HYD 3.7

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: PRELIMINARY REPORT #2 - HYDRAULIC AND ELECTRIC ANALOGY MODEL STUDIES OF THE PROPOSED IMPERIAL DAM AND APPURTENANT WORKS

By J. N. BRADLEY AND J. B. DRISKO,
ASSISTANT ENGINEERS

and D. J. HEBERT, JUNIOR ENGINEER

Under direction of

E. W. LANE, RESEARCH ENGINEER

TECHNICAL MEMORANDUM NO. 471

Denver, Colorado

July 15, 1935

(PRICE $6.00)

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HYDRAULIC MODEL STUDIES

by

J. B. DRISKO

and

J. M. BRADLEY,

ASSISTANT ENGINEERS

Since Technical Memoranda Nos. 429 and 430 were written in January, 1935 (preliminary reports of model studies of proposed design of Imperial Dam) the model studies have been continued.

SPILLWAY SECTION

Crest studies. The original crest, as first studied, is shown in figure 1, and the final design is given in figure 2. There were several reasons for changing the profile, perhaps the foremost of which was the fact that flow over the original crest produced negative pressures on the downstream face of the dam, just below the crest. Figure 4 is a plot of these underpressures for various discharges. Figure 5 is a similar plot for the revised design. The slight underpressures occurring with this design at the highest discharge is not serious, because of its small magnitude, and because the new design foresees anchoring the slab to the ribs of the dam.

The head discharge relation for the two crest shapes, with coefficient curves, are given in figures 8 and 9.

Studies were made to determine the change of coefficient and consequent increase of head over the dam for various discharges, with the floor of the approach channel raised. Figure 6 shows this effect. The studies were made to represent the condition which would

obtain if the reservoir filled with silt.

Stilling pool. The tailwater rating curve of figure 7 is the curve for the river at present. After the dam is constructed and the river flow is regulated from Boulder Dam, the river bed below the dam may retrogress, or may fill with silt and vegetation, and the tailwater rating curve may be greatly different from the one shown. Hence it is necessary to provide for a large range of tailwater level in the design of the stilling pool. While the model studies showed that it is possible to cause a hydraulic jump to form on the apron with a tailwater elevation as low as 158 for the maximum discharge of 150,000 c.f.s. by means of baffles coupled with a high river bed below the apron, the high velocities over the raised river bed were deemed inadvisable and the type of baffle was felt to be questionable from a structural standpoint. For these reasons, the design shown in figure 2 was adopted. This design insures a satisfactory hydraulic jump at a discharge of 150,000 c.f.s. with the tailwater at or above elev. 163.5. The toe of the jump does not move upstream enough to form over the hollow part of the dam until the tailwater climbs to elev. 168.5, for a discharge of 150,000 c.f.s.

Figures 10 to 13 show a number of the stilling pool layouts which were studied, and figure 14 is a resume of the tailwater ranges for these designs. Figure 14 shows the tailwater which makes the

jump form on the hollow part of the dam, the minimum tailwater which will form a jump on the apron, and the range between these points, for a discharge of 150,000 c.f.s. Figure 15 shows details of the various sills used in the tests. Figure 16 is a longitudinal profile of the stilling pool for the final design, showing water surface and pressures on the pool floor.

In all, 297 comparative runs were made on various permutations and combinations of about 70 sills, together with variations of the river bed below the pool.

SLUICEWAY

Model studies of the proposed sluiceway have been practically completed. The original plan contemplated 6 gates with a normal maximum discharge of 12,000 c.f.s., and the model was built accordingly. Subsequently, the sluiceway was enlarged to include 8 gates, with a corresponding discharge of 16,000 c.f.s. The model was left as originally constructed, and was considered as a partial model of the entire structure.

The uncertainty of the tailwater conditions below the sluiceway made it necessary to develop a design which would function safely at a very low tailwater elevation, and would also perform satisfactorily with a normal or high tailwater level. The rating curve at at the damsite shows a water surface elevation of about 159 for a

discharge of 16,000 c.f.s. If the river erodes between Imperial and Laguna the tailwater will be lower than that shown on the rating curve; it may conceivably drop to El. 154, since the Laguna crest is at El. 151, the Laguna gate sill is at El. 138, and a flow of 16,000 c.f.s. past Laguna with the gates open, gives a water surface elevation of about 152, at Laguna. Laguna is 5 miles below Imperial, and the slope between the two would bring the water surface at Imperial up to Elev. 154. If, on the other hand, the river becomes choked with silt and vegetation, the tailwater may be higher than shown on the rating curve.

Double pool. At first, considerations of the stability and cost of the structure as a function of the uplift pressures and necessary seepage length led to the development of a stilling pool design which insured dissipation of the energy "in a couple of jumps" (figures 17 and 18). For a normal tailwater elevation, a hydraulic jump was formed in an orthodox pool with its floor at elevation 146. This pool was terminated at its lower end by a dentated sill and a raised section which, if the tailwater dropped below the rating curve value, acted as a control to hold the hydraulic jump in the stilling pool. In passing the control section, the water acquired a velocity greater than critical, and a second hydraulic jump formed. A depressed floor at Elev. 140 with a small

sill at its downstream end, was provided to hold this second jump in its proper place.

Sloping apron. As an alternate layout, a design was proposed which had a long apron sloping gently at 1 to 4 from the downstream end of the sluiceway piers to elevation 140. This slope is flat enough to insure the formation of a satisfactory jump at any tail-water from Elev. 154 up, and was chosen for the final design. Figure 19 shows this pool, with a water surface profile.

Details of pool. The special features of the stilling pool include a row of teeth at the top of the sloping apron, between the pier ends, a second row of teeth at the lower end of the sloping apron, and a row of teeth or baffle blocks similar to a Rebbock dentated sill, at the downstream end of the flat pool floor. The two sets of teeth on the apron are placed with thin edges upstream so as to receive little or no impact. Their function is that of corrugating the high-velocity sheet of water so that the internal friction is greatly increased, and so that the roller of the hydraulic jump has a greater surface on which to work. The teeth at the downstream end of the flat pool floor act much as a Rebbock sill: a submerged roller is formed downstream from the sill, which lessens or prevents scour of the river bed.

Additional features. Measurements were made in the model of the pressure on the crest, on the apron, and under the jump, to aid

in the structural design of the sluiceway. Tests were made at various discharges, and with several tailwater elevations, and in no case did the final design show any tendency to questionable or dangerous performance or harmful scour downstream from the structure. About 170 runs were made on the sluiceway, and these tests included studies of some 20 sills of various designs.

SEEPAGE AND UPLIFT STUDIES

The 1:50 scale model of a section of the Imperial Dam permeable foundation has not yielded the results hoped for; it has indicated other interesting things, however. The model was made of silt brought from the damsite, and this very fine material is unsuited for model studies. It is practically impossible to place the material in the model so that it is homogeneous and compact and free of air. Once the silt is in place in the model, the flow through it is very slow, the numerous piezometer openings are easily clogged, and the results are not at all consistent.

Two interesting facts which developed concern the flow into and out of the silt bed. A blanket seemed to form over the surface of the silt where the water entered the silt bed. This blanket increased the "entrance loss" of the seepage flow very noticeably, and is a condition which will probably occur in nature. The blanket, in the prototype, will probably have relatively much less effect. The flow of water out of the silt bed was through a reversed filter

made up of successive layers of sorted sand of increasing mean diameter, and the tests showed an excessive loss through this filter. This has led to a more careful study of the filter design, supplemented by further experimental investigation of the filter alone. These investigations are now in progress.

Figure 20 is a plot of the pressure drop under the dam, measured during a run in which there was flow from headwater to the drain, and no flow either from or to the tailwater. The excessive losses at entrance to the silt layer, and through the filter may be noted on this plot.

SLUDGE SCRAPERS - DESILTING WORKS

Two types of silt scrapers were tested in the laboratory by means of a full scale model of a portion of the scraper. The first was a 4-foot length of rectangular scraper which was placed perpendicular to the line of travel and accumulated the silt in front of itself as it moved; in the prototype, the silt would be dumped into trenches spaced at intervals along the floor of the desilting tank and parallel to the scraper. The second type of scraper tested was a diagonal or snow-plow scraper, which was placed at an angle to the line of travel, and moved the silt laterally; in the prototype, a group of these scrapers on a rotating arm would move the silt to the center of the circular area swept by the arm.

Although 195 runs were made with the rectangular scraper, including 3 depths of silt and 4 speeds of scraper travel, the results were so inconsistent that little could be gathered from them. The diagonal scraper, on the other hand, gave very good results. As the testing proceeded, it became more and more apparent that the final design would make use of diagonal scraping, and for this reason, no further investigation was made of the erratic results obtained with the rectangular scraper. The laboratory setup has been retained, and if necessary, further testing can be carried on.

Rectangular scraper. Evaluation of the tests made on the full-sized part model of the rectangular sludge scrapers has indicated a peculiarity of behavior which has not been fully explained. The tests, in many instances, showed that the total force required to pull the scraper increased for a distance, and then remained constant, or decreased. The forces necessary to pull the scraper at the higher speeds were not much larger, in many cases, than those required for lesser speeds. Both of these facts have indicated the possibility of a hydraulic lubrication of the silt moving in front of the scraper. Because of either the high speed of the scraper, or the large size of the pile of silt, the trapped water in the pores of the material is unable to flow out as fast as the material piles up and the result is a sort of internal hydraulic

lubrication of the material. The short length of travel of the laboratory scraper made it very difficult to guess what the conditions would be for a longer distance.

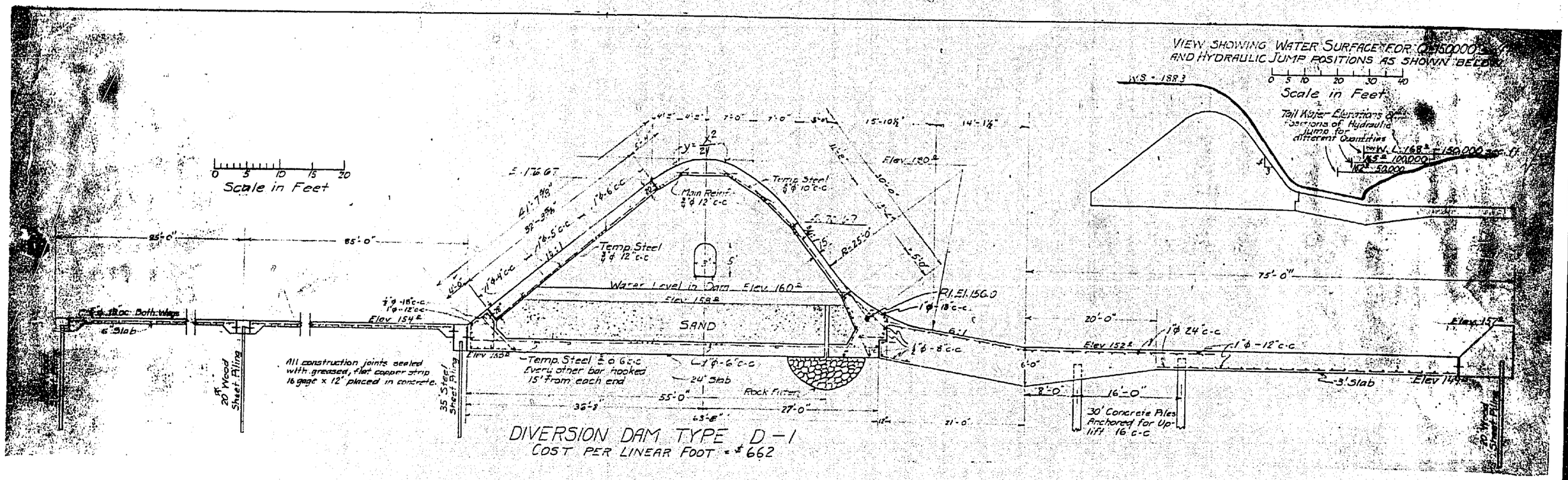
Another factor which was probably responsible for the very inconsistent results of the tests is that of varying consolidation of the material. The process of spreading the silt preparatory to scraping was always carried out in the same manner, yet great differences in the consistency of the silt were noticeable, and it is probable that the sludge which settles naturally in the full-sized settling tanks will have a consistency markedly different from that of the silt which was used over and over in the laboratory.

The tests did indicate very definitely that the pull on the scraper could be greatly reduced by a suitable design of the scraper blade. A horizontal pan resembling a Fresno scraper was very effective, but impractical. Large cow-catcher-like plows immediately in front of the scraper were also helpful in reducing the pull necessary, and are felt to be practical.

Diagonal. The tests made with the diagonal, or "snow-plow" scraper, have yielded very acceptable results. The many data from the 180 runs have been summarized in a chart (fig. 21), which shows the relation of the coefficient of friction of the silt on the bottom with the amount of silt moved, for various speeds of

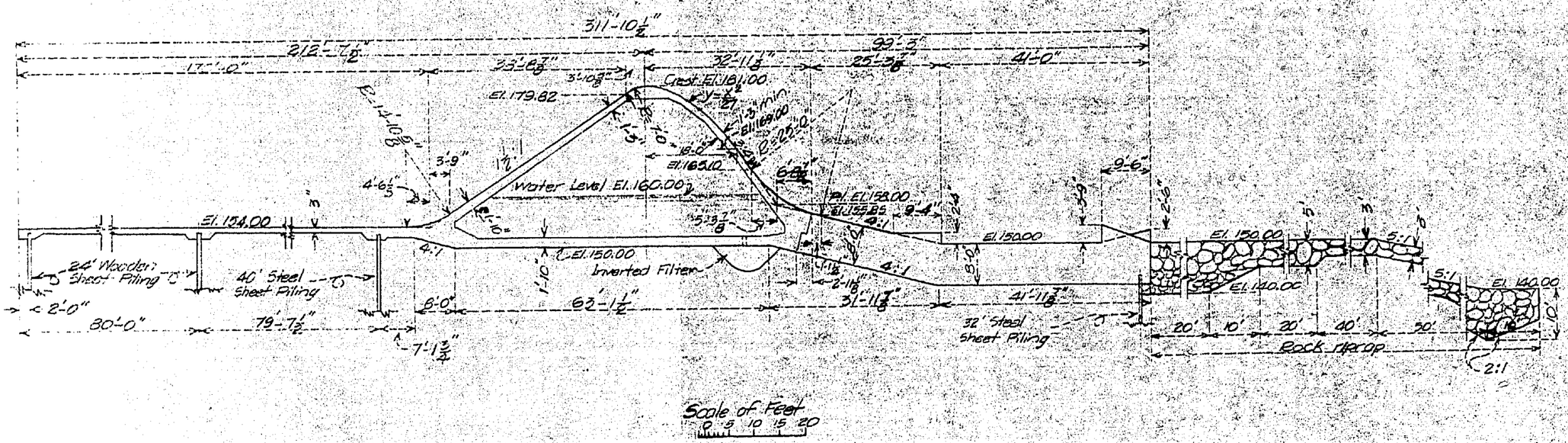
scraper travel. With the aid of this chart, the power necessary to run the desilting mechanism for various quantities of silt can be predicted.

FIG. 1

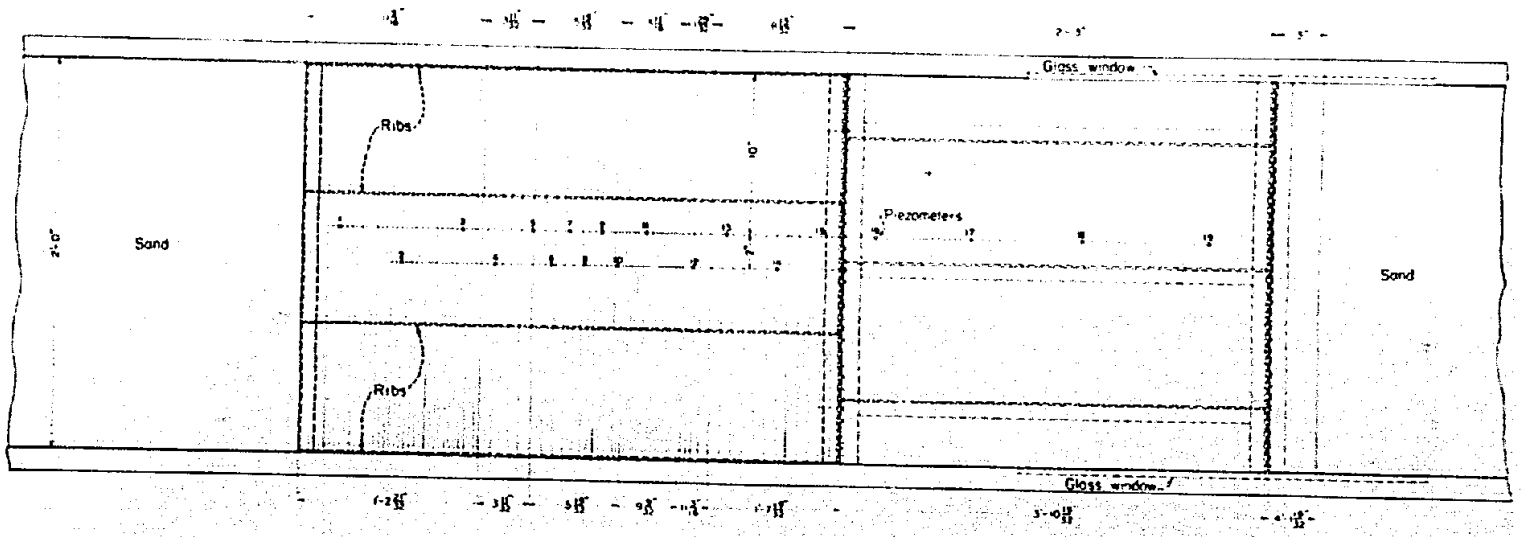


DIVERSION DAM TYPE D-1
COST PER LINEAR FOOT = $662

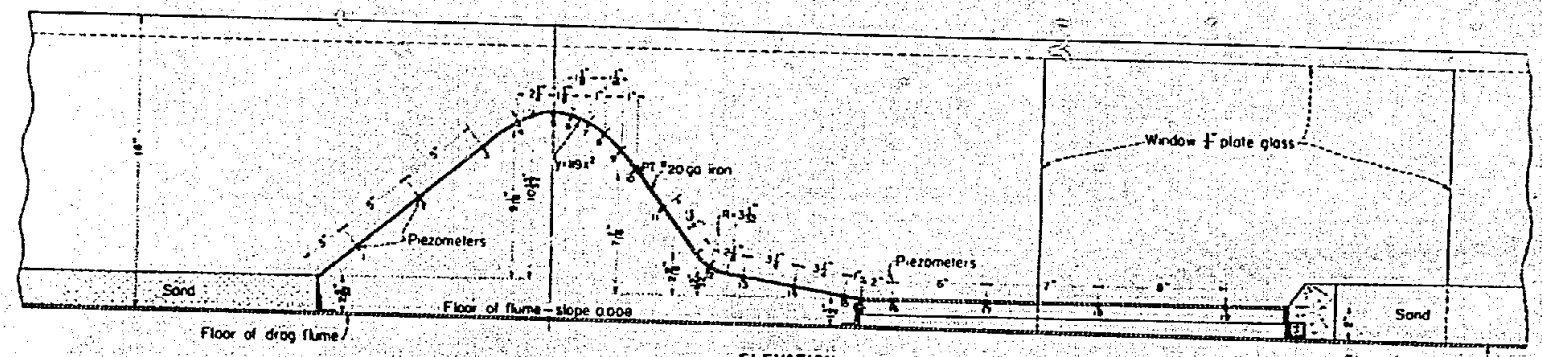
FIG. 2



TYPICAL SECTION — REVISED DESIGN
IMPERIAL DAM SPILLWAY SECTION
Denver, Colo. U.S.B.R. July 13, 1938
R.K.V.



