5-2-1934

Memorandum to Chief Designing Engineer, Subject: Hydraulic Model Experimnets for the Design of the Hyrum Spillway

J. B. Drisko

W. M. Borland

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL EXPERIMENTS FOR THE DESIGN

OF

THE HYRUM SPILLWAY

J. B. DRISKO, ASSISTANT ENGINEER

and

W. M. BORLAND, JUNIOR ENGINEER

Under direction of

E. W. LANE, RESEARCH ENGINEER

TECHNICAL MEMORANDUM NO. 380

Denver, Colorado

May 2, 1934

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Project

The Hyrum dam is part of the Hyrum project on the Little Bear River, about one mile southwest of Hyrum, Utah. The spillway for this dam, which is designed to pass a maximum flow of 6166 sec. ft., is a gate-controlled open channel, leading from the rim of the reservoir, some 1200 feet north of the dam. (Fig. 1) Three radial (sector or Tainter) gates will admit water into the 1100 foot long, concrete-lined, trapezoidal channel (Fig. 2) which extends some 700 feet at a slight slope and then drops abruptly for a distance of perhaps 240 feet into the stilling pool. The total drop from maximum pond level to stilling pool tailwater is about 90 feet. To insure a safe and economical design of the stilling pool, model studies of the entire spillway were made in the Denver laboratory of the Bureau.

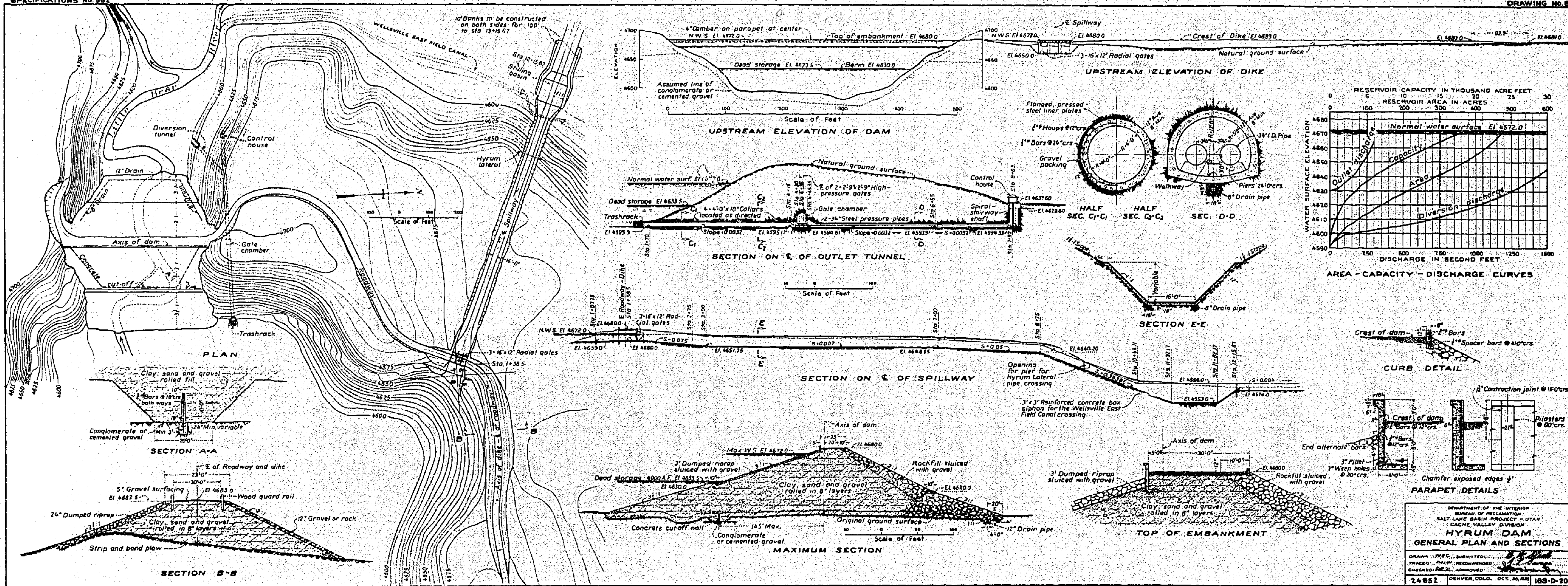
Laboratory

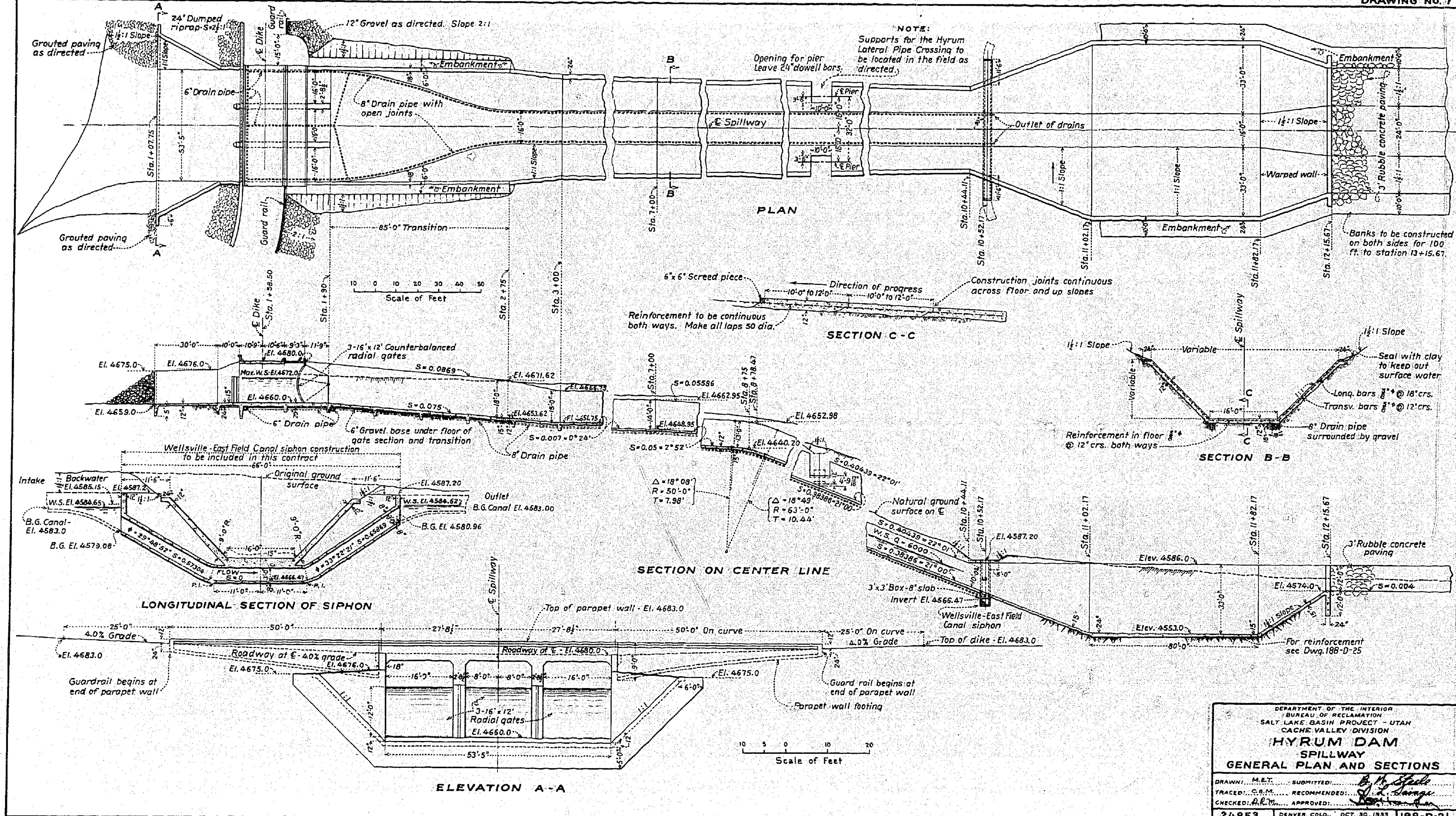
The hydraulic laboratory of the Bureau is in the basement of the Old Custom House, 16th and Arapahoe Streets, Denver (Fig. 3). The water supply system, which recirculates the same water, includes a weir tank with a 90° V-notch weir and a pump sump, set somewhat below floor level, a 6-inch centrifugal pump with a discharge of up to 3.5 second feet, 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.

Fig. 1

SPECIFICATIONS No. 552

DRAWING No. 6




PLAN
SECTION C-C
SECTION B-B
SECTION ON CENTER LINE
LONGITUDINAL SECTION OF SIPHON
ELEVATION A-A
NOTE:
Supports for the Hyrum Lateral Pipe Crossing to be located in the field as directed.
24" Dumped riprap
Grouted paving as directed
12" Gravel as directed. Slope 2:1
Embankment
Guard rail
6" Drain pipe
8" Drain pipe with open joints
85'-0" Transition
Opening for pier Leave 24" dowell bars
℄ Spillway
℄ Pier
Outlet of drains
Warped wall
3' Rubble concrete paving
Banks to be constructed on both sides for 100 ft. to station 13+15.67
Scale of Feet
6"x6" Screed piece
Direction of progress
Construction joints continuous across floor and up slopes
Reinforcement to be continuous both ways. Make all laps 50 dia.
3-16'x12' Counterbalanced radial gates
6" Gravel base under floor of gate section and transition
Seal with clay to keep out surface water
Long. bars @ 18" crs.
Transv. bars @ 12" crs.
Reinforcement in floor @ 12" crs. both ways
8" Drain pipe surrounded by gravel
Wellsville-East Field Canal siphon construction to be included in this contract
Original ground surface
Intake
Backwater
Outlet
B.G. Canal El. 4583.00
Natural ground surface on ℄
3'x3' Box-8" slab
Invert El. 4566.47
Wellsville-East Field Canal siphon
For reinforcement see Dwg. 188-D-25
Top of parapet wall - El. 4683.0
4.0% Grade
Roadway at ℄ - 4.0% grade
Roadway at ℄ - El. 4680.0
50'-0" On curve
25'-0" On curve
Top of dike - El. 4683.0
Guardrail begins at end of parapet wall
Guard rail begins at end of parapet wall
Parapet wall footing
3-16'x12' Radial gates
El. 4660.0
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SALT LAKE BASIN PROJECT - UTAH
CACHE VALLEY DIVISION
HYRUM DAM
SPILLWAY
GENERAL PLAN AND SECTIONS
DRAWN: M.E.T.
TRACED: C.B.M.
CHECKED: D.R.M.
SUBMITTED:
RECOMMENDED:
APPROVED:
24853
DENVER, COLO., OCT. 30, 1933
188-D-21

