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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM

HYDRAULIC LABORATORY REPORT NO. HYD-3.05

Technical Memorandum No. 404

HYDRAULIC MODEL STUDIES FOR THE DESIGN OF DRAFT TUBES FOR WHEELER DAM

by

G. J. HORNSBY, ASSISTANT ENGINEER

Denver, Colorado
October 8, 1934

UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

TENNESSEE VALLEY AUTHORITY

WHEELER DAM

MEMORANDUM TO THE CHIEF DESIGNING ENGINEER

SUBJECT: HYDRAULIC MODEL STUDIES FOR THE DESIGN OF DRAFT TUBES FOR WHEELER DAM

By G. J. HORNSBY, ASSISTANT ENGINEER

Under Direction of

E. W. LANE, RESEARCH ENGINEER

TECHNICAL MEMORANDUM NO. 404

Denver, Colorado

October 8, 1934.

(PRICE $4.00)

WHEELER DAM DRAFT TUBE TESTS

1. Purpose of Tests.

In any medium or low-head plant the effectiveness of the draft tube in utilizing the energy of the water flowing through it is of much importance because every foot of head regained may be an appreciable percentage added to the operating head of the plant. Wheeler Dam, in general, is the usual design of low-head plant stepped up in every dimension. The runner discharge diameter considered in these studies is approximately 22-1/4 feet and as the ratio of discharge diameter to depth of draft tube is 1:2.2 to 1:2.5, the problem of excavation for draft tubes in the case of Wheeler Dam is a serious one. Besides, it is proposed to use propeller or Kaplan-type runners, which discharge the water at high velocities.

Available draft-tube test data indicates that some energy is recovered by increasing the length of the horizontal section of an elbow draft tube especially at high angles of whirl at the runner discharge. This raises the question of economy in length.

To reduce cavitation to a minimum the runners are set very low and this fact together with the large size of the runners make great depth of excavation necessary for the draft tubes. It was therefore suggested that the outflow end of the elbow draft tube be sloped upward. Before this is done it was thought desirable to investigate the limits of this slope.

The efficiency of energy regain from the high velocity

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The efficiency of energy regain from the high velocity

at the runner discharge being the criterion for all these tests it was necessary to test the various types under various conditions for efficiency and performance. Among the draft-tube designs submitted for Wheeler power plant, some show one pier in the draft tube and some show two piers. The question therefore arises as to which design is more desirable.

The river channel immediately below the power house is very shallow so that when all runners are discharging at full capacity the tailwater attains a much higher velocity than that of the draft-tube discharge. This creates a condition such that the water leaves the draft tube at one velocity, passes through the tail race at a much lower velocity and again increases to nearly twice the draft-tube discharge velocity as it flows out onto the river bed. The question arises as to whether this is a desirable condition or whether corrective measures from a standpoint of economy should be considered.

The purpose of the tests therefore resolves itself into five different points of consideration:

(a) To determine most economical length for horizontal section of draft tube.

(b) To ascertain the effect of sloping the horizontal section of the draft tube upward beyond certain limits.

(c) To compare the efficiencies of various types and designs within the limits described in (a) and (b).

(d) To compare the performance of the various types of draft tubes with 2 piers vs. 1 pier.

(e) To determine the effect on energy regain by allowing the draft-tube-outflow velocity to be less than the velocity on the river bed below the power plant.

2. Flume Construction and Equipment.

In view of the many phases to be investigated in these tests it was necessary to build a test flume to include a model to simulate the downstream face of the power house, the tail race excavation and a part of the river bed some distance downstream from the power house. The space available permitted the use of a flume in connection with river bed and tail race model to a scale of 1:50. The draft-tube models were, of course, built to the same scale.

On the prototype the water discharged from the wheels flows both downstream from the power house and parallel to it. That is the tail race excavation spills its water both downstream and towards the center of the river. This made it necessary to build an L-shaped weir. This weir started at the river bank some distance downstream from the power house and extended an equal distance beyond the power house and then turning at right angles extended upstream to the face of the dam. (See Dwg. 232-D-578). The upstream edge of the weir was hinged to the model of the river bed while the lower edge was raised or lowered by means of cables spaced at intervals and wound on shafts which were controlled by means of cranks.

This made possible the control of the tailwater height and at the same time permitted the flow to simulate prototype conditions.

The water spilling over the adjustable weir was trained into a measuring weir box of the usual type with 90° V-notch weir, the head over which was measured by means of an ordinary hook gage. The quantities flowing were calculated from the hook-gage readings.

The water supply came from a tank in an adjoining room through a 4-1/2-inch siphon and discharged through an expanding nozzle onto the floor of the stilling box with a minimum of disturbance. The water was then led through stilling racks to the flume in which was placed the draft-tube orifice. (See Dwg. 232-D-579 - Details).

The orifice casting was made of brass and machined to conform to the lower gate ring, shroud and draft-tube entrance of the prototype. The crown plate was machined to conform to the flow lines of the water entering the runner. Outside of the orifice and in about the relative position of the speed ring a groove was machined to receive the deflector-vane rings. The deflector vanes were of brass about 1/16-inch thick. The lower ends were soldered to a flat ring made to fit in the groove mentioned and the upper ends were soldered to the extension flange of the crown or cover plate. Four sets of vane and cover-plate assemblies were used: One with vanes in radial position, one with vanes 15° off the radial, one with vanes 30° off the radial and one with vanes 45° off the radial. Each angle shown was turned on the arc of a given radius from the axis of the orifice. These angles were turned in a counter-clockwise

direction, thus giving the water a whirl in a clockwise direction. Twenty vanes equally spaced were placed in each deflector-vane set and the sets were interchangeable. Over the deflector vanes was placed an inverted bowl to exclude air at low heads. (See detail Dwg. 232-D-579).

The head-gage piezometers were designed as shown and one was placed on each side of the head flume a short distance downstream from the stilling racks. These were connected together beneath the flume and a common connection led to the hook-gage pot. The tail-gage piezometer was placed on the tail-race-excavation slope immediately below the draft-tube outflow. A rubber hose led from the piezometer to the hook-gage pot.

Both the head-gage pot and the tail-gage pot were mounted on a swinging hinge and each was independently adjustable for height. The micrometer hook-gage was rigidly mounted above the pots in such position that either the head-gage pot or the tail-gage pot might be swung beneath it. The purpose of this arrangement was to enable one to read the water levels in each pot and, subtracting the one from the other, get the net head directly without having to bother with gage zeroing. The reason for using the micrometer hook-gage was that extreme accuracy was necessary because of small head differentials.

3. Procedure.

Five basic draft-tube designs were included in these tests. One of these was designed by the Bureau of Reclamation, one was submitted by Tennessee Valley Authority and the other three from designs

frequently used in hydro-electric power plants for water turbines. The first two are designated as Tube A and B respectively, and the other three are Tubes C, D, and E. Alterations on Tube A are designated as Tube A-I and A-II and alteration on Tube D is designated as Tube D-I.

Tube A-I was the same as Tube A except that the outflow edge of the roof was lowered to reduce the outflow area from 84.1 square inches to 74.4 square inches for the 100-foot prototype length and correspondingly for the 77-foot length.

Tube A-II was the same as Tube A except that the roof was curved upward from point of tangency at elbow discharge thus increasing the discharge area at 77-foot prototype length from 71.17 square inches to 100.28 square inches, or 32%. This was 54% greater than Tube A-I at 77-foot length prototype.

Tube D-I was the same as Tube D except that a splitter was introduced in the elbow as indicated in sketch on curve sheet 28. Tube D was selected for this alteration because of unusually large areas in the elbow section. The results are not comparable in that the splitter decreased the areas to a considerable extent which may be responsible for the increase in work done by the tube at 0° and 15° vane angles. The reduction in C_2 for 30° and 45° vane angles is due to interference with whirl caused by the splitter.

All draft-tube models were made of wood to facilitate construction and to make alterations easier. The elbow sections were split in a vertical plane through the transverse centerline of the

unit. The horizontal section was divided in a plane lying midway between the floor and the roof except Tube A-II in which the dividing plane was in the same position as in Tube A-I relative to the floor.

Considerable difficulty was encountered in these wooden models due to swelling. The wood swelled when submerged in water and the joints opened up making cracks in the draft-tube models. These cracks produced counter flows which affected the efficiency of the models. These were corrected and check runs made to ascertain the true performance of the models. A small roll of plasticene was placed in the joints as the sections were assembled and drawn together with bolts.

Steel rings or collars were made to fit onto the discharge side of the orifice casting and a rubber gasket was used to make a tight seal. These rings were fitted onto the throat of the models when constructed and when installed were bolted tightly onto the orifice outlet thus holding the model in place for testing.

A row of piezometer openings was placed along the centerline of the draft tube model on the slope representing the tail race excavation. Another was placed in like position on the centerline of an adjacent unit. As both gave the same results, the one placed along the centerline of the operating unit was used in these tests. These openings were connected together and to a tail-water-hook-gage pot mounted upon a swinging bracket with the head-water hook-gage pot. The latter was connected to piezometers located one on each side of the head bay as previously described just below the

stilling racks. (See Dwg. 232-D-578).

The difference between the water levels in these pots as measured by a micrometer hook-gage was taken as the operating head on the models.

The head over the tail-gage weir was measured by means of an ordinary hook-gage reading in hundredths of a foot on the staff and in thousandths of a foot on the vernier.

Head and weir-gage readings were taken simultaneously at intervals of thirty seconds. Five readings on head-water level and then five readings on the tail-water level were taken. The difference between these averages was the head. The quantities of water flowing through the model were calculated from the average of the ten weir-gage readings.

Five piezometers consisting of perforated plates as shown and spaced along the river bed model as indicated on drawing 232-D-578 were connected each to a manometer tube. These tubes were mounted together on a graduated manometer board. The height of the tial water was controlled by means of these manometers and the adjustable weir.

In order to arrive at a basis of comparison for the effectiveness of the various draft tubes as such it seemed best to compare their absolute efficiencies. Methods of arriving at the efficiencies of draft tubes were investigated. These methods, or formulas, indicated in their derivation that certain data, which would not be practicable to obtain in our present set-up, would be required to compute the absolute efficiencies of draft tubes. The

forumlas referred to are fully discussed in the appendix to this report.

Since the data obtainable was only sufficient to give a comparison of efficiencies of the draft tubes and as the coefficient of discharge, C_2, would give the same thing it was decided to make the comparison on the basis of the latter.

Runners of the conventional design when operating at or near the point of best efficiency, discharge the water in an axial direction. When over-loaded the discharge is spiral in a direction opposite that of the runner and vice versa when underloaded. As no runner was used in these tests vanes were set in the crown plate as previously described and as shown on drawing 232-D-579, for the purpose of simulating the discharge condition of runners operating at various gate openings and constant speeds. These are referred to as "vane angles" and are fixed at 0°, 15°, 30°, and 45°, as the models were symmetrical the vanes were set to cause the water to whirl in a clockwise direction only.

The coefficient of discharge, C_2, was measured for the different vane angles and for different velocities ranging from about 2 feet per second to 7.5 feet per second on the model. The normal model velocity is 4 feet per second to correspond to normal velocity in prototype.

A throat velocity - C_2 curve was plotted for each vane angle for each draft tube test. As it is generally conceded that C_2, and therefore the effectiveness of the draft tube, is independent of the

velocity above a certain point, a velocity of six feet per second was selected as a point at which to compare the effectiveness of the model draft tubes in these tests.

Taking V_2 at 6 feet per second for each vane angle, C_2 was plotted against vane angle in degrees. These curves show the coefficient of discharge of the draft tubes for any angle of discharge from the runner.

The set of curve sheets No. 2 to 34 inclusive, drawing 232-D-580, shows a comparison of discharge coefficients for each draft tube tested at 54-foot, 77-foot and 100-foot lengths, 1 and 2 piers, insofar as it was considered advisable to test all three lengths. Sheet No. 36 shows a comparison of the performance of all draft tubes tested with 2 piers at 77-foot length and sheet No. 35 shows a comparison of all draft tubes tested with 1 pier at 77-foot length.

At the discharge end of tube B at 77-foot length the outflow passages are raised four feet. This makes it possible to reduce the necessary tail race excavation by this amount. The floor representing the tail race excavation in the model was raised correspondingly for the test and this should be considered in evaluating this draft tube.

In order to study flow condition in the tail race and on the river bed as the water leaves the tail race excavation, profiles of the water surface were made. Sheet No. 37 shows unit No. 1 operating alone with tail water level at Elev. 505, sheet No. 38

shows unit No. 3 operating with tail water at Elev. 505 and sheet No. 39 shows all units operating at normal discharge with tail water at Elev. 505, Elev. 508, and Elev. 512. Profiles were taken opposite each of the three outlet passages and the averages of these readings plotted.

When only one unit is operating the water so spreads over the river bed as it flows from the tail race that it is difficult to determine the velocities. From observation of the model and from profile shown on sheets No. 38 and 39 it is apparent that the velocity is very near the critical at a point in line with the draft tube outlet.

With all units operating at normal discharge of 10,500 second feet each and tail water level at Elev. 505.0 a distinct hydraulic jump occurs just below the edge of the tail race excavation. As the tail water level rises the hydraulic jump moves farther upstream and finally disappears at the point of critical flow where

$$V = \sqrt{gd}$$

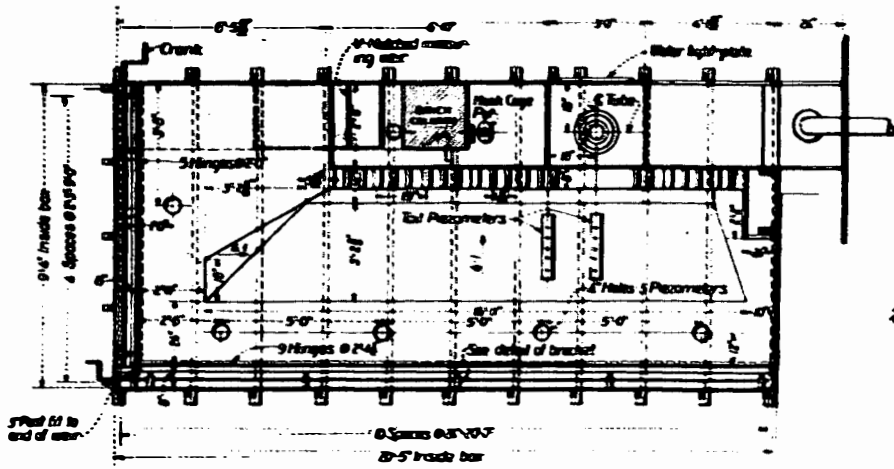
This condition can do no harm insofar as the efficiency of the plant is concerned. On the other hand it may do much good by cutting out the river bed below the tail race excavation and thus lowering the level of the water at the draft tube outlets.

4. Conclusions.

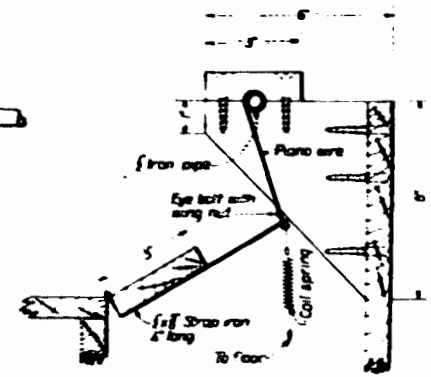
These tests indicated that to increase the length of the horizontal section of the draft tube from 77 feet to 100 feet increases its efficiency. It is doubtful, however, that this increase will be sufficient to outweigh the additional cost of constructing this additional length to the horizontal section of the draft tube.

From these tests it seems that the limit of upward slope for the horizontal section of the draft tube has not been reached. Draft tube B, which has a slope greater than the six degrees which previous tests show to be near the upper limit, shows quite as good results as tubes A and A-I. It will be necessary to further increase this slope in order to determine what the limit is for this particular design of draft tube. Further tests are to be made along this line in connection with Columbia River Project.

It may be seen from the Coefficient-Throat Velocity Curves, that a very unstable condition obtains when the throat velocity reaches a value of around six feet per second. A great many check runs were made at this point to determine the reason for this break in the curve. It was concluded that the cusp was caused by vortices forming in the forebay and extending into the throat of the model. To correct this would have necessitated a major alteration in the flume. A better way might have been to use V_2 at a higher value for the C_2-Vane Angle Curves. This would have necessitated raising the height of the flume to give the required value for V_2.



PLAN

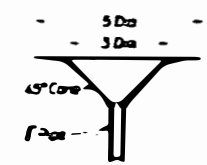


ADJUSTABLE WEIR AND BRACKET DETAIL

SCALE OF INCHES

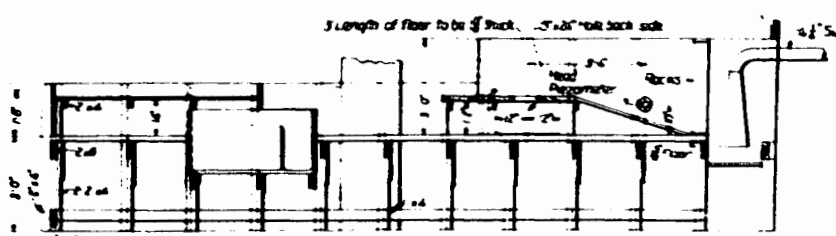
HINGE DETAIL

NOTE:
Plane of floor and gate and ℄ of hinge must intersect at one point

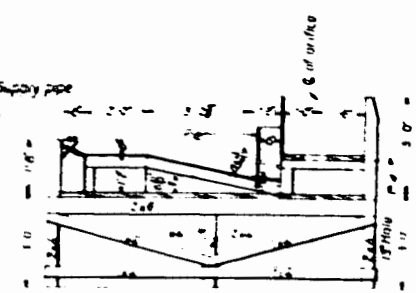


PIEZOMETER DETAIL

NOTE:



SECTION ALONG ℄ OF ORIFICE

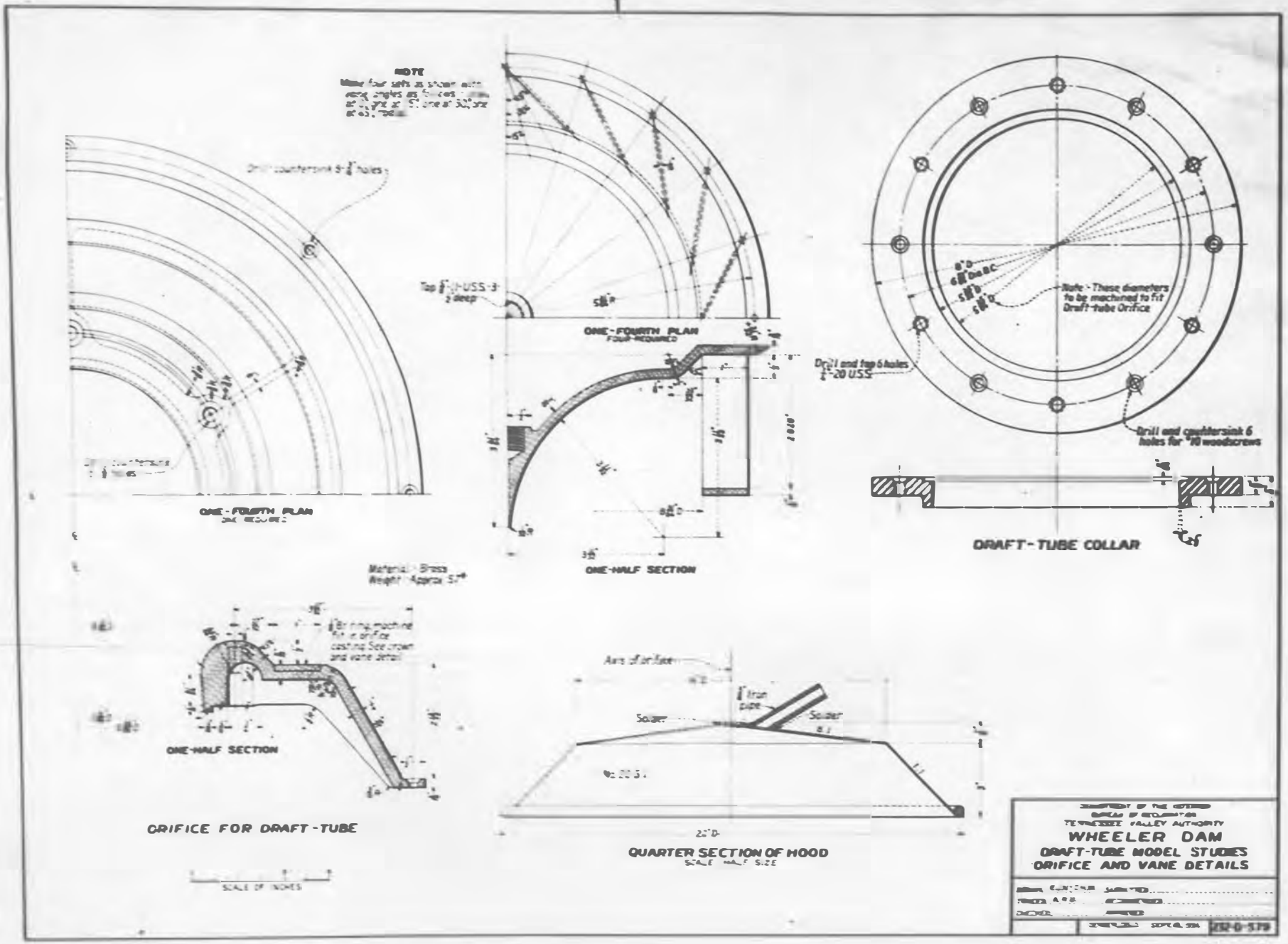


SECTION ALONG ℄ OF ORIFICE

NOTES

WHEELER DAM
DRAFT-TUBE MODEL STUDIES
TEST FLUME DETAILS

232-D 578


NOTE
ONE-FOURTH PLAN
ONE-FOURTH PLAN
FOUR REQUIRED
ONE-HALF SECTION
Note - These diameters to be machined to fit Draft-tube Orifice
Drill and tap 6 holes
Drill and countersink 6 holes for #10 woodscrews
DRAFT-TUBE COLLAR
Material - Brass
Weight - Approx 57#
ONE-HALF SECTION
ORIFICE FOR DRAFT-TUBE
SCALE OF INCHES
Axis of orifice
Solder
Solder
QUARTER SECTION OF HOOD
SCALE HALF SIZE
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT-TUBE MODEL STUDIES
ORIFICE AND VANE DETAILS
232-D-579