PLAN



ELEVATION
SECTION ALONG CENTER LINE

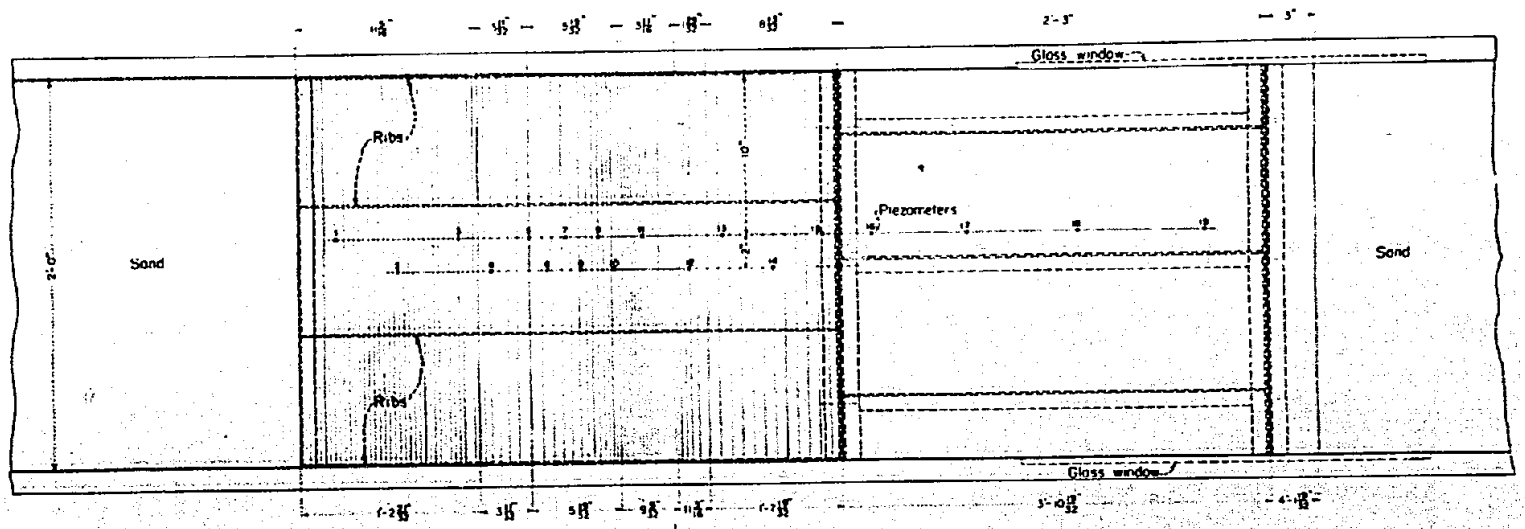
MODEL SCALE IN INCHES
0 10 20 30
PROTOTYPE SCALE IN FEET

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

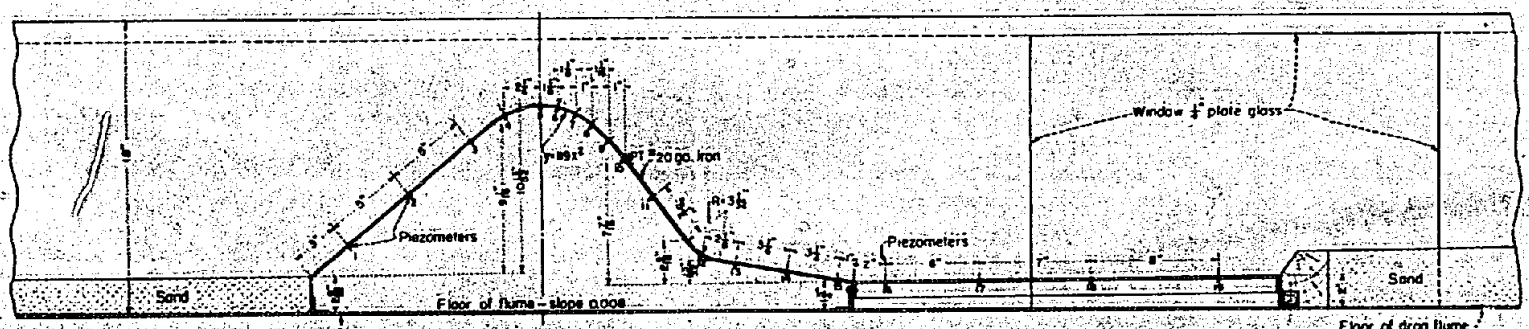
IMPERIAL DAM TYPE D-1
GENERAL PLAN OF MODEL
MODEL SCALE 1:30

DRAWN CHM ECP SUBMITTED
TRACED LMK JDK RECOMMENDED
CHECKED APPROVED
DENVER, COLO AUGUST 15, 1934

FIGURE 3



PLAN



ELEVATION
SECTION ALONG CENTER LINE

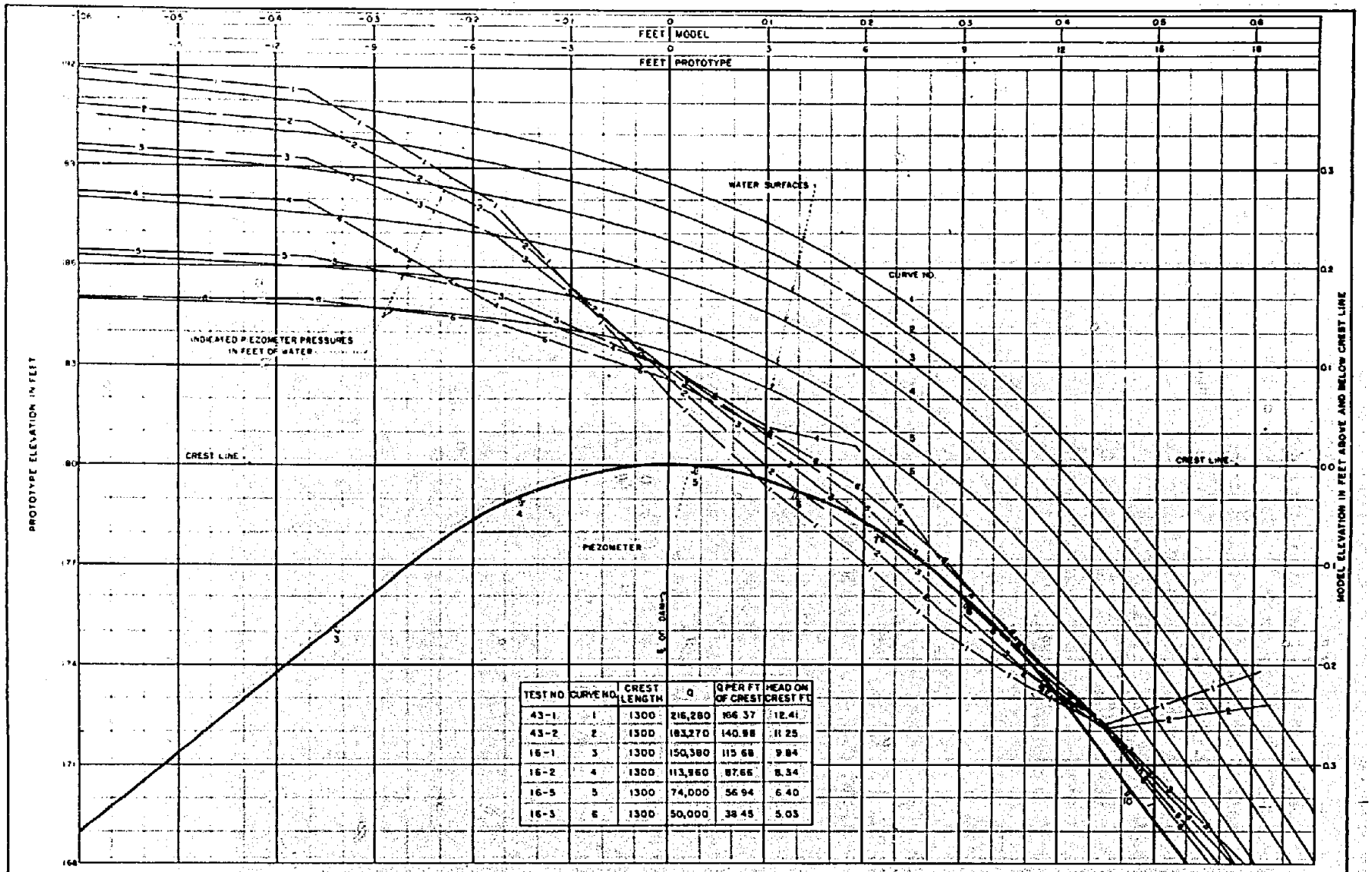
MODEL SCALE IN INCHES
0 1 10 20 30
PROTOTYPE SCALE IN FEET

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM TYPE D-1
GENERAL PLAN OF MODEL
MODEL SCALE 1:30

DRAWN CHG E.C.P. SUBMITTED
TRACED L.H.R. J.O.T. RECOMMENDED
CHECKED APPROVED
DENVER, COLO. AUGUST 15, 1934

FIGURE 3



TEST NO	CURVE NO.	CREST LENGTH	Q	Q PER FT OF CREST	HEAD ON CREST FT
43-1	1	1300	216,280	166.37	12.41
43-2	2	1300	183,270	140.98	11.25
16-1	3	1300	150,380	115.68	9.84
16-2	4	1300	113,960	87.66	8.34
16-5	5	1300	74,000	56.94	6.40
16-3	6	1300	50,000	38.45	5.03

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BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
COMPARISON OF WATER SURFACES AND INDICATED PRESSURES ON DAM

DRAWN F.P. A.R. SUBMITTED
TRACED A.V.P. E.E.B. RECOMMENDED
CHECKED APPROVED
DENVER, COLO. NOV 4, 1934

FIGURE 4

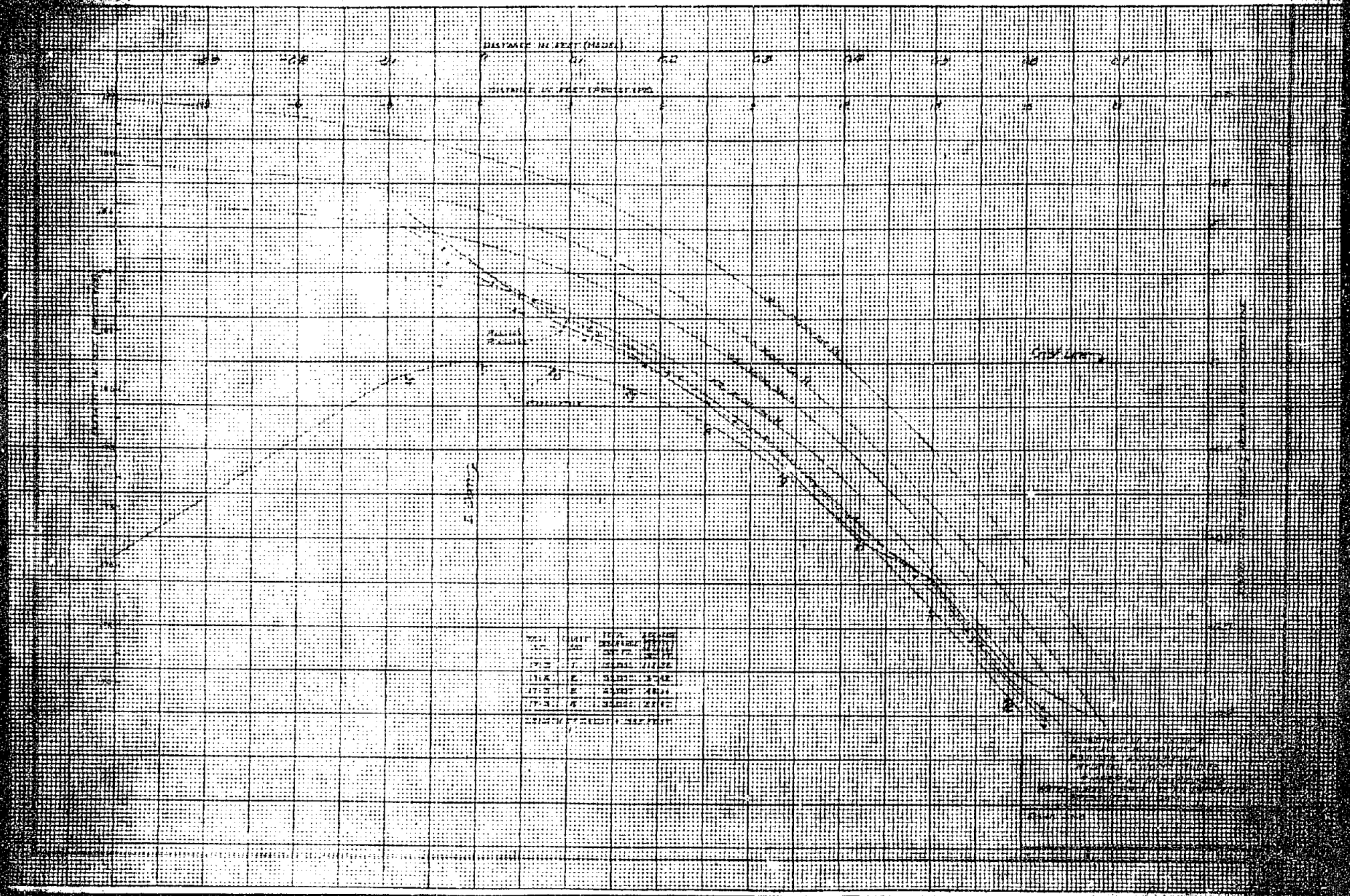
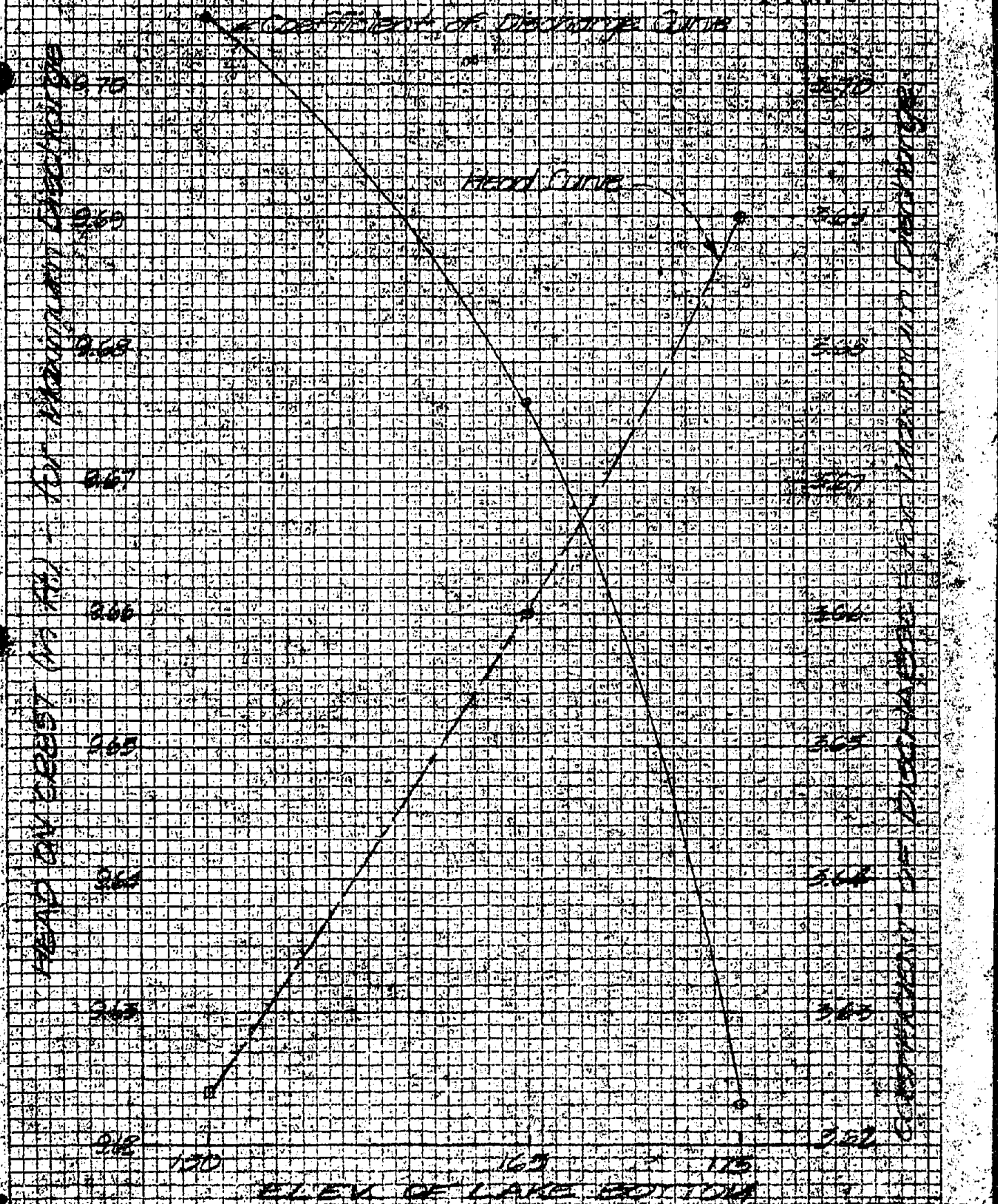
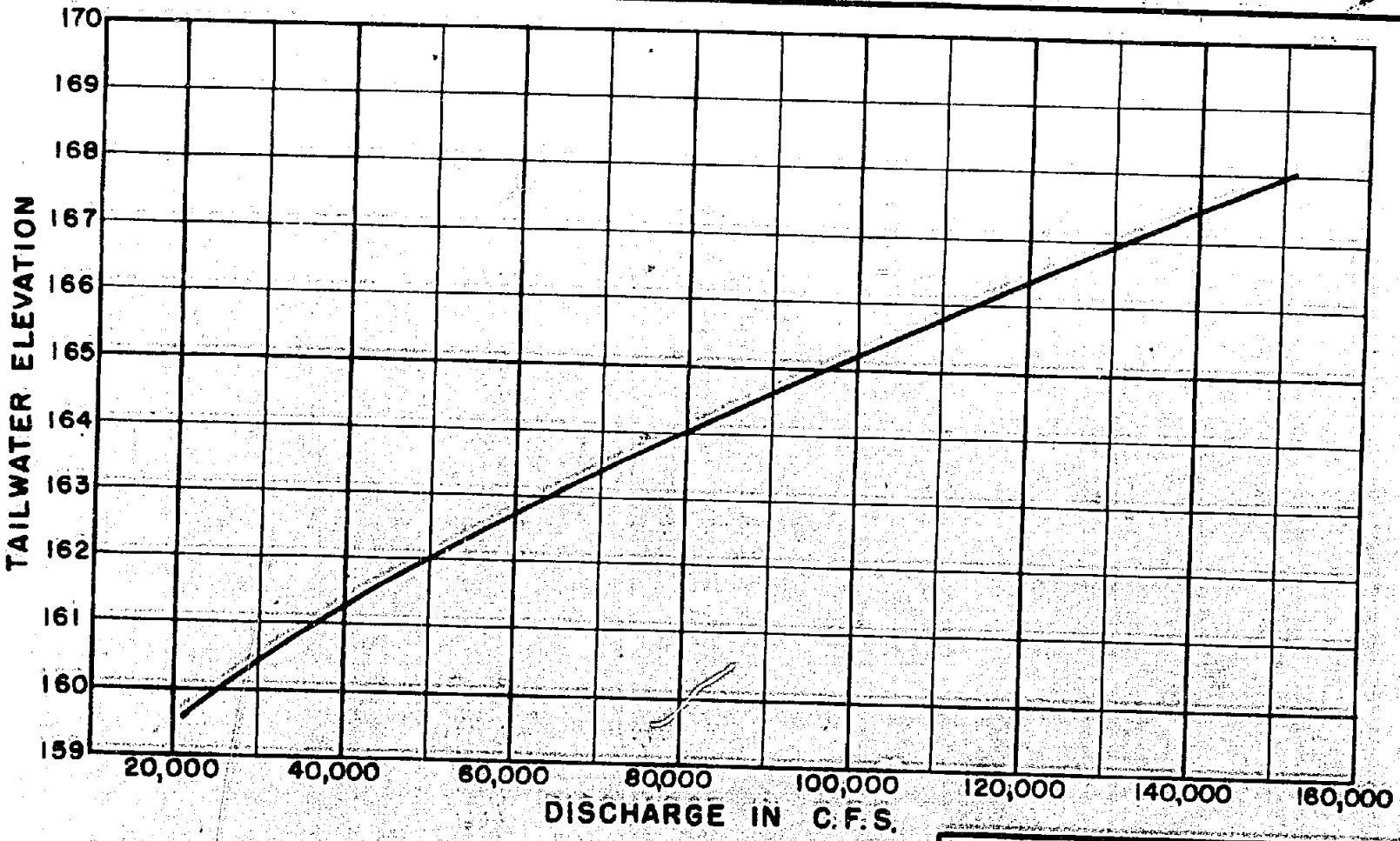


FIG. 6



REVISED IMPERIAL DAM
CURVE SHOWING EFFECT OF VARYING
ELEV OF APPROACH FLOW ON THE
COEFF. OF DISCHARGE AND ON THE HEAD
DENVER, COLO. JULY 11, 1928



DEPARTMENT OF THE INTERIOR
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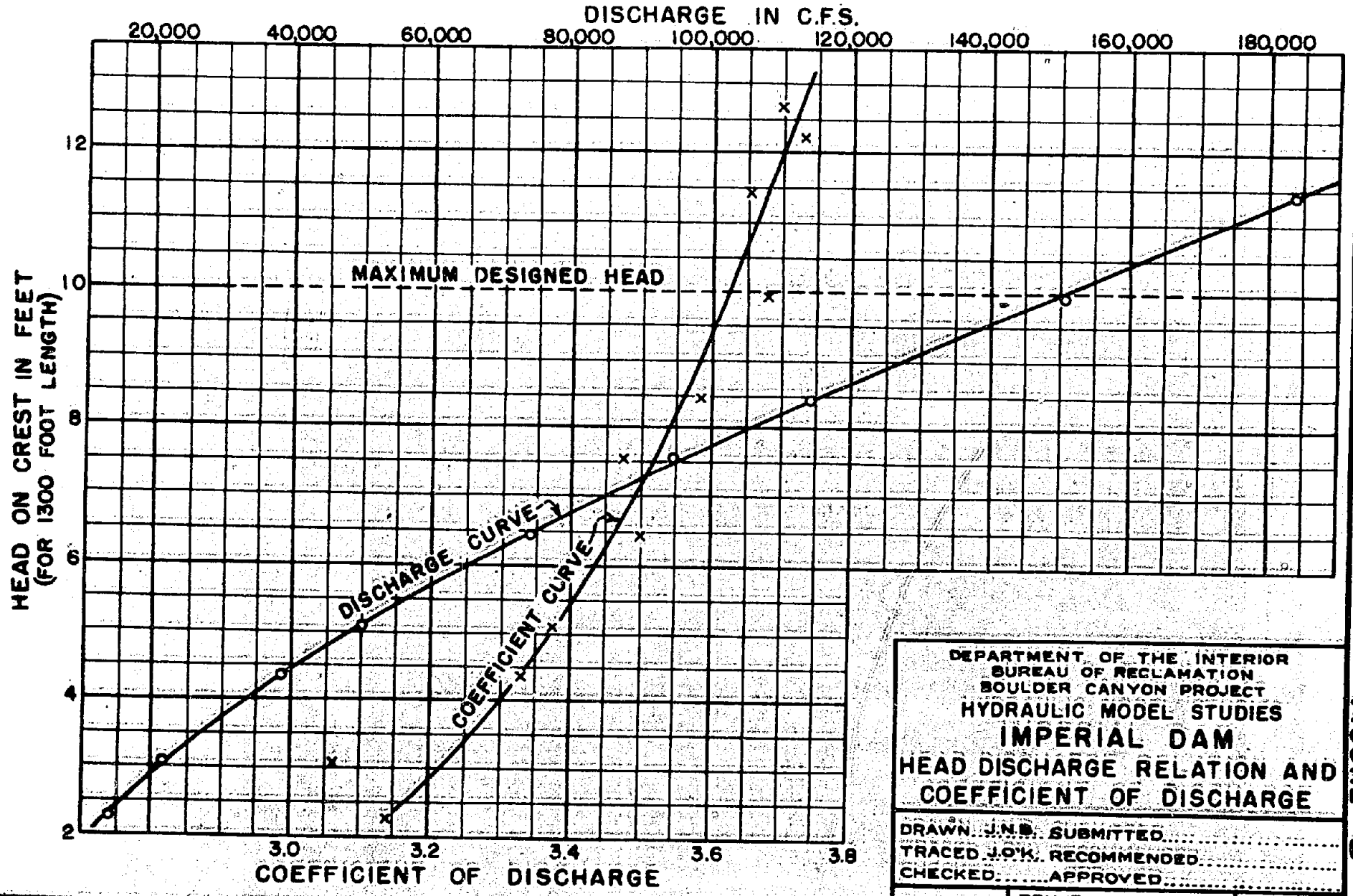
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
PREDICTED TAILWATER CURVE
BELOW IMPERIAL DAM

