UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES FOR THE DESIGN OF CANAL CHUTES

By

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HYD 3.6

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Denver, Colorado,

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GENERAL CHUTE TESTS

MILL COULEE CANAL CHUTE

Sta. 259+35

SUN RIVER PROJECT - MONTANA

General Description

The Bureau of Reclamation has constructed chute drops on many of the irrigation projects it has undertaken. These vary in capacity depending upon the size of the canal, but the majority of them are similar in shape for earth sections. The chute drop has proven itself to be the ideal structure for dealing with sudden changes of slope in canals. It dissipates the excess energy effectively and requires a small amount of maintenance. Other structures serving a similar purpose have in some cases required a considerable amount of maintenance when based on their initial costs.

The bureau has constructed some chute drops (in loose earth) similar to the one shown on figure 1. The chute proper is rectangular in section, the floor of the stilling pool is the same width as the chute, the side slopes of the pool are usually about 1:1 with the result that the pool is very wide in comparison with the inclined chute, and a very abrupt transition is required to connect the two. The design of a typical chute drop of this type, which was proposed for the Mill Coulee Canal on the Sun River Project, was submitted for model tests.

The Model

A model of the Mill Coulee chute drop was constructed on a scale of 1:10 in the laboratory. A drawing of the prototype is shown in figure 1 and a drawing of the model is shown in figure 3. Figure 2 shows a plan of the laboratory. The maximum discharge for the model was 0.44 c.f.s. which corresponds to 139 c.f.s in the prototype. The chute and pool were constructed of wood and lined with sheet metal. Rather than make the chute the full length, which would necessitate using a very small stilling pool, only the lower portion was represented in the model making it possible to use a much larger model scale. A specially made square gate valve (see fig. 3) by means of which the depth of flow could be controlled, was installed in the chute at station 265.74.3. The depth of flow and the velocity at this point were computed and plotted for various discharges, so that in order to duplicate prototype conditions, it was merely necessary to properly adjust the gate for the corresponding depth of flow and regulate the amount of pressure behind it to give the desired velocity.

Water for the model was measured over a V-notch weir and then pumped into a large steel pressure tank. A 4-inch pipe carried the water from this tank to the model. A sheet metal transition

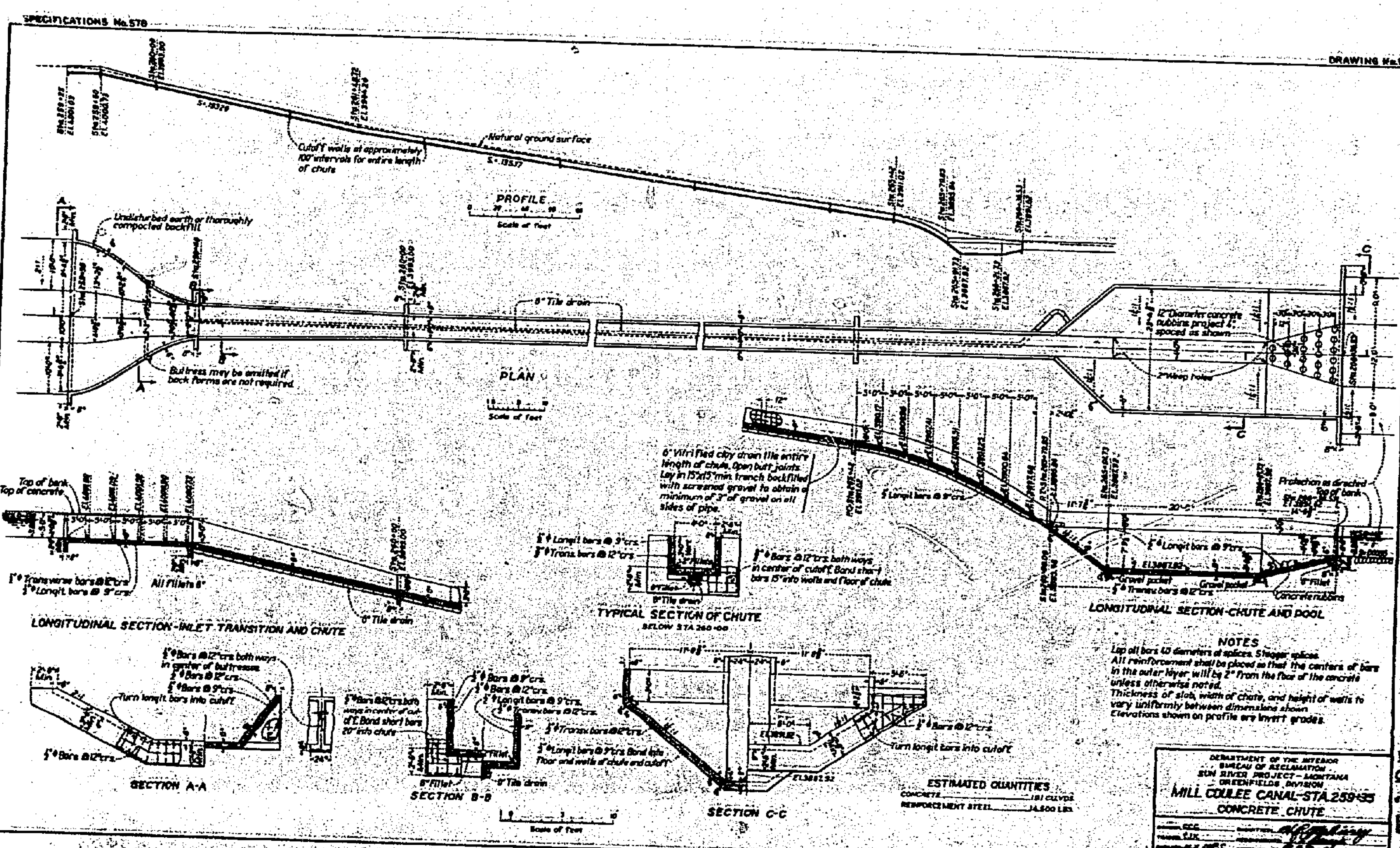

SPECIFICATIONS No. 578
DRAWING No. 10
Cutoff walls at approximately 100' intervals for entire length of chute
Natural ground surface
PROFILE
Scale of Feet
Undisturbed earth or thoroughly compacted backfill
8" Tile drain
12" Diameter concrete nubbins project 4", spaced as shown
2" Weep holes
Buttress may be omitted if back forms are not required.
PLAN
Scale of Feet
6" Vitrified clay drain tile entire length of chute. Open butt joints. Lay in 15"x15" min. trench backfilled with screened gravel to obtain a minimum of 3" of gravel on all sides of pipe.
Protection as directed
Top of bank
Top of concrete
All fillets 6"
6" Tile drain
LONGITUDINAL SECTION-INLET TRANSITION AND CHUTE
TYPICAL SECTION OF CHUTE
BELOW STA. 260+00
Gravel pocket
Concrete nubbins
LONGITUDINAL SECTION-CHUTE AND POOL
NOTES
Lap all bars 40 diameters at splices. Stagger splices.
All reinforcement shall be placed so that the centers of bars in the outer layer will be 2" from the face of the concrete unless otherwise noted.
Thickness of slab, width of chute, and height of walls to vary uniformly between dimensions shown.
Elevations shown on profile are invert grades.
Turn longit. bars into cutoff
SECTION A-A
SECTION B-B
Turn longit bars into cutoff
ESTIMATED QUANTITIES
CONCRETE 181 CU.YDS.
REINFORCEMENT STEEL 14,500 LBS.
SECTION C-C
Scale of Feet
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
GREENFIELDS DIVISION
MILL COULEE CANAL-STA. 259+35
CONCRETE CHUTE
23300
28-D-018

FIG. 1

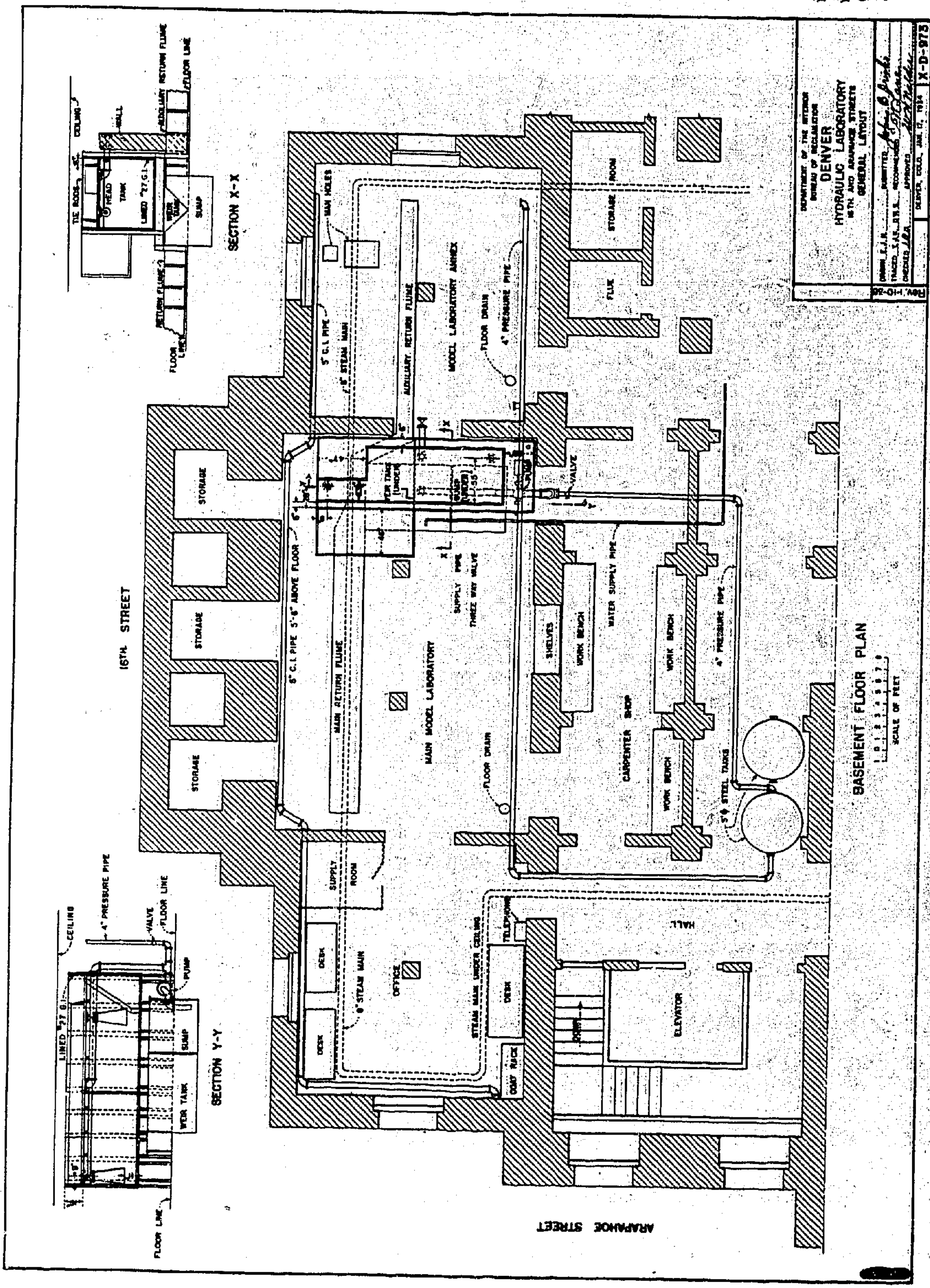
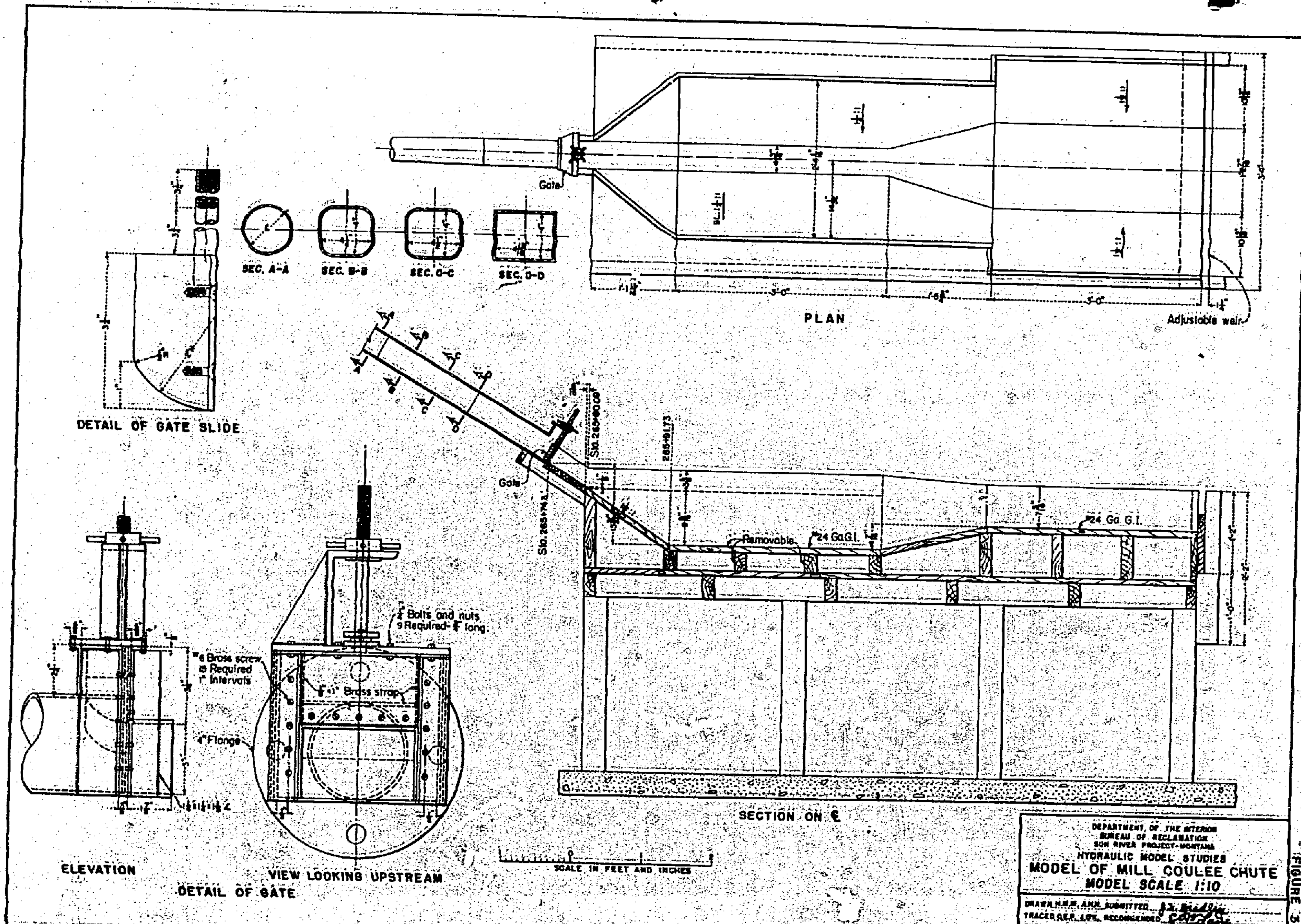

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
DENVER
HYDRAULIC LABORATORY
16TH AND ARAPAHOE STREETS
GENERAL LAYOUT
X-D-973
BASEMENT FLOOR PLAN
SCALE OF FEET
16TH STREET
ARAPAHOE STREET
SECTION X-X
SECTION Y-Y
STORAGE
STORAGE ROOM
FLUE
MODEL LABORATORY ANNEX
AUXILIARY RETURN FLUME
MAIN RETURN FLUME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

FIG. 2



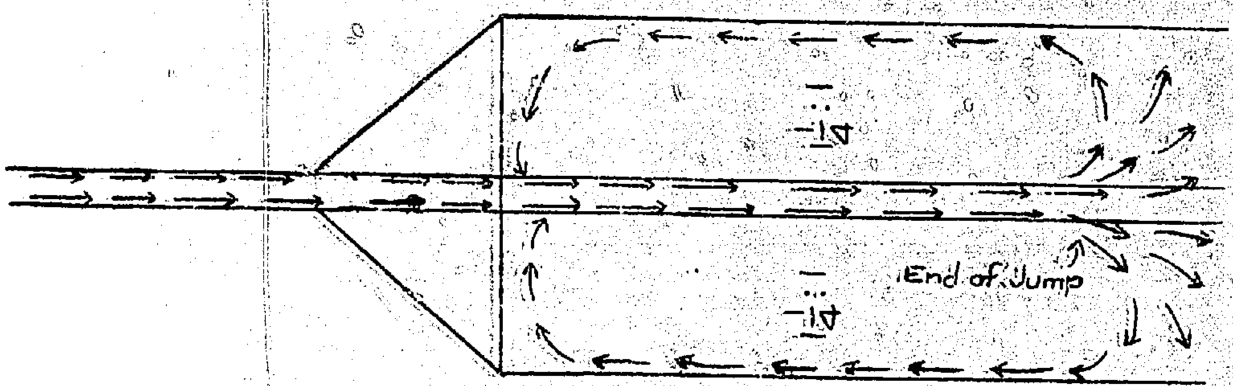
PLAN
Gate
Adjustable weir
SEC. A-A
SEC. B-B
SEC. C-C
SEC. D-D
DETAIL OF GATE SLIDE
Gate
Sta. 265+74.1
Sta. 265+80.08
265+91.73
Removable
24 Ga.G.I.
24 Ga. G.I.
SECTION ON ℄
SCALE IN FEET AND INCHES
Bolts and nuts 9 Required
Brass strap
6 Brass screw 15 Required 1" intervals
4" Flange
ELEVATION
VIEW LOOKING UPSTREAM
DETAIL OF GATE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
HYDRAULIC MODEL STUDIES
MODEL OF MILL COULEE CHUTE
MODEL SCALE 1:10
DENVER, COLO.
28-D-333

FIGURE 3

transformed the circular pipe section into a rectangular section just above the gate valve. Four piezometers installed in the same plane (one connected to each side of the square portion of the transition) were located just above the valve. Each piezometer was connected to a separate manometer. The average height to which the water rose in the four manometers above the center of the gate opening was considered the pressure behind the gate in feet of water. The tailwater was regulated during the first tests by a weir, and during the remainder, by an adjustable shutter which can be seen in the background in photograph C, plate 4. After leaving the model, the water was returned to the measuring weir and thus was recirculated thru the system. The tailwater elevation was observed from a piezometer which was connected to the tailwater box.

