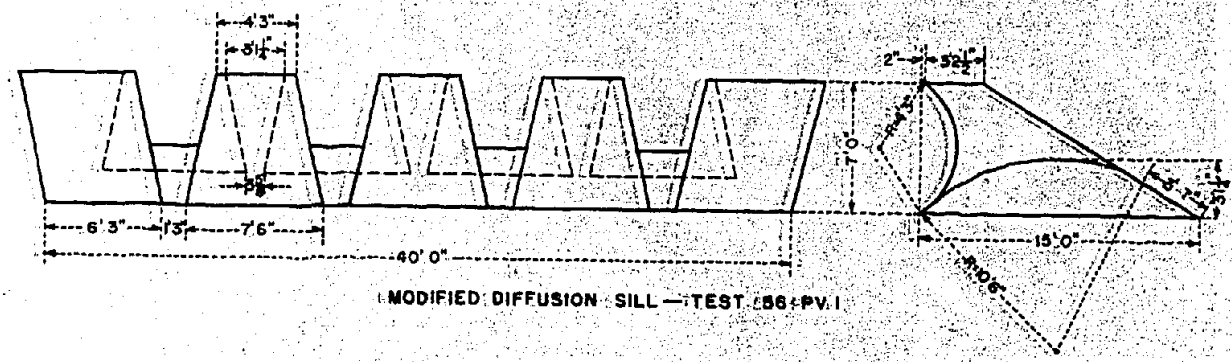
REHBOCK SILL — TEST 35 PV I



REHBOCK SILL — TEST 54 PV I



DIFFUSION SILL — TEST 55 PV I



MODIFIED DIFFUSION SILL — TEST 56 PV I

0 1 2 4 6 8 10 12 14 16 18 20

SCALE IN FEET — PROTOTYPE

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT—UTAH

HYDRAULIC MODEL STUDIES

PINEVIEW SPILLWAY

SILLS USED DURING EXPERIMENTS

DRAWN H.R.S. SUBMITTED John R. Weeks
TRACED H.R.S. J.O.K. RECOMMENDED
CHECKED J.B.D. APPROVED

DENVER, COLO. AUG. 3, 1934 | 236-D-134

FIG. 11

because of its simpler construction and lesser liability to damage.

Sloping Floors. Sloping stilling pool floors, starting from a point on the chute 8 or 10 ft. above the original pool floor, and dropping to the original floor at the downstream end of the pool, were tested. The general effect was a material lowering of the water surface in the pool, coupled with much greater turbulence. The next variation studied was a fillet, or slight break in the slope of the chute, at entrance to the pool. This had very little effect at maximum discharge but produced better conditions at flows less than the maximum, and was recommended for the final design.

Downstream end of pool. The model tests showed clearly the importance of a gradual smooth transition from stilling pool to lead-off channel as shown in plate IX. Sharp corners, angles, or abrupt changes led to the formation of eddies which scoured the material close to the foot of the wall, and would threaten the stability of the structure.

Pool E - Final Design.

The great turbulence which was evident in practically all of the previous layouts led to the change to Pool E, which differs from previous pools in its larger cross-section (Fig. 9 and Plate IX). The break in chute slope at the pool entrance was retained and because of the similarity of this pool to previous pools, tests were made only for the comparison of various toothed sills intended to reduce the scour in the lead-off channel.

It was also found that with the larger dimensions of Pool E

because of its simpler construction and lesser liability to damage.

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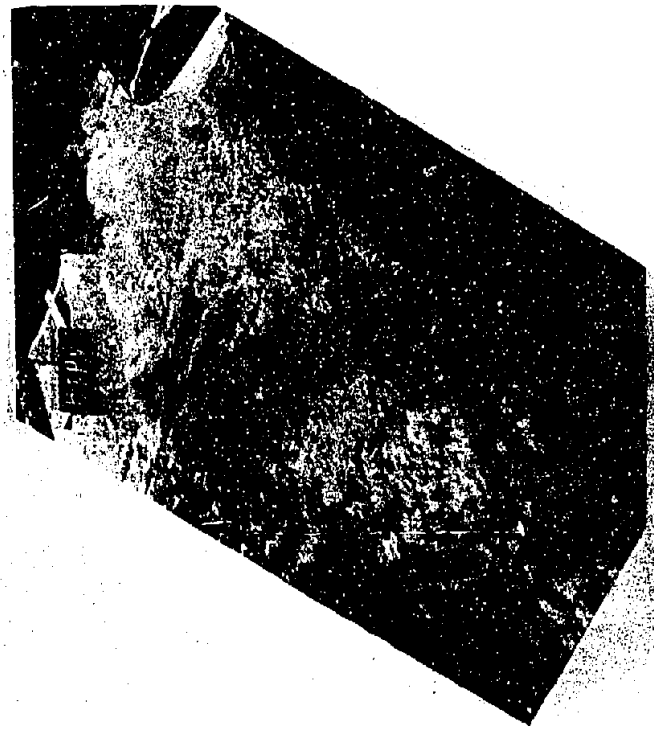
It was also found that with the larger dimensions of Pool E