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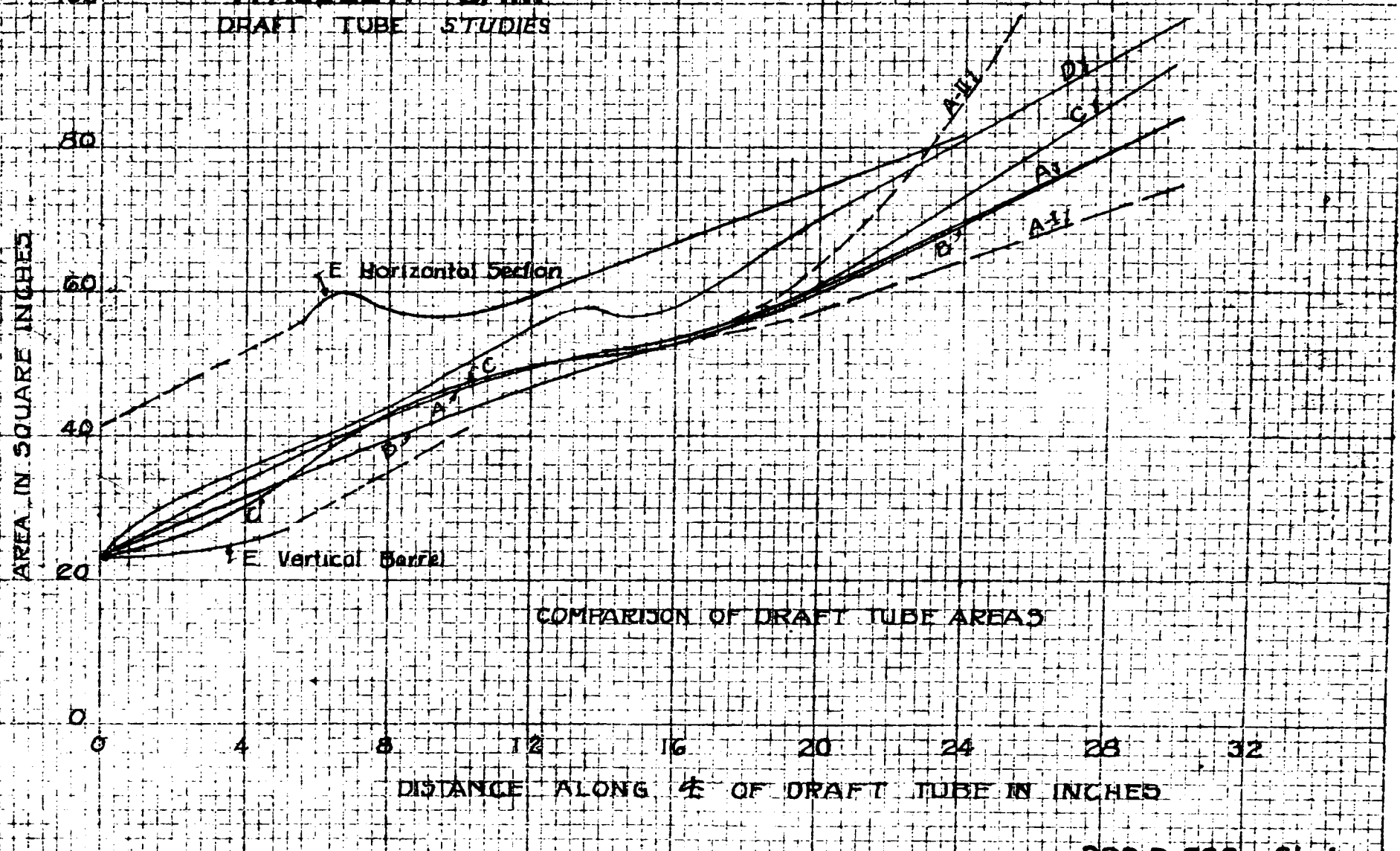
WHEELER DAM

DRAFT TUBE STUDIES



COMPARISON OF DRAFT TUBE AREAS

232-D-580 Sh 1

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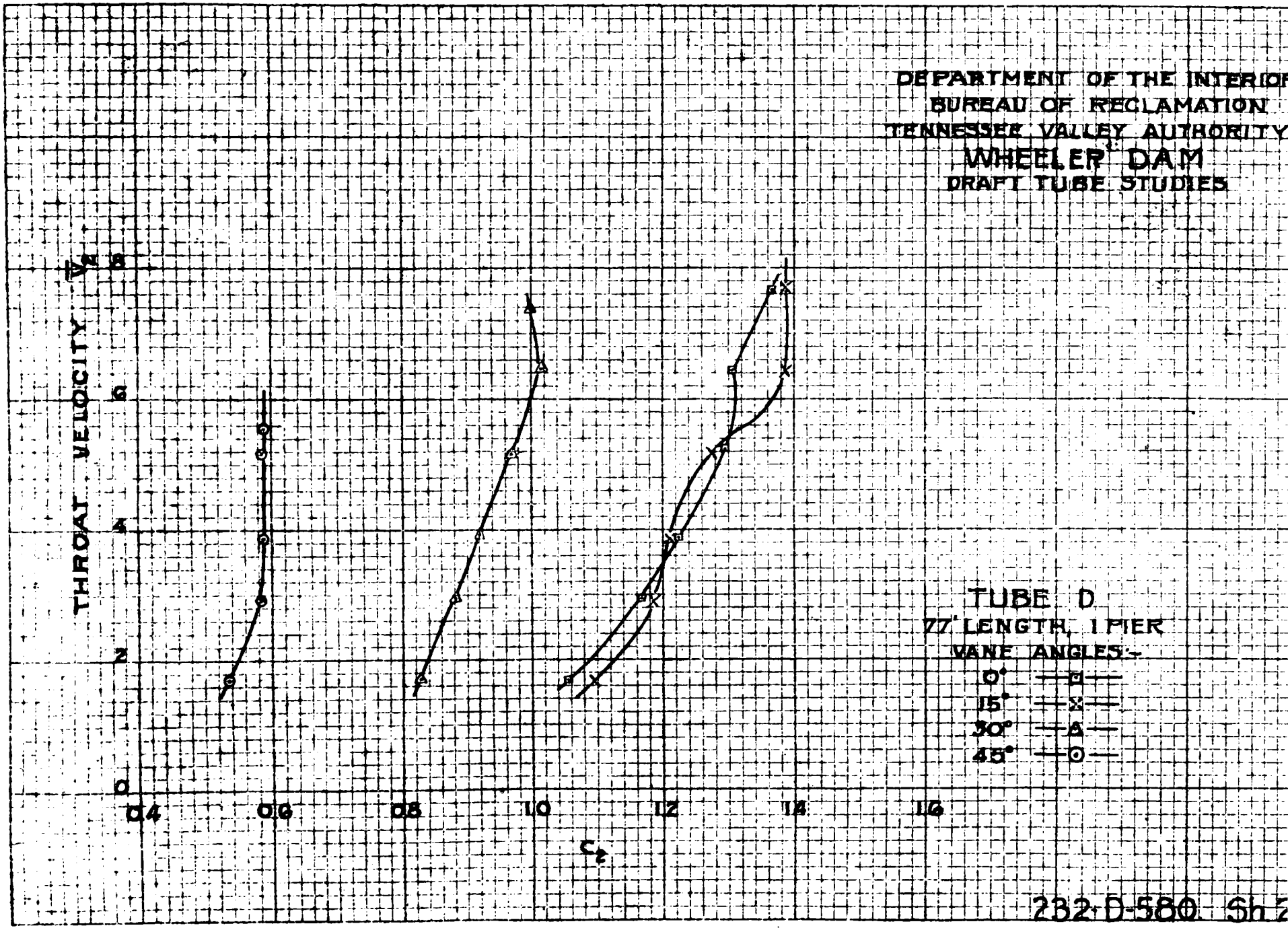
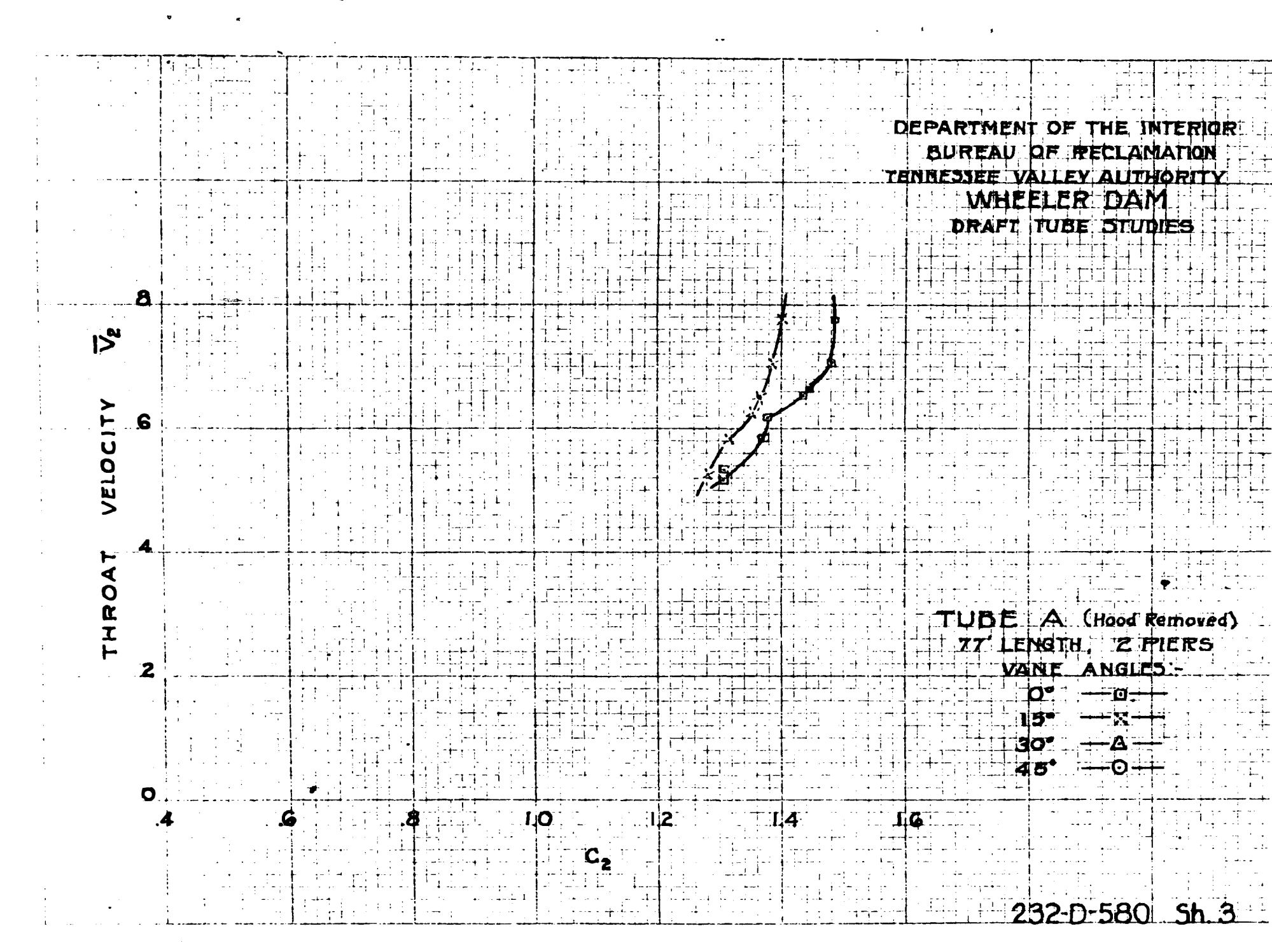
WHEELER DAM
DRAFT TUBE STUDIES



232-D-580 Sh 2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WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
0
2
4
6
8
.4
.6
.8
1.0
1.2
1.4
1.6
C_2
TUBE A (Hood Removed)
77' LENGTH, 2 PIERS
VANE ANGLES:-
0°
15°
30°
45°
232-D-580 Sh. 3

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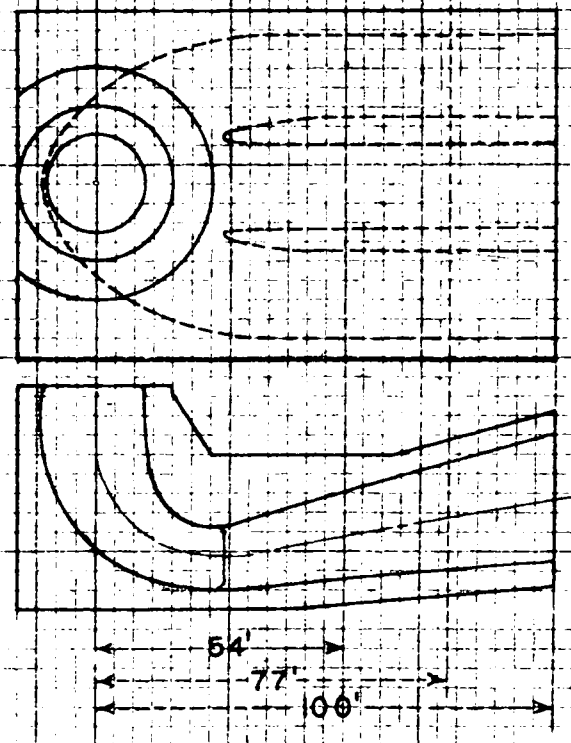
DRAFT TUBE STUDIES



TUBE - A
Length 100
77
54
Test No. 173-196
Series GG-HH-II

DISCHARGE COEF. C_2 AT V = 6'/SEC.

1.4
1.2
1.0
.8
.6
.4

0
15
30
45

VANE ANGLE IN DEGEES

232-D-580 Sh 4

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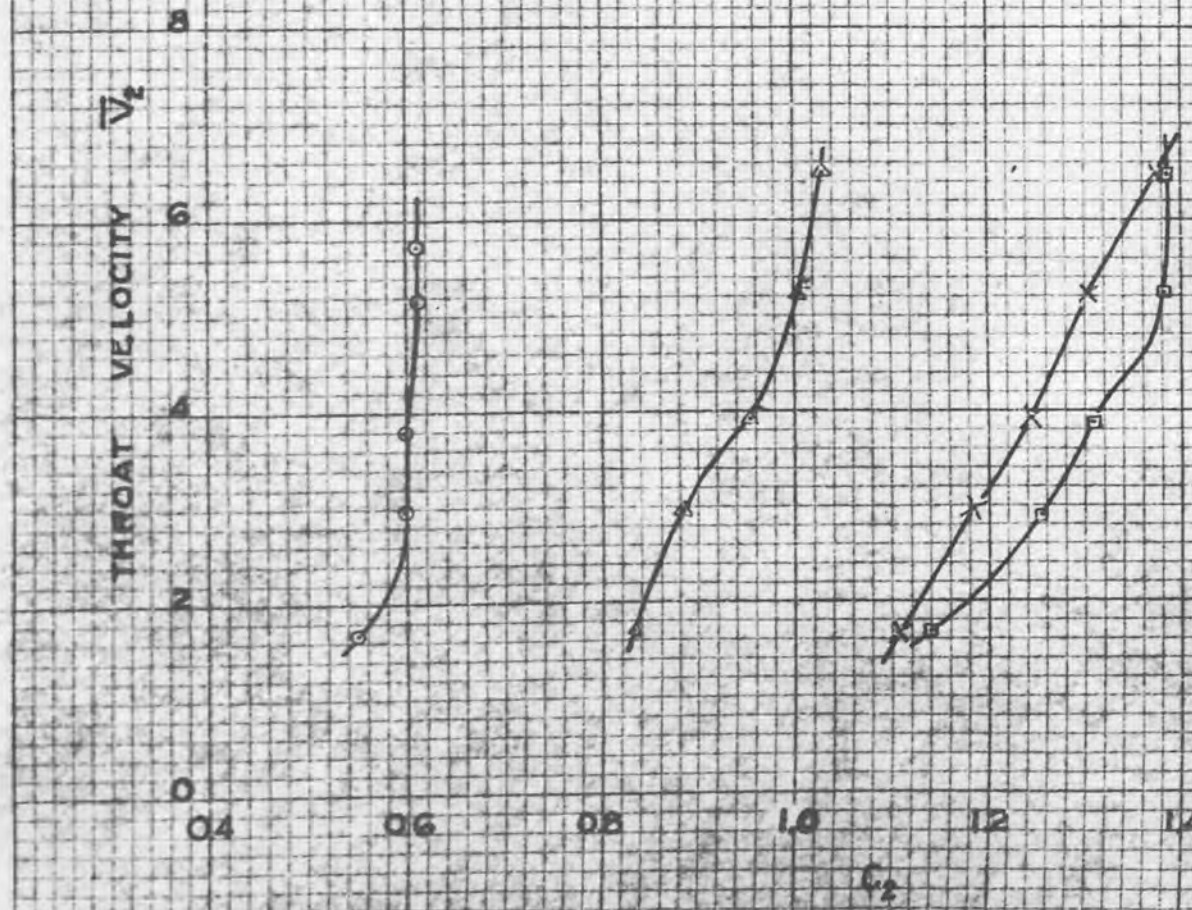
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES



TUBE A-1
77' LENGTH I PIER
VANE ANGLES:-
0° —□—
15° —×—
30° —△—
45° —⊙—

232-D-580 SH 5

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WHEELER DAM
DRAFT TUBE STUDIES

DISCHARGE COEF. C_d AT V = 6.7 SEC.