Discussion of Results

This chute has an objectionable feature from a hydraulic standpoint. It is practically impossible to obtain a good stable hydraulic jump in a trapezoidal pool which has side slopes as flat as $1\frac{1}{4}$:1 and especially so when the width of the chute is small compared with the width of the pool. The sketch below demonstrates the action which is inevitably found in stilling pools of this general shape.



The narrow jet of water issuing from the chute does not spread; consequently, the jump is effective only in the center of the pool. Due to the difference in elevation between the tailwater and the water surface at the front of the jump, a continual flow in an upstream direction persists on both sides of the pool as there is no force present to oppose it. The potential energy innate in the tailwater causes a portion of the water leaving the jump to part in opposite directions, turn, and flow back along the sides of the pool.

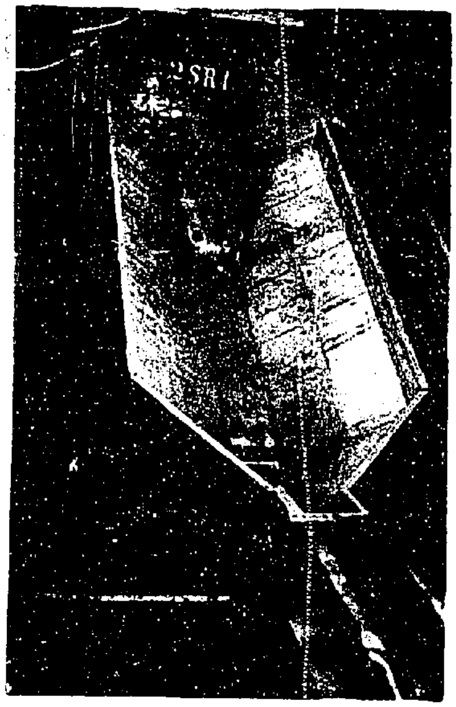
This water again contacts the jet which is entering the pool, goes thru the jump, and a portion of it again returns by way of the sides of the pool to recontact the jet. As a result, the water in the pool assumes a constant whirling motion in both directions as indicated by the sketch.

When the tailwater was below normal, the water in the pool occasionally whirled in just one direction. By interrupting this motion with a board, the whirl could be reversed. In either case, it persisted without assistance and the entire pool adopted this motion.

Another objectionable feature to a pool of this type with return flow on the sides is its instability and its propensity for splashing up alternately on the flat sloping sides of the pool, creating very pronounced lateral waves in the tailrace, which in an earth canal would endanger the side slopes. The action is somewhat similar to that observed on a large body of water. The roughest waves form on the shallow beach rather than over the deeper portion of the body of water. The flat side slopes of the stilling pool simulate the beach effect and the surface disturbances thus created are translated to all parts of the pool with the result that the water surface is continually in a choppy state. The photographs that follow show convincing evidence of the action just described.

Discussion of Stilling Pool Tests

Photographs of the original design are shown in views A and B, plate 1. Photograph A shows the model as originally designed, and photograph B shows the stilling pool in operation for the maximum discharge and corresponding tailwater. The purpose of the "nubbins" on the sloping floor at the downstream end of the pool was to aid in keeping the jump in the pool at low tailwater depths. Notice in photograph B that the jump is only effective in the center of the pool. Also notice the water flowing back on each side of the jump. Test 2-1 (figure 4) shows a profile of the water surface in the pool measured along the center line. The beginning and end of the roller is indicated in this and the following profiles. The beginning of the roller was located from inspection and the end was located by dropping a chip of wood on the water until a point was found at which it was carried in either direction. Velocity measurements were taken on the center line of the pool by means of a pitot tube, and these results are plotted to scale on the profile drawings. The photographs in some cases are of more value than the plotted profiles as they show the general action over the entire pool, while the profiles indicate conditions on the center line where the action is at its best.

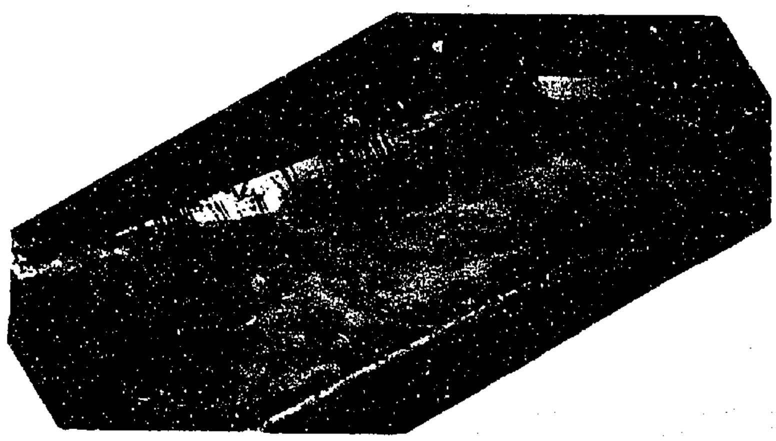


A. VIEW OF STILLING POOL AND LOWER PORTION OF CHUTE.

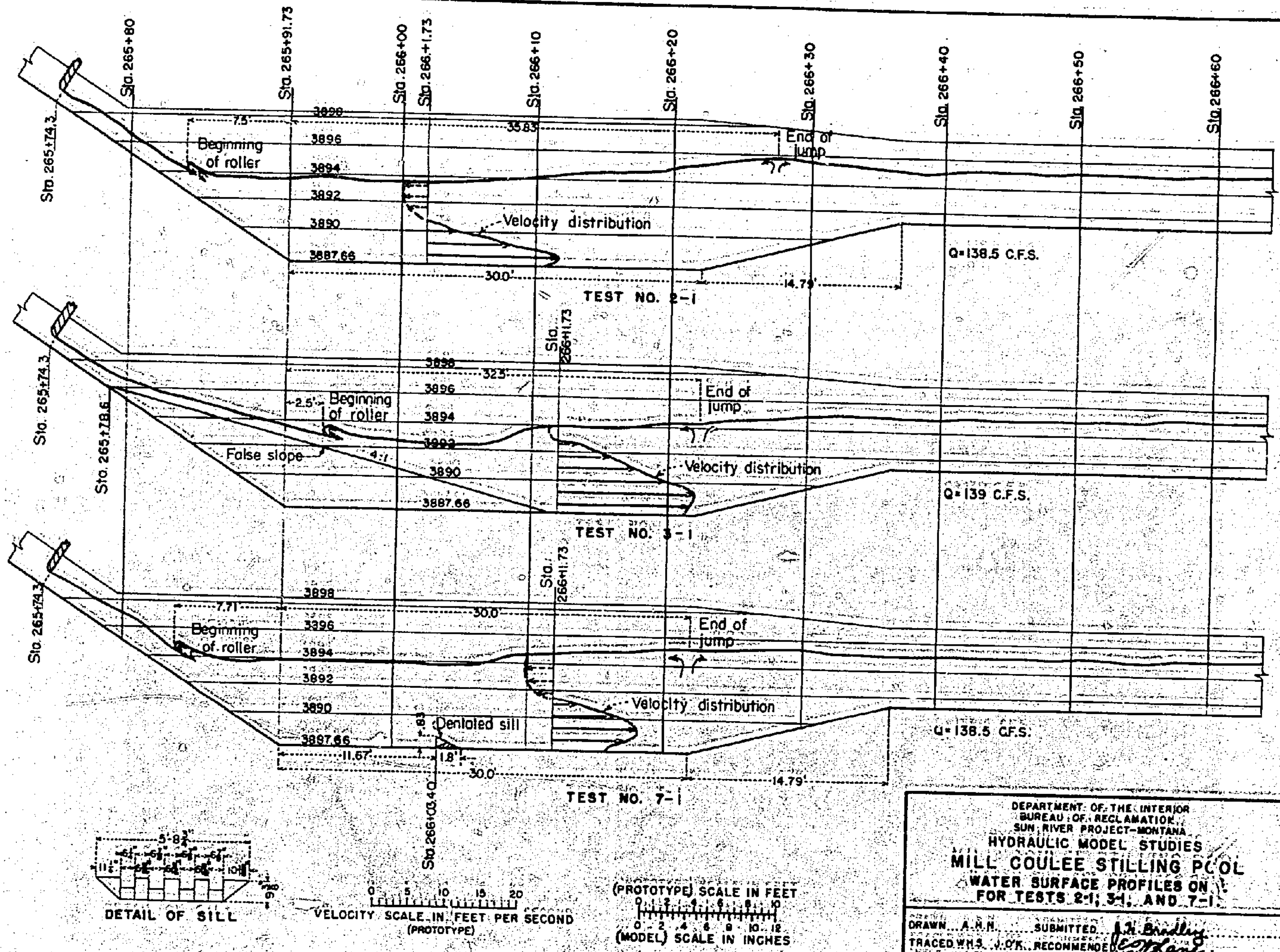
B. DISCHARGE 138.5 SECOND-FEET.

ORIGINAL DESIGN.

C. SLOPE DECREASED AT LOWER END OF CHUTE TO SPREAD JET.



D. DISCHARGE 139 SECOND-FEET.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT—MONTANA
HYDRAULIC MODEL STUDIES

MILL COULEE STILLING POOL

WATER SURFACE PROFILES ON FOR TESTS 2-1, 3-1, AND 7-1

DRAWN A.H.N. SUBMITTED J.N. Bradley
TRACED W.H.S. J.O'K. RECOMMENDED
CHECKED A.H. APPROVED
DENVER, COLO. MARCH 20, 1935 28-D-334

FIGURE 4

An extensive amount of testing was done on the model in an effort to improve pool conditions by merely making minor revisions. As the velocity on the floor of the pool in test 2-1 was high, an attempt was made to improve this distribution. In test 3-1 (figure 4), the slope at the end of the chute was reduced for the purpose of spreading the jet in a lateral direction before it entered the pool. A piece of sheet metal commencing at station 265+78.6 was soldered in the model on a slope of 4:1 as shown in test 3-1 and photograph C, plate 1. The change in slope failed to spread the jet any appreciable amount but it did alter the velocity distribution in the pool and shorten the length of the roller by about 13 feet. Photograph D (plate 1) shows this pool in operation for a discharge of 139 c.f.s.

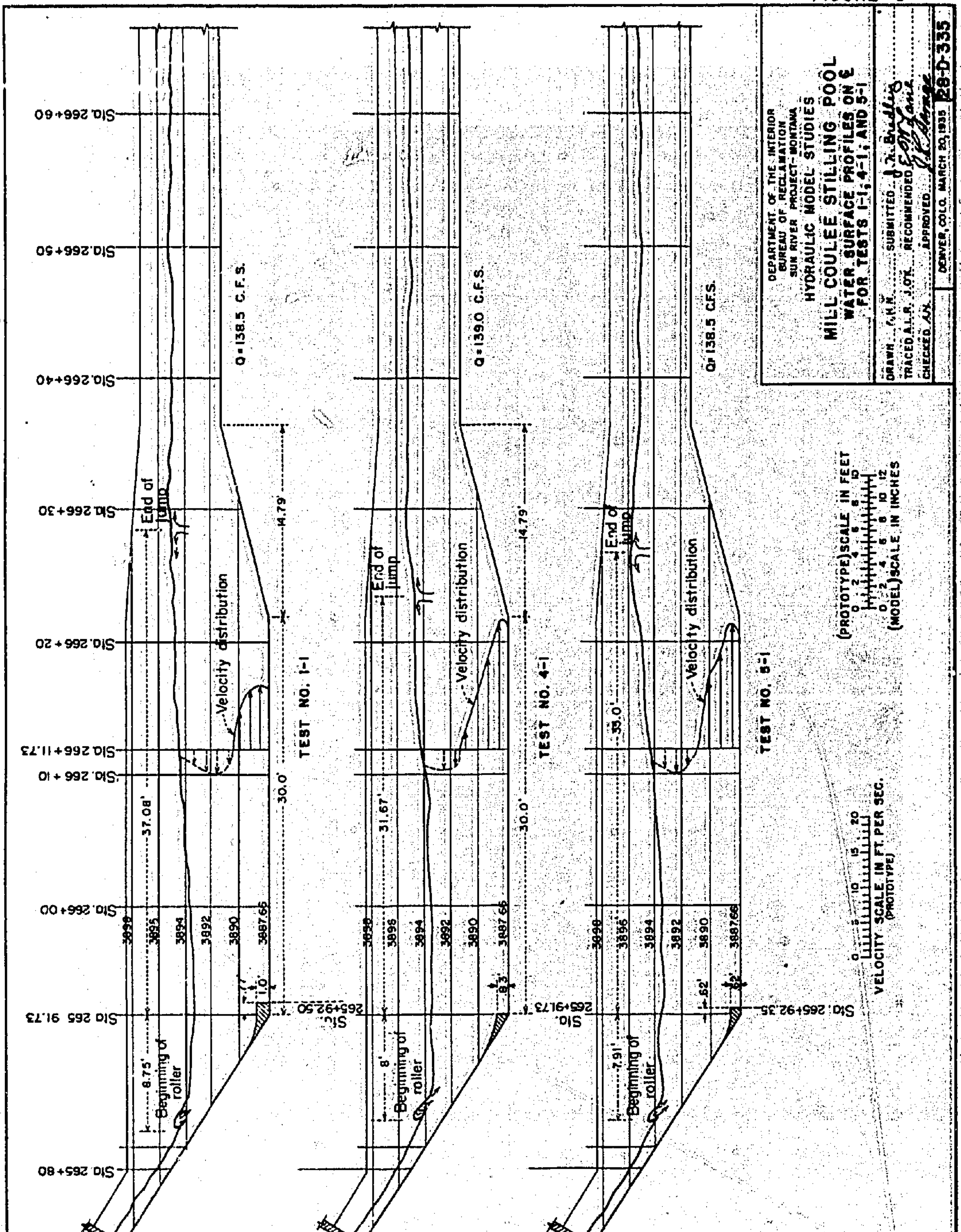
The false slope was removed and a small Rehbock sill was installed on the pool floor at station 266+03.40 as shown in test 7-1, figure 4. The sill was very effective in improving the velocity distribution and energy dissipation in the center of the pool, but the same back flow conditions existed along the side walls. Photograph A (plate 3) shows the sill installed, and photograph B shows the pool for a discharge of 138.5 c.f.s.

In another attempt to spread the jet and in this case lift it off the floor, a stepped apron was built into the lower end of the chute as shown in test 1-1 (figure 5) and photograph A (plate 2). The downstream end of the apron was 1.0 foot above the pool floor. A very good velocity distribution was obtained with this stepped apron but, contrary to expectations, the length of the roller was exceptionally long. Photograph C (plate 2) shows this pool in action for the maximum discharge. Notice that the jump is still confined to the center of the pool and that all efforts so far made have failed to prevent the back flow near the sides.

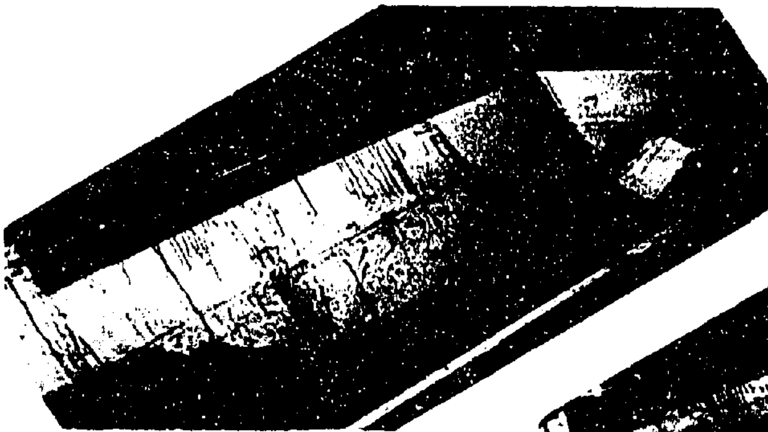
Two other stepped aprons were tried in tests 4-1 and 5-1 (figure 5). The lower ends of these were 0.83 and 0.62 feet, respectively, above the pool floor. Photograph B (plate 2) was taken of the pool during test 4-1 and photograph D was taken during test 5-1. There is a negligible difference between these tests as can be observed from the profile plots. The length of jump is shorter in the latter two tests than in test 1-1, but the velocity distribution in the center of the pool using the highest apron is preferable.