A-Before Run



B
Q = 10,020

C-After Run

POOL E—FINAL DESIGN

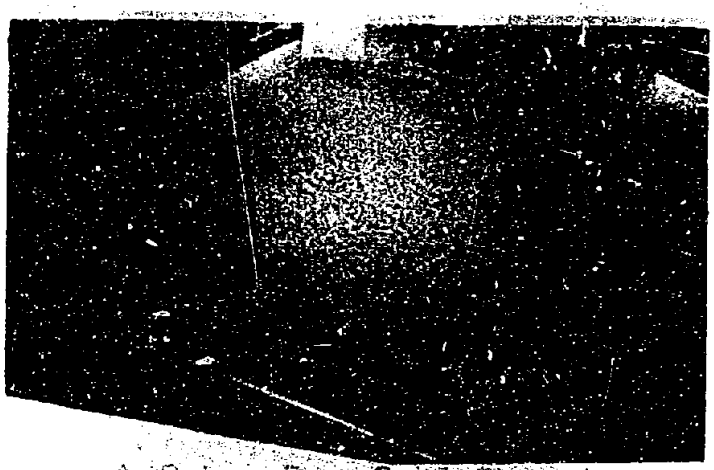
and the gradual flare at its downstream end, the tailway was satisfactory when excavated only down to elevation 4807, as in the original design. One test was made with the sand formed to correspond to the existing topography in nature, i.e. no excavation in the tailway (Plate X). This condition caused a much higher tailwater level, but was otherwise satisfactory. The pool action was much quieter and the splash heights were also less than for a shallower pool.

The final pool design recommended and adopted included a small fillet at the upstream end of the pool and a dentated sill at the downstream end (Fig. 9 and 12). Some sort of gradual flaring transition between pool and tailway is to be included, the details to be worked out in the field at the time of construction, and suited to the terrain.

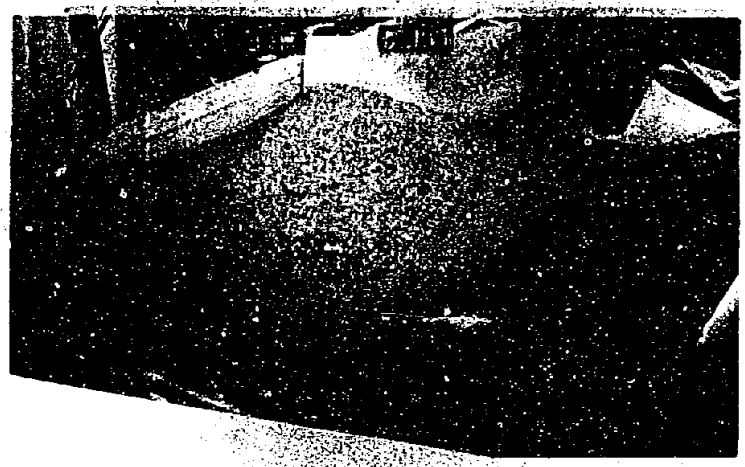
Gate Transition Studies

The original transition below the gates, as previously explained, caused very bad flow conditions in the chute. The slope of the chute was changed and a new transition designed, giving flow conditions which were somewhat better, but still not entirely satisfactory (Fig. 13 and Plate XI), particularly at low flows and uneven gate openings.

Later, as a result of the work done on other spillway models, it was decided to further improve the flow conditions through the transition and down the chute by causing an hydraulic jump to



A-Before Run, Sand Shaped
Like Existing River Bed.