14
12
10
8
6
4

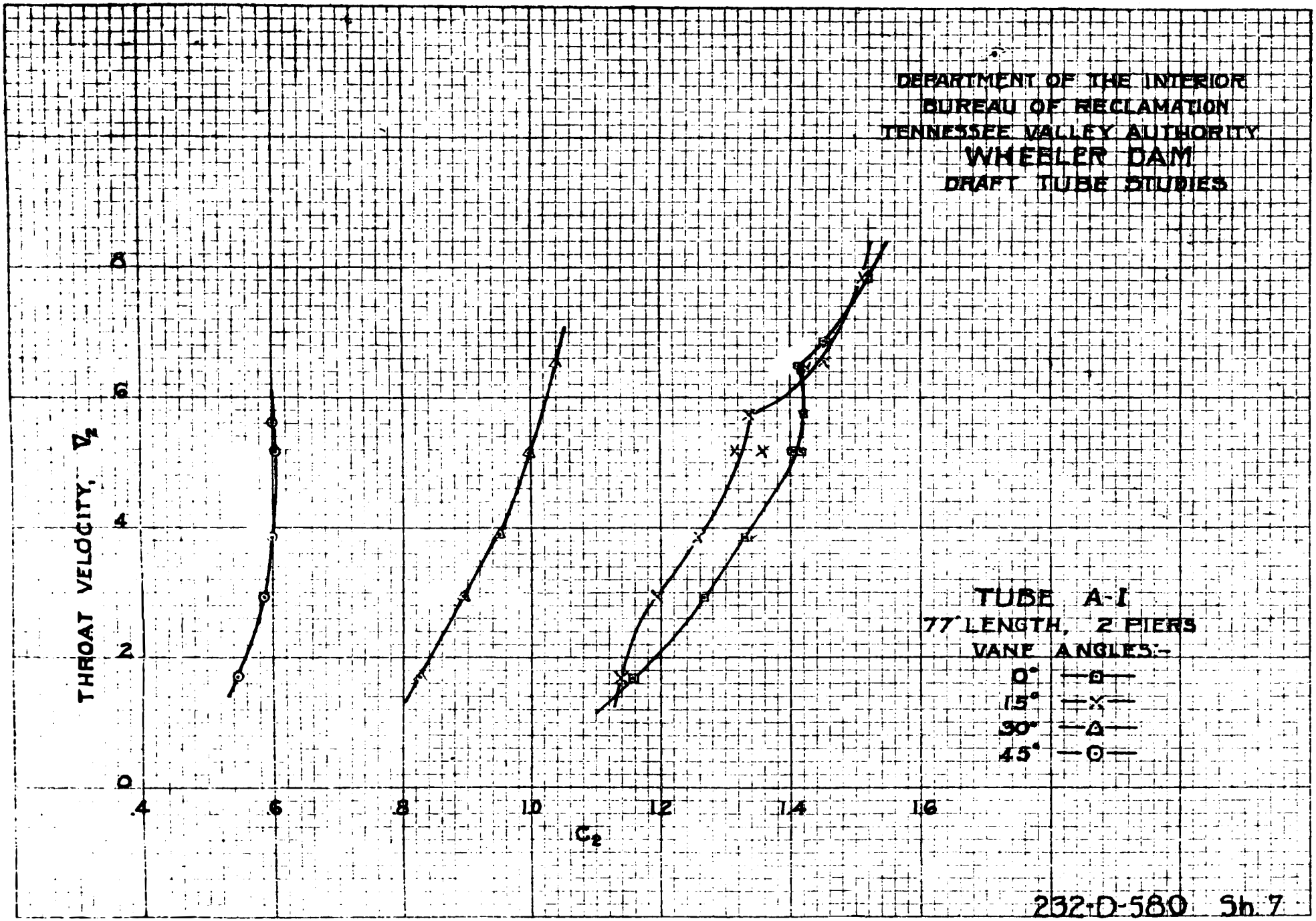
0
15
30

VANE ANGLE IN DEGREES

TUBE A-1
Length 77'
54'
Test No. 52 - 61
Series K-L

54'
77'

232D-560 Sh 6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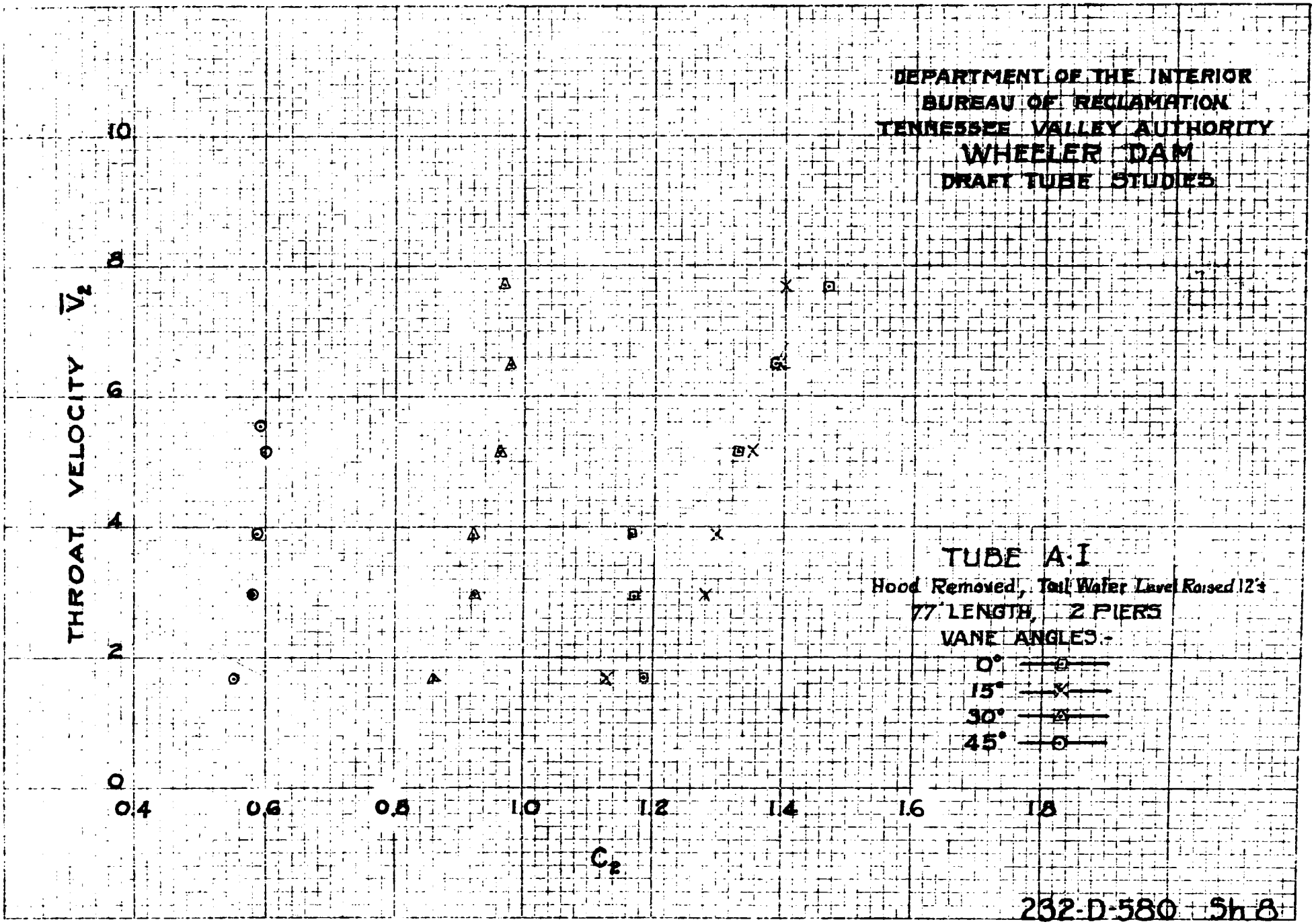
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY, V_2
C_2
TUBE A-1
77' LENGTH, 2 PIERS
VANE ANGLES:-
0°
15°
30°
45°
232-D-580 Sh. 7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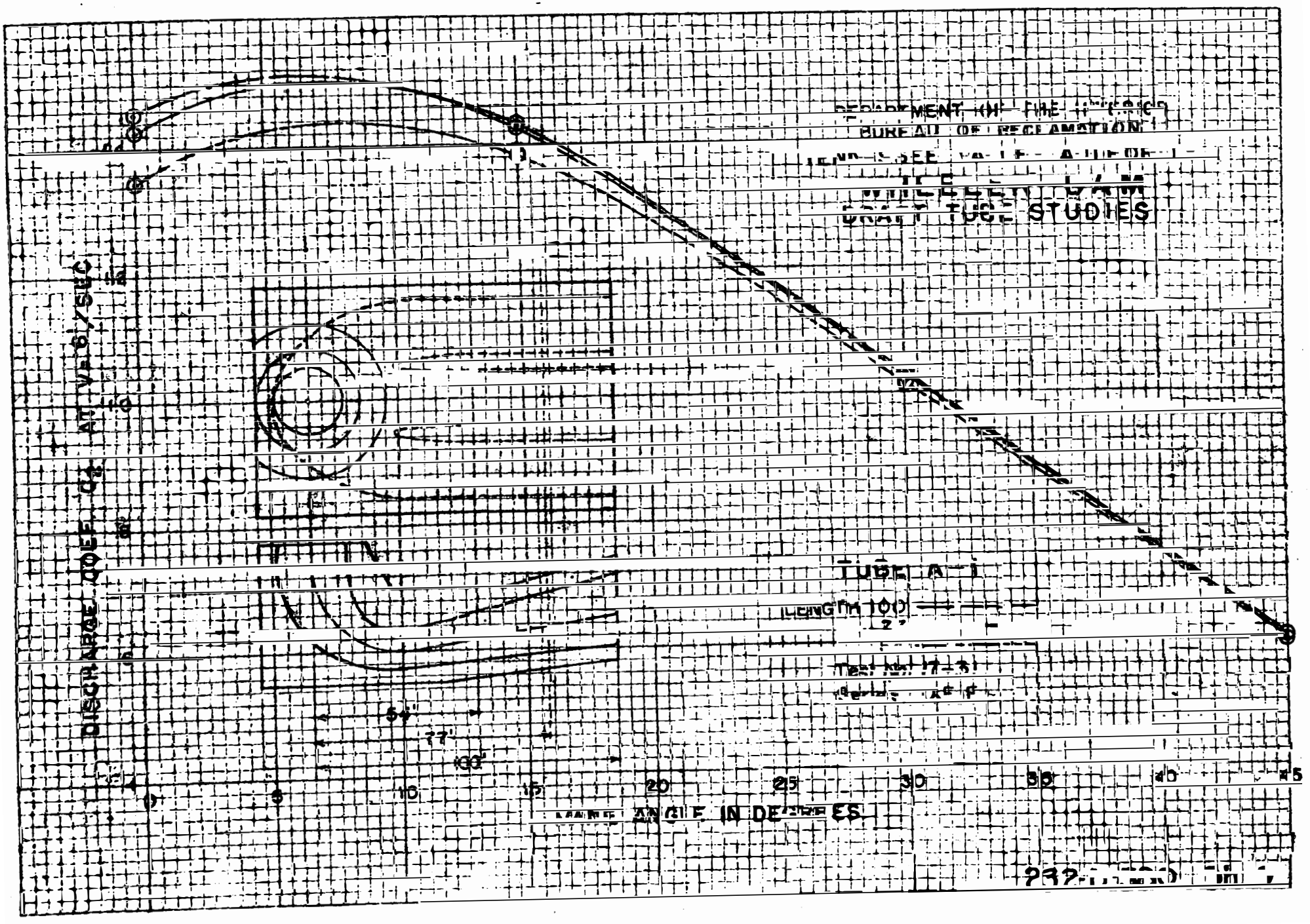
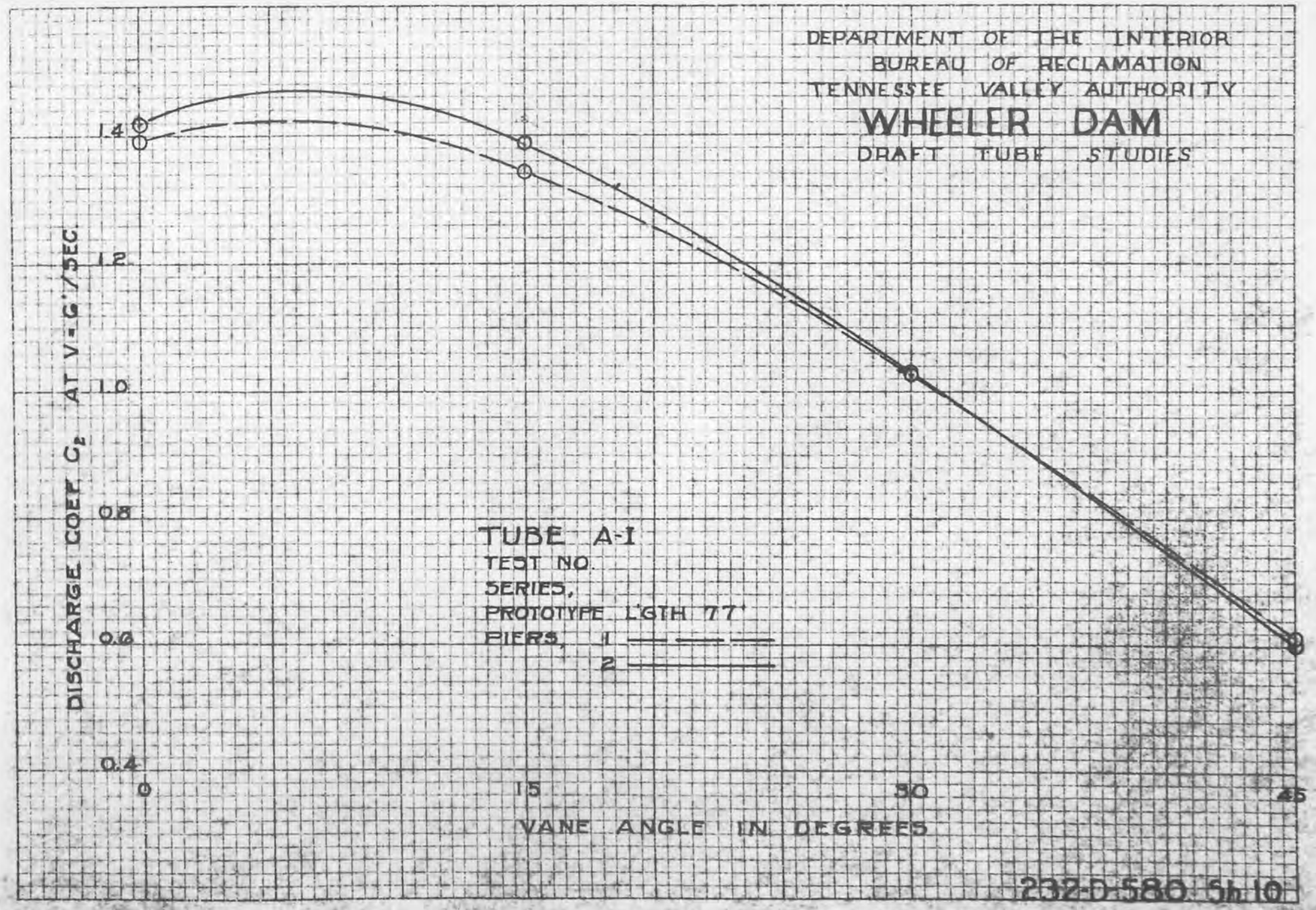
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
10
8
6
4
2
0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
C_2
TUBE A-I
Hood Removed, Tail Water Level Raised 12'±
77' LENGTH, 2 PIERS
VANE ANGLES -
0°
15°
30°
45°
232-D-580 Sh 8



BUREAU OF RECLAMATION
DRAFT TUBE STUDIES
TUBE A-1
LENGTH 100
54'
77'
100'
DISCHARGE COEF. C_d AT V=6'/SEC
0
5
10
15
20
25
30
35
40
45
ANGLE IN DEGREES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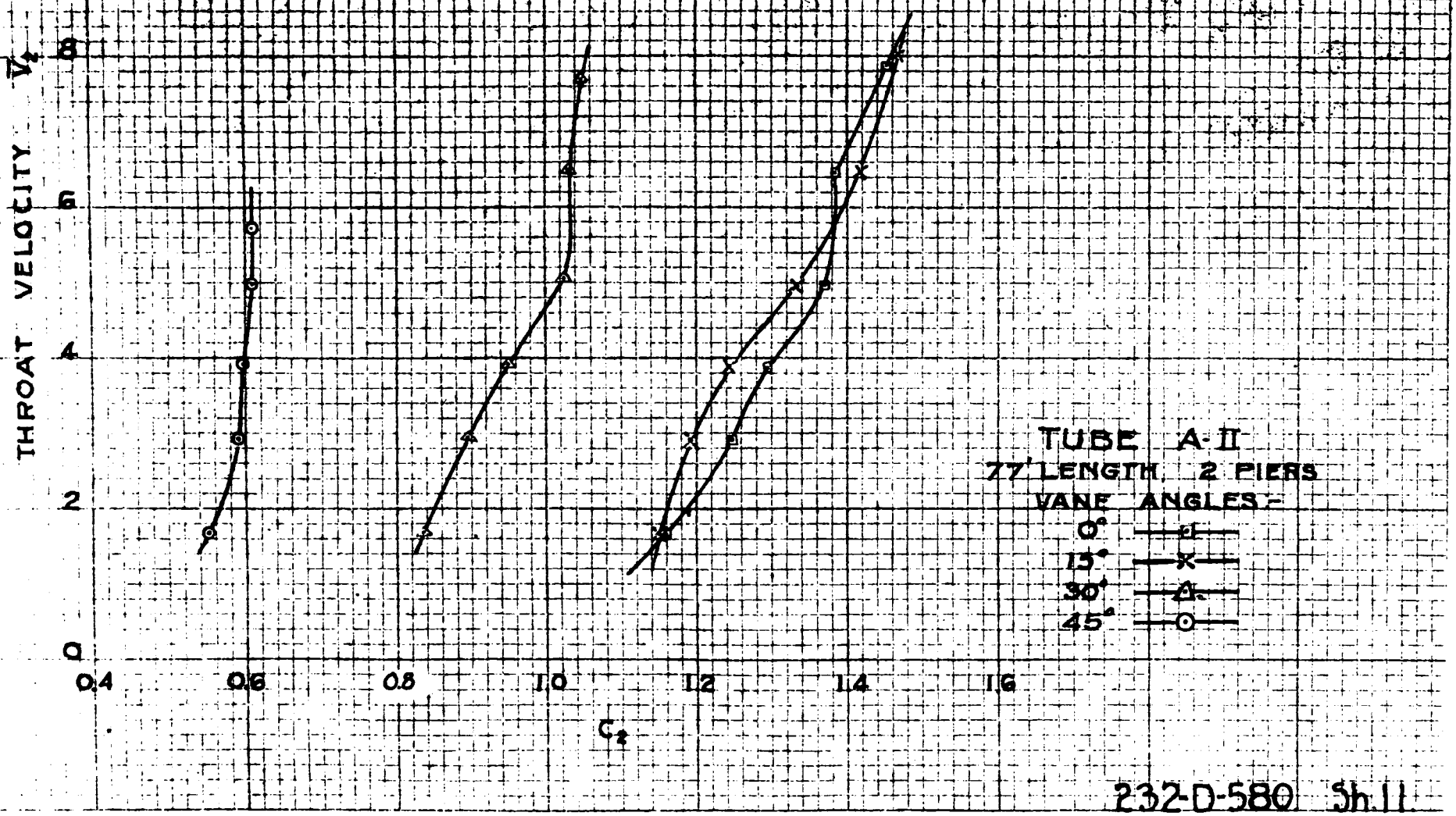
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DISCHARGE COEF. C_2 AT V = G'/SEC.
1.4
1.2
1.0
0.8
0.6
0.4
0
15
30
45
VANE ANGLE IN DEGREES
TUBE A-1
TEST NO.
SERIES,
PROTOTYPE LGTH 77'
PIERS, 1
2
232-D-580 Sh 10

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES



232-D-580 Sh.11

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

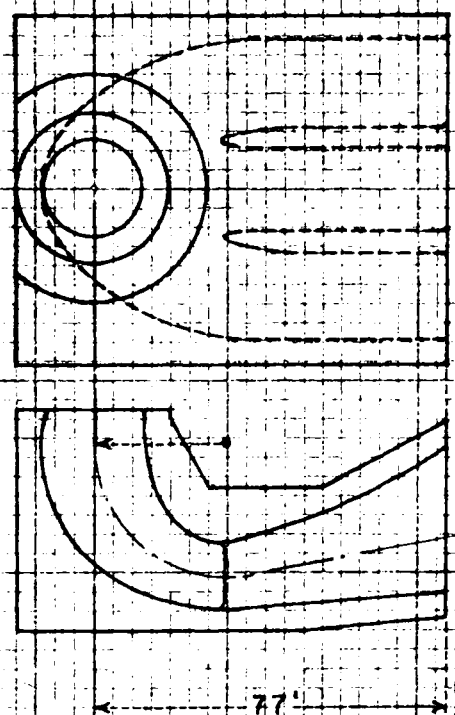
WHEELER DAM
DRAFT TUBE STUDIES

DISCHARGE COEF. C_2 AT V = 6 '/SEC.