In another attempt to improve pool conditions, a false floor was installed 0.83 feet above the original pool floor as shown on the profile for test 6-1 (figure 6) and in photograph C (plate 3). Photograph D shows the pool in action for maximum discharge with the false floor installed. A slight improvement was noticeable but pool conditions in general were materially unchanged.

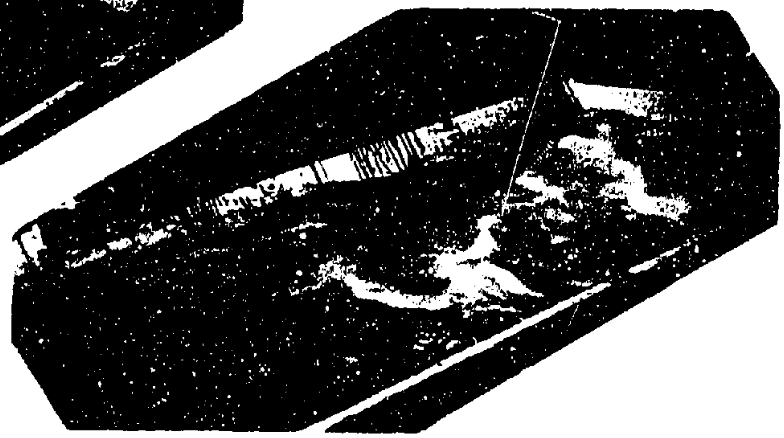
FIGURE 5



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
HYDRAULIC MODEL STUDIES
MILL COULEE STILLING POOL
WATER SURFACE PROFILES ON ℄
FOR TESTS 1-1, 4-1, AND 5-1
DENVER, COLO. MARCH 20, 1935
28-D-335
TEST NO. 1-1
TEST NO. 4-1
TEST NO. 5-1
Q=138.5 C.F.S.
Q=139.0 C.F.S.
Q=138.5 C.F.S.
Velocity distribution
End of jump
Beginning of roller
Sta. 265+74.3
Sta. 265+80
Sta. 265 91.73
Sta. 266+00
Sta. 266+10
Sta. 266+11.73
Sta. 266+20
Sta. 266+30
Sta. 266+40
Sta. 266+50
Sta. 266+60
Sta. 265+92.50
Sta. 265+91.73
Sta. 265+92.35
37.08'
31.67'
35.0'
30.0'
14.79'
8.75'
8'
7.91'
3898
3896
3894
3892
3890
3887.66
(PROTOTYPE) SCALE IN FEET
(MODEL) SCALE IN INCHES
VELOCITY SCALE IN FT. PER SEC. (PROTOTYPE)

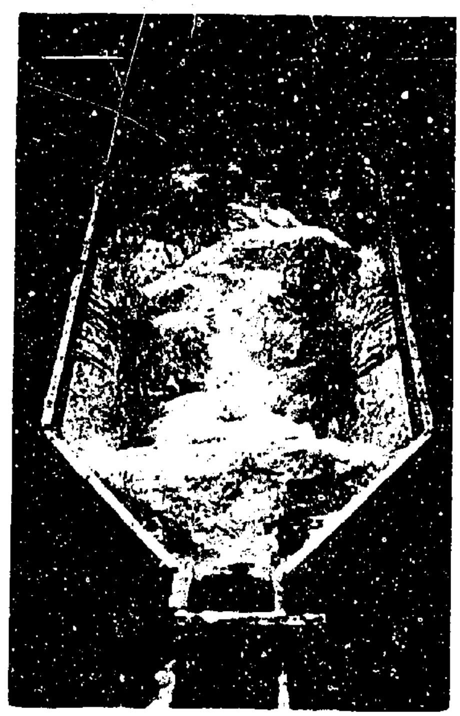


A. STEPPED APRON INSTALLED AT LOWER END OF CHUTE.

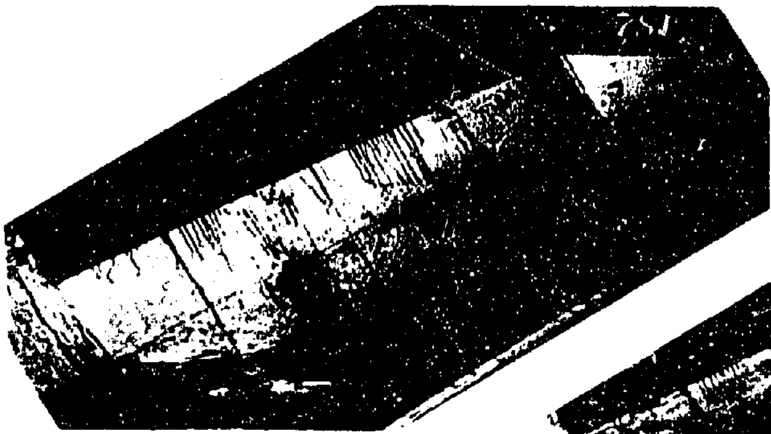


B. DISCHARGE 139 SECOND-FEET. STEPPED APRON 0.83 FOOT ABOVE POOL FLOOR.

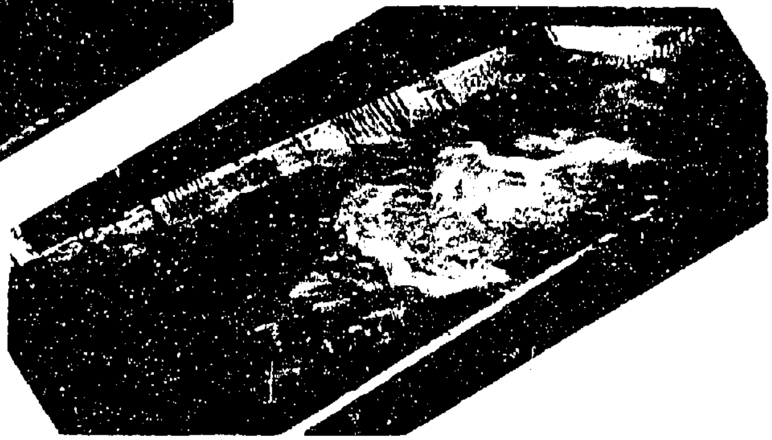
C. DISCHARGE 138.5 SECOND-FEET. STEPPED APRON 1.0 FOOT ABOVE POOL FLOOR.



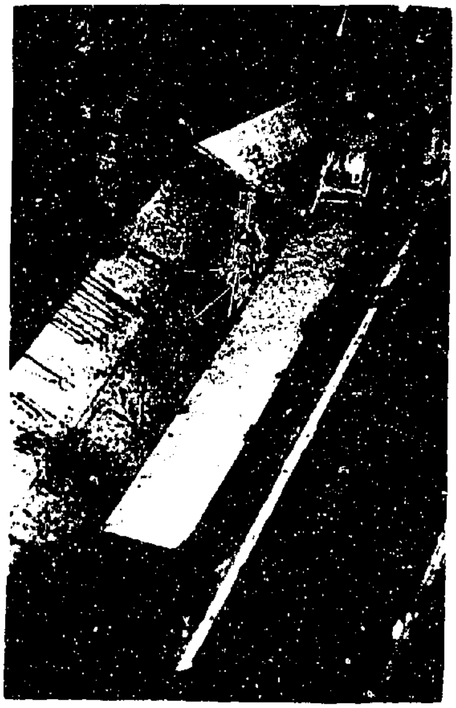
D. DISCHARGE 138.5 SECOND-FEET. STEPPED APRON 0.62 FOOT ABOVE POOL FLOOR.



A. REHBOCK SILL INSTALLED ON STILLING POOL FLOOR.

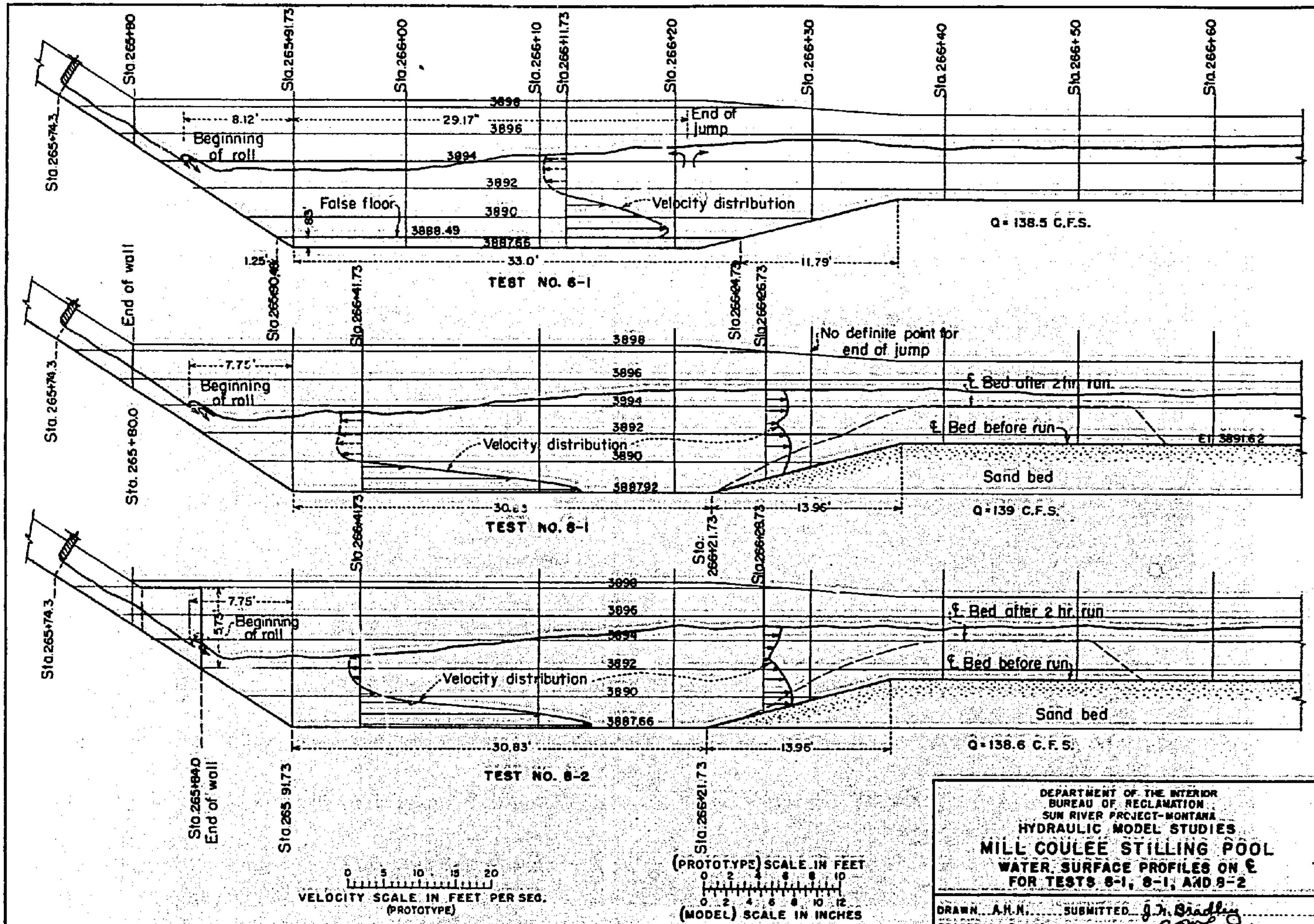


B. DISCHARGE 138.5 SECOND-FEET. REHBOCK SILL INSTALLED.



C. FALSE FLOOR INSTALLED 0.83 FOOT ABOVE ORIGINAL POOL FLOOR.

D. DISCHARGE 138.5 SECOND-FEET. FALSE FLOOR INSTALLED.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
HYDRAULIC MODEL STUDIES
MILL COULEE STILLING POOL
WATER SURFACE PROFILES ON ℄
FOR TESTS 6-1, 8-1, AND 8-2

DRAWN A.H.N.	SUBMITTED J. N. Bradley
TRACED A.L.R.-J.O.K.	RECOMMENDED E. W. Lane
CHECKED A.N.	APPROVED [illegible]
	DENVER, COLO. MARCH 20, 1935 28-D-336

FIGURE 6

The motive behind practically all revisions thus far described was to spread the jet in some way or another. Water flowing at super critical velocities such as in this case can be spread in a lateral direction only very gradually unless an appreciable amount of centrifugal force is created in the zone where the slope of the chute changes to horizontal. In this case, the contrifugal force was small and the jet failed to spread.

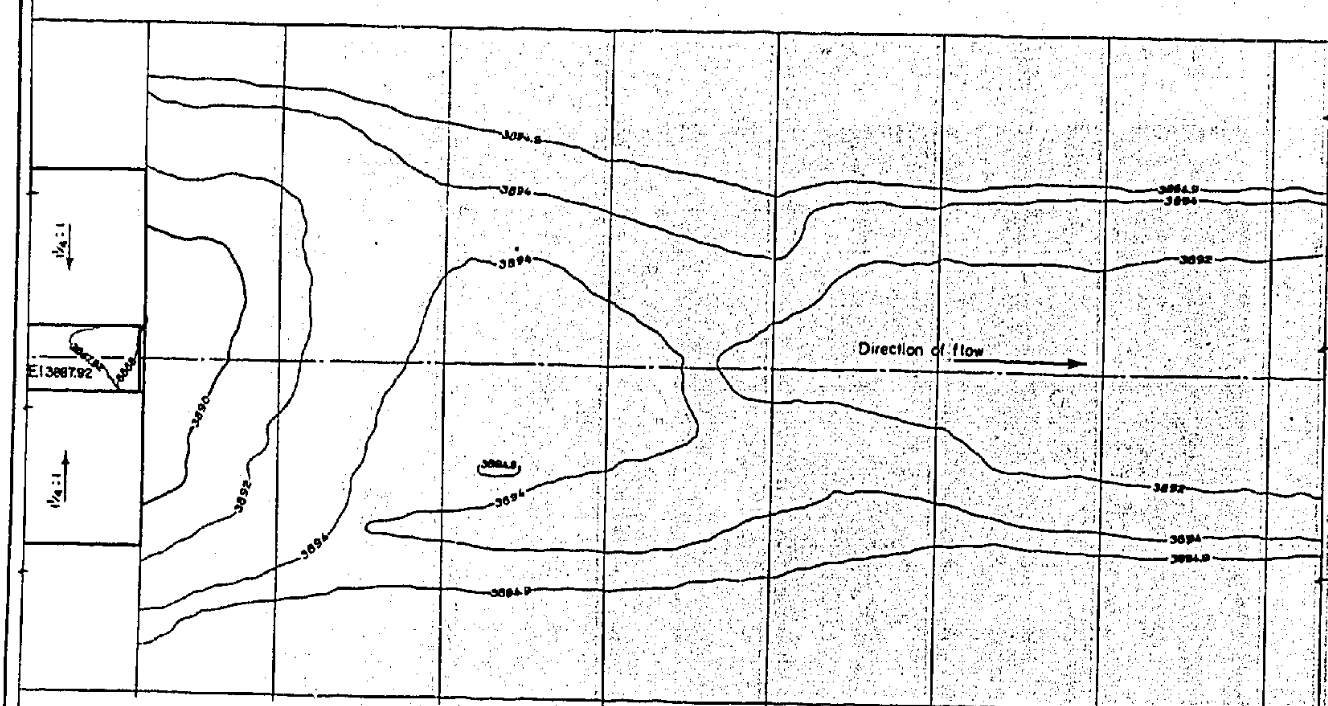
Erosion Studies Downstream from Stilling Pool

As chutes of this type usually lead to earth or gravel sections immediately downstream, it is important that water leaving the stilling pool be quiet. Choppy surface disturbances or turbulent conditions in an earth channel will undercut the sides, causing them to cave in, and this will require unnecessary maintenance. It is therefore expedient to design chutes and stilling pools which will be effective in their action so that the water leaving the jump will be quiet and possess a minimum amount of energy.