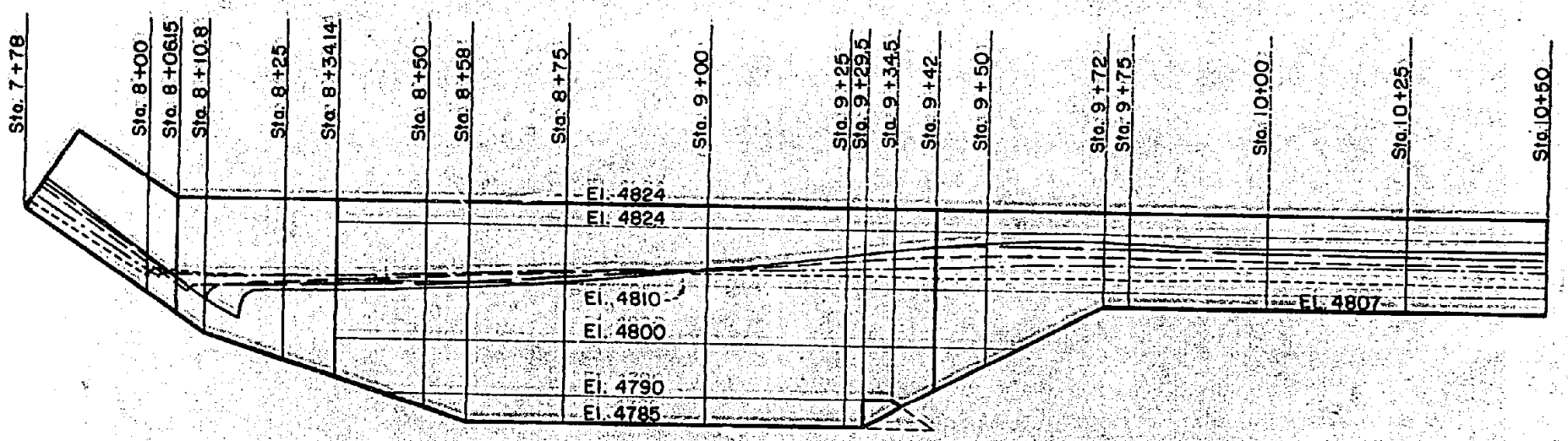
C-After Run

B
Q = 10,000
Note High Tailwater

POOL E-FINAL DESIGN

PLATE X

TEST 54-PV-1 DISCHARGE = 10,000 C.F.S.
TEST 57-PV-1 DISCHARGE = 8,000 C.F.S.
TEST 57-PV-2 DISCHARGE = 6,000 C.F.S.
TEST 57-PV-3 DISCHARGE = 4,000 C.F.S.
TEST 57-PV-4 DISCHARGE = 2,000 C.F.S.



FINAL DESIGN

PROTOTYPE SCALE IN FEET
0 10 20 30 40 50 60
0 6 12 18 24
MODEL SCALE IN INCHES

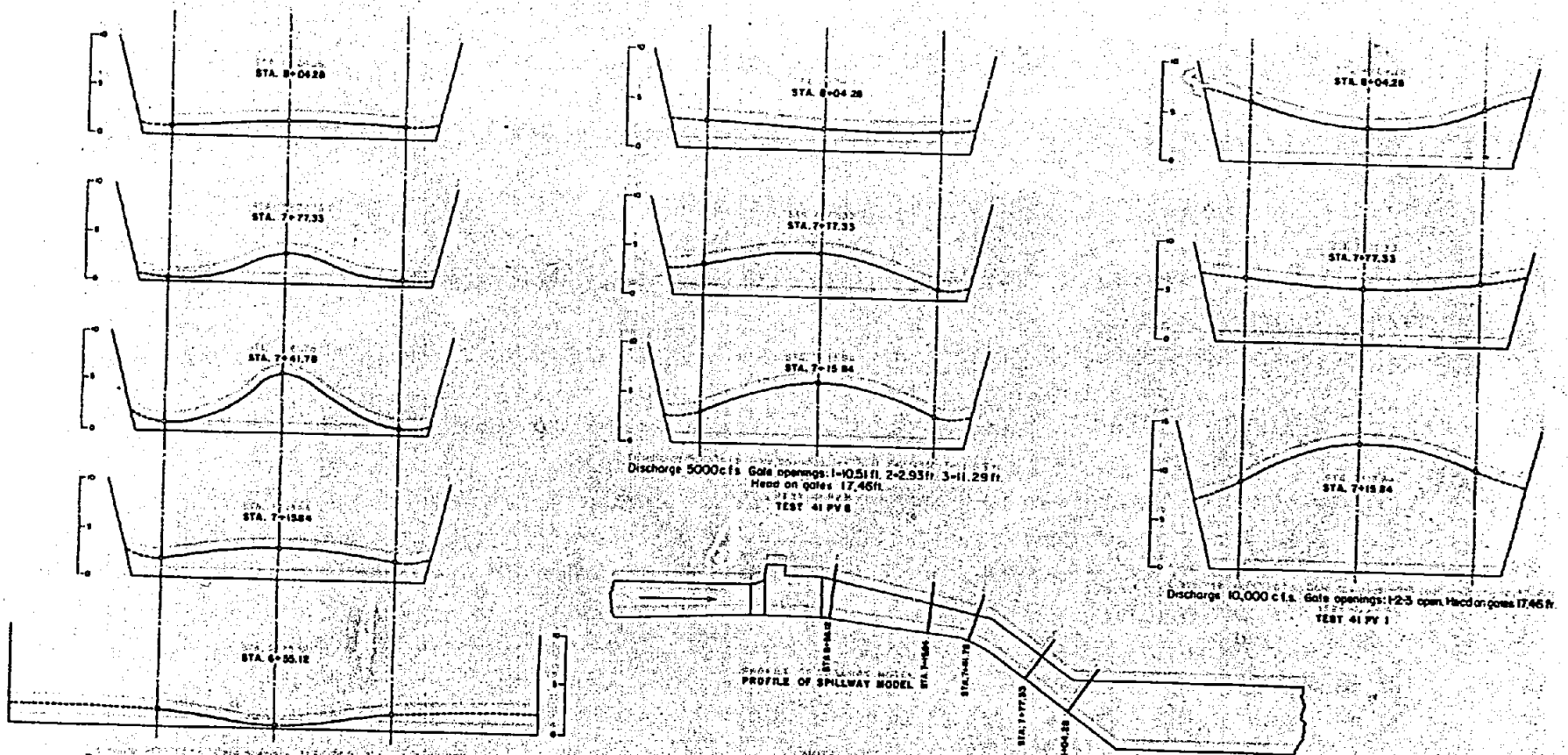
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT-UTAH
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY

