UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

TENNESSEE VALLEY AUTHORITY

WHEELER DAM

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MEMORANDUM TO THE CHIEF DESIGNING ENGINEER

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

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Under Direction of

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## 1. Introduction.

Wheeler Dam, a project of the Tennessee Valley Authority, is located on the Tennessee River about fifteen miles eastward and upstream from Wilson Dam in Alabama. The power plant is at the south end of the dam and the draft tubes discharge into the headwaters of the pool formed by Wilson Dam. This report deals with a study of the performance of the draft tubes and on the tail water conditions in the vicinity of the power plant.

Because of the enormous size of the units in this installation, it was desirable to use a draft tube design which would be efficient and at the same time be relatively inexpensive to install. The elbow type, having these qualities, as evidenced by recent practice, was favored for Wheeler Power Plant. In order to further reduce the installation cost for this design it was proposed to shorten the vertical section by reducing the length of the conical section immediately beneath the runner. A seemingly insignificant change in the shape of a draft tube may have far-reaching effects upon its performance. It was therefore decided to make a series of comparative tests on models of various draft tube designs in the laboratory in order to ascertain as nearly as possible what results might be expected from the proposed alterations.

In the short period from the time these tests were decided upon until pouring of concrete in the power house substructure was to begin it was impossible to conduct a series of highly refined tests, but the results obtained are consistent and reasonably accurate.

The tests were authorized by the Tennessee Valley Authority and were executed by the U. S. Bureau of Reclamation in its hydraulic laboratory located in the basement of the old customhouse at Arapahoe and Sixteenth Streets, Denver, Colorado.

The work was carried on under the supervision of E. W. Lane, Research Engineer, and under the direction of J. L. Savage, Chief Designing Engineer. It is also desired to acknowledge the valuable suggestions furnished by I. A. Winter of the Electrical Department and the splendid cooperation of the hydraulic laboratory staff.

## 2. 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 $22\frac{1}{2}$ feet, and as the ratio of discharge diameter to depth of draft tube is usually from 1:2.2 to 1:2.5, the problem of excavation for draft tubes in the case of Wheeler Power Plant was a serious one. Besides, it was proposed to use propeller or Kaplan-type runners, which discharge the water at high velocities, leaving much work to be done by the draft tube.

Available data on draft tube tests indicate 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. Just how long a draft tube should be then, involves the question of economic balance, the data for which can be obtained only through model experimentation.

In order 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 making this change, it was thought desirable to investigate the limits of this slope.

As the efficiency of energy regain from the high velocity at the runner discharge was the criterion for the draft tube tests, it was necessary to test the various types of tubes under different conditions for efficiency and performance. Among the draft tube designs submitted for Wheeler Power Plant, some show one pier and some show two piers in the horizontal section. It is entirely possible that one pier may work more satisfactorily in a given design, while two piers may give decidedly better results in another design. It was therefore thought advisable to make a comparison of the two conditions in this series of tests.

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 tailrace at a much slower 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 the most economical length for the horizontal section of the 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.

## 3. 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 simulating the downstream face of the power house, the tailrace excavation and a part of the river bed some distance downstream from the power house. The space available permitted the use of a flume to represent the river bed and a tailrace model built to a scale of 1:50. The draft tube models were, of course, built to the same scale.

The water discharging from the draft tubes will be confined on the left side of the tailrace by a retaining wall built along the left bank of the river but will not be confined on the right side. This permits the water to spread toward 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. The upstream edge of the weir was hinged to the model of the river bed while the lower edge could be 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 test flume is shown in detail in fig. 1.

The water spilling over the adjustable weir was trained into a measuring weir box of the usual type with a 90° V-notch weir. The head on the weir 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.

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. Details of orifice and deflector vanes are shown in fig. 2.

The water discharging through the expanding nozzle into the stilling box created very little disturbance. The turbulence was further reduced by baffles constructed of rough-sawed boards three-eighths of an inch thick and four inches wide spaced three-quarters of an inch on centers. This produced very satisfactory flow conditions in the head bay as the water approached the orifice.

The head-gage piezometers were installed as shown in fig. 1, 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 slope of the tail race excavation 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.

4. Models Tested.

Five basic draft tube designs were included in the original schedule of model tests, and one other design was authorized just about the time that the original schedule was completed. These draft tube models were designated as tube A, tube B, tube C, etc. Roman numerals following letters indicate alterations in the basic design as tube A-I, etc. Model tube A was designed by the Bureau of Reclamation, model tubes B and F were submitted by the Tennessee Valley Authority and model tubes C, D, and E are from designs frequently used for water turbines in hydro-electric power plants.

Draft tube model A, with alterations, is shown in fig. 3. 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. This was done for the 100-foot prototype length as well as for the 77-foot length.

Tube A-II was the same as tube A except that the roof was curved upward from the point of tangency at the downstream end of the elbow, 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 A-III was the same as tube A except that a splitter was introduced into the horizontal section as shown in fig. 16.

Draft tube model B is shown in fig. 17. This tube was designed by the Tennessee Valley Authority and differs from tube A principally in that thr horizontal section has a steeper upward slope and the areas are slightly less than corresponding areas in tube A. It will be seen that the area curve is a straight line throughout the greater part of the elbow. The performance of this tube is shown in fig. 18 to fig. 22 inclusive.

Draft tube model C is shown in fig. 23. This tube is similar in most respects to tube A. The greatest difference is that the height at the downstream end of the elbow is much less than that in tube A, thus restricting the area at this point. This is shown in the area curve.

Draft tube model D is shown in fig. 29. This tube is also similar in most respects to the tubes described. The principal difference being that the height at the downstream end of the elbow is greater than that in tube A. This is clearly shown in the area curve.

Tube D-I was the same as tube D except that a splitter was introduced in the elbow in a manner similar to European practice. This is also shown in fig. 29.

Draft tube model E is shown in fig. 37. This design is radically different from any of the others tested. It consists of a vertical barrel and a horizontal section with an easy transition from one to the other in which sort of hydraucone action is supposed to take place.

Draft tube model F is shown in Fig. 43. The elbow section of this tube is identical with tube B. The horizontal section is similar except that it has a much steeper slope than any of the other models tested.

All draft-tube models were made of wood to facilitate construction and to make alterations easier. The elbow sections were split in avertical plane through the transverse center line 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. This is shown in figs. 3 and 14.

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 checkruns made to ascertain the true performacne of the models. Plasticene modeling clay was placed in the joints as the sections were assembled to keep water from flowing through the wood joints.

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, all connected together to give an average value, was placed along the extended centerline of the draft tube model on the slope representing the tailrace excavation. Another row was placed in like position on the center line of an adjacent unit. As both gave the same results, the one placed along the centerline of the operating unit was used in those tests. This row of piezometers was connected to a tailwater hook-gage pot mounted upon a swinging bracket with the head water hook-gage pot as previously described. The latter was connected to piezometers located one on each side of the head bay just below the stilling racks as previously described. This arrangement is shown in fig. 1.

5. Procedure.

In order to determine the amount of work being done by the draft tube models, it was necessary to measure the head between the forebay and the tailwater levels, and the quantity of water flowing. The difference between the water levels in the head-gage pot and the tail-gage pot was taken as the operating head on the models. In order to be sure of accurate results, the head was measured with a micrometer hook-gage reading to thousandths of an inch.

The head over the measuring weir was determined by means of an ordingary hook-gage reading in hundreths 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 the head-water level and then five readings on the tail-water level were taken. The difference between these averages was the head used. 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 and spaced along the river bed model as indicated in fig. I, were connected each to a manometer tube. These tubes were mounted together on a graduated manometer board. The height of the tail 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, it seemed best to compare their absolute efficiencies. Methods of arriving at the efficiencies of draft tubes were investigated. These methods, or formulae, indicated in their derivation that certain data, which would not be practicable to obtain in the original set-up and with the time available, would be required to compute the absolute efficiencies of draft tubes. The formulae referred to are fully discussed in appendix A of 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 in fig. 2, 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 were 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 throat velocities ranging from about 2 feet per second to 7.5 feet per second on the model. The normal model velocity was 4 feet per second to correspond to the normal velocity of 27 feet per second in prototype.

A throat velocity --- $C_2$ curve was plotted for each vane angle for each draft tube tested. As it is generally conceded that ($C_2$), and 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 from the draft tubes for angles of discharge ranging from 0° whirl up to 45°.

Calculations were made and curves plotted showing a comparison of discharge coefficients for each draft tube model tested at 54-foot, 77-foot, and 100-foot lengths, using one and two piers, insofar as it was considered advisable to test all three lengths. A comparison of the performance of all draft tube models tested with two piers at 77-foot length, except tube F, is shown in fig. 49; and a comparison of all draft tube models tested with one pier at the 77-foot length is shown in fig. 50.

At the discharge end of tube B using the 77-foot length, the outflow passages were raised four feet. This made it possible to reduce the necessary tailrace excavation by this amount. The floor representing the tailrace excavation in the model was raised correspondingly for the test and this should be considered in evaluating the merits of this draft tube. The floor was not raised in the case of tube F.

6. Performance of Models.

The performance of each model is represented graphically. First the discharge coefficient ($C_2$) was determined from the formula

$$C_2 = \frac{Q}{A\sqrt{2gh}}$$

where Q is the quantity of water flowing in c.f.s., A is the area of the draft tube throat in square feet, and h is the head on the model. The throat velocity was calculated from the formula

$$\overline{V_2} = \frac{Q}{A}$$

Values of $\overline{V_2}$ were plotted against values of $C_2$ for each whirl angle.

Taking a value of $\overline{V_2}$ at six feet per second, $C_2$ was plotted against angle of whirl in degrees. These curves were plotted for each model tested.

The performance of tube A is shown in figs. 4, 5, and 6; that of tube A-I in figs. 7 to 12, inclusive; that of tube A-II in figs. 13 and 14; and that of tube A-III in figs. 15 and 16.

The performance of tube B is shown in figs. 18 to 22, inclusive.

The performance of tube C is shown in figs. 24 to 28, inclusive.

The performance of tube D is shown in figs. 30 to 34, inclusive, and that of tube D-I is shown in figs. 35 and 36.

The performance of tube E is shown in figs. 38 to 42, inclusive.

The performance of tube F is shown in figs. 44 and 45, and that of tube F-I is shown in figs. 46 and 48.

7. Internal Pressure and Flow Conditions.

In draft tubes the size of those required for the Wheeler Power Plant, the stresses imposed by inside pressure conditions are considerable. Pressure tests were made on draft tube models A, F, and F-I. A row of piezometers was placed along the center line of the roof and one along the center line of the floor, both rows extending from the outlet back through the horizontal section and up to the throat. A row of piezometers was also placed in the roof of each of the side passages of the horizontal section.

Pressure readings were taken on each model operating at normal discharge of 10,500 c.f.s. and at $0^\circ$, $15^\circ$, $30^\circ$, and $45^\circ$ angles of whirl. The pressures recorded at $0^\circ$ and $15^\circ$ whirls were so nearly alike that only $0^\circ$, $30^\circ$, and $45^\circ$ angles were plotted.

The results for tube A are shown in fig. 51, those for tube F in fig. 52, and those for F-I in fig. 53. It is interesting to note the changes in pressure in the side passages as the angle of whirl increases.

Photographs of paint tests made on tube A-II are shown on Plates I and II. Where the velocities are sufficiently high, the flow lines etch themselves into the fresh paint. Where eddies occur, there is a piling up of the paint. Also, the point where the water fails to flow the surface of the passage wall is clearly indicated. In studying these paint tests it must be kept in mind that the flow lines indicate only the surface conditions and that the internal conditions may be entirely different.

8. Tailrace Flow Conditions.

In order to study flow conditions in the tailrace and on the river bed as the water leaves the tailrace excavation, profiles of the water surface were made. A point gage was so mounted that it could be moved to any point in the tailrace. By this means, profiles of the bottom of the model tailrace were taken opposite each of the three draft tube outlet passages. At the same time, profiles of the water surface were taken at the same positions. The averages of these profiles were plotted for each condition.

The first condition was with unit number one operating at the normal discharge of 10,500 c.f.s. with no restriction on the left bank. The river surface was at Elev. 505. The profile of the tailrace water surface for these conditions is shown in fig. 54. Fig. 55 shows the profile of the tailrace under same conditions except for a retaining wall extending straight downstream from the left side of the draft tube outlet. The profile of the tailrace water surface for unit number three, operating alone and discharging 10,500 c.f.s. with river surface at Elev. 505 is shown in fig. 56.

Tests were made to determine what the conditions would be with eight units operating at normal discharge and with the river surface at various elevations. Fig. 57 shows conditions with all units operating at normal discharge with river surface 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 tailrace that it is difficult to determine the velocities. From observations on the model and from the profile shown on fig. 56, 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 the normal discharge of 10,500 second feet each, and the river surface at Elev. 505.0, a distinct hydraulic jump occurs just below the edge of the tailrace 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 tailrace excavation and thus lowering the level of the water at the draft tube outlets.

It was suggested that the pond elevation at Wilson Dam be raised in order to increase the tailwater depth at Wheeler Dam. This would decrease the operating head at Wheeler while increasing it at Wilson. This relation is shown in fig. 58.

## 9. 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 the 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 a draft tube of this particular design was reached. Tube B and tube F are similar except for the slope of their horizontal sections. Tube B has a slope of about 13° while tube F slopes about 18°. The curves indicate that tube F is slightly off in performance when compared with tube B. This may indicate that the upper slope limit has been reached for this particular design of draft tube but it does not indicate that it has been greatly exceeded. It is believed that the permissible slope depends a great deal upon the design of the elbow section and that much may be gained by an investigation of this feature. In installations like Wheeler Dam, it seems possible that much excavation might be saved. Further tests along this line are to be made in connection with the Grand Coulee development.

It may be seen from the Coefficient-Throat Velocity Curves, that a very unstable condition developed when the throat velocity reached a value of approximately 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 which formed in the forebay and extended 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 $V_2$.

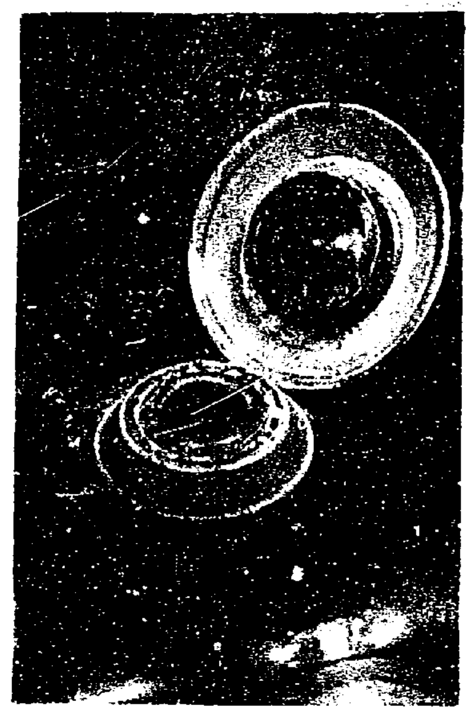
As tube A-I and tube B both showed a better performance with two piers, it was thought unnecessary to test tube A with one and two piers also. Tube C showed a better performance with one pier at a 15° vane angle but not as good at 0°. Tube D, while not as efficient, behaved in exactly the same manner. Tube E showed a consistent advantage of one pier over two for all vane angles.

After the water leaves the draft-tube outlet and the shock loss caused by the sudden change in velocity is sustained and accounted for, any other changes in velocity where the water is unconfined will not affect the head on the turbine. The head required to supply the energy for the hydraulic jump shown in figs. 55, 56, and 57 may be added to the gross operating head of the plant by excavating the river bed to a depth sufficient to keep the velocity less than that of critical flow as it leaves the tailrace excavation.

Taking the sum of the heads on Wheeler Dam and Wilson Dam into consideration it is seen that by raising the pool elevation of Wilson Dam within certain limits, while decreasing the head on Wheeler Dam a lesser amount, will increase the sum of the two heads. It may be seen from the curve in fig. 58 that little advantage is to be gained by raising the pond elevation of Wilson Dam more than four feet.