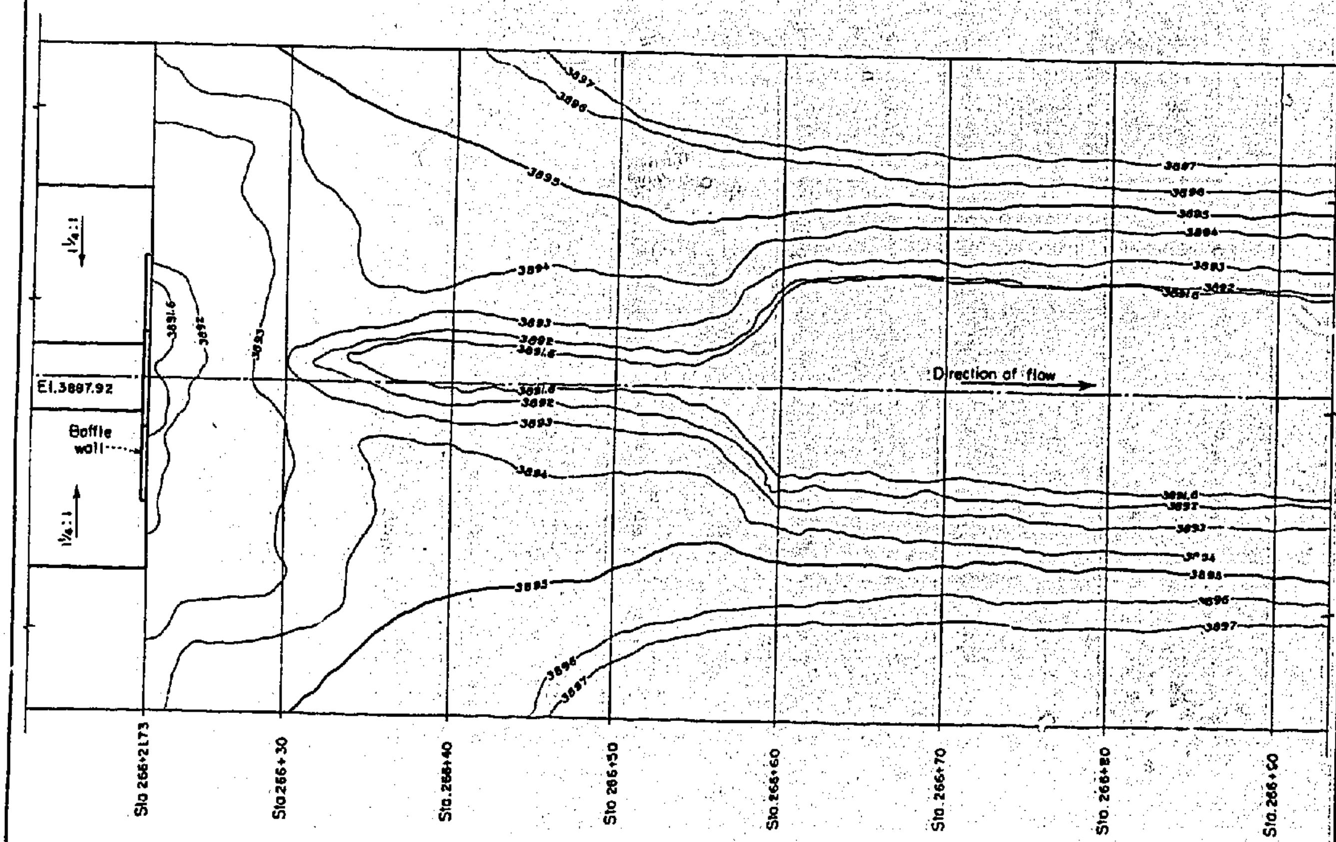
In order to duplicate field conditions to some extent, the stilling pool was cut off at station 266+21.73 and a sand box was substituted for the downstream portion. The false floor used in the previous test was removed so the model again represented the original design except for the addition of the sand box. Before each test, the sand in the box was troweled to the same shape that the sheet metal assumed in the former tests. Test 8-1 (figure 6) shows the profile of a run made at maximum discharge with the model revised. A topographic plot of the sand surface taken after the test had proceeded for two hours is shown plotted as test 8-1 on figure 7. Photograph A (plate 4) shows the revised model in operation, and photograph B is a view of the sand bed after the two hour run. As can be observed, most of the erosion occurred directly downstream from the stilling pool.

Test 8-2 plotted on figure 6 much resembled the previous test 8-1. The only difference between the two being that the vertical chute walls ended at station 265+80 in test 8-1 and in all previous tests, while in test 8-2 these walls were extended downstream to station 265+84.00. The results obtained from this test were practically identical with those witnessed for test 8-1, therefore, they will not be discussed further.

FIGURE 7



TEST NO. 8-1 Q=139 C.F.S.



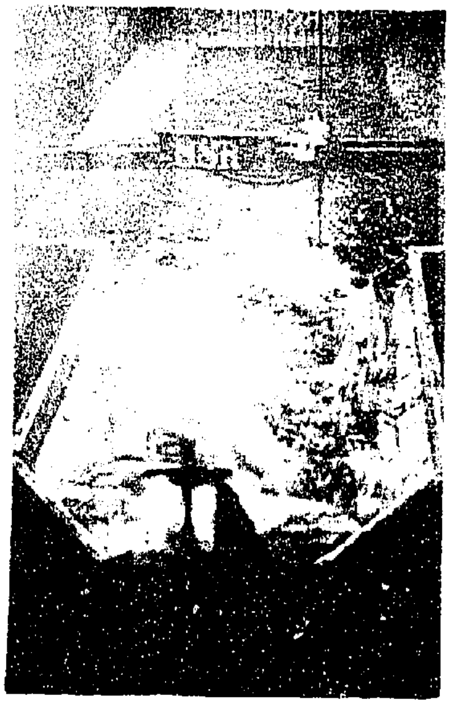
TEST NO. 10-1 Q=139 C.F.S

SCALE IN FEET - PROTOTYPE
SCALE IN INCHES - MODEL

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
HYDRAULIC MODEL STUDIES
MILL COULEE STILLING POOL
PROFILES OF SAND SURFACES TAKEN AFTER RUNS OF 2 HOUR DURATION

DRAWN A.M.R. SUBMITTED J. E. Bradley
TRACED G.G.R.-J.O.K. RECOMMENDED
CHECKED A.N. APPROVED

DENVER, COLO. MARCH 30, 1938 28-D-337



A. DISCHARGE 139 SECOND-FEET. LOWER PORTION OF POOL REPLACED BY SAND BOX.

B. VIEW OF SAND BED AFTER A 2-HOUR RUN AT MAXIMUM DISCHARGE.

C. ONE OF THE BAFFLE WALLS TRIED.

D. DISCHARGE 139 SECOND-FEET. BAFFLE WALL SHOWN IN PHOTOGRAPH C, INSTALLED.

Baffle Walls, Weirs, and Boxes

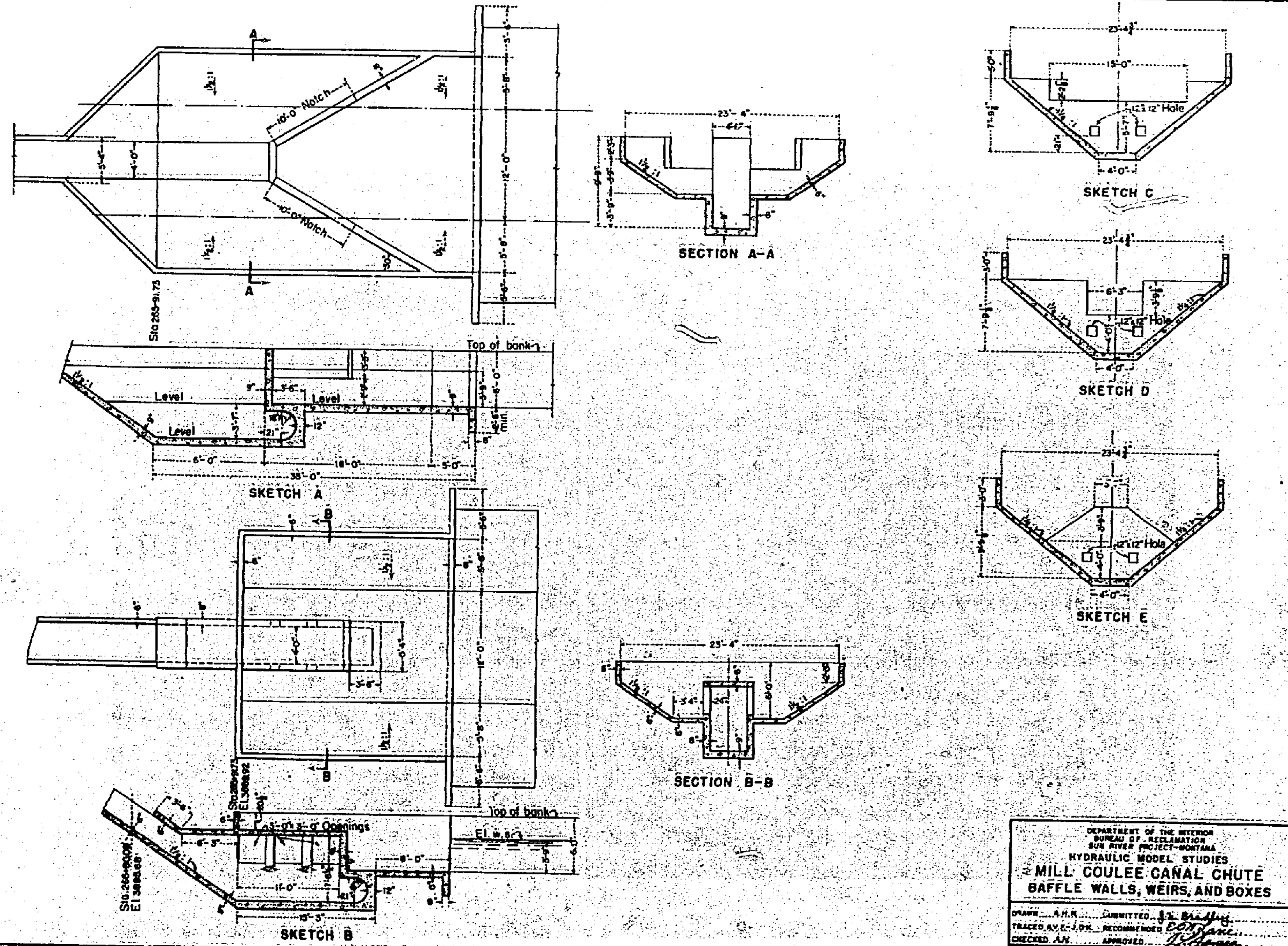
It was suggested that various baffle arrangements be tried in an effort to improve the action in the stilling pool. One of these is shown installed on the model in photograph C (plate 4). A detailed drawing of this baffle is shown as sketch E on figure 8. Photograph D (plate 4) shows the stilling pool in operation for the maximum discharge of 139 c.f.s. The topography of the sand surface which was taken after a two hour run is shown as test 10-1 on figure 7. As the baffle wall obstructed part of the channel, the velocity was increased at this point, and erosion of the sand directly below it was very pronounced. Photograph D (plate 4) shows the water surface in the pool to be very turbulent with this baffle installed.

Two other baffles closely resembling the one just described were installed consecutively in the same position in the model. These are shown in detail as sketches C and D on figure 8. The results were very similar to those obtained for test 10-1.

A fourth baffle arrangement which was tried is shown as sketch A on figure 8. It is shown installed in the model on photograph A, plate 5. Photograph B shows the pool in operation at maximum discharge with this baffle installed.

A fifth design somewhat similar to the last one was a baffle box which is shown as sketch B on figure 8. Photograph C (plate 5) shows this box built into the model. The purpose of the box was to turn the jet of water issuing from the chute back on itself and then change the direction of flow. There were six windows in the box but most of the water squirted out of the two farthest downstream as can be seen in photograph D, plate 5. These two jets were so concentrated that it was necessary to nail pieces of sheet metal on the sides of the channel to keep the water from shooting out of the pool. A portion of the two downstream windows was then blocked off and the box performed somewhat better. Considerable disturbance however, was again produced when the tailwater depth was decreased.

There are three disadvantages to baffle weirs and boxes of this type in stilling pools. First, they are expensive to construct. Second, this type of baffle is a trash collector especially when it is small such as this one. Cleaning would be necessary and this would involve increased maintenance costs. Third, baffle weirs and boxes of this type would be a detriment to life. If a man or an animal accidentally fell into a chute and was carried thru one of these, he would be fortunate to emerge alive. It is easily possible for a man to be carried thru an open hydraulic jump, if not too large, without injury.

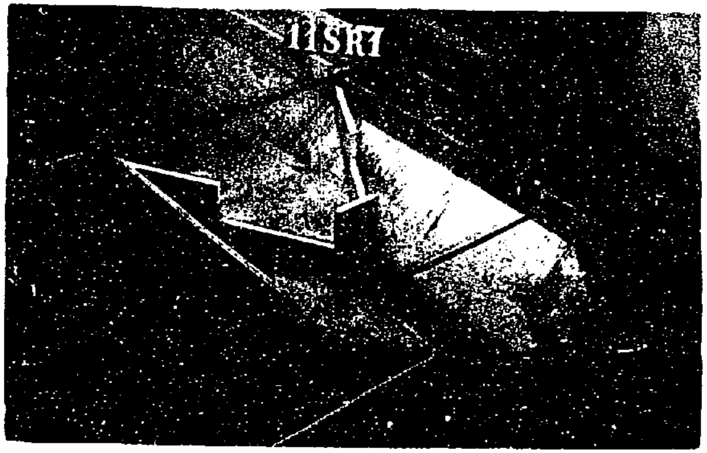


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SUN RIVER PROJECT-MONTANA
HYDRAULIC MODEL STUDIES
MILL COULEE CANAL CHUTE
BAFFLE WALLS, WEIRS, AND BOXES

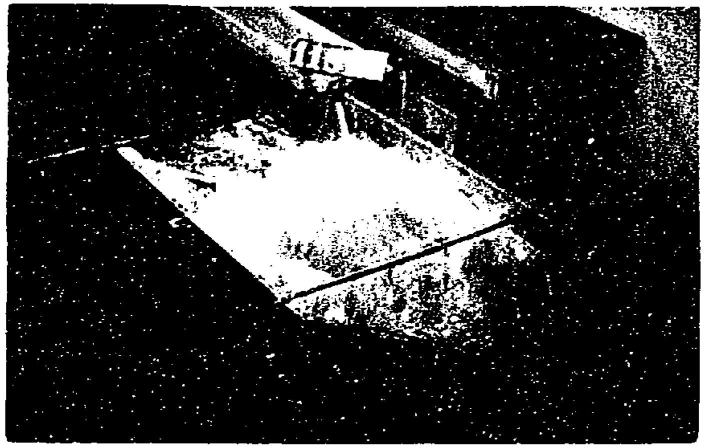
DRAWN A.H.R. SUBMITTED
TRACED A.V.E.-J.O.K. RECOMMENDED
CHECKED A.N. APPROVED

DENVER, COLO., MARCH 20, 1936 PB-D-338

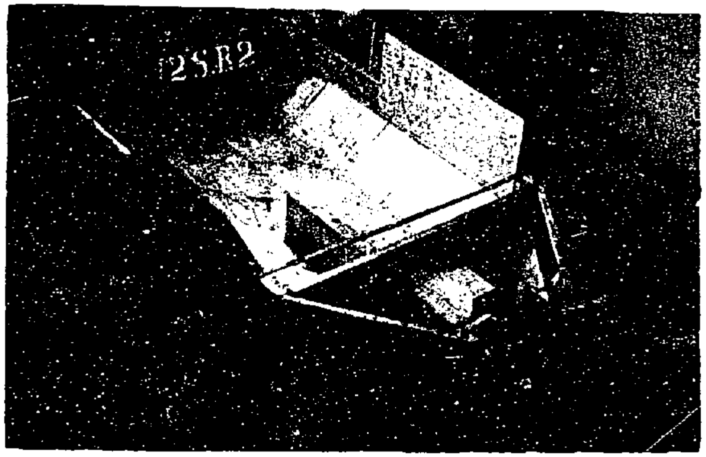
FIGURE 8



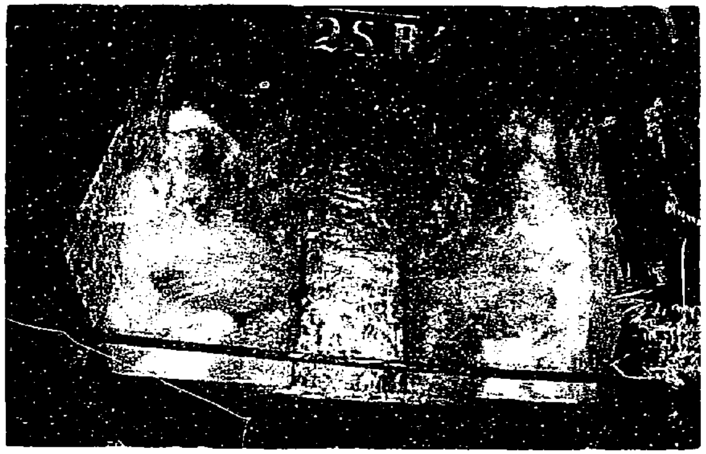
A. BAFFLE WEIR INSTALLED IN MODEL.



B. DISCHARGE 139 SECOND-FEET.
BAFFLE WEIR INSTALLED.



C. BAFFLE BOX INSTALLED IN MODEL.



D. DISCHARGE 139 SECOND-FEET.
BAFFLE BOX INSTALLED.

Hydraulic Jump Experiments

A series of experiments were made on the model as originally designed in order to determine the hydraulic jump characteristics for a trapezoidal channel of this nature. Due to the roughness of the water surface in the pool, it was very difficult to accurately measure the depth at the beginning and end of the jump. Due to the indefinite nature of the jump, which formed only in the center of the pool, measurements concerning its length were slightly better than a guess. Velocity measurements too, were very confusing except when taken near the center of the pool as water was continually flowing upstream without restraint along both sides of the pool. In short, the hydraulic jump experiments netted no reliable data.

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SOUTH CANAL CHUTE

Sta. 25+19

UNCOMPAHGRE PROJECT - COLORADO

General Description

A chute drop was designed to replace a series of drops which have become excessively worn on the South Uncompahgre Canal. A model of the original design which is shown in prototype on figure 9 was constructed and tested in the laboratory. As can be observed from the drawing, the general shape of this chute drop was very similar to the one previously described on the Mill Coulee canal. The results were also very similar to those obtained on the Mill Coulee chute.

Acting upon the failure to obtaine the desired results on this and the previously described models, together with suggestions made by the laboratory force, a redesigned chute was submitted for testing. A drawing of the new design is shown as chute B, figure 9. In this case, the chute and stilling pool were rectangular in section throughout. Model tests showed the chute proper to flare too rapidly and the stilling pool to be too wide. As a result, the depth of flow in the sloping chute varied from maximum at the center to practically nothing at the sides, and the jump was much more effective in the center of the stilling pool than near the sides. The pool was subjected to some whirling motion and the jump lacked stability. In spite of these flaws, this chute exhibited a considerable improvement over the original design.