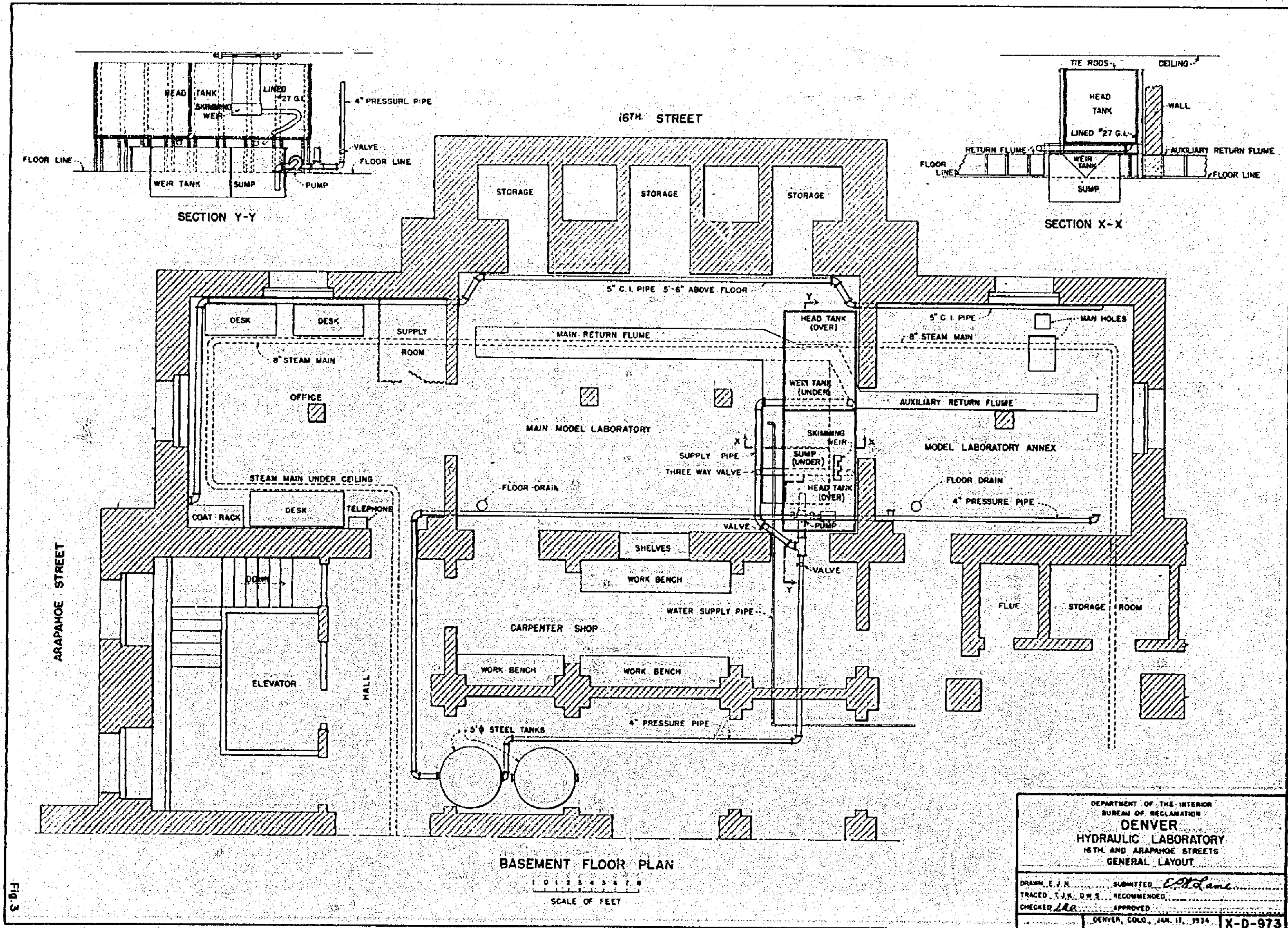

SECTION Y-Y
HEAD TANK
SKIMMING WEIR
LINED #27 G.I.
4" PRESSURE PIPE
VALVE
FLOOR LINE
FLOOR LINE
WEIR TANK
SUMP
PUMP
16TH. STREET
SECTION X-X
TIE RODS
CEILING
HEAD TANK
LINED #27 G.I.
WALL
RETURN FLUME
AUXILIARY RETURN FLUME
FLOOR LINE
FLOOR LINE
WEIR TANK
SUMP
STORAGE
STORAGE
STORAGE
5" C.I. PIPE 5'-6" ABOVE FLOOR
DESK
DESK
SUPPLY ROOM
8" STEAM MAIN
OFFICE
MAIN RETURN FLUME
MAIN MODEL LABORATORY
HEAD TANK (OVER)
WEIR TANK (UNDER)
SKIMMING WEIR
SUMP (UNDER)
HEAD TANK (OVER)
PUMP
5" C.I. PIPE
8" STEAM MAIN
MAN HOLES
AUXILIARY RETURN FLUME
MODEL LABORATORY ANNEX
SUPPLY PIPE
THREE WAY VALVE
STEAM MAIN UNDER CEILING
FLOOR DRAIN
FLOOR DRAIN
4" PRESSURE PIPE
COAT RACK
DESK
TELEPHONE
VALVE
VALVE
SHELVES
WORK BENCH
WATER SUPPLY PIPE
CARPENTER SHOP
WORK BENCH
WORK BENCH
FLUE
STORAGE ROOM
ARAPAHOE STREET
DOWN
ELEVATOR
HALL
4" PRESSURE PIPE
5'Ø STEEL TANKS
BASEMENT FLOOR PLAN
0 1 2 3 4 5 6 7 8
SCALE OF FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER
HYDRAULIC LABORATORY
16TH. AND ARAPAHOE STREETS
GENERAL LAYOUT
DRAWN E.J.N.
SUBMITTED
TRACED T.J.K. D.W.S.
RECOMMENDED
CHECKED
APPROVED
DENVER, COLO., JAN. 11, 1934
X-D-973

Fig.3

The proximity of the laboratory to the offices of the Bureau made it convenient for members of the design staff to visit the laboratory frequently during the model testing, and to see their various ideas tried out "on the spot." The impromptu research thus afforded proved very helpful and many of the ideas inspired have been incorporated in later designs.

Model

The Hyrum model was built at a scale of 1 to 48 and included the complete spillway from the headgates down to a point below the stilling pool (Fig. 4 and Plate I). The gate structure and transition were made of unlined wood, and the channel and stilling pool were lined with sheet metal. The slope of the model was increased slightly over that of the prototype design in order to produce velocities at the pool entrance corresponding to those in nature. The value of Kutter's "n" used for the prototype was n = .014 in the transition and n = .010 in the channel; in the model n = .010 was used throughout. Measurements of the upper portion of the model channel where the slope is slight gave a value of "n" varying from .0091 to .0108 (see appendix A). The velocities at entrance to the pool in the model checked within 1 to 2 per cent of the calculated velocities for the prototype. Longitudinal profiles of the water surface are shown in Figure 5.

Stilling Pool Tests

Comparative tests were run on various devices and layouts

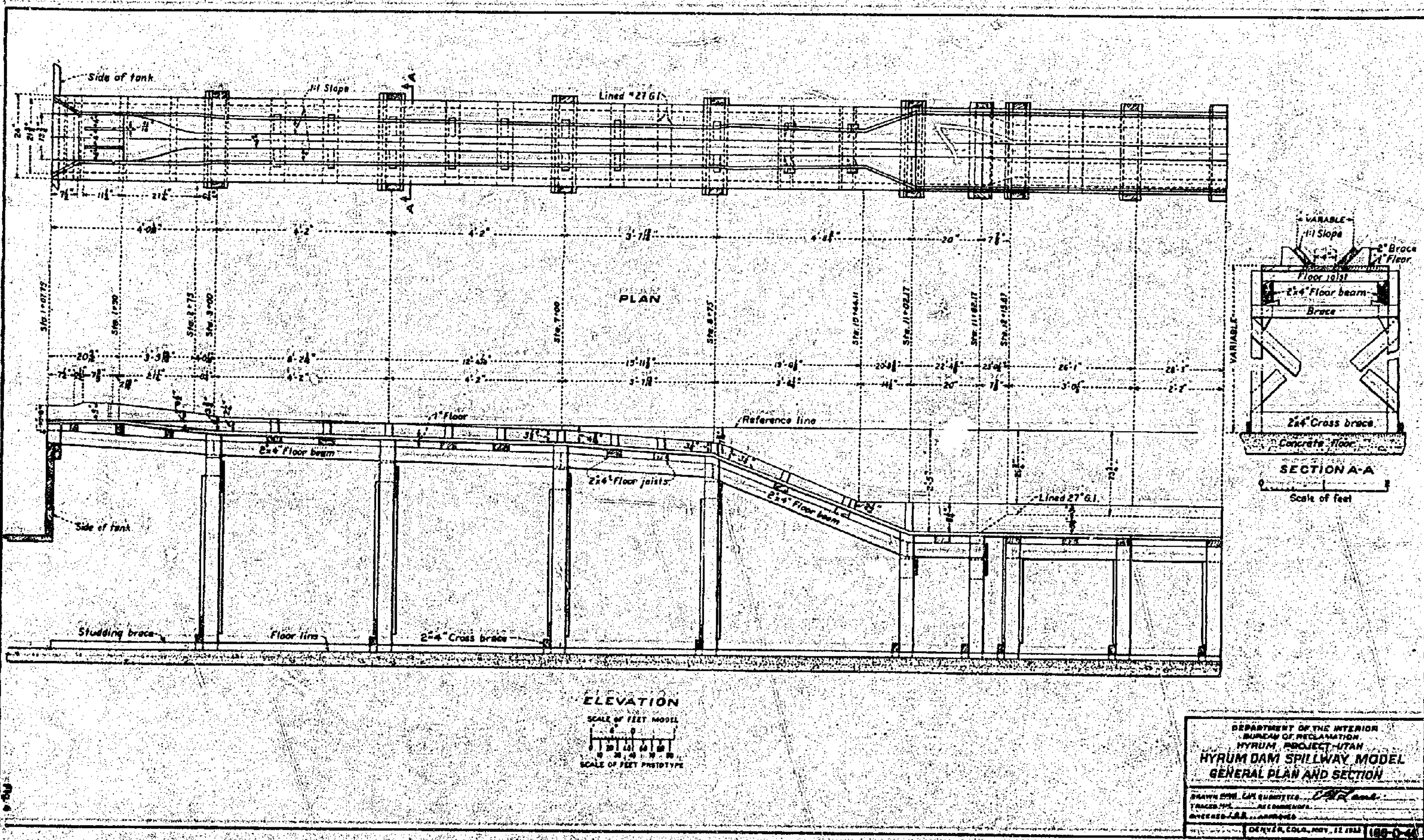
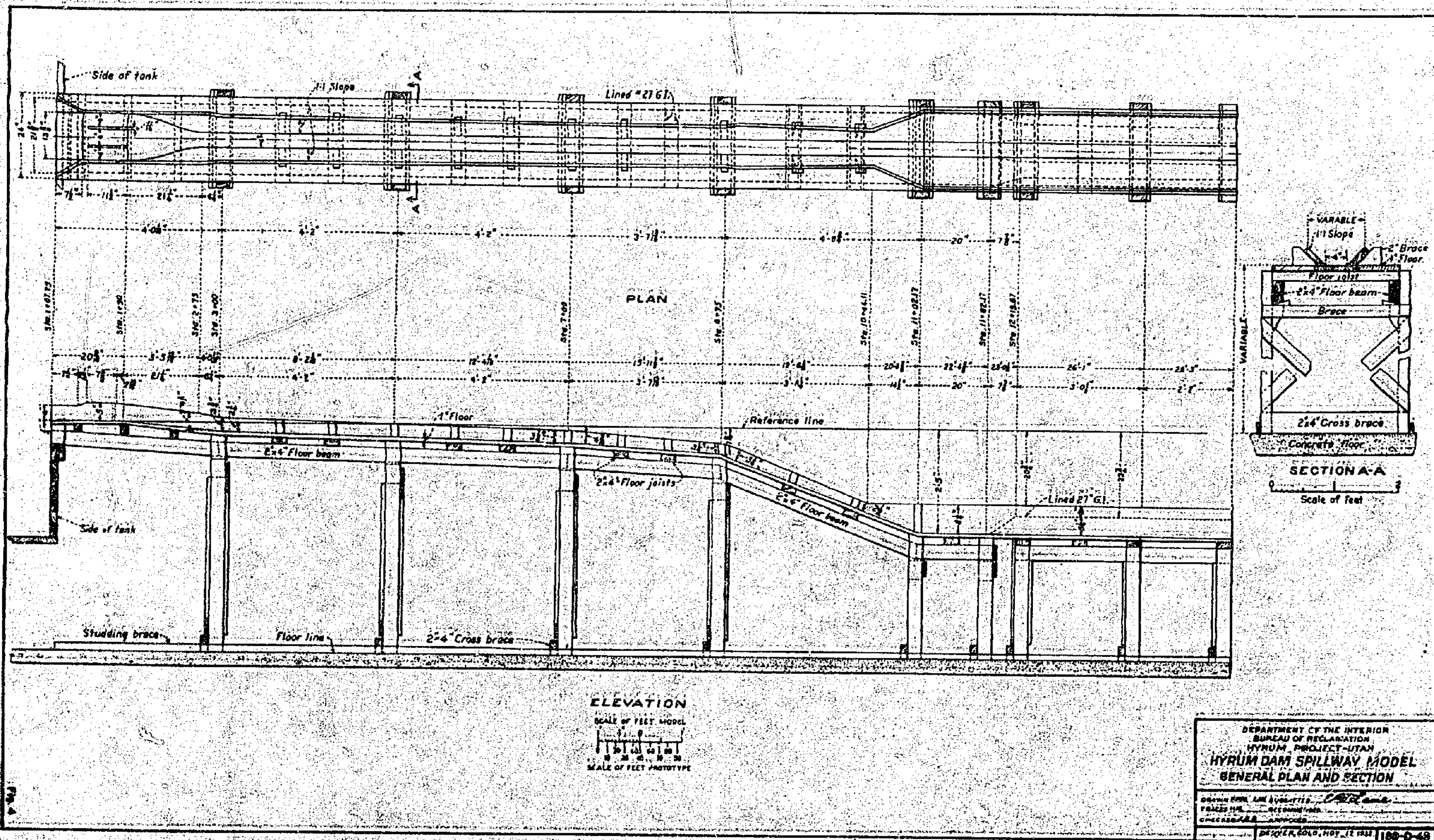
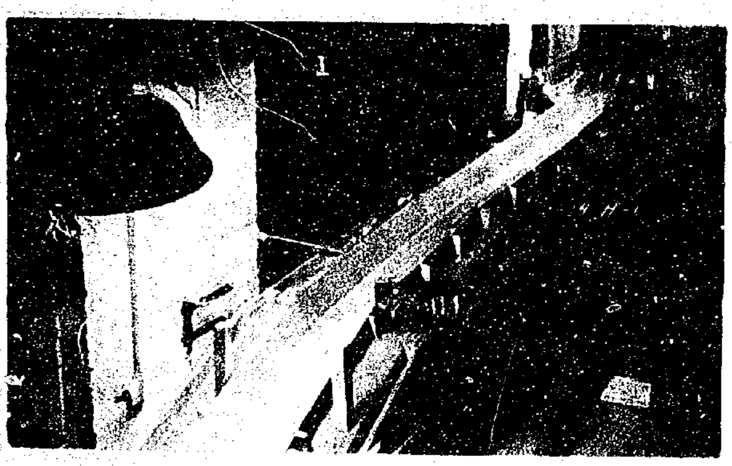

Side of tank
1:1 Slope
Lined #27 G.I.
PLAN
Sta. 1+07.79
Sta. 1+30
Sta. 2+75
Sta. 3+00
Sta. 7+00
Sta. 8+75
Sta. 10+44.11
Sta. 11+02.17
Sta. 11+82.17
Sta. 12+15.67
1" Floor
Reference line
2x4" Floor beam
2x4" Floor joists
Lined 27" G.I.
Studding brace
Floor line
2x4" Cross brace
ELEVATION
SCALE OF FEET MODEL
SCALE OF FEET PROTOTYPE
VARIABLE
2" Brace
1" Floor
Floor joist
2x4" Floor beam
Brace
2x4" Cross brace
Concrete floor
SECTION A-A
Scale of feet
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT-UTAH
HYRUM DAM SPILLWAY MODEL
GENERAL PLAN AND SECTION
DENVER, COLO., MAY 12 1933
168-D-46