WATER SURFACE PROFILES-FINAL DESIGN

DRAWN H.W.B. SUBMITTED John B. Drisko
TRACED O.R.S. RECOMMENDED
CHECKED J.B.D. APPROVED
DENVER, COLO., 7-3-34 236-D-135

FIG. 12



Discharge 2000 c.f.s. Gate openings: 1=3.075ft 2 closed 3=2.975ft.
Head on gates 17.49ft.
TEST 41 PV 8

Discharge 5000 c.f.s. Gate openings: 1=10.51 ft. 2=2.93 ft. 3=11.29 ft.
Head on gates 17.46ft.
TEST 41 PV 8

Discharge 10,000 c.f.s. Gate openings: 1-2-3 open. Head on gates 17.46 ft.
TEST 41 PV 1

NOTE
Scales show feet of depth in prototype measured perpendicular to the channel.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER RIVER PROJECT-UTAH
HYDRAULIC MODEL STUDIES
PINE VIEW SPILLWAY
TRANSVERSE WATER SURFACE PROFILES IN CHUTE AFTER FIRST REVISION

DRAWN E.C.P. SUBMITTED John B. Drisko
TRACED J.P.T. RECOMMENDED
CHECKED J.R.B. APPROVED
JENNER, COLO. AUG. 1, 1934 236-D-136

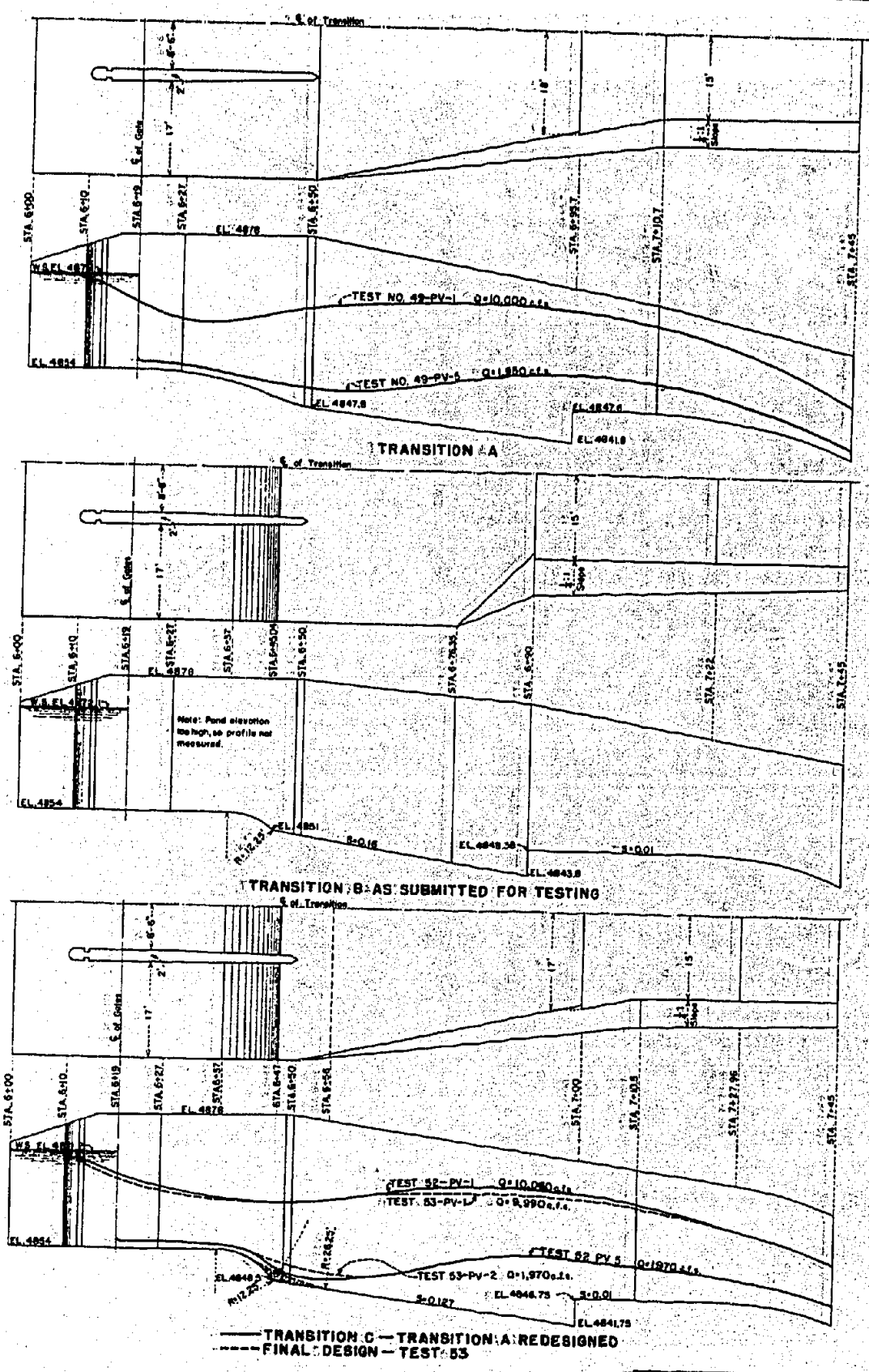
FIG. 13

form immediately below the gates. The model was altered to a design similar to that shown in Fig. 14-A and Plate XI. Tests were made of various transitions, differing in the warped walls, the elevation of the sill or stop-up below the gates and the slope and tilt of the depressed floor.