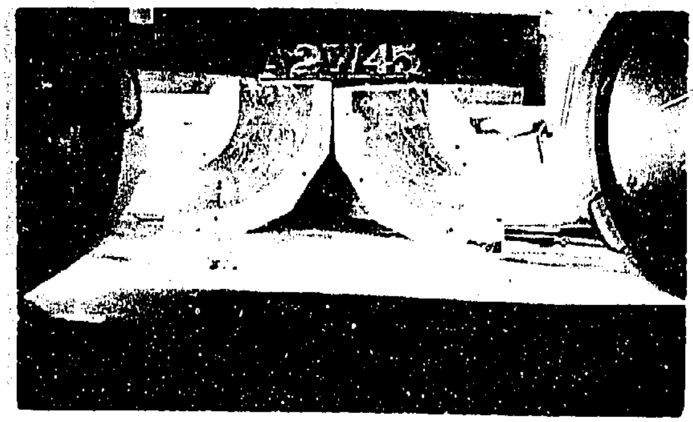

A. FLOW LINES AT OUTFLOW.
0° ANGLE.


B. FLOW LINES IN ELBOW AND FLOOR.
0° ANGLE.

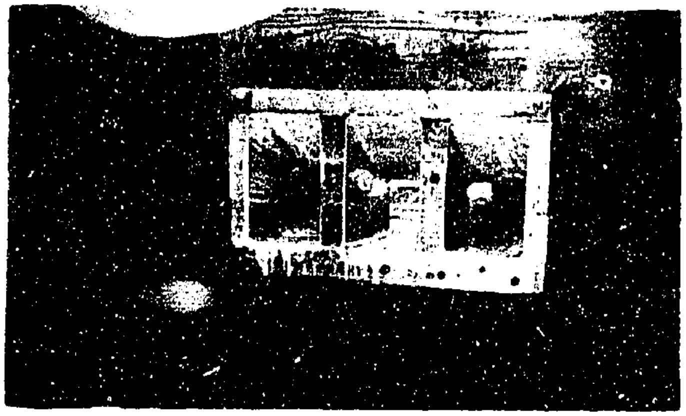


C. FLOW LINES IN ORIFICE, DEFLECTOR VANES AND HOOD.
30° ANGLE.

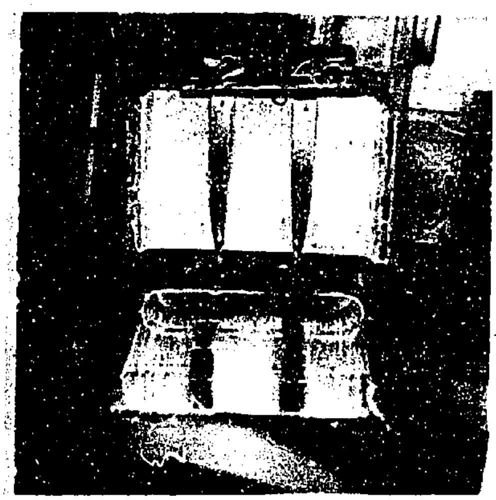
PAINT TEST ON DRAFT TUBE MODEL A-II
SHOWING DIRECTION OF FLOW.



A. FLOW LINES THROUGH ELBOW.
45° ANGLE.

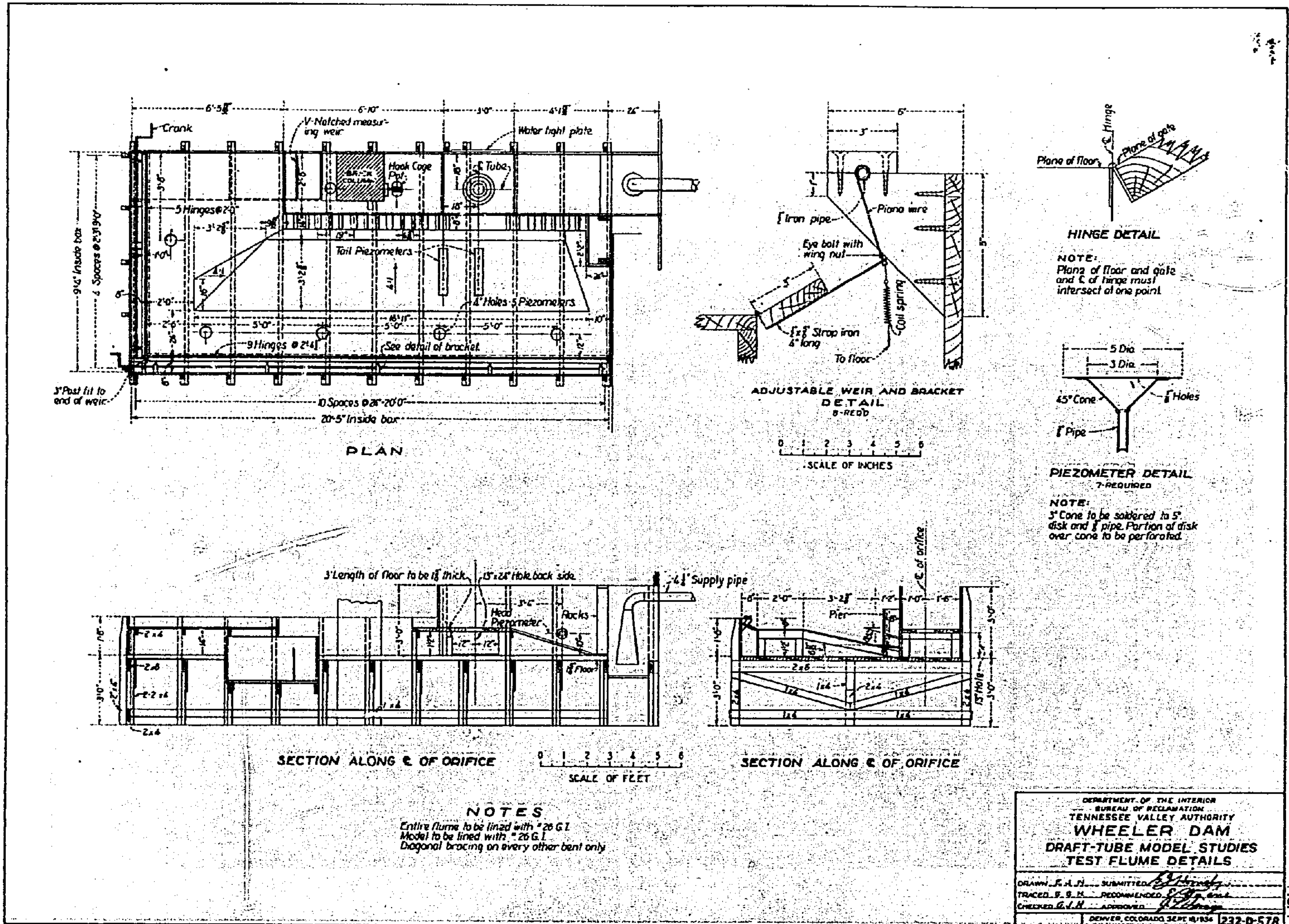


B. FLOW LINES AT OUTFLOW.
45° ANGLE.



C. FLOW LINES IN ROOF AND FLOOR.
45° ANGLE.

PAINT TEST ON DRAFT TUBE MODEL A-II
SHOWING DIRECTION OF FLOW.


PLAN
Crank
V-Notched measuring weir
Water tight plate
Hook Gage Pot
℄ Tube
5 Hinges @ 2'0"
Tail Piezometers
4" Holes-5 Piezometers
9 Hinges @ 2'4½"
See detail of bracket
9'4" Inside box
4 Spaces @ 2'3" 9'0"
3" Post fit to end of weir
10 Spaces @ 2'0" 20'0"
20'-5" Inside box
ADJUSTABLE WEIR AND BRACKET DETAIL
8-REQ'D
¾" Iron pipe
Piano wire
Eye bolt with wing nut
Coil spring
To floor
SCALE OF INCHES
HINGE DETAIL
Plane of floor
℄ Hinge
Plane of gate
NOTE:
Plane of floor and gate and ℄ of hinge must intersect at one point.
PIEZOMETER DETAIL
7-REQUIRED
5 Dia
3 Dia
45° Cone
⅛" Holes
NOTE:
3" Cone to be soldered to 5" disk and ⅜" pipe. Portion of disk over cone to be perforated.
3' Length of floor to be 1½" thick.
15"x24" Hole back side
Head Piezometer
Racks
Supply pipe
SECTION ALONG ℄ OF ORIFICE
SCALE OF FEET
℄ of orifice
Pier
SECTION ALONG ℄ OF ORIFICE
NOTES
Entire flume to be lined with #26 G.I.
Model to be lined with #26 G.I.
Diagonal bracing on every other bent only
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WHEELER DAM
DRAFT-TUBE MODEL STUDIES
TEST FLUME DETAILS
DENVER, COLORADO
232-D-578
FIG. 1

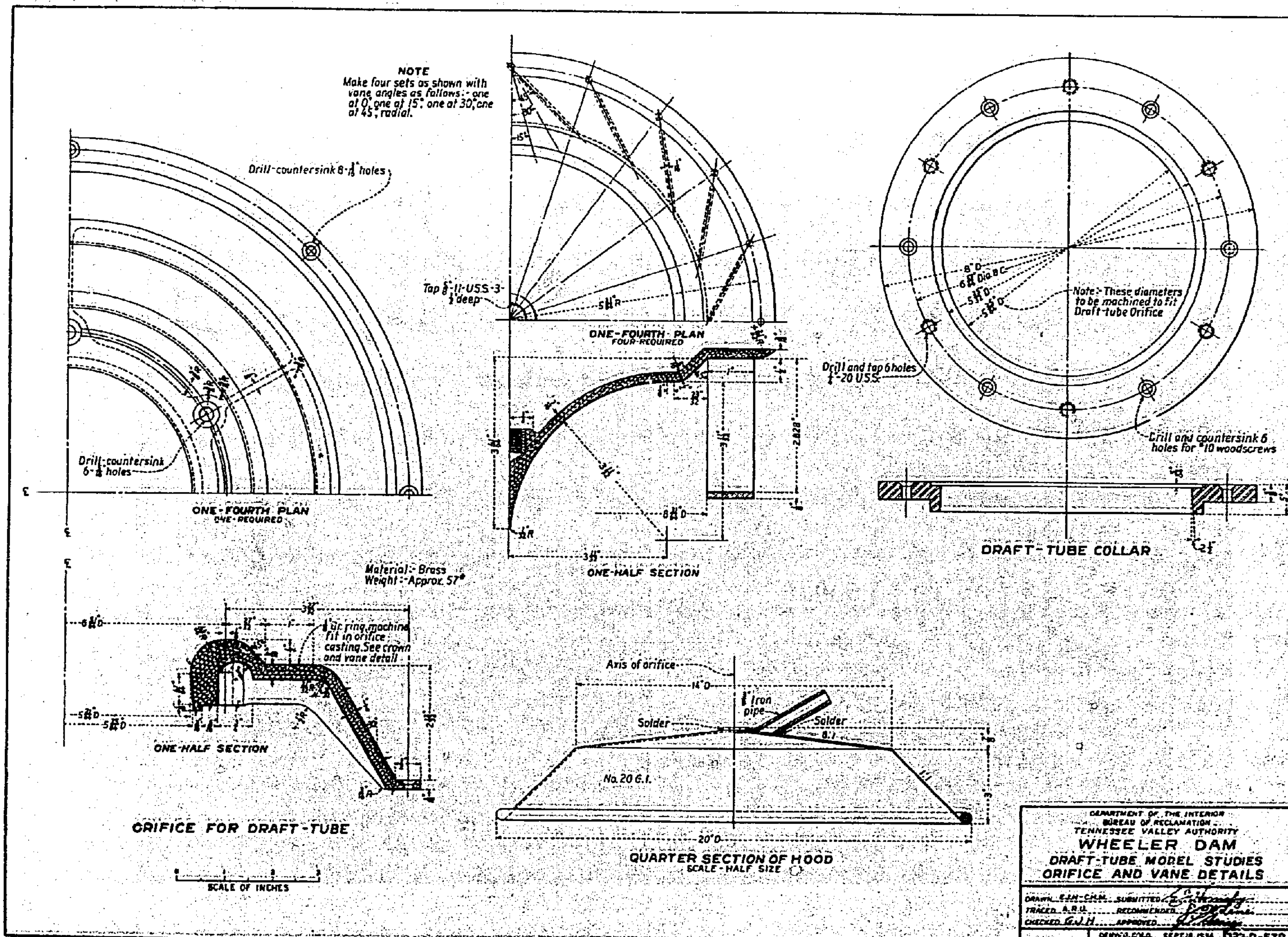
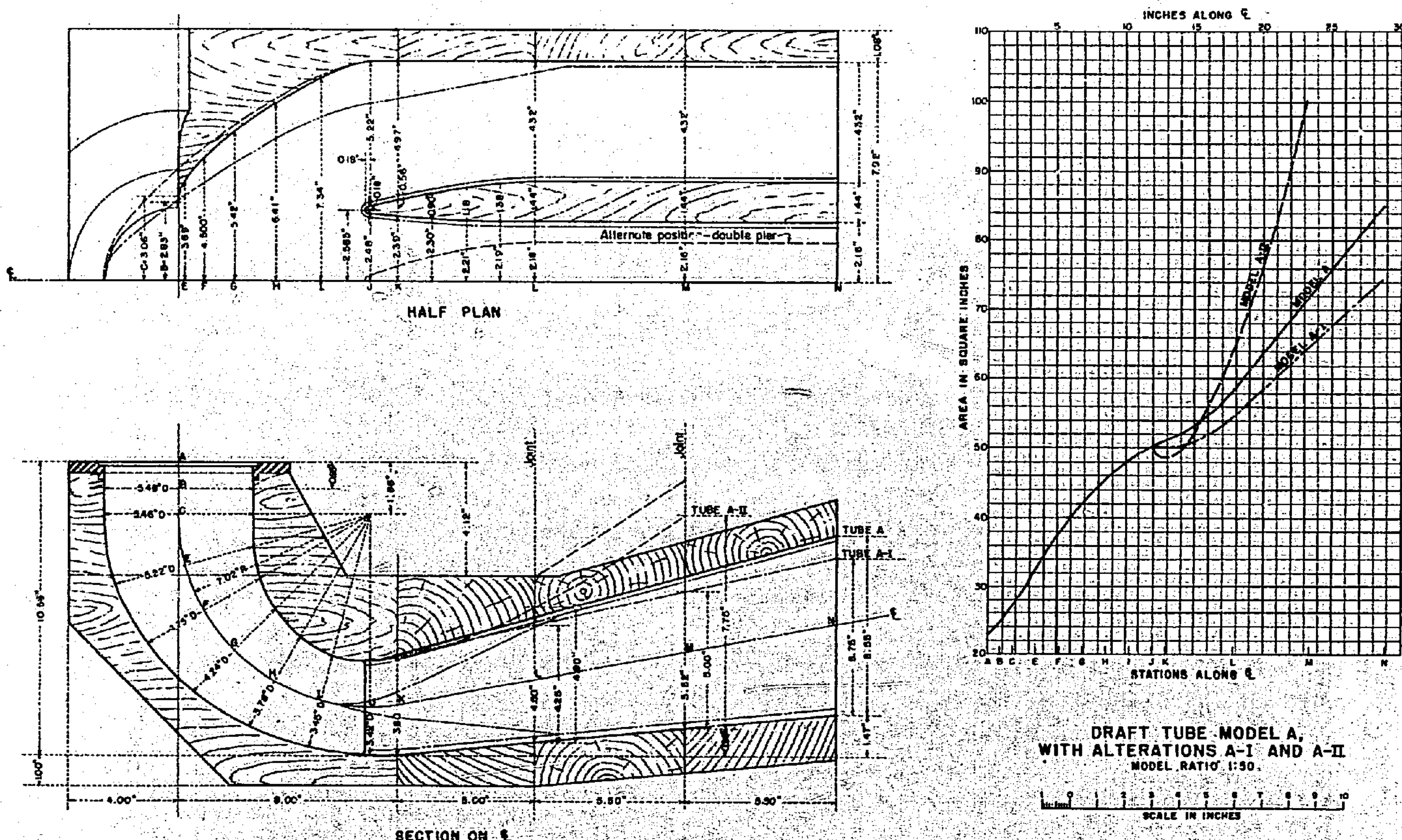

NOTE
Make four sets as shown with vane angles as follows:- one at 0°, one at 15°, one at 30°, one at 45°, radial.
Drill-countersink 8-¼" holes
Drill-countersink 6-¼" holes
ONE-FOURTH PLAN
ONE-REQUIRED
Tap ⅜"-11-USS-3-½" deep
ONE-FOURTH PLAN
FOUR-REQUIRED
ONE-HALF SECTION
Note:- These diameters to be machined to fit Draft-tube Orifice
Drill and tap 6 holes ¼"-20 USS.
Drill and countersink 6 holes for #10 woodscrews
DRAFT-TUBE COLLAR
Material:- Brass
Weight:- Approx. 57#
ar ring, machine fit in orifice casting. See crown and vane detail
ONE-HALF SECTION
ORIFICE FOR DRAFT-TUBE
SCALE OF INCHES
Axis of orifice
14" D
Iron pipe
Solder
Solder
No. 20 G.I.
20" D
QUARTER SECTION OF HOOD
SCALE - HALF SIZE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT-TUBE MODEL STUDIES
ORIFICE AND VANE DETAILS
DRAWN E.J.H.-C.H.M. SUBMITTED
TRACED A.B.U. RECOMMENDED
CHECKED G.J.H. APPROVED
DENVER, COLO. SEPT. 18, 1934. 232-D-579

FIG. 2




DRAFT TUBE MODEL A, WITH ALTERATIONS A-I AND A-II
MODEL RATIO 1:50.