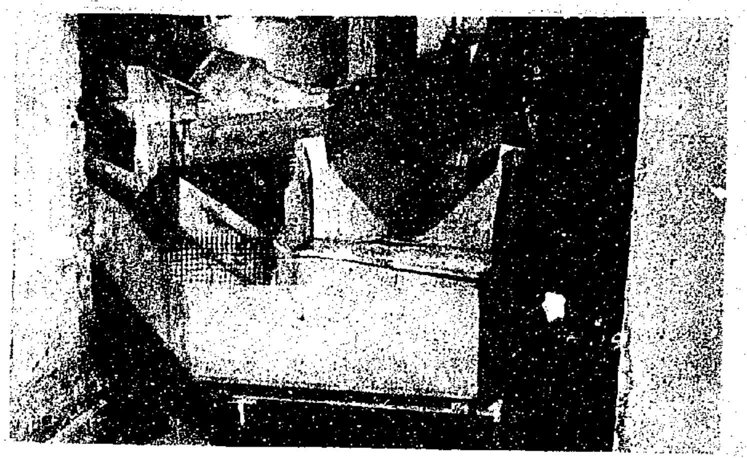
Fig. 4


Side of tank
1:1 Slope
Lined #27 G.I.
A
PLAN
Sta. 7+00
Sta. 8+75
Sta. 10+4.11
Sta. 11+02.17
Sta. 11+82.17
Sta. 12+19.87
1" Floor
Reference line
2"x4" Floor beam
2"x4" Floor joists
Lined 27 G.I.
Side of tank
Studding brace
Floor line
2"x4" Cross brace
ELEVATION
SCALE OF FEET MODEL
SCALE OF FEET PROTOTYPE
VARIABLE
1:1 Slope
2" Brace
1" Floor
Floor joist
2"x4" Floor beam
Brace
2"x4" Cross brace
Concrete floor
SECTION A-A
Scale of feet
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT-UTAH
HYRUM DAM SPILLWAY MODEL
GENERAL PLAN AND SECTION
DENVER, COLO.
188-D-48
Fig. 4

General View of Model



Upper End of Channel



Lower End of Model

PLATE I

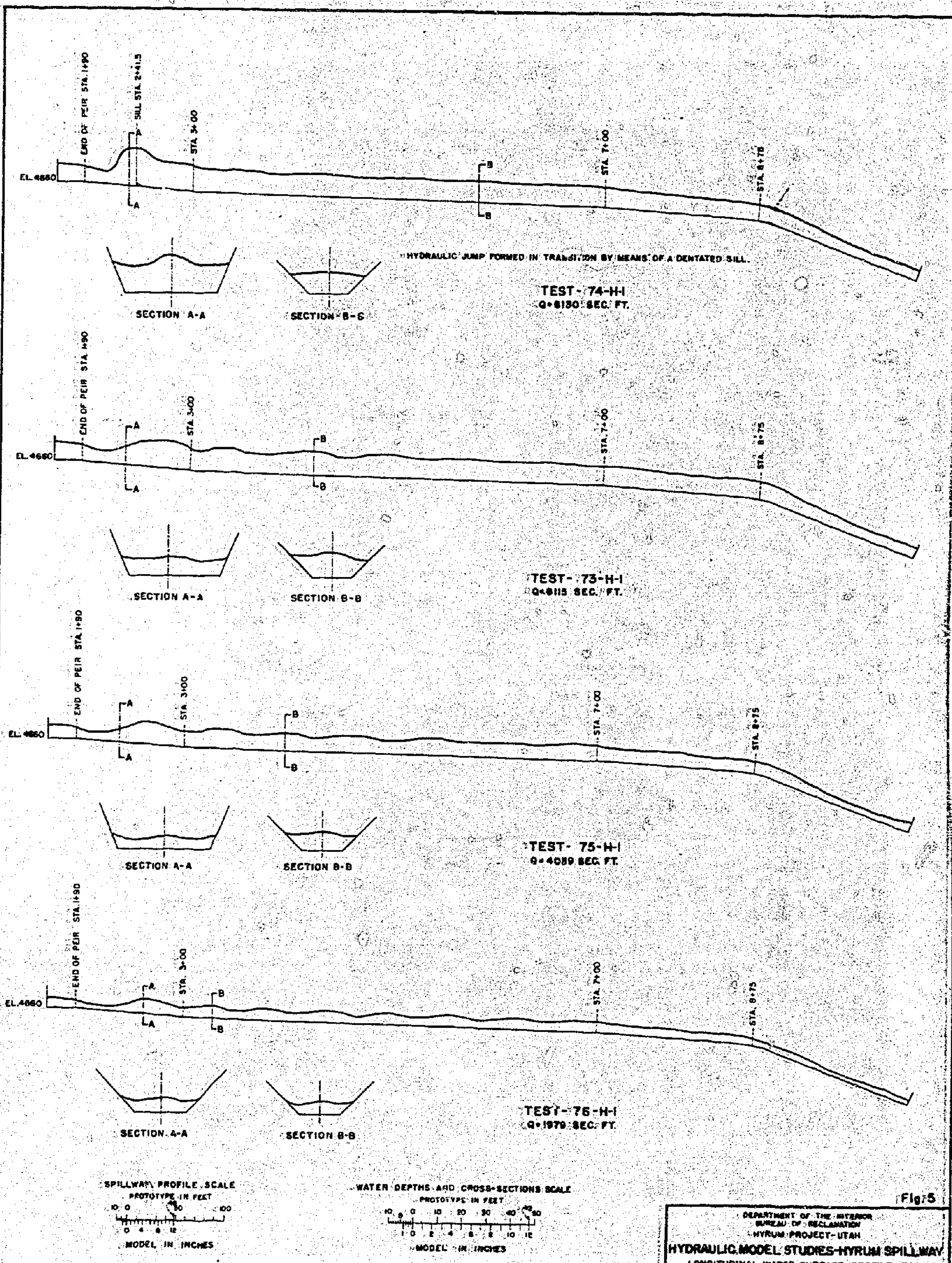


Fig. 5

NOTE

Profiles taken along Center Line of Spillway.
Sections A-A are Worst Conditions in Transition.
Sections B-B are Worst Conditions below Transition.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT - UTAH

HYDRAULIC MODEL STUDIES - HYRUM SPILLWAY

LONGITUDINAL WATER SURFACE PROFILE FOR VARIOUS DISCHARGES - ORIGINAL SPILLWAY DESIGN

DRAWN D.C.W. SUBMITTED
TRACED A.G.R. RECOMMENDED
CHECKED L.E.P. APPROVED

DENVER, COLO. 168-D-82

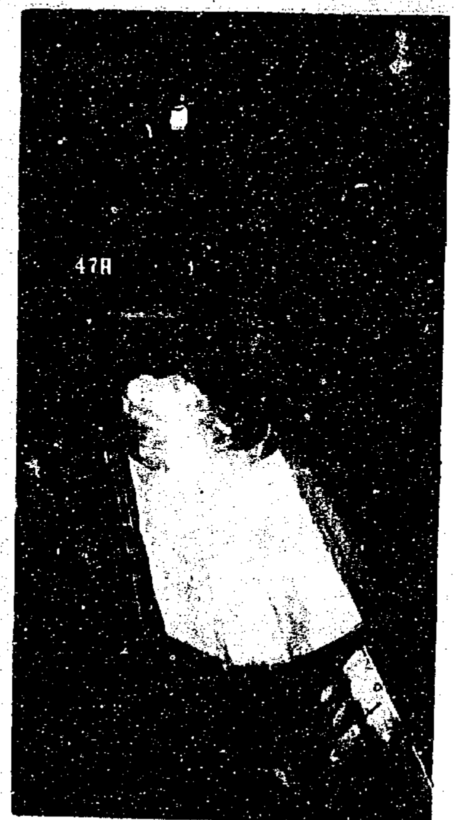
intended to improve the action of the stilling pool, as well as on the pool as originally designed. In general, these tests included measurements of the discharge, the head on the entrance gates, the water surface profile in the stilling pool, and (indirectly) the velocity at entrance to and exit from the pool. All comparative tests were run at a discharge corresponding to the maximum expected flood discharge of 6166 second feet in nature. Measurements were made on the final design of pool at two partial discharges.

During the period of testing the model, two shifts were on duty, each consisting of one junior engineer and two laborers.

The various devices and designs tested may be divided into five general classes: baffle piers and dentated sills, stepped aprons delivering the water horizontally into the pool at some depth above the floor, various lengths of stilling pool, various sizes and elevations of the lead-off channel, and various modifications of the rising slope at the downstream end of the pool.

The original pool design (Plate II and Figure 6) produced an incomplete jump which was both unstable and unsatisfactory. A flow slightly in excess of the maximum discharge was sufficient to wash the jump out of the pool; the stream traveled through the pool with sensibly undiminished velocity, rode up the slope at the far end of the pool and shot up into the air, describing the well-known "perfect parabola"; and striking the lead-off flume at a distance downstream.

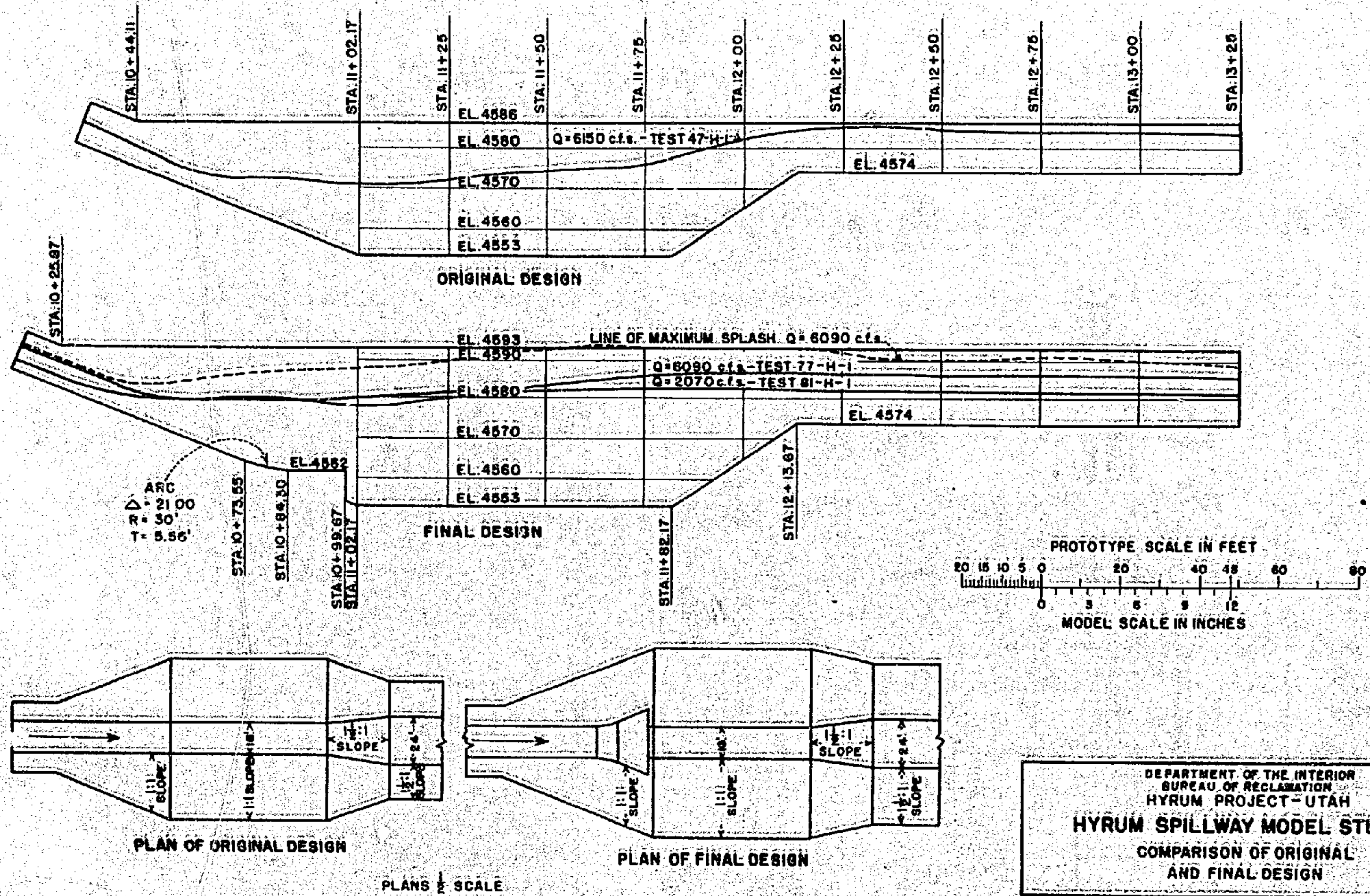
A-Original Design of Pool with Splash Wall Added



B-Original Pool at Maximum Flow
Q = 6150 c. f. s.

