1952

Model tests of proposed design of antietam (waynesboro) dam shaft spillway structure, February 1962

M. B. McPherson

MODEL TESTS OF PROPOSED DESIGN OF ANTIETAM

(WAYNESBORO) DAM SHAFT SPILLWAY STRUCTURE

FOR

GANNETT, FLEMING, CORDDRY AND CARPENTER, INC.,

HARRISBURG, PENNSYLVANIA

BY

MURRAY B. McPHERSON

AT

THE HYDRAULIC LABORATORY

DEPARTMENT OF CIVIL ENGINEERING & MECHANICS

FRITZ LABORATORY

FEBRUARY 1952

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On September 14, 1951, authorization to make and test a 1:20 scale model of a design then under consideration for the proposed Waynesboro Dam was issued by Mr. C. E. Ryder of Gannett, Fleming, Corddry & Carpenter, Inc. Negotiations for these tests were under the supervision of Prof. W. J. Eney, Director of Fritz Laboratory and Head of the Department of Civil Engineering and Mechanics. Account No. 508 and Fritz Laboratory Project No. 225 were assigned for the tests.

Construction of Model:

Pertinent drawings of the proposed structure are given in Figs. Two to Six. A scale of 1:20 was selected as being the largest convenient ratio consistent with reliability and economy. The earth dam upstream slope was reproduced in the model tank; the equivalent width of earth dam was 80 feet. This special tank was built to minimize the possibility of dissimilar approach conditions.

The tower, entire shaft, and conduit were constructed of clear plastic. Inasmuch as the conduit would not flow full at all heads, the exact conditions therefore were immediately observable. The sections of plastic conduit were spliced at all points where a change in design would require a new part. An exit box was made to accomodate the stilling pool.

A hook gage was installed in the entrance tank and zeroed relative to the weir crest of the tower. A total of 51 piezometer taps were made in the shaft, elbow, and conduit sections. An existing 35 tube piezometer panel was connected to these taps. No gages were installed in the stilling pool, since no prototype tailwater data was available, and only the evaluation of approximate conditions was warranted.

The shaft, elbow, and conduit were square throughout. No attempt was made to reproduce the 8" conduit Fillet or the low-flow conduit channel.

Preliminary Testing:

The model entrance tank, shaft, tower and elbow were first installed, followed by the exit box and then the conduit, which was temporarily placed in a horizontal position. A series of runs was made to ascertain the friction factor and head loss for flowing- full conditions. The head loss from pipe friction was found to be proportionate to that for the prototype, with an equivalent value of Manning's n of 0.0135 for the prototype. The similarity of roughness was therefore quite satisfactory, and the conduit was adjusted to the prototype slope of 0.010, and the stilling pool connected to the conduit.

Discharge Characteristics:

The head-discharge curves of Figure One include data of Table 1, obtained on 28 Nov., 1 Dec., and 5 Dec. Note that the full-flow data plots as two distinct separate lines. This performance is typical of drop-inlet flow when rotation of flow is not prevented at entrance.

Small vortexes were present at all heads. The conduit was flowing full at a weir head of about 10.8 feet, but large air pockets occasionally passed through the conduit. With heads of 6 feet to 10 feet a severe vortex formed in the throat of the tower near the crest. There was intermittent open and closed conduit flow from a head of about 6 feet to 9 feet. The performance of the weir was unsatisfactory at all but very low heads.

In Fig. One it may be observed that there may be a variation of 200 cfs at a given head, or a variation of 3.5 feet of head for a given discharge. An immediate change in stage is not possible in the prototype, but the relatively small entrance tank makes this change possible in the model. In the prototype an equivalent effect would occur: the effective weir head would change constantly, accompanied by an unsteady flow rate and consequent severe surging in the tower and conduit. This surging could quite possibly result in structural failure in the prototype.

The cause of the surging is twofold. The tower piers were inadequate in directing the flow towards the center of the shaft. The abruptly sharp weir crest was too close to the shaft, resulting in a "reentrant tube" separation.

Head Losses:

The data for full-flow conditions is given in Table One. Graphs of each of the six runs shown in this table are included in this report. The graph for Run A-1 is completely labeled. The elbow head loss represents the loss over and above that for pipe friction in the elbow. The entrance head loss is much less than that anticipated by the writer. The exit loss was entirely overlooked in the initial model calculations. This "loss" is actually an increased pressure, or back-pressure, resulting from an abrupt change in grade between the conduit floor (0.01) and the entrance section (-0.10) of the stilling pool floor, and arises from a change of momentum rather than energy attrition. Extra taps were made in the top of the conduit near the stilling pool to prove that the exit condition was not one of sudden loss. The exit loss appears to be the only item appreciably affected by the spiral velocity currents at "vortex" heads.

Elbow Pressures:

Assuming that a high entrance loss would occur, and overlooking the exit "loss", pressure heads in excess of -20. feet were predicted. Insofar as the tested design is concerned, this prediction was unfounded, as may be seen in Table Two. Assuming potential flow (vr = constant) and the total energy measured at the centerline, maximum negative pressure heads were calculated. These latter values check the actual values within the accuracy of the tests.

One would probably assume that the energy at the elbow centerline would be obtained by working between some point as reference, and charging half of the elbow loss to the 45° point of the elbow. Such an assumption, as shown in the table, results in a calculated value about six feet in excess of the actual. Since it is known that rectangular elbows have a low head loss, and ignoring the exit "loss", (as was done in preparatory calculations) the calculated values, as shown in the table, are off by about 12 feet for the normal heads and 15.5 feet for the "vortex" heads. These figures emphasise the importance of model studies as a tool to hydraulic design.

Stilling Pool:

At the request of Mr. C. E. Ryder during his observation of the model performance on the 5th of Dec., 1951, the tailwater was raised to El. 1210, a level higher than any reasonable tailwater, with the reservoir level at about El. 1272. The jet leaving the conduit was neither submerged nor affected in any way. The stilling pool was not capable of forming a stable jump. It was observed that the sills did little to form a jump, and would probably be seriously eroded if constructed.

Therefore, at maximum discharge, and with a tailwater depth which would endanger the downstream portion of the earth dam, the stilling pool would not function properly. By the same token, and as evidenced during the tests, it would not control the jump at lower rates of discharge. Under all combinations of discharge and tailwater levels, the outside curved wall was badly overtopped.

Maximum Possible Discharge and Negative Pressures:

The maximum discharge (El. 1272) for the design tested with the model would be 2200 c.f.s., as opposed to the anticipated design value of 2430 c.f.s. Although this reduction in discharge might be acceptable, performance would be poor and probably dangerous, unless the tower were redesigned.

If the entrance were redesigned so that the losses there were insignificant, and the stilling pool floor (redesigned) was at the same slope as the conduit near the exit of the conduit, the discharge would be about 2450. c.f.s., or the required value determined from flood routing. For this combination the pressure head in the elbow most probably would not exceed - 24 feet, a marginal value, but reasonably safe.

On the other hand, if the stilling pool design were retained but the entrance was redesigned, as above, the maximum discharge would be 2370 c.f.s.

From the above it may be seen that the effect of the exit "loss" on the discharge is not great, but in this instance reduces the maximum negative pressure head to a safer value. The results of these tests emphasise the wisdom of testing a hydraulic structure as a whole, and relegating no part to chance or assumption.

Concluding Remarks:

While the model tests were underway, the sponsoring firm decided to change the design to a conventional overflow spillway, one of the major reasons being that a substantial savings would be possible through a reduction in height of dam required. Abandonment of the design under discussion leaves two questions of redesign unanswered: the tower entrance and the stilling pool. Provided that the space occupied by the model is not committed in the meanwhile, the redesign of the stilling pool will be held in high priority as a senior or graduate student problem. The writer is presently engaged in the preparation of a thesis for the Civil Engineer Degree for Bucknell University, tentatively entitled "Hydraulic Characteristics of Bends in Hydraulic Structures." One special test, using the Waynesboro model, has been made for use in this paper. It is intended to redesign the tower to obtain contrasting information for the thesis, utilizing to some extent data presented in this report and related to pressure distribution in the elbow. Naturally, copies of any reports will be forwarded to the sponsors of this model study.

The writer is grateful for the cooperation of Mr. C. E. Ryder in making this material available to him, and for Mr. Ryder's unfailing attention during the project,

and the generous completion date which he made possible.

Mr. P. S. Eagleson was Assistant Engineer on the project, and was of great value in constructing and testing the model. Erection of the model parts was under the supervision of Mr. R. Gosztonyi;, assisted by Messrs. D. Taylor and R. Rowles. Photographs are by Mr. K. Harpol.