DRAWN J.N.B. SUBMITTED
TRACED J.O'K. RECOMMENDED
CHECKED APPROVED
DENVER, COLO. 4-16-35

FIGURE 7



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM

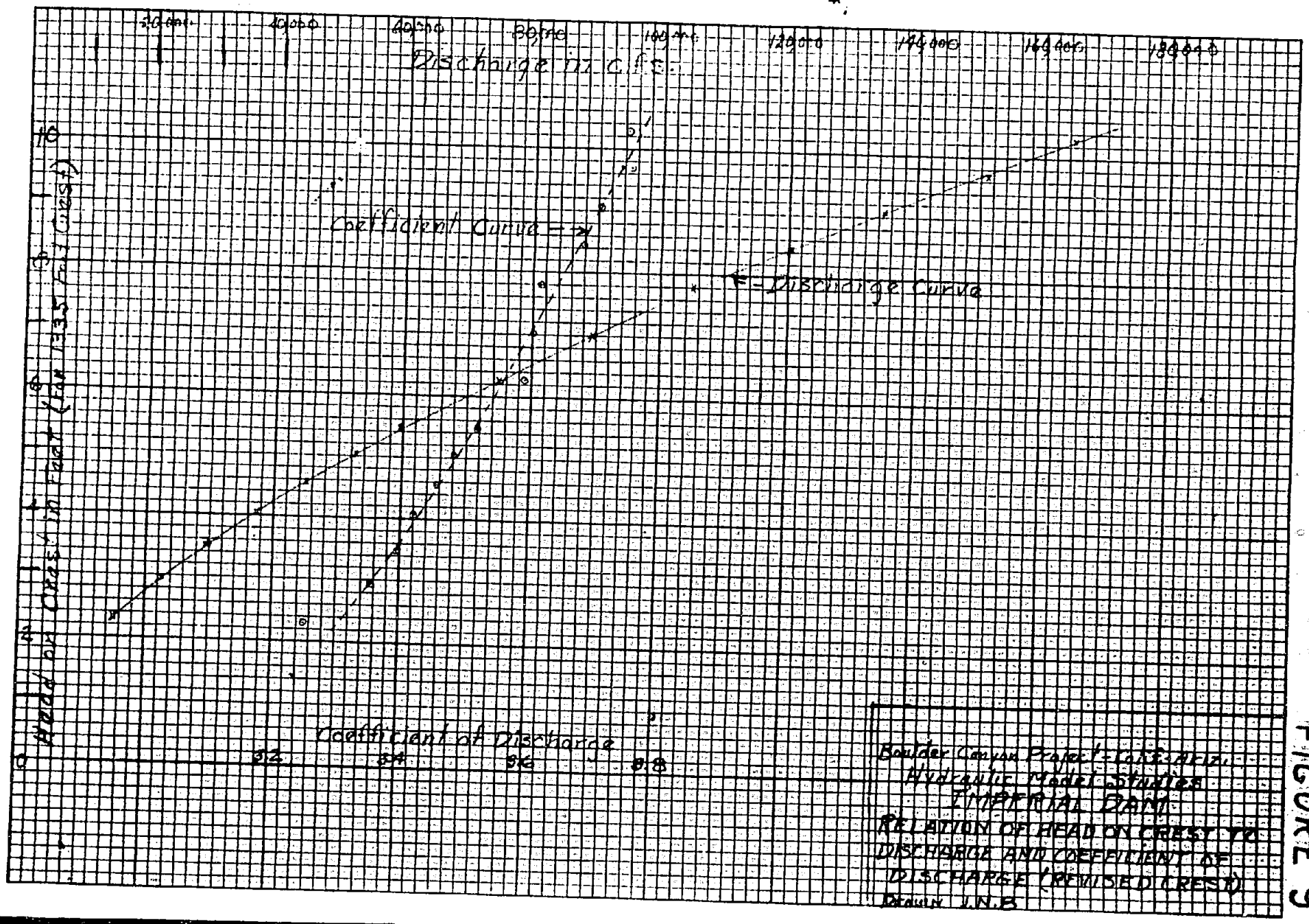
HEAD DISCHARGE RELATION AND COEFFICIENT OF DISCHARGE

DRAWN J.N.B. SUBMITTED
TRACED J.O'K. RECOMMENDED
CHECKED APPROVED

DENVER, COLO. 4-16-35

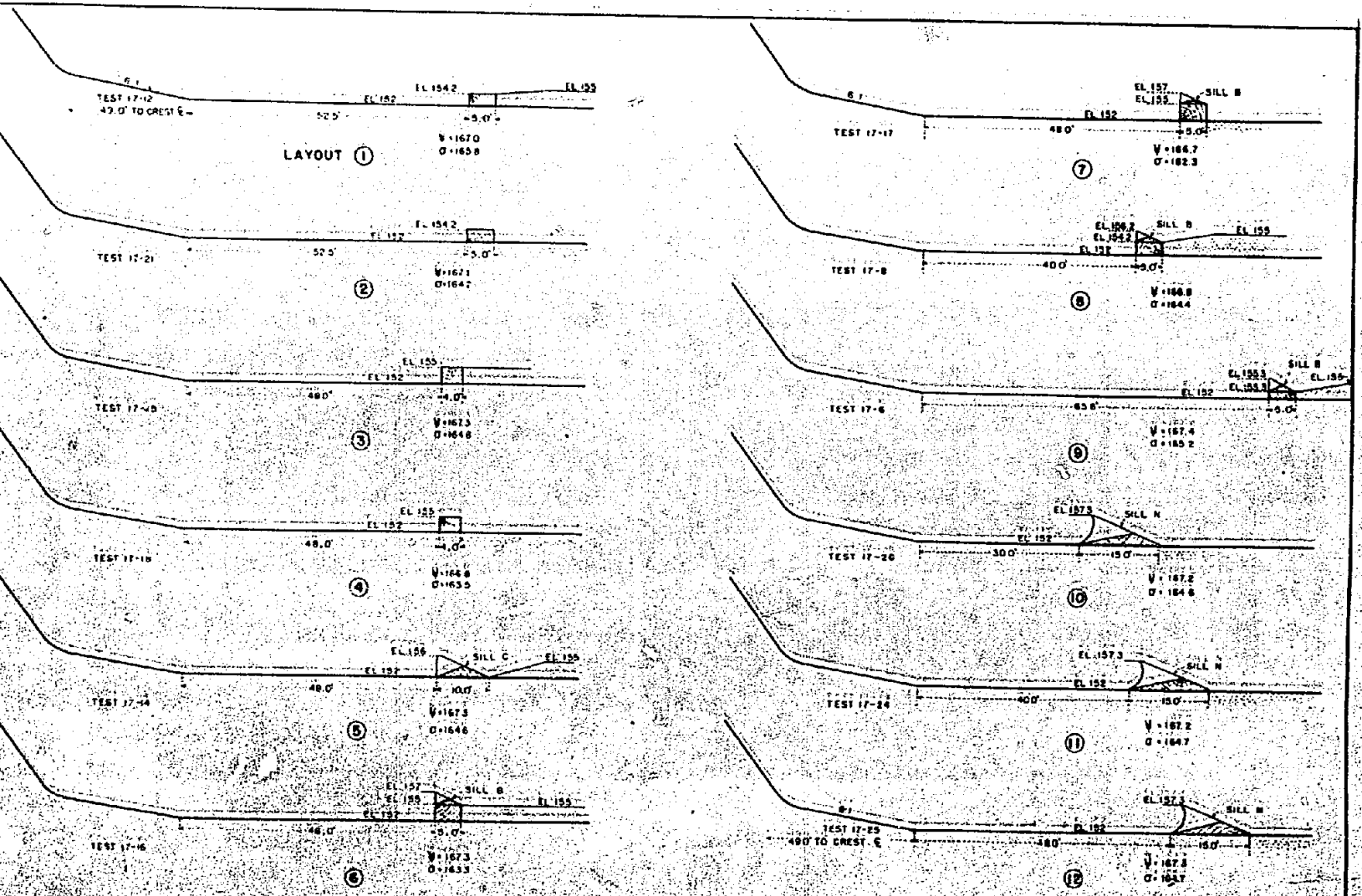
FIGURE 8

KEUFFEL & ESSER CO., N. Y. NO. 359-5
10 x 10 to the inch.



Boulder Canyon Project - Colorado
Hydraulic Model Studies
IMPERIAL DAM
RELATION OF HEAD ON CREST TO DISCHARGE AND COEFFICIENT OF DISCHARGE (REVISED CREST)
DRAWN J.N.B.

FIGURE 9



For Silt Details See Figure 7

V = Tailwater elevation recorded when front of jump moved up on dam to elevation 156.

σ = Tailwater elevation recorded just as jump left the pool

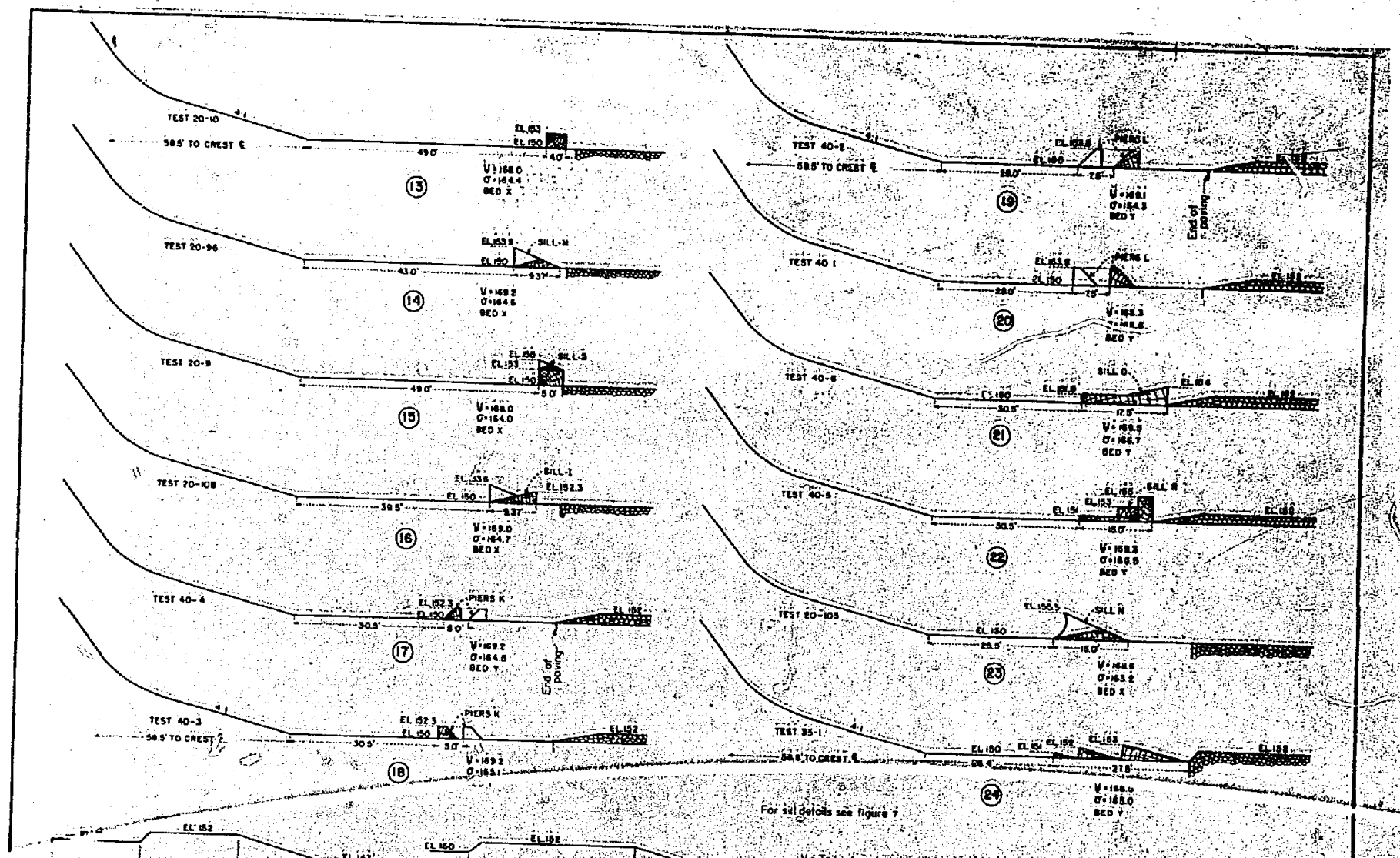
POOL FLOOR AT ELEVATION 152.0
LENGTH OF CREST 1732 FEET

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.M.R. SUBMITTED
TRACED A.V.F., O.R.J. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., DEC. 6, 1954

FIGURE 10


TEST 20-10
58.5' TO CREST ℄
EL 153
EL 150
49.0'
4.0'
V=168.0
d=164.4
BED X
13
TEST 20-9B
EL 153.9
SILL-M
EL 150
43.0'
9.37'
V=168.2
d=164.6
BED X
14
TEST 20-9
EL 156
EL 153
EL 150
SILL-S
49.0'
5.0'
V=168.0
d=164.0
BED X
15
TEST 20-10B
EL 155
SILL-T
EL 150
EL 152.3
39.5'
9.37'
V=168.0
d=164.7
BED X
16
TEST 40-4
EL 152.3
PIERS K
EL 150
30.5'
5.0'
EL 152
V=169.2
d=164.6
BED Y
17
End of paving
TEST 40-3
58.5' TO CREST ℄
EL 152.3
PIERS K
EL 150
30.5'
5.0'
EL 152
V=169.2
d=165.1
18
TEST 40-2
58.5' TO CREST ℄
EL 150
PIERS L
28.0'
2.5'
V=168.1
d=164.3
BED Y
19
End of paving
TEST 40-1
EL 153.5
PIERS L
EL 150
28.0'
2.5'
V=168.3
d=164.8
BED Y
20
TEST 40-6
SILL O
EL 150
EL 154
30.5'
17.5'
V=168.9
d=166.7
BED Y
21
TEST 40-5
EL 156
SILL R
EL 153
EL 151
EL 155
30.5'
15.0'
V=168.3
d=165.5
BED Y
22
TEST 20-10B
EL 156.5
SILL N
EL 150
25.5'
15.0'
V=168.6
d=163.2
BED X
23
TEST 35-1
58.5' TO CREST ℄
EL 150
EL 151
EL 152
EL 153
EL 155
28.4'
27.5'
V=168.0
d=165.0
BED Y
24
For sill details see figure 7
EL 152
EL 147
50.0'
50.0'
50.0'
End of paving
PROFILE BED X
EL 150
EL 152
EL 147
10.0'
50.0'
End of paving
PROFILE BED Y
V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.
d = Tailwater elevation recorded just as jump left the pool.
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1500 FEET
LAYOUTS WITH SILLS
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS
DRN. AHN
TRACED WHS, EEB
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO NOV. 7, 1934
FIGURE 11

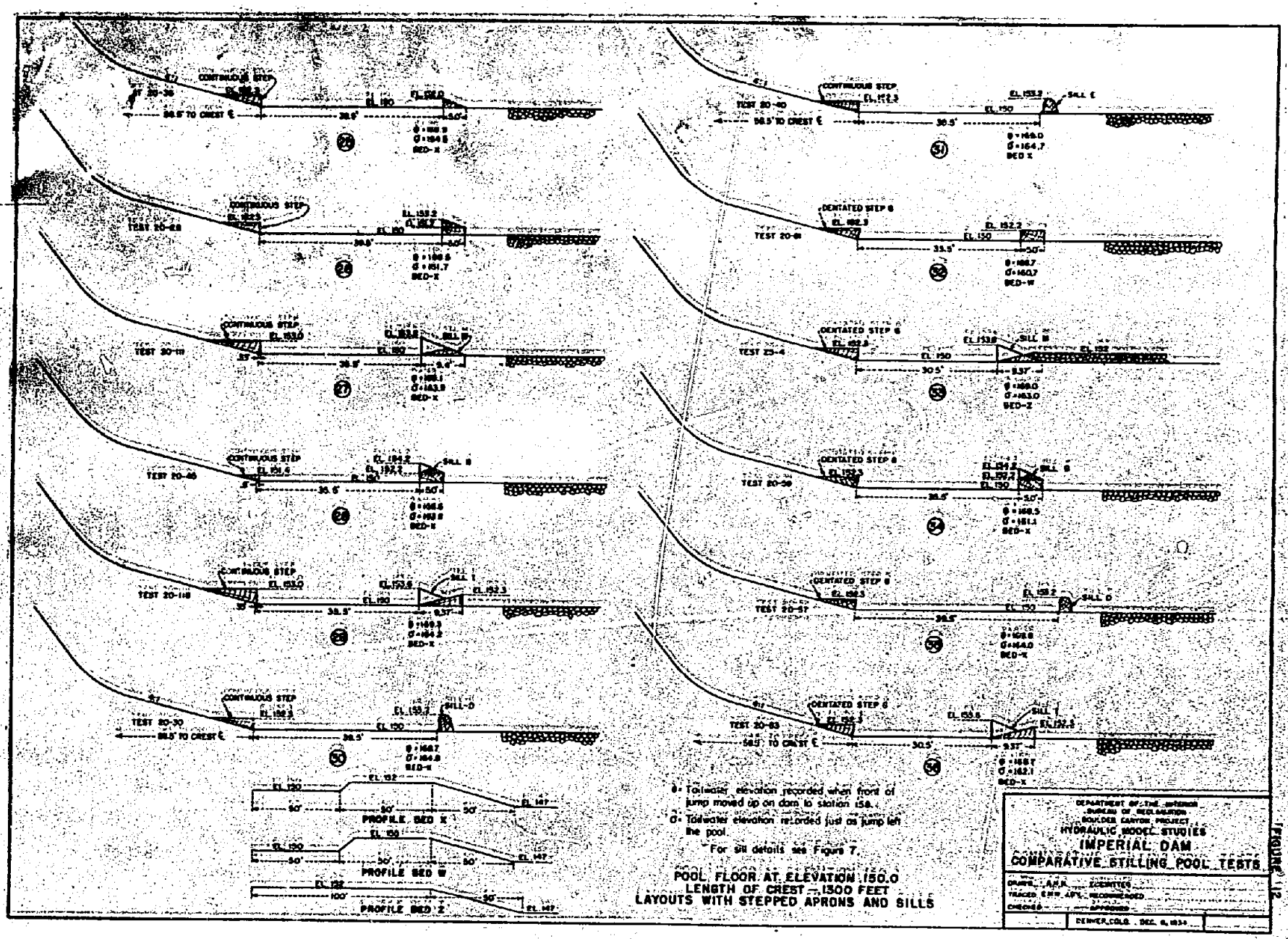
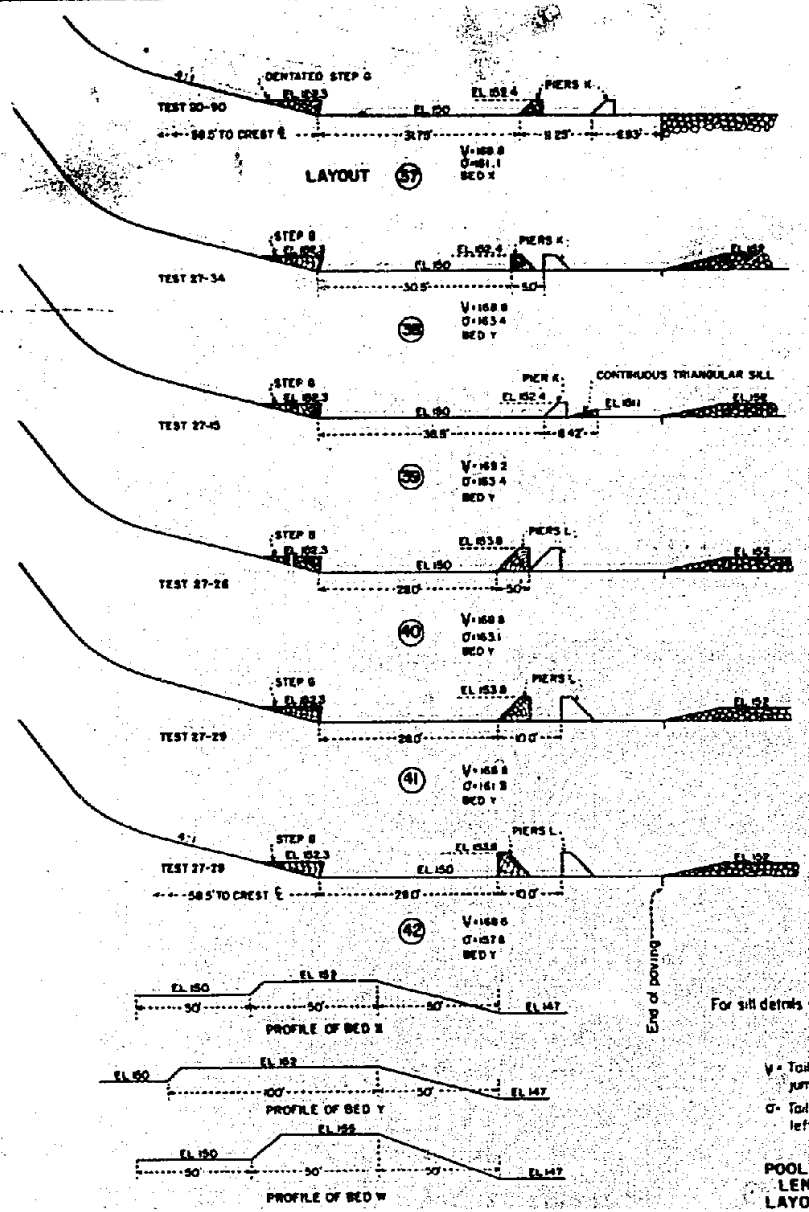
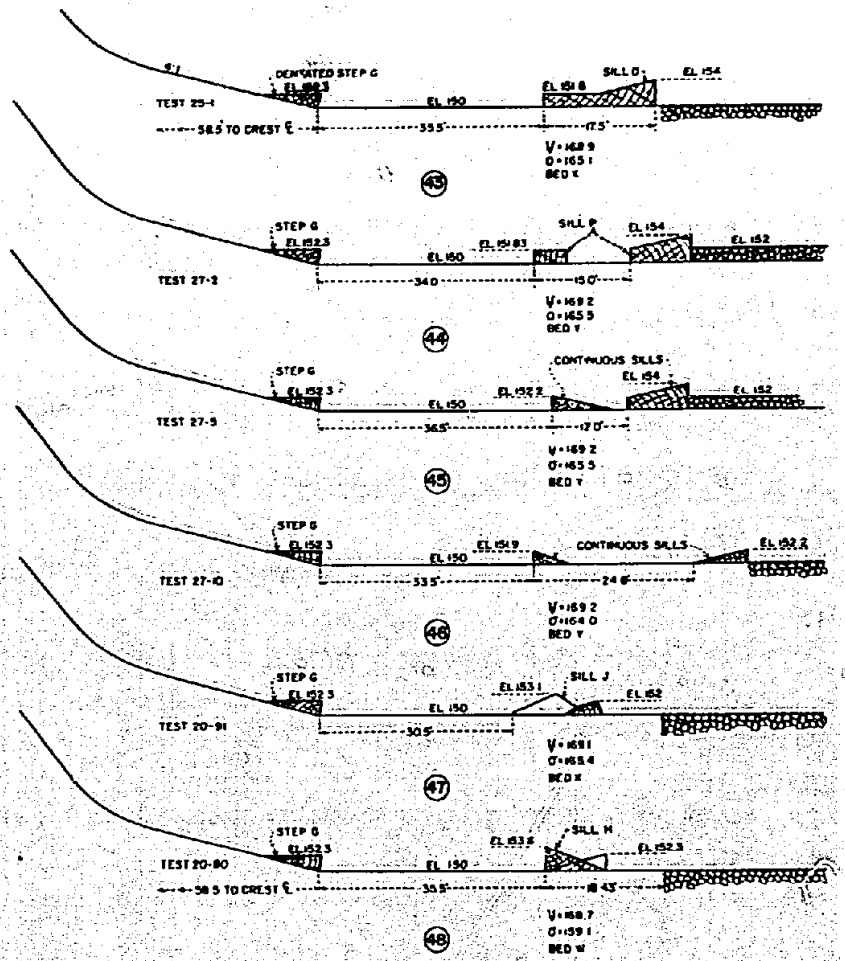

TEST 20-26
TEST 20-28
TEST 20-30
TEST 20-40
TEST 20-41
TEST 20-42
TEST 20-43
TEST 20-46
TEST 20-48
TEST 20-49
TEST 20-50
TEST 20-51
TEST 20-52
TEST 20-53
TEST 20-54
TEST 20-55
TEST 20-56
TEST 20-57
TEST 20-58
CONTINUOUS STEP
DENTATED STEP 6
SILL 0
SILL 1
SILL 6
SILL 8
SILL 10
EL. 150
EL. 152
EL. 147
PROFILE BED X
PROFILE BED W
PROFILE BED Z
θ = Tailwater elevation recorded when front of jump moved up on dam to station 158.
σ = Tailwater elevation recorded just as jump left the pool.
For sill details see Figure 7.
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST — 1300 FEET
LAYOUTS WITH STEPPED APRONS AND SILLS
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS
DENVER, COLO. DEC. 6, 1934

FIGURE 12





For sill details see figure 7

V = Tailwater elevation recorded when front of jump moved up on dam to elevation 158.