C-Jump Swept Out of Pool

PLATE II



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT - UTAH

HYRUM SPILLWAY MODEL STUDIES

COMPARISON OF ORIGINAL AND FINAL DESIGN

DRAWN C.H.M. SUBMITTED E.M. Lane
TRACED E.E.B. RECOMMENDED
CHECKED J.B.B. APPROVED
DENVER, COLO. FEB. 27, 1934 188-D-51

Fig. 6

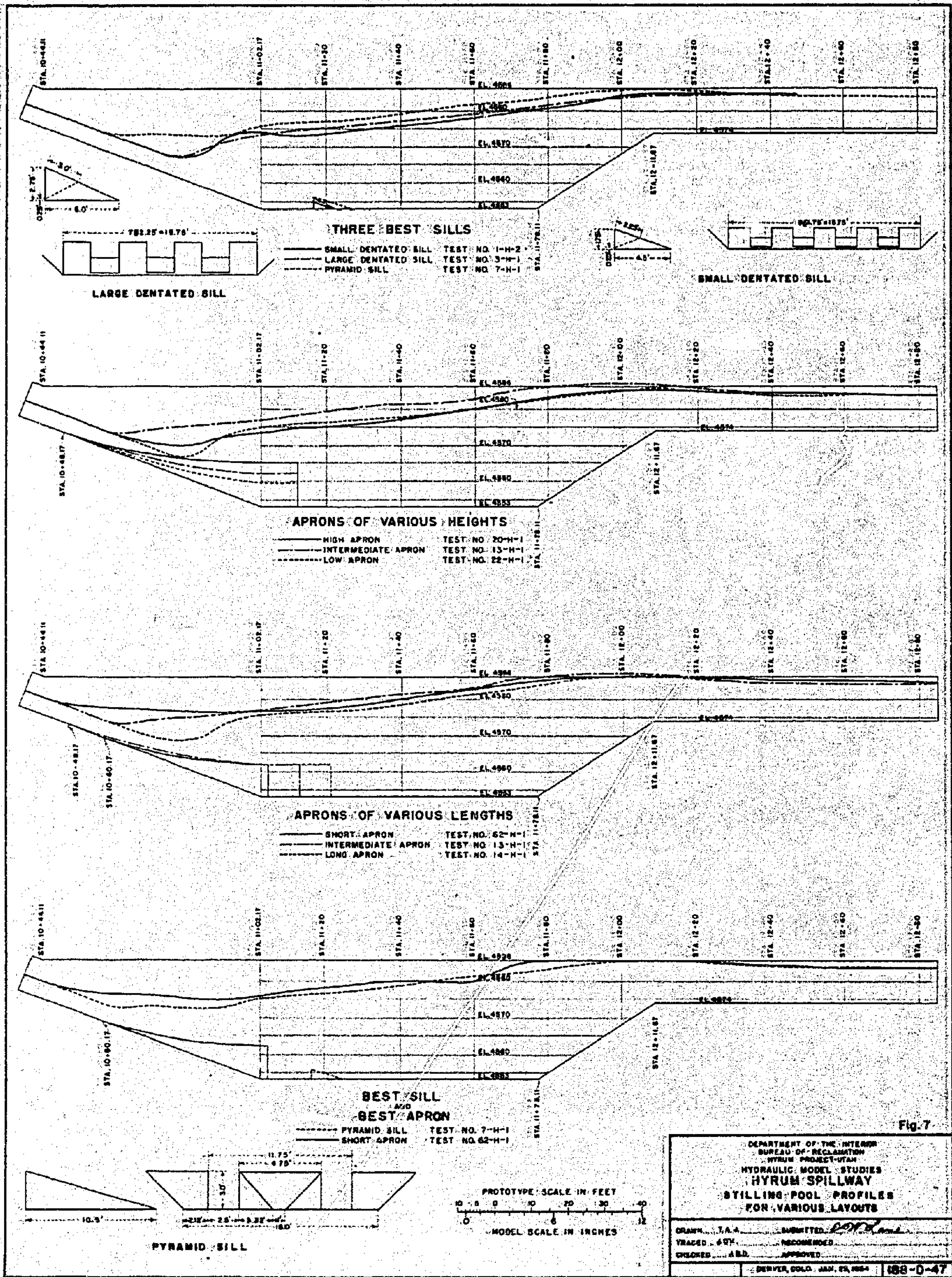
With the jump forming in the pool, the water surface was very turbulent, and a large amount of kinetic energy was left in the flow leaving the pool, which was at a velocity greater than critical.

The side walls of the pool and of the canal below the pool as originally designed were not high enough to hold the water at a depth sufficient to accelerate the water into the canal, when a jump was formed in the pool, much less to prevent the turbulent waters from slopping over.

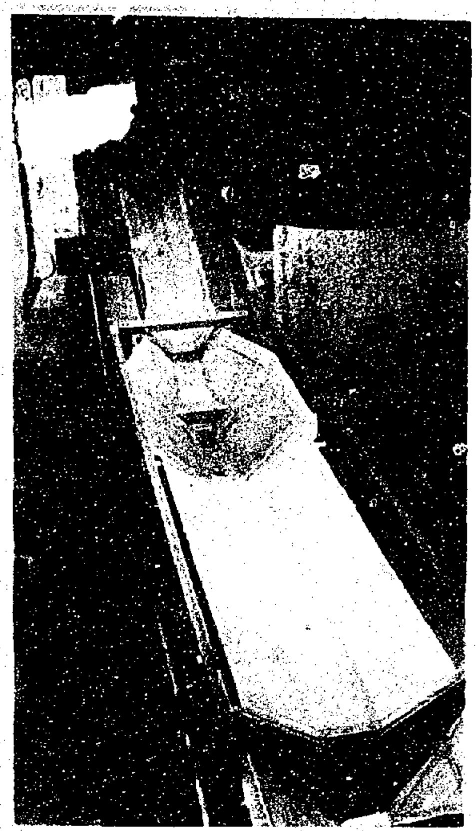
The model tests indicated a modification of the original design which will insure the formation of a complete jump at the maximum flow, and furnished data regarding the height of splash along the sides of the pool and canal.

Numerous types of baffle piers and dentated sills were tried. Baffle piers (Figure 7) placed on the floor of the pool, just below the entrance, were in some cases effective in maintaining the jump in the pool. The jump, however, was not complete, the water surface in the pool was low, and the velocities at exit were high, indicating that some of the kinetic energy of the entering stream was retained through the jump into the discharge.

The most effective design, without greatly altering the pool, was an apron (Figures 6 and 7, and Plate III) which delivered the entering stream horizontally into the pool. This type of device produced the best jump, the highest water surface in the pool, the quietest conditions, and left a minimum of kinetic energy



THREE BEST SILLS
SMALL DENTATED SILL TEST NO. 1-H-2
LARGE DENTATED SILL TEST NO. 3-H-1
PYRAMID SILL TEST NO. 7-H-1
LARGE DENTATED SILL
SMALL DENTATED SILL
APRONS OF VARIOUS HEIGHTS
HIGH APRON TEST NO. 20-H-1
INTERMEDIATE APRON TEST NO. 13-H-1
LOW APRON TEST NO. 22-H-1
APRONS OF VARIOUS LENGTHS
SHORT APRON TEST NO. 62-H-1
INTERMEDIATE APRON TEST NO. 13-H-1
LONG APRON TEST NO. 14-H-1
BEST SILL AND BEST APRON
PYRAMID SILL TEST NO. 7-H-1
SHORT APRON TEST NO. 62-H-1
PYRAMID SILL
PROTOTYPE SCALE IN FEET
MODEL SCALE IN INCHES
Fig. 7
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT-UTAH
HYDRAULIC MODEL STUDIES
HYRUM SPILLWAY
STILLING POOL PROFILES
FOR VARIOUS LAYOUTS
DENVER, COLO. JAN. 29, 1934
188-D-47



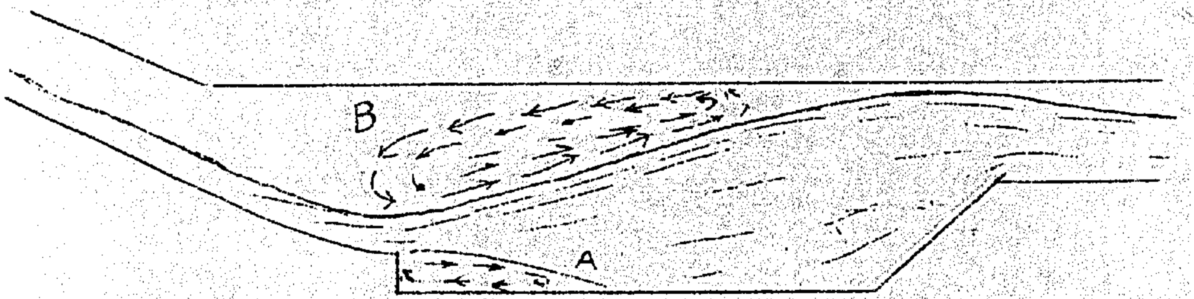
A - Final Design of Stilling Pool

B - Final Design at Maximum Flow
Q = 6090 c. f. s.

PLATE III

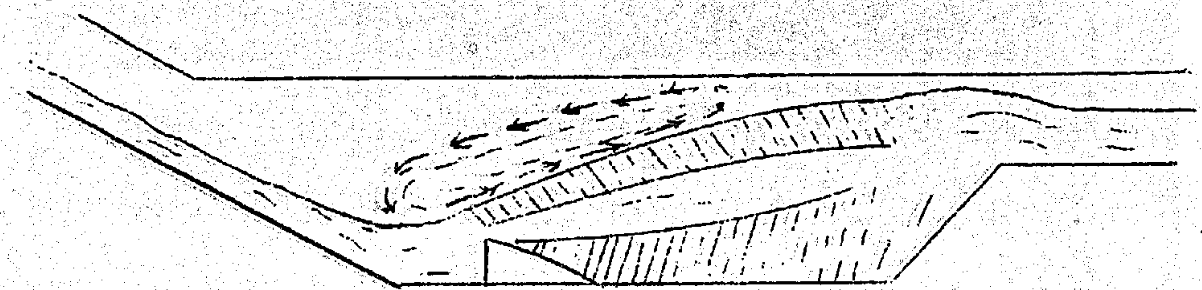
in the stream at exit from the pool. Various heights and lengths of apron were compared, and the most effective selected.

The effective action of the apron is most easily explained by the accompanying sketch.



The entering stream, in being deflected to a horizontal direction, is spread laterally to a greater width and lesser thickness, which greatly facilitates the energy dissipation. With an apron nine feet higher than the pool floor, the stream is more than doubled in width. It then shoots off of the step, and gradually expands to fill the depth of the pool. The step makes it possible for a submerged roller A to form beneath the jet, in addition to the surface roller B. Rollers are very effective in removing energy from flowing water.

The lesser effectiveness of the dentated sills may be similarily explained. The incoming stream is broken into two ragged portions, as shown.

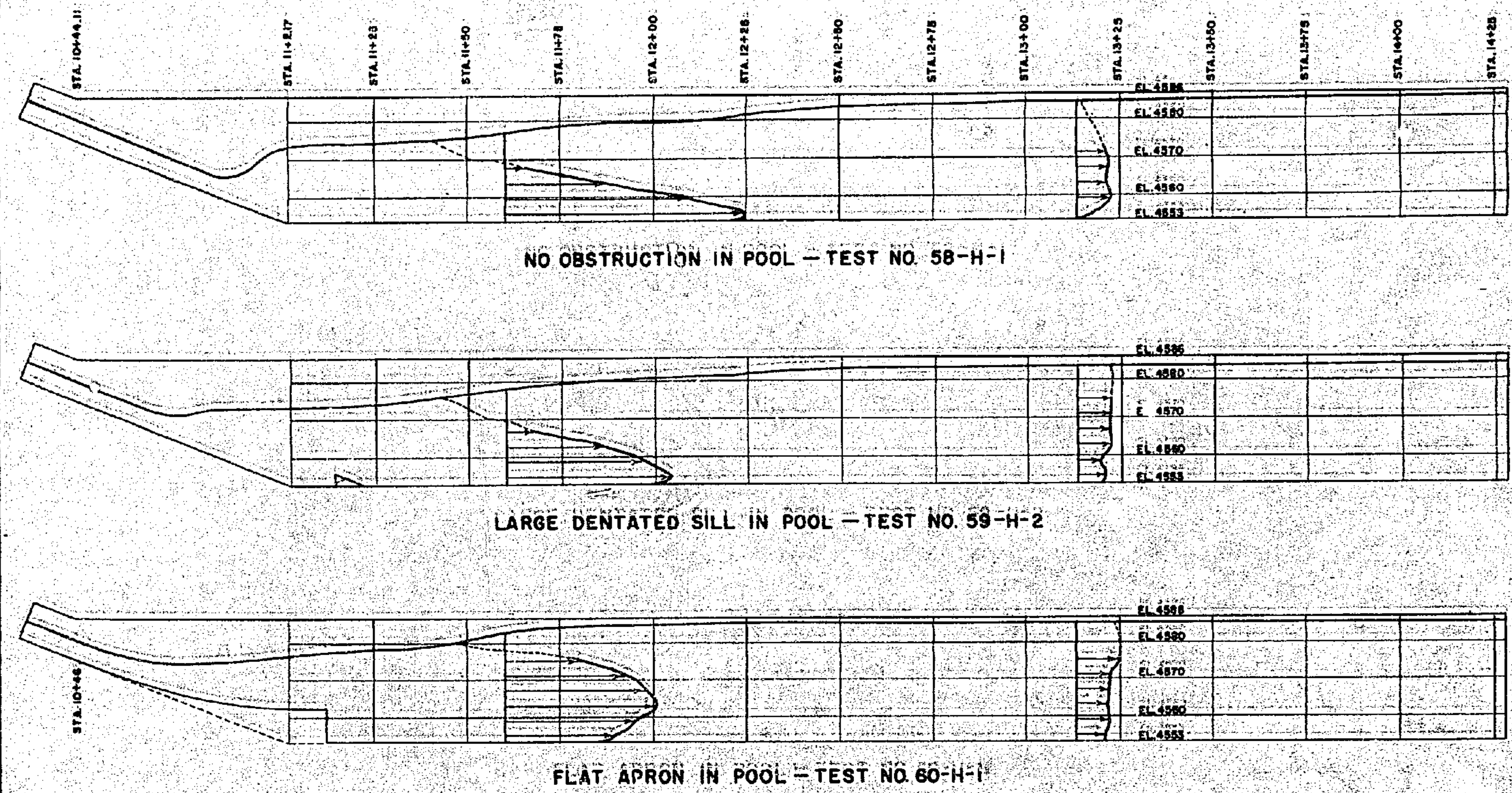


The upper portion supports a surface roller; the lower portion, however, carries on through the pool, and flushes out the region behind the sill, thus preventing the formation of a submerged or bottom roller. The only energy loss (in addition to the surface roller) is the friction and eddy loss around the teeth of the sill, which is not nearly as large as the loss in the submerged roller formed below the apron of the previous sketch.