TABLE ONE

Test No.	Head Above Crest, Ft.	Q, c.f.s.	f, Friction Factor	Head Loss, Elbow	Head Loss, Entrance	Head Loss, Exit	Conditions
A-1	19.58	2300	0.0167	2.0'	5.4'	5.7'	Max. Head
A-3	13.04	2165	0.0167	2.0'	5.8'	5.8'	" "
A-2	10.76	2100	0.0175	2.2'	6.0'	5.0'	" "
A-4	19.04 to 19.44	2215	0.0174	2.0'	5.4'	9.1'	"Vortex" Head
A-1-A	16.74	2170	0.0166	2.0'	4.6'	10.0'	" "
A-2-A	14.18	2090	0.0168	2.0'	6.2'	9.0'	" "

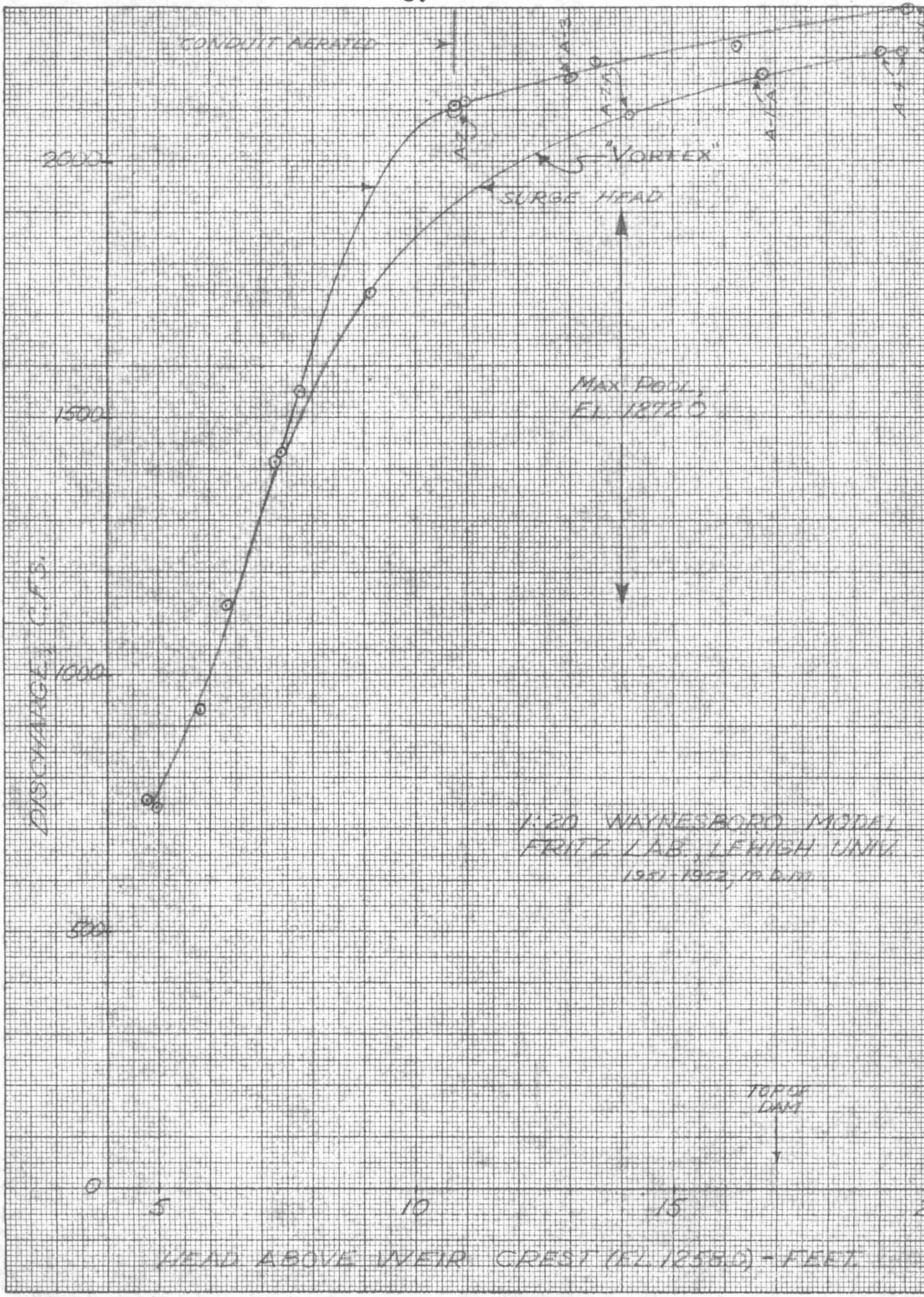
(Above Data from tests on model with stilling pool, i.e. simulating prototype).

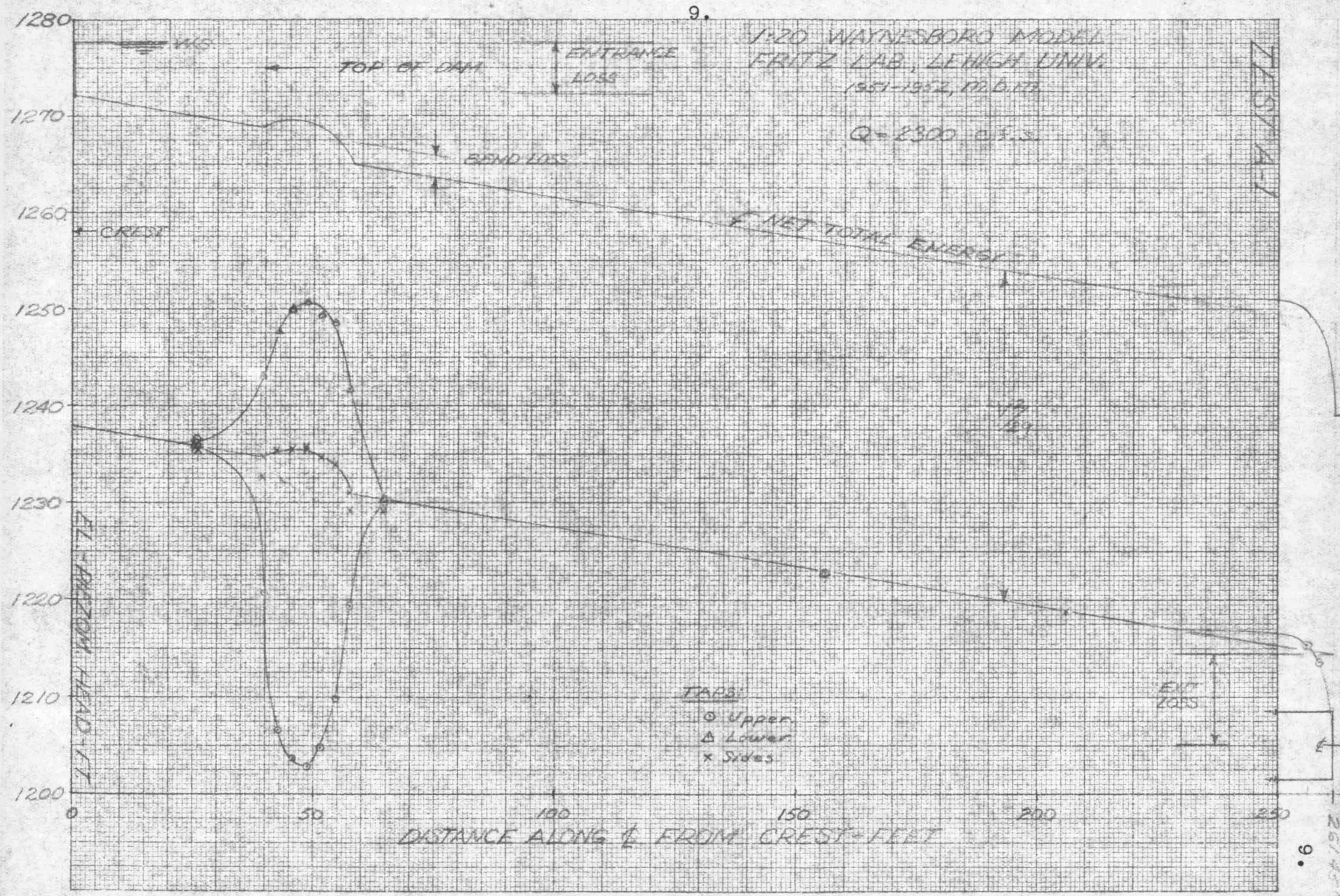
TABLE TWO

Pressure Head at Inside of Bend. (45°) (Max.)

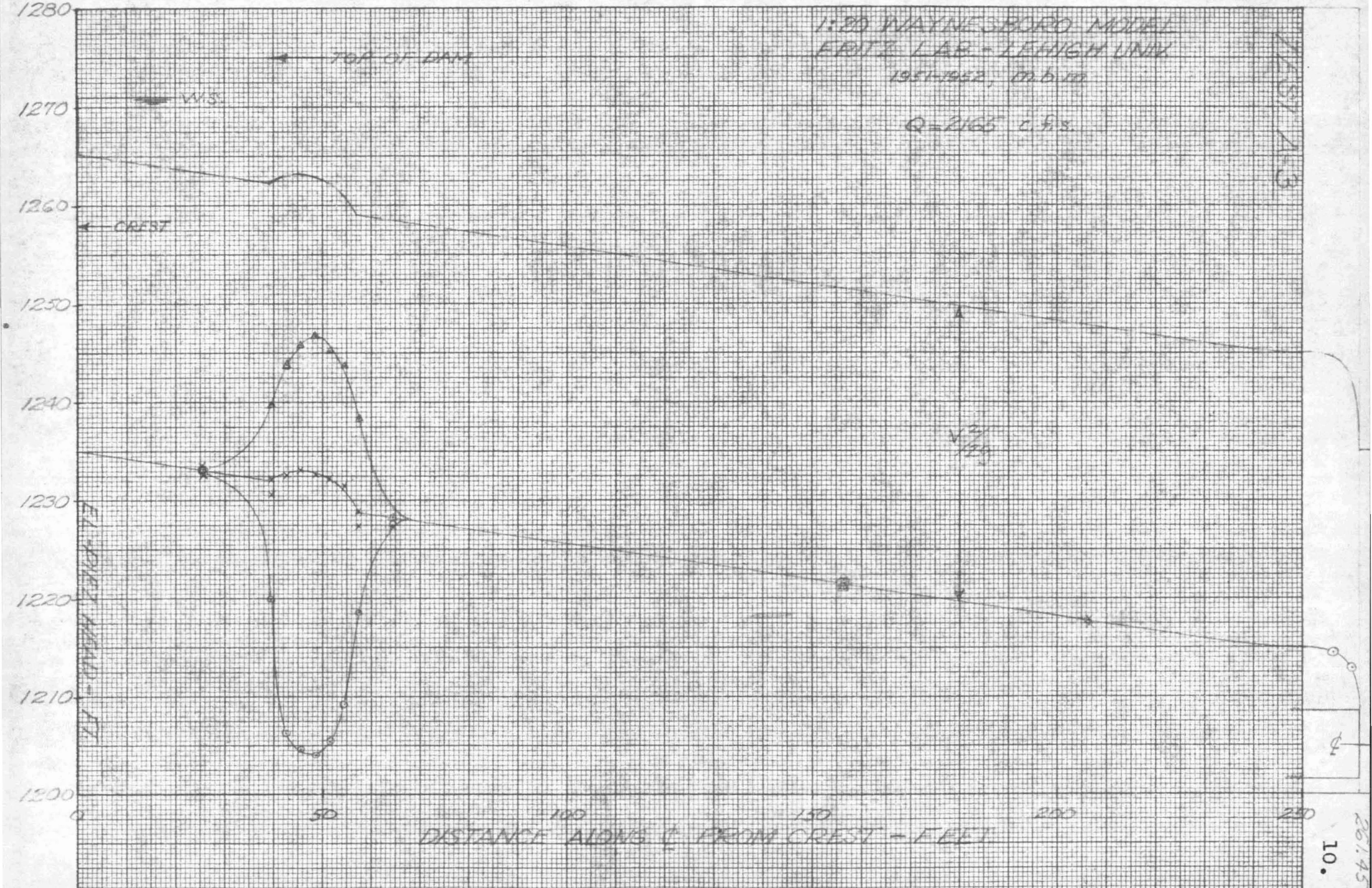
Test No.	A-1	A-3	A-2	A-4	A-1-A	A-2-A
Q, c.f.s.	2300	2165	2100	2215	2170	2090
Actual Pi/γ	-10.0'	-8.8'	-8.4'	-5.6'	-4.6'	-5.2'
Calculated Pi/γ, using model actual total energy at elbow centerline, and potential, vr= const.	-10.6'	-9.4'	-9.0'	-6.1'	-5.3'	-5.0'
Calculated Pi/γ, letting half elbow loss occur by 45° point, and using model data for pipe friction, elbow and exit loss	-16.3	-14.4'	-14.2'	-11.4'	-10.6'	-10.3'
Calculated Pi/γ, assuming no loss at exit and bend; pipe friction only	-23.0'	-21.2'	-20.2'	-21.5'	-21.6'	-20.3'