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WHEELER DAM
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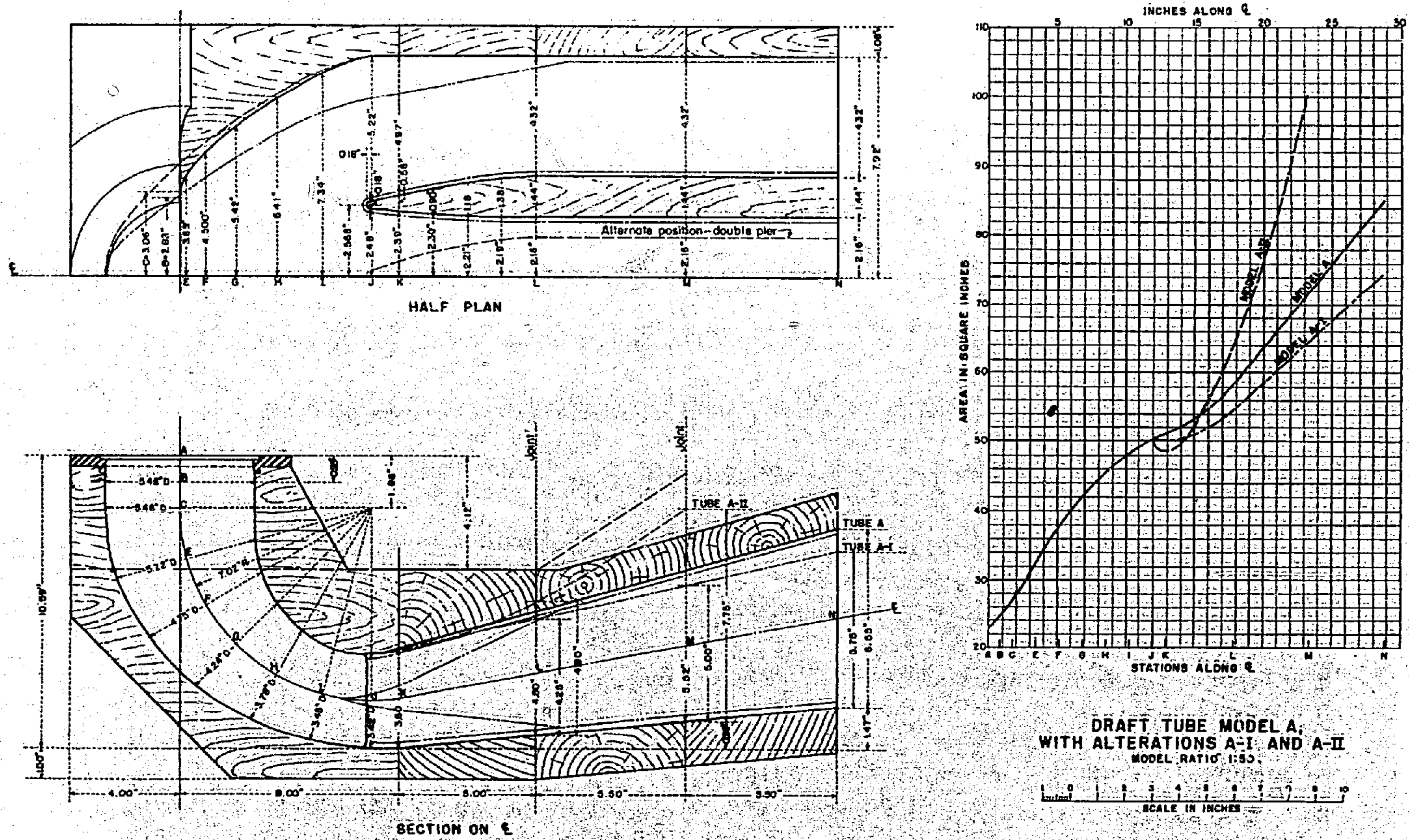
CHECKED G.J.H. APPROVED
Sheet 1 of 6 DENVER, COLO. MAR. 27, 1936 232-D-1560

FIG. 3




DRAFT TUBE MODEL A,
WITH ALTERATIONS A-I AND A-II
MODEL RATIO 1:53

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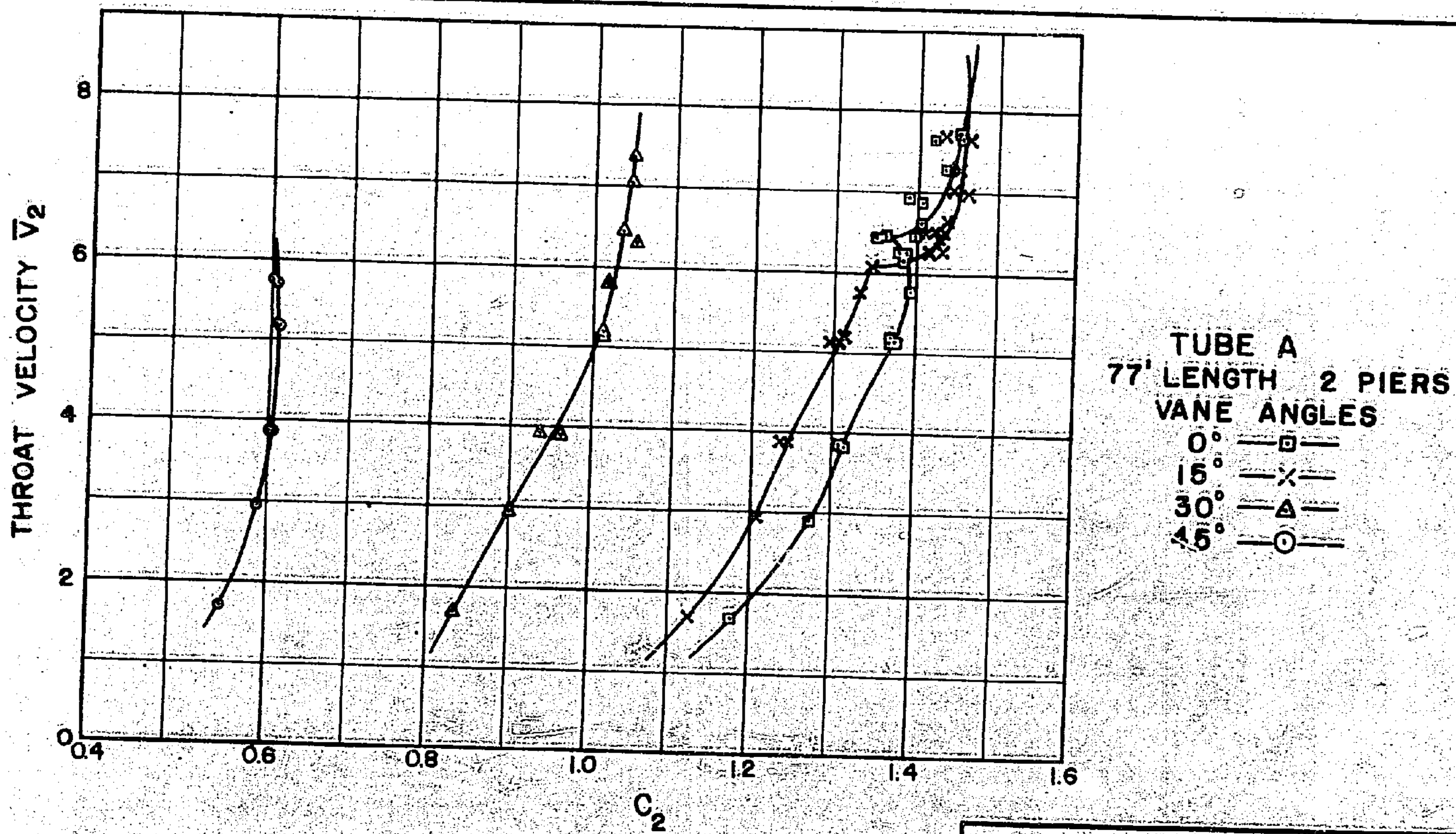
Sheet 1 of 6 DENVER, COLO. MAR. 27, 1935 232-D-1560

FIG. 3

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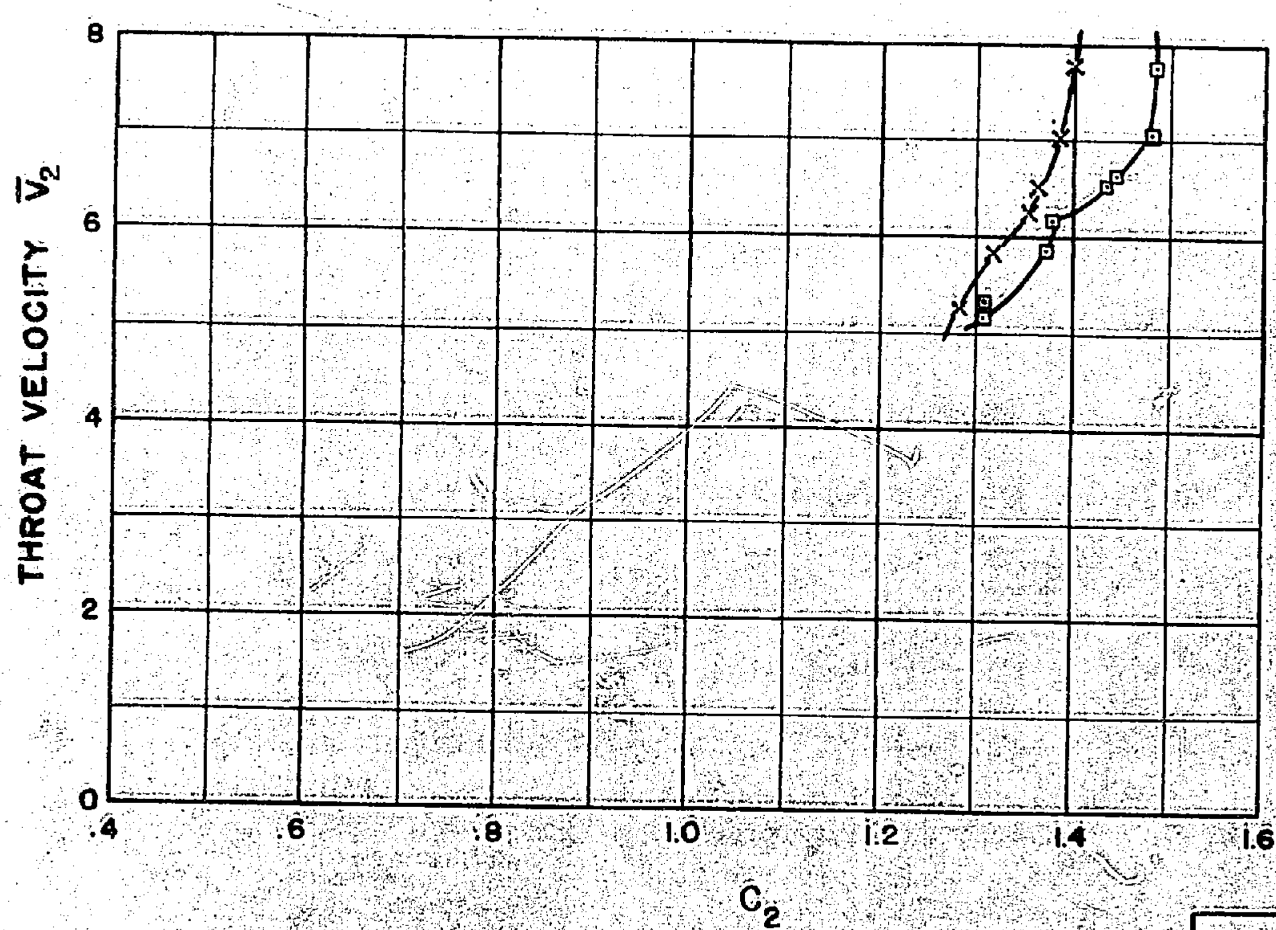
CHECKED G.J.H. APPROVED [signature]

Sh. 1 of 50 | DENVER, COLO. | 232-D-1510

FIG. 4




TUBE A (Hood Removed)
77' LENGTH 2 PIERS
VANE ANGLES–
0° —⊡—
15° —×—
30° —△—
45° —⊙—

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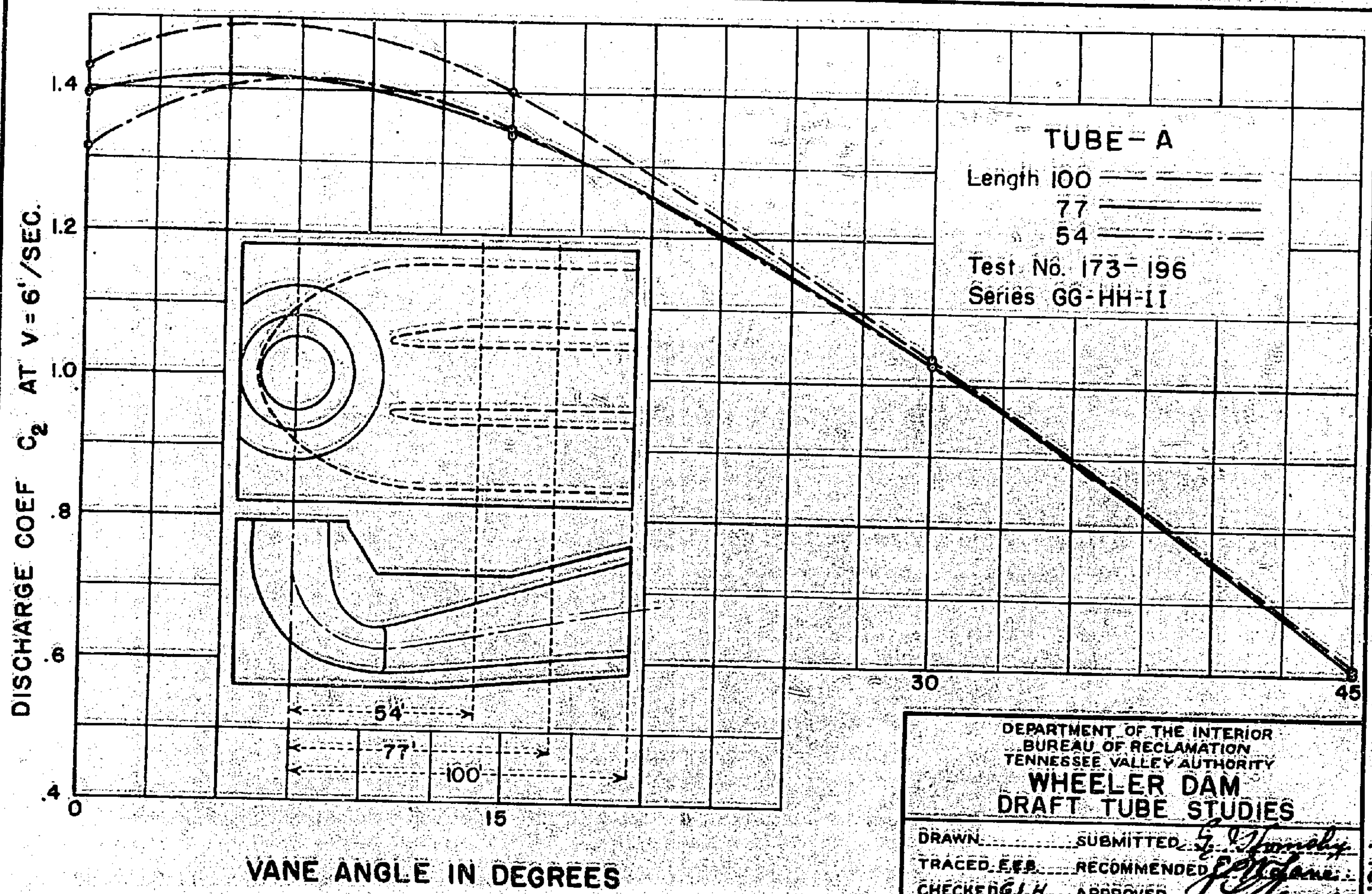
CHECKED G.J.H. APPROVED [signature]