For comparison three runs were made with the pool extended full depth for a length much greater than required for the complete formation of a jump. (Figure 8) One set-up was the bare pool, one included the best apron, and one contained the best sill, as found from previous tests. It will be seen from the figure that the apron yields a much more satisfactory velocity distribution than either of the other layouts. The advantage of the apron may be more clearly understood if it is remembered that the pool is wider nearer the top, and that the amount of water flowing per unit depth, is greater near the top of the pool, for equal velocities.

With various aprons installed, tests were run with varying elevations of the pool floor downstream from the apron. These tests showed that any decrease in the depth of pool seriously lessened its effectiveness.

Various sizes and bottom elevations of lead-off channel were tried, with little or no success. In general, a larger lead-off channel with lower velocities requires a greater length of pool.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT—UTAH

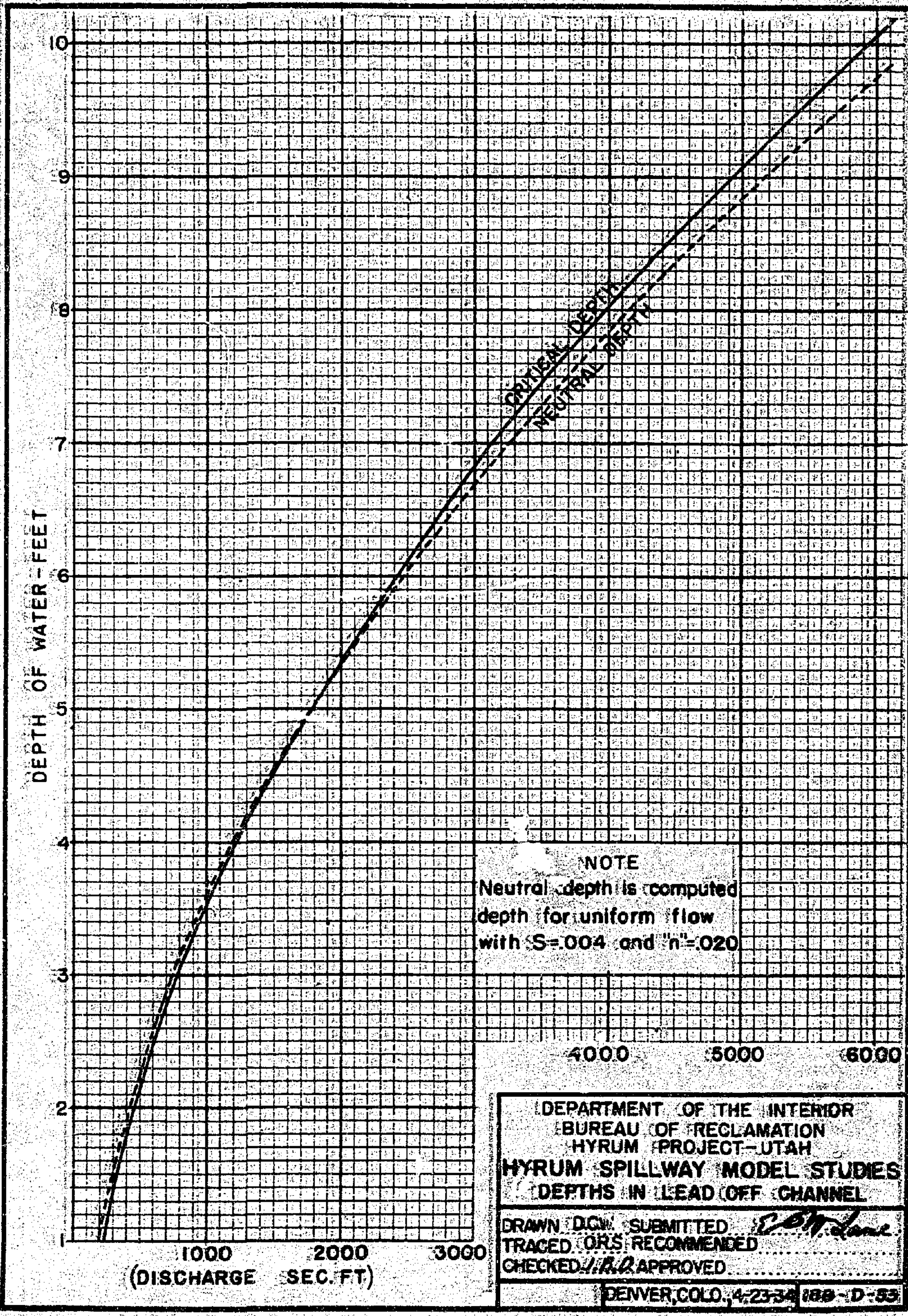
HYRUM SPILLWAY MODEL STUDIES

HYDRAULIC JUMP AND VELOCITY DISTRIBUTION AS AFFECTED BY LAYOUT

DRAWN C.H.H.	SUBMITTED E.W. Lane
TRACED J.O.K.	RECOMMENDED
CHECKED J.E.D.	APPROVED
DENVER, COLO. JAN. 26, 1934	188-D-45

Fig. 8

An interesting feature came to light in comparing the action of various devices. The partially complete jumps resulted in a high velocity and low stage at exit from the pool; the water was "shot" into the lead-off channel at velocities greater than critical. The complete jump brought about a higher stage and lower velocity at the pool exit. The water surface then dropped (along the axis of the lead-off channel), in order to accelerate the slow-moving water to its higher final velocity in the lead-off channel. It should be noted that except at very low flows the entrance to the lead-off channel is a control which maintains the depth in the stilling pool. It is essential that this control be maintained, in order to insure a tailwater depth sufficient for the formation of a jump in the pool. Figure 9 gives a curve of critical depths in the lead-off channel for various flows. The second curve shows the depth of uniform flow in the lead-off channel for a value of "n" = .020. If the channel is rougher than assumed this curve will be higher and the channel, or its outlet, will act as control. The data originally supplied gave a tailwater depth of 6 feet for maximum flow of 6166 second feet, a depth much lower than can actually occur. Because the pool outlet acted as a control to maintain the depth in the pool, all tests were run this way. Should the river level rise, downstream, and produce a greater depth in the lead-off channel than shown in Figure 9, the freeboard in the pool will be less, but the jump will be quieter and the splash will be less.



DEPTH OF WATER - FEET
1
2
3
4
5
6
7
8
9
10
1000
2000
3000
4000
5000
6000
(DISCHARGE SEC. FT.)
CRITICAL DEPTH
NEUTRAL DEPTH
NOTE
Neutral depth is computed depth for uniform flow with S=.004 and "n"=.020
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT-UTAH
HYRUM SPILLWAY MODEL STUDIES
DEPTHS IN LEAD OFF CHANNEL
DRAWN D.C.W. SUBMITTED
TRACED O.R.S. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., 4-23-34
189-D-53

FIG. 9

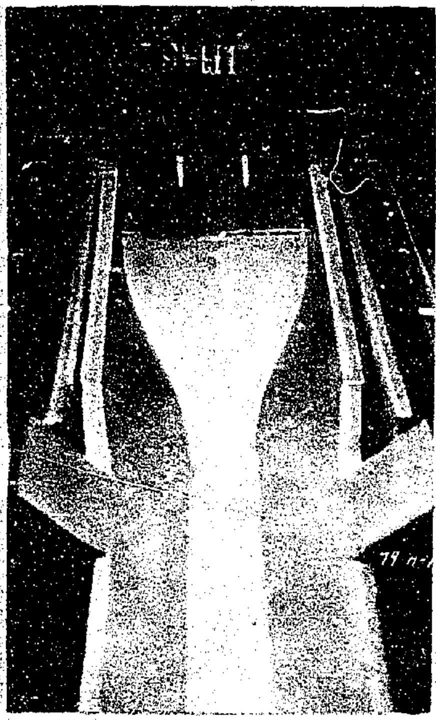
The only changes in the essential dimensions of the pool and lead-off channel which were effective were, really, an increase in the length of the pool. All changes of this nature, however, were discarded for economic reasons.

The most effective layout consistent with economy was found to be a simple apron nine feet high added to the pool as originally designed (Figure 6 and Plate III). This apron fostered the formation of two rollers, one submerged, and one on the surface which caused a maximum loss of energy from the entering stream. The height of the side walls in the original design was increased to prevent overtopping. Lengthening the pool was found to be especially effective particularly in conjunction with the apron, but was not considered economically feasible.

Appendix B gives a resume of the tests made, with comments on the pool action.

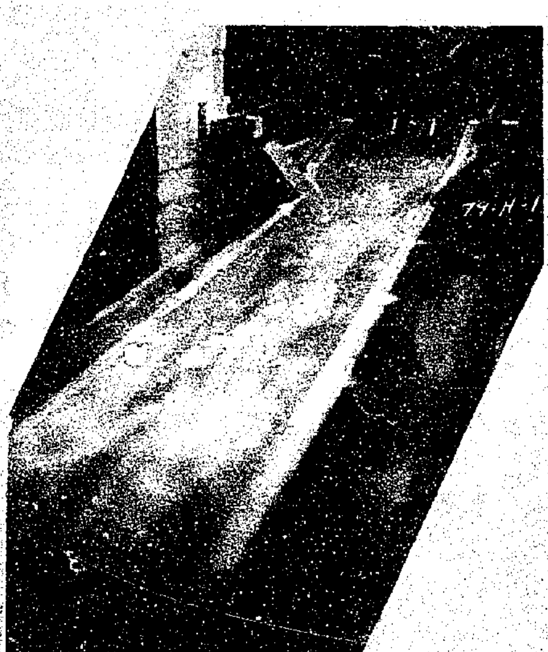
Canal Entrance Tests.

The flow through the transition below the headgates, as originally designed, was unsatisfactory. Water left the gates at shooting velocities, bounced off the sidowlls of the transition, and produced very undesirable standing wave phenomena in the channel (Figure 5 and Plates IV and V). This condition was studied in the original model, and as a remedy, the formation of a jump immediately below the gate piers was suggested. The model was rebuilt at this section in such a way that different transitions could be built in readily (Figure 10).



A - Original Design

B - Original Design at Maximum Flow
Q = 6070 c. f. s.

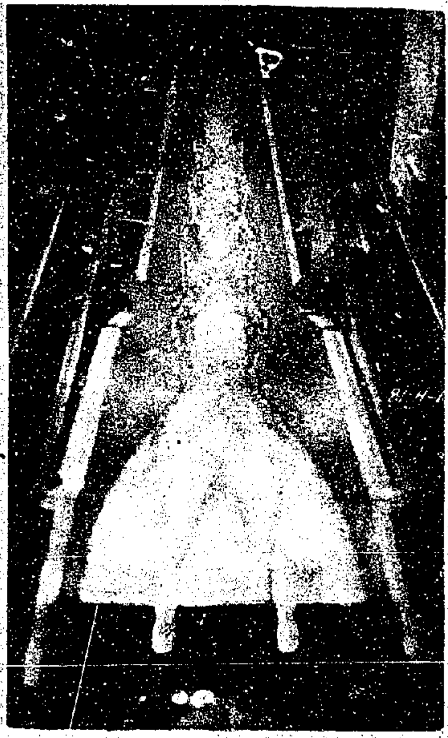


C - Original Design at Maximum Flow
Q = 6070 c. f. s.

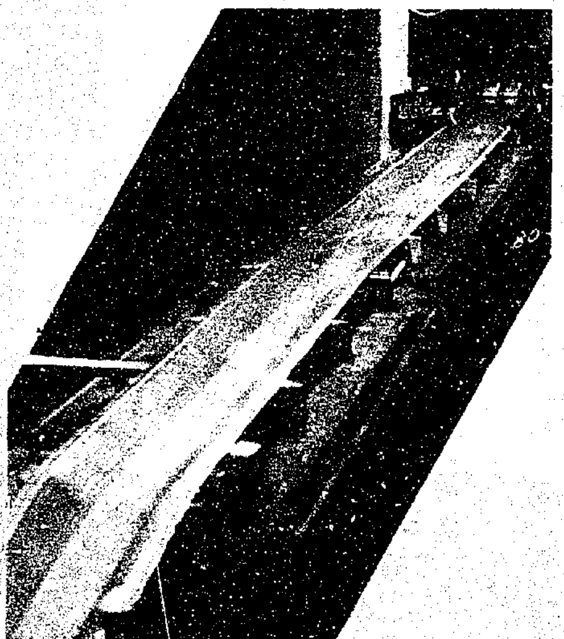
WARPED TRANSITION

PLATE IV

A - Q = 3835 c. f. s.