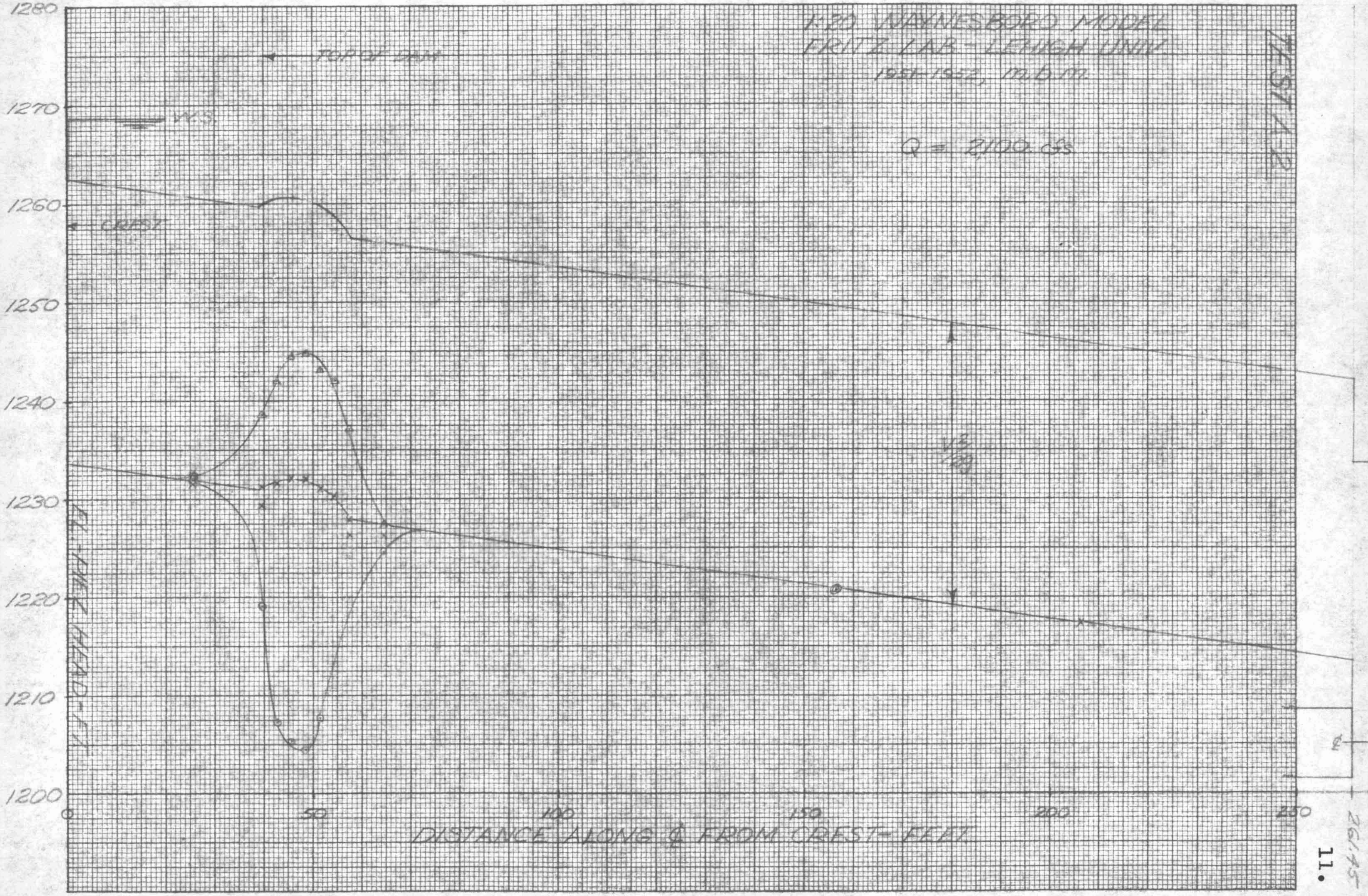
FIGURE ONE


CONDUIT AERATED
A-3
A-2
A-2A
A-1A
A-1
"VORTEX"
SURGE HEAD
MAX. POOL, EL. 1272.0
2000
1500
1000
500
0
DISCHARGE C.F.S.
1:20 WAYNESBORO MODEL
FRITZ LAB., LEHIGH UNIV.
1951-1952, M.D.M.
TOP OF DAM
5
10
15
20
HEAD ABOVE WEIR CREST (EL. 1258.0) - FEET

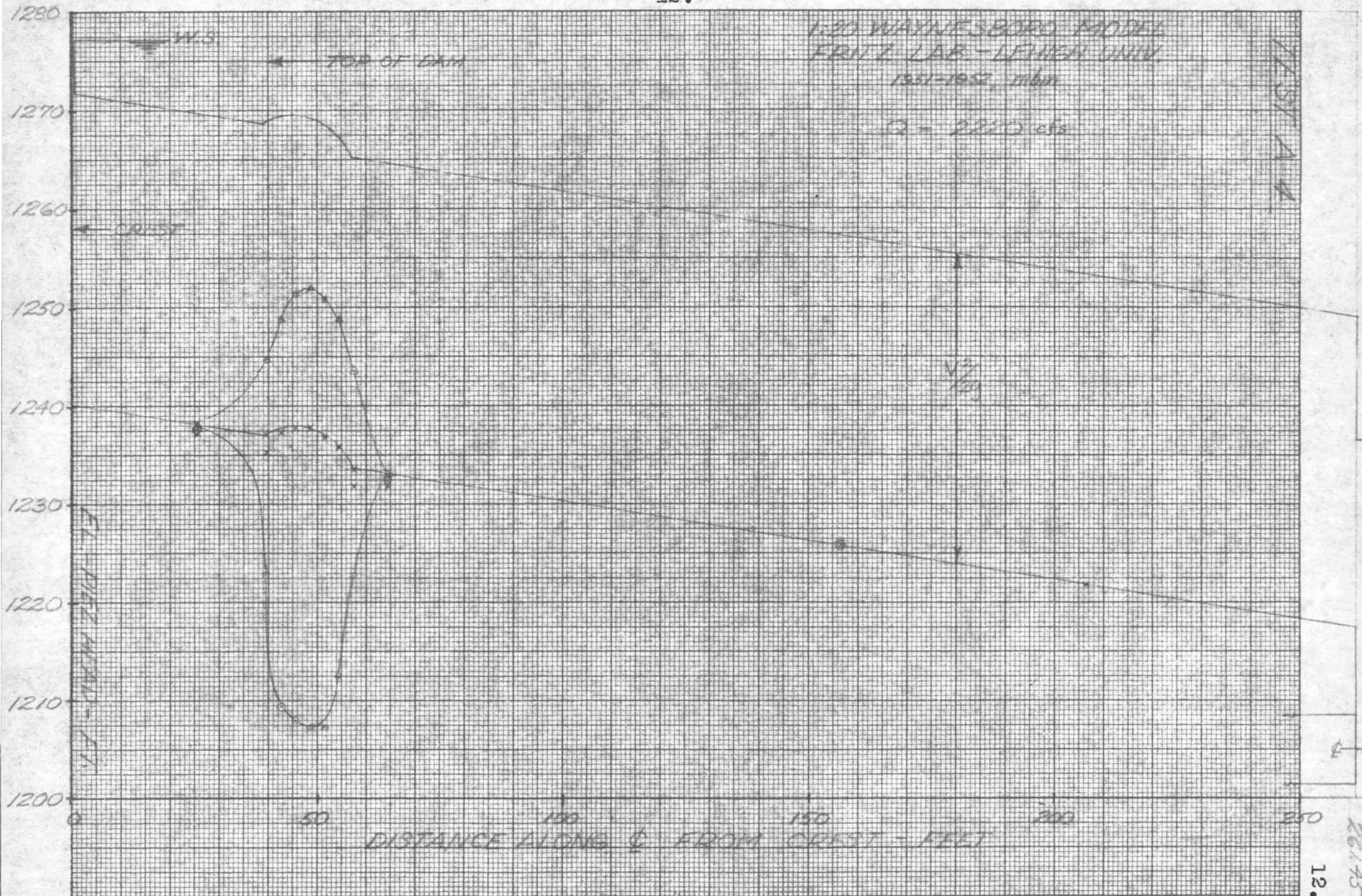

1:20 WAYNESBORO MODEL
FRITZ LAB, LEHIGH UNIV.
1951-1952
Q = 2300 c.f.s.
TEST A-1
W.S.
TOP OF DAM
ENTRANCE LOSS
BEND LOSS
CREST
℄ NET TOTAL ENERGY
EXIT LOSS
TAPS:
⊙ Upper
Δ Lower
× Sides
EL-PIEZOM HEAD-FT
DISTANCE ALONG ℄ FROM CREST-FEET
1280
1270
1260
1250
1240
1230
1220
1210
1200
0
50
100
150
200
250

359-14 KEUFFEL & ESSER CO.
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U. S. A.