Sh. 2 of 50 DENVER, COLO., 12-6-34 232-D-1511

FIG. 5

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WHEELER DAM
DRAFT TUBE STUDIES

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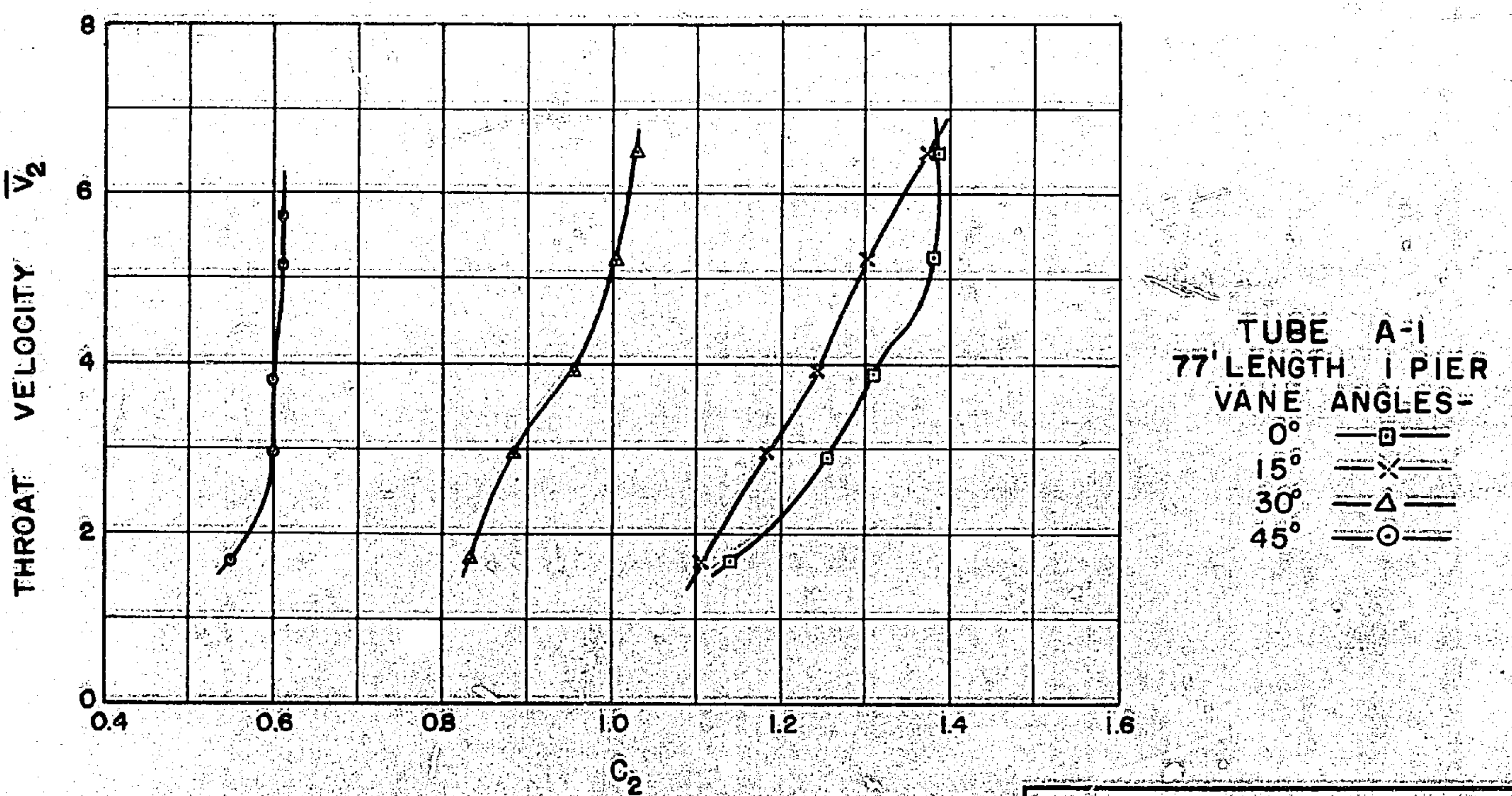
TRACED E.E.B. RECOMMENDED ____
CHECKED G.L.H. APPROVED ____

Sh. 3 of 50 | DENVER, COLO. 12-6-34 | 232-D-1512

FIG. 6

FIG. 7

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WHEELER DAM
DRAFT TUBE STUDIES

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TRACED E.E.B. RECOMMENDED
CHECKED G.J.H. APPROVED

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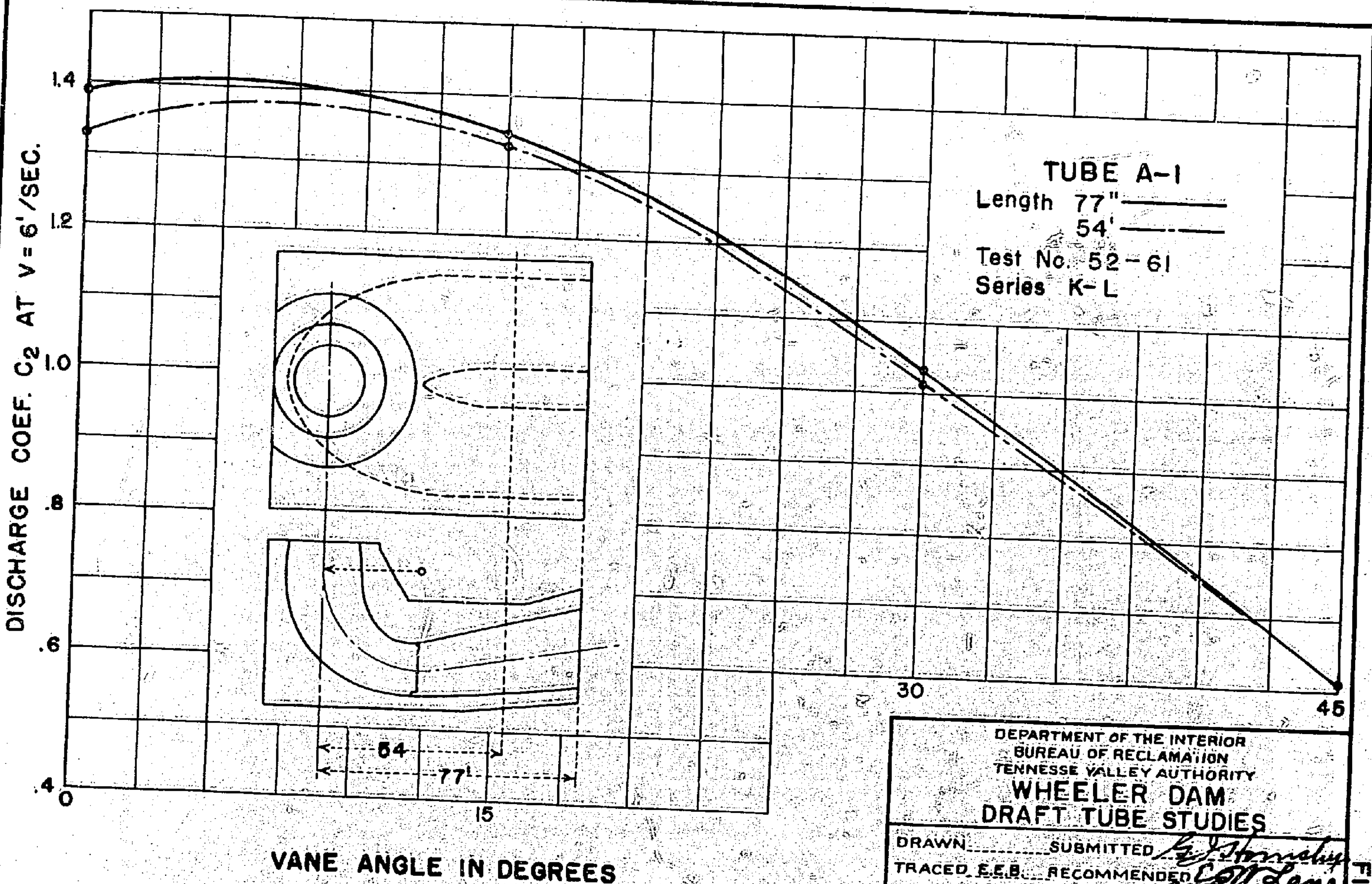


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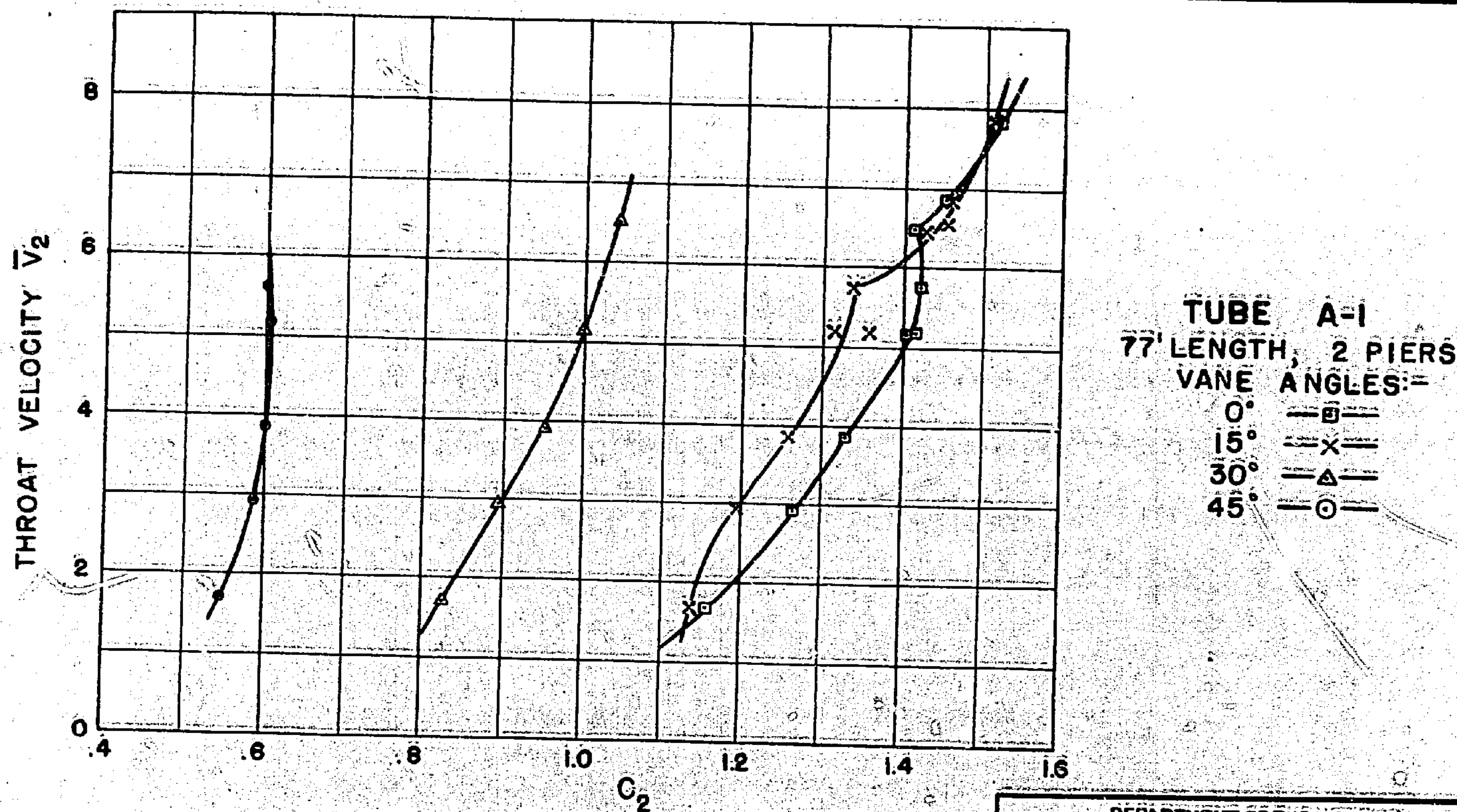
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN ________ SUBMITTED G. J. Hornsby
TRACED E.E.B. RECOMMENDED C. W. Lane
CHECKED G.J.H. APPROVED J. L. Savage

Sh. 5 of 50 | DENVER, COLO., 12-4-34 | 232-D-1514

FIG. 8

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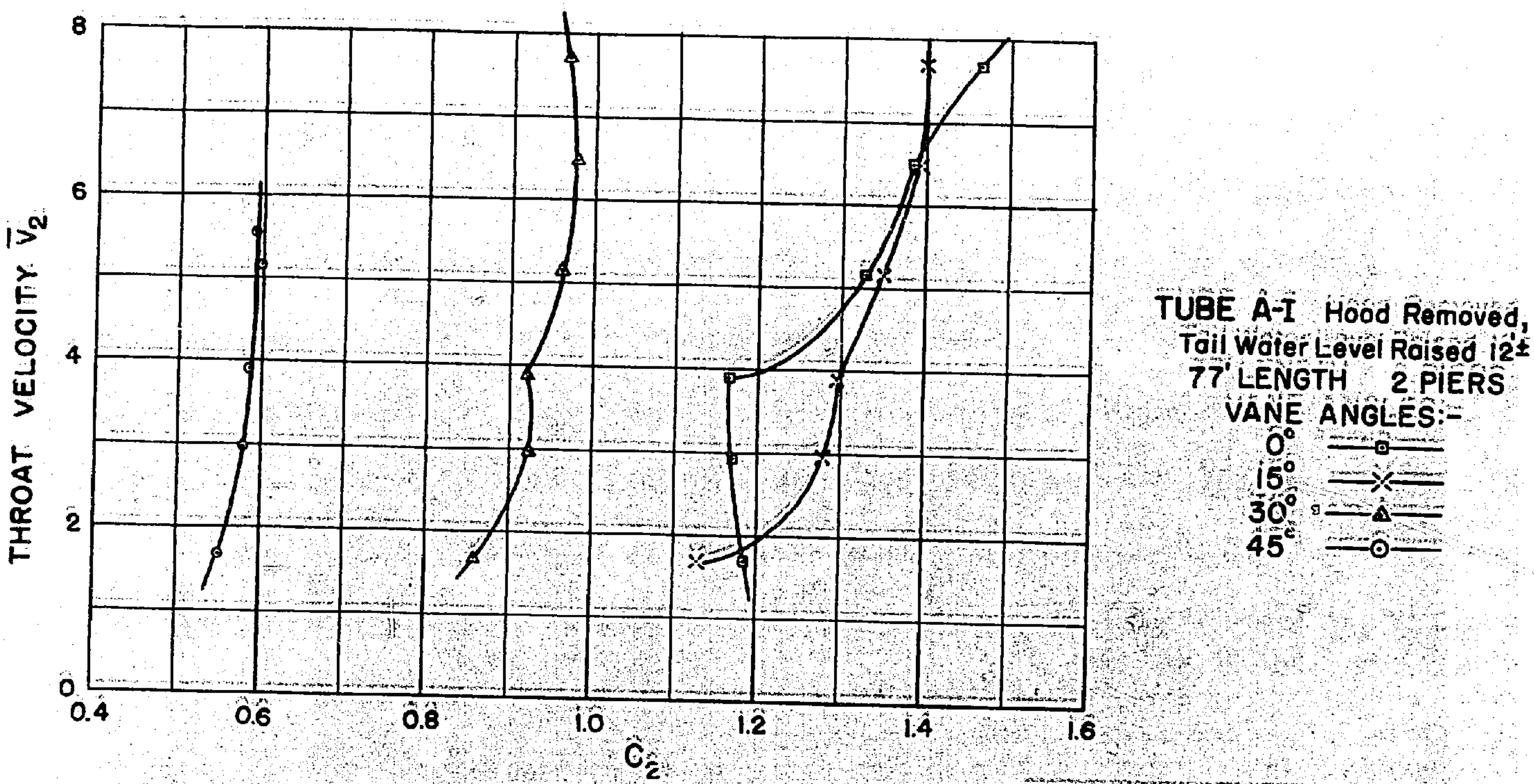
WHEELER DAM
DRAFT TUBE STUDIES

| | |
|---|---|
| DRAWN ______ | SUBMITTED G. J. Hornsby |
| TRACED E.E.B. | RECOMMENDED E. W. Lane |
| CHECKED G.J.H. | APPROVED J. L. Savage |

Sh. 6 of 50 | DENVER, COLO., 12-6-34 | 232-D-1515

FIG. 9

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WHEELER DAM
DRAFT TUBE STUDIES