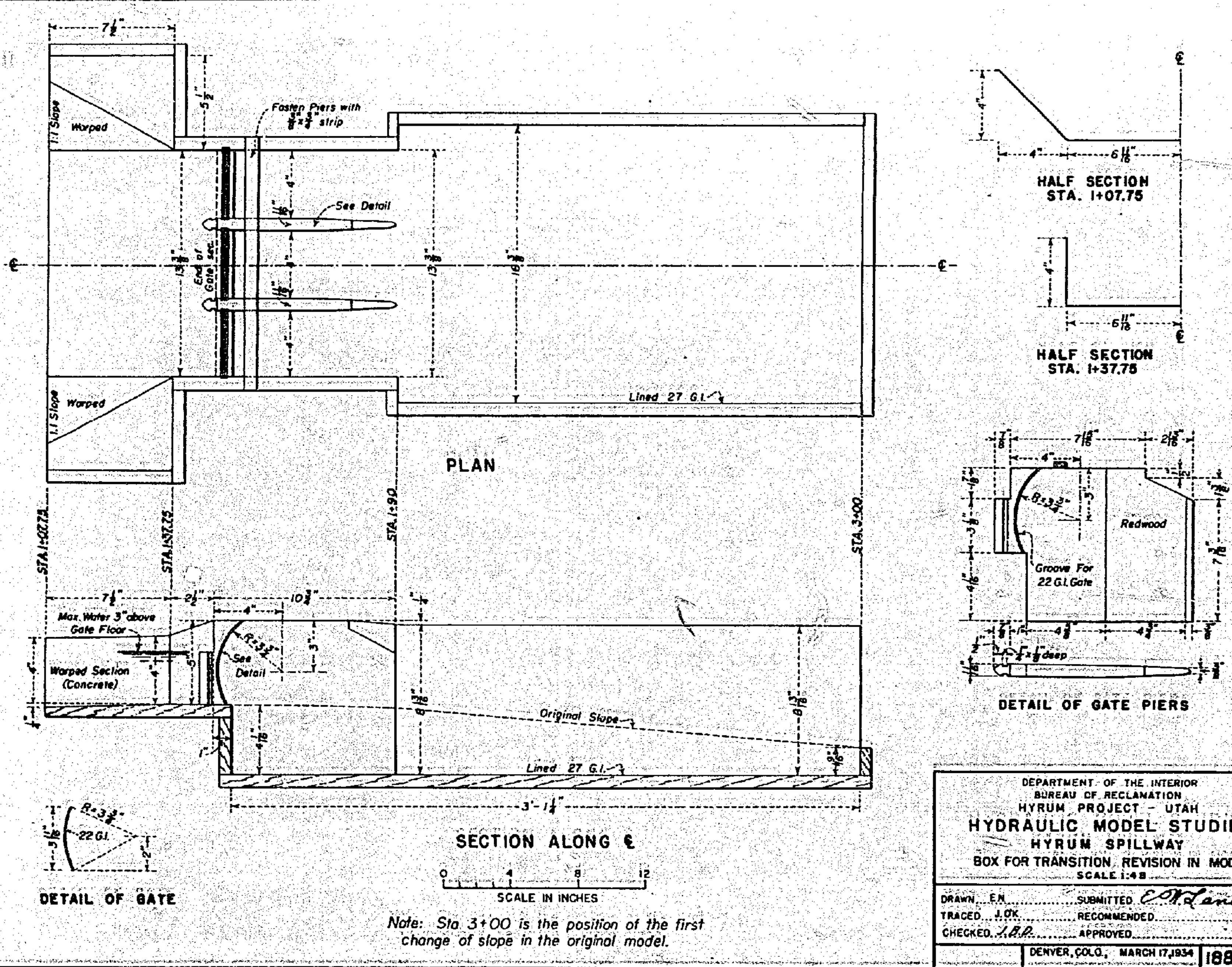


B - Q = 2075 c. f. s.



C - Q = 3835 c. f. s.

WARPED TRANSITION
Original Design at Partial Flows



Note: Sta 3+00 is the position of the first change of slope in the original model.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT - UTAH

HYDRAULIC MODEL STUDIES

HYRUM SPILLWAY

BOX FOR TRANSITION, REVISION IN MODEL

SCALE 1:48

DRAWN E.N. SUBMITTED E.W. Lane
TRACED J.O.K. RECOMMENDED
CHECKED J.B.D. APPROVED

DENVER, COLO., MARCH 17, 1934 | 188-D-50

Fig. 10

Various designs of transition below the head gates were then investigated at both full and partial discharge, since it was desired to have a jump form at all flows.

The tests demonstrated that shooting water cannot be deflected, even through a smooth transition, without danger of wave formation. Slow-moving or streaming water, on the other hand, may be easily deflected. Any disturbances generated in streaming water travel upstream at approximately the wave velocity, and are swallowed by the upstream flow.

The only prerequisite to the formation of a jump is a great enough length and a sufficient downstream depth. In the present case, this can be insured by constricting the channel section at a point below the jump and thus backing up the water. The constriction may be of three types: vertical, lateral, or a combination of the two. In studying the flow in the model, all of these types of constriction were studied. The behavior of the various setups is given below.

The transition as designed was not constricted sufficiently to form a jump at either high or low flow.

Raising the floor of the original design through the transition without widening the channel was effective only at high flow.

Constricting the original warped-wall transition laterally produced a jump at high flows, but failed to do so at low flows.

The two above-mentioned changes were tried extemporaneously, and no measurements or photographs were taken. The transition section was then rebuilt to permit various other layouts.

The first layout consisted wholly of vertical contraction (Figure 11). The original longitudinal profile of the canal bed was retained, the transition section was kept the full width of the gate section, and a sill with its crest at the elevation of the gate sill was placed at the lower end of the steeper slope just below the gate section.

The operation of this setup was highly satisfactory from the point of view of forming a jump at all flows. However, the water left the downstream side of the sill at shooting velocities and waves were formed at entrance to the canal which were quite as bad as in the original design (Plate VI).

It was found that the sill could be moved upstream for some distance and still retain its effectiveness in forming the jump at all flows, provided the crest was kept at the elevation of the gate sills, but the difficulty of diverting the shooting water into the channel could not be remedied. Various types of transitions between the sill and the canal entrance were tried, but had little effect. The failure of this setup boils down to the fact that the stream had to be narrowed from the sill length (essentially the width of gate section) to the narrower canal, and shooting water (as it is when leaving the sill) cannot be appreciably deflected, whether abruptly or by transitions, without the formation of standing waves.

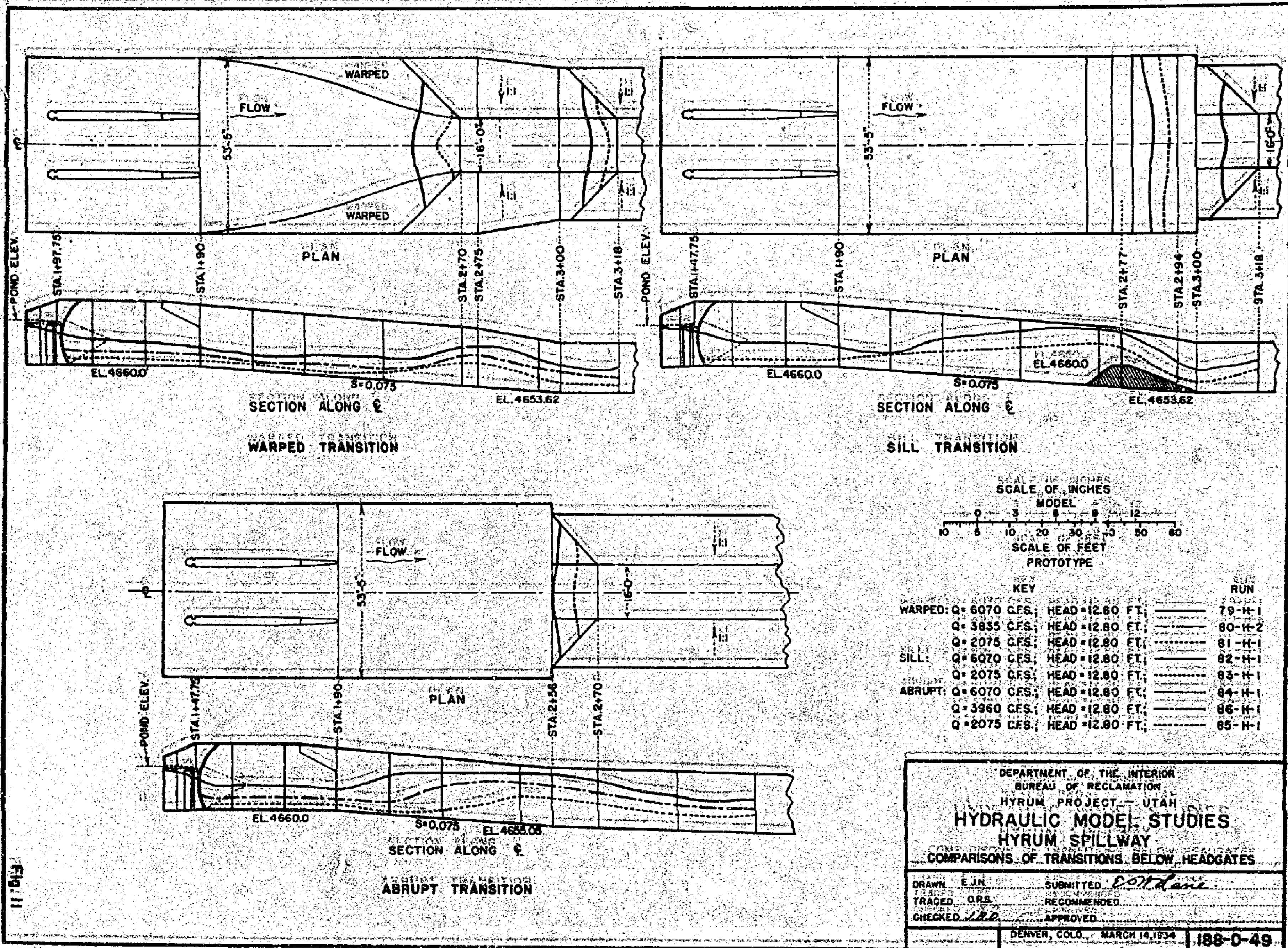
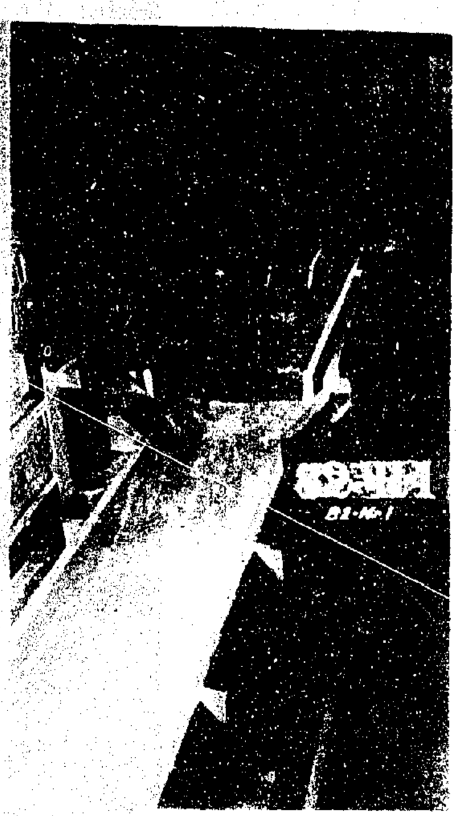
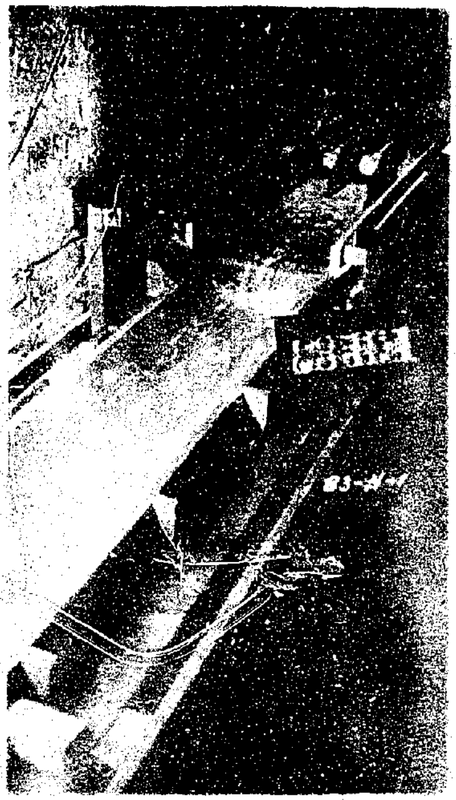

WARPED
FLOW
53'-5"
16'-0"
1:1
PLAN
POND ELEV.
STA.1+97.75
STA.1+90
STA.2+70
STA.2+75
STA.3+00
STA.3+18
EL.4660.0
S=0.075
EL.4653.62
SECTION ALONG ℄
WARPED TRANSITION
STA.1+47.75
STA.2+77
STA.2+94
SILL TRANSITION
STA.2+56
EL.4655.05
ABRUPT TRANSITION
SCALE OF INCHES
MODEL
SCALE OF FEET
PROTOTYPE
KEY
RUN
WARPED: Q=6070 C.F.S.; HEAD=12.80 FT. 79-H-1
Q=3835 C.F.S.; HEAD=12.80 FT. 80-H-2
Q=2075 C.F.S.; HEAD=12.80 FT. 81-H-1
SILL: Q=6070 C.F.S.; HEAD=12.80 FT. 82-H-1
Q=2075 C.F.S.; HEAD=12.80 FT. 83-H-1
ABRUPT: Q=6070 C.F.S.; HEAD=12.80 FT. 84-H-1
Q=3960 C.F.S.; HEAD=12.80 FT. 86-H-1
Q=2075 C.F.S.; HEAD=12.80 FT. 85-H-1
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYRUM PROJECT — UTAH
HYDRAULIC MODEL STUDIES
HYRUM SPILLWAY
COMPARISONS OF TRANSITIONS BELOW HEADGATES
DRAWN E.J.N.
TRACED O.R.S.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO., MARCH 14, 1934
188-D-49

Fig. 11



A - Q = 6070 c. f. s.

B - Q = 6070 c. f. s.



C - Q = 2075 c. f. s.

D - Q = 2075 c. f. s.