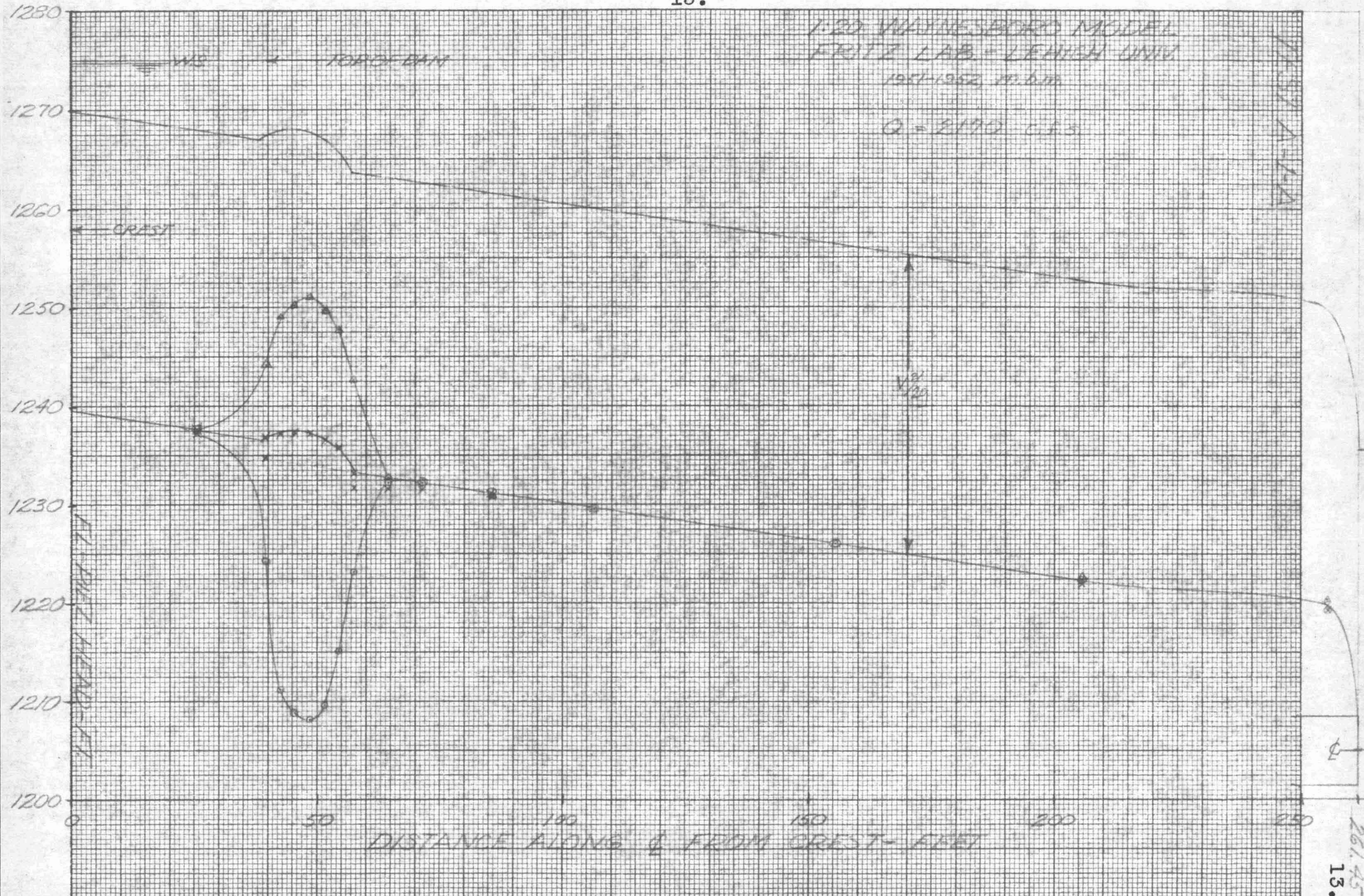


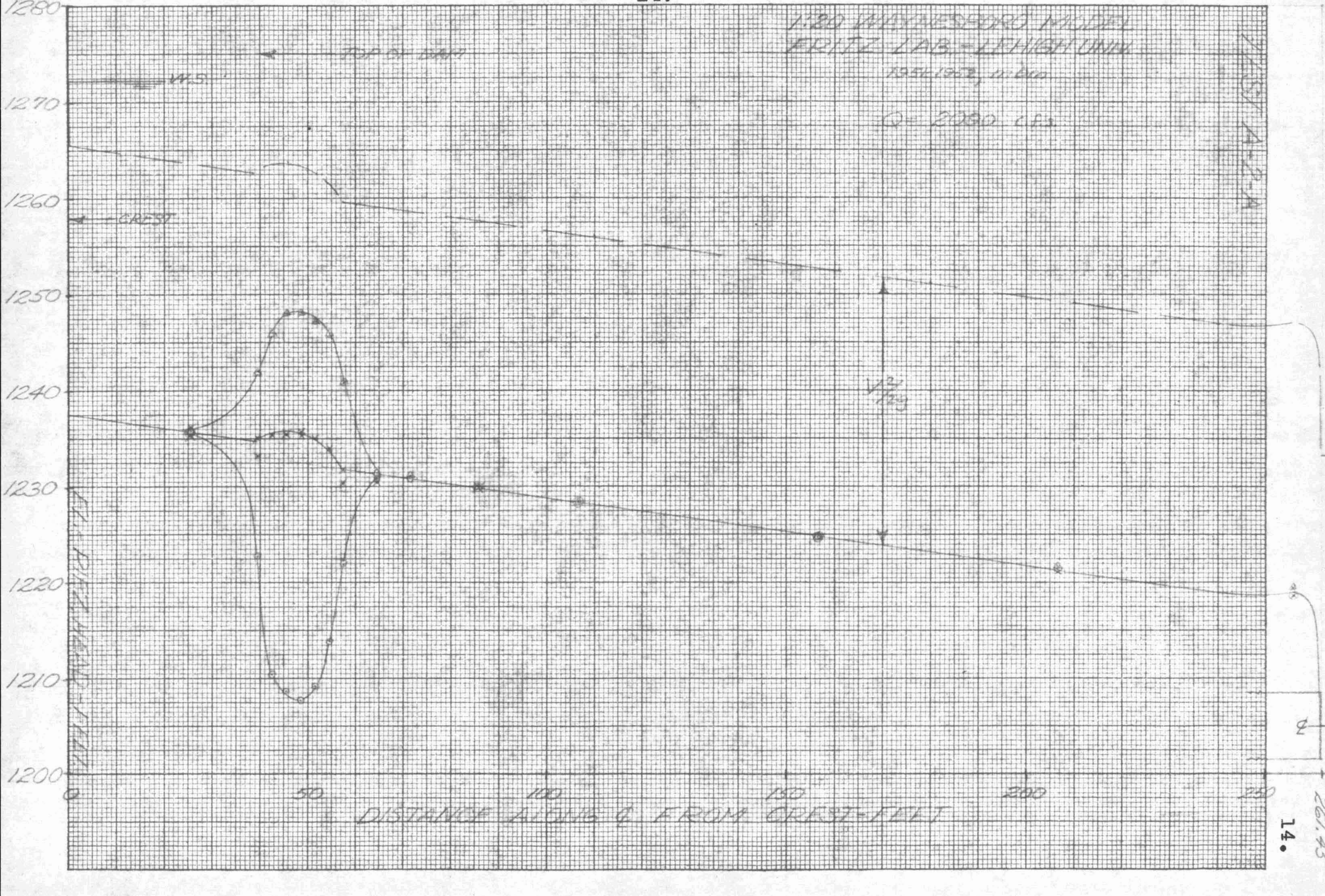

1:20 WAYNESBORO MODEL
FRITZ LAB - LEHIGH UNIV.
1951-1952, M.D.M.
TEST 1-2
Q = 2100 cfs
TOP of DAM
W.S.
CREST
$\frac{V^2}{2g}$
EL. - THE HEAD - FT.
DISTANCE ALONG ℄ FROM CREST - FEET
1280
1270
1260
1250
1240
1230
1220
1210
1200
0
50
100
150
200
250
261.75

11.