1.4
1.2
1.0
.8
.6
.4

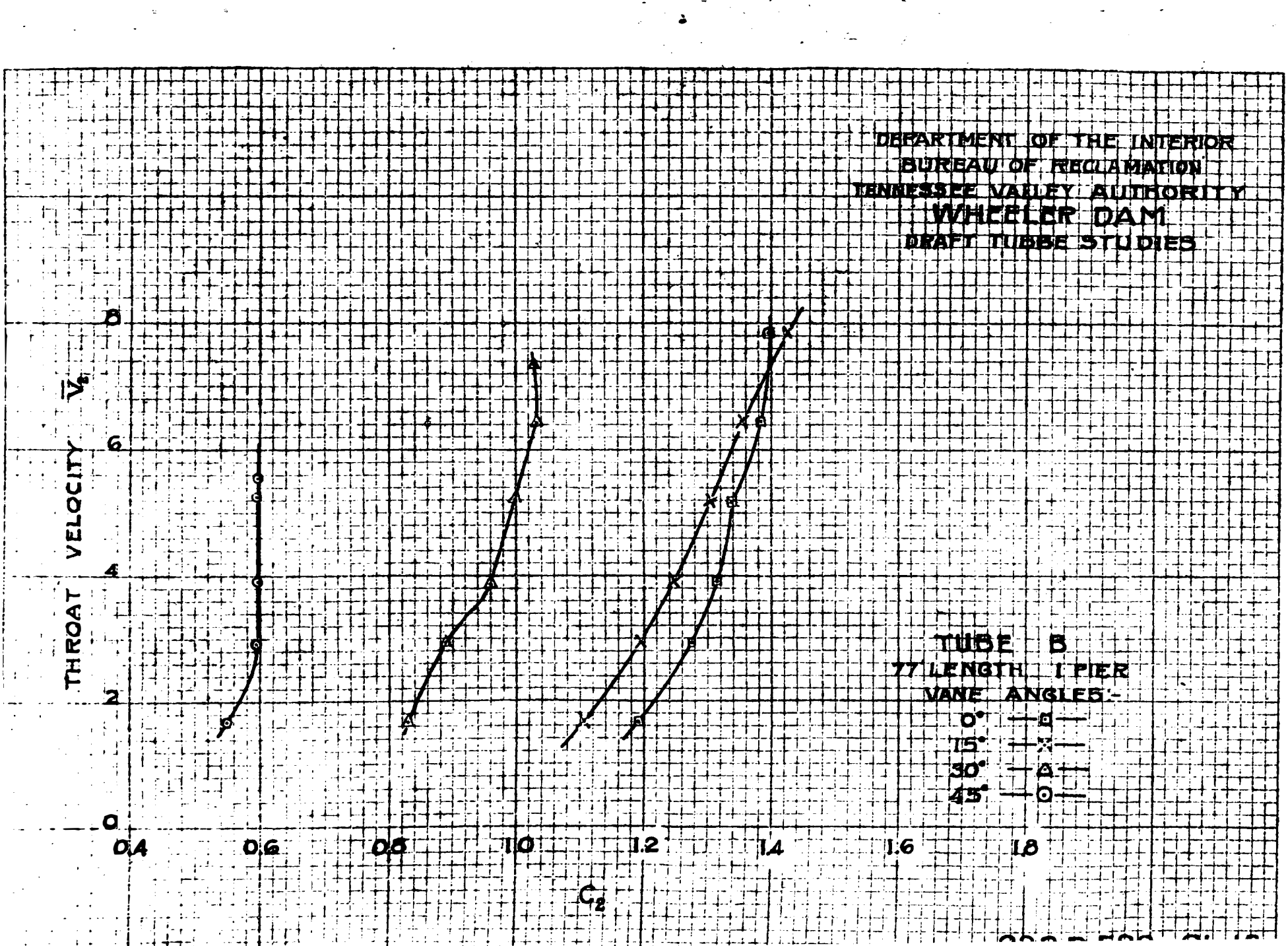
0
15
30
45

VANE ANGLE IN DEGREES



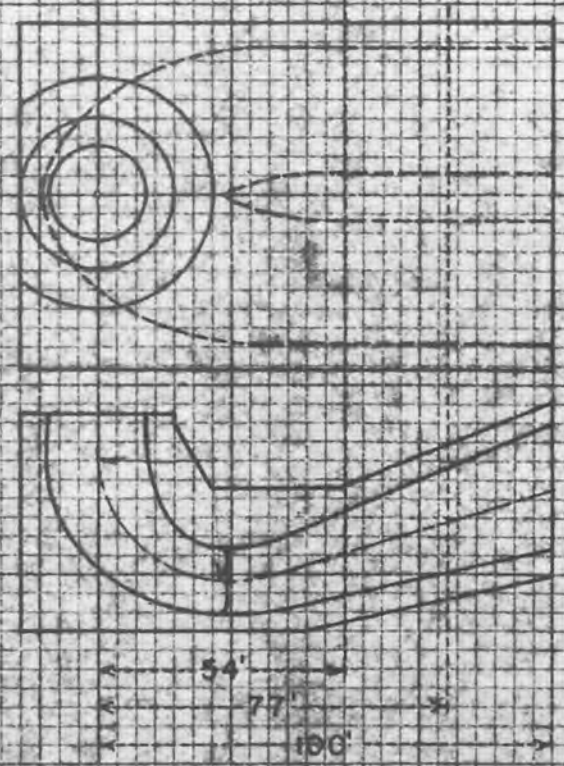
TUBE A-II
Length 77'
Test No. 153 - 158
Series C C

232-D-580 Sh 12


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBBE STUDIES
THROAT VELOCITY $\bar{V}_2$
0
2
4
6
8
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
C_2
TUBE B
77 LENGTH I PIER
VANE ANGLES -
0°
15°
30°
45°

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES



TUBE B
Length 100' ——
77' ——
54' ——
Test No. B6-102
Series T R S

DISCHARGE COEF. C_Q AT V=6'/SEC.

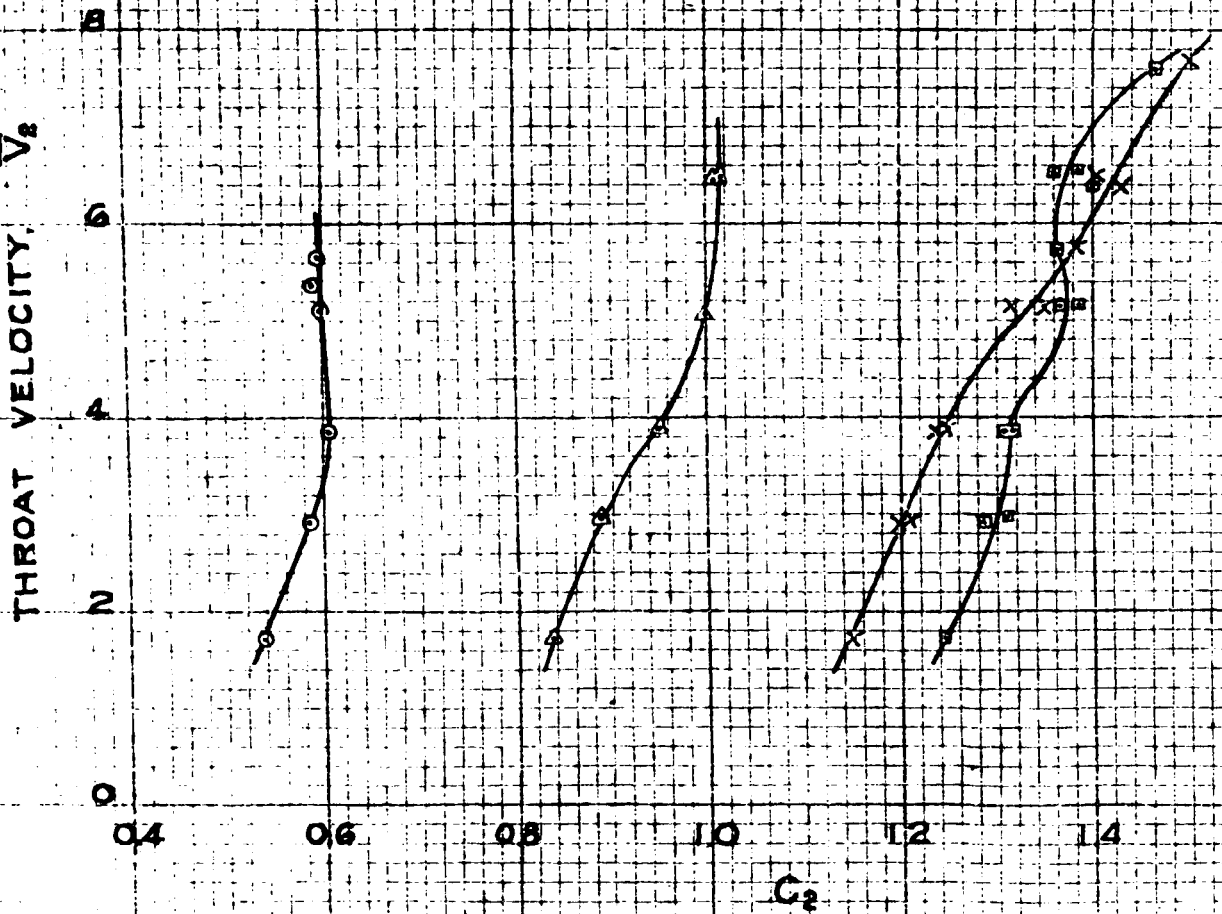
1.4
1.2
1.0
.8
.6
.4

0
15
30

VANE ANGLE IN DEGREES

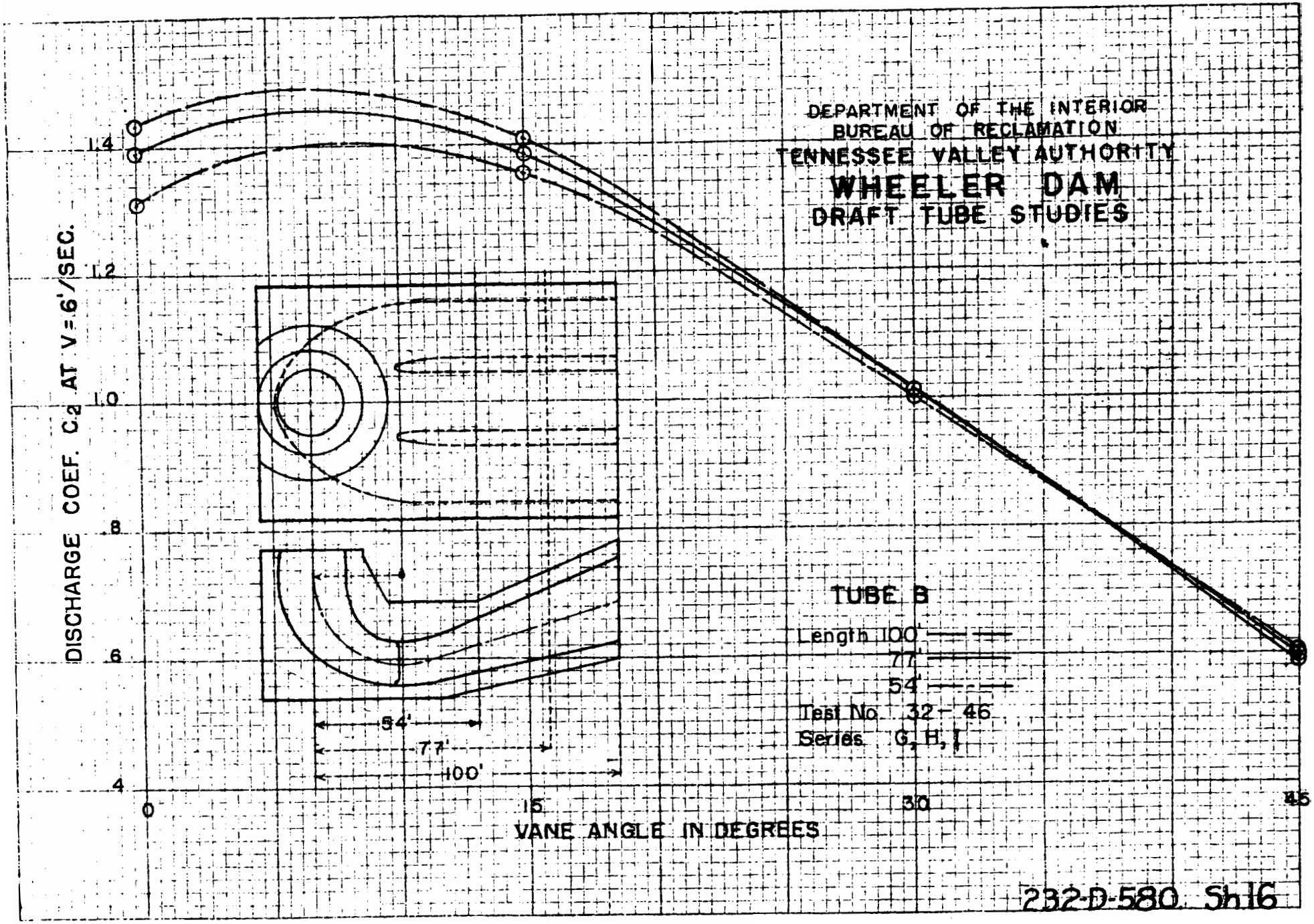
232-D-580 Sh 14

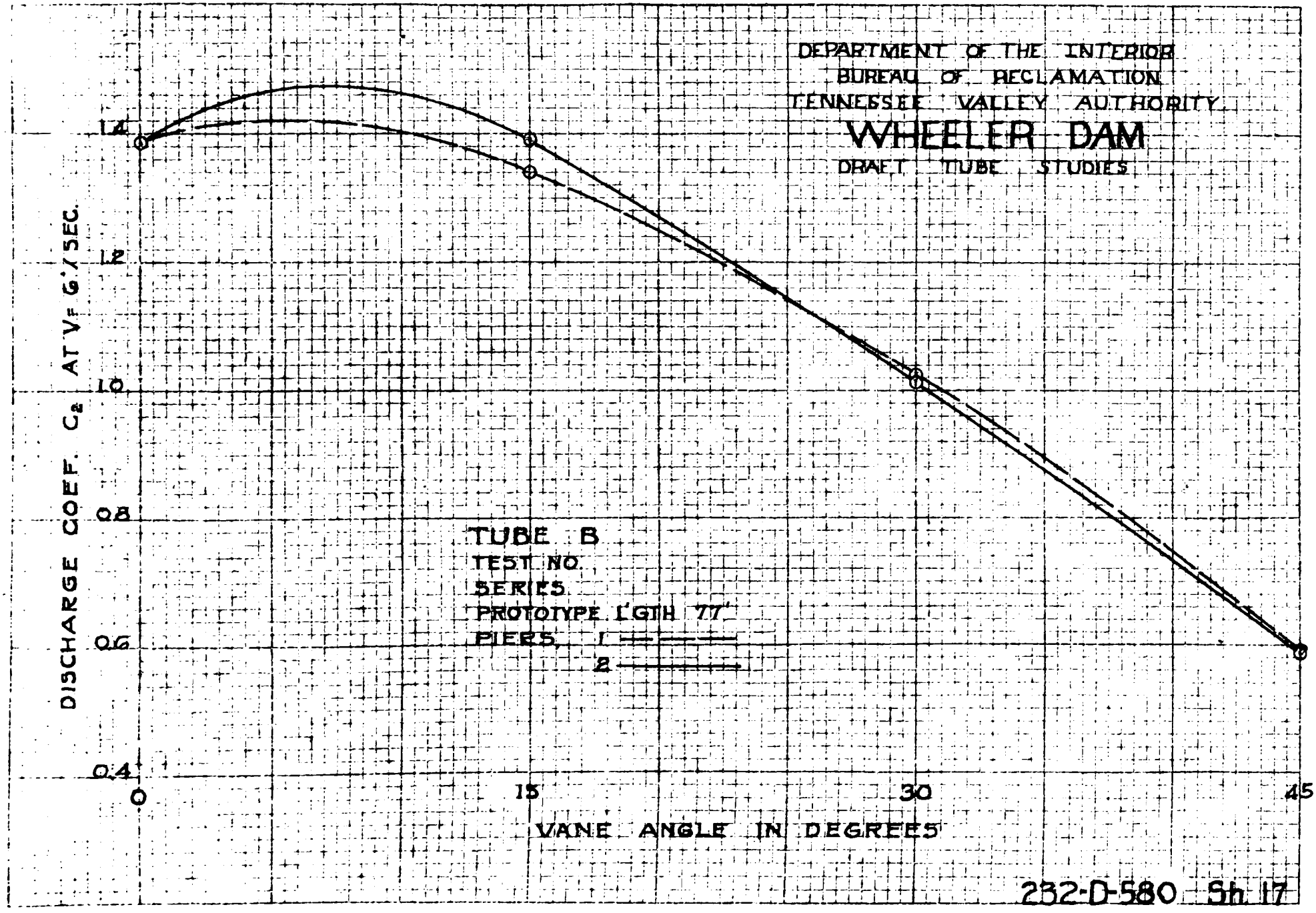
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES



TUBE B
77' LENGTH, 2 PIERS
VANE ANGLES -
0°
15°
30°
45°

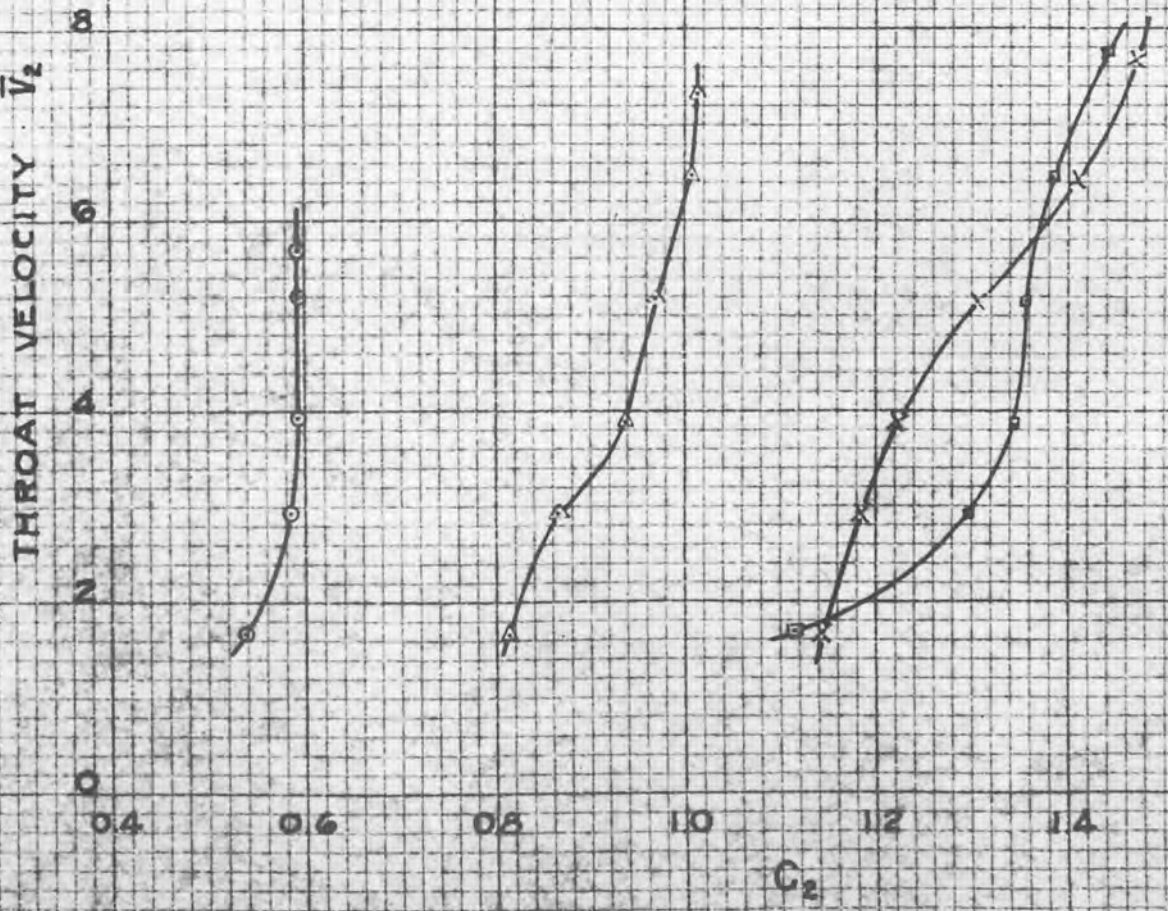
232-D-580 Sh 15


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
TUBE B
Length 100'
77'
54'
Test No. 32 - 46
Series G, H, I
54'
77'
100'
DISCHARGE COEF. C_2 AT V=6'/SEC.
1.4
1.2
1.0
.8
.6
.4
0
15
30
45
VANE ANGLE IN DEGREES
232-D-580 Sh16


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DISCHARGE COEF. C_2 AT V_F 6.7 SEC.
1.4
1.2
1.0
0.8
0.6
0.4
0
15
30
45
VANE ANGLE IN DEGREES
TUBE B
TEST NO.
SERIES
PROTOTYPE L'GTH 77'
PIERS, 1
2
232-D-580 Sh 17