The pool was then contracted from a width of 36 feet to 24 feet and the flare of the chute was reduced accordingly by installing false side walls in the model as indicated by the dotted lines in Design B, figure 9. The spread of the jet in the chute was much more uniform and pool conditions were greatly improved. These encouraging results led up to another design which proved to be very satisfactory.

This third design which was presented for model studies is shown as chute C on figure 9. The flare of the chute was gradual and in this case, it continued thru to the end of the stilling pool. The chute and pool remained rectangular in cross section. The pool floor for this design was in two forms; namely, that shown in Design C (figure 9) and an alternate pool floor shown as "The Recommended Design" in the same figure. The two worked equally well but the alternate design proved to be the favorite because of structural reasons. The advantages of a chute drop of this type are:

(1) The jet succeeds in expanding uniformly in the sloping chute before it reaches the stilling pool;

(2) The jump forms with nearly equal effectiveness across the entire pool; and

(3) Whirling motion is totally eliminated.

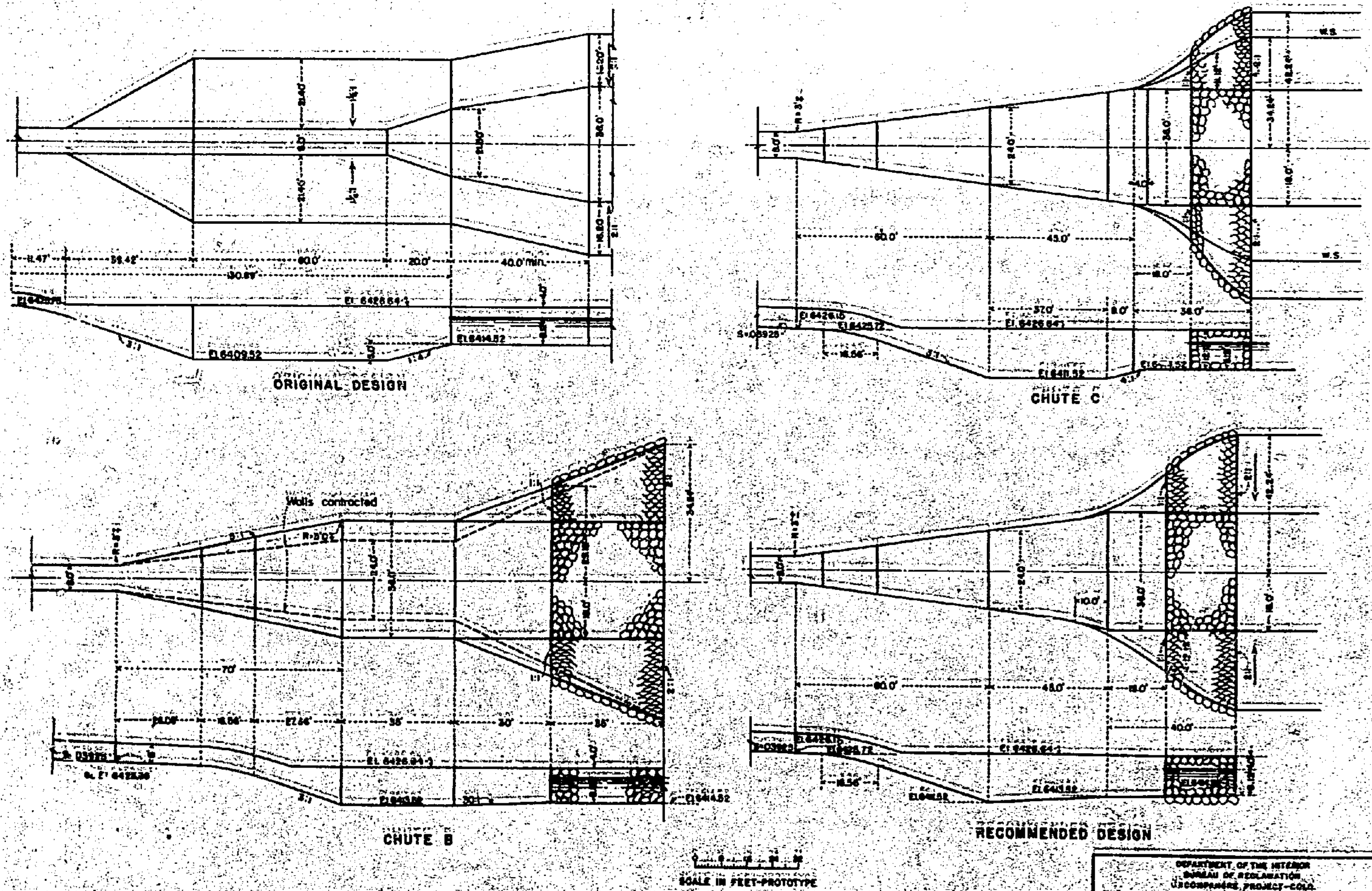


FIGURE 9

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UNCOMPAHGRE PROJECT—COLO.
HYDRAULIC MODEL STUDIES

COMPARISON OF VARIOUS CHUTE DESIGNS

DRAWN A.H.R. SUBMITTED
TRACED R.L.S. D.R.S. RECOMMENDED
CHECKED A.W. APPROVED
DENVER, COLO.
31-D-171

A prototype drawing of the chute as recommended is shown in figure 10. Results up to this point were judged mainly from visual observations. No actual measurements were recorded.

The Model of the Recommended Chute

A model of the recommended design was constructed on a scale of 1:20 and is shown drawn on figure 11. Except for the sheet metal transition below the stilling pool, it was made entirely of wood. The water was measured over a small V-notch weir after it had passed thru the model. From here, it flowed into the main laboratory equipment and was pumped up into the laboratory head tanks. It then flowed by gravity to the forebay of the model. The chute connected to the forebay thru a rectangular hole in one of the forebay walls. A rectangular gate was located at this point by which the depth of flow in the chute could be regulated. After passing thru the model, the water again entered the small weir box and thus commenced another cycle thru the system. Water surface measurements down the chute and in the pool were made with a point gage. Velocities in the chute were obtained from pitot tube readings. Tailwater elevations were observed from a piezometer.

Tests on the Recommended Chute

The recommended design is shown in prototype dimensions on figure 10. Photographs illustrating the construction of the model are shown as A and B on plate 6. Tests 1 to 3 (figure 12) show profiles of the water surfaces in the chute and in the pool for the maximum discharge of 950 c.f.s. using three tailwater elevations, namely, 6422.7, 6423.3, and 6421.9. As the tailwater that will be encountered in the field is somewhat uncertain, it was thought expedient to use a range of tailwater depths for each discharge. The dotted line plotted in the chute represents the water surface measured on the center line and the full line indicates the water surface near the sides. All water surface measurements in the pool were taken near the side walls. Photographs showing the chute in operation for the three tailwater depths just mentioned are shown in views C and D (plate 6) and A (plate 7). The profiles and photographs both show the jump to be of moderate length and very effective in its action. Notice that the water directly below the jump is quiet.

This particular chute will be located near the Montrose hydraulic laboratory, and it is intended that after its completion the laboratory staff will take measurements on the prototype structure. This will afford an excellent opportunity to compare results from model and prototype.

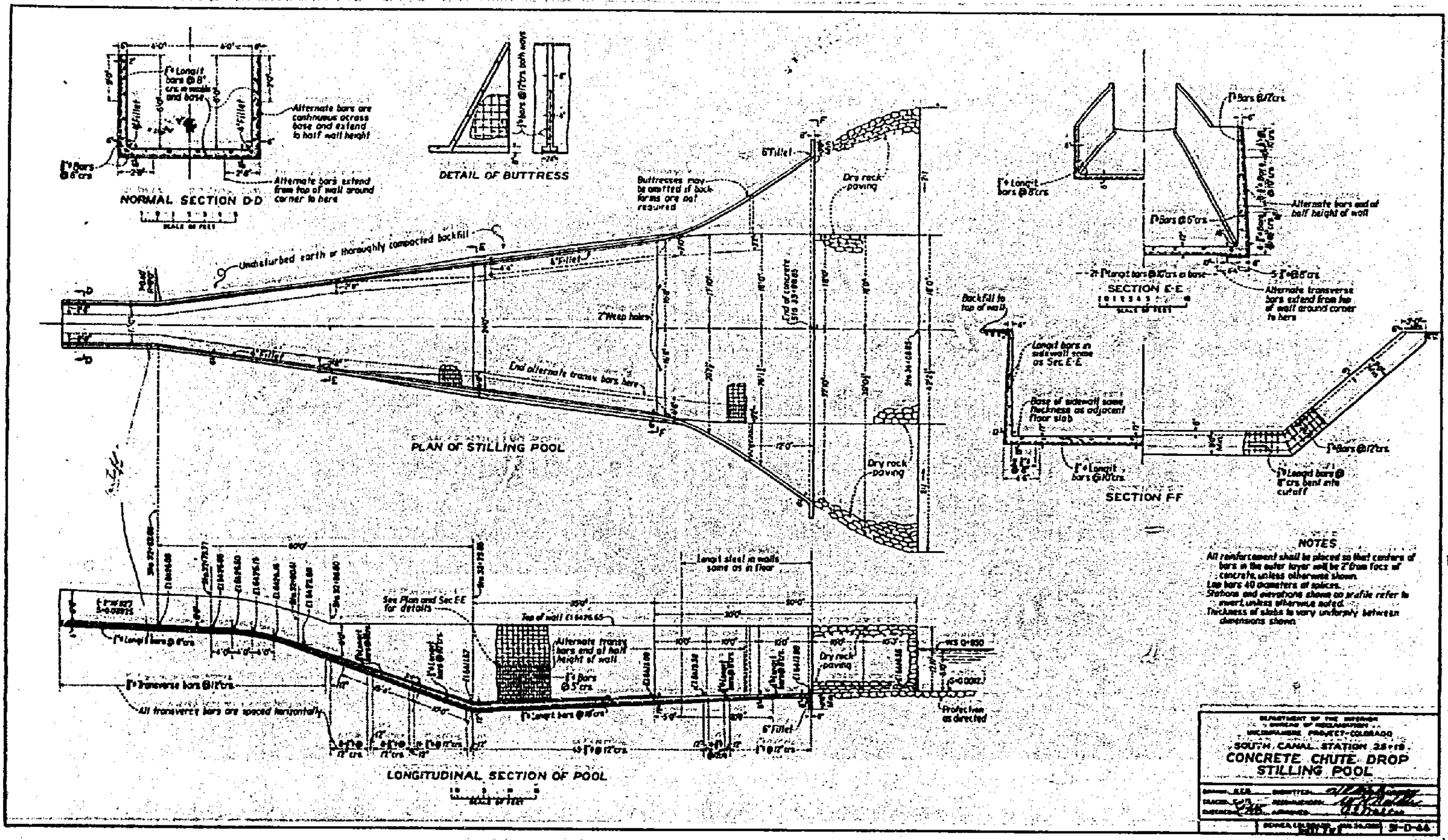

NORMAL SECTION D-D
DETAIL OF BUTTRESS
PLAN OF STILLING POOL
SECTION E-E
SECTION F-F
LONGITUDINAL SECTION OF POOL
Undisturbed earth or thoroughly compacted backfill
Buttresses may be omitted if back forms are not required
Dry rock paving
NOTES
All reinforcement shall be placed so that centers of bars in the outer layer will be 2" from face of concrete, unless otherwise shown.
Lap bars 40 diameters at splices.
Stations and elevations shown on profile refer to invert, unless otherwise noted.
Thickness of slabs to vary uniformly between dimensions shown.
SOUTH CANAL STATION 25+18
CONCRETE CHUTE DROP
STILLING POOL

FIG. 10

FIGURE 11

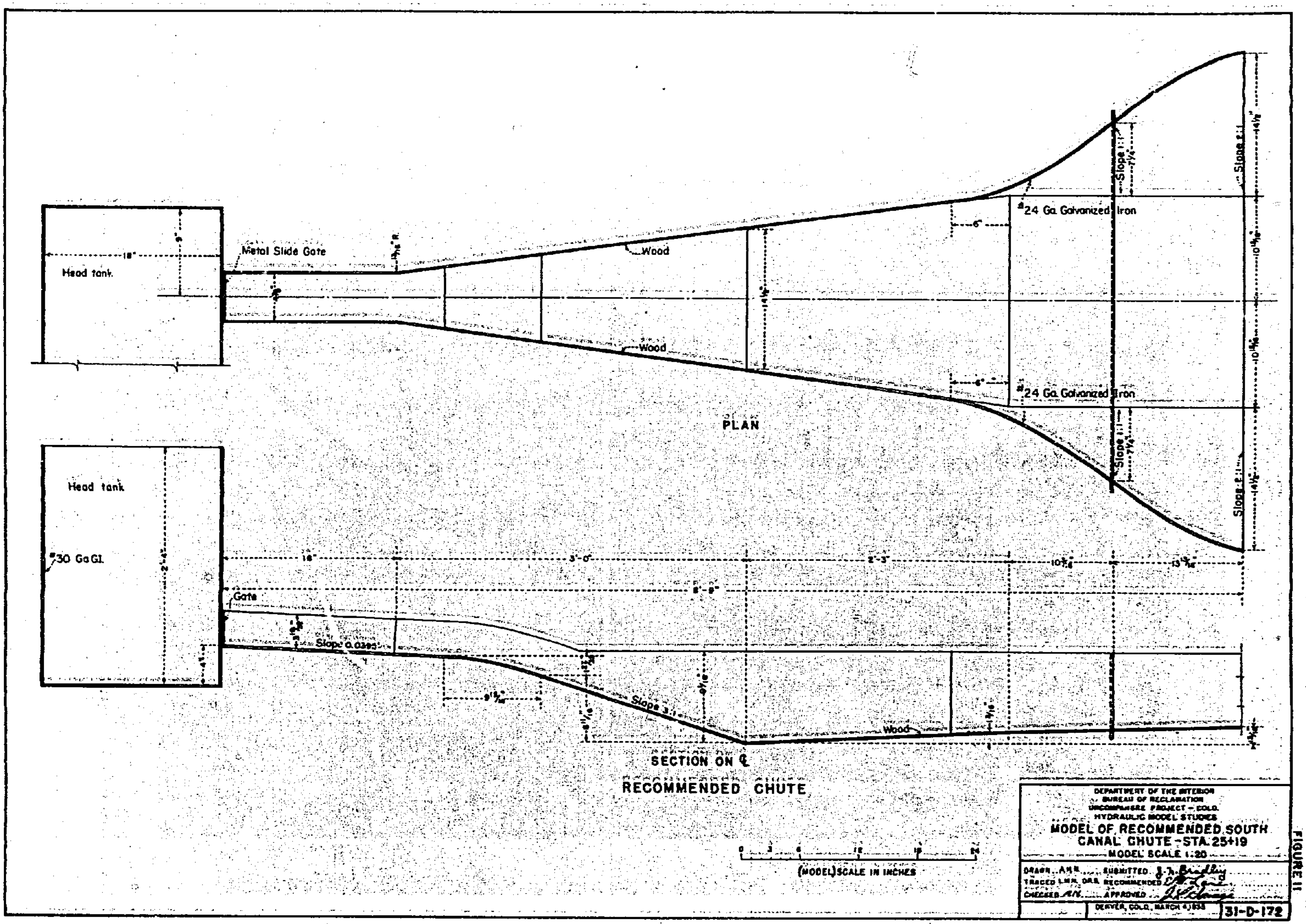
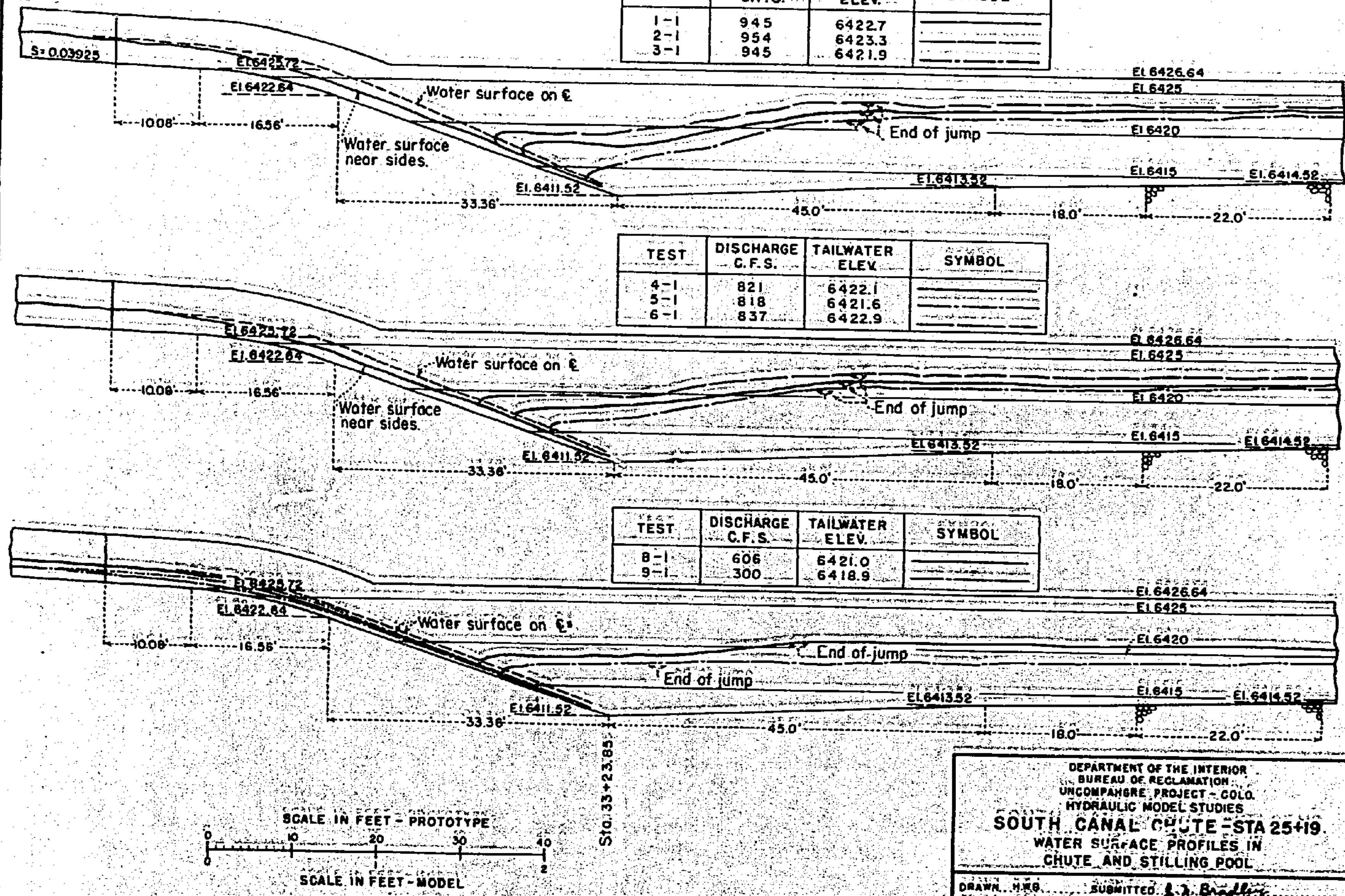