σ = Tailwater elevation recorded just as jump left the pool

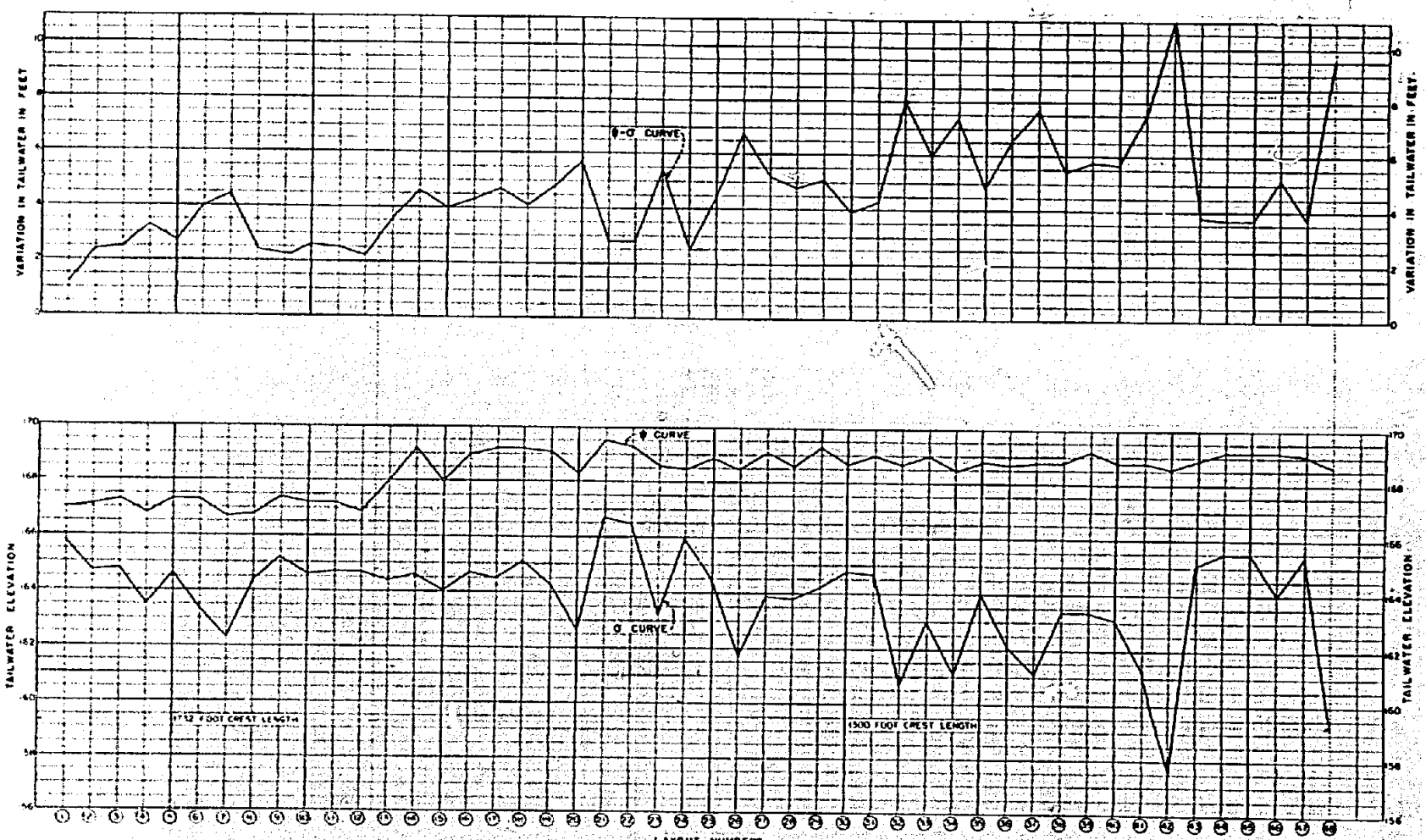
POOL FLOOR AT ELEVATION 150.0
LENGTH OF CREST 1300 FEET
LAYOUTS WITH DENATED STEPPED APRON AND SILLS

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM
COMPARATIVE STILLING POOL TESTS

DRAWN A.H.N. SUBMITTED
TRACED T.J.K. C.E.B. RECOMMENDED
CHECKED APPROVED
DENVER, COLO., DEC 8, 1934

FIGURE 13



Φ = Tailwater elevation recorded when front of jump moved up on dam face to elevation 68

O = Tailwater elevation recorded just as jump left the pool

U O = Permissible tailwater range for each layout

All comparative runs were made at the maximum [illegible]

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES

IMPERIAL DAM

CURVES SHOWING TAILWATER RANGES FOR COMPARATIVE RUNS

DRAWN J.N.B. SUBMITTED
TRACED H.W. J.C.K. RECOMMENDED
CHECKED APPROVED
DENVER, COLO.

FIGURE 14

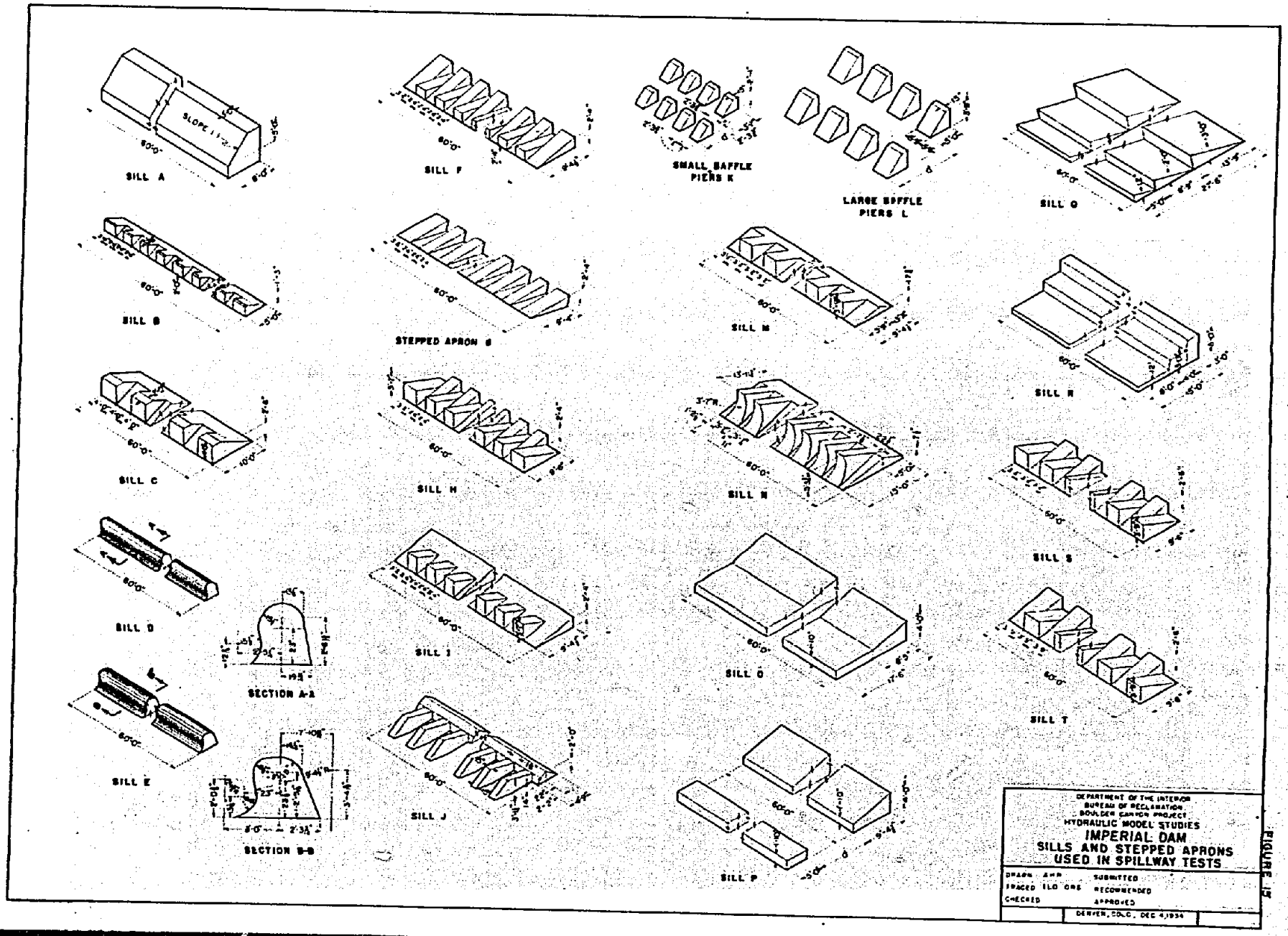

SILL A
SLOPE 1:1
SILL B
SILL C
SILL D
SILL E
SECTION A-A
SECTION B-B
SILL F
STEPPED APRON G
SILL H
SILL I
SILL J
SMALL BAFFLE PIERS K
LARGE BAFFLE PIERS L
SILL M
SILL N
SILL O
SILL P
SILL Q
SILL R
SILL S
SILL T
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT
HYDRAULIC MODEL STUDIES
IMPERIAL DAM
SILLS AND STEPPED APRONS
USED IN SPILLWAY TESTS
DRAWN AMB
TRACED ILO ORS
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLO., DEC 4, 1934

FIGURE 17

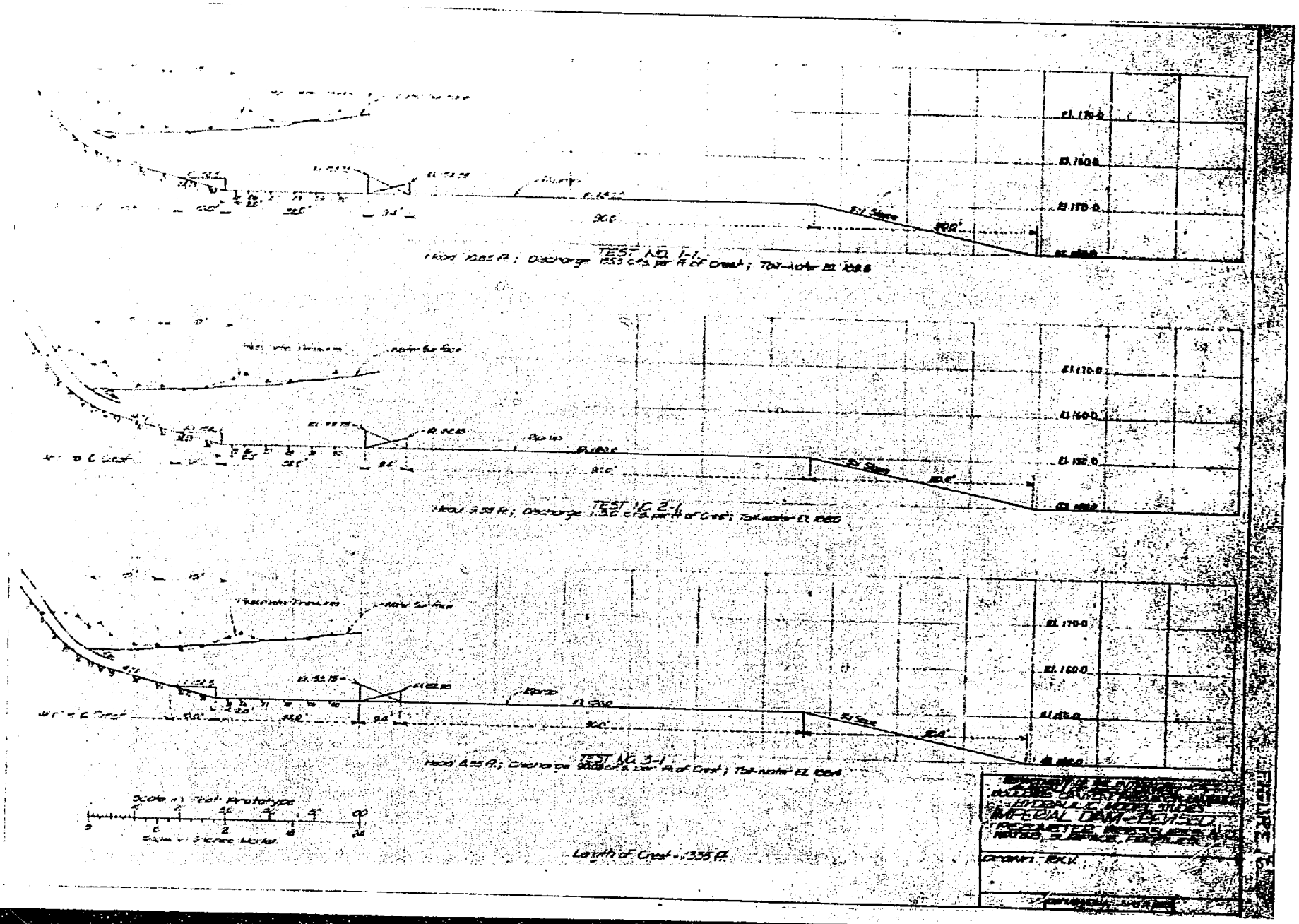
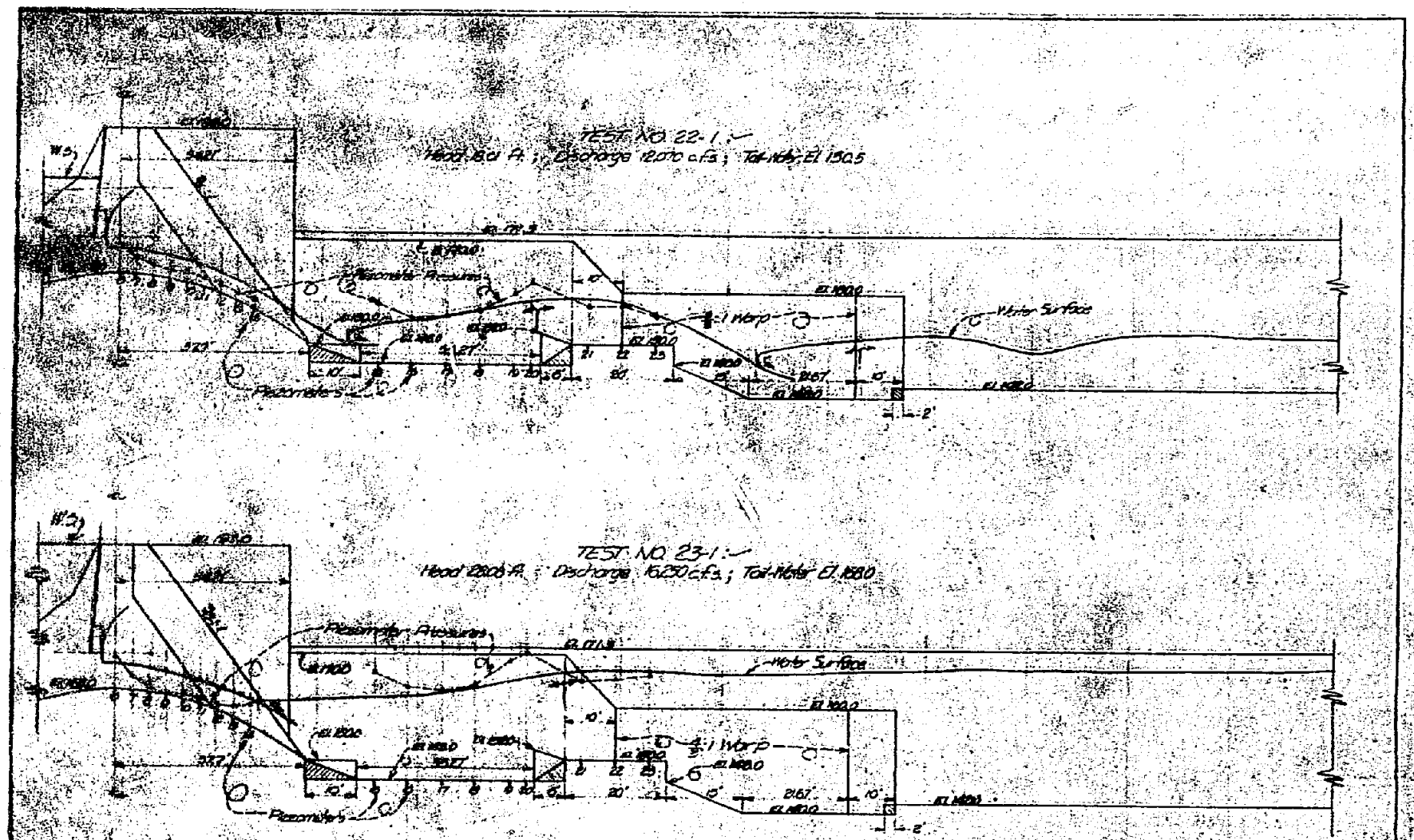

TEST NO. 1-1
TEST NO. 2-1
TEST NO. 3-1
Prototype
Length of Crest ... 355 ft
Drawn: RKK

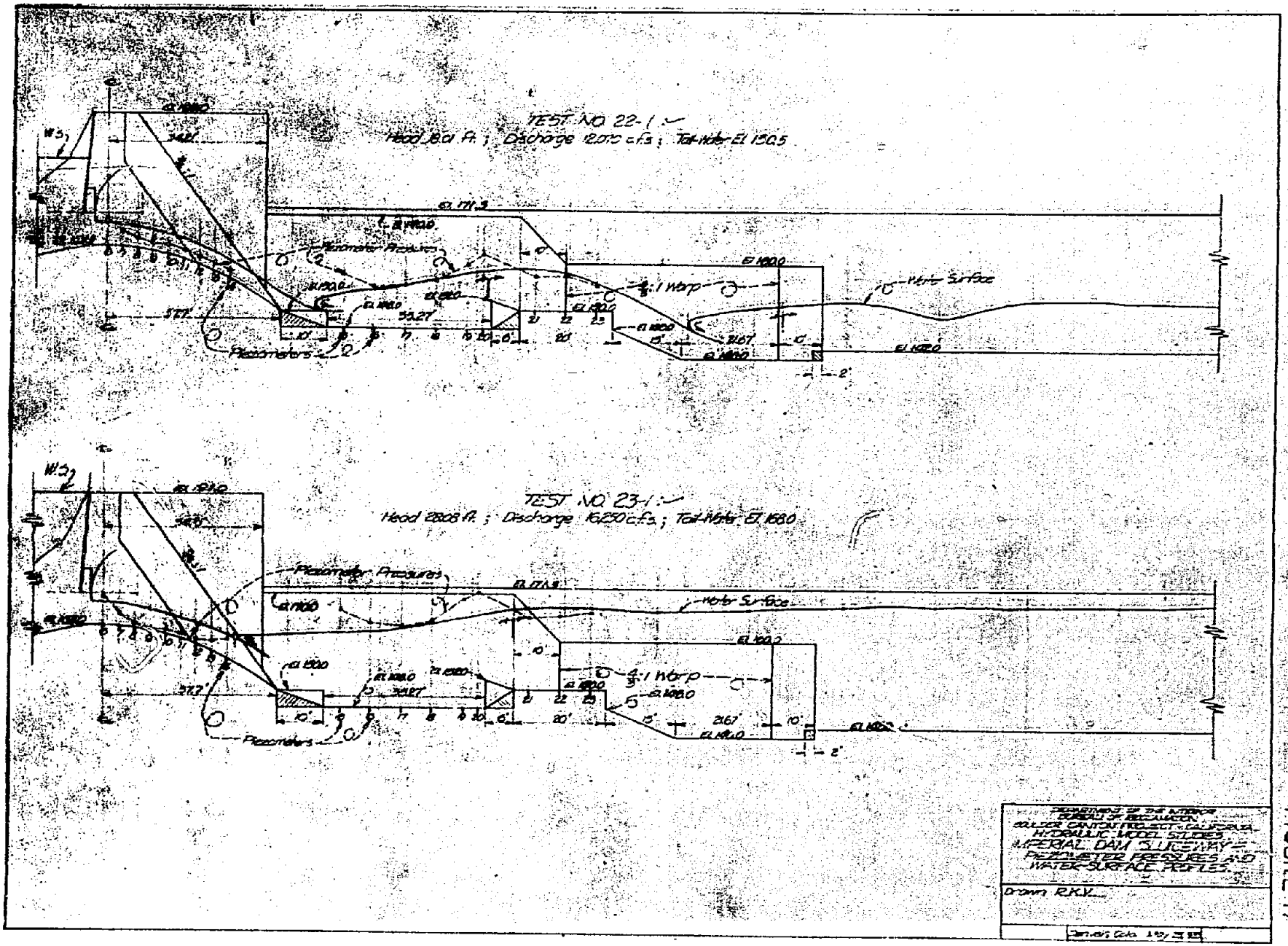
FIGURE 5



GOVERNMENT OF THE UNITED STATES
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT, CALIFORNIA
HYDRAULIC MODEL STUDIES
IMPERIAL DAM SLUICEWAY —
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES

Drawn R.K.V.