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

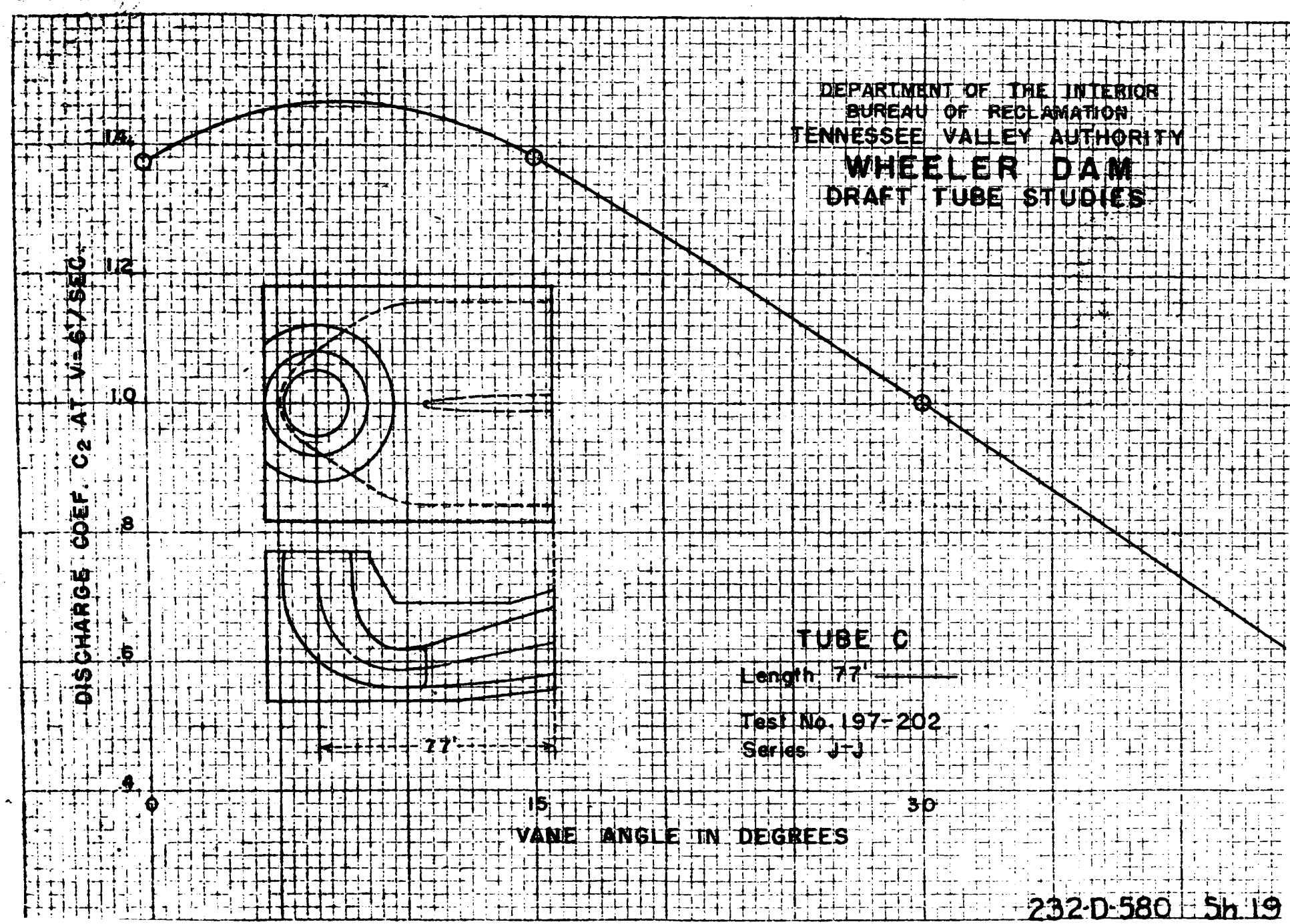


TUBE C
77' LENGTH, 1 PIER
VANE ANGLES:-
0° —□—
15° —×—
30° —△—
45° —⊙—

232-D-580 Sh 18

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

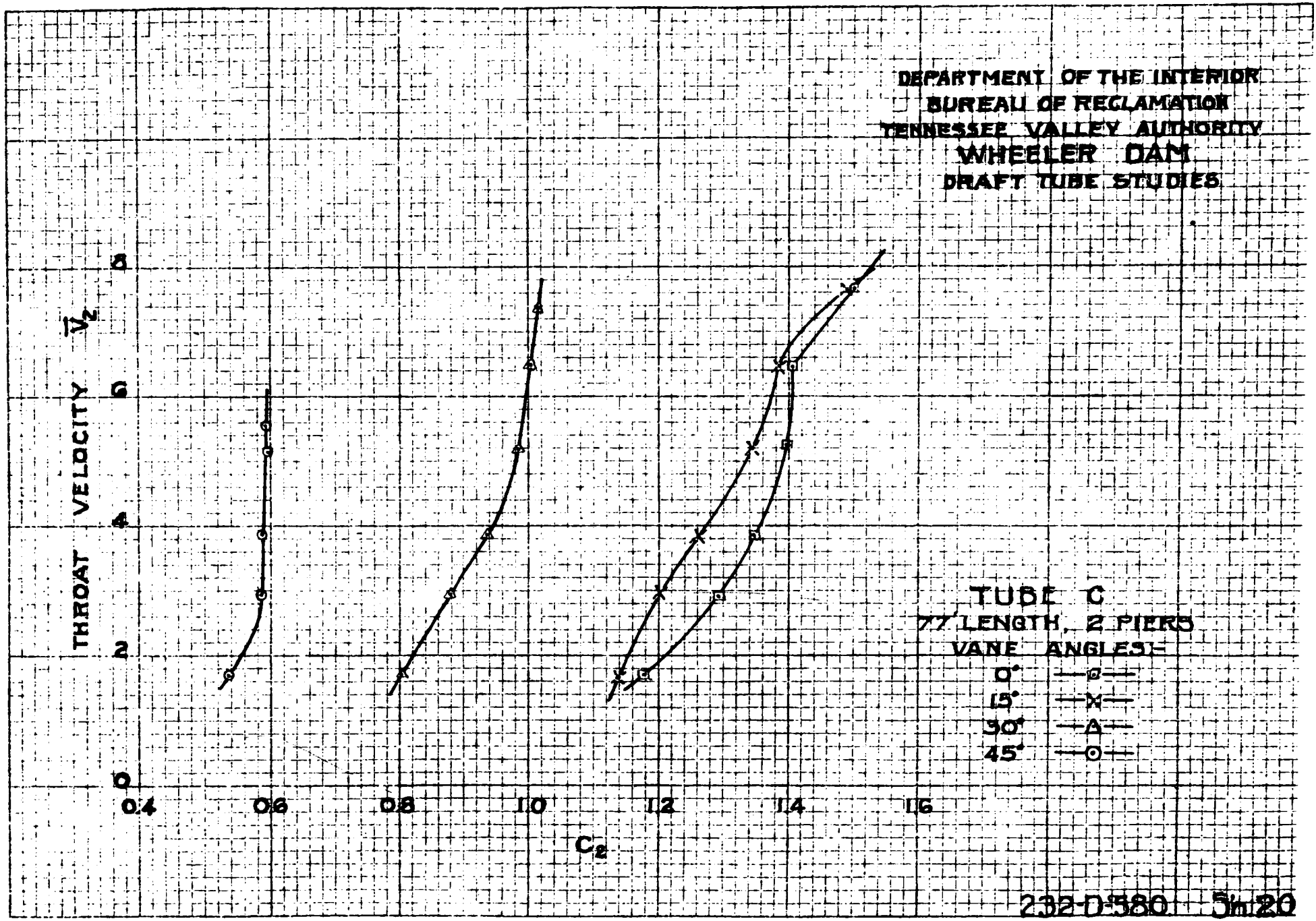


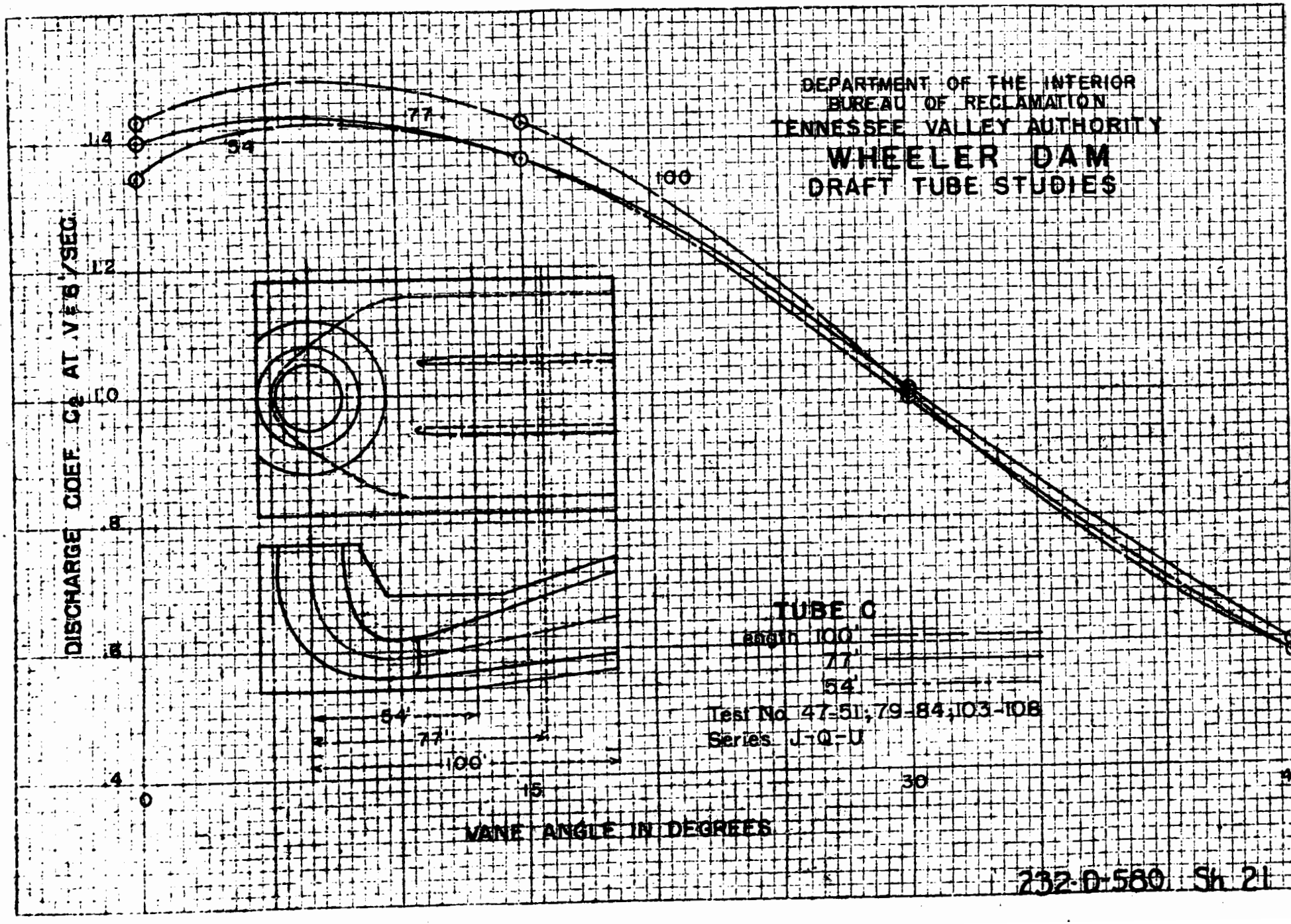
TUBE C

Length 77'

Test No. 197-202
Series J-J

232-D-580 Sh 19

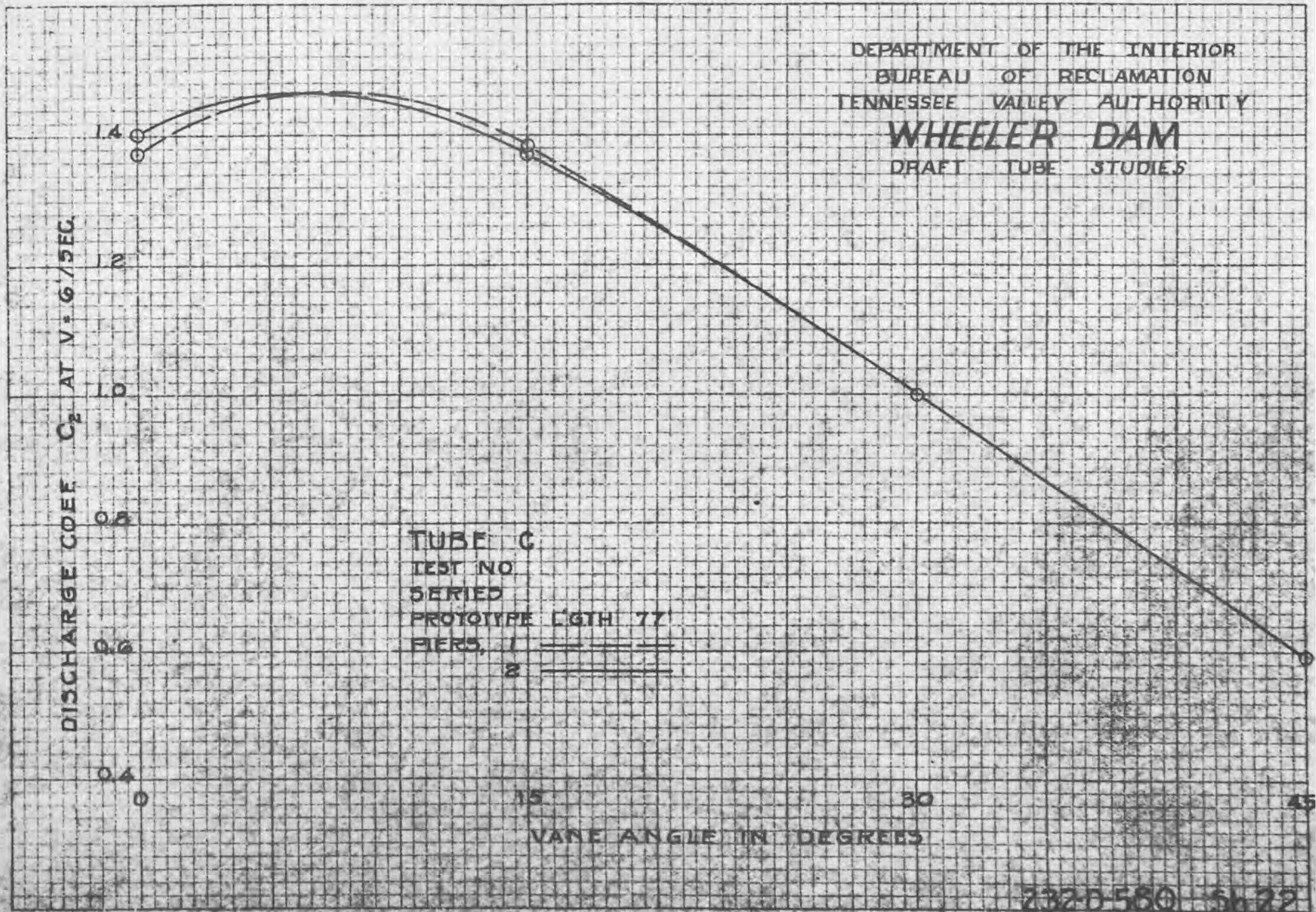

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
0
2
4
6
8
0.4
0.6
0.8
1.0
1.2
1.4
1.6
C_2
TUBE C
77' LENGTH, 2 PIERS
VANE ANGLES:-
0°
15°
30°
45°
232-D-580
5-11-20


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DISCHARGE COEF. C_2 AT V=6'/SEC.
1.4
1.2
1.0
.8
.6
.4
0
15
30
VANE ANGLE IN DEGREES
54
77
100
54'
77'
100'
TUBE C
Length 100'
77'
54'
Test No. 47-51; 79-84; 103-108
Series J-Q-U
232-D-580 Sh 21

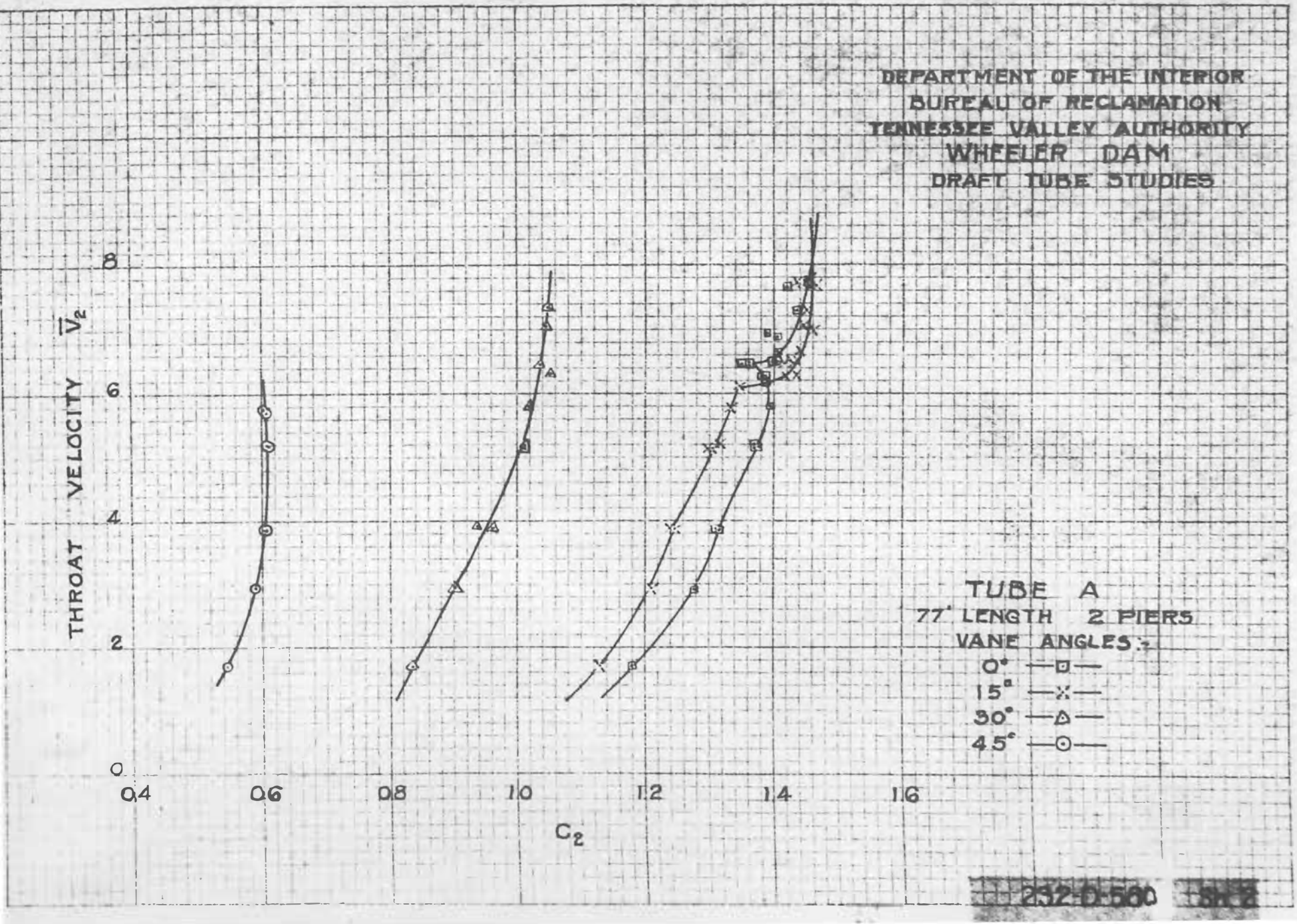
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM

DRAFT TUBE STUDIES



232-D-580 Sh 22

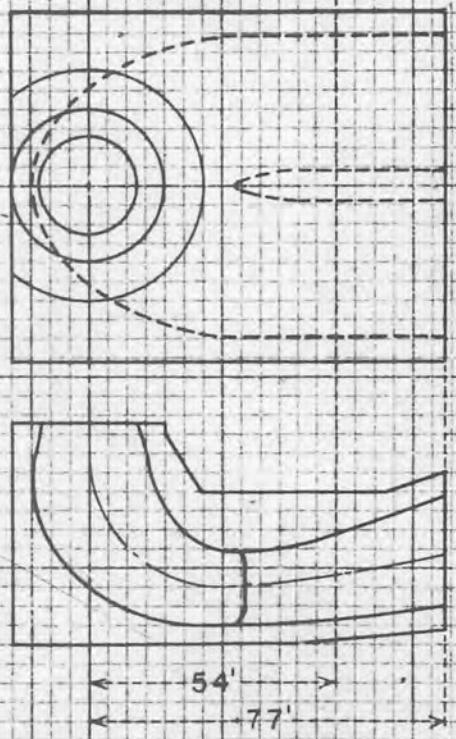

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
0
2
4
6
8
0.4
0.6
0.8
1.0
1.2
1.4
1.6
C_2
TUBE A
77' LENGTH 2 PIERS
VANE ANGLES:-
0° —□—
15° —×—
30° —△—
45° —⊙—

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

DISCHARGE COEF C_d AT V = 6'/SEC.