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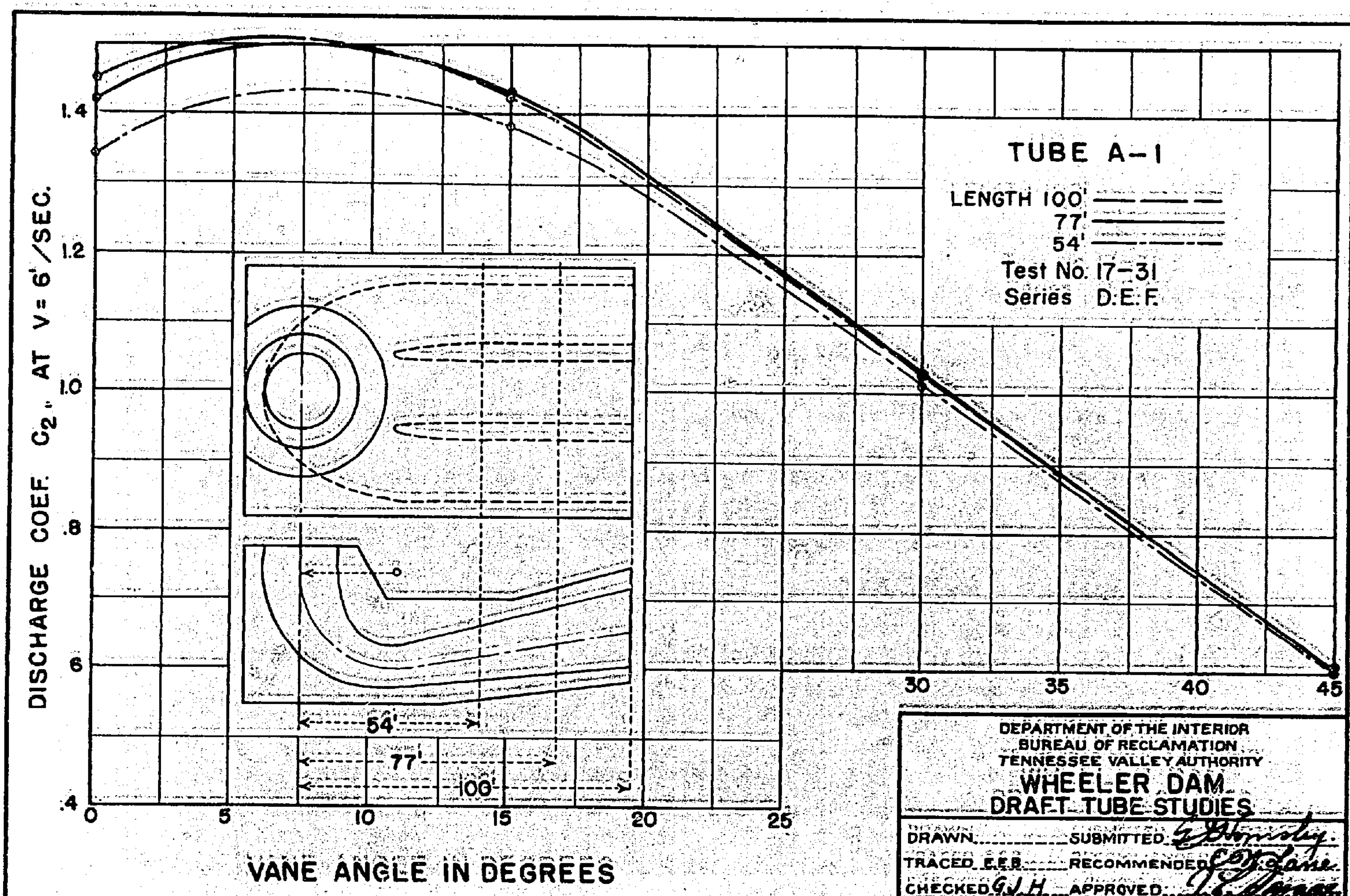
TRACED E.E.B. RECOMMENDED C. M. Lane
CHECKED G.J.H. APPROVED J. L. Savage

Sh. 7 of 50 DENVER, COLO. 12-6-34 232-D-1516

FIG. 10

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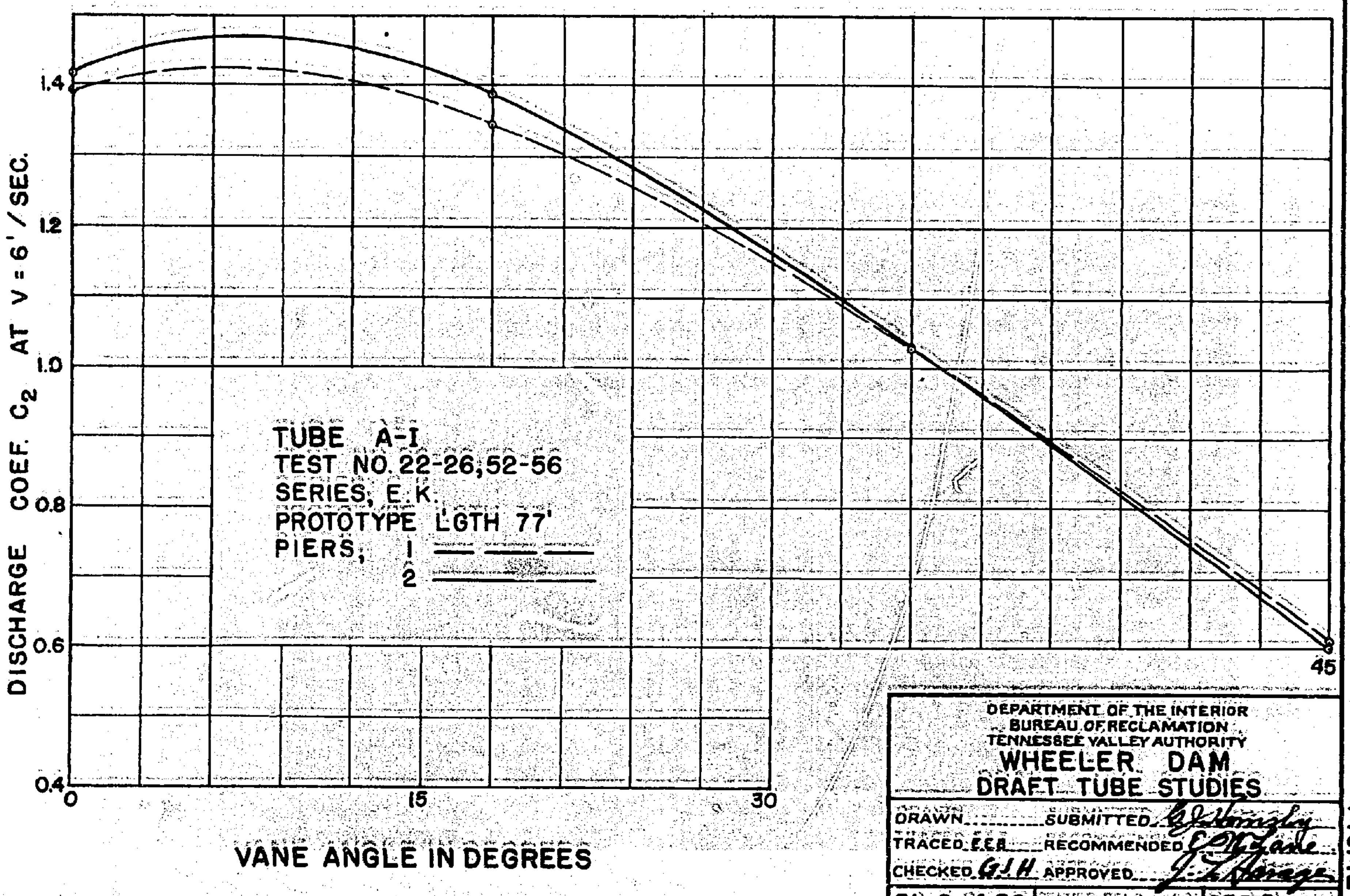
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN ........ SUBMITTED [signature]
TRACED E.E.B. ........ RECOMMENDED [signature]
CHECKED G.J.H. ........ APPROVED [signature]

Sh. 8 of 50 | DENVER, COLO. 12-6-34 | 232-D-1517

FIG. 11

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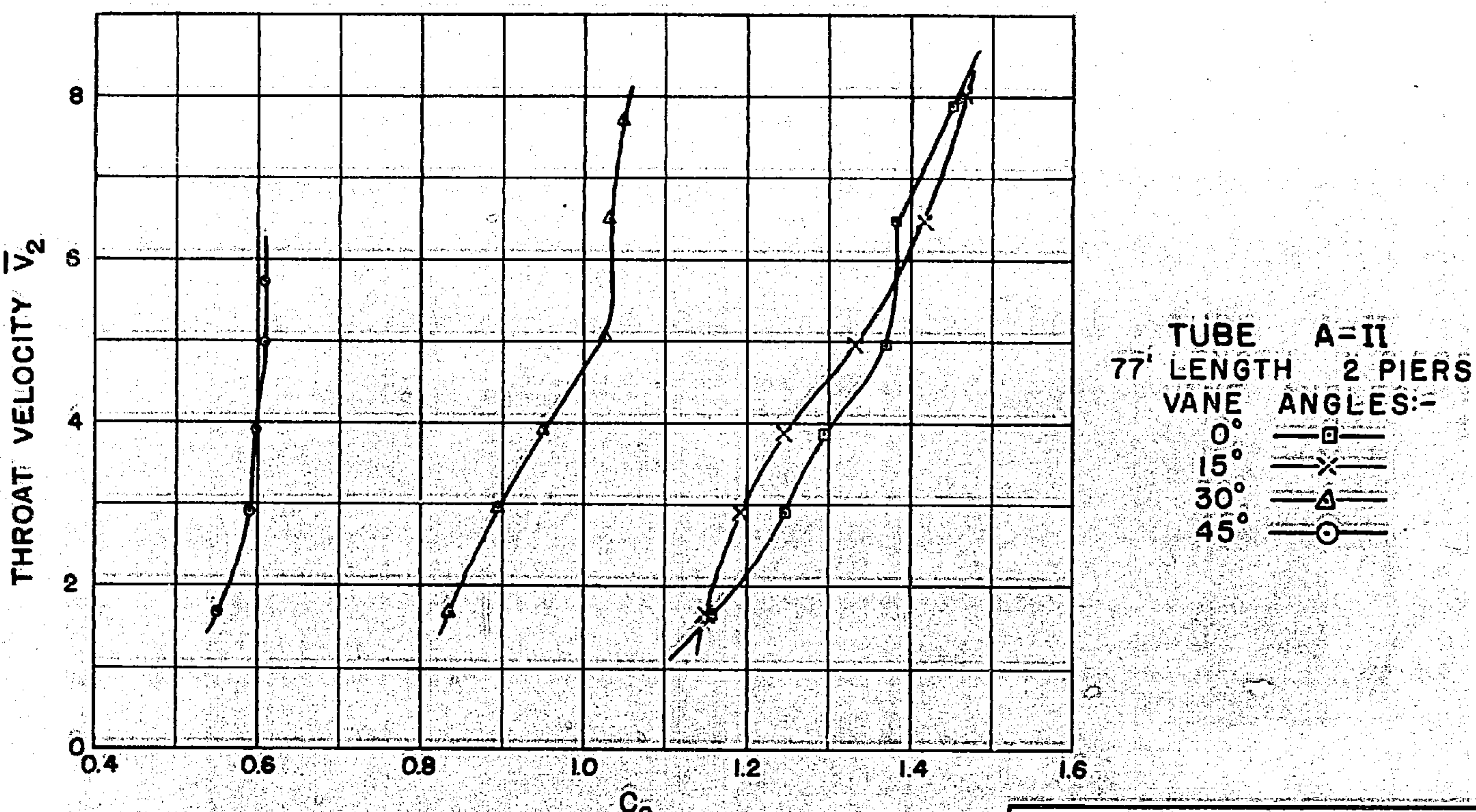
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN ........ SUBMITTED [signature]
TRACED E.E.B. RECOMMENDED [signature]
CHECKED G.J.H. APPROVED [signature]

Sh. 9 of 50 | DENVER, COLO., 12-6-34 | 232-D-1518

FIG. 12

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WHEELER DAM
DRAFT TUBE STUDIES

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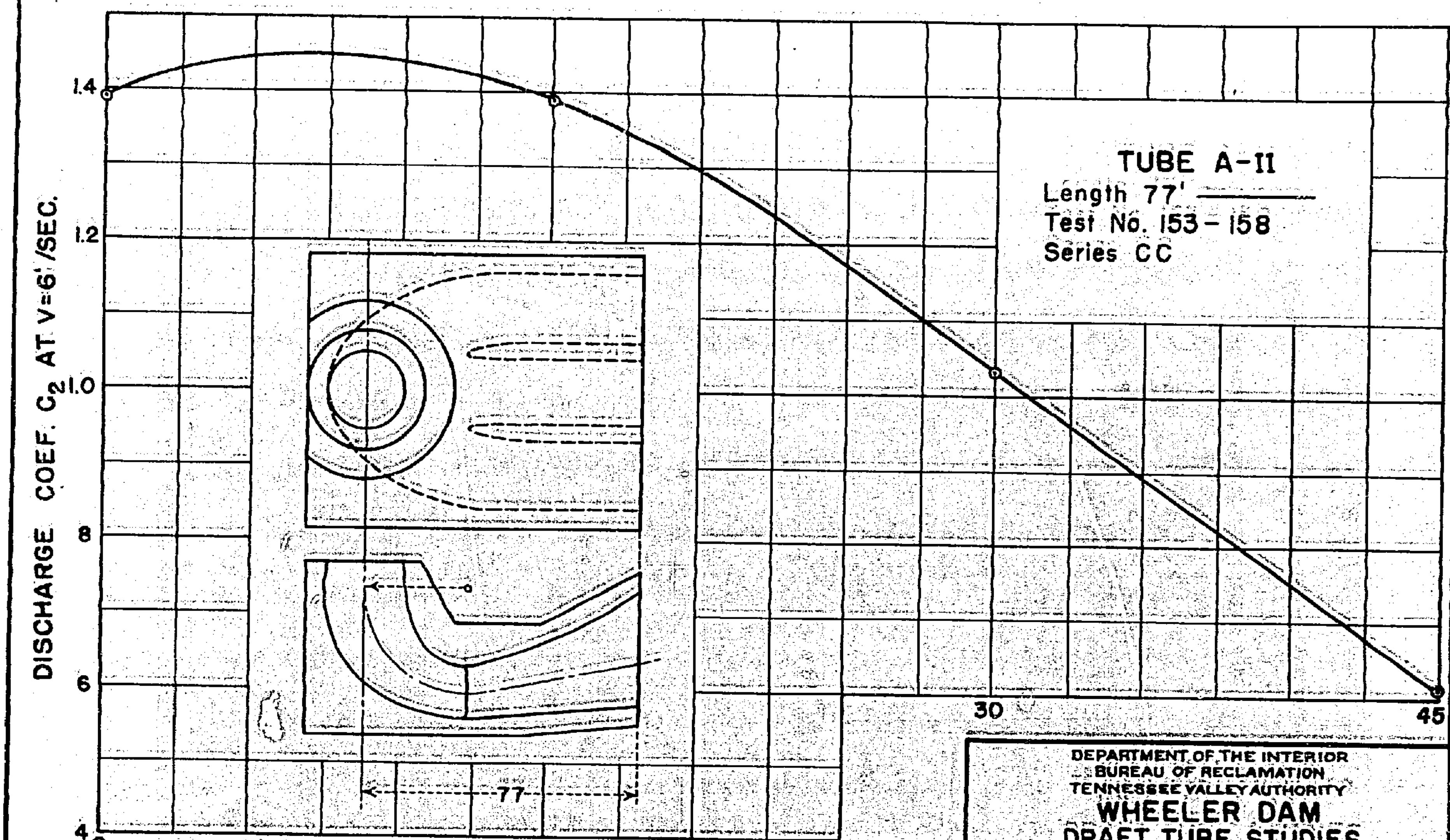
TRACED E.E.S. RECOMMENDED ______
CHECKED G.J.H. APPROVED ______