SILL TRANSITION

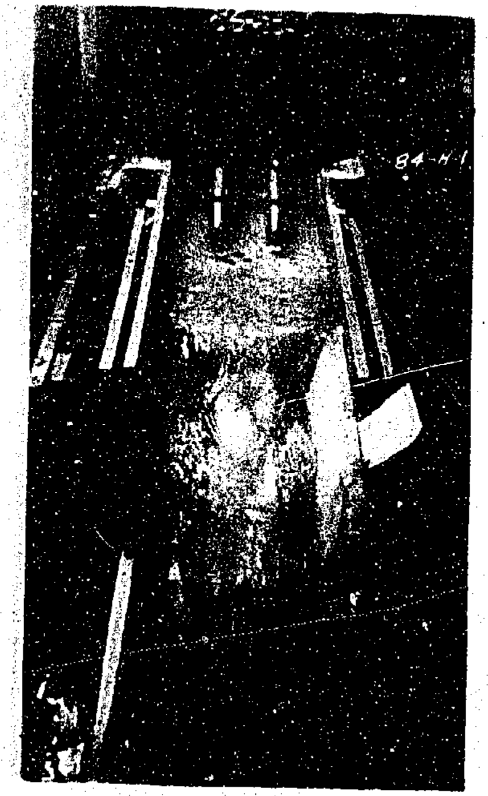
PLATE VI

In connection with the sill as described above, one setup suggested was tried in which the floor through the piers was tilted downstream from the gate sill (at the upper end of piers) and brought up to gate sill level rather steeply just below the piers. It was hoped that at low flows a jump would be formed at this point, and that a different control at a point slightly downstream (sill or lateral contraction) would form a jump at maximum flow. The setup was not satisfactory, due, perhaps to the limitations of the model as regards floor slope. This test was made hurriedly and no photographs were taken.

The third design tried was, in reality, a modification of the original design (Figure 11). In place of the expensive warped transitions, an abrupt contraction was introduced changing from the rectangular section through the gates to the trapezoidal section. The slope of the floor was broken at this transition, merely for ease of construction in the model.

This setup produced the desired result at all flows (Plates VII and VIII and Figure 11). The abrupt change in section caused a loss in addition to that in the jump, and the water entered the canal at velocities less than shooting. The flow went through the critical depth at a point well below the contraction, i.e., in the final canal section where the stream was fully deflected and no standing waves formed.

The design as shown (Figure 11) could be somewhat improved



A – Q = 6070 c.f.s.

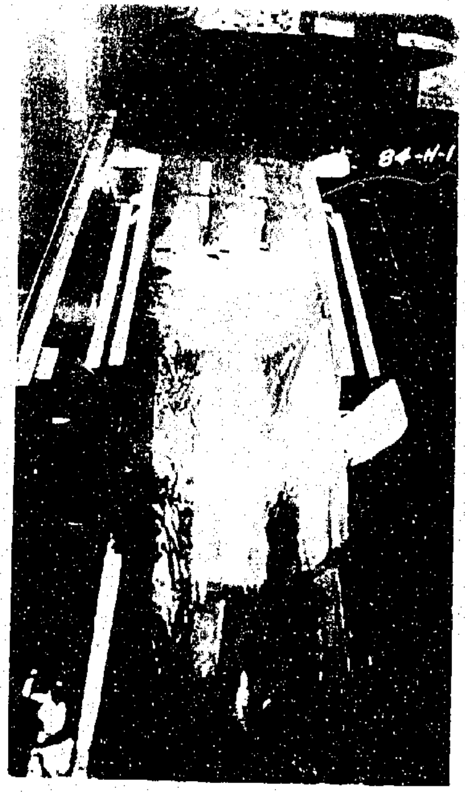
B – Q = 6070 c.f.s.

C – Q = 3960 c.f.s.

D – Q = 3960 c.f.s.

ABRUPT TRANSITION

PLATE VII



A - Q = 6070 c.f.s.

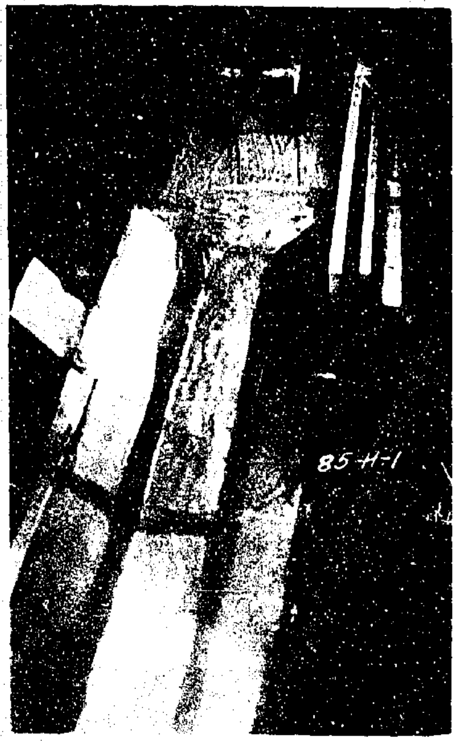
B - Q = 6070 c.f.s.

C - Q = 3960 c.f.s.

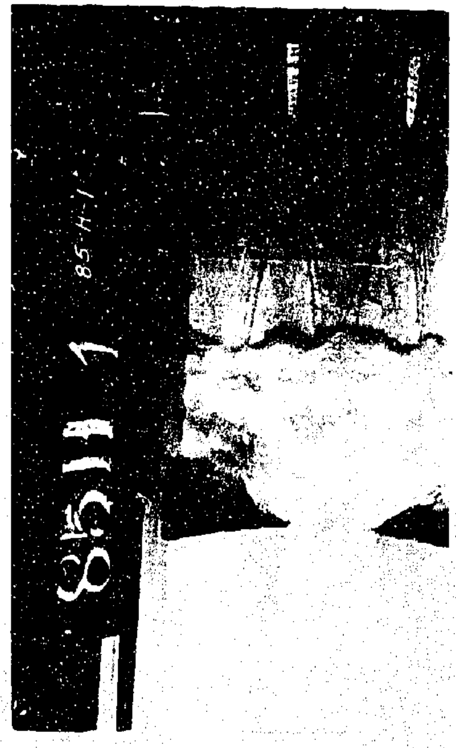
D - Q = 3960 c.f.s.

ABRUPT TRANSITION

PLATE VII



A - Abrupt Transition
Q = 2075 c.f.s.



B - Abrupt Transition
Q = 2075 c.f.s.

C - Original Warped Transition
Maximum pond level, right and center gates open 3.75 ft., left gate fully drawn.

by sloping the floor between the piers slightly downstream. The abrupt contraction could then be moved upstream, the jump would form between the piers, and yet the sloping floor would insure that it would not travel upstream toward the pond and thus raise the pond level above the maximum allowable elevation. With the floor through the piers horizontal, it is essential that the jump form well below the piers, as, once formed between the piers, any slight irregularity would immediately cause it to travel upstream through the pier section.

A rather disconcerting conclusion in regard to expensive warped transitions, in locations such as the above, where loss of head is of no consequence, is that, at shooting velocities, the warped transition is unsatisfactory, and at less than shooting velocities, it is unnecessary.

Operation of Head Gates.

In connection with the studies of transitions, the operation of the gates in the model of the original design was investigated. It was found that the smoothest conditions were obtained by leaving the center gate closed and opening the two side gates an equal amount. This suffices up to flows of about 4000 second feet. For larger flows, the center gate should be drawn, leaving the side gates fully raised.

Opening the center gate alone gave very bad flow conditions, as did any unsymmetrical gate openings (Plates VIII and IX).

A–Maximum pond level, center gate fully drawn, left and right gates one–quarter drawn.

B–Maximum pond level, right gate fully drawn, center gate closed, left gate one-half drawn.

C–Maximum pond level, center gate fully drawn, left and right gates one–quarter drawn.

ORIGINAL WARPED TRANSITION

PLATE IX

APPENDIX A

Computation of "n" values in model from test 74-H-1.

These computations give values of "n" for Kutter's C, from $V = C\sqrt{Rf}$, where f is the slope value (sine of angle of inclination of the energy grade line to the horizontal). C is computed from flow data, and "n" is taken from tables.

Nomenclature:

d = water depth, measured vertically, in feet.

A = area at section, in square feet

R = hydraulic radius, in feet

V = velocity = Q/A, in feet/second

$V^2/2g$ = velocity head, in feet

ΔZ = drop of channel bottom in length L, in feet

L = distance between sections measured along channel, in feet

ΔE = drop of energy grade line in length L, in feet

f = sine of angle of energy grade line to horizontal or $\Delta E/L$

Computation of "n" from test 74-H-1. Hydraulic Model Studies, Hyrum Spillway

Section	d	A	V	$V^2/2g$	ΔZ	$E = \Delta Z+d+V^2/2g$	ΔE	L	$\Delta E/L=f$	R	$C=\frac{V}{\sqrt{Rf}}$	n
17.11	.1958	.1036	3.700	.2132	.1996	.6086				.1168	88	.0108
15.62	.1927	.1010	3.798							.1150	91	.0106
14.58	.1902	.0996	3.852							.1144	93	.0105
13.54	.1875	.0978	3.928							.1135	95	.0104
12.50	.1834	.0948	4.042							.1116	98.5	.0100
11.46	.1823	.0941	4.081							.1108	100	.0099
10.42	.1771	.0905	4.240							.1085	105	.0095
9.48	.1740	.0882	4.352							.1075	107	.0093
8.32	.1719	.0869	4.420	.3038	0	.4757	.1329	8.79	.01512	.1060	110	.0091
8.32	.1669	.0834	4.600	.3292	.204	.7001				.1035	100	.0097
5.39	.1430	.0680	5.645	.4970	0	.6400	.0602	2.93	.0205	.0922	128	.0080
4.77	.1404	.0610	6.285	.6165	1.161	1.9179				.0867	62	.0132
1.50	.1003	.0401	9.585	1.4350	0	1.5353	.3826	3.27	.1169	.0668	108	.0085

APPENDIX B

Log of Tests.

Test Number		Setup	Comments
1-H-2	Toothed Sills	Small Dent. Sill, Teeth upstream	Unsatisfactory
2-H-1		Small Dent. Sill, Teeth upstream	Unsatisfactory
3-H-1		Large Dent. Sill, Teeth upstream	Fair, Jump rough
4-H-1		Large Dent. Sill, Teeth downstream	Fair, Jump very rough, Splash
5-H-1		Pyramid Sill "A", Teeth upstream	Jump formed O.K., rough
6-H-1		Pyramid Sill "A", Teeth downstream	Unsatisfactory, Velocity too high
7-H-1		Pyramid Sill "B", Teeth upstream	Jump starts O.K. and is fairly steady
8-H-1		Pyramid Sill "B", Teeth downstream	Jump unsteady
13-H-1	Apron	Apron 9'H, 10.5'L and 58.5'T	Jump unsteady, Heavy whirls
14-H-1		Apron 9'H, 19'L and 58.5'T	Heavy whirls in pool, Jump not constant
15-H-1		Apron 9'H, 27'L and 58.5'T	Pool rough heavy splash
16-H-1		Apron 16.25'H, 10'L and 59.5'T	Very unstable condition, High tail velocity
17-H-1		Apron 16.25'H, 10'L 59.5'T and 4' false floor	Jump not symmetrical but constant
18-H-1		Apron 16.25'H, 10'L, 59.5'T and 8' false floor	Could not hold jump
19-H-1		Apron 12'H, 10'L, 59.5'T and Rehbock Sill, 8' false floor	Unsatisfactory
20-H-1		Apron 12' H, 10'L and 59.5'T	Held jump very well, better than before
20-H-2		Apron 12'H, 10'L and 59.5'T, 4' false floor	Unsatisfactory, think sill too high

APPENDIX B (Continued)

Log of Tests

Test Number		Setup	Comments
21-H-1	Apron (Continued)	Apron 7.6'H, 10'L and 57'T	Flow very turbulent
22-H-1		Apron 6.5'H, 10'L, 57'T	Flow very turbulent
22-H-2		Apron 6.5'H, 10'L, 57'T and Rehbock Sill 4¼'W and 1½'H teeth upstream	Very turbulent, Splash, Good flow beyond
22-H-3		Apron 6.5'H, 10'L, 57'T and Rehbock Sill 4¼'W and 1½'H teeth downstream	Not satisfactory, spray and splash, rough pool
25-H-1	Crowned Apron	Crowned Apron 10'H, 27'L, 71'T	Unsymmetrical, Whirls, Splash over sides
26-H-1		Crowned Apron 10'H, 19'L, 71'T	Flow turbulent, Whirls, Bad setup
27-H-1		Crowned Apron 10'H, 10'L, 71'T	Better but still turbulent
27-H-2		Crowned Apron 10'H, 10'L, 71'T and Dent. Sill 3½' below Apron teeth upstream	Bad, worse than no sill at all
27-H-3		Crowned Apron 10'H, 10'L, 71'T and Dent. Sill 3½' below Apron teeth downstream	Bad, high waves and splash
27-H-4		Crowned Apron 10'H, 10'L, 71'T and Pyra. Sill at end of Apron	Better, but still very rough
30-H-1		Crowned Apron 10'H, 27'L, 71'T and Channel widened	Jump went out
30-H-2		Crowned Apron 10'H, 27'L, 71'T and Channel widened also pyra. Sill at end	Jump still went out
30-H-3		Crowned Apron 10'H, 10'L, 71'T large Dent. Sill 40' from Apron	Short jump, did not kill velocity
31-H-1	Sill	Large Dent. Sill 20' below P.T.	Will not hold jump at all times, unsteady
32-H-1		Flat Apron 8½'H, 10'L, 60'T	Would not hold jump

APPENDIX B (Continued)