1:20 WAYNESBORO MODEL
FRITZ LAB - LEHIGH UNIV.
1951-1952, mbm
Q = 2220 cfs
TEST A-4
W.S.
TOP OF DAM
CREST
V²/2g
EL. PIEZ HEAD - FT.
DISTANCE ALONG ℄ FROM CREST - FEET
1280
1270
1260
1250
1240
1230
1220
1210
1200
0
50
100
150
200
250

359-14 KEUFFEL & ESSER CO.
Millimeters, 5 mm. lines accented, cm. lines heavy.
MADE IN U. S. A.




1:20 WAYNESBORO MODEL
FRITZ LAB.-LEHIGH UNIV.
Q= 2090 cfs
TOP OF DAM
W.S.
CREST
$V^2/2g$
1280
1270
1260
1250
1240
1230
1220
1210
1200
0
50
100
150
200
250
EL.-PIEZ. HEAD-FEET
DISTANCE ALONG ℄ FROM CREST-FEET
261.45

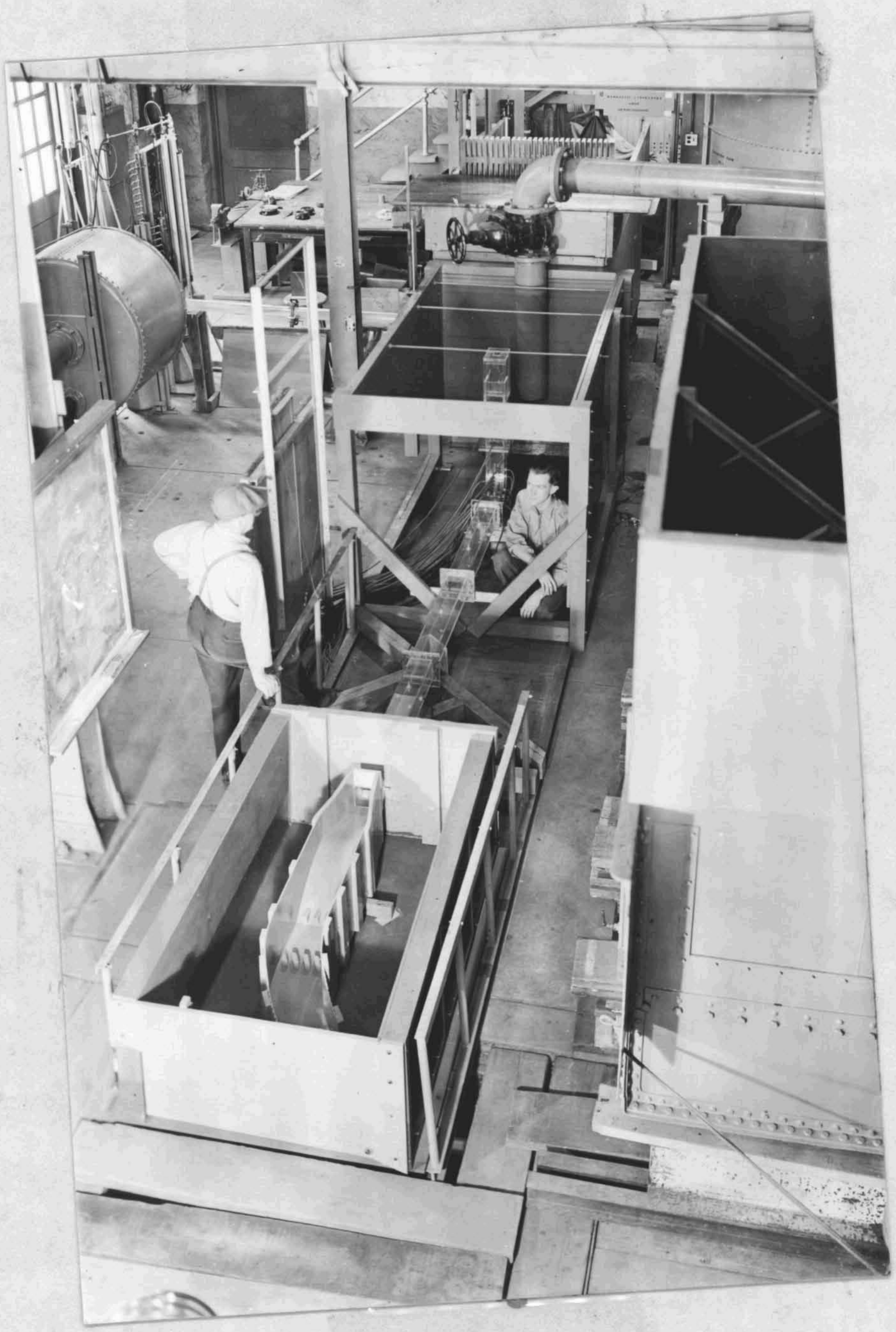


Photo No. One: Model of Waynesboro Dam. Overall View looking upstream.

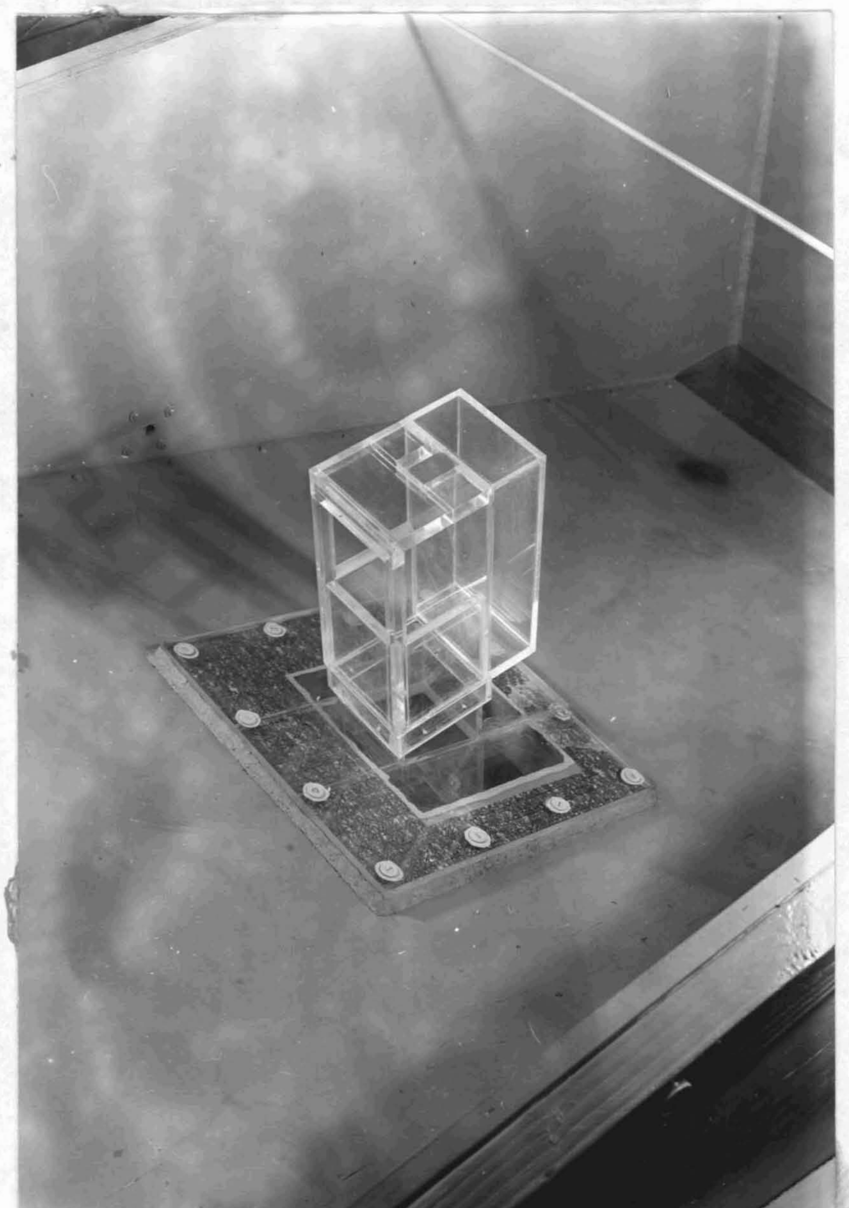


Photo No. Two: Model of Waynesboro Dam.

Closeup view of entrance tower.