Sh.10 of 50 DENVER, COLO. 12-6-34 232-D-1519

FIG. 13

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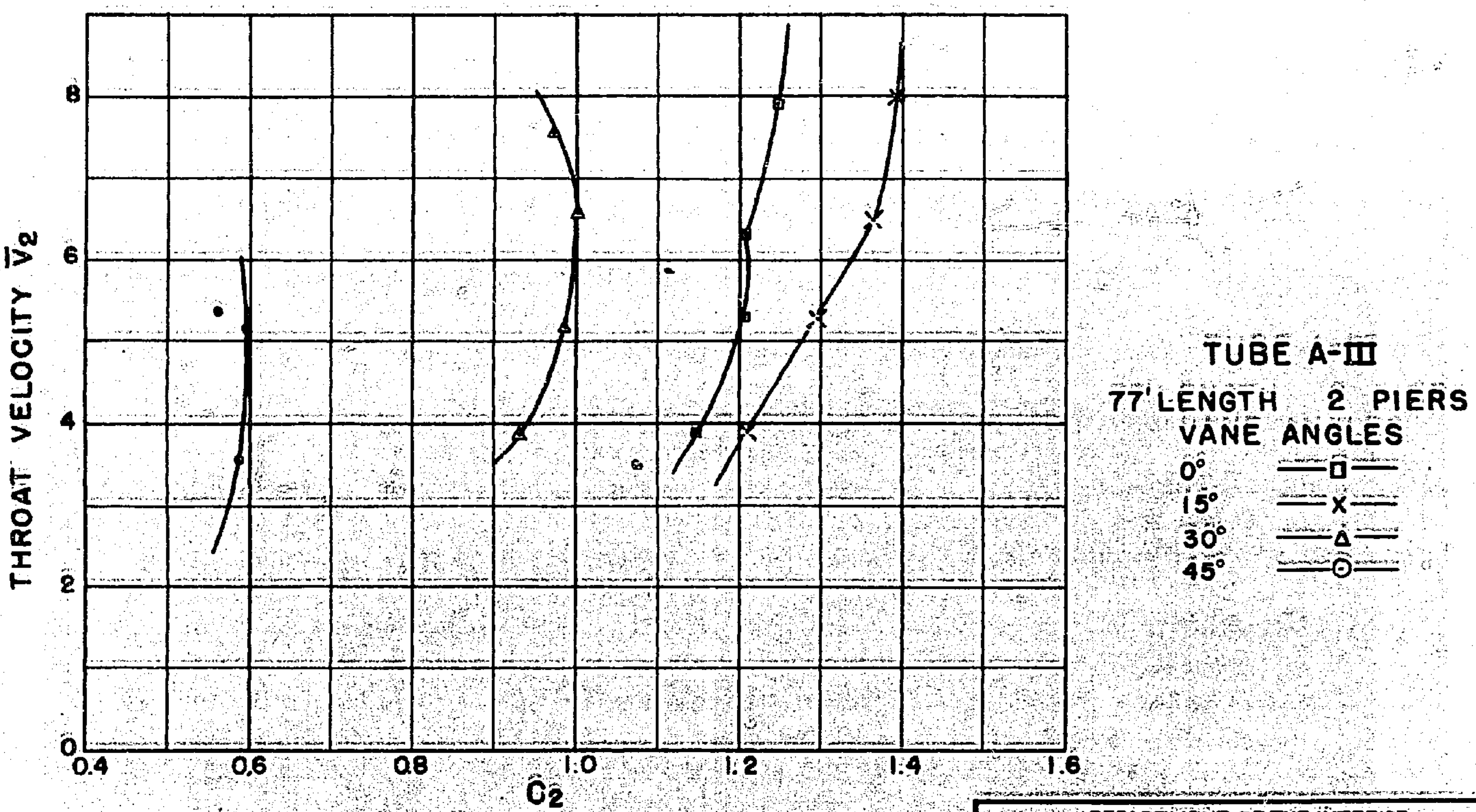
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

| | | | |
|---|---|---|---|
| DRAWN | | SUBMITTED | [signature] |
| TRACED | E.E.B. | RECOMMENDED | [signature] |
| CHECKED | G.J.H. | APPROVED | [signature] |
| Sh. 11 of 50 | DENVER, COLO. 12-6-34 | 232-D-1520 | |

FIG. 14

FIG. 15

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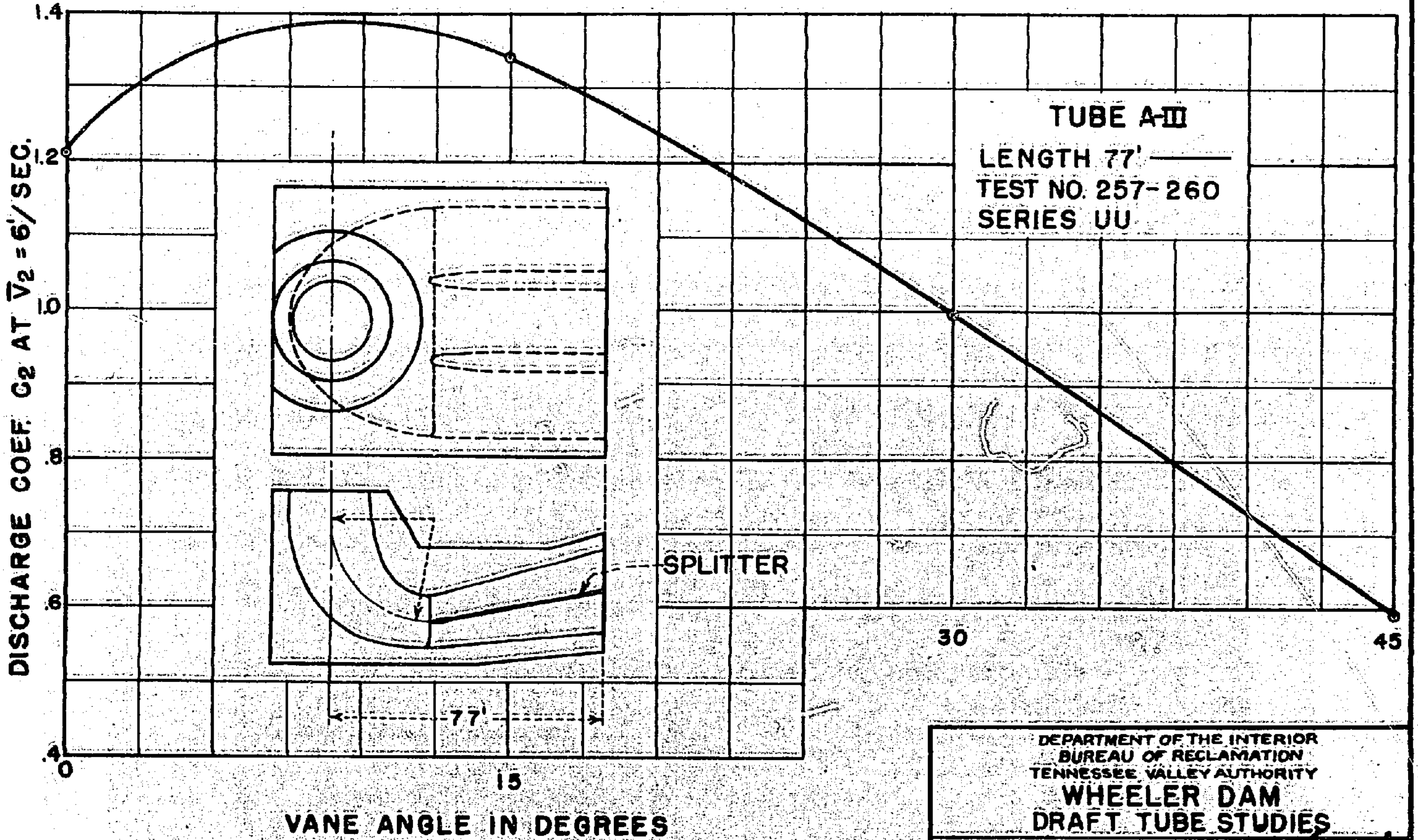
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

| | |
|---|---|
| DRAWN. . . . . . . . . . | SUBMITTED G. J. Hornsby |
| TRACED . . O.R.S. . . . | RECOMMENDED E. W. Lane |
| CHECKED G.J.H. . . . | APPROVED . J. L. Savage |
| Sh 12 of 50 DENVER, COLO. 12-6-34 | 232-D-1521 |

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WHEELER DAM
DRAFT TUBE STUDIES

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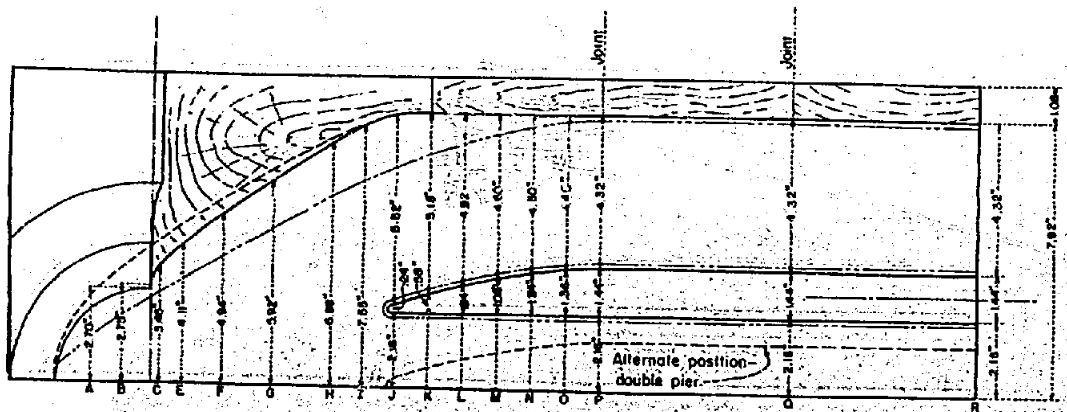
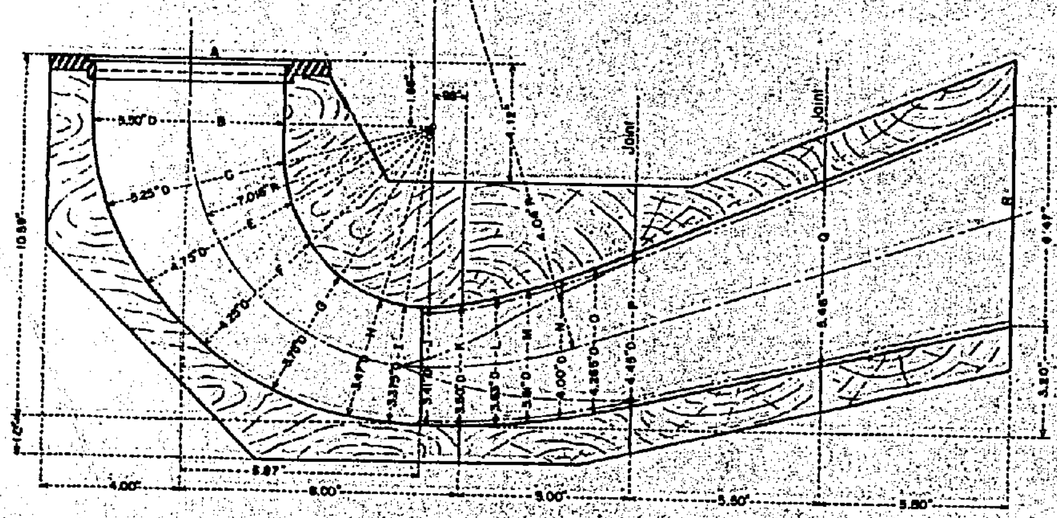
TRACED O.R.S. RECOMMENDED [signature]
CHECKED G.J.H. APPROVED [signature]