The design shown in figure 14-A with the stop at station 6+95.7 lowered 3/4 foot, was recommended as a result of the model tests. A slightly different design which was suggested (Fig. 14-B) was also tried, and found to require a greater head on the gates for maximum discharge than previous designs. A modification of the recommended design was submitted for test (Fig. 14-C and Plate XII); the restoration of the reverse curve just below the gates, as originally recommended, (dotted in Fig. 14-C) greatly improved the flow conditions at low discharges (Plate XIII).

The essential requirements for a satisfactory jump below the gates are: that the pool have sufficient length to contain the jump at all flows; that the height of the step, the elevation of the step, and the contraction in cross section are so related and dimensioned as to create a sufficient backwater depth to form a jump at all discharges.

The flow accelerates through critical to shooting velocity in the gate section. It then goes through a jump and flows out of the transition section at streaming (sub-critical) velocity. Then, after entering the final chute section, it accelerates and again passes through critical velocity to shooting flow. The chief losses



TRANSITION C — TRANSITION A REDESIGNED
FINAL DESIGN — TEST 53

PROTOTYPE SCALE IN FEET
0 10 20 30
0 3 6 9 12
MODEL SCALE IN INCHES

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT-UTAH
HYDRAULIC MODEL STUDIES

PINE VIEW SPILLWAY
COMPARISON OF VARIOUS TRANSITION DESIGNS TESTED

DRAWN C.H.M. SUBMITTED John B. Drisko
TRACED J.A.R. J.O.K. RECOMMENDED
CHECKED J.B.D. APPROVED
DENVER, COLO. JUNE 16, 1934 236-D-137

FIG. 14

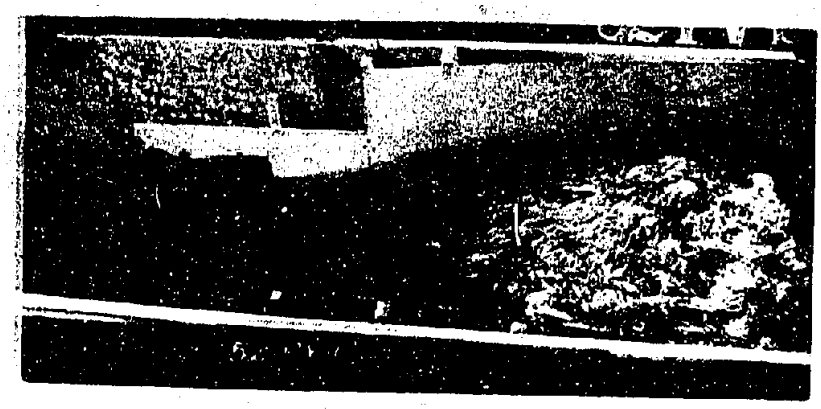
TRANSITION BELOW GATES

A-Headgates and Transition

C
Q=10,000

B-Headgates and Transition

PLATE XI



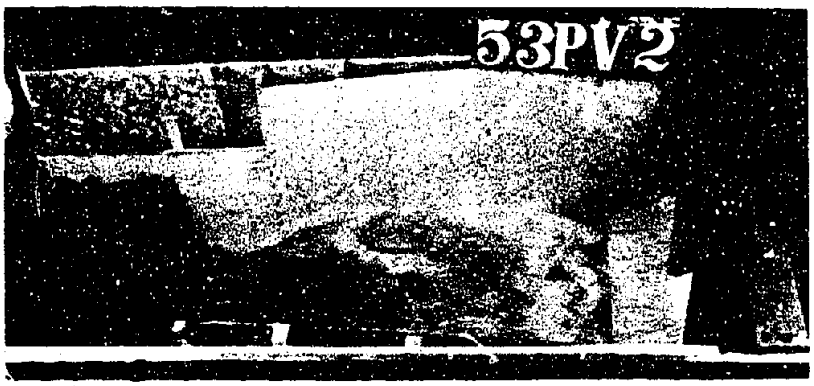
Q = 10,000

Q = 1970
Note irregular flow at
downstream end of piers

TRANSITION C AS SUBMITTED
FOR TEST

PLATE XII

Q = 9990



Q = 1970

FINAL TRANSITION DESIGN

PLATE XIII

from pond level to chute are the loss through the piers, the loss in the jump, and the loss due to change in section in entering the chute.