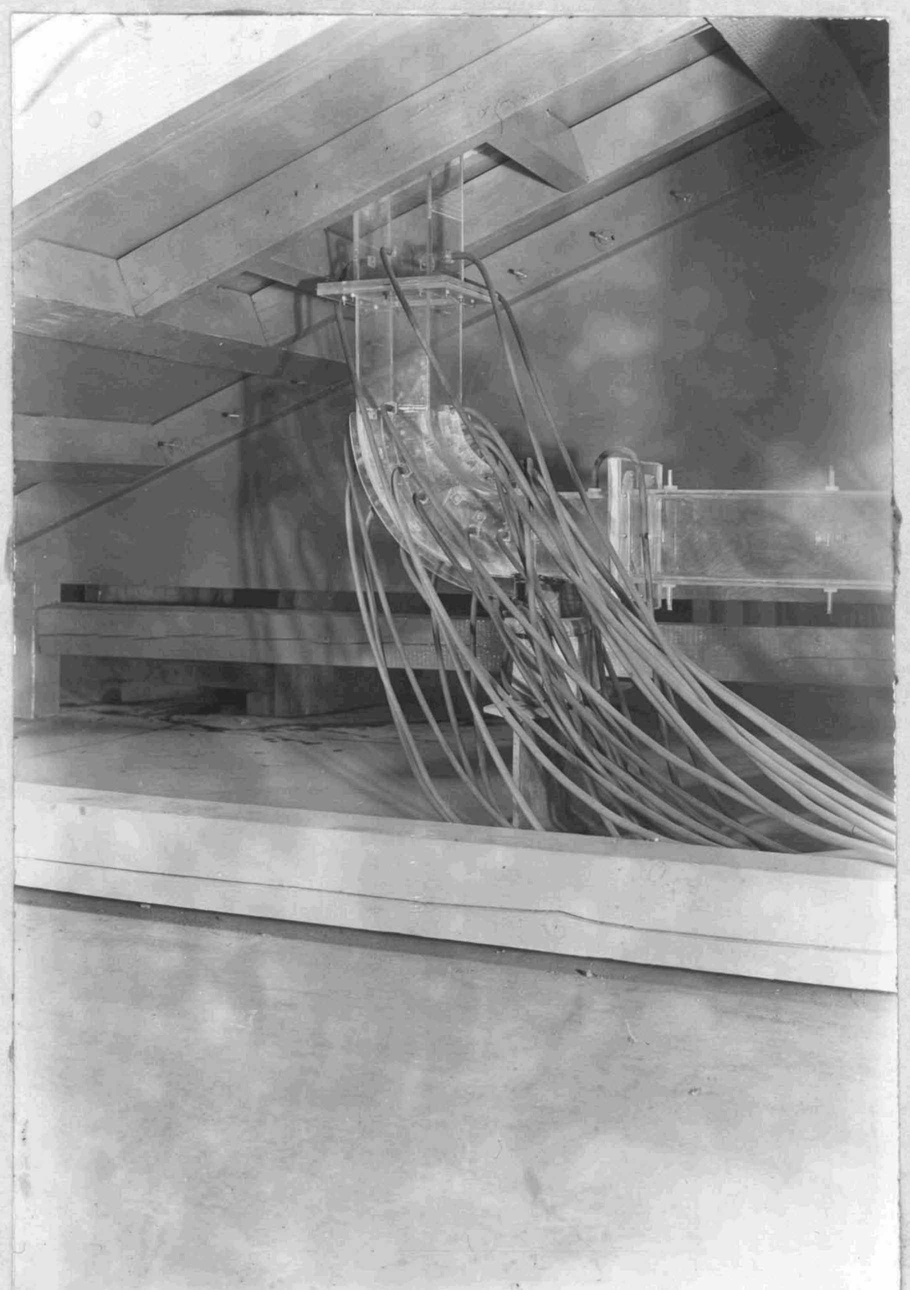


Photo No. Three: Model of Waynesboro Dam. Closeup view of plastic elbow.

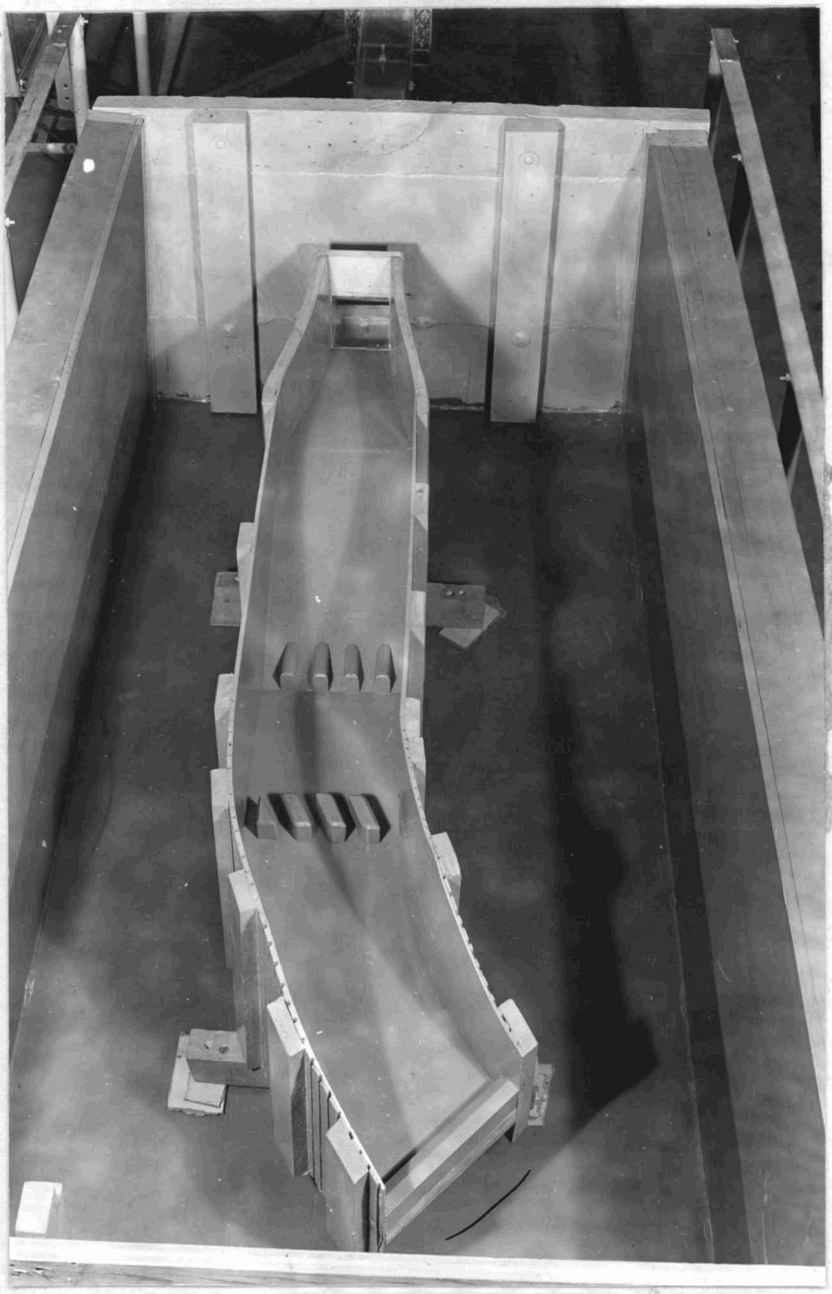


Photo No. Four: Model of Waynesboro Dam. Closeup view of stilling pool.

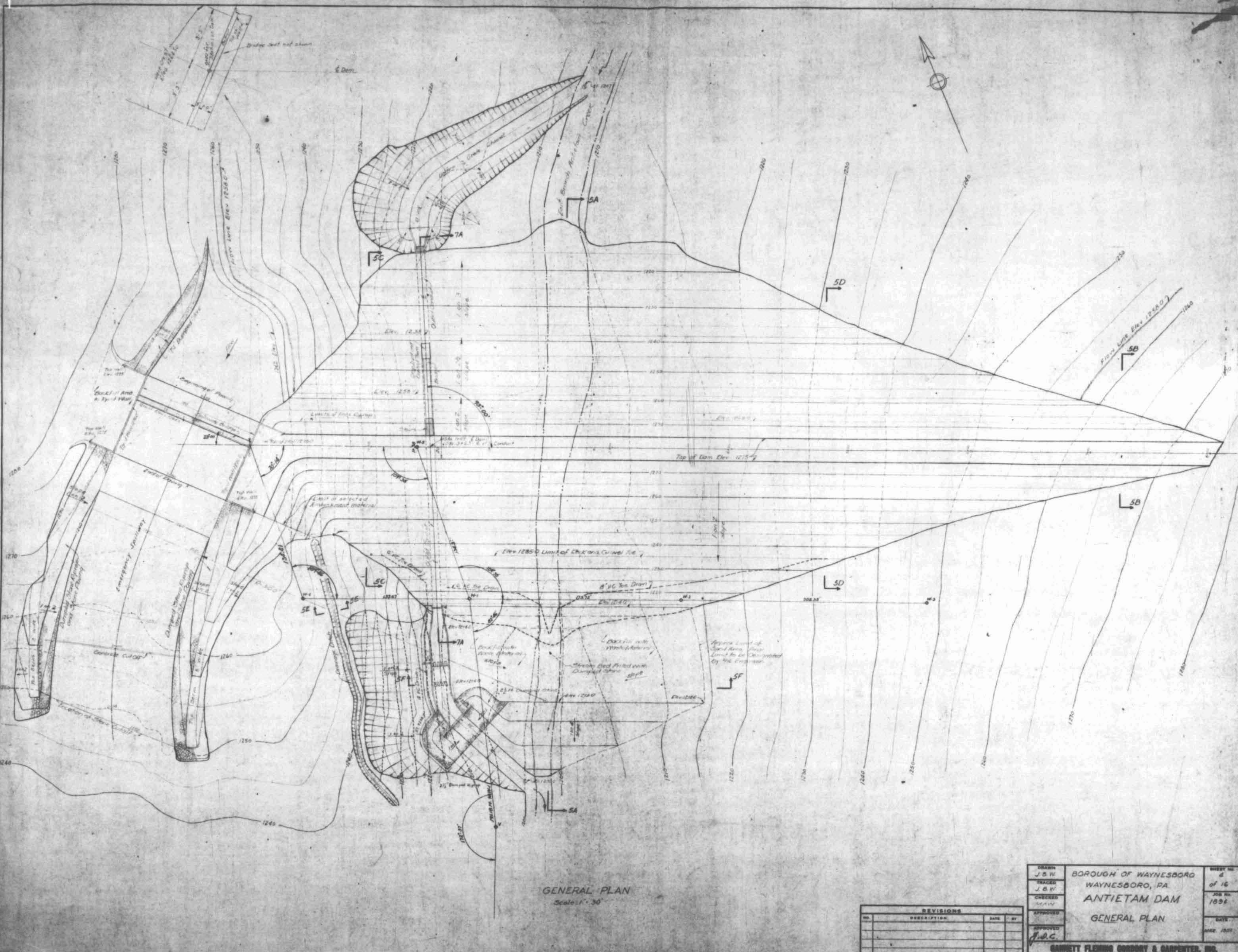

GENERAL PLAN
Scale 1" = 30'
Top of Dam Elev 1275
Emergency Spillway
BOROUGH OF WAYNESBORO
WAYNESBORO, PA.
ANTIETAM DAM
GENERAL PLAN
REVISIONS
DESCRIPTION
DATE
DRAWN
TRACED
CHECKED
APPROVED
of 16
GANNETT FLEMING CORDDRY & CARPENTER, INC.
ENGINEERS
600 N. SECOND ST.
HARRISBURG, PENNA.