Sh. 13 of 50 | DENVER, COLO., 12-6-34 | 232-D-1522

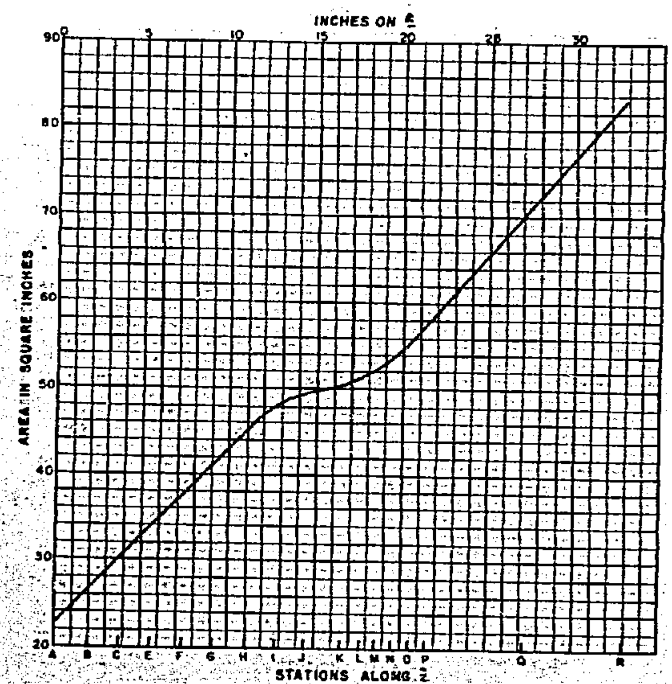
FIG. 16




HALF PLAN




SECTION ON ℄




## DRAFT TUBE MODEL B

MODEL RATIO 1:50

SCALE IN INCHES

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TENNESSEE VALLEY AUTHORITY

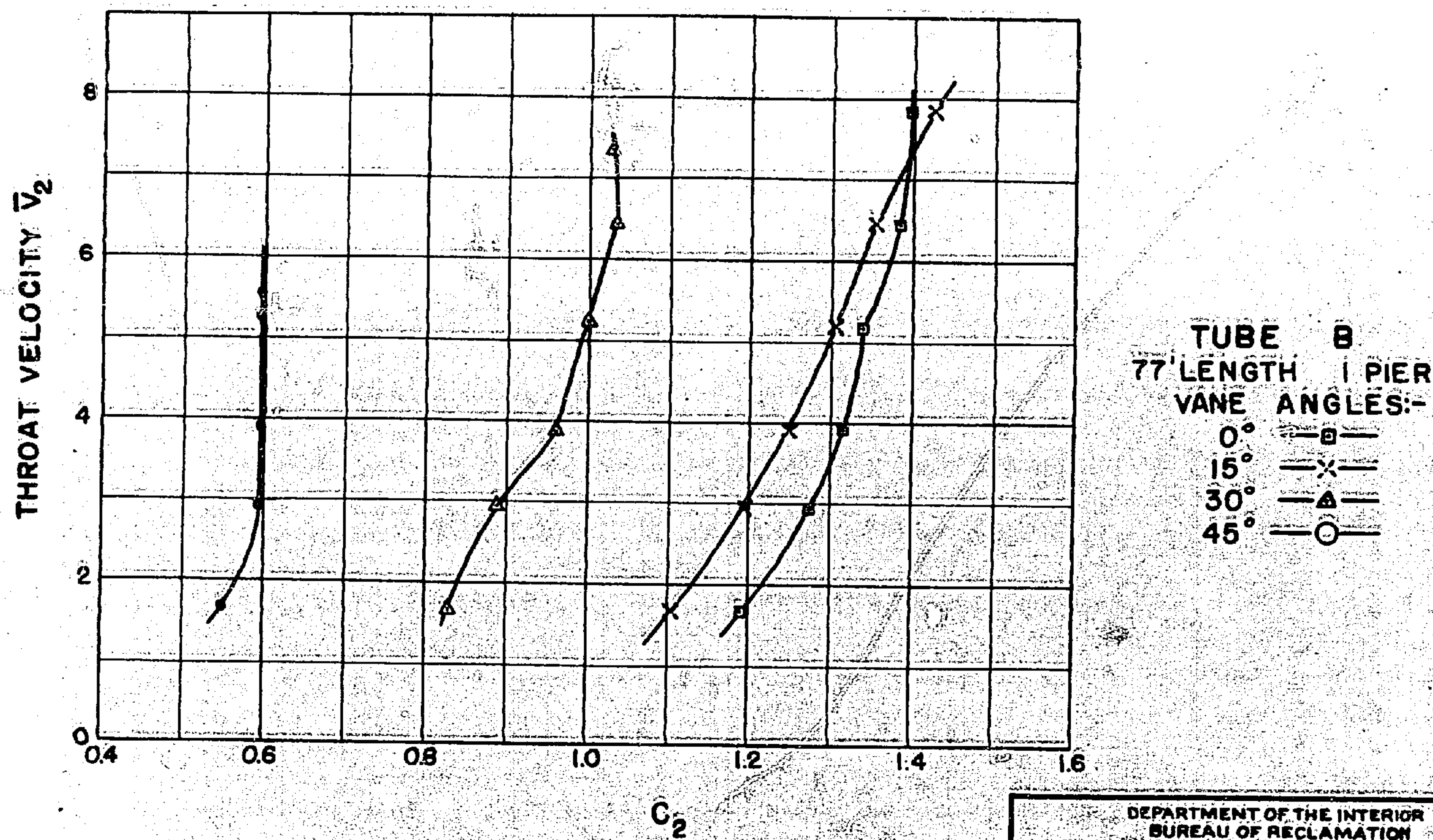
**WHEELER DAM**

**DRAFT TUBE STUDIES**

DRAWN E.C.P. SUBMITTED
TRACED N.F.W. J.O.K. RECOMMENDED
CHECKED E.J.H. APPROVED

Sheet 2 of 5 | DENVER, COLO. MAR. 27, 1935 | 232-D-1361

FIG. 17

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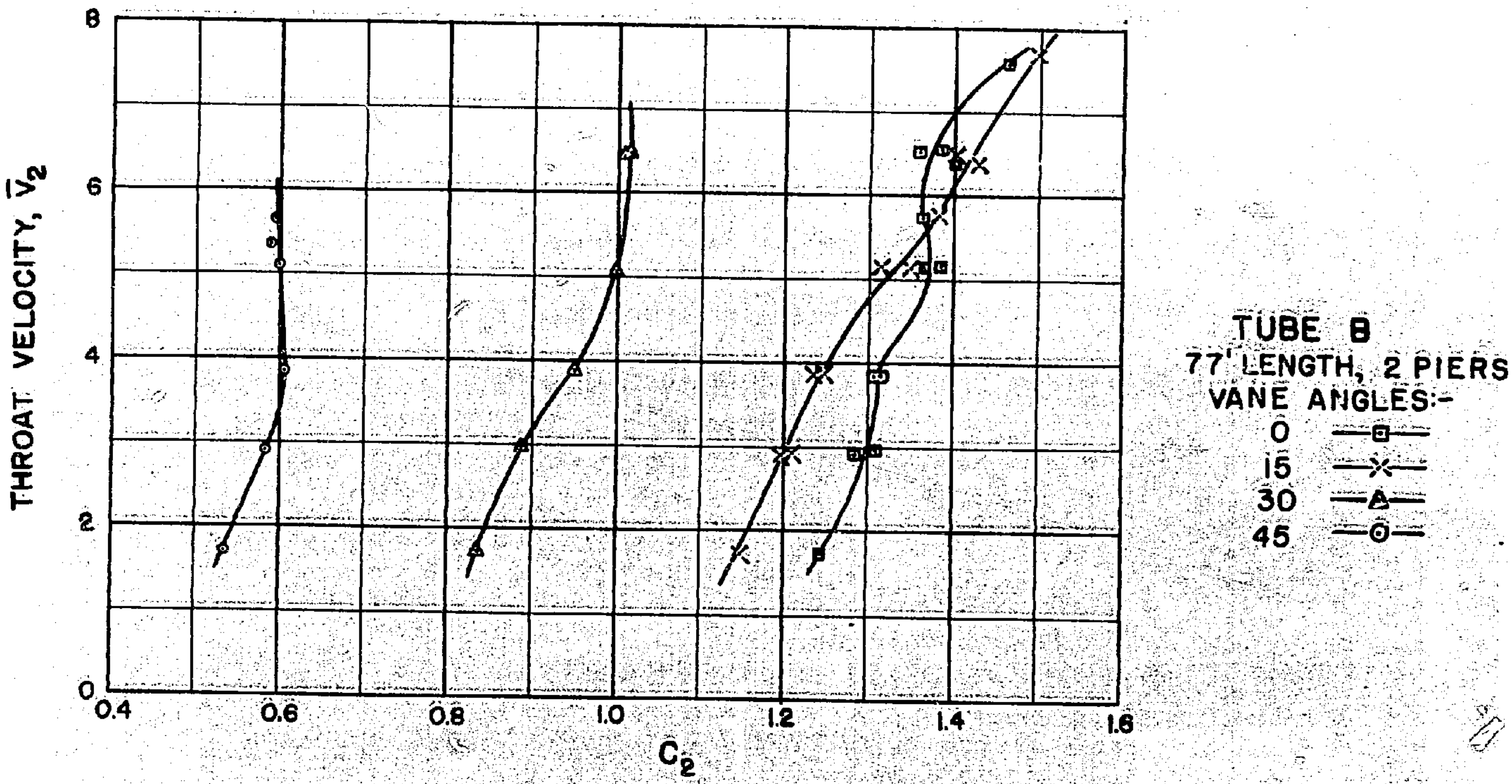
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

| | |
|---|---|
| DRAWN G.J.H. | SUBMITTED [signature] |
| TRACED E.E.B. | RECOMMENDED [signature] |
| CHECKED G.J.H. | APPROVED [signature] |

Sh. 14 of 50 | DENVER, COLO., 12-6-34 | 232-D-1523

FIG. 18.




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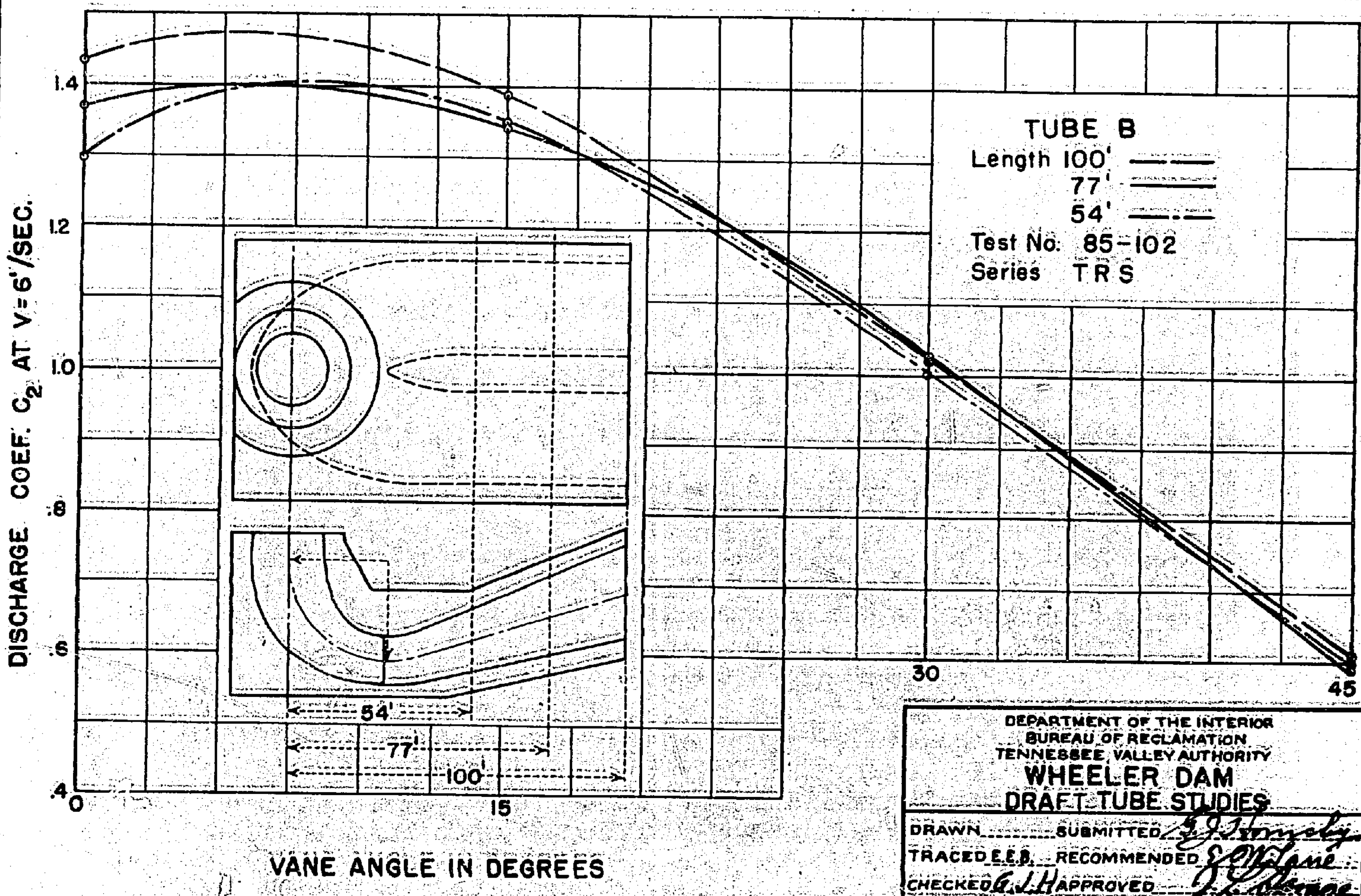
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN........ SUBMITTED
TRACED O.R.S. RECOMMENDED
CHECKED G.L.K. APPROVED

Sh. 15 of 50 | DENVER, COLO., 12-6-34 | 232-D-1524

FIG. 19

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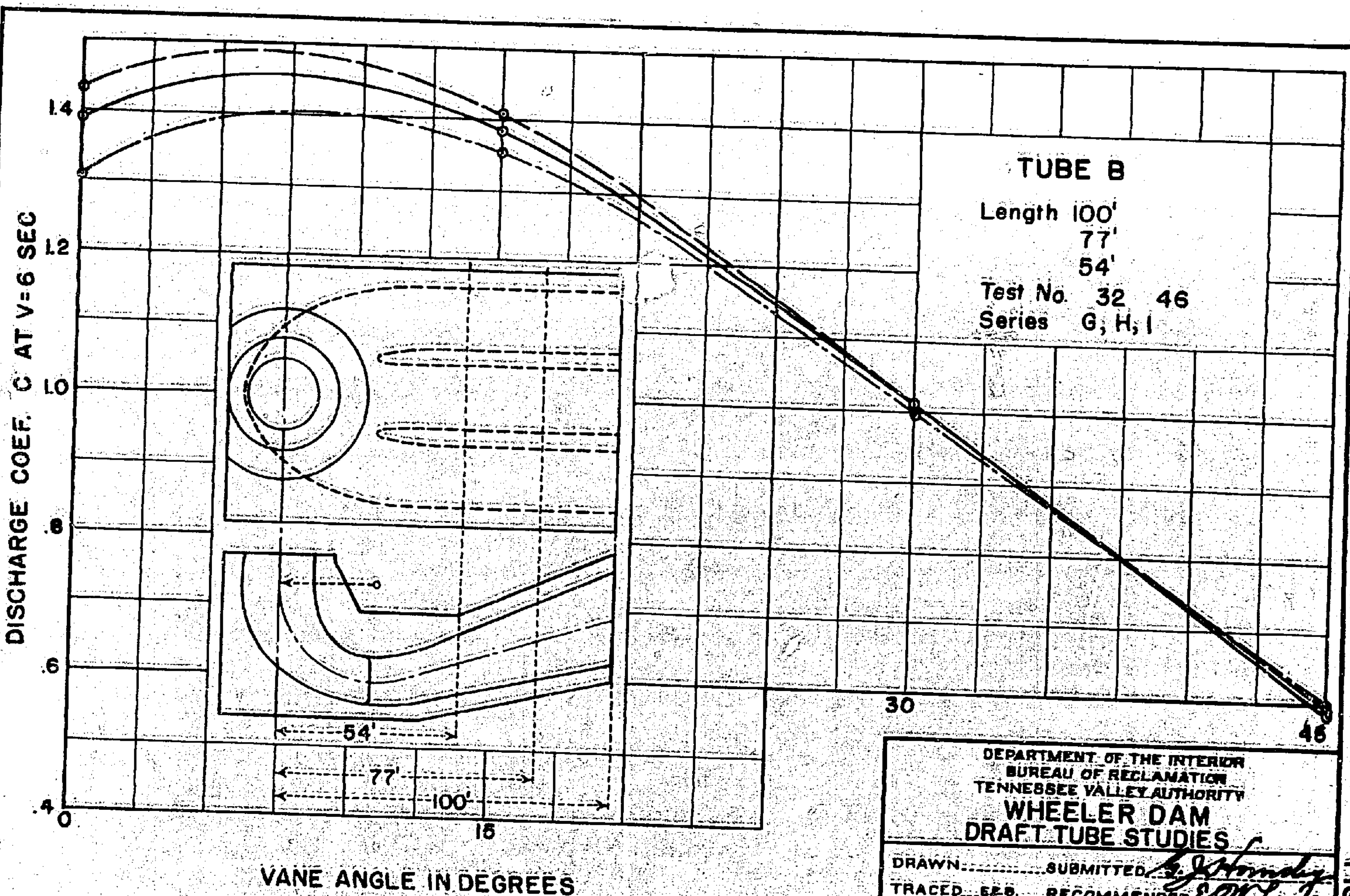
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN ........ SUBMITTED
TRACED E.E.B. RECOMMENDED
CHECKED G.J.H. APPROVED

Sh. 16 of 50 DENVER, COLO. 12-6-34 232-D-1525

FIG. 20

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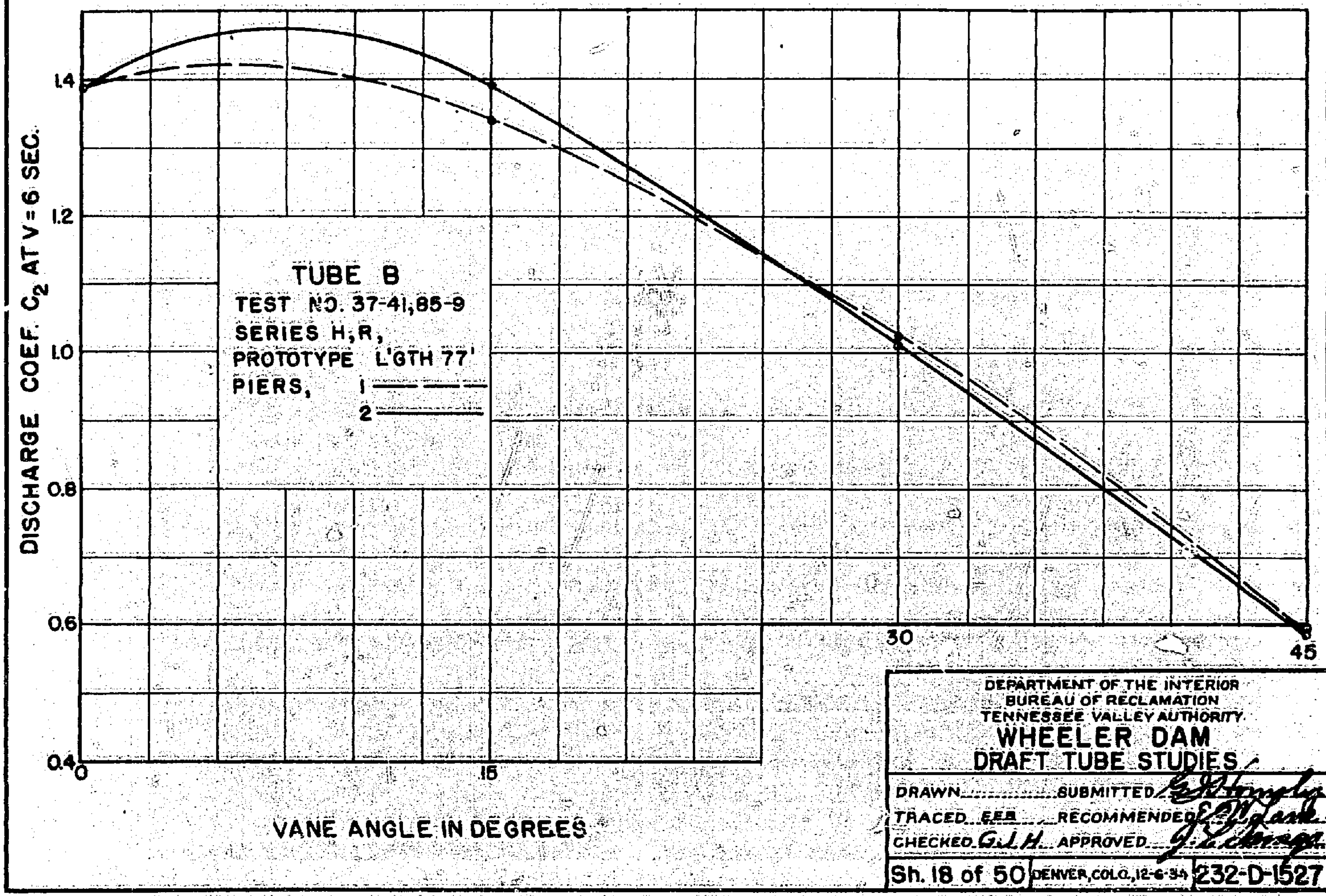
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