1.4
1.2
1.0
.8
.6
.4

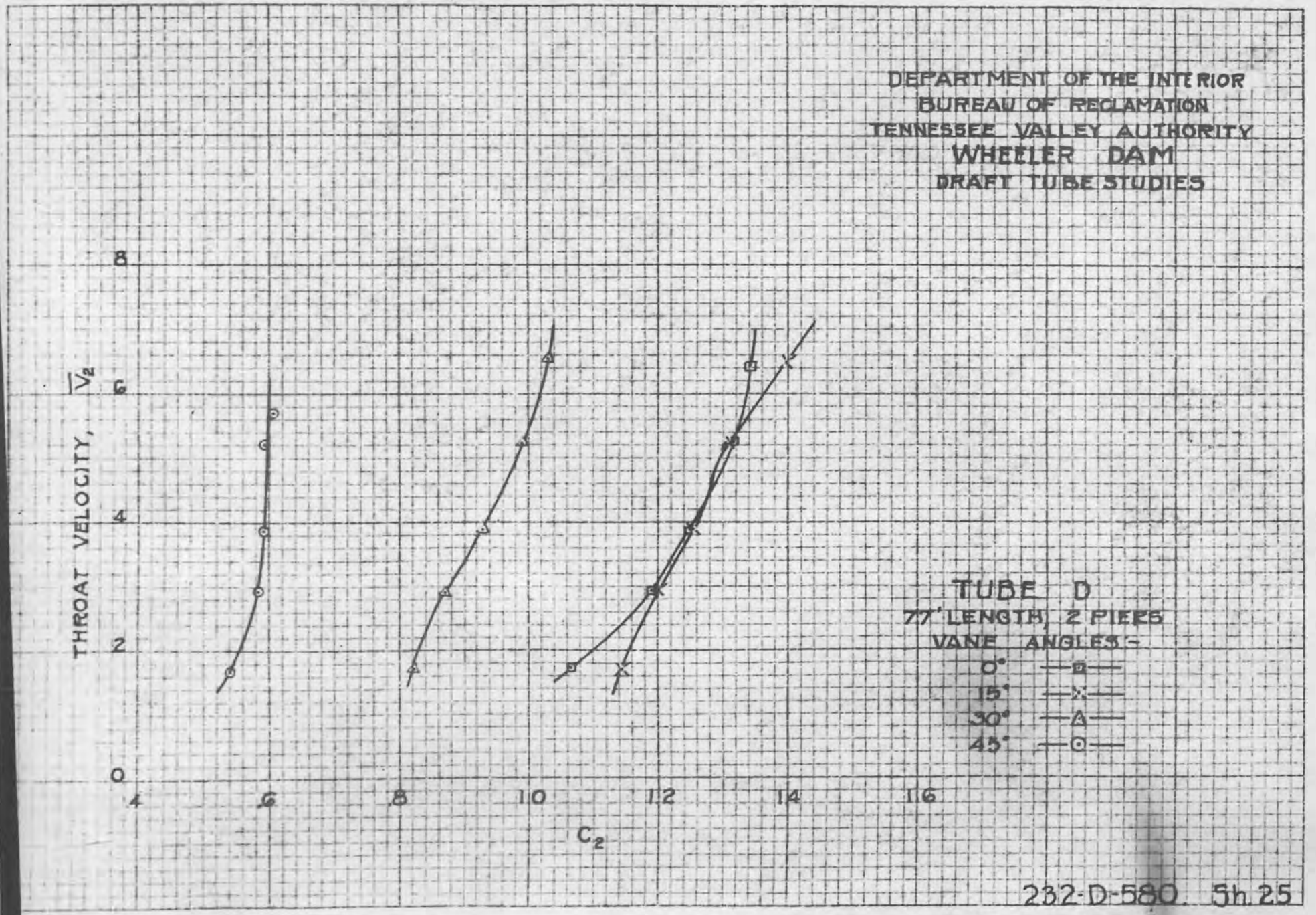


TUBE D
Length 54' ——
77' ——
Test No. 127-139
Series YZ

0
15
30

VANE ANGLE IN DEGREES

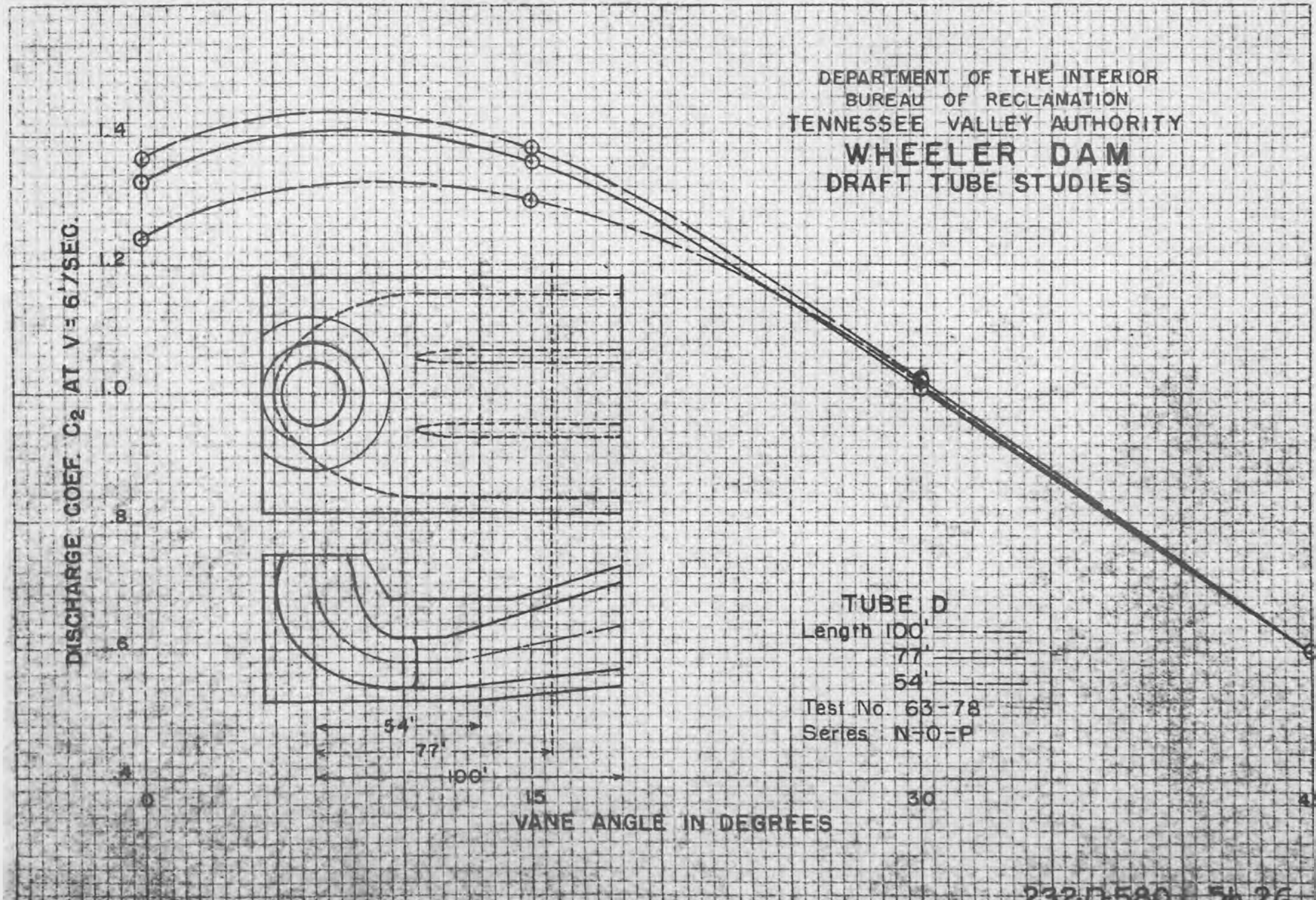
232-D-580


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY, $\overline{V}_2$
C_2
0
2
4
6
8
4
6
8
10
12
14
16
TUBE D
77' LENGTH, 2 PIERS
VANE ANGLES -
0°
15°
30°
45°
232-D-580. Sh 25

10 × 10 to the inch

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES



232-D-580 | 5h.26

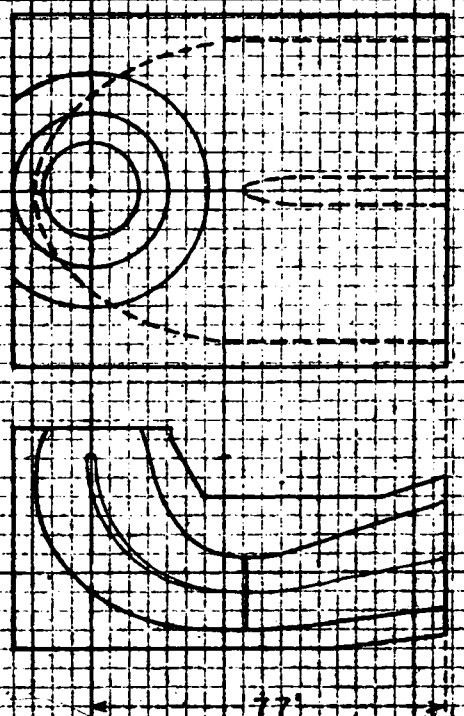
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

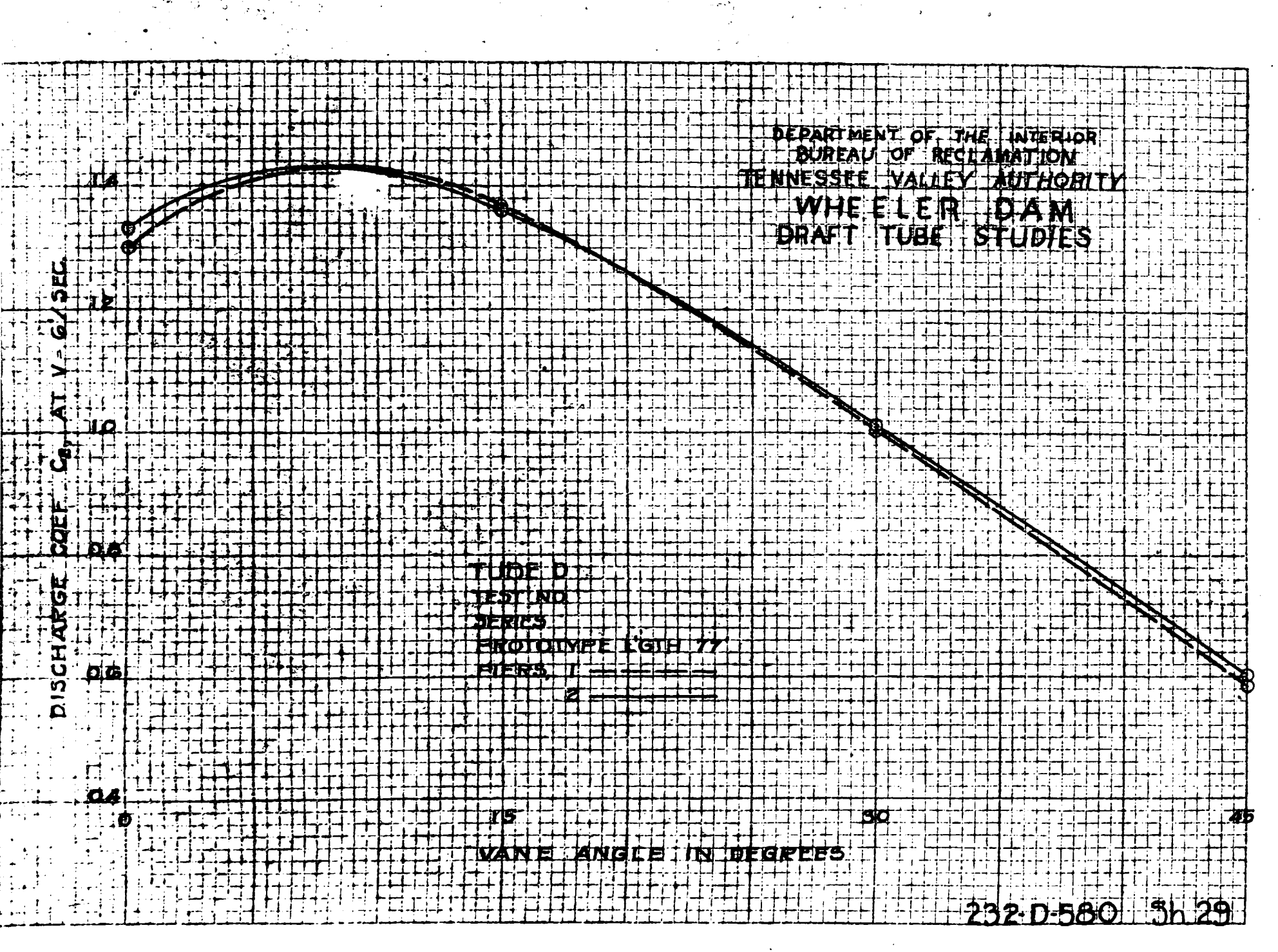
DISCHARGE COEF C_2 AT V= 6 FT/SEC

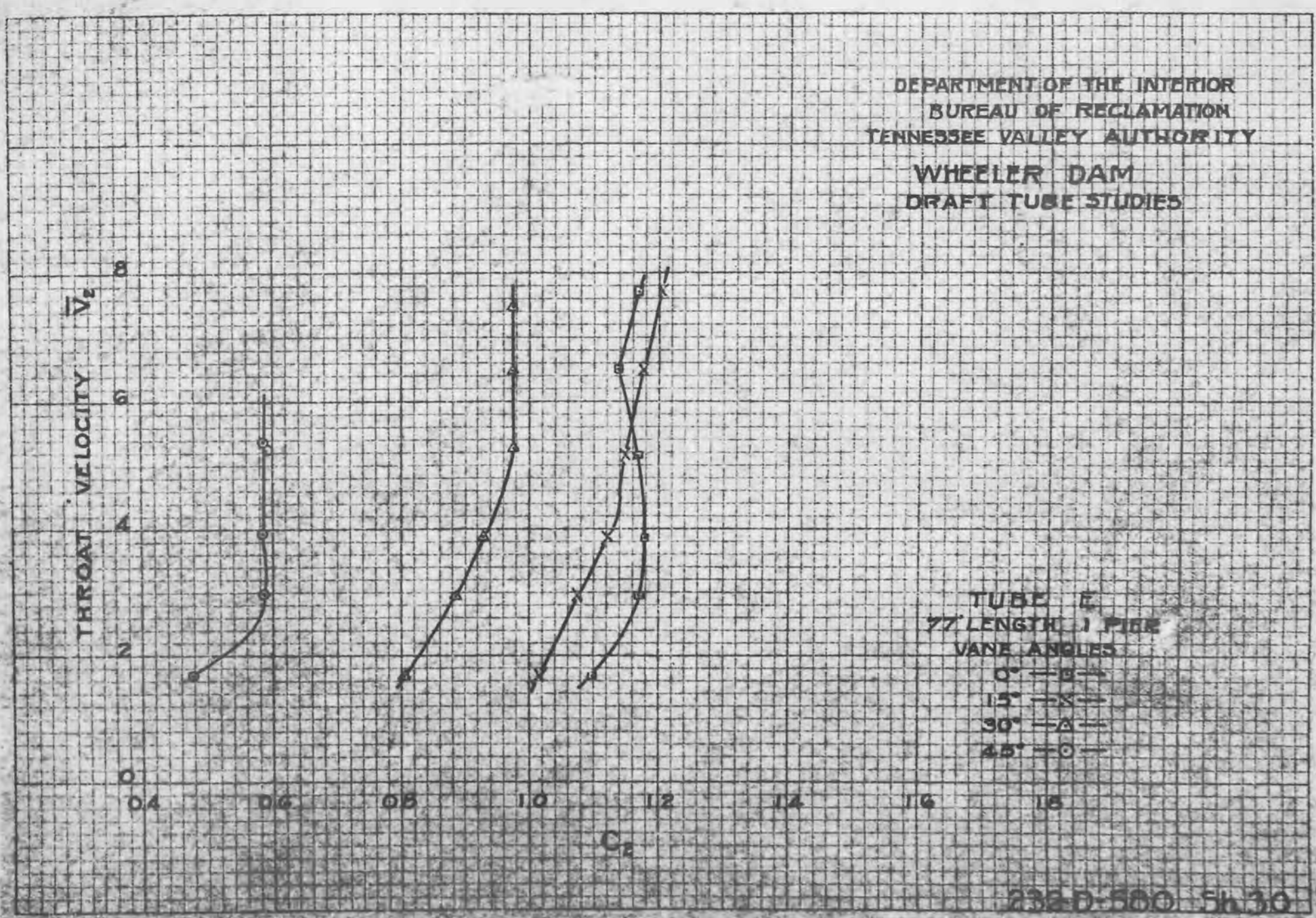


TUBE D-1
Length 77'
Test No. 147-152
Series BB

VANE ANGLE IN DEGREES

232-D-580 Sh 28


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DISCHARGE COEF $C_{Q'}$ AT $V = G'/SEC$
1.4
1.2
1.0
0.8
0.6
0.4
0
15
30
45
VANE ANGLE IN DEGREES
TUBE D
TEST NO.
SERIES
PROTOTYPE LENGTH 77'
PIERS, 1
2
232-D-580 Sh 29

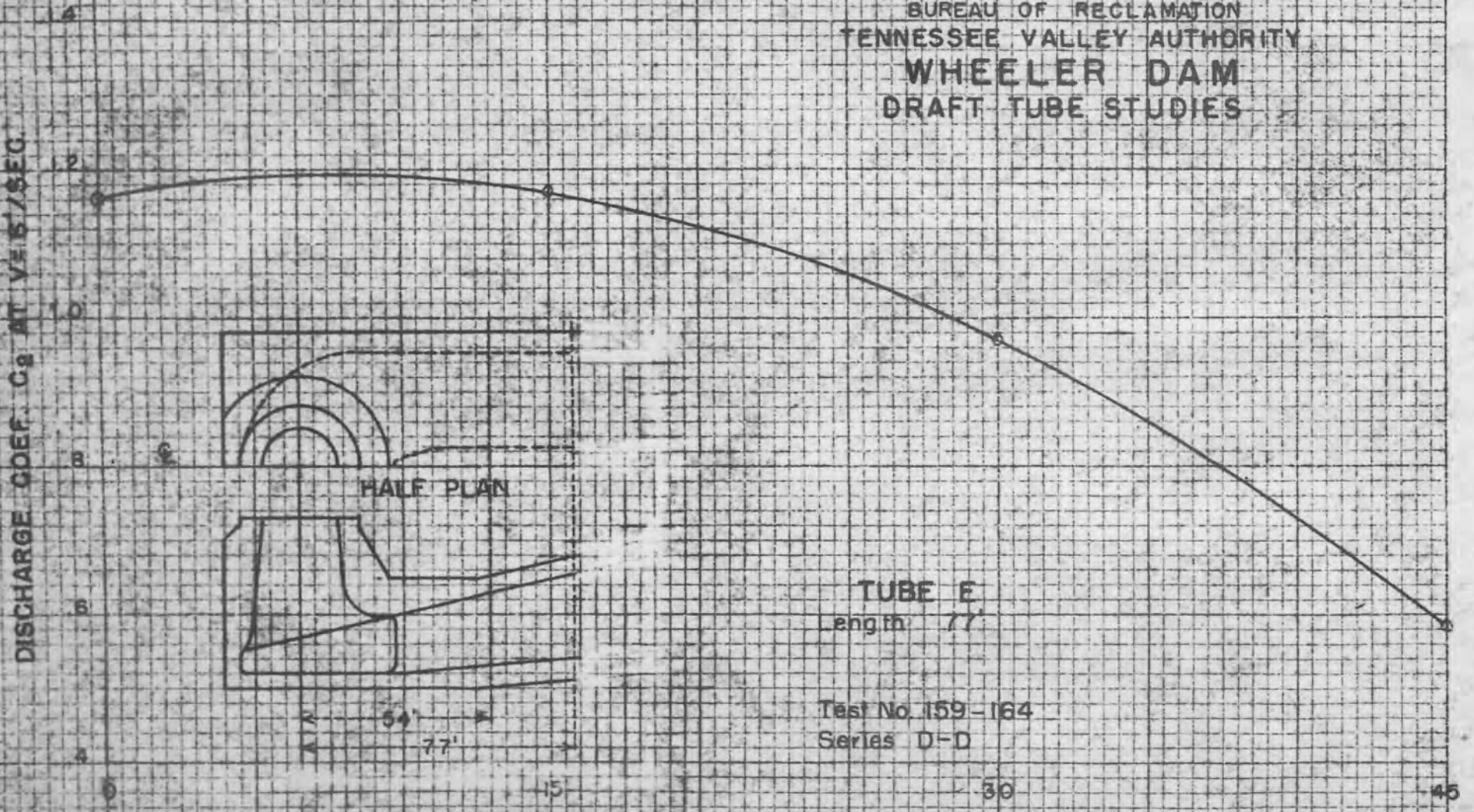

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
8
6
4
2
0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
C_2
TUBE E
77' LENGTH, 1 PIER
VANE ANGLES
0° —□—
15° —X—
30° —△—
45° —○—
233-D-500 Sh 30