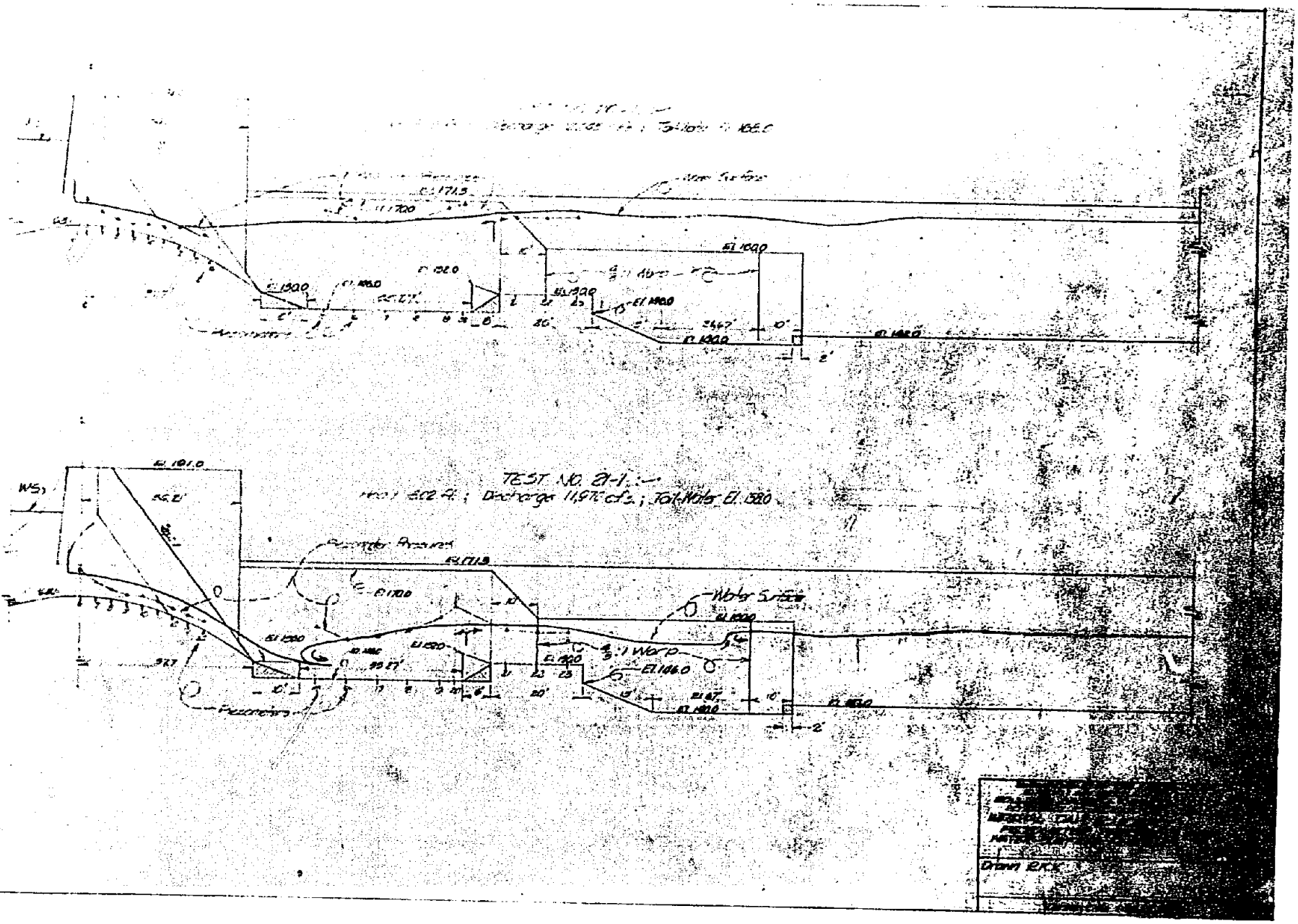
FIGURE 17



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOULDER CANYON PROJECT - CALIFORNIA
HYDRAULIC MODEL STUDIES
MATERIAL DAM SPILLWAY -
PIEZOMETER PRESSURES AND
WATER-SURFACE PROFILES

Drawn R.K.V.

FIGURE 17


TEST NO. 21-1
Discharge 11.97 cfs ; Tail-Water El. 158.0
Water Surface
Piezometers
El. 171.5
El. 100.0
El. 101.0
WS
Drawn R.K.K.

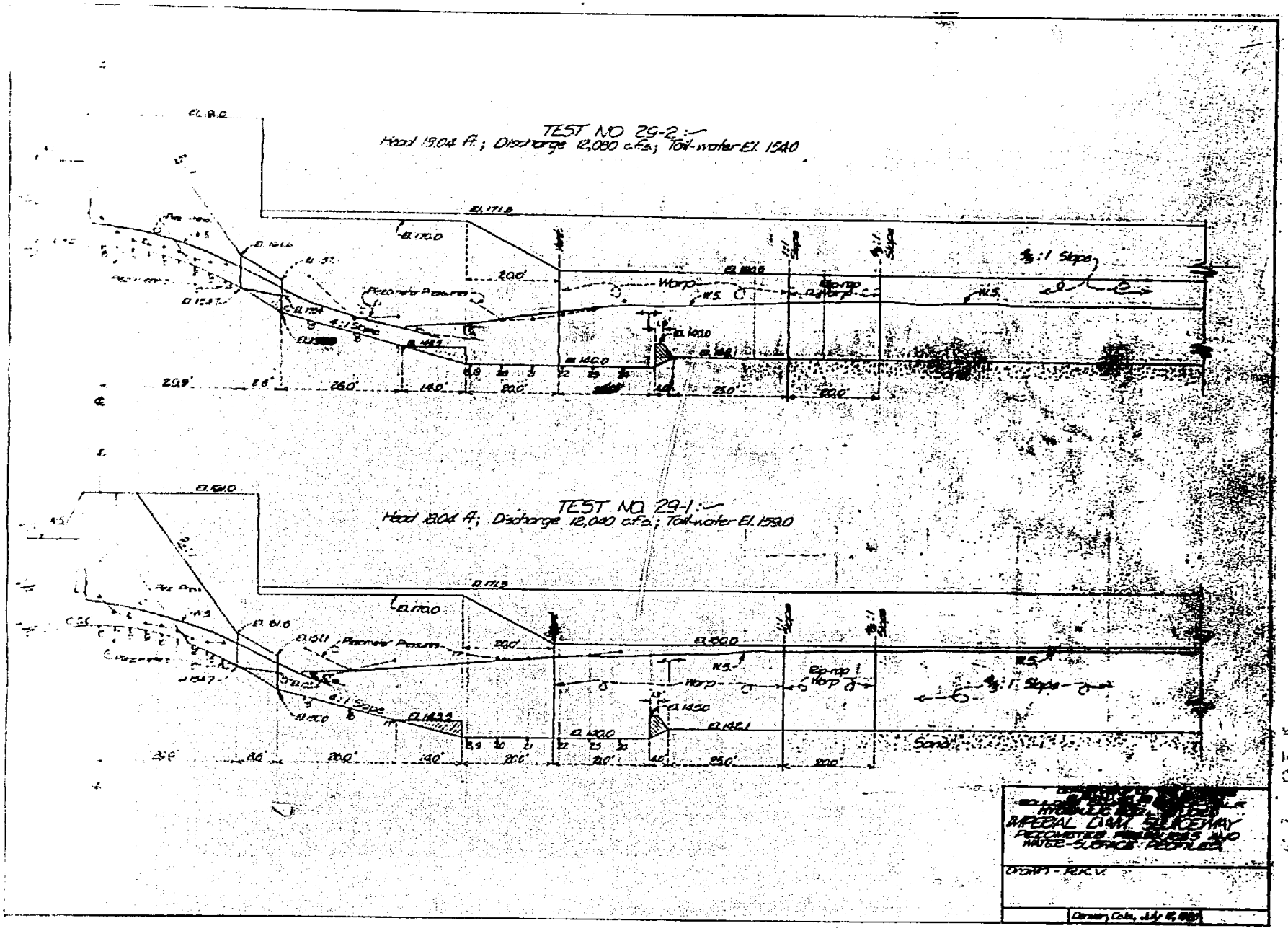

TEST NO 29-2:—
Head 19.04 ft; Discharge 12,000 cfs; Tail-water El. 1540
TEST NO 29-1:—
Head 18.04 ft; Discharge 12,000 cfs; Tail-water El. 1520
Warp
Sand
4:1 Slope
Pioneer Peak

FIG 1

Head Water: El. 19[illegible]

Note: No [illegible] Flow [illegible] of [illegible]

Silt Surface ?

10%

15%

20%

25%

30%

35%

40%

Spillway Water El. 19.5

Note: No Seepage Flow [illegible]

Silt Surface ?

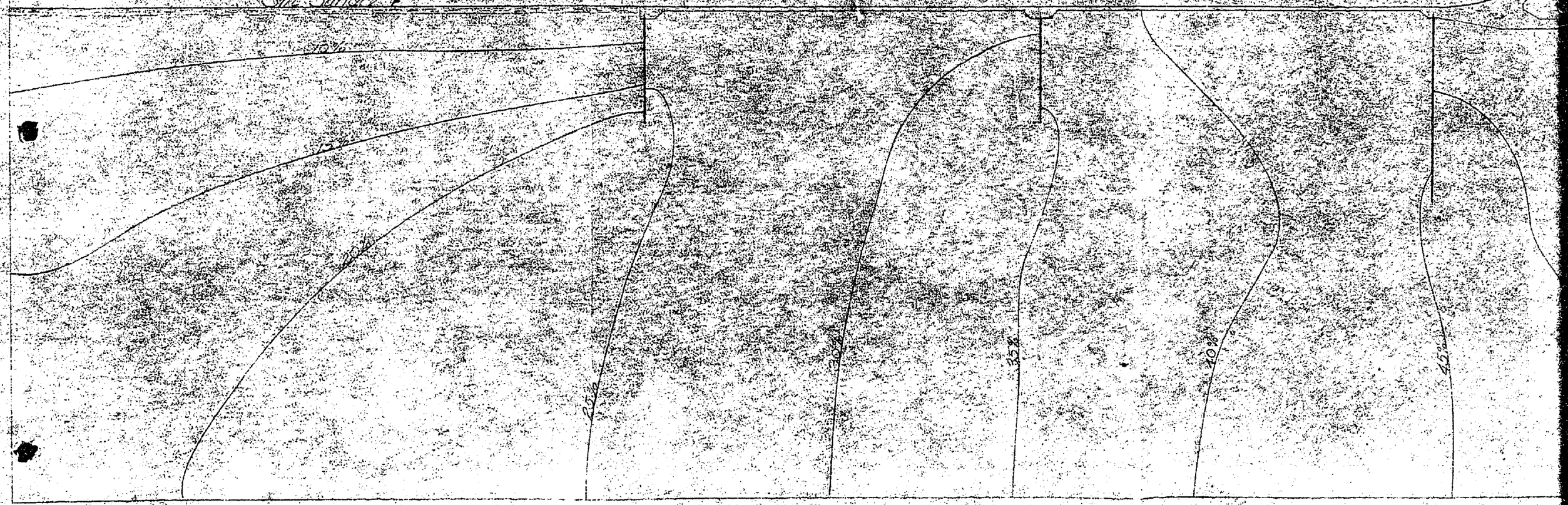
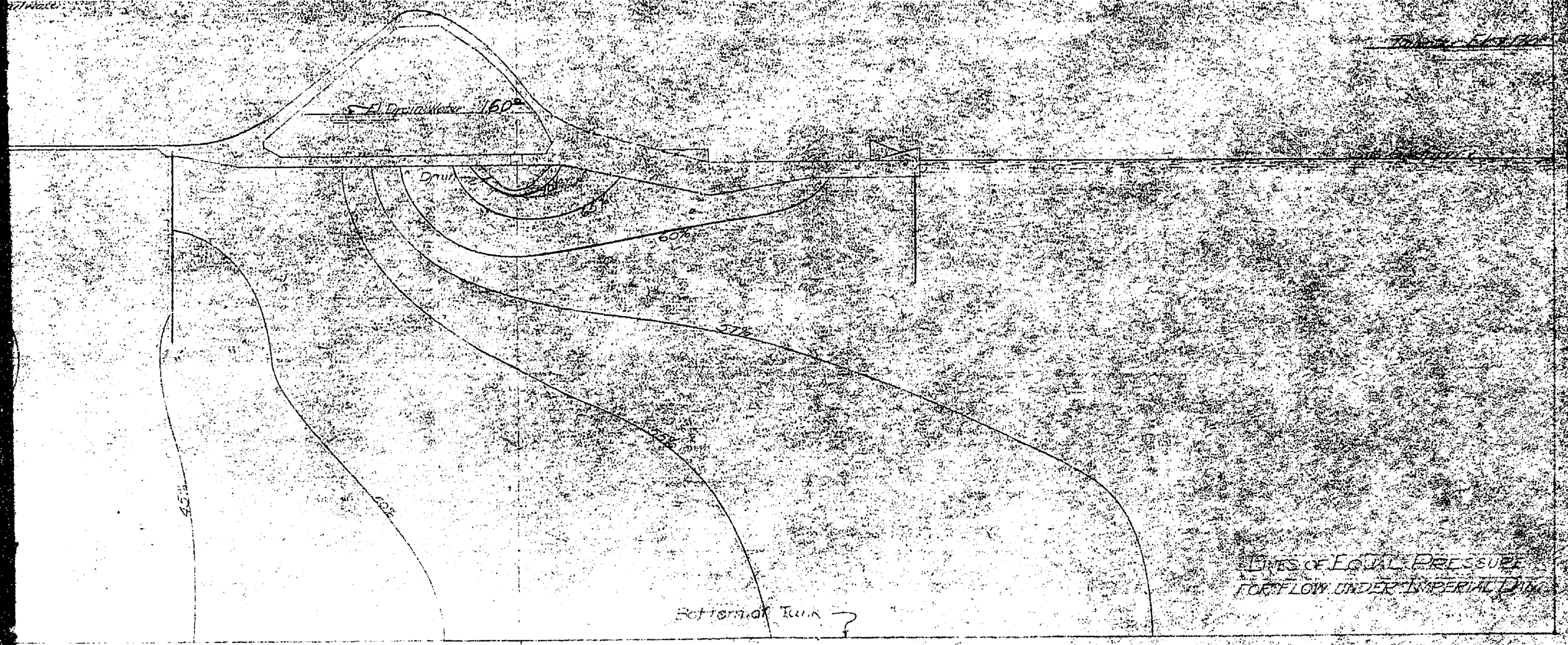
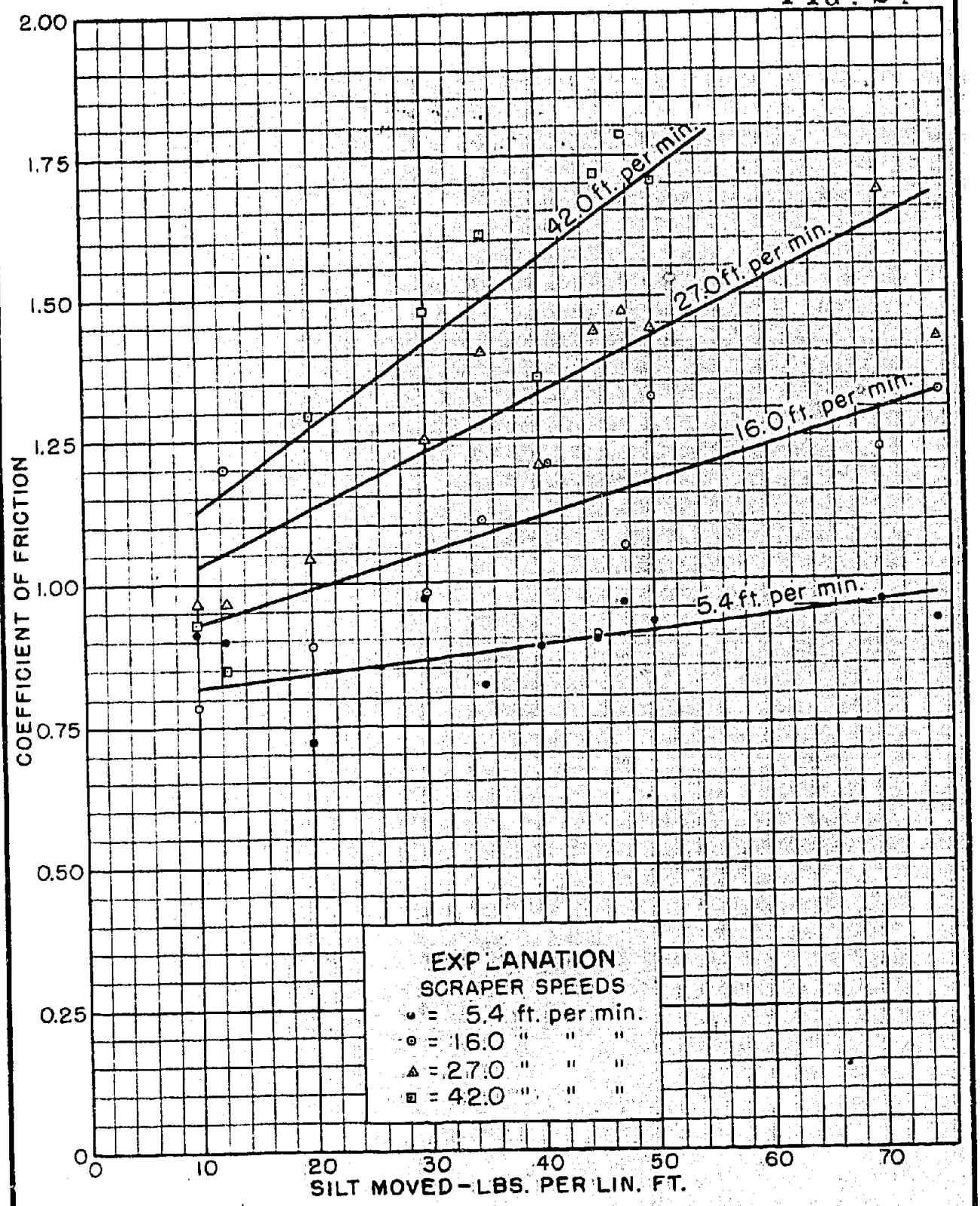


FIGURE 20



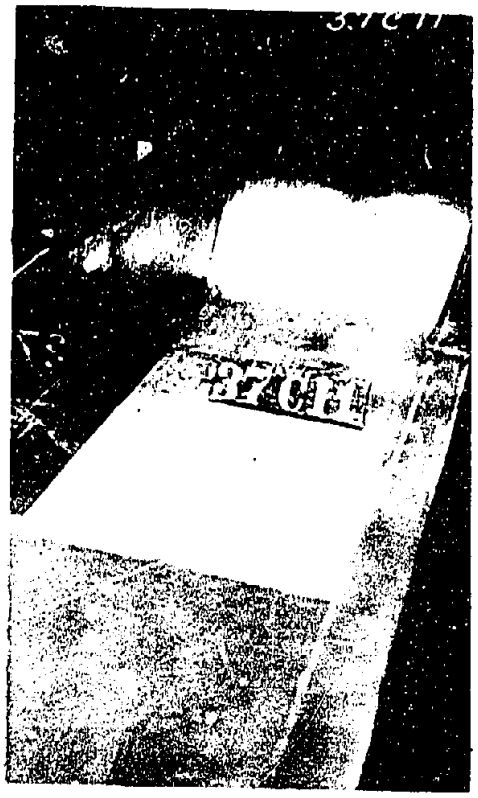
LINES OF EQUAL PRESSURE
FOR FLOW UNDER IMPERIAL DAM

FIG. 21



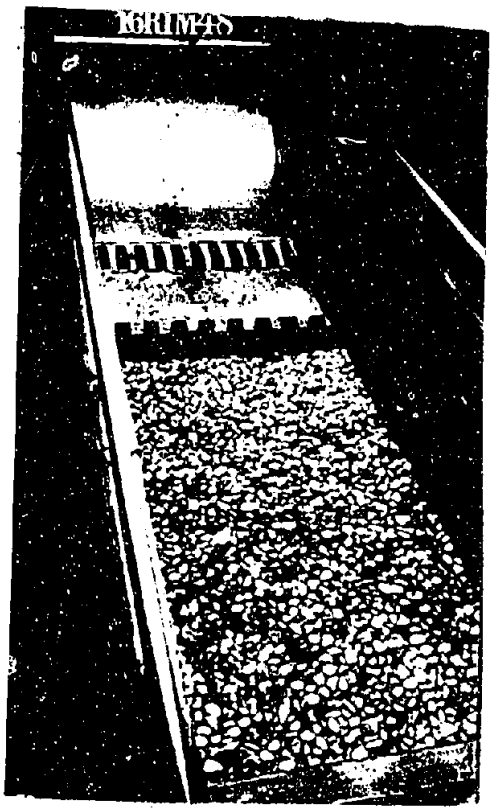
COEFFICIENT OF FRICTION FOR COLORADO RIVER SILT MOVED BY DIAGONAL SCRAPER AT VARIOUS SPEEDS

FROM AVERAGE FORCES OBSERVED IN TESTS USING 8 FT. SCRAPER BLADE AT ANGLES OF 20° TO 35° WITH THE DIRECTION OF MOTION



A-VIEW OF ORIGINAL DAM

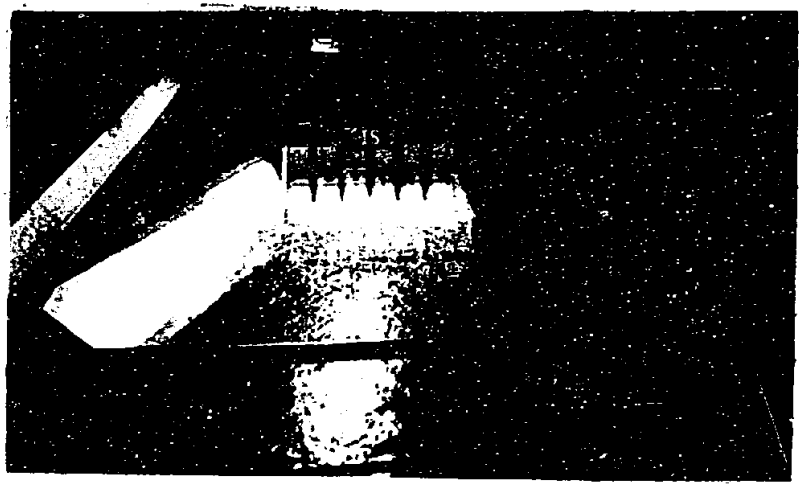
B-DISCHARGE 150,000 C.F.S.
TAILWATER 167.3 (ORIGINAL)