Head tank
Metal Slide Gate
Wood
Wood
#24 Ga. Galvanized Iron
#24 Ga. Galvanized Iron
PLAN
Head tank
#30 Ga G.I.
Gate
Slope 0.0385
Slope 3:1
Wood
SECTION ON ℄
RECOMMENDED CHUTE
(MODEL) SCALE IN INCHES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
HYDRAULIC MODEL STUDIES
MODEL OF RECOMMENDED SOUTH
CANAL CHUTE - STA. 25+19
MODEL SCALE 1:20
31-D-172

FIGURE 12



TEST	DISCHARGE C.F.S.	TAILWATER ELEV.	SYMBOL
1-1	945	6422.7	
2-1	954	6423.3	
3-1	945	6421.9	

TEST	DISCHARGE C.F.S.	TAILWATER ELEV.	SYMBOL
4-1	821	6422.1	
5-1	818	6421.6	
6-1	837	6422.9	

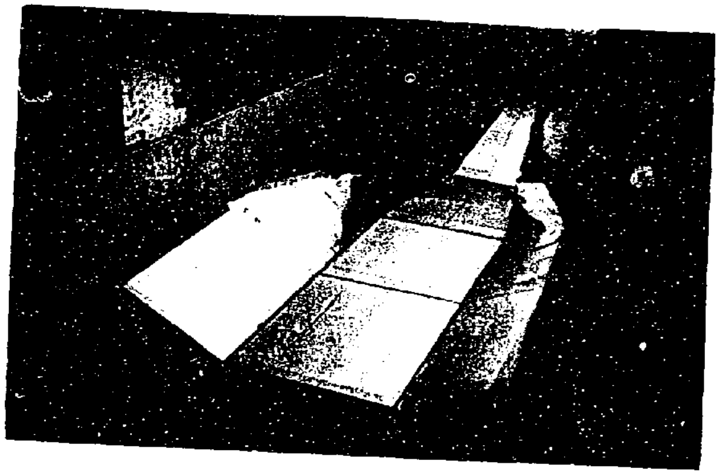
TEST	DISCHARGE C.F.S.	TAILWATER ELEV.	SYMBOL
8-1	606	6421.0	
9-1	300	6418.9	

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UNCOMPAHGRE PROJECT - COLO.
HYDRAULIC MODEL STUDIES

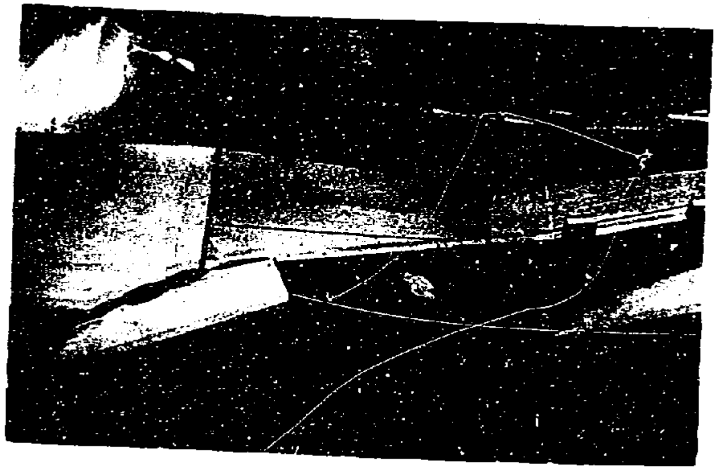
SOUTH CANAL CHUTE - STA 25+19.
WATER SURFACE PROFILES IN CHUTE AND STILLING POOL

DRAWN H.K.B. SUBMITTED J. J. Bradley
TRACED A.E.L. OR S. RECOMMENDED E. W. Lane
CHECKED A.H.H. APPROVED J. L. Savage

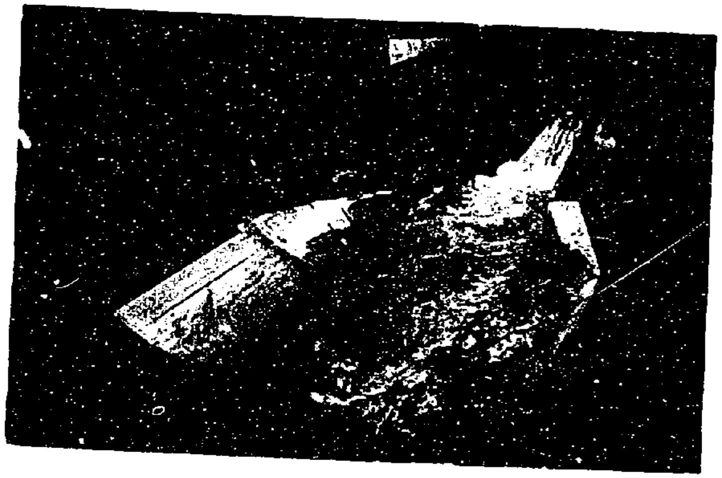
DENVER, COLO., MARCH 4, 1935 31-D-173



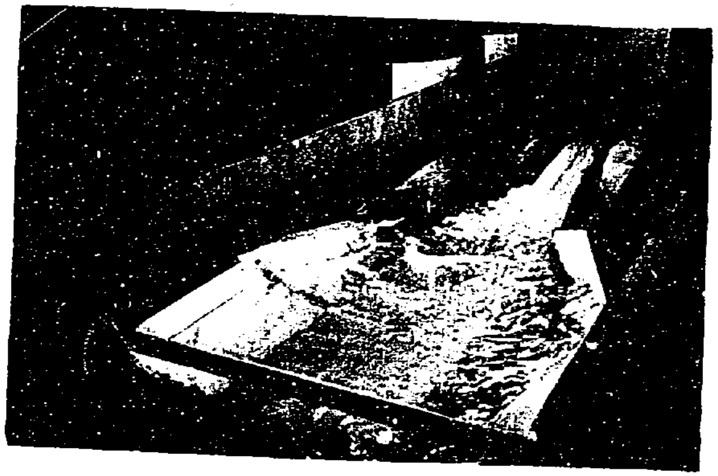
A. VIEW SHOWING CONSTRUCTION OF CHUTE.



B. VIEW SHOWING CONSTRUCTION OF STILLING POOL.



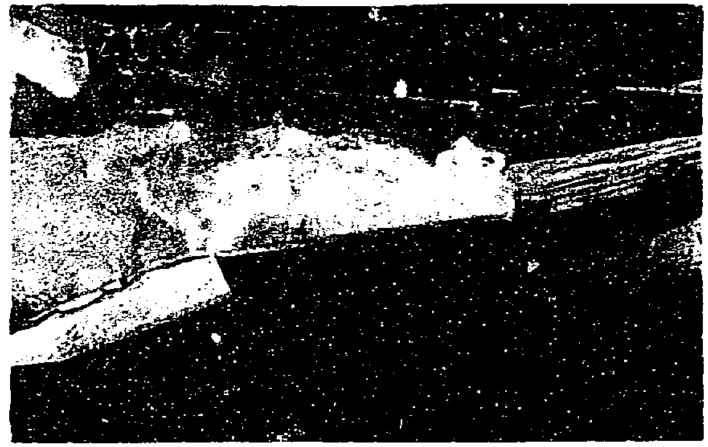
C. DISCHARGE 945 SECOND-FEET.
TAILWATER ELEVATION 6422.7.



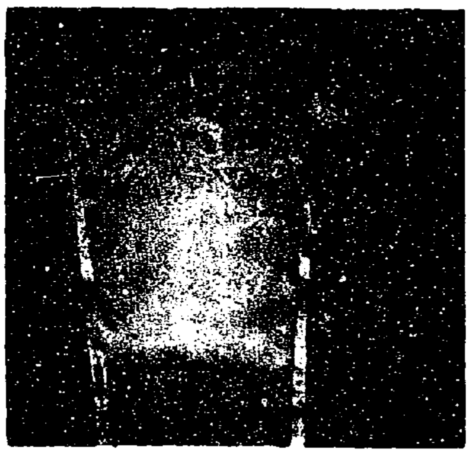
D. DISCHARGE 954 SECOND-FEET.
TAILWATER ELEVATION 6423.3.

RECOMMENDED DESIGN.

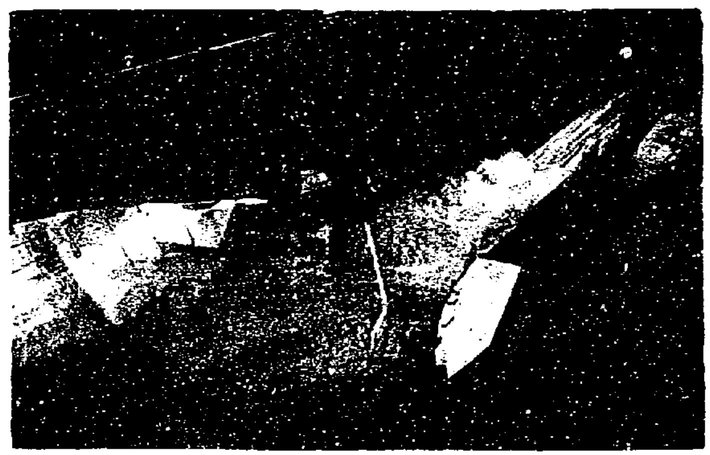
A. DISCHARGE 945 SECOND-FEET.
TAILWATER ELEVATION 6421.9.



B. DISCHARGE 821 SECOND-FEET.
TAILWATER ELEVATION 6422.1.



C. DISCHARGE 818 SECOND-FEET.
TAILWATER ELEVATION 6421.6.



D. DISCHARGE 837 SECOND-FEET.
TAILWATER ELEVATION 6422.9.

RECOMMENDED DESIGN.

As the chute was shortened considerably in the model, prototype conditions were duplicated by adjusting the discharge together with either the depth of flow or the velocity at station 32+63.85 so as to correspond with the computed values. In some tests, the discharge and depth of flow were adjusted and the velocity was measured. The measured velocities checked the computed values fairly well.

Tests 4, 5, and 6 were made at discharges of about 825 c.f.s. for tailwater elevations of 6422.1, 6421.6, and 6422.9. Profiles of these tests are shown plotted on figure 12, and photographs of the pool in action are shown in views B, C, and D on plate 7.

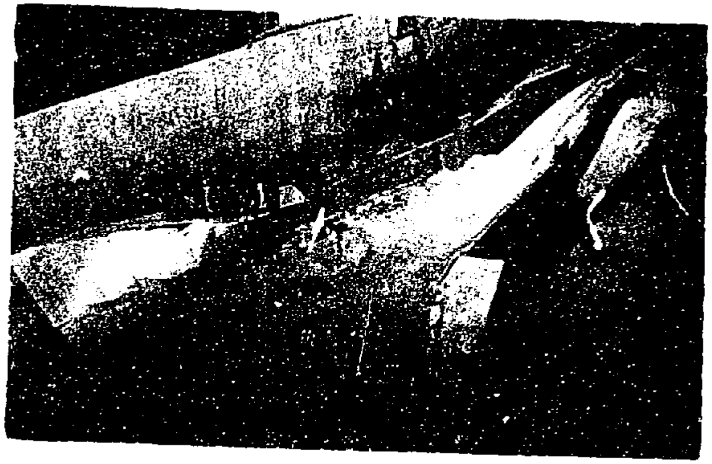
Tests 8 and 9 shown plotted on figure 12, were a continuation of the tests previously described. These were made at discharges of 606 and 300 c.f.s. with tailwater elevations of 6421.0 and 6418.9 respectively. In these two tests just one tailwater depth was used for each discharge. Photographs A and B (plate 8) show the pool for these two tests.

Addition of sills on pool floor

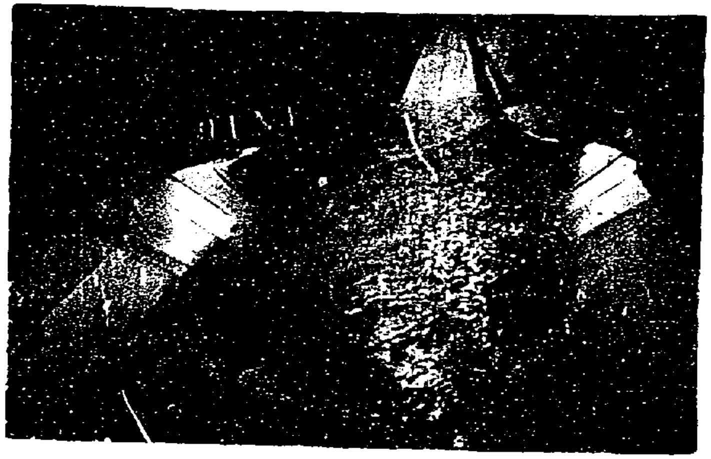
In order to investigate the merits of sills in a pool of this kind, a few were tried. Tests 11, 14 and 15 (figure 13) were made at various discharges and tailwater elevations with the downstream edge of a rectangular sill 2.0 feet wide and 1.0 foot high placed across the pool at station 33+58.85. Photographs A, B, and C (plate 9) show the water surface in the stilling pool for the three tests just mentioned. This sill produced very little change in the shape of the water surface in the pool and very little difference in the length of jump but it did aid in stabilizing it at all tailwater depths.

Test 16 (figure 14) was made at a discharge of 331 c.f.s. and a tailwater elevation of 6418.9 with a rectangular sill 1.5 feet high and 2.0 feet wide placed with the downstream edge at station 33+58.85. A photograph of the pool taken during this test is shown as D on plate 9. The sill raised the water surface slightly but made possible a jump which was stable in character and very effective in its action.

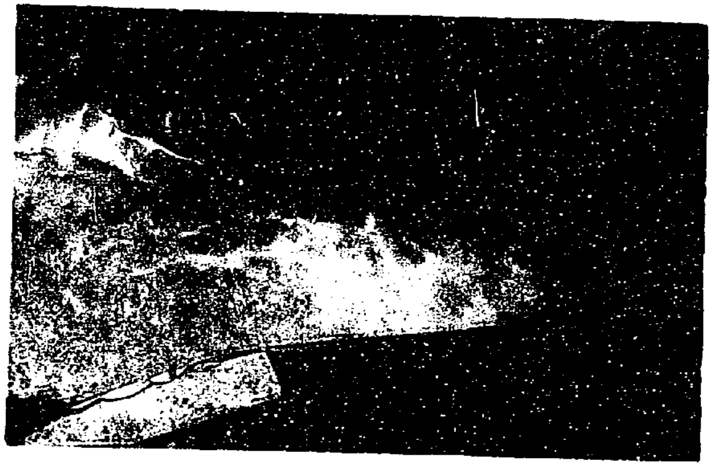
Tests 10 and 13 (figure 13) were conducted using each of the two sills previously described, modified so that the upstream faces were beveled at an angle of 45 degrees as shown. Photographs of the two tests are shown in pictures C and D, plate 8. These two sills were not as effective as the former ones in confining the jump to the pool for the lower tailwater depths.