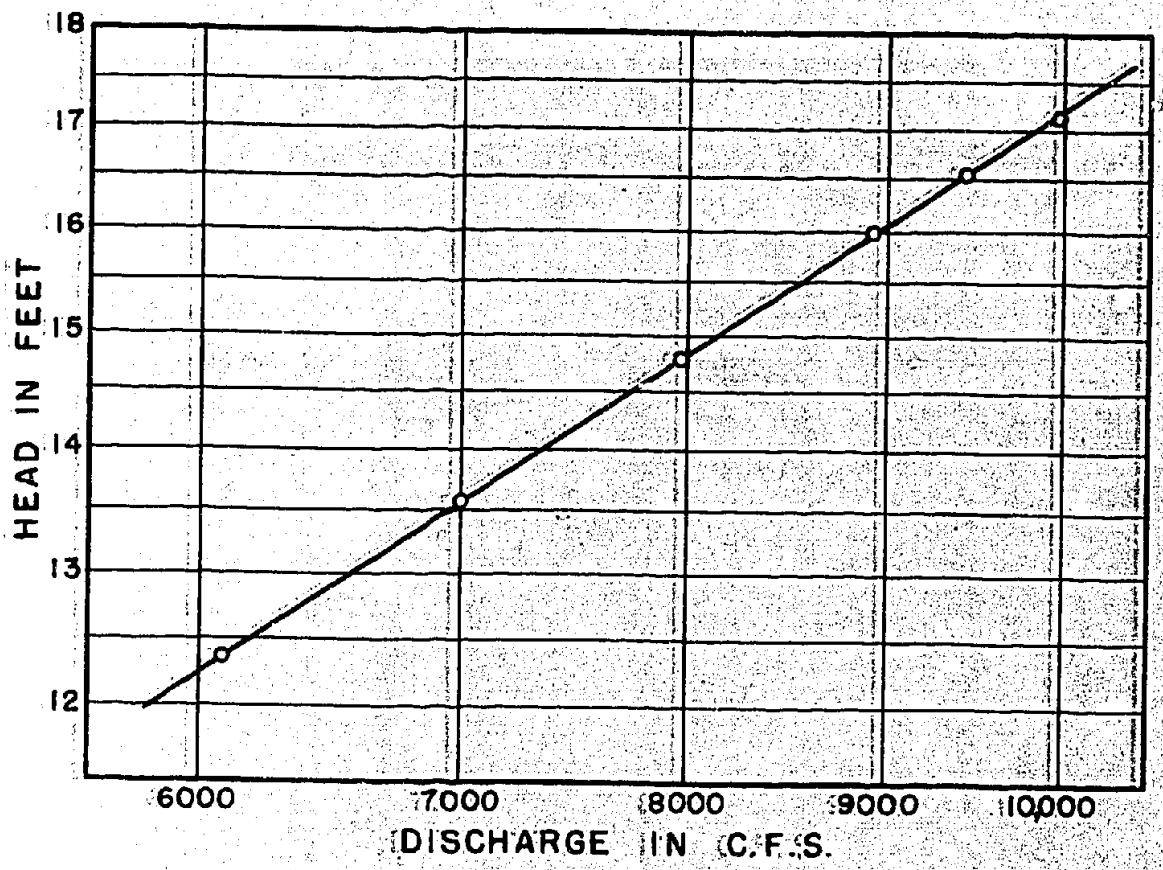
Discharge through gates

Measurements of the discharge through the gate and pier section showed it to be according to the formula $Q = 2.75\ LH^{\frac{3}{2}}$, where L is the net gate opening and H is the height of the pond level above the gate sill. Fig. 15 is a logarithmic plot of head, H, against discharge, Q, for the pier section.

from pond level to chute are the loss through the piers, the loss in the jump, and the loss due to change in section in entering the chute.

Discharge through gates

Measurements of the discharge through the gate and pier section showed it to be according to the formula $Q = 2.75\ LH^{\frac{3}{2}}$, where L is the net gate opening and H is the height of the pond level above the gate sill. Fig. 15 is a logarithmic plot of head, H, against discharge, Q, for the pier section.



$Q = 2.74\,L \cdot H^{1.50}$

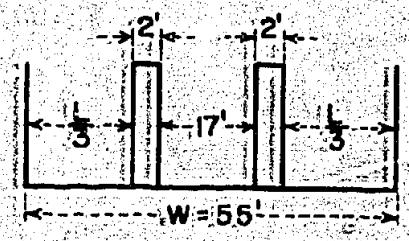
Q = discharge in c.f.s.

L = Net length of pier openings = 51'.

H = Depth of Reservoir over gate sill.

W = Total width of gate section = 55'.

$\frac{L}{W}$ = Percentage opening = .927



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
OGDEN RIVER PROJECT
HYDRAULIC MODEL STUDIES
PINEVIEW SPILLWAY
HEAD DISCHARGE RELATION FOR GATES