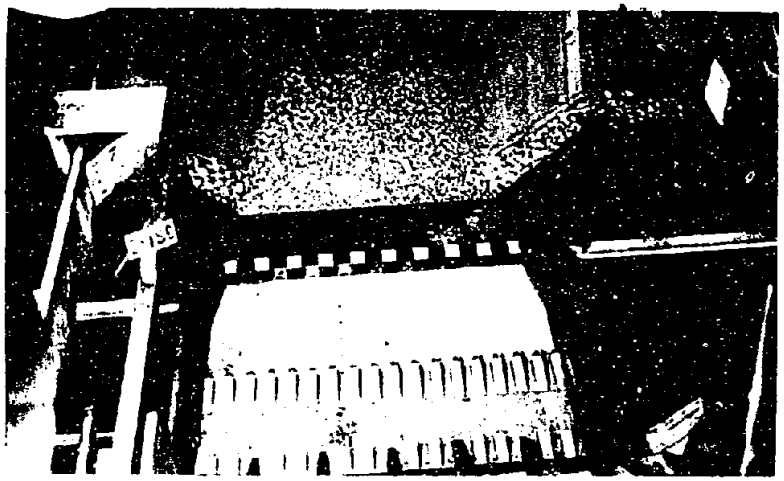
C-REVISED DAM AND STILLING POOL

D-DISCHARGE 180,000 C.F.S.
TAILWATER 166.0 (REVISED)

A-ORIGINAL SLUICEWAY MODEL



B-DISCHARGE 2,000 C.F.S.
(ORIGINAL)

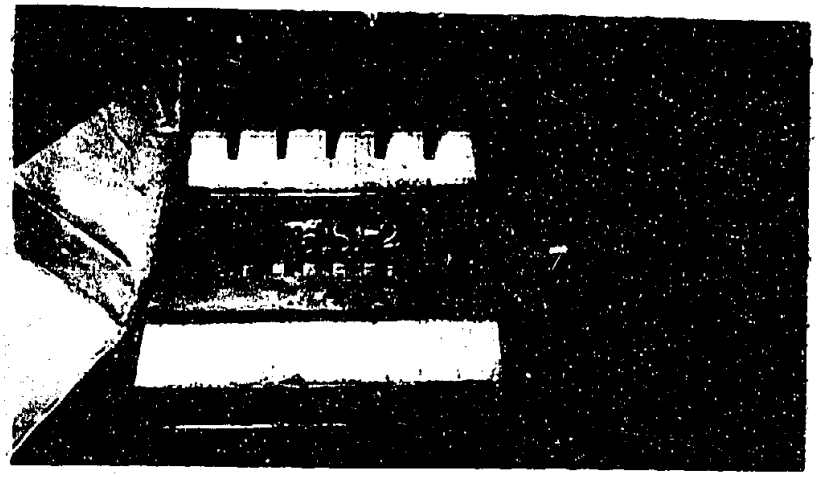


C-REVISED STILLING POOL

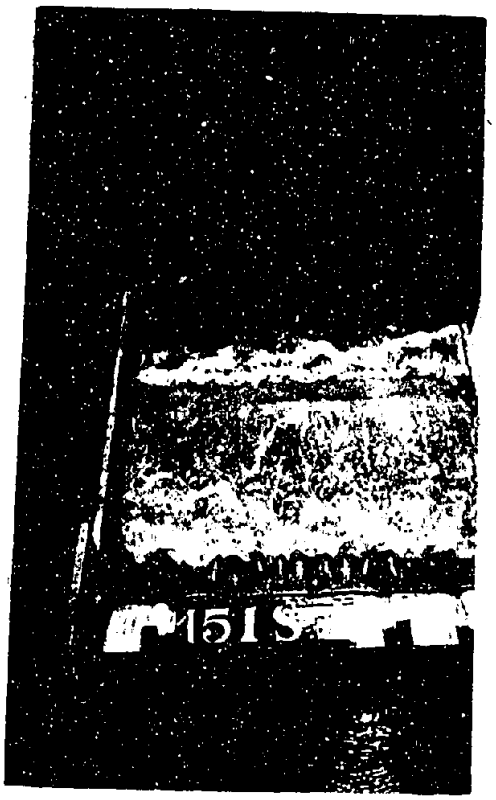
D-DISCHARGE 12,000 C.F.S.
TAILWATER 154.0 (REVISED)

IMPERIAL SLUICEWAYS

PLATE II



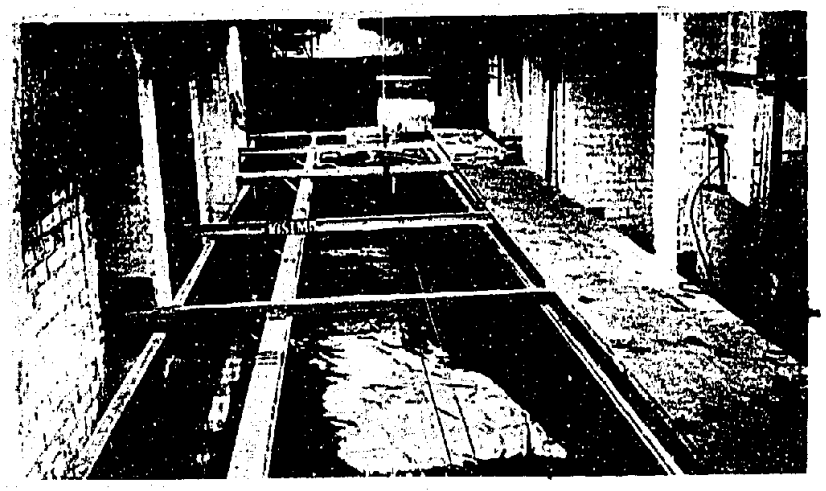
A-VIEW OF DOUBLE JUMP POOL



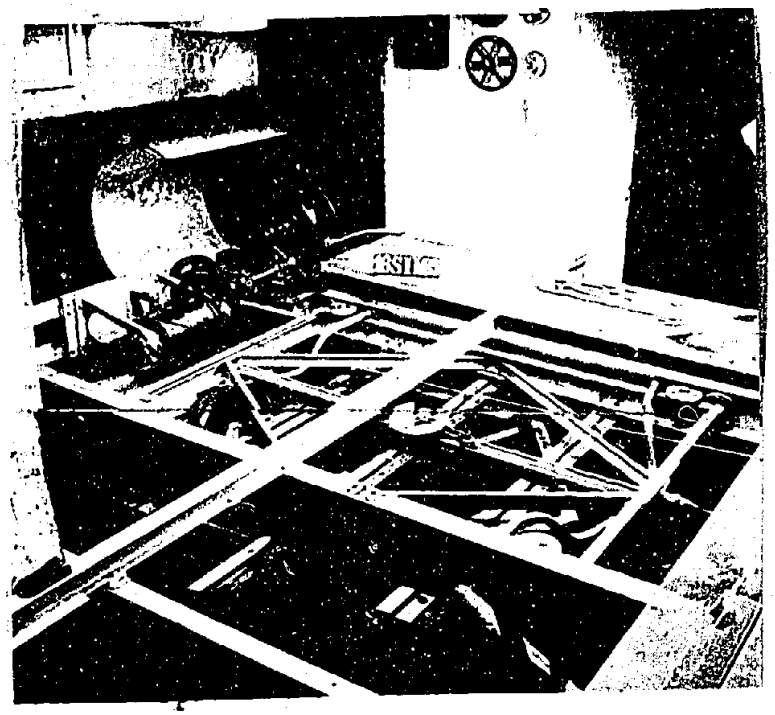
B-DISCHARGE 12,000 C.F.S.
TAILWATER 153.6
NOTICE SECONDARY JUMP.

C-DISCHARGE 12,000 C.F.S.
TAILWATER 155.0
SECONDARY JUMP HAS FLOODED OUT.

IMPERIAL SLUICEWAYS



A-VIEW ALONG TANK SHOWING RAILS AND SCRAPER CARRIAGE IN BACKGROUND. DIAGONAL SCRAPER IN PLACE.



B-CLOSE-UP OF SCRAPER CARRIAGE AND PULLING MECHANISM.

IMPERIAL SCRAPER TESTS

ELECTRIC ANALOGY STUDIES

by

D. J. HEBERT, JUNIOR ENGINEER

ELECTRIC ANALOGY STUDIES OF SEEPAGE AND UPLIFT PRESSURES UNDER IMPERIAL DAM

Tests to Determine Dimensions of Hydraulic Model

Before a hydraulic model could be designed it was necessary to know the clearances, between the dam and the sand box which contains it, which would insure an unrestricted flow. If sufficient clearance were not provided, the uplift pressures measured in the model would be in error. The determination of the allowable dimensions was made with an electric analogy model.

From borings made at the site it was known that the porous foundation upon which the dam is to be placed extended down over 100 ft. Assuming then a large but undetermined depth there remained to find the location of a bottom boundary such that when it is moved to a lower position no change occurs in the magnitude of the uplift pressures.

A model of the under-profile of the dam was constructed out of pyralin to a scale of 1 in. = 30 ft. and was set up in the electric analogy testing tray with liberal clearances allowed by the boundaries. The potential loss to 18 significant points under the dam was measured and recorded. The boundaries were moved inwards and another set of observations taken at the same 18 points. It was at once evident that the second set of boundary conditions were too restricted because the potential loss at each point had changed by about 5 percent. The boundaries were then spread on all three sides to two new positions and measurements taken for each position. The values of potential loss for the final position were practically identical with those for the initial

position. This final position differed from the initial one enough to indicate that beyond this setup the boundaries were no longer effective in changing the pattern of equi-potential lines. The four positions of the boundaries together with the corresponding measurements are shown on fig. A.

Upon completion of the tests for the determination of the hydraulic model dimensions it was decided to set up several different combinations of potential levels and observe the net of equi-potential lines. These nets together with the potentials which were applied are shown on figs. 1 to 3.

A more detailed and complete study of the potential lines was made when a schedule of headwater and tailwater elevations became available. For this study tinfoil sheets were used because of the greater ease of handling as compared with the salt solution model. The schedule used for testing is as follows:

No.	Elev. Headwater	%	Elev. Drain	%	Elev. Tailwater	%
1	191	0	160	100	168	74.2
2	191	0	160	100	160 plus	
3	191	0	160	100	160	100.0
4	191	0	160	95.5	159	100
5	191	0	160	67.7	150	100

The potential line nets for each one of the different numbers is shown on figs. 4 to 6. From these nets which have been observed it is now possible to compute the theoretical uplift pressures exerted upon the under side of the dam. Since the nets are plotted in percent the pres-

sures can be computed for any head. The pressures expressed in feet of head have been computed for each combination of potential levels and are shown on figs. 7 to 11 plotted directly on the profile of the dam. In order to find the pressure at any point under the dam it is necessary only to scale the vertical distance from the point to the line of piezometric levels. The pressure distribution along the cut-off walls is indicated by the horizontal distances as indicated by the arrows.

A few remarks are inserted at this point to explain fig. 6A. It represents an attempt to explain an unexpected condition which was observed in the hydraulic model for the following condition of heads. The headwater was set and maintained with the drain open to discharge water and the tailwater confined with no outflow from it. From analogy tests it was predicted that the potential of the tailwater for this setup, after equilibrium had been attained, would be approximately 10% above the drain potential. In the model, however, the tailwater rose to a level 30% above the drain. At the same time the two piezometers located at the outer surface of the filter which surrounds the drain showed a potential of about 30% above the drain indicating that there was a loss of 30% of the total head through the filter and drain. It seemed to be indicated that the drain or filter had become choked in some manner. That this was the explanation was proved by the following electric analogy test. The choking of the drain was accomplished by interposing whitewash powder between the drain electrode and the tinfoil of which the model was constructed. After a number of trials the quantity of powder necessary to raise the tailwater potential to 37% was found.

With this condition of the drain, the potential at the location of the two piezometers mentioned above was about 30%. See Run A, fig. 6A. By merely decreasing the size of the drain it was found that the tail-water elevation could be raised no higher than about 15%. Therefore it must have been the condition of the drain rather than its size which caused the high loss.

Quantitative Studies

The use of the electric analogy method for making quantitative studies is still rather new. As a preliminary to the description of the quantitative studies of the flow through the porous foundation of Imperial Dam a brief discussion of the basis for such studies will be given.

The equations which form the basis of the analogy are Ohm's Law and Darcy's Law. Ohm's Law, which has been proved beyond any doubt, states the relationship between electrical potential and the corresponding current of electricity in a conductor:

$$I = E/R \qquad \text{----------(1)}$$

Darcy's Law gives the relationship between the head of water on a porous medium and the corresponding velocity of flow in it:

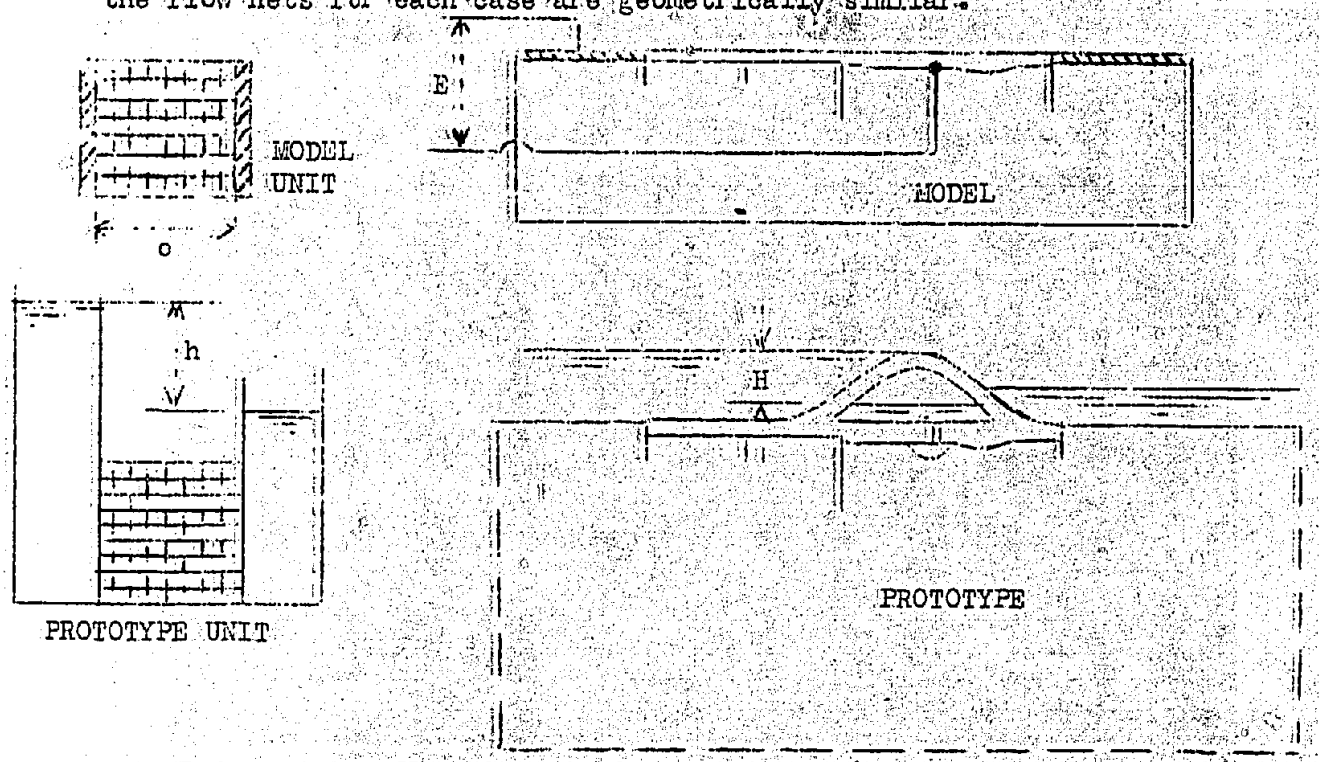
$$v = k\,h/L \quad \text{or} \quad Q = A\,k\,h/L$$

setting $A\,k/L = 1/R'$

then $Q = h/R' \qquad \text{----------(2)}$

It can be seen that equations (1) and (2) have exactly the same form and that both state the law of potential flow. Since the two functions expressed in (1) and (2) are analogous they determine analogous flows

when the same boundary conditions are imposed and it can be said that the flow nets for each case are geometrically similar.



Let: Q = flow through the prototype

H = head on the prototype

n = scale ratio

q = flow through a unit of the prototype

h = head on the unit

I = current through the electrical model

E = voltage impressed upon electrical model

i = current through a unit of the electrical model

e = voltage impressed upon unit

Starting with the two units the similarity of the flow nets can be seen rather clearly. The flow lines will be horizontal and the equi-potential lines, which may be designated as lines of equal piezometric level in the

prototype unit, are vertical. In order to change the flow net from the model unit to the model it is necessary to resort to conformal mapping. This is merely a mathematical device for changing the flow pattern or flow net to fit the new boundary conditions. It is accomplished by means of a transformation equation $f(z)$ where $z = x + iy$. If the relationship between the model and its unit is the same as that between the prototype and its unit the transformation equation is identical for each change. Then if $q = C\,i$

$$Q = C\,I$$

$$\text{and } q/i = Q/I \quad \text{or} \quad Q = q\,I/i \text{ ----------(3)}$$

(q) is evaluated by means of the equation

$$q = k\,h\,n/n \quad \text{where} \quad h = H\,e/E$$

substituting in (3) $\quad Q = k\,H\,e/E\,(I/i)$ ----------(4)

Equation (4) can be set up to give a more direct expression for Q as follows:

$$E = I\,R$$

$$e = i\,r$$

$$\text{so} \quad e/E = i\,r/I\,R$$

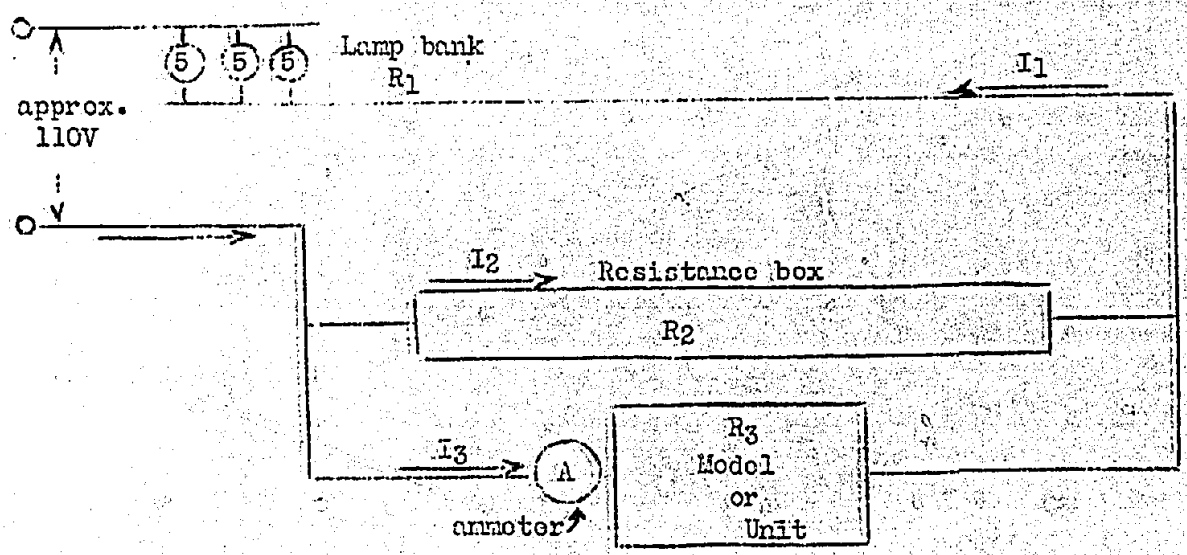
substituting in (4) $\quad Q = k\,H\,\frac{i\,r}{I\,R}\left(\frac{I}{i}\right)$

$$\text{so} \quad Q = k\,H\,\frac{r}{R} \text{ ----------(5)}$$

With the preceding analysis as a basis a series of measurements was taken. The procedure in making the measurements was as follows: The circuit was arranged as shown in the sketch (page 6). The unit which consisted of a square container $1\frac{1}{32}$ in. deep with electrodes along two

opposite sides was filled with a salt solution, placed in the circuit and the current measured by means of an ammeter. The salt solution was then siphoned from the container into the model which was inserted in the circuit in place of the unit. In addition to measuring the current through the model it is necessary to also measure the depth of salt solution so that the resistances of model and unit can be computed for equivalent thicknesses. The depth was measured by means of a micrometer depth gage. These measurements furnish sufficient data to compute quantities in the prototype. The value of " k " in equation ((5) is usually designated as the " percolation coefficient " and is measured in the laboratory by means of percolation cylinders.

Method for Computing Resistances



(1) $I_3R_3 = I_2R_2$

(2) $I_1R_1 + I_3R_3 = 110$

(3) $I_2R_2 + I_1R_1 = 110$

(4) $I_1 = I_2 + I_3$

transposing (2) $I_1 = \frac{110 - I\,R}{R}$

transposing (3) $I_2 = \frac{110 - I\,R}{R}$

substituting from (2)

(5) $I_2 = \frac{110 - (110 - I_3R_3)R_1/R_1}{R_2} = \frac{I_3R_3}{R_2}$

substitute (5) & (2) in (4)

$$\frac{110 - I_3R_3}{R_1} = \frac{I_3R_3}{R_2} + I_3$$

$$110 - I_3R_3 = I_3\left(\frac{R_3R_1}{R_2}\right) + I_3R_1$$

$$R_3 = \frac{110 - I_3R_1}{I_3(R_1/R_2 + 1)}$$ (solve for R_3 with I_3 measured and R_1/R_2 known.)

RESULE OF QUANTITATIVE MEASUREMENT OF CURRENT THROUGH THE ELECTRIC ANALOGY MODEL OF IMPERIAL DAM

The formula used in computing quantity of water flowing from a measurement of the current in the electric analogy model is:

$Q = k\,H\,r/R \times$ width

where r = resistance of unit having the same thickness as the depth of water in the model.

R = resistance of the model.

The measurements will be expressed in terms of this ratio (r/R) which shall be designated (β)

<u>Condition 1</u> ---- Headwater at 190; tailwater at 168; drain at 160 (73.4%)

Jan. 2 β = 0.213

Jan. 3 β = 0.217 (these measurements were made with boundaries at 7.0; rt. 9.0; lt. 8.0)

Condition 2 ---- New boundaries, the same as those which are to be used in the hydraulic model--- 6.8; rt. 9.5; lt. 9.0. The heads are the same as condition 1.

Jan. 8 β = 0.219

Condition 3 ---- Headwater at 180; tailwater at 158; drain at 160 (90.0%)

Jan. 10 β = 0.242

Condition 4 ---- Assuming that no attempt is made to control the potential of the drain. Water goes to the drain until the drain reaches the potential of 67% loss and then the drain acts as a large piezometer tube.