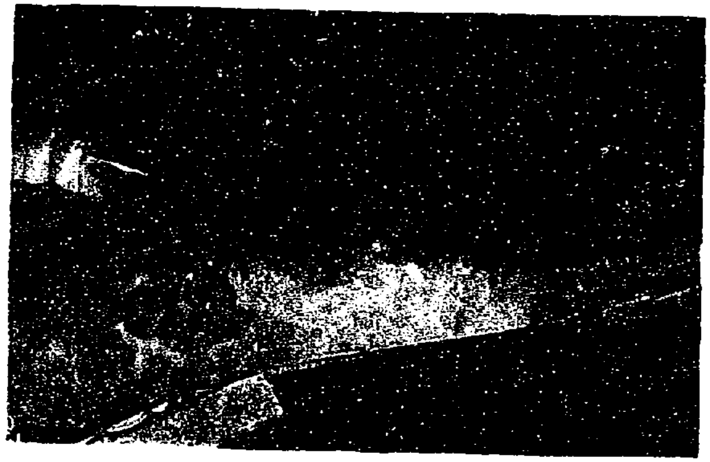
A. DISCHARGE 606 SECOND-FEET.
TAILWATER ELEVATION 6421.0.



B. DISCHARGE 300 SECOND-FEET.
TAILWATER ELEVATION 6418.9.



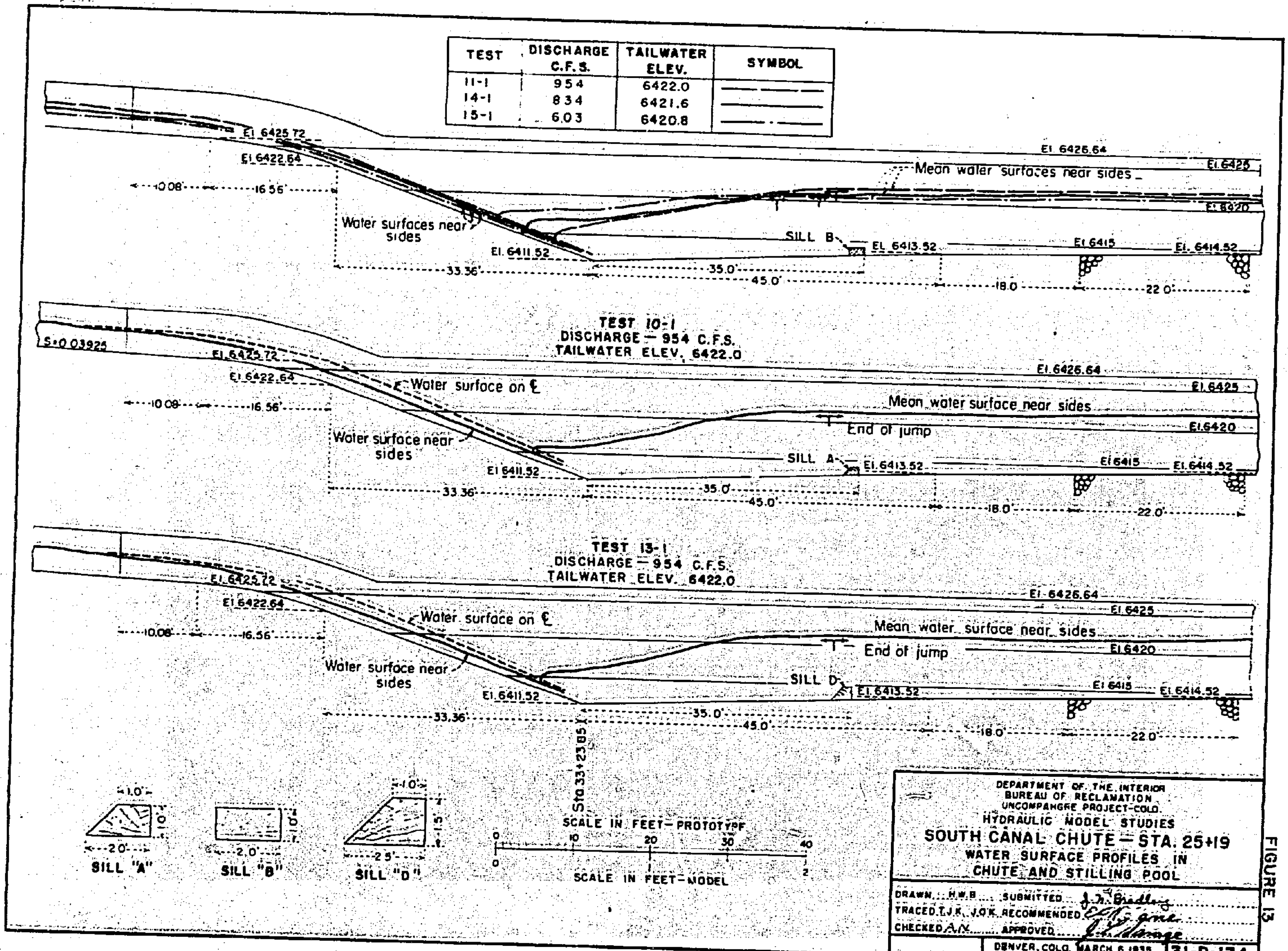
C. BEVELED SILL 1.0 FOOT HIGH INSTALLED.
DISCHARGE 954 SECOND-FEET.
TAILWATER ELEVATION 6422.0.



D. BEVELED SILL 1.5 FEET HIGH INSTALLED.
DISCHARGE 954 SECOND-FEET.
TAILWATER ELEVATION 6422.0.

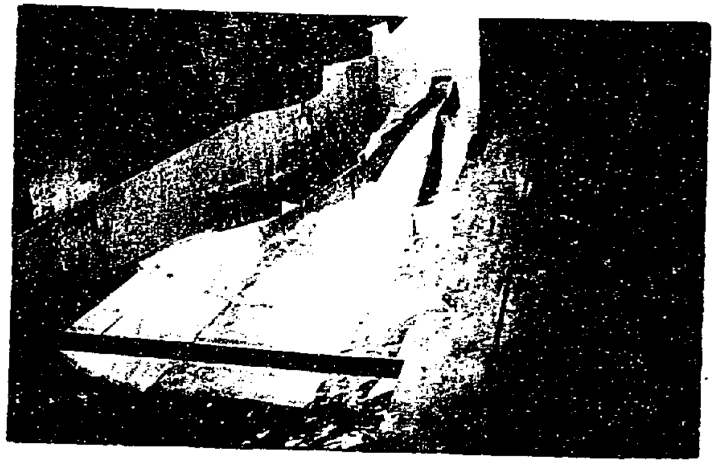
RECOMMENDED DESIGN.

FIGURE 13



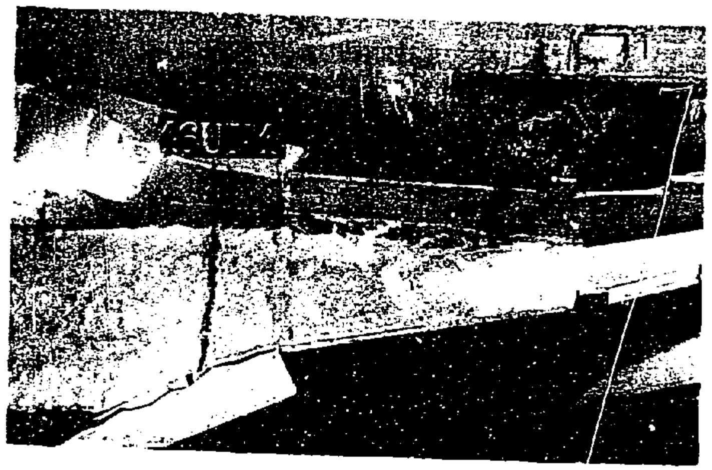
TEST	DISCHARGE C.F.S.	TAILWATER ELEV.	SYMBOL
11-1	954	6422.0	————
14-1	834	6421.6	— — —
15-1	6.03	6420.8	—·—·—

A. RECTANGULAR SILL 1.0 FOOT HIGH INSTALLED.
DISCHARGE 954 SECOND-FEET.
TAILWATER ELEVATION 6422.0.



B. RECTANGULAR SILL 1.0 FOOT HIGH INSTALLED
DISCHARGE 834 SECOND-FEET.
TAILWATER ELEVATION 6421.6.

C. RECTANGULAR SILL 1.0 FOOT HIGH INSTALLED.
DISCHARGE 603 SECOND-FEET.
TAILWATER ELEVATION 6420.8.



D. RECTANGULAR SILL 1.5 FEET HIGH INSTALLED.
DISCHARGE 331 SECOND-FEET.
TAILWATER ELEVATION 6418.9.

RECOMMENDED DESIGN.

The sills in general affected the length and shape of the jump only slightly but increased its stability over a wide range of tailwater depths. The jump, on the other hand, performed very satisfactorily without the sills and therefore their addition is optional.

Effect produced by increasing slope of chute

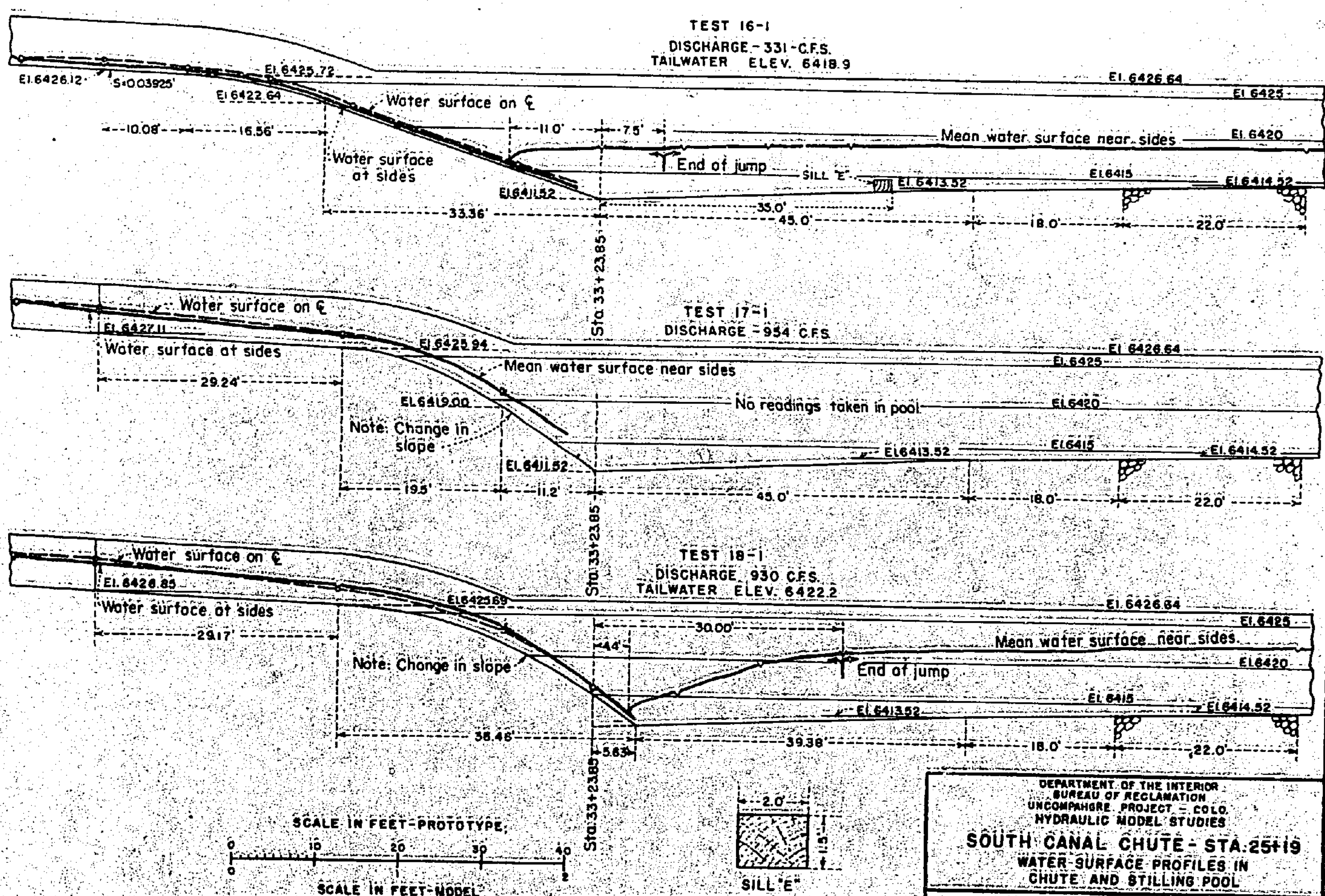
Two attempts were made to increase the slope at the lower end of the chute in order to observe the effect this would produce on conditions in the pool. The profiles for tests 17-1 and 18-1 on figure 14 indicate these slopes. Photograph A (plate 10) shows the model revised to represent the steepest slope tried and photograph B shows the chute in operation at the maximum discharge. Test 17-1 (figure 14) shows a profile of the water surface for this slope. It can be observed both from the profile and the photograph that the jet actually sprung clear of the floor when this steepest slope was used. Notice the fins near the side walls in photograph B. Pool conditions were practically unchanged and therefore were not plotted.

Test 18-1 (figure 14) shows a profile of the water surface using an intermediate slope and photograph C (plate 10) shows a view taken during this test. Notice in photograph C that the fins were still present in the chute. This slope also proved to be slightly excessive.

As a continuation of study along this line, a series of general experiments were performed in the laboratory on chutes having various slopes. An account of these experiments is included in this report under the heading of "General Chute Tests."

Summary

The model of the chute known as the "Recommended Design" in figure 9 was very satisfactory (with or without a sill) and it is believed that this design will prove very satisfactory under all conditions encountered in the field. The bureau constructs a number of canal chutes each year, and for this reason it is felt that the model studies on these small structures have been justifiable. A comparison of the costs of the original and recommended designs for the Uncompahgre chute drop showed very little difference, while the difference in the hydraulic action in the two was remarkable.



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UNCOMPAHGRE PROJECT - COLO.
HYDRAULIC MODEL STUDIES

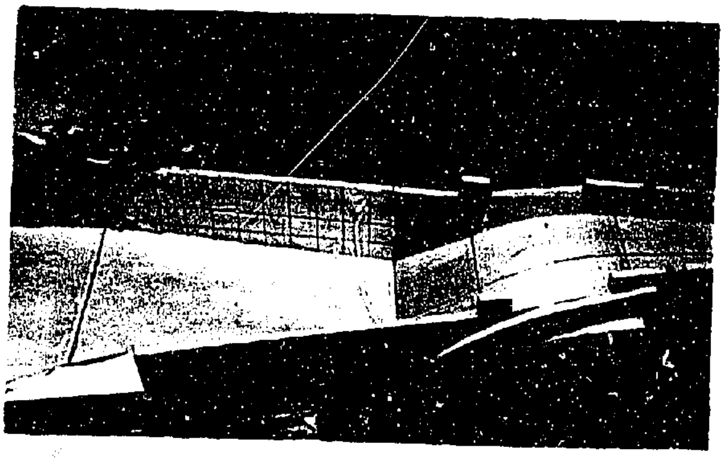
SOUTH CANAL CHUTE - STA. 25+19

WATER SURFACE PROFILES IN CHUTE AND STILLING POOL

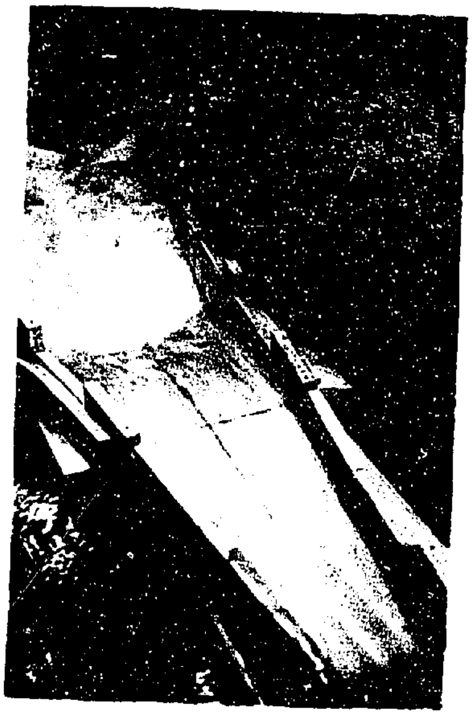
DRAWN H.W.B. SUBMITTED J. E. Bradley
TRACED RAP. ORS. RECOMMENDED E. W. Lane
CHECKED A.H.H. APPROVED J. L. Savage

DENVER, COLO., MARCH 4, 1935 31-D-175

FIGURE 14



A. SLOPE OF CHUTE INCREASED.



B. MAXIMUM CHUTE SLOPE.
DISCHARGE 954 SECOND-FEET.

C. INTERMEDIATE CHUTE SLOPE.
DISCHARGE 930 SECOND-FEET.

GENERAL CHUTE TESTS

Description of Layout

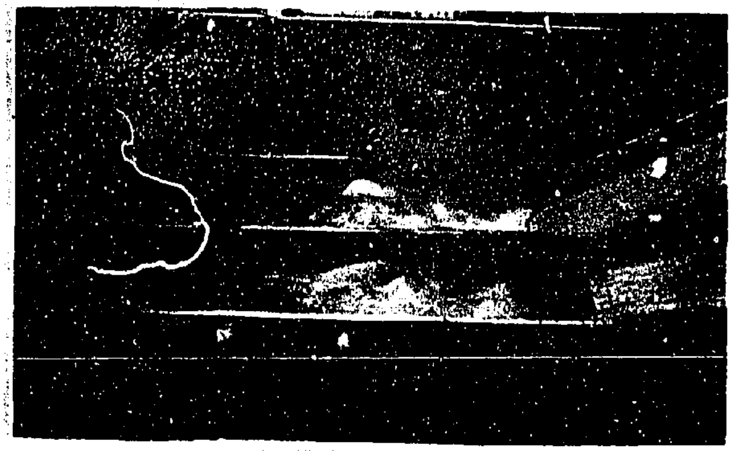
Several general tests were made in order to determine the effect produced on the hydraulic jump when the shape of the pool and the slope of the chute leading to the pool were varied. The layout consisted of two chutes each 10-7/16 inches wide located adjacent to one another as shown in photograph B, plate 11. The chute on the right looking downstream in photograph B, and which will be referred to as Chute A, was on a slope of $1\frac{1}{2}$:1 and it remained unchanged throughout the following tests. It represented an average chute and pool and was used as a means by which the others could be compared. A profile of the water surface in chute A is shown on figure 15, for a discharge of 0.285 c.f.s. and a tailwater depth of $5\frac{1}{2}$ inches. The length of the jump measured from the intersection of the sloping chute with the horizontal pool floor, which joint will be donoted as "0", to the downstream end of the roller, averaged 17-3/4 inches. When the tailwater depth was decreased to 5 inches, the jump was swept out of the pool. It will be advisable to keep these figures in mind as the following tests will be compared in accordance with the results obtained on chute A.