Fig. 2

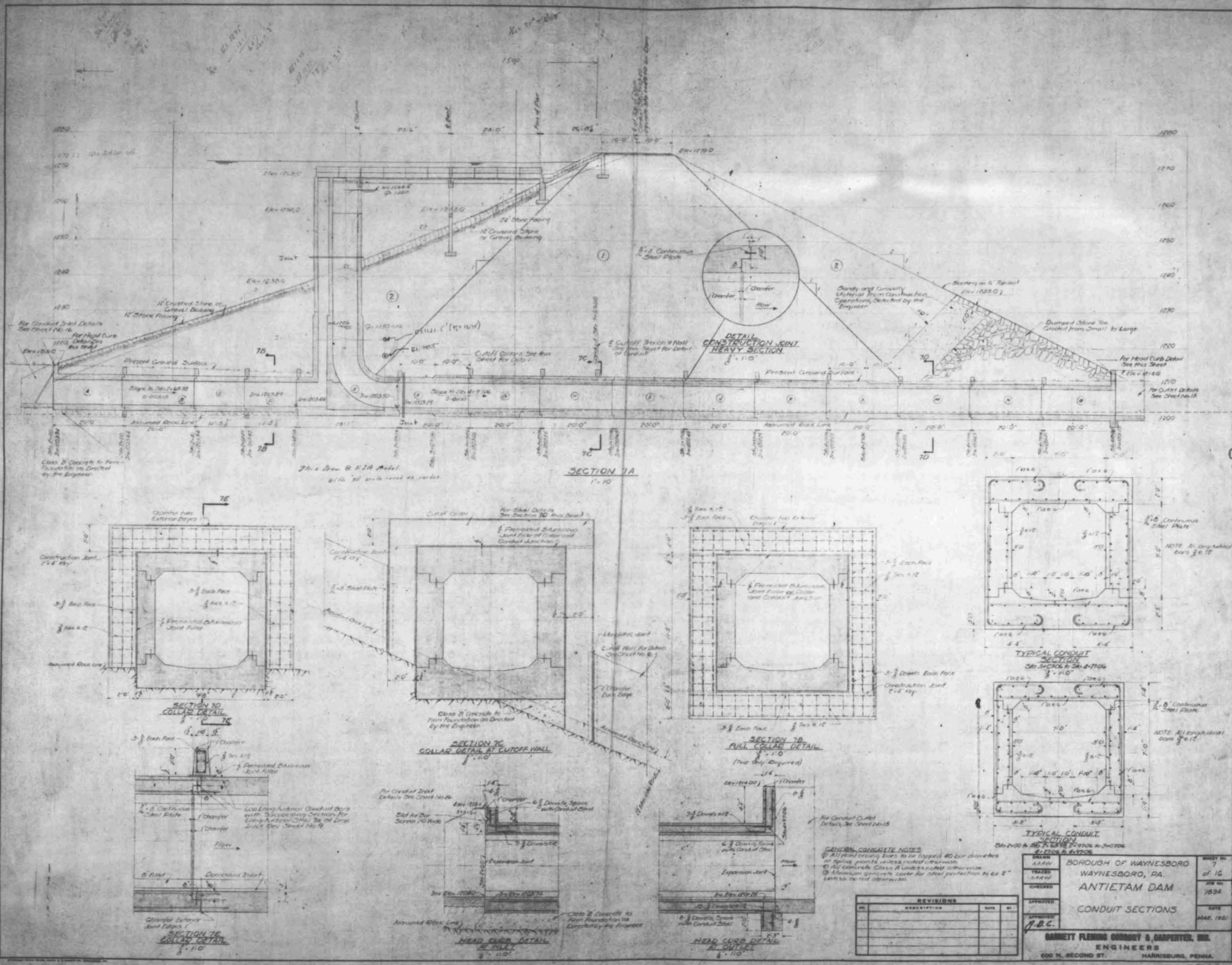
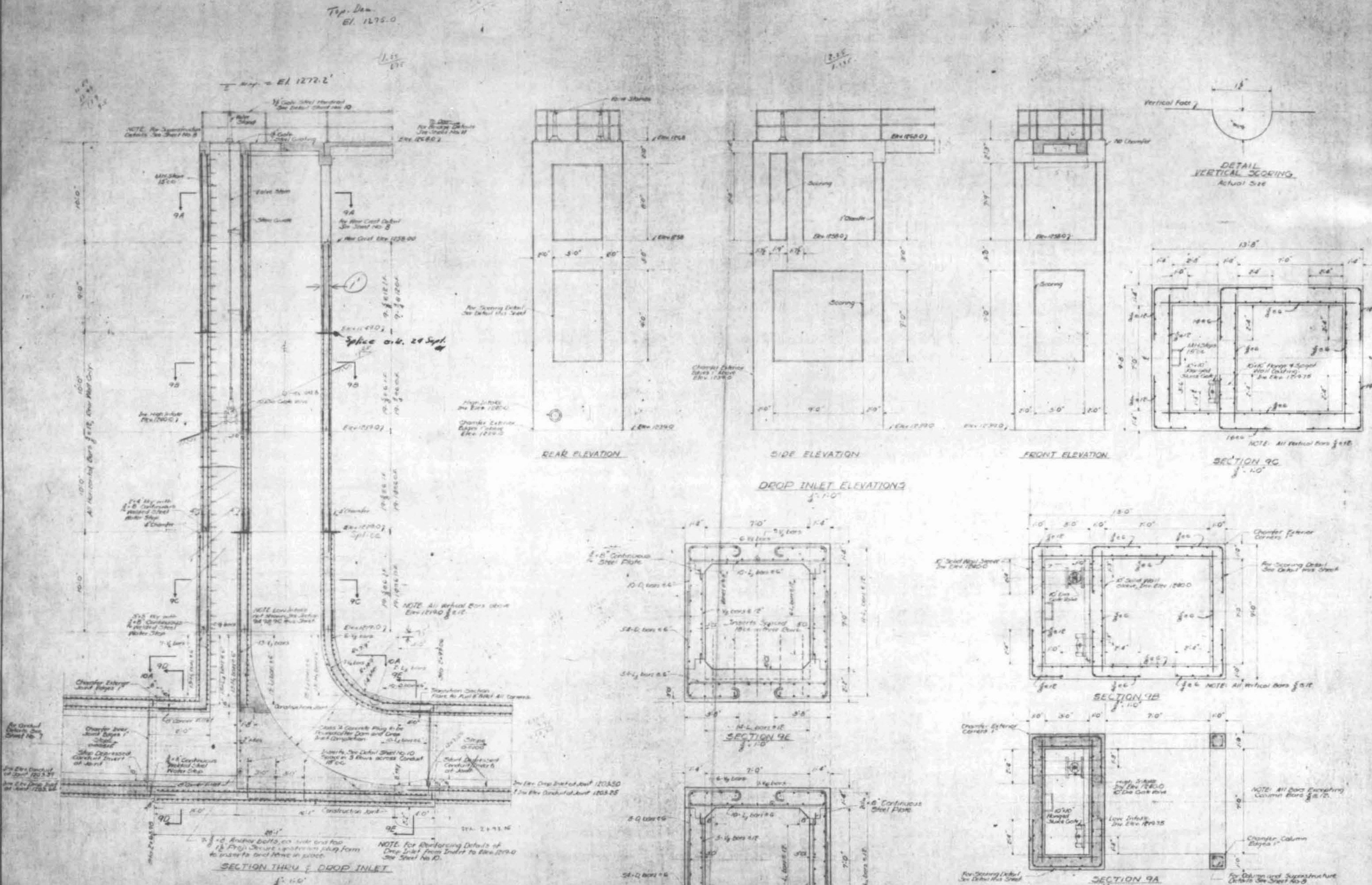

SECTION 7A
1" = 10'
DETAIL CONSTRUCTION JOINT HEAVY SECTION
SECTION 7D COLLAR DETAIL
SECTION 7C COLLAR DETAIL AT CUTOFF WALL
SECTION 7B FULL COLLAR DETAIL
TYPICAL CONDUIT SECTION
SECTION 7E COLLAR DETAIL
HEAD CURB DETAIL AT INLET
HEAD CURB DETAIL AT OUTLET
GENERAL CONCRETE NOTES
① All reinforcing bars to be lapped 40 bar diameters at splice points unless noted otherwise.
② All concrete Class A unless noted otherwise.
③ Minimum concrete cover for steel protection to be 2" unless noted otherwise.
REVISIONS
BOROUGH OF WAYNESBORO
WAYNESBORO, PA.
ANTIETAM DAM
CONDUIT SECTIONS
SHEET NO. 7 of 16
JOB NO. 1894
DATE MAR. 1951
ENGINEERS
600 N. SECOND ST.
HARRISBURG, PENNA.
F-7634

Fig. 3



DRAWN	BOROUGH OF WAYNESBORO	SHEET No.
MAW	WAYNESBORO, PA.	9 of 16
TRACED AFAW	ANTIETAM DAM	JOB No. 1894
CHECKED		
APPROVED	DROP INLET SECTIONS	DATE
APPROVED J.D.C.		MAR 1951

GANNETT FLEMING CORDDRY & CARPENTER, INC.
ENGINEERS
500 N. SECOND ST. HARRISBURG, PENNA.