Jan. 10 β = 0.167

For condition 3 a measurement was made to find the proportions of total current going out the drain and out the tailwater.

Jan. 11 Total current entering model = 1.22 amps.

Current passing out the drain electrode = 0.725

Flow through the drain = 0.725/1.22 = 60% of total.

The measurements listed in the preceding pages were taken before a definite schedule was available. They are included as a matter of record. When the schedule for testing had been fixed a series of qualitative studies were made using tinfoil sheets. These studies are treated in the preceding pages. An attempt was then made to use the tinfoil models for quantitative studies with little success. The resistance of the foil is so small that when the instruments are inserted for measuring currents the percentage loss in the meters is large enough to damp out the variation which would occur due to changes

in the model. The salt solution model was resorted to for additional tests. Those tests differed from the preceding ones in that the current passing out the drain was measured instead of the total current entering the model. A measurement was made for each condition except for the case where the tailwater was not connected. The following results were obtained:

	Current
No. 1	0.59 amps.
No. 2	0.53 "
No. 3	0.55 "
No. 4	---- "
No. 5	0 "

It can be seen that the maximum discharge occurs for condition no. 1, when flow is contributed from both the headwater and the tailwater. The estimated flow for this, the worst condition, computed according to the method previously outlined is:

$$\frac{R_3}{R_3'} = \frac{\dfrac{110 - I_3R_1}{I_3(R_1/R_2+1)} \times \dfrac{d_1}{d}}{\dfrac{110 - I_3R_1}{I_3'(R_1/R_2+1)}} = \frac{(110 - I_3R_1)I_3'(R_1/R_2+1)}{(110 - I_3'R_1)I_3(R_1/R_2+1)} \frac{d_1}{d}$$

where R_3 = resistance of unit

R_3' = resistance of model

I_3 = current through unit

I_3' = current through model

I_3' = 0.59 headwater at 0% loss
drain at 100% loss

I_3 = 1.09 tailwater at 74.2% loss

R_1 = 81.5 (resistance of lamp bank) $\frac{d_1}{d} = .616$

$$R_3/R_3' = \frac{(110 - 1.09 \times 81.5)0.59}{(110 - 0.59 \times 81.5)1.09 \times .616} = \frac{21.165 \times 0.59}{61.915 \times 1.09 \times .616}$$

$R_3/R_3' = 0.3$

assuming a value for "k" of .03 cm. per sec.

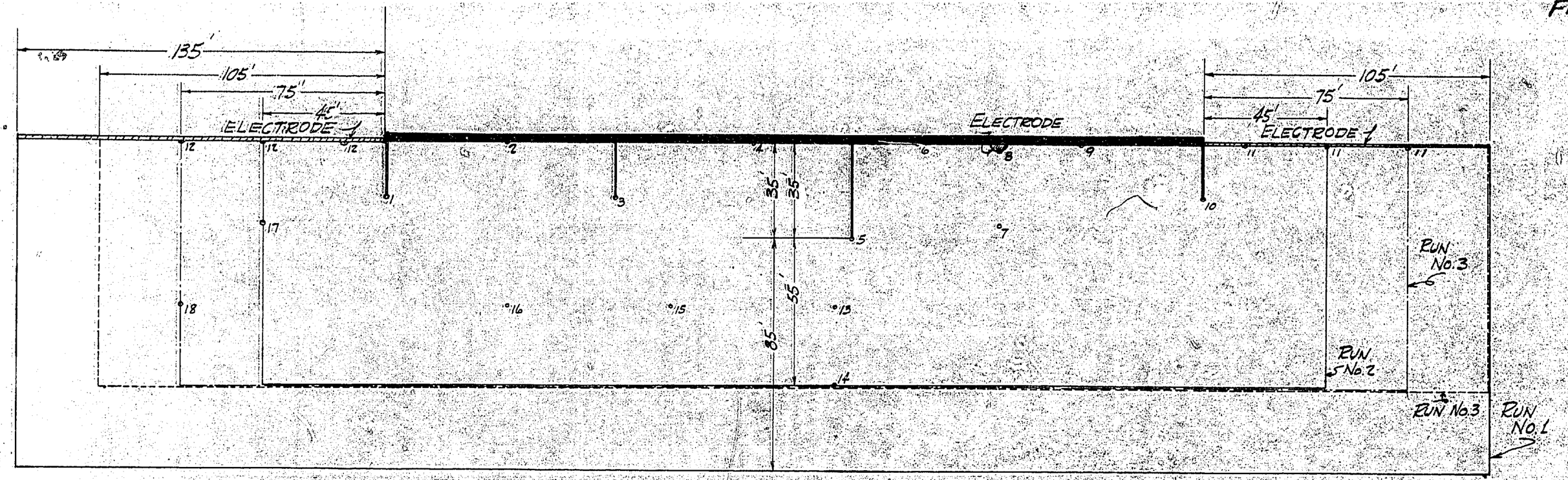
$Q = K\ H\ r/R \times \text{width}$

$Q = .03 \times 31' \times 30.48 \times 0.3 \times 30.48$ c.c. per sec. per ft. width

$Q = 259$ c.c. per sec. per ft. width of dam

$Q = 4.1$ gal. per min. " " " " "

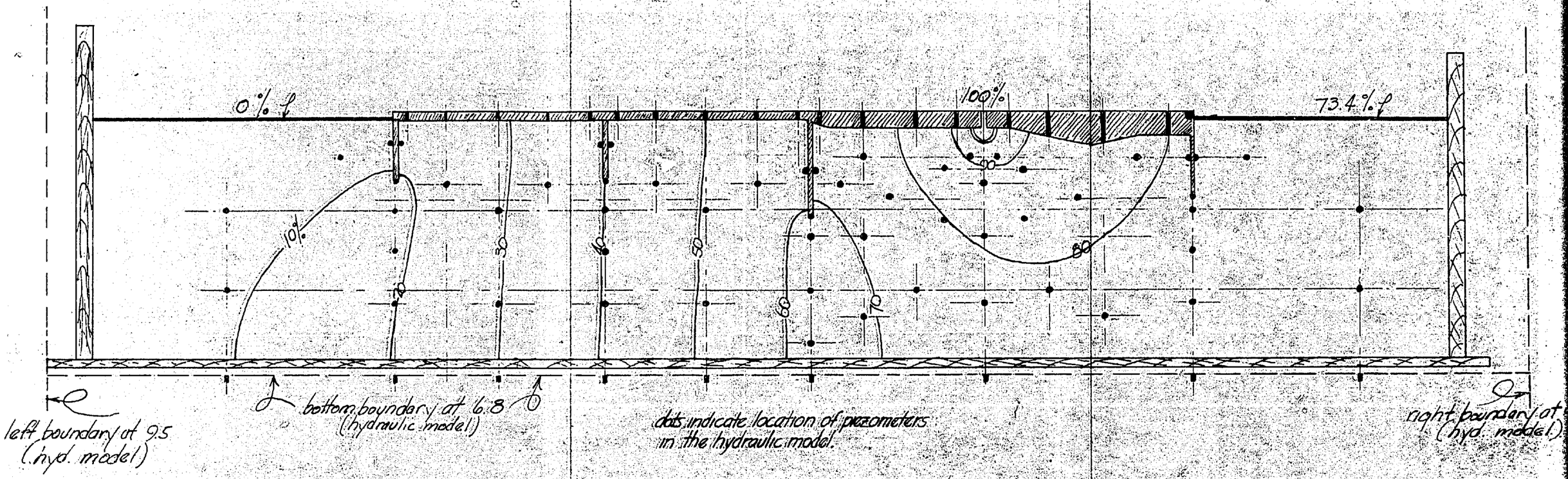
FIG.



BINT	% LOSS RUN 1	RUN 2	RUN 3	RUN 4
1	13	17.2	14	12.5
2	25	30	28	26
3	35.5	40	37.7	35.7
4	47.5	51.0	50.0	47.5
5	59.5	63.5	63	61.0
6	77	77	77.3	75.5
7	76.0	77.7	78	77.0
8	100	100	100	100
9	78	79.5	79.5	77.5
10	69.7	71.5	71.5	70.8
11	66.0	66.0	66.0	66.0
12	0	0	0	0
13	55.7	60.5	59.5	58.0
14	54.2	60.0	58.8	57.0
15	40.5	45.7	43	41.0
16	26.5	34.4	28	26.0
17	5.0	11.0	7.0	5.2
18	6.5	—	—	6.0

SCALE: 1" = 30'

FIG. 1



SCALE 1"=30'

IMPERIAL DAM - ANALOGY STUDIES

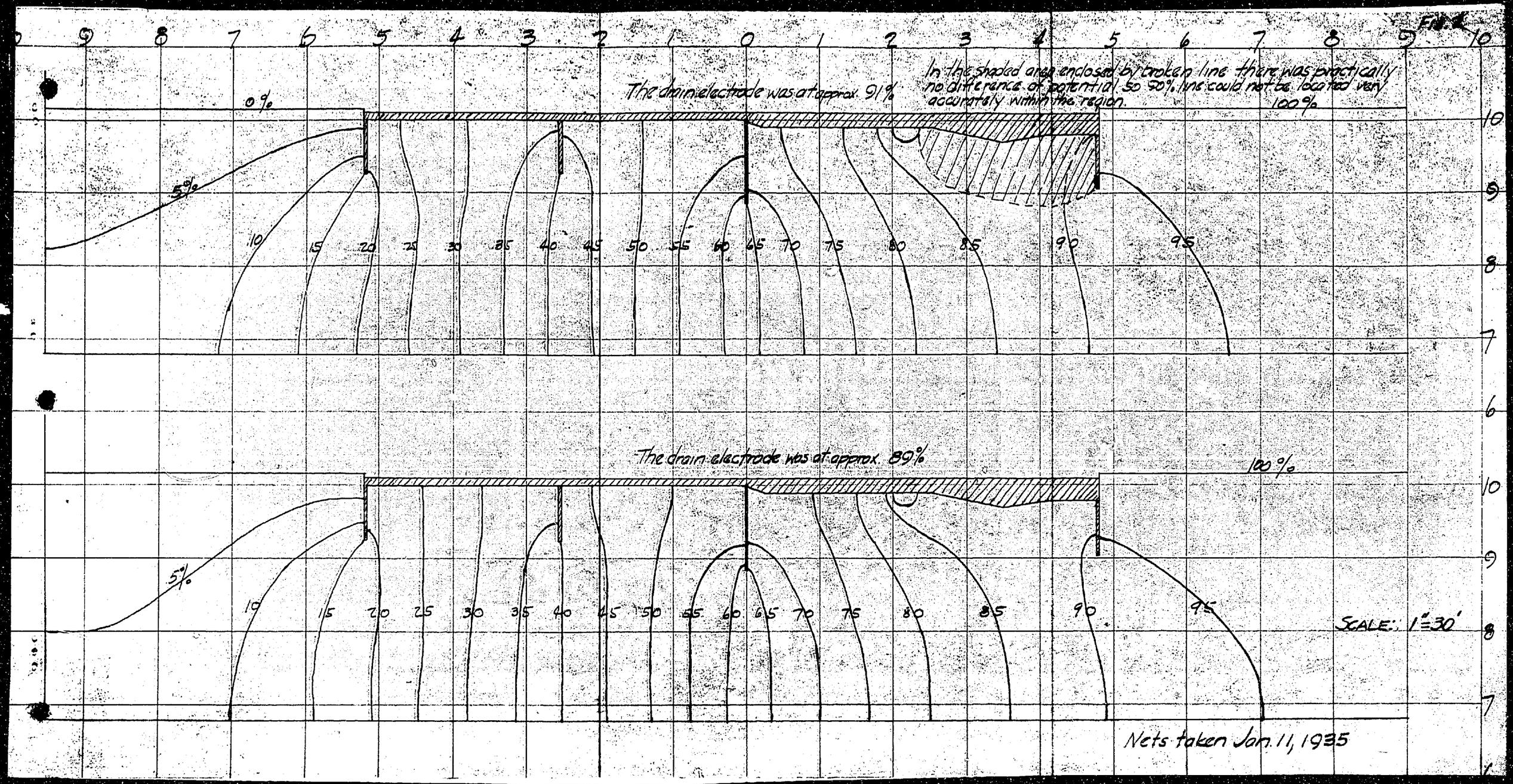
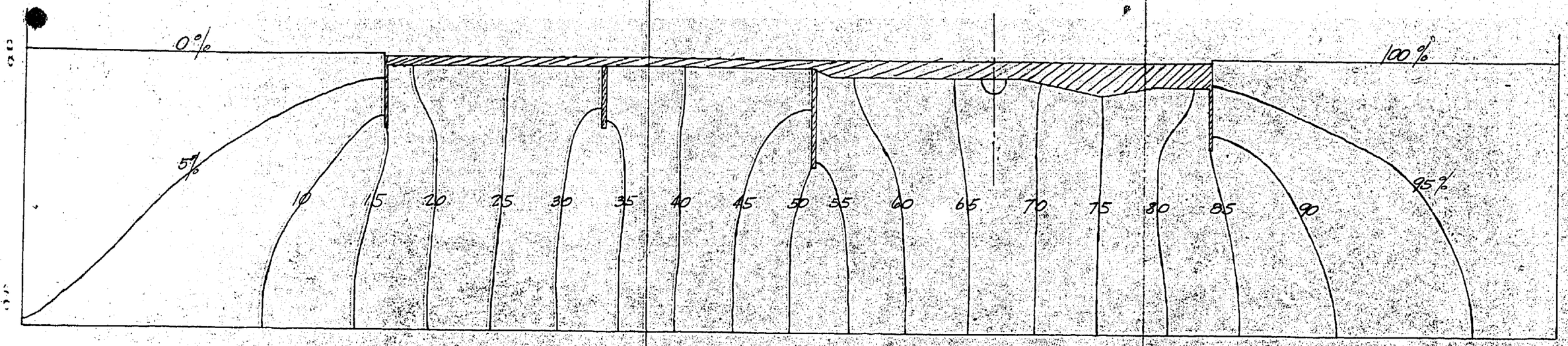
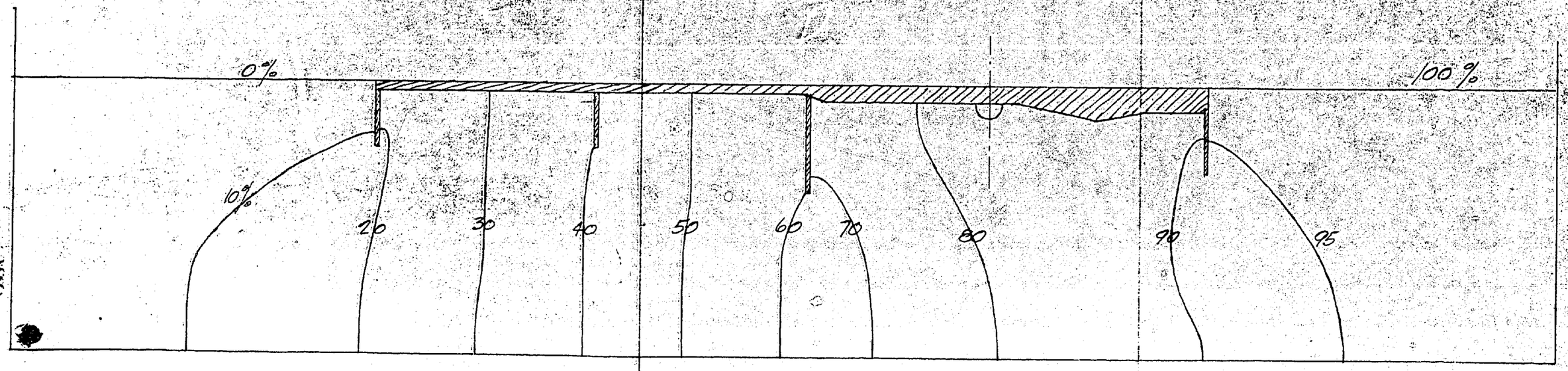


Fig. 2
The drain electrode was at approx. 91%
In the shaded area enclosed by broken line there was practically no difference of potential so 90% line could not be located very accurately within the region.
0%
100%
5%
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
The drain electrode was at approx. 89%
100%
5%
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
SCALE: 1" = 30'
Nets taken Jan. 11, 1935

FIG. 3

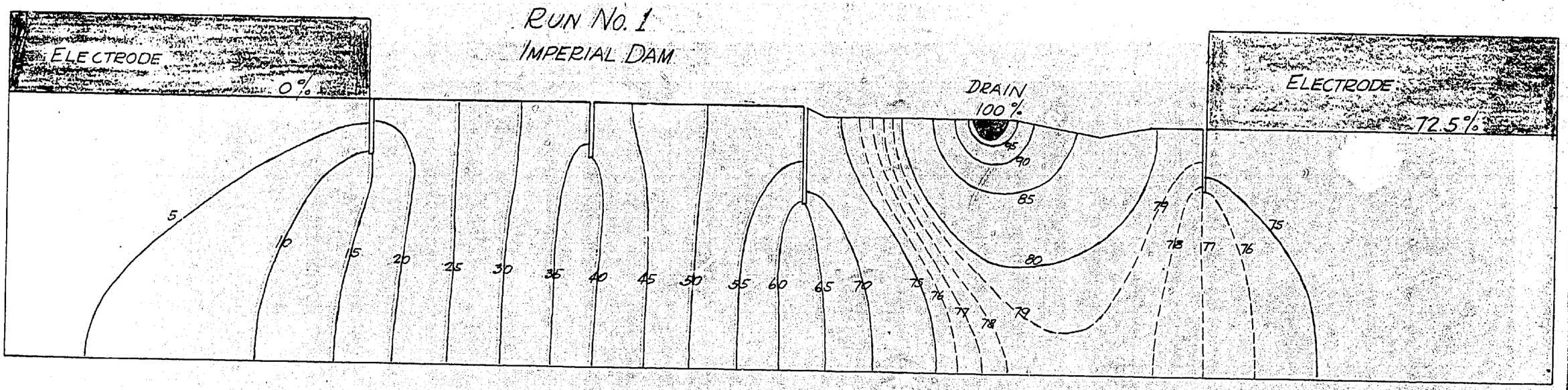




SCALE: 1" = 30'

FIG. 4

RUN No. 1
IMPERIAL DAM



RUN No. 1A
This run differs from No. 1 in the position of the tail-water electrode.

Scale: 1" = 30'

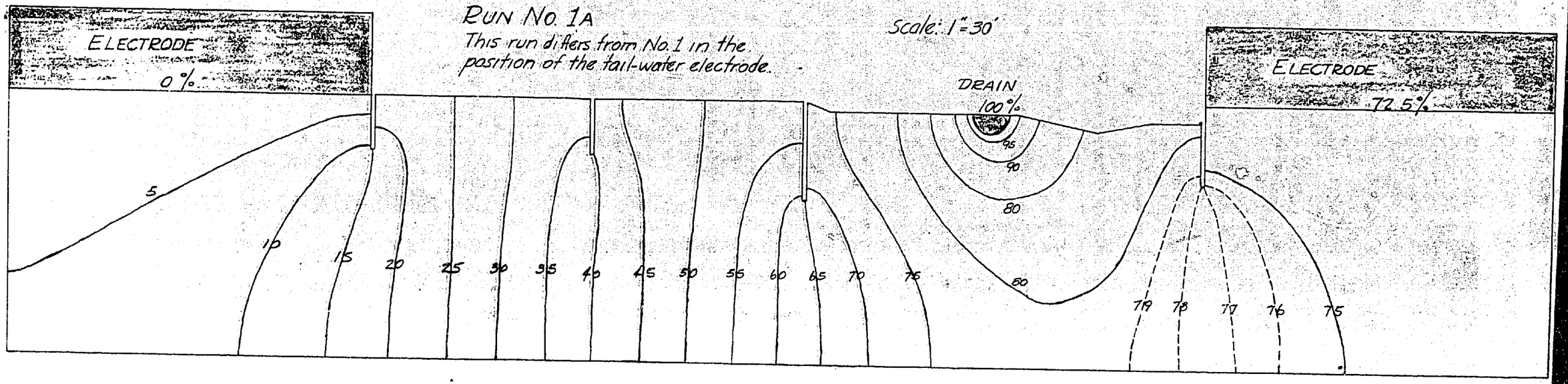
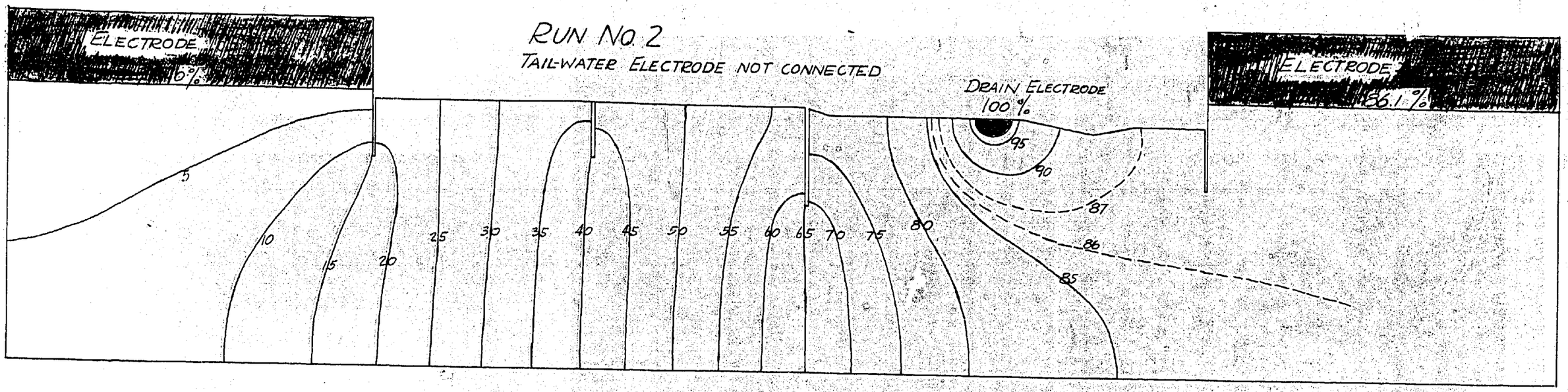


FIG. 5


RUN No. 2
TAIL-WATER ELECTRODE NOT CONNECTED
ELECTRODE
6%
DRAIN ELECTRODE
100%
ELECTRODE
56.1%
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
86
87
90
95