Log of Tests

Test Number		Setup	Comments
32-H-2	Apron and Sill	Flat Apron $8\frac{1}{2}$'H, 10'L, 60'T, Large Dent. Sill at end Teeth upstream	Would not hold jump
32-H-3		Flat Apron $8\frac{1}{2}$'H, 10'L, 60'T, Large Dent. Sill 30' below Apron,	Whirls, left to right, Flow bad
33-H-1		Largest possible Pool 217' Long at bottom Same Tailwater	Good but too long to be practical
34-H-1	Change in Pool Lengths	Pool 164' long at bottom	Good but not practical
35-H-1		Pool 150' long at bottom	O.K. but still too long to be practical
36-H-1		Pool 132' long at bottom	Small roll, but pool not practical
37-H-1		Pool 116' long at bottom	Small roll, jump smooth, not practical
38-H-1		Pool 100' long at bottom	Large rolling jump at end of pool
39-H-1		Pool 88' long at bottom	Jump still in pool, Tail rough and wavy
40-H-1		Pool 84' long at bottom	Jump very rough
41-H-1		Pool 80' long at bottom	Jump rough, but not unstable
42-H-1		72' long at bottom	Jump unstable Went out once a minute
43-H-1		80' long at bottom	Jump rough, but not unstable
44-H-1		80' long at bottom, polished model	Did not change jump
45-H-1		Pool 76' long at bottom	Jump can be easily washed out

APPENDIX B (Continued)

Log of Tests

Test Number		Setup	Comments
46-H-1	Change in Pool Lengths (Continued)	76' long at bot. Correct tail slope and Channel	Jump went out in 38 seconds
47-H-1	Change in Pool Lengths (Continued)	80' long at bot. Correct tail slope	Jump rough but not unstable ORIGINAL DESIGN
48-H-1	Change in Pool Lengths (Continued)	100' long at bot. Correct tail slope	Jump steady and in Pool
49-H-1	Change in Pool Lengths (Continued)	120' long at Bot. Correct tail slope	Jump very steady, completely worked out
50-H-1	Change in Pool Lengths (Continued)	140' long at bot. Correct tail slope	Jump very rough
51-H-1	Change in Pool Lengths (Continued)	Exact Duplicate of Proto. But tail floor 16'H	Jump goes out immediately
52-H-1	Change in Pool Lengths (Continued)	Duplicate but Pool 100' long Tail 16'	Jump goes out immediately
53-H-1	Change in Pool Lengths (Continued)	Duplicate but Pool 120' long Tail 16'	Jump went out in 16 seconds
54-H-1	Change in Pool Lengths (Continued)	Duplicate but Pool 140' long Tail 16'	Jump went out and then in
55-H-1	Change in Pool Lengths (Continued)	Duplicate but Pool 160' long Tail 16'	Jump rough but in pool, Tail flow fair
56-H-1	Tail Race Change	Duplicate but tail 16', Race 240' long	Same as before, jump goes out
56-H-2	Tail Race Change	Duplicate but tail 16' and Race 240' long tailwater raised	Jump rough
57-H-1	Tail Race Change	Duplicate, Tail 16', Race 240' Apron 10.5'H, 10'L and 60.75'T, Held Tailwater	Jump rough

APPENDIX B (Continued)

Log of Tests

Test Number		Setup	Comments
58-H-1	No Tail Race	No Tailway, Raised Tailwater	Smooth very clear and quiet
59-H-1	No Tail Race	No Tailway, Raised Tailwater	Smooth
59-H-2	No Tail Race	No Tailway, Raised Tailwater, Sill 20' from P.I.	Smooth, No change noted
60-H-1	No Tail Race	No Tailway, Raised Tailwater, Apron 9'H, 10'L, 60.75'T	Jump smooth
61-H-1	Original + Aprons	Apron 9'H, 10'L, 60'T, 80' Pool, New variable slope	Water rough and splashing, no foam
62-H-1	Original + Aprons	Original setup, Apron 9'H, 2'L, 58.75'T	Jump rough and splashing
63-H-1	Original + Aprons	Original setup, Apron 11'H, 10'L, 61.5'T Blocks	Heavy eddies, Heavy splash
64-H-1	Original + Aprons	Original setup, Apron 9'H, 10'L, 61.5'T, Blocks	No change
65-H-1	Original + Aprons	Original setup, Straight Apron 9'H, 2'L	Heavy waves and splash
66-H-1	Original + Aprons	Original Pool 85' Modified tail	Poor jump water rough
67-H-1	Pool Varied (original)	Pool 85', Tail 24', Vert. End, Apron 9'H, 2'L, 58'T	Jump very good, but high splash
68-H-1	Pool Varied (original)	Pool 100' , Vert. Tail, Apron 9'H, 2'L, 42'T	Rough, heavy splash, high bulge at lower end of pool
69-H-1	Pool Varied (original)	Pool 100', Vert. Tail	Rough heavy splash
70-H-1	Pool Varied (original)	Pool 80.25' Long Tail at 1:3 slope 63' Long	Jump O.K. Splash high at end
71-H-1	Pool Varied (original)	Pool 80.25' Long Tail at 1:3 slope Apron 9'H, 2'L, 58.5'T	Jump quiet, very good setup
72-H-1	Pool Varied (original)	Pool 80.25' Long Tail at 1:3 slope 63' Long Apron 9'H, 10'L 58.5'T	Jump rough, heavy splash

APPENDIX B (Continued)

Log of Tests

Test Number		Setup	Comments
73-H-1	"n" values	Maximum discharge	
74-H-1	"n" values	Maximum discharge, jump below gates	
75-H-1	"n" values	Flow = 4000 second feet	
76-H-1	"n" values	Flow = 2000 second feet	
77-H-1	Final	Original Design + Short Straight Apron 10.1'H, 95.5'L New Piers, and Gates	Jump very symmetrical FINAL DESIGN
78-H-1	Final	Original Design + Apron 9'H, 20'L 37.5'T	Flow O.K. Jump at end of pool
79-H-1	Transition Studies	Gate Studies Final Design, Warped Q = Max.	Flow bad, cross waves
80-H-1	Transition Studies	Warped Q = 4000 All Gates Open	Flow same as above
80-H-2	Transition Studies	Warped, Q = 4000, Gates set to give pond correct elevation	Not much change in flow
81-H-1	Transition Studies	Warped, Q = 2000, Pond elevation same also pool measurements	Flow bad until steep slope
82-H-1sp	Gate Studies (Warped)	Warped, Left Gate open	Flow unsymmetrical
82-H-2sp	Gate Studies (Warped)	Warped, Right Gate open	Flow unsymmetrical
82-H-3 sp	Gate Studies (Warped)	Warped, Center Gate open	Fin at end of transition
82-H-4sp	Gate Studies (Warped)	Warped, C-open L-$\frac{1}{2}$, R closed	Unsymmetrical, but not so bad
82-H-5sp	Gate Studies (Warped)	Warped, C-open R-varied, L-closed	Opposite to above
82-H-6sp	Gate Studies (Warped)	Warped, C-open R. & L. $\frac{1}{4}$	Worst condition

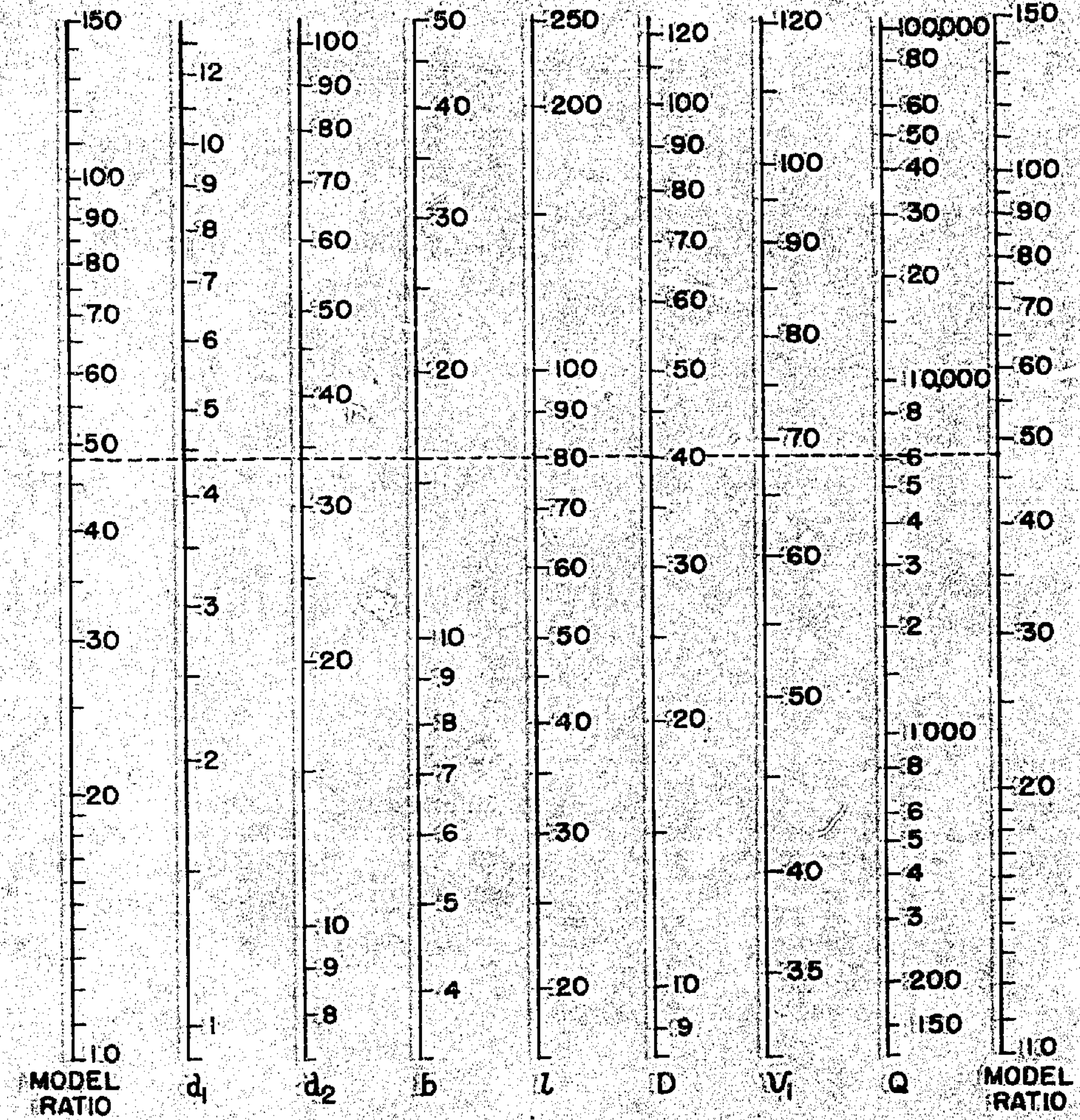
Log of Tests

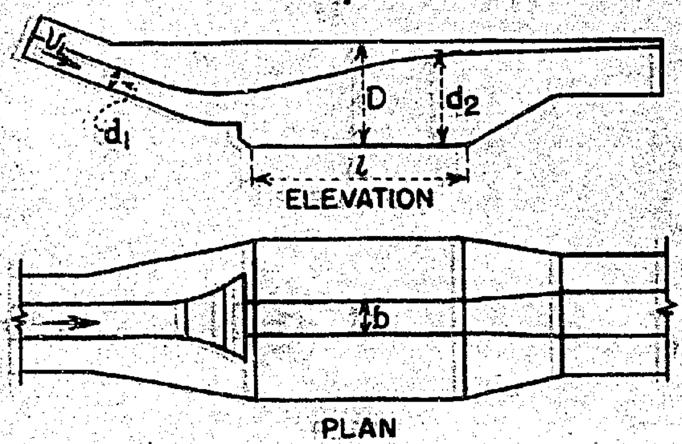
Test Number		Setup	Comments
82-H-7sp	Gate Studies (Warped) -- (Continued)	Warped C-closed, R. & L. open	Best condition
82-H-8sp		Warped R-$\frac{1}{4}$, 1-$\frac{3}{4}$, C-$\frac{1}{2}$	Unsymmetrical, not as bad as #6
82-H-9sp		Warped R-open, C-closed, L-$\frac{1}{2}$	Unsymmetrical, not as bad as #6
82-H-10sp		Warped all open 3.75 feet	High Fin, rough
82-H-11sp		Warped R & C open, L closed	High Fin, rough
82-H-12sp		Warped R closed, L & C open	High Fin, Opposite #11
82-H-13sp		Warped R-closed, L-Open, C 4'open	Medium Fin, rough
82-H-14sp		Warped R-open, L-closed, Center 4'	Opposite #13
82-H-15sp		Warped L & C open 4', Right open	Large transverse waves
82-H-16sp		Warped C & R open 4', Left open	Large transverse waves
82-H-1	Transition Studies	11 Wall Transition with sill Q = Max.	Flow fairly good throughout
83-H-1		11 Wall with Sill Q = 2000	Same conditions
84-H-1		11 Wall abrupt change Q = Max.	Jump good, best setup yet
85-H-1		11 Wall abrupt change Q = 2000	Same as above
86-H-1		11 Wall abrupt change Q = 4000	Same as above

APPENDIX C

Design of similar stilling pools.

In order that the information gleaned from these tests may be readily available for the design of similar stilling pools having a greater or less discharge, the accompanying chart (Figure 12) was prepared. If a stilling pool similar to the Hyrum pool is to be designed to handle a maximum discharge of, say, 15,000 c.f.s., then the Hyrum model may be considered a 1:70 model of this proposed pool. The chart shows immediately the essential dimensions of similar pools for a large range of discharges. If the proposed pool is not exactly similar to the Hyrum design, then the designer must judge how closely the dimensions are applicable. It must also be borne in mind that, inasmuch as the Hyrum spillway will very rarely operate at maximum discharge, its dimensions were pared to a minimum; furthermore, a hydraulic jump formed in a trapezoidal cross section is not generally as satisfactory as one formed in a rectangular section.





HYRUM SPILLWAY EXPERIMENTS

DIMENSIONS OF OTHER SPILLWAYS TO WHICH MODEL TESTS ARE APPLICABLE

E.J.N.

FIG. 12

188-D-70