DRAWN E.C.P. SUBMITTED John B. Drisko
TRACED J.P.K. RECOMMENDED
CHECKED J.B.D. APPROVED

DENVER, COLO. JUNE 6, 1934 236-D138

FIG. 15

APPENDIX A

LOG OF PINE VIEW TESTS

TEST NUMBER	DISCHARGE	POOL	SETUP	REMARKS
12-PV-1	9910	B-1	Bare pool	Very turbulent; slops over sides.
13-PV-1	9910	B-1	Bare pool. Entrance from Reservoir revised.	Flow more symmetrical down chute than 12-PV-1.
14-PV-1	9910	B-1	Apron H,8.5'; L,16.5'; T,27.'	Standing wave in tailrace.
15-PV-1	10000	B-1	Flat fillet L,16.5';Slope 3:1 (Nomenclature for aprons and fillets: H is height, L is length extending downstream from R.P., T is distance of tangent point upstream from R.P. (measured along slope.)	Tailrace very rough, flow down chute unsymmetrical.
16-PV-1	9950	B-1	Flat apron H,8.5';L,16.5'	Flow very turbulent.
17-PV-1	9960	B-1	Flat apron H,8.5';L,0	Pool very frothy.
18-PV-1	9960	B-2	Bare pool	Water in pool very sloppy.
19-PV-1	9990	B-2	Flat apron H,8.5';L,16'	Water splashes over sides occasionally, standing wave in tailrace.
20-PV-1	9990	B-3	Flat apron H,8.5';L,16.5'	Jump very foamy, tailrace very good compared to previous runs.
20-PV-3	5780	B-3	Same as 20-PV-1)	(Very unstable condition
20-PV-4	7200	B-3	Same as 20-PV-1)	(for those runs; jet rises
20-PV-5	8400	B-3	Same as 20-PV-1)	(to surface of pool.
21-PV-1	9960	B-3	Bare pool	Flow very turbulent, slops over the sides frequently.
22-PV-1	10000	B-3	Flat apron H,6.0';L,16.5'	Flow quite turbulent but better than 21-PV-1.
23-PV-1	9930	B-3	Curved apron H,5.75'; L,3.0'; T,15.5'	Better than any previous run; jump fairly quiet.
24-PV-1	9960	B-3	Curved apron H,4.5'; L,6.25'; T,12.0'	Conditions in pool and tailrace very good; no splash.
25-PV-1	9990	B-3	Curved apron H,7.0'; L,2.0'; T,17.0'	Pool not as quiet as tests 23 & 24 but better than 20; pool too short for height of apron.

APPENDIX A

LOG OF PINE VIEW TESTS

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12-PV-1	9910	B-1	Bare pool	Very turbulent; slops over sides.
13-PV-1	9910	B-1	Bare pool. Entrance from Reservoir revised.	Flow more symmetrical down chute than 12-PV-1.
14-PV-1	9910	B-1	Apron H,8.5'; L,16.5'; T,27.'	Standing wave in tailrace.
15-PV-1	10000	B-1	Flat fillet L,16.5';Slope 3:1 (Nomenclature for aprons and fillets: H is height, L is length extending downstream from R.P., T is distance of tangent point upstream from R.P. (measured along slope.)	Tailrace very rough, flow down chute unsymmetrical.
16-PV-1	9950	B-1	Flat apron H,8.5';L,16.5'	Flow very turbulent.
17-PV-1	9960	B-1	Flat apron H,8.5';L,0	Pool very frothy.
18-PV-1	9960	B-2	Bare pool	Water in pool very sloppy.
19-PV-1	9990	B-2	Flat apron H,8.5';L,16'	Water splashes over sides occasionally, standing wave in tailrace.
20-PV-1	9990	B-3	Flat apron H,8.5';L,16.5'	Jump very foamy, tailrace very good compared to previous runs.
20-PV-3	5780	B-3	Same as 20-PV-1)	(Very unstable condition
20-PV-4	7200	B-3	Same as 20-PV-1)	(for those runs; jet rises
20-PV-5	8400	B-3	Same as 20-PV-1)	(to surface of pool.
21-PV-1	9960	B-3	Bare pool	Flow very turbulent, slops over the sides frequently.
22-PV-1	10000	B-3	Flat apron H,6.0';L,16.5'	Flow quite turbulent but better than 21-PV-1.
23-PV-1	9930	B-3	Curved apron H,5.75'; L,3.0'; T,15.5'	Better than any previous run; jump fairly quiet.
24-PV-1	9960	B-3	Curved apron H,4.5'; L,6.25'; T,12.0'	Conditions in pool and tailrace very good; no splash.
25-PV-1	9990	B-3	Curved apron H,7.0'; L,2.0'; T,17.0'	Pool not as quiet as tests 23 & 24 but better than 20; pool too short for height of apron.

APPENDIX A

LOG OF PINE VIEW TESTS (Cont.)

TEST NUMBER	DISCHARGE	POOL	SETUP	REMARKS
26-PV-1	9900	C-1	Curved apron H,5.75'; L,2.5'; T,17.0'	
27-PV-1	9920	C-1	Curved apron H,5.75'; L,11.75'; T,14.0'	Jump quite rough; spray splashes over sides; flow intermittently unsymmetrical.
28-PV-1	9920	C-1	Curved apron H,4.5'; L,11.5'; T,15.0'	Pool a bit rougher than 27-PV-1.
29-PV-1	9920	C-1	Curved apron H,7.0'; L,10.0'; T,16.0'	Pool very rough and foamy; back currents along the sides.
30-PV-1	9960	C-2	Curved apron H,6.0'; L,12.0'; T,18.0'	Better by observation than any previous run.
31-PV-1	9950	C-3	Same as 30-PV-1 except for tailrace approach.	Pool free of foam; flow solid and symmetrical.
32-PV-3	10110	D	Curved apron H,6.5'; L,12.0'; T,22.0'; Sand El. 4800	Apron too high causing water to be very rough and to splash over sides; pulsating stream leaves the pool.
33-PV-1	10000	D	Same as 32-PV-3	No measurements made. Sand removed to obtain elevation of tailwater at which jump would go out.
34-PV-1	10110	D	Apron same as 32-PV-3 Plain triangular sill at end of pool. Sand El. 4790.	Flow very distorted through transition, piles up on one side, Apron too high, water very foamy and splashes over sides.
34-PV-2	10060	D	Same as 34-PV-1 except for warped wall at end of pool.	Flow looks very good; water splashes over sides a little but is quite smooth at end of tailrace.