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

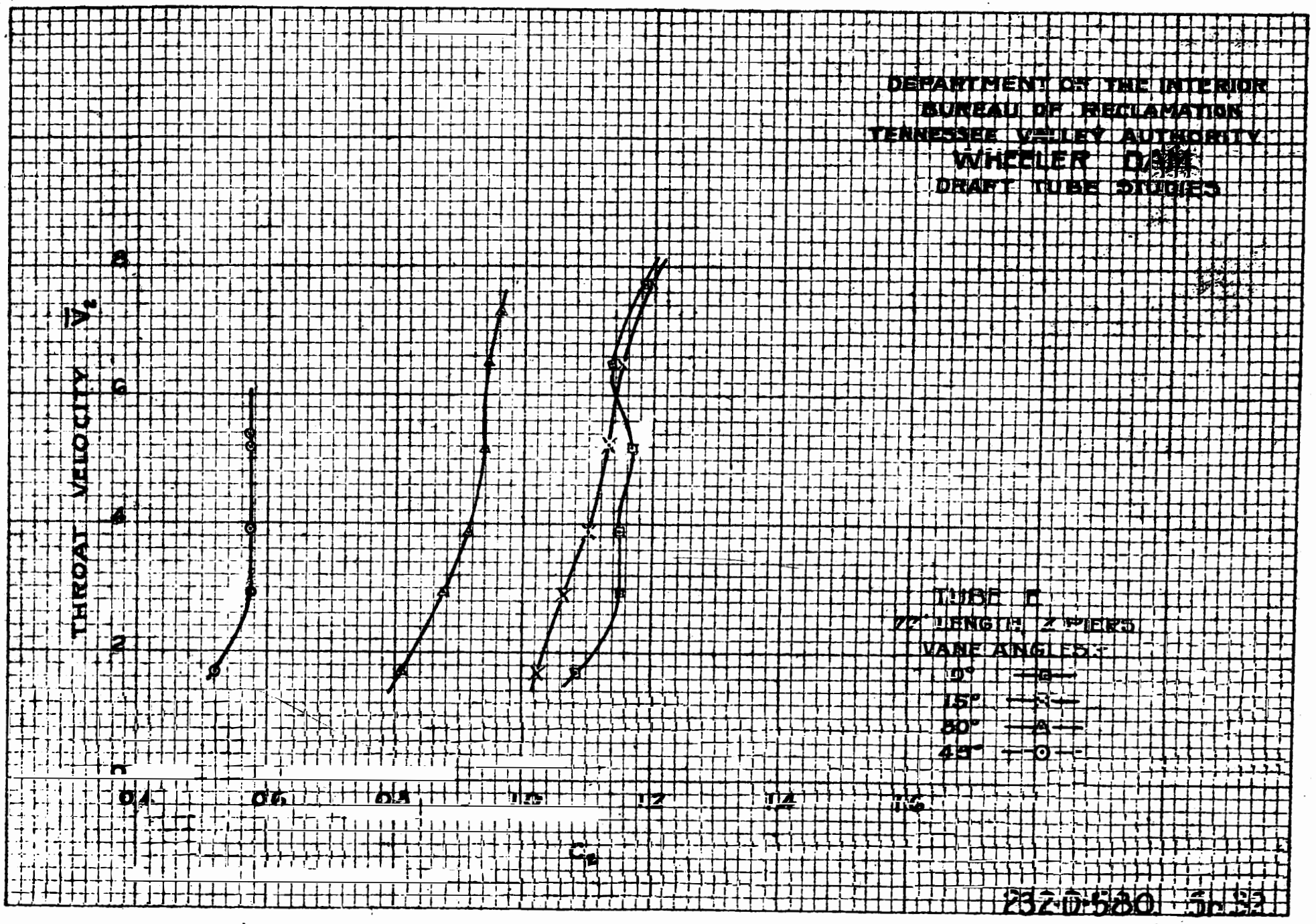
WHEELER DAM
DRAFT TUBE STUDIES

TUBE E
Length 77'

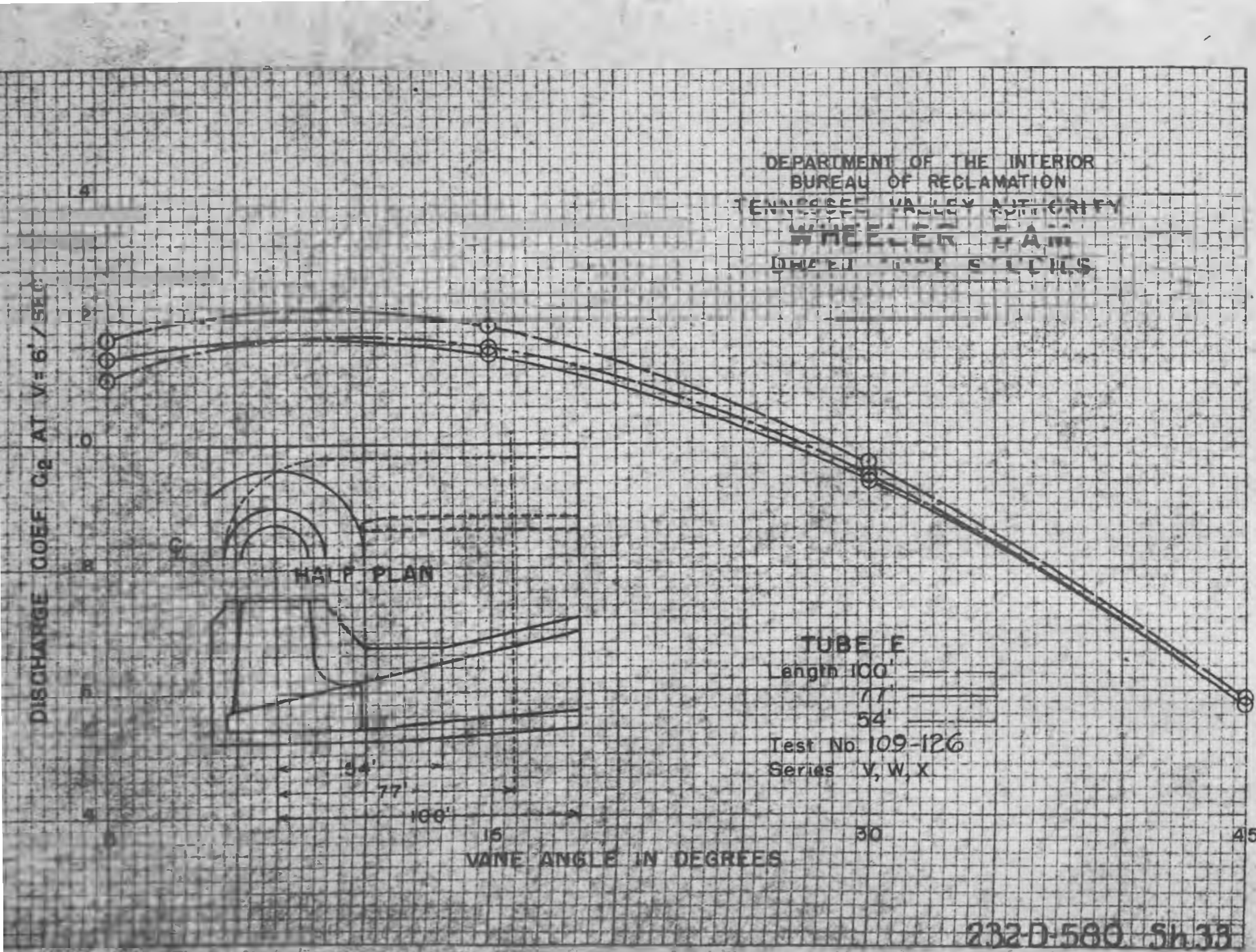
Test No. 159-164
Series D-D



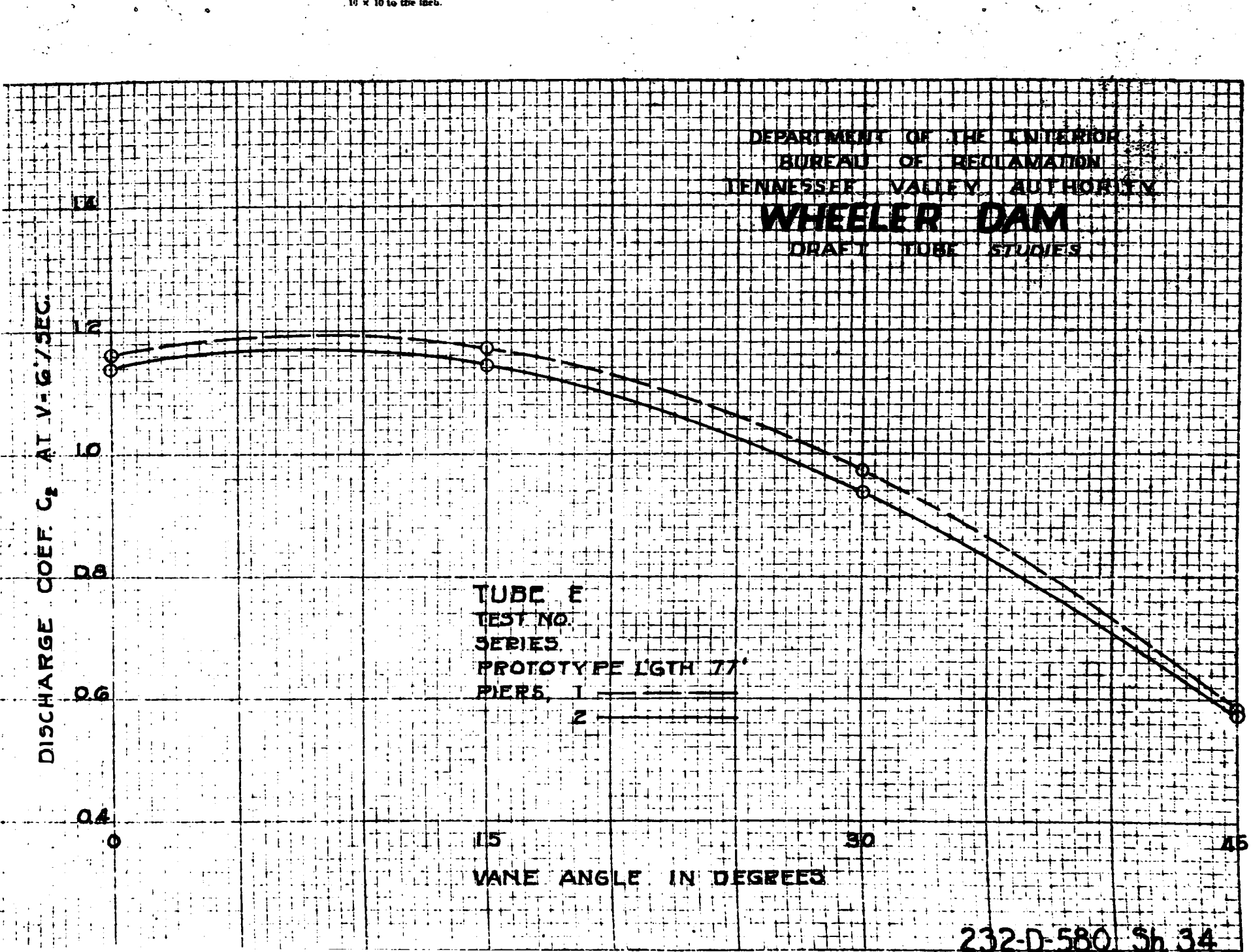
232-D-580 Sh 31


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
THROAT VELOCITY $\bar{V}_2$
8
6
4
2
0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
C_2
TUBE E
77' LENGTH, 2 PIERS
VANE ANGLES:
0°
15°
30°
45°
232-D-580

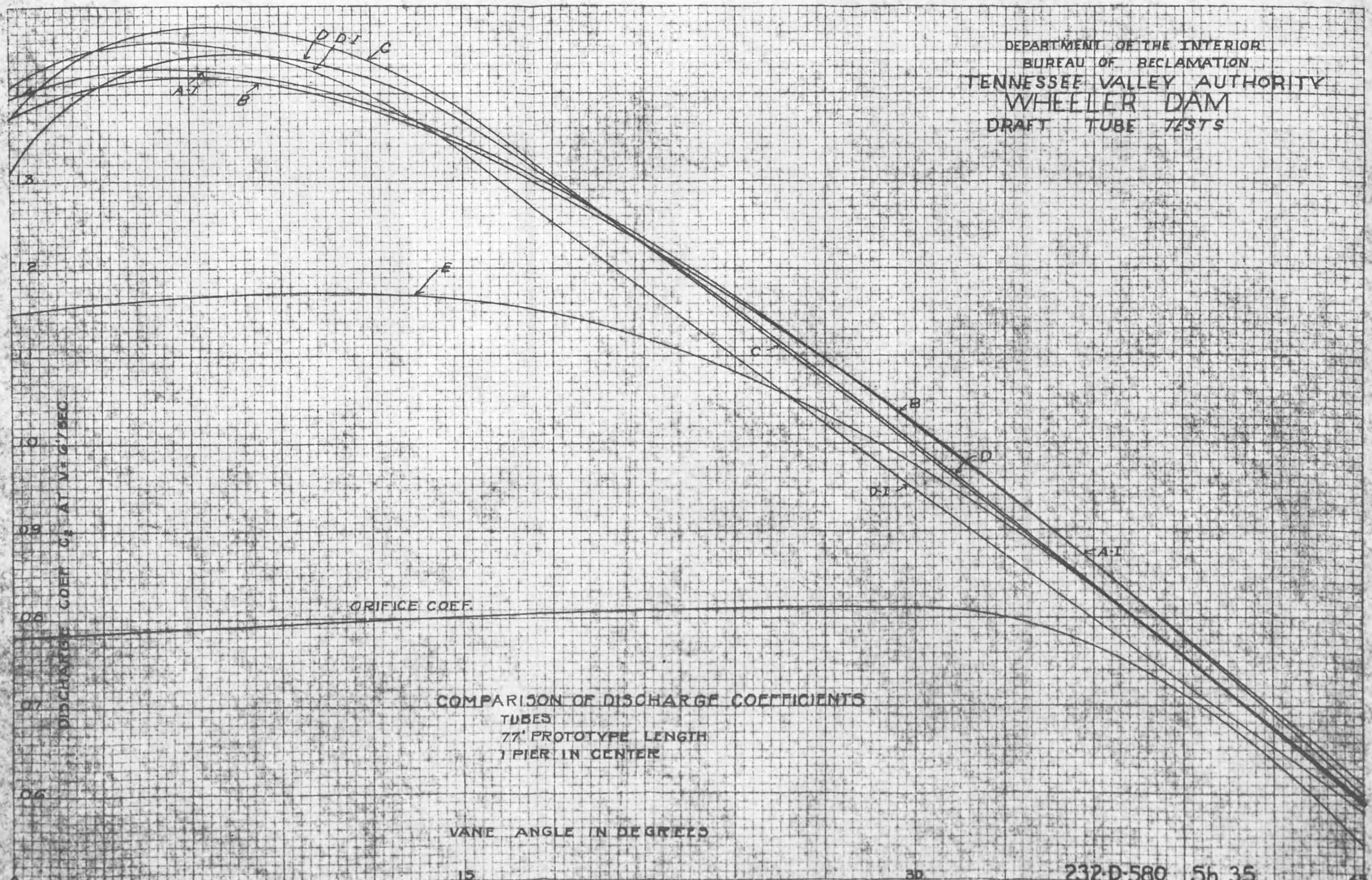
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE FLOWS



232-D-580 Sh 38


DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DISCHARGE COEF. C_2 AT V = 6.7 SEC.
1.4
1.2
1.0
0.8
0.6
0.4
0
15
30
45
VANE ANGLE IN DEGREES
TUBE E
TEST NO.
SERIES
PROTOTYPE LGTH 77'
PIERS, 1
2
232-D-580 Sh 34

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE TESTS

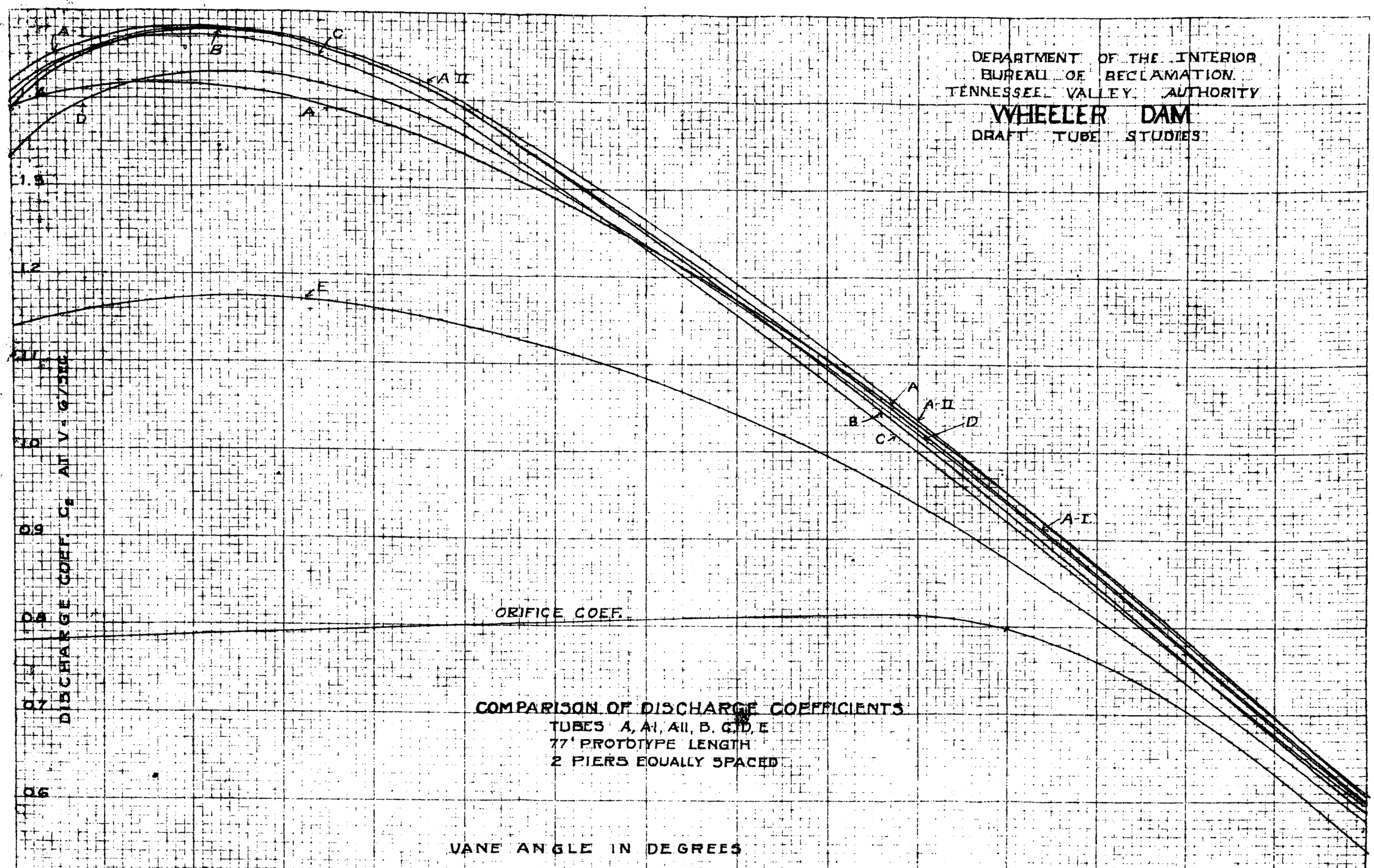


COMPARISON OF DISCHARGE COEFFICIENTS
TUBES
77' PROTOTYPE LENGTH
1 PIER IN CENTER

232-D-580 Sh 35

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES



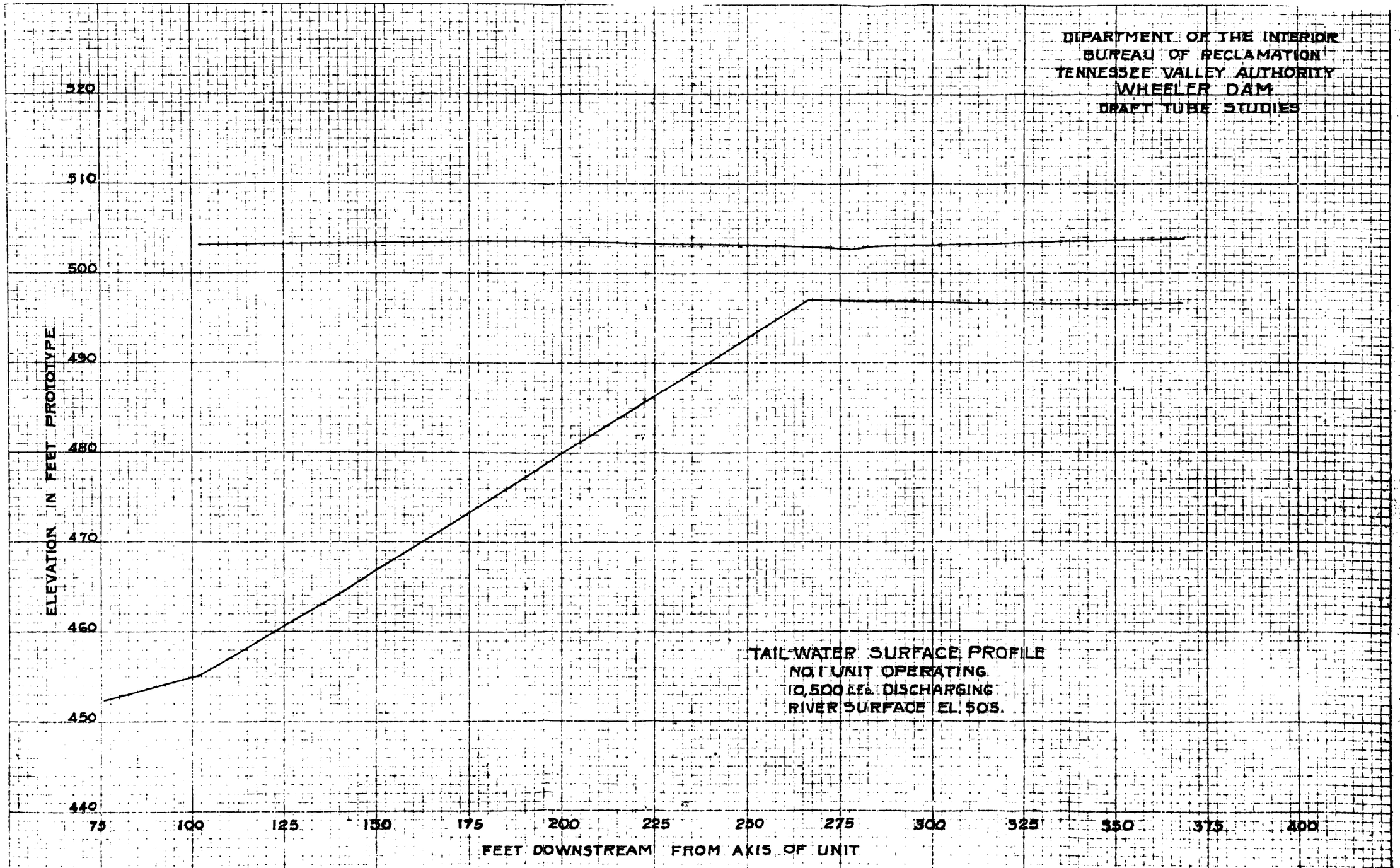
COMPARISON OF DISCHARGE COEFFICIENTS
TUBES A, A-I, A-II, B, C, D, E
77' PROTOTYPE LENGTH
2 PIERS EQUALLY SPACED