Varying the Slope of the Chute

Test 1 (figure 15) shows a profile of the chute on the left, which will be referred to as chute B, used in that test and photograph B (plate 11) shows the two chutes in operation each at a discharge of 0.285 c.f.s. Incidentally, all tests were made at this same discharge. In test 1, the two chutes were identical except that the slope for B was 3:1 while that for /A was $1\frac{1}{2}$:1. The jump in each case was practically the same length when measured from point 0 to the downstream end of the roller, and in both cases, the jump was swept out of the pool when the tailwater was dropped to 5 inches.

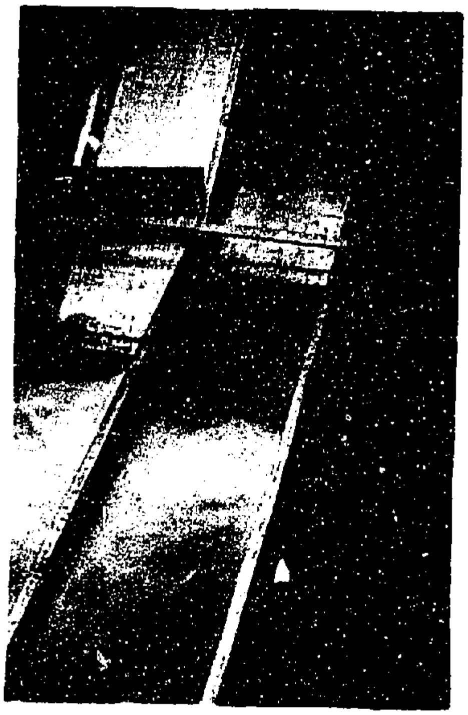
In test 5 (figure 15) the slope of chute B was just slightly less than that for chute A. The length of the jump measured from the point 0 to the downstream end of the roller was again practically the same as that for chute A. Again, in this case, the jump left the pool when the tailwater depth was reduced to 5 inches.

In test 6, the slope of chute B leading to the pool was further increased and the length of the jump measured downstream from point 0 was somewhat longer than in test 5 although the distance from point 0 to the beginning of the roller was less in test 6.

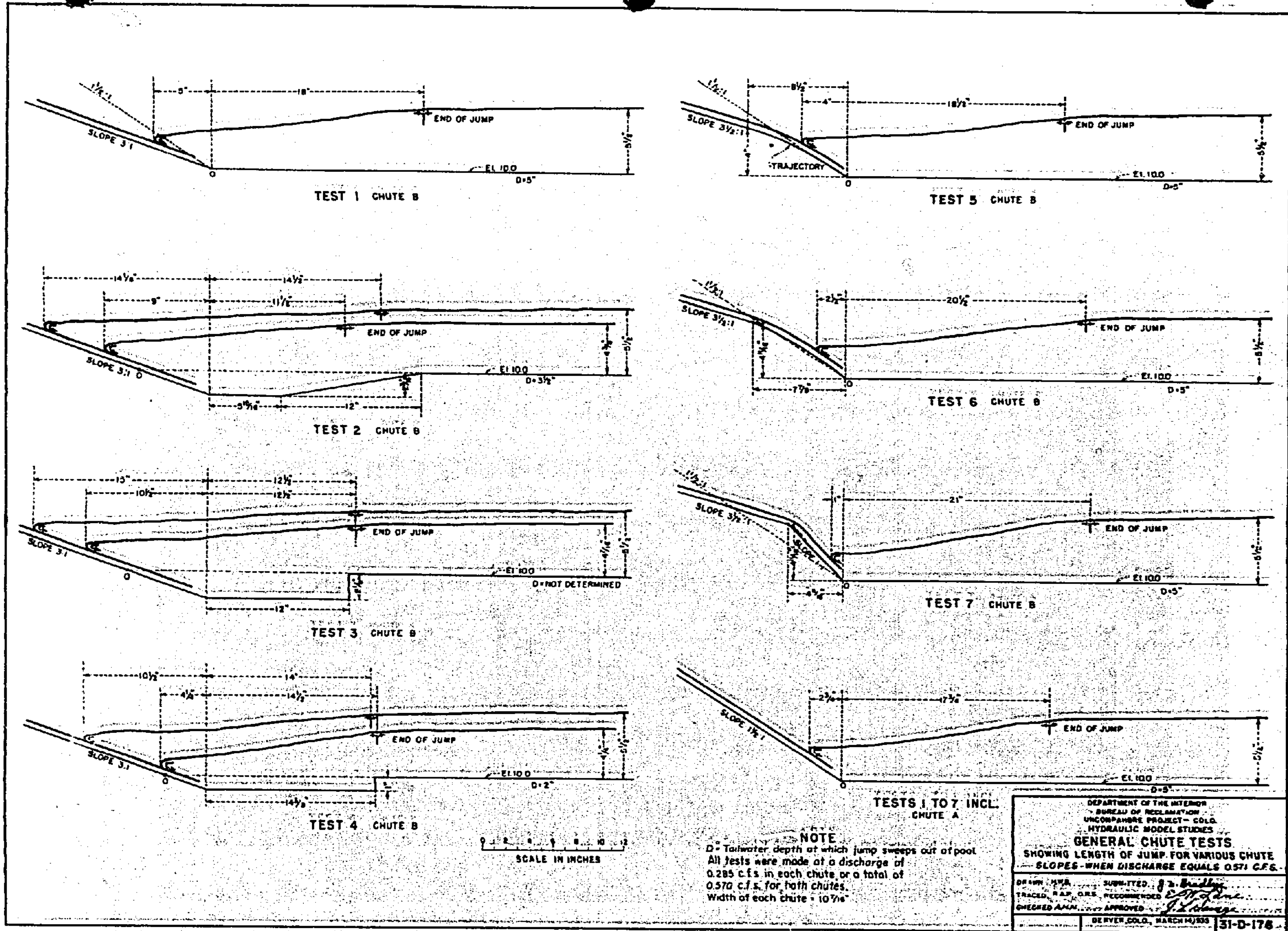


A. TOTAL DISCHARGE 0.570 SECOND-FEET.
TAILWATER 5-1/2 INCHES.

B. TOTAL DISCHARGE 0.570 SECOND-FEET.
TAILWATER 5-1/2 INCHES.



C. TOTAL DISCHARGE 0.570 SECOND-FEET.
TAILWATER 5 INCHES.


TEST 1 CHUTE B
SLOPE 3:1
END OF JUMP
El. 100
D=5"
TEST 2 CHUTE B
SLOPE 3:1
END OF JUMP
El. 100
D=3½"
TEST 3 CHUTE B
SLOPE 3:1
END OF JUMP
El. 100
D=NOT DETERMINED
TEST 4 CHUTE B
SLOPE 3:1
END OF JUMP
El. 100
D=2"
SCALE IN INCHES
TEST 5 CHUTE B
SLOPE 3½:1
TRAJECTORY
END OF JUMP
El. 100
D=5"
TEST 6 CHUTE B
SLOPE 3½:1
END OF JUMP
El. 100
D=5"
TEST 7 CHUTE B
SLOPE 3½:1
END OF JUMP
El. 100
D=5"
TESTS 1 TO 7 INCL. CHUTE A
SLOPE 1½:1
END OF JUMP
El. 100
D=5"
NOTE
D= Tailwater depth at which jump sweeps out of pool.
All tests were made at a discharge of 0.285 c.f.s. in each chute or a total of 0.570 c.f.s. for both chutes.
Width of each chute = 10 7/16"
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
UNCOMPAHGRE PROJECT – COLO.
HYDRAULIC MODEL STUDIES
GENERAL CHUTE TESTS
SHOWING LENGTH OF JUMP FOR VARIOUS CHUTE SLOPES – WHEN DISCHARGE EQUALS 0.571 C.F.S.
DRAWN H.F.B. SUBMITTED
TRACED R.A.P. O.R.S. RECOMMENDED
CHECKED A.M.M. APPROVED
DENVER, COLO., MARCH 14, 1935
31-D-178

Photograph A (plate 11) shows chutes A and B for test 6 in operation with a tailwater depth of $5\frac{1}{2}$ inches. The jump again left the pool for a tailwater depth of 5 inches.

In test 7, the slope of the chute was increased to 1:1 and the length of the jump measured from point O was slightly longer than in test 6 although the total length of the roller was less. In this case, the jet actually sprang clear of the floor on the 1:1 slope. Photograph C (plate 11) shows chutes A and B operating at a tailwater depth of 5 inches. It can be observed from the photographs that the jumps in both pools are just on the verge of being swept out.

Comparing tests 1, 5, 6, and 7, it is found that the total length of jump in each case is sensibly the same.

Varying the Shape of the Pool

In test 2, a portion of the pool floor was dropped 2-3/16 inches as shown in figure 15. The jump appeared flooded with a tailwater depth of $5\frac{1}{2}$ inches and was found to be more effective when the tailwater was dropped to the vicinity of 4-3/8 inches. The jump with this layout did not leave the pool until the tailwater was dropped to $3\frac{1}{2}$ inches, which definitely illustrates the advantage of a depressed pool floor.

Test 3 was somewhat similar to the one just described except a sharp break was made in the pool floor. A portion of the floor of chute B was dropped 2-1/8 inches as shown in figure 15. Photograph A (plate 12) shows the layout and photograph B shows the two chutes in operation for a tailwater depth of 4-7/16 inches. Notice that the jump has left the pool in chute A but chute B is operating very nicely. For a tailwater depth of 3-1/4 inches, which was the lowest tried in this test, the jump in chute B remained in the pool.

Test 4 was very similar to test 3 except in this case a portion of the pool floor was dropped 1 inch. Photograph C (plate 12) shows the layout for this test and photograph D shows chutes A and B operating with a tailwater depth of $5\frac{1}{2}$ inches. Chute B was more effective in its action for a depth of 4-1/4 inches. The tailwater was dropped to a depth of 2 inches before the jump showed any tendancy toward leaving the pool while in chute A, the jump was swept out at a tailwater depth of 5 inches. Notice in the last two tests that the downstream end of the roller was directly above the break in the floor. Also observe the superiority of this type of pool with a sharp break in the floor to the one in test 2 where the change in elevation is gradual.

A. SET-UP

B. TOTAL DISCHARGE 0.570 SECOND-FEET.
TAILWATER 4-7/16 INCHES.

C. SET-UP.

D. TOTAL DISCHARGE 0.570 SECOND-FEET.
TAILWATER 5-1/2 INCHES.

Conclusions on General Tests

The preceding tests show that the slope of the chute leading to the pool seems to make no appreciable difference in the total length of the jump.

Pools with portions of their floors depressed are much more desirable than those without this feature when low tailwater depths are involved. The floor with the sharp break has an advantage over the one with the gradual change in that with the first, the jump will stay in the pool for lower tailwater depths. Also with the sharp break in the floor, the length of jump can be regulated within a certain limited range by shifting this break up or downstream.

A complete summary of all tests made on the chutes described in this report can be found in appendices A and B.

Acknowledgments

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APPENDIX A

MILL COULEE CANAL CHUTE DROP
SUN RIVER PROJECT
LOG OF TESTS

Test No.	Discharge C. F. S.	Gate Opening Ft.	Head of water on gate (Model)	Tail-water El.	Stepped apron	Nubbins at lower end of pool	Length of jump on centerline of pool	Additional remarks on the layout.	Remarks on Results
1-1	138.5	.112	1.737	3895.5	1.0' High	12" Dia. 4" High	45.8		Spread of jet poor. Water in pool was whirling and unsymmetrical.
2-1	138.5	.112	1.744	"	None	"	43.3	Original design.	Velocity concentrated on floor of pool. Pool symmetrical.
2-2	138.5				None	None			Velocity measurement only.
3-1	139.0	.112	1.751	"	None	12" Dia. 4" High	30.0	False 4:1 slope installed at lower end of chute.	Very short length of jump. Very peculiar velocity distribution. Not very satisfactory.
4-1	139.0	.112	1.748	"	.83' High	"	39.7		Best layout using stepped aprons.
5-1	138.5	.112	1.747	"	.62' High	"	42.9		Unsuitable pool conditions.
6-1	138.5	.112	1.743	"	None	"	37.3	False floor in pool 0.83' above original floor.	Increased effective width of pool, made possible a shorter length of jump.
7-1	138.5	.112	1.747	"	None	None	37.7	Rehbock sill installed at Sta. 266+03.4	Improved velocity distribution in middle of pool.

APPENDIX A (Cont.)

MILL COULEE CANAL CHUTE DROP
SUN RIVER PROJECT
LOG OF TESTS

Test No.	Discharge C.F.S.	Gate Opening Ft.	Head of water on gate (model)	Tail water El.	Stepped apron	Nubbins at lower end of pool	Length of jump on centerline of pool	Additional remarks on the layout.	Remarks on Results
8-1	138.5	.112	1.737	3395.5	None	None	not definite	Sand bed installed below sta. 266+21.73.	Erosion occurs directly below stilling pool. Very rough water surface.
8-2	138.6	.112	1.45	"	"	"	"	Vertical chute walls extended down to Sta. 265+84.00.	Results identical with those for test 8-1
Sp-0	Various	Various	Various	**	**	***	***		Runs for calibrating gate in chute.
9-1	139.0	"	"	Various	None	None	not definite	Baffle wall C installed at sta. 266+21.00 (see sketch C fig. 8)	Large boil over baffle wall and excessive erosion.
9-2	139.0	"	"	"	"	"	"	Baffle wall D installed at sta. 266+21.0 (see sketch D fig. 8)	Results very similar to test 9-1.
10-SR1	139.0	"	"	"	"	"	"	Baffle wall E installed at sta. 266+21.0 (see sketch E fig. 8 and photo C plate 4)	Very rough water surface and excessive erosion.

APPENDIX A (Cont.)

MILL COULEE CANAL CHUTE DROP
SUN RIVER PROJECT
LOG OF TESTS

Test No.	Discharge C.F.S.	Gate Opening Ft.	Head of water on gate (model)	Tail-water El.	Stepped apron	Nubbins at lower end of pool	Length of jump on centerline of pool	Additional remarks on the layout	Remarks on Results
11-1	139.0	Various	Various	Various	None	None	not definite	Baffle weir installed in pool. See sketch A fig. 8 and photo A plate V.	Unsatisfactory - splash in pool 8' high.
12-1	139.0	"	"	"	"	"	"	Baffle box installed in pool (See sketch B fig. 8 and photo C plate V	Unsatisfactory - Water squirted out the two downstream holes only & part of it went over the sides of the pool.
12-2	139.0	"	"	"	"	"	"	Same as 12-1 except areas of downstream holes were reduced.	Action in pool improved for the higher tailwater depths only.
1J-1 to 18J-3								67 runs made for the purpose of investigating the hydraulic jump.	Due to the indefinite nature of the jump measurements were in error and the results unreliable.

APPENDIX B

SOUTH CANAL CHUTE DROP
UNCOMPAGHRE PROJECT
LOG OF TESTS

Test No.	Discharge C.F.S.	Tailwater Elev.	Total length of jump - ft.	Sills	Slope of chute	Remarks
1-1	945	6422.7	41.0	None	3:1	
2-1	954	6423.3	44.8	"	"	Flow slightly unsymmetrical.
3-1	945	6421.9	31.9	"	"	Flow slightly unsymmetrical.
4-1	821	6422.1	39.6	"	"	
5-1	818	6421.6	32.7	"	"	Jump fairly symmetrical. Pool quite rough.
6-1	837	6422.9	45.3	"	"	
7-1	837	6422.1	40.5	"	"	Same as 4-1 except for head on orifice.
8-1	606	6421.0	37.9	"	"	
9-1	300	6418.9	18.5	None	"	
10-1	954	6422.0	38.7	A	"	Better than 3-1. No boil over sill.
11-1	954	6422.0	35.8	B	"	Similar to 10-1.
12-1	954	6422.0	37.9	C	"	Pool rougher than 3-1. Slight boil over sill.
13-1	954	6422.0	37.7	D	"	Similar to 12-1
14-1	834	6421.6	36.3	B	"	Better than 5-1. Jump symmetrical and rough.
15-1	603	6420.8	36.3	B	"	Very good. Pool symmetrical.
16-1	331	6418.9	18.5	E	3:1	Good pool.
17-1	954	Not recorded		None	$1\frac{1}{2}$:1	Jet jumps clear of chute at start of $1\frac{1}{2}$:1 slope. No change in pool.
18-1	930	6422.2	25.6	None	Trajectory	Jet fair-small fins. Pool good.