APPENDIX A

LOG OF PINE VIEW TESTS (Cont.)

ER	DISCHARGE	POOL	SETUP	REMARKS
-4	9780	D	Same as 39-PV-2.	
-5	9780	D	Same as 39-PV-2 except that sill was removed.	Swift velocities not checked until they hit sand bed. False bottom makes the effective length of the pool less.
-6	5030	D	Same as 39-PV-2.	Jump takes place completely in pool. Water very quiet in tailrace.
-7	2640	D	Same as 39-PV-2.	Jump forms completely in pool. Water very quiet in tailrace. Transition terrible.
-8	9960	D	Same as 39-PV-2 except that false bottom slopes from chute at El.4792 to Sta. 8+99.	Looks better than longer false bottom but not as good as no false bottom at all.
-1	10000		Velocity measurements at lower end of chute.	
-1-10			Determining gate openings for different quantities.	
-1	10000	D	Fillet L,26.0'; slope 3:1. Rehbock sill. Sand same as 38-PV-1.	Sand was washed down quickly, rip-rap moved very little, very little movement of material downstream.
-1	9960	D	Same as 42-PV-1 with fillet removed.	

APPENDIX A

LOG OF PINE VIEW TESTS (Cont.)

TEST NUMBER	DIS-CHARGE	TRANSITION SETUP	REMARKS
44-PV-1		In these runs attempts were made to change the transition at the upper end of the chute so that a jump would be formed just below the gates for all flows.	
45-PV-1, 2,3,4,5, &6.	10000 2000	Abrupt drop at downstream end of piers and long warped change of section.	Approach conditions to gates very bad. Jump stays in for all flows but drop at end of piers to abrupt for low flows.
46-PV-1, 2,3,4, & 5.	10000 2000	Similar to 45-PV-1; drop moved upstream from lower end of piers.	Jump looks quite good for all flows; pool probably a little too long.
47-PV-1, 2,3,4, & 5.	10000 2000	Similar to 46-PV-1; transition composed of warp and smooth curve.	Flow is good but not as good as previous test due to the construction of the transition.
48-PV-1, 2,3,4, & 5.	10000 2000	Similar to 46-PV-1; transition composed of warp and straight part.	Jump all right but rougher for partial flows than full flows.
49-PV-1, 2,3,4, & 5.	10000 2000	Similar to 46-PV-1; straight line transition.	Approach conditions still bad; conditions within the transition about the same as previous tests.
50-PV-1, 2,3,4,5, & 6.	10060 7000	Curved drop upstream from lower end of piers; short pool with vertical sides and short warp.	Tests for pond elevations. Pond elevation too high.
51-PV-1, 2,3,4,5, & 6.	9990 6080	Curved drop as in 50-PV-1; short pool with full length warp.	Tests for pond elevations. Pond elevation all right.
52-PV-1, 2,3,4, & 5.	10060 1970	Same as 51-PV-1.	Approach conditions are still bad; causing unsymmetrical flow; jump at end of piers.
53-PV-1, &2.	9990 1970	Same as 51-PV-1 except ogee drop in place of curved.	Flow slightly unsymmetrical; jump about end of piers.

APPENDIX A

LOG OF PINE VIEW TESTS (Cont.)

TEST NUMBER	DISCHARGE	POOL	SETUP	REMARKS
54-PV-1	10020	E	Flat fillet L,23.0' slope 3:1; Rehbock sill 5' high; sand slopes 2:1 from back of sill to El.4807; curved wall on one side, warped wall on other.	Rip-rap at end of curved wall washed down back of sill; sand slope completely washed out. FINAL DESIGN
55-PV-1	10000	E	Same as 54-PV-1 except diffusion sill used in place of Rehbock sill.	Sand slope washed down immediately; Some rip-rap washed down behind sill.
56-PV-1	10020	E	Same as 54-PV-1 except modified diffusion sill used in place of Rehbock sill.	Looks similar to 55-PV-1.
57-PV-1	8000	E	Same as 54-PV-1.	Water quiet in tailrace; jump good; front of jump frothy and splashy.
57-PV-2	6000	E	Same as 54-PV-1.	Roller type of action in pool; pool fairly rough; tailrace very quiet.
57-PV-3	4000	E	Same as 54-PV-1.	Front of jump still a bit splashy; water in pool practically level; water in tailrace free of air and very quiet.
57-PV-4	2030	E	Same as 54-PV-1.	Jump practically submerged; water in pool and tailrace very quiet; no movement of material.
58-PV-1	10000	E	Same as 54-PV-1 except that existing prototype river bed was shaped in sand bed.	Rip-rap eroded slightly; not much sand erosion. Tailwater held up by high tailway.