VANE ANGLE IN DEGREES

232-D-580 Sh 36

KEUFFEL & ESSER CO., N. Y. NO. 365-61
10 X 10 to the inch

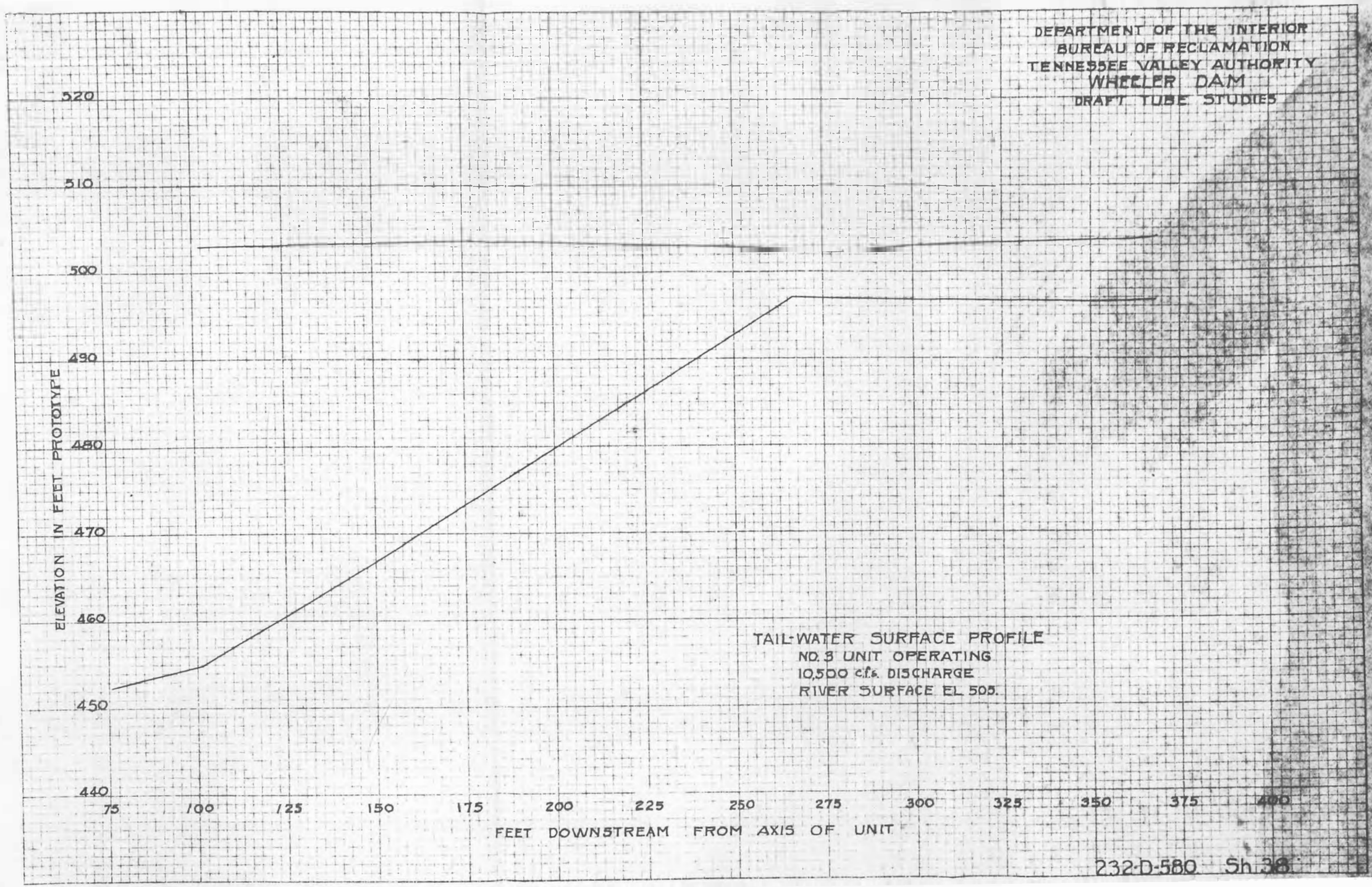
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES



TAIL-WATER SURFACE PROFILE
NO. 1 UNIT OPERATING.
10,500 c.f.s. DISCHARGING
RIVER SURFACE EL. 505.

232-D-580 Sh 37

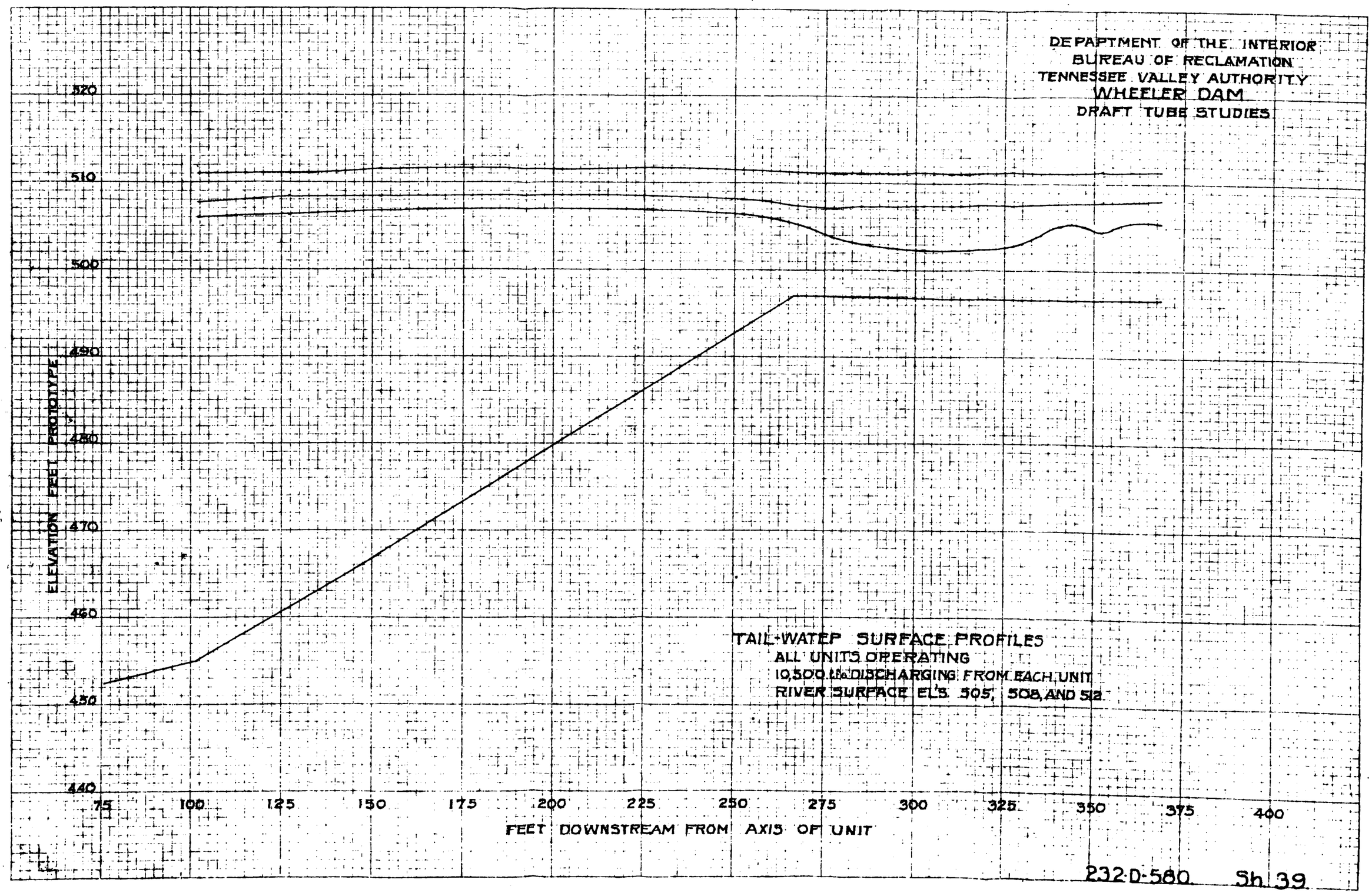
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES



TAIL-WATER SURFACE PROFILE
NO. 3 UNIT OPERATING
10,500 c.f.s. DISCHARGE
RIVER SURFACE EL. 505.

232-D-580 Sh. 38

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES



TAIL-WATER SURFACE PROFILES
ALL UNITS OPERATING
10,500 c.f.s. DISCHARGING FROM EACH UNIT
RIVER SURFACE EL'S. 505', 508, AND 512

232-D-580 Sh 39

KEUFFEL & ESSER CO., N.Y. NO. 359-51
10 X 10 to the inch

APPENDIX A

MEMORANDUM ON METHOD OF COMPUTATION OF DRAFT-TUBE EFFICIENCIES

by

V. L. Streeter, Junior Engineer

This memorandum is a discussion of draft-tube-efficiency formulas. The quantities necessary to be measured in order to obtain a correct efficiency formula are discussed. As it was impractical to get all the data required to obtain the actual efficiency, only those data were procured which would aid in obtaining relative efficiencies. The relative efficiency of two draft tubes for the same discharge and vane angle may be obtained, however, by a comparison of the heads required to produce the given discharge.

In the draft-tube-model tests for Wheeler Dam the difference in elevation of headwater and tailwater is recorded for certain discharges and vane angles without a draft tube attached to the downstream side of the orifice.

The efficiency of a draft tube is defined as the ratio

$$\frac{\text{kinetic energy converted into pressure energy}}{\text{kinetic energy available at draft-tube entrance}}$$

or

$$\frac{\text{work done by the draft tube}}{\text{energy available to do work}}$$

Two methods of deriving the efficiency formula are given. The first derivation will be similar to that used in deriving the efficiency formula for the draft-tube-model tests made by Mr. I. A.

Winter at the Alabama Power Company Hydraulic Laboratory during the summer of 1924. The formula, with the exception of the velocity distribution factors, was derived by Mr. S. H. Woodard, a consultant for the Alabama Power Company. The second derivation was worked out from suggestions made by Prof. S. M. Woodward, consultant for TVA, at Denver July 25, 1934.

NOTATION

Q_2 = volume discharged by orifice in unit time

A = cross-sectional area of throat of orifice

$\overline{V}_2$ = Q_2/A = average axial velocity at throat

C_1 = a coefficient for the orifice, vanes, etc., without the draft tube attached, which varies for different vane angles and discharges

C_2 = a coefficient for the orifice and draft tube, which varies for different vane angles, discharges, and draft tubes

h = head required for discharge Q_2 through setup without draft tube attached

h_1 = head required for discharge Q_2 through setup with draft tube attached

R = hydraulic radius

K.E. = kinetic energy

w = unit weight of water

g = gravity

V_a = axial velocity at variable distance r from center of orifice

V_t = tangential velocity at variable distance r from center of orifice

V_r = radial velocity at variable distance r from center of orifice

α = velocity distribution coefficient for the orifice with draft tube attached

α_1 = velocity distribution coefficient for the orifice without draft tube attached

α_3 = velocity distribution coefficient for downstream end of draft tube

W = work done in unit time

e = efficiency

$\overline{V}_3$ = average axial velocity at exit of draft tube

E_{1-2} = loss due to friction between headwater surface and orifice

E_{2-3} = loss due to friction in draft tube

E' = loss due to friction from orifice to tailwater surface without draft tube attached

E'' = loss from exit of draft tube to tailwater surface

FIRST METHOD

This method consists of measuring and comparing the head required for a given discharge through the vanes, orifice, etc. with and without the draft-tube model attached. Conditions of discharge and rotating motion of water, are made to vary, but the comparison is always the head with and without the draft tube attached under the same conditions of discharge and angular rotation.

With the notation as given on pages 2 and 3,

$$Q_2 = A\overline{V}_2 = C_1 A \sqrt{2gh} \qquad (1)$$

$$Q_2 = A\overline{V}_2 = C_2 A \sqrt{2gh_1} \qquad (2)$$

Equation (1) gives the relation of head to discharge for the orifice without the draft tube attached. Equation (2) gives the relation of

head to produce the same discharge with the draft tube installed. With conditions of set-up the same, h_1 will always be less than h. The difference $h-h_1$ is the head induced by the draft of the draft tube. The draft head, $h - h_1$, is obtained by converting kinetic energy of the flowing water into work. The kinetic energy in the water passing the orifice in unit time is

$$\text{K.E.} = \pi \frac{w}{g} \int_0^{r'} V_a(V_a^2 + V_t^2 + V_r^2)\, dr$$

where r' indicates the radius of the orifice opening. The expression for total kinetic energy may be written

$$\text{K.E.} = \alpha \tfrac{1}{2} \frac{w}{g} A \overline{V}_2^3 ,$$

where α is a coefficient greater than unity.

The work done upon the quantity, $Q_2 = A\overline{V}_2$, in increasing the head from h_1 to h is

$$W = wQ_2(h-h_1)$$

and the efficiency of the draft tube is

$$e = \frac{W}{\text{K.E.}} ,$$

or the ratio between the work done and the energy available for doing that work.

$$e = \frac{W}{\text{K.E.}} = \frac{wQ_2(h - h_1)}{\alpha \tfrac{1}{2} \frac{w}{g} A\overline{V}_2^3} = \frac{h - h_1}{\alpha \frac{1}{2} \frac{\overline{V}_2^2}{g}} \qquad (3)$$

Eliminating h and h_1 between Equations (1), (2), and (3) results in the formula

$$e = \frac{1}{\alpha} \left(\frac{1}{C_1^2} - \frac{1}{C_2^2}\right)$$

C_1 and C_2 are obtained from the test data. α, the velocity distribution coefficient, would require a velocity traverse over the orifice area for the three components of the velocity.

SECOND METHOD

The kinetic energy converted into pressure energy in the draft tube must equal the total kinetic energy available at the draft tube entrance minus the energy lost due to friction in the draft tube and the kinetic energy lost at the exit of the tube, or

$$A_w\bar{V}_2\left(\alpha_2\frac{\bar{V}_2^2}{2g} - \alpha_3\frac{\bar{V}_3^2}{2g} - E_{2-3}\right). \qquad (4)$$

The head on the draft tube, h_1, is utilized in overcoming friction and in building up the exit velocity head, or

$$h_1 = E_{1-2} + E_{2-3} + \alpha_3\frac{\bar{V}_3^2}{2g} \qquad (5)$$

Substituting (5) in (4)

$$A_w\bar{V}_2\left(\alpha_2\frac{\bar{V}_2^2}{2g} + E_{1-2} - h_1\right)$$

As the kinetic energy available at the orifice is

$$\alpha_2\frac{\bar{V}_2^2}{2g}A_w\bar{V}_2$$

the efficiency is

$$e = \frac{A_w\bar{V}_2\left(\alpha_2\frac{\bar{V}_2^2}{2g} + E_{1-2} - h_1\right)}{A_w\bar{V}_2\,\alpha_2\frac{\bar{V}_2^2}{2g}}$$

or

$$e = \frac{\alpha \frac{\overline{V}_2^2}{2g} + E_{1-2} - h_1}{\alpha \frac{\overline{V}_2^2}{2g}} \qquad (6)$$

For a given discharge and vane angle, α, $\overline{V}_2$, and E_{1-2} are constant regardless of the draft tube used. Hence the formula may be written

$$e = \frac{B' - h_1}{B}$$

where B' and B are constants. This formula holds only for a comparison of two draft tubes at the same vane angle and discharge, provided the values of the constants B' and B are known.

COMPARISON OF THE TWO METHODS

Examining the two efficiency Equations, (3) and (6), it is evident that they are identical if

$$h - h_1 = \alpha \frac{\overline{V}_2^2}{2g} + E_{1-2} - h_1$$

or

$$h = \alpha \frac{\overline{V}_2^2}{2g} + E_{1-2}.$$

which states that the head, h, on the orifice without a draft tube attached is completely utilized in overcoming friction from the headwater to the orifice, and in building up the kinetic energy available at the orifice. It also implies the assumption that $\alpha = \alpha_1$. In other words, to obtain the coefficient C_1 the orifice should discharge into a large reservoir in such a manner that no additional losses occur due to friction between the orifice and the tailwater surface. As this is not the case for the Wheeler draft-tube-model tests C_1 will

have too small a value.

ESTIMATE OF THE VALUE OF α

Without the draft tube attached

$$h = \alpha_1 \frac{\overline{V}_2^2}{2g} + E_{1-2} + E'$$

with the draft tube attached

$$h_1 = \alpha_3 \frac{\overline{V}_3^2}{2g} + E_{1-2} + E_{2-3} + E''$$

subtracting the second from the first

$$h - h_1 = \alpha_1 \frac{\overline{V}_2^2}{2g} - \alpha_3 \frac{\overline{V}_3^2}{2g} - E_{2-3} + E' - E'' \qquad (7)$$

for an average throat velocity of 6 ft. per sec., $\overline{V}_2$ and $\overline{V}_3$ are known E_{2-3} may be estimated from the Darcy formula,

$$h_f = \frac{fLv^2}{d2g} ,$$

by substituting 4R for d, the diameter. A mean value of f, the friction factor, for the draft-tube surface is estimated. Then for sections throughout the draft tube, the quantity $\frac{fv^2}{8Rg}$ is plotted as ordinate against L, the distance of the section from the entrance measured along the centerline of the tube, as abscissa. The area under this curve is an estimate of the loss due to friction in the draft tube. As flow conditions are very irregular within the tube, this may safely be taken as the minimum loss due to friction for the given velocity. Equation (7) may be written in the form

$$\alpha_1 = \frac{h - h_1 + \alpha_3 \frac{\overline{V}_3^2}{2g} + E_{2-3} + E'' - E'}{\frac{\overline{V}_2^2}{2g}}$$

The difference, $h - h_1$, is obtained from the tests. For a certain Q, $\overline{V}_2$ and $\overline{V}_3$ are known. E_{2-3} may be estimated from Darcy's Formula. $E'' - E'$ will be neglected. Assume that α_3 equals 1, its minimum value. From this Equation a value of α_1 may be obtained which is reasonably sure to be a minimum. As $E'' - E'$ is negative, although undoubtedly small, it cannot be stated that α_1 has its absolute minimum value. Making the assumption that $\alpha_1 = \alpha$ for the same conditions of discharge and vane angle, a minimum value of α may be estimated. This value of will result in a maximum value of $1/\eta$. As C_1 is also too small, a maximum value of efficiency will be estimated. E_{2-3} has been computed for tube B, 100 ft. length (prototype), and amounts to 0.162 ft. (model) loss for an average throat velocity of 6 ft. per sec. model. This results in a value of α of 1.52 as a minimum for the vane angle 0°. For the 15° vane angle, α amounts to 1.45 as a minimum. For the vane angles of 30° and 45° this method gives no additional information, as the value comes out less than 1.0 which is impossible. From the draft-tube-model tests the maximum value of the efficiency would be about 76% for tube B, 2 piers, 100 ft. length (prototype), while it is probable that the efficiency is considerably lower.

CONCLUSION

The velocity distribution coefficient, α_3, might have values as high as 10. With vane angles of 30° and 45°, the water frequently has a very poor distribution at the exit of the draft tube. With a draft tube with two piers, if the water were to come out of one opening only, α_3 would be at least 9.

As the factors α, α_1, α_3, C_1, E_{1-2}, and E_{2-3} cannot be accurately determined from the available experimental data it is impossible to obtain the actual efficiencies. The time and expense involved in measuring velocity distribution coefficients prohibit their determination for these tests. To obtain α, it would be necessary to make a velocity traverse over the orifice area for the three components of the velocity with the draft tube in place. The velocity distribution coefficient, α_1, would also have to be determined by the same method as the determination of α. The experimental equipment would have to be altered, however, so that the orifice would discharge into a large reservoir before α_1 could be measured. If the time and expense were taken to obtain α, α_1, C_1, etc., the actual efficiencies of the draft-tube models with vanes above them would be determined. As the prototype draft tubes have runners above them, it would be impossible to predict their correct efficiencies because of the lack of similitude above the orifice. At best comparative efficiencies would be given for the prototype. Comparative efficiencies can be obtained from the C_2 coefficients, thus eliminating the necessity of determining α, α_1, C_1, etc.

The C_2 coefficients allow a comparison of two draft tubes for the same discharge and vane angle. By this comparison one tube may be selected as better than another, but a quantitative result cannot be obtained.