REVISIONS			
No.	DESCRIPTION	DATE	BY

I-7636

Fig. 4

21

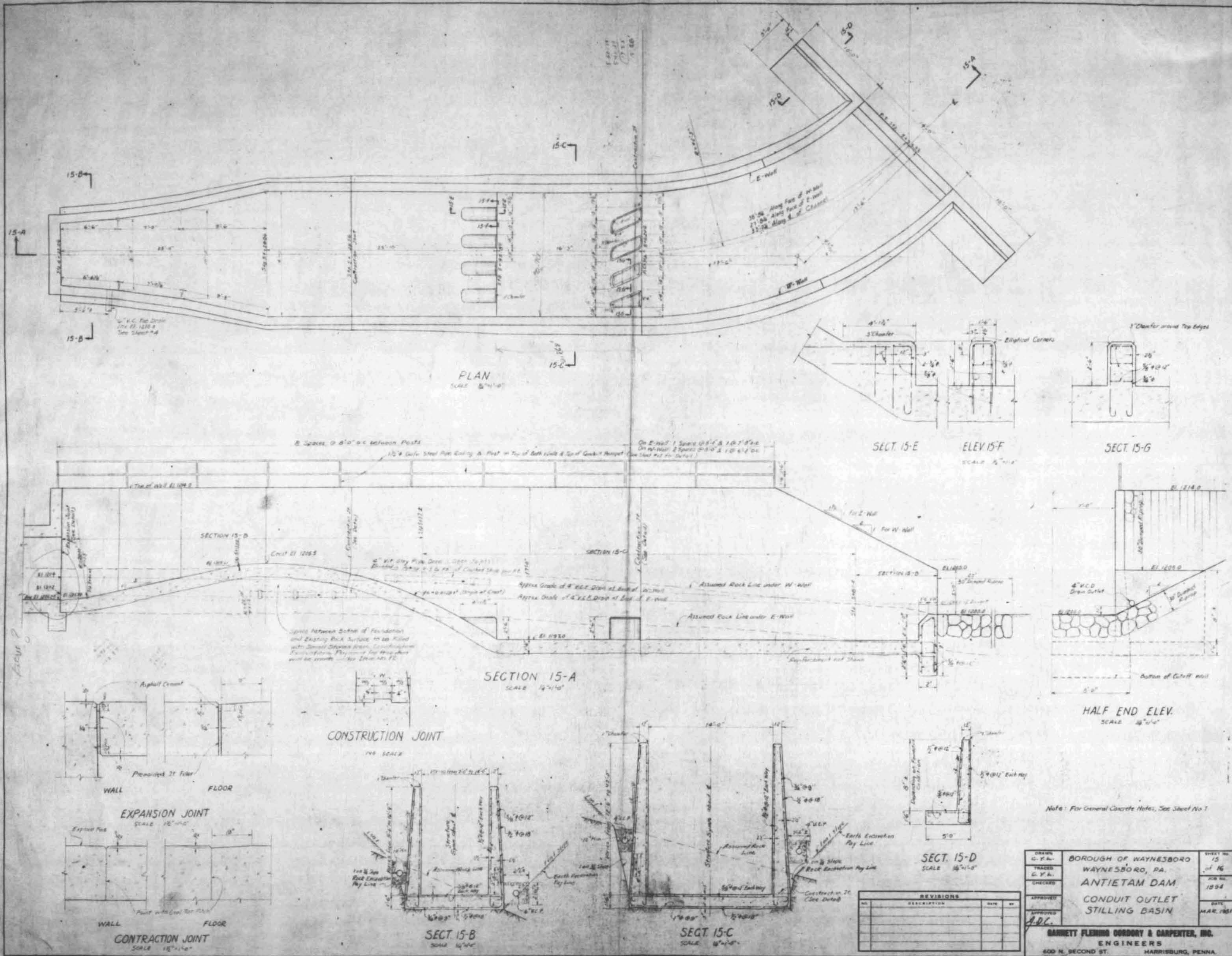

PLAN
SECTION 15-A
SECT. 15-E
ELEV. 15-F
SECT. 15-G
HALF END ELEV.
CONSTRUCTION JOINT
EXPANSION JOINT
CONTRACTION JOINT
WALL
FLOOR
SECT. 15-B
SECT. 15-C
SECT. 15-D
Assumed Rock Line under W-Wall
Assumed Rock Line under E-Wall
Note: For General Concrete Notes, See Sheet No 1
REVISIONS
DRAWN C.Y.L.
TRACED C.Y.L.
CHECKED
APPROVED
APPROVED A.D.C.
BOROUGH OF WAYNESBORO
WAYNESBORO, PA.
ANTIETAM DAM
CONDUIT OUTLET
STILLING BASIN
SHEET NO. 15 of 16
JOB NO. 1894
DATE MAR. 1951
GANNETT FLEMING CORDDRY & CARPENTER, INC.
ENGINEERS
600 N. SECOND ST. HARRISBURG, PENNA.
I-7642

Fig. 5

22.

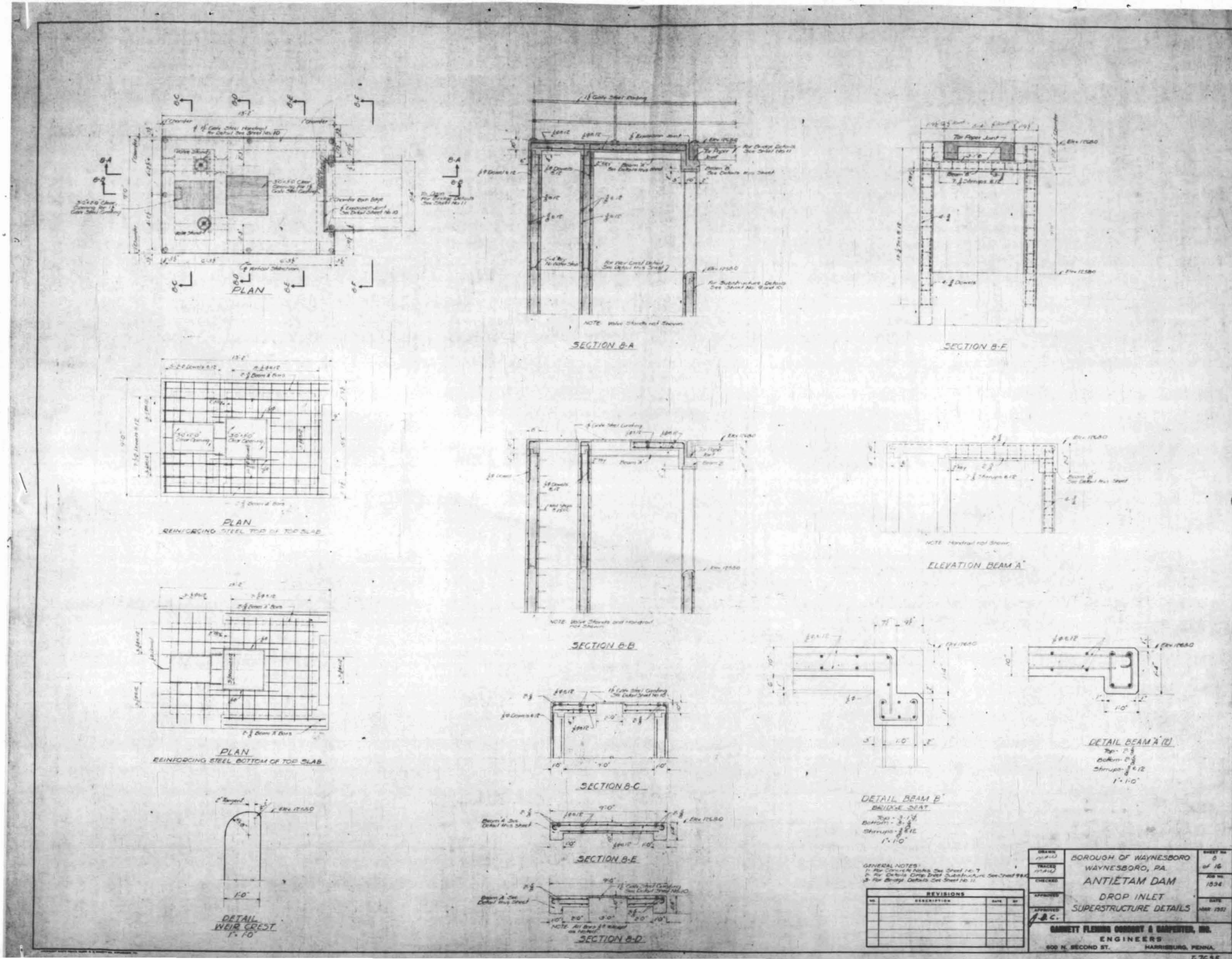

PLAN
SECTION B-A
SECTION B-F
PLAN
REINFORCING STEEL TOP OF TOP SLAB
SECTION B-B
ELEVATION BEAM "A"
PLAN
REINFORCING STEEL BOTTOM OF TOP SLAB
SECTION B-C
DETAIL BEAM "B"
BRIDGE SEAT
DETAIL BEAM "A" (2)
DETAIL WEIR CREST
1" = 1'-0"
SECTION B-E
SECTION B-D
GENERAL NOTES:
1- For Concrete Notes See Sheet No. 7
2- For Details Drop Inlet Substructure See Sheet 9 & 10
3- For Bridge Details See Sheet No. 11
REVISIONS
NO.
DESCRIPTION
DATE
BY
DRAWN
TRACED
CHECKED
APPROVED
APPROVED
BOROUGH OF WAYNESBORO
WAYNESBORO, PA.
ANTIETAM DAM
DROP INLET
SUPERSTRUCTURE DETAILS
SHEET No. 8 of 16
JOB No. 1894
DATE MAR 1951
GANNETT FLEMING CORDDRY & CARPENTER, INC.
ENGINEERS
600 N. SECOND ST.
HARRISBURG, PENNA.

Fig. 6

23.