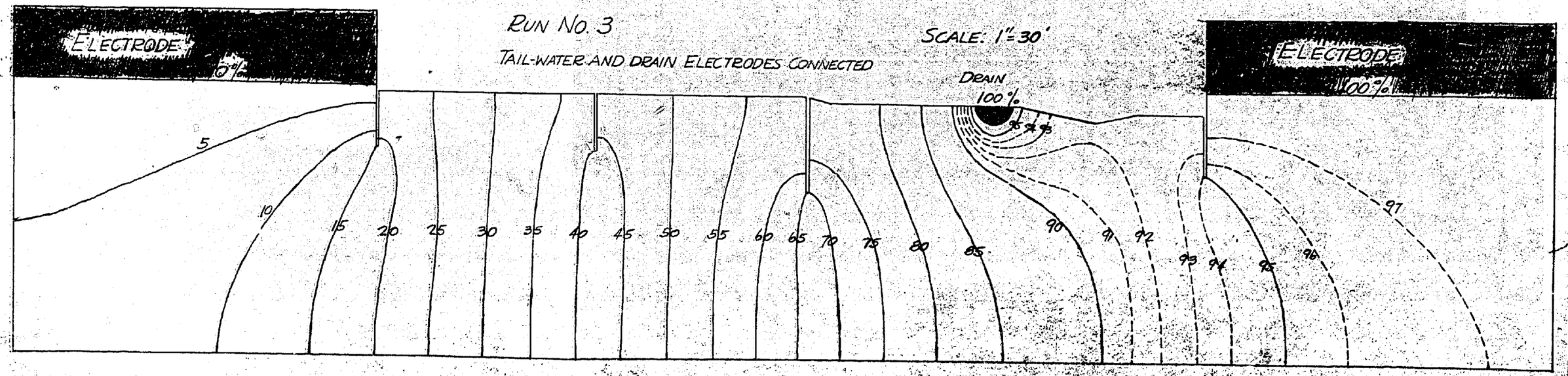
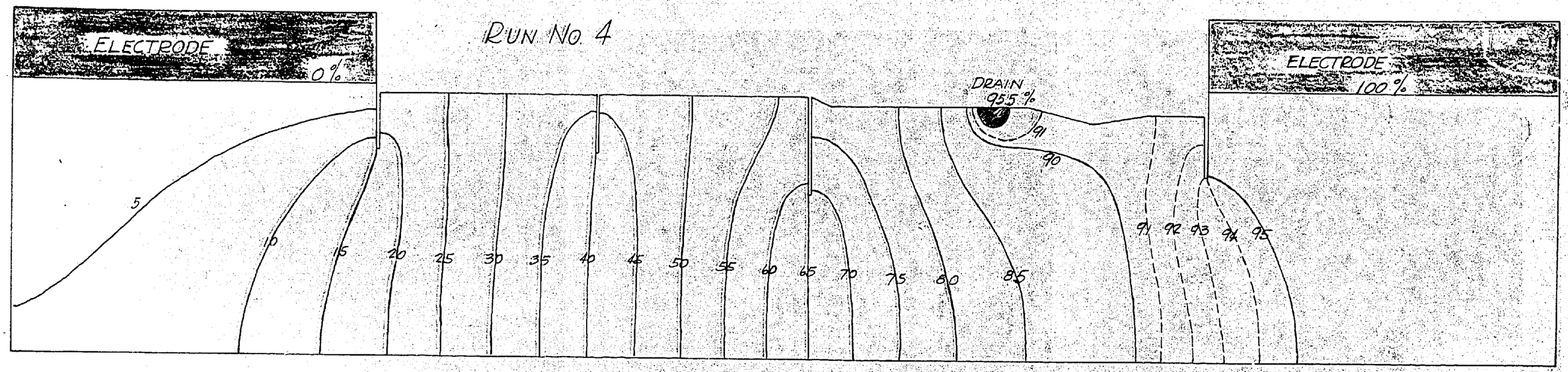

RUN No. 3
TAIL-WATER AND DRAIN ELECTRODES CONNECTED
SCALE: 1" = 30'
ELECTRODE
6%
DRAIN
100%
ELECTRODE
100%
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
91
92
93
94
95
96
97

FIG. 6


RUN No. 4
ELECTRODE
0%
ELECTRODE
100%
DRAIN
95.5%
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
91
92
93
94
95

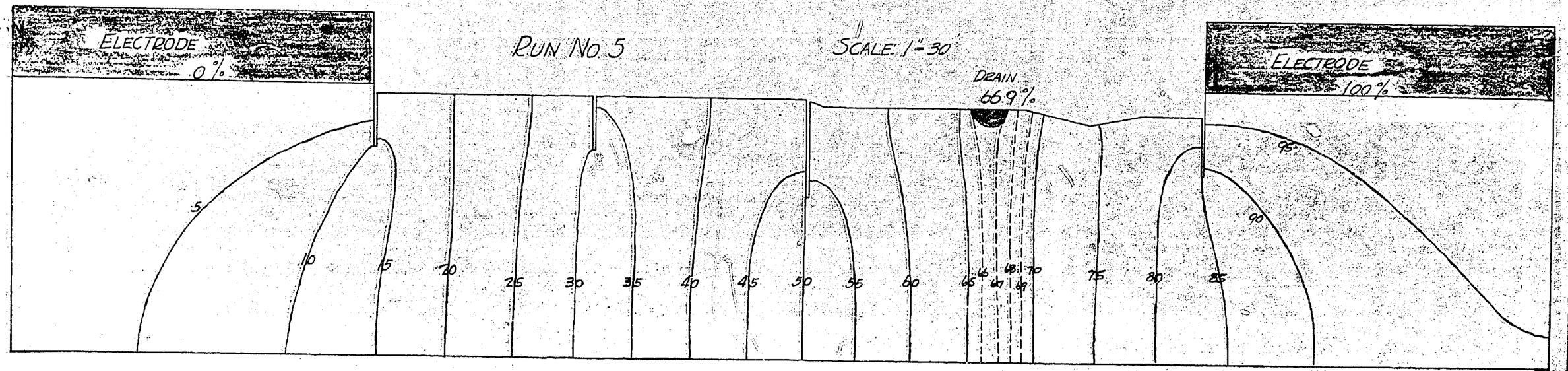
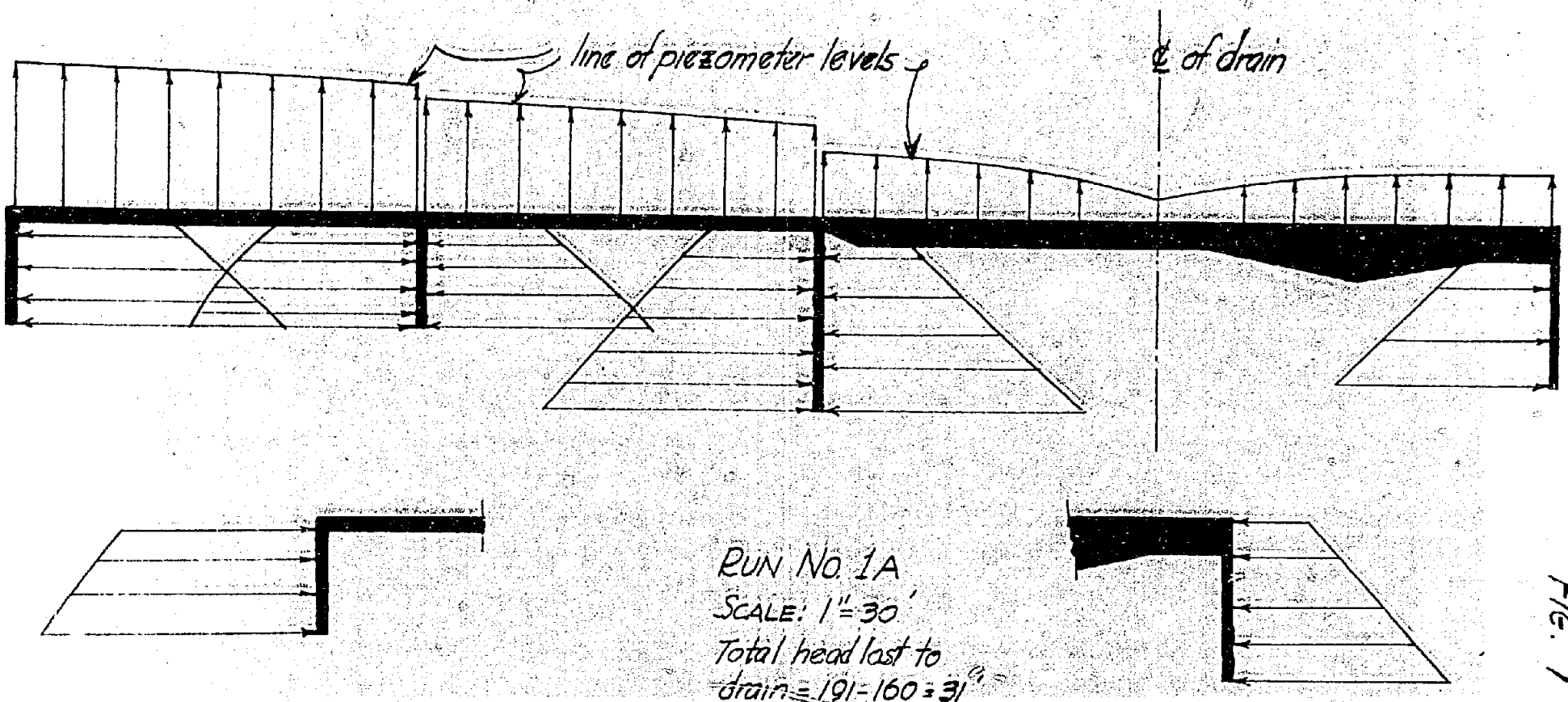

RUN No. 5
SCALE: 1"=30'
ELECTRODE
0%
ELECTRODE
100%
DRAIN
66.9%
5
10
15
20
25
30
35
40
45
50
55
60
65
66
67
68
69
70
75
80
85
90
95

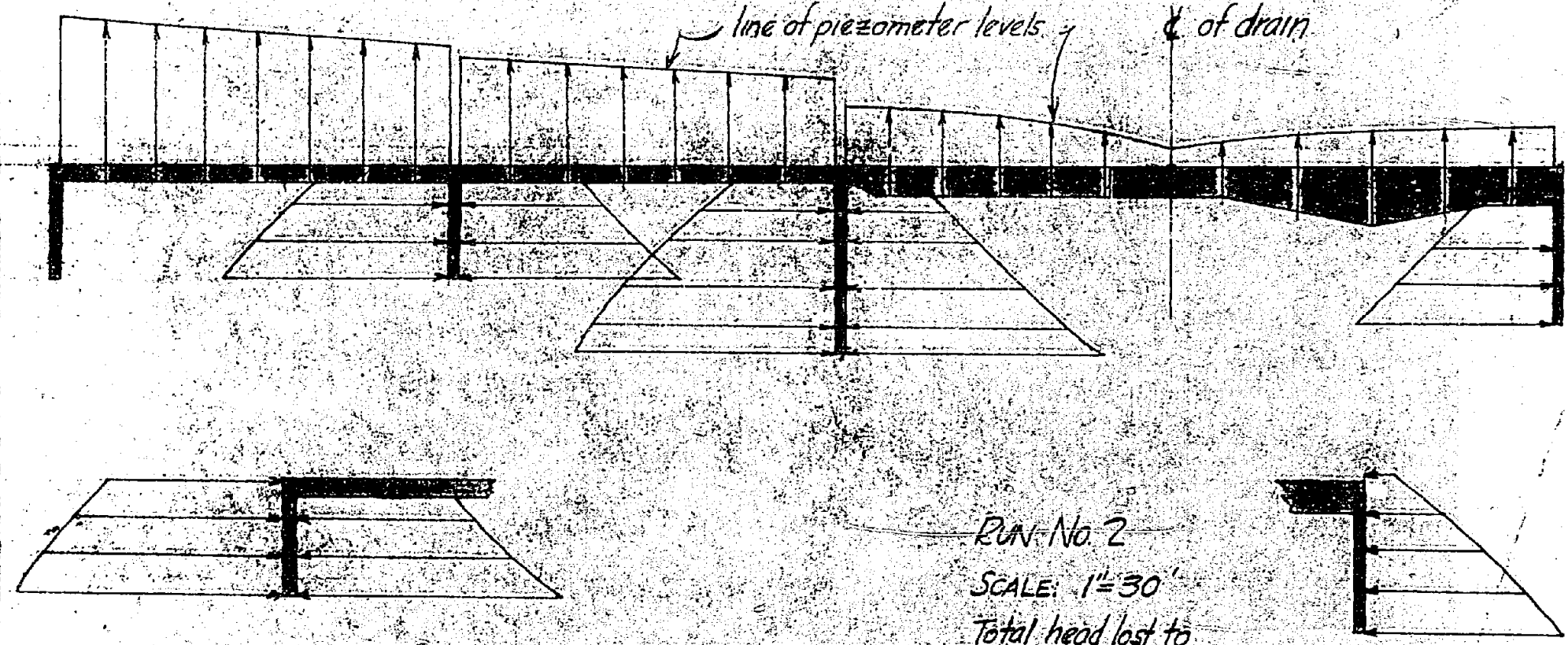
FIG. 6A

SCALE: 1" = 30'



RUN No. 1A
SCALE: 1" = 30'
Total head lost to drain = 191 - 160 = 31'

Fig. 7

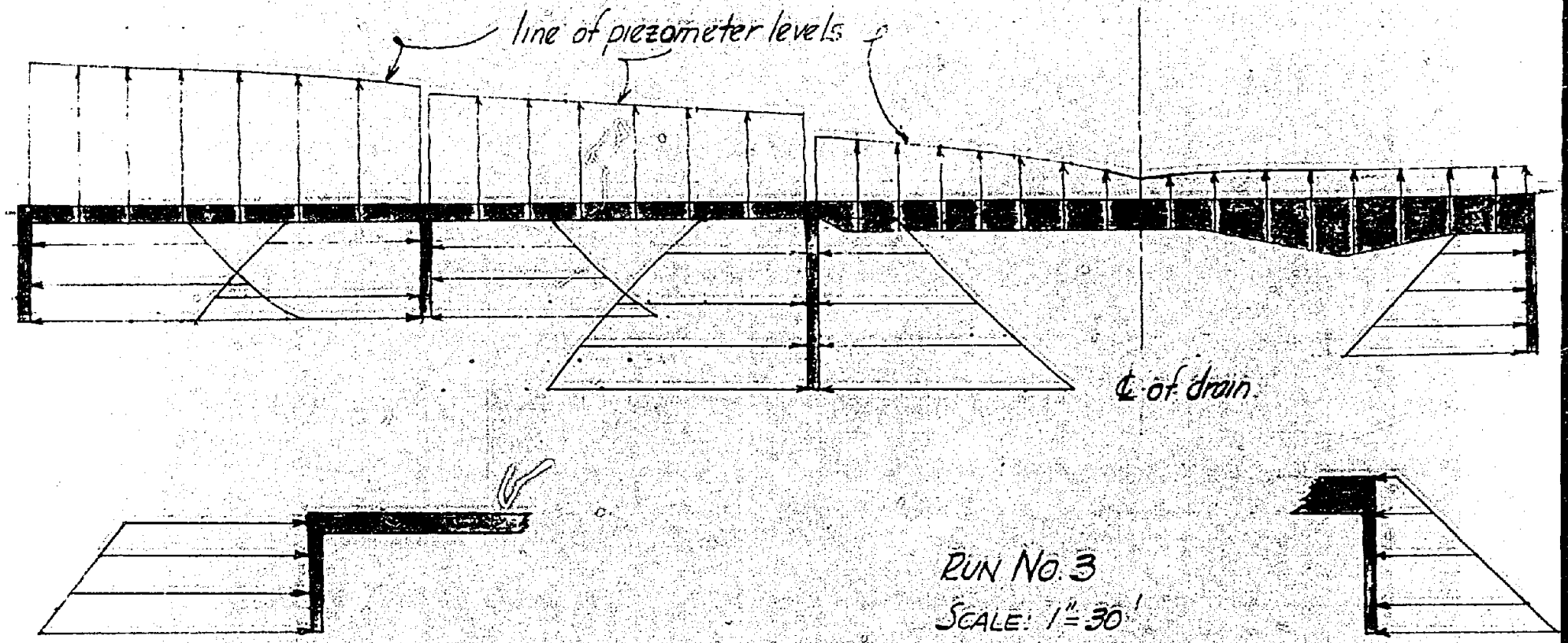


RUN No. 2

SCALE: 1" = 30'

Total head lost to drain = 191 - 160 = 31'

FIG. 8

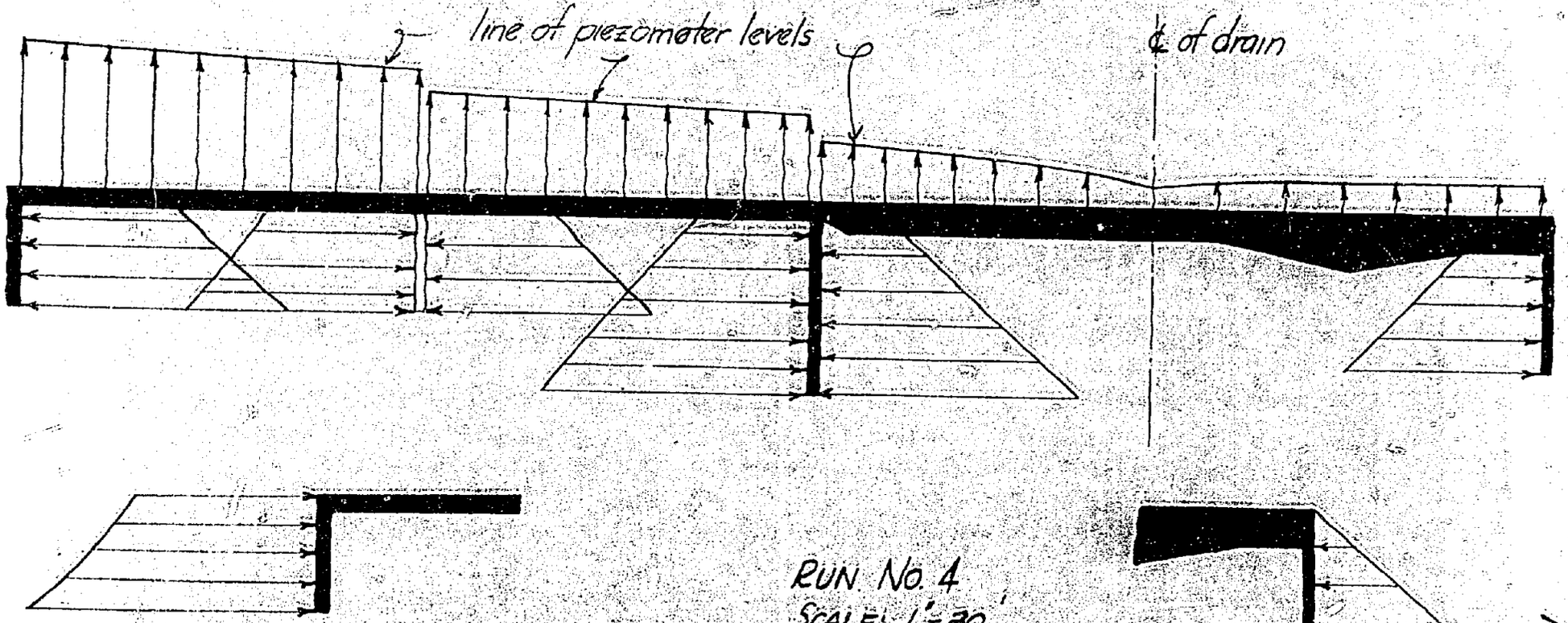


RUN No. 3

SCALE: 1" = 30'

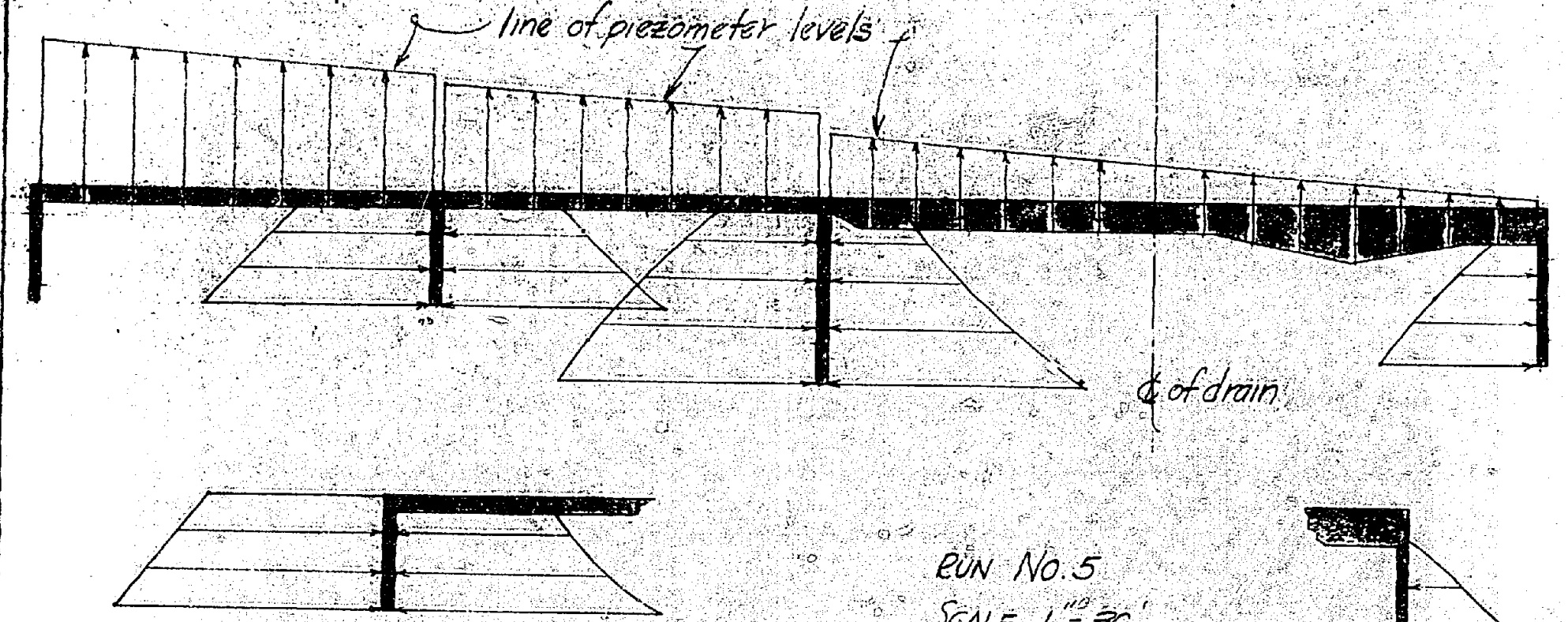
Total head lost to drain = 191 - 160 = 31'

FIG. 4



RUN No. 4
SCALE: 1" = 30'
Total head lost
to tailwater = 191 - 159 = 32

FIG. 10



RUN No. 5

SCALE 1" = 30'

Total head lost to tailwater = 191-150 = 41'

FIG. 11