| | |
|---|---|
| DRAWN........ | SUBMITTED |
| TRACED ..E.F.B.. | RECOMMENDED |
| CHECKED G.I.H. | APPROVED |

Sh. 17 of 50 | DENVER, COLO., 12-6-34 | 232-D-1526

FIG. 21

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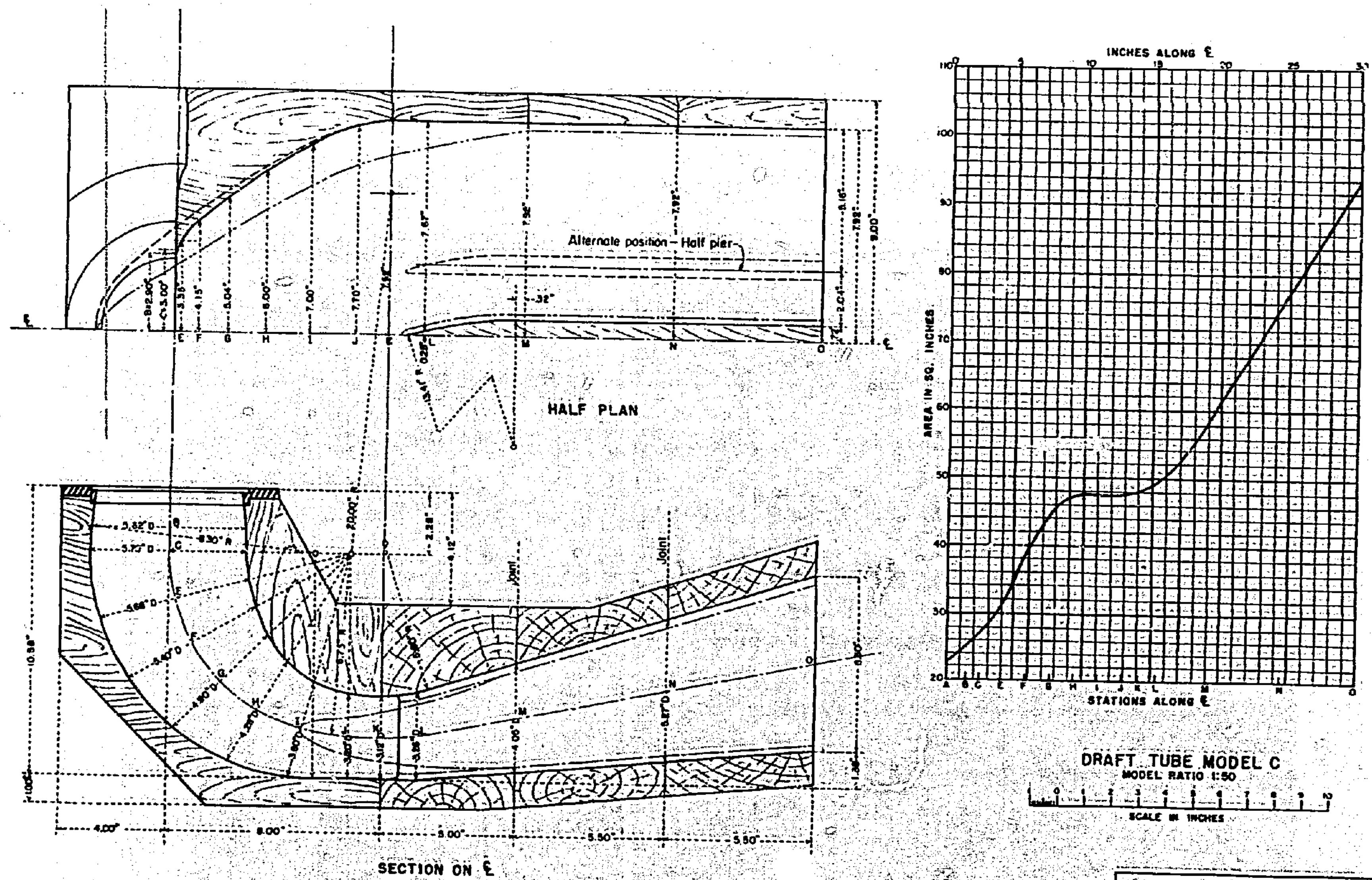
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

DRAWN.............. SUBMITTED [signature]
TRACED EEB RECOMMENDED [signature]
CHECKED G.J.H. APPROVED [signature]

Sh. 18 of 50 DENVER, COLO., 12-6-34 232-D-1527

FIG. 22

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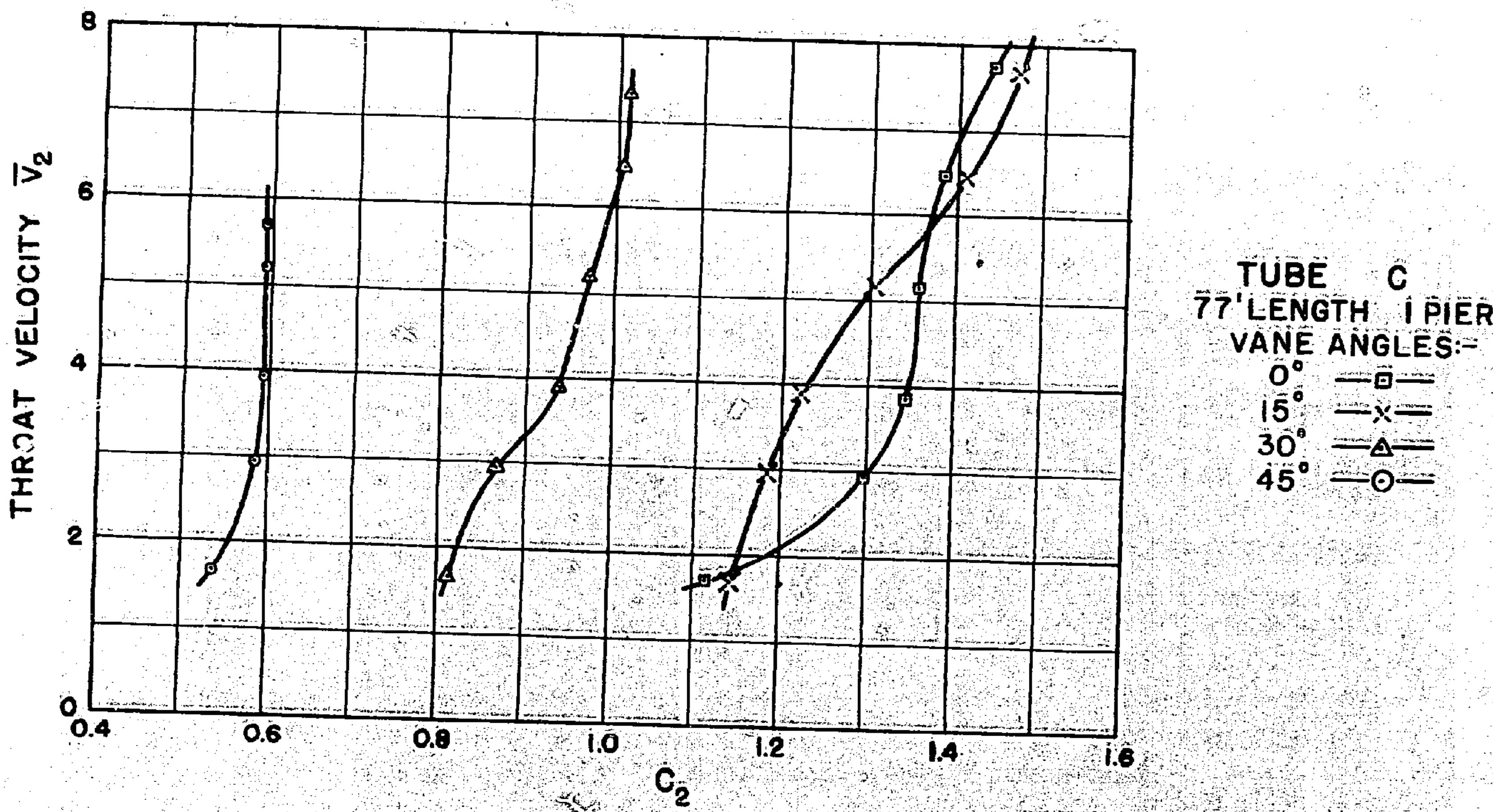
**WHEELER DAM**

**DRAFT TUBE STUDIES**

DRAWN E.C.P. SUBMITTED
TRACED L.H.H. J.C.K. RECOMMENDED
CHECKED G.L.H. APPROVED
Sheet 3 of 6 DENVER, COLO. MAR. 28, 1935 232-D-1562

FIG. 23

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WHEELER DAM
DRAFT TUBE STUDIES

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TRACED E.E.B. RECOMMENDED

CHECKED G.J.H. APPROVED

Sh. 19 of 50 | DENVER, COLO. 12-6-34 | 232-D-1528

FIG. 24

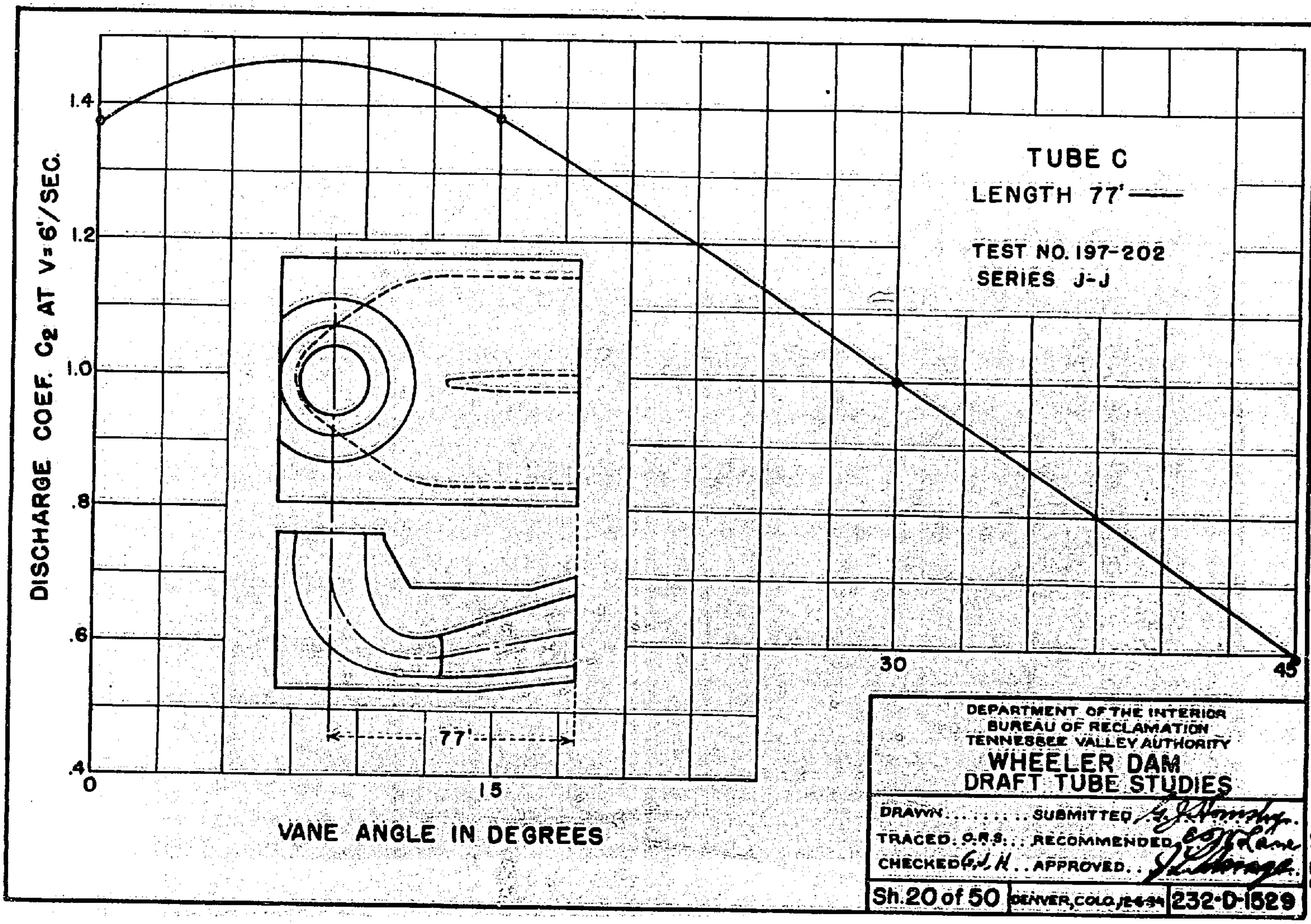
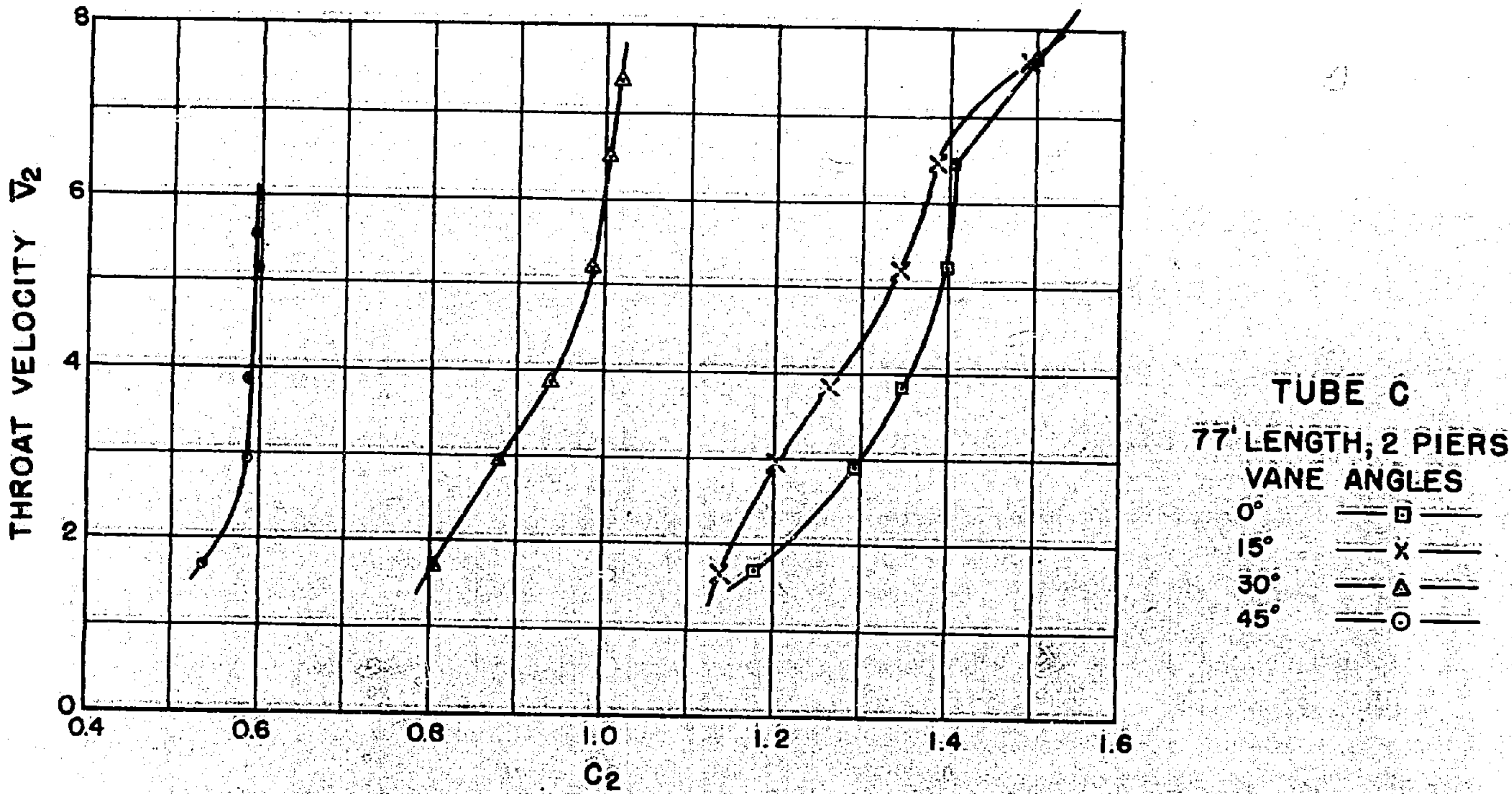

TUBE C
LENGTH 77'
TEST NO. 197-202
SERIES J-J
DISCHARGE COEF. $C_2$ AT V=6'/SEC.
1.4
1.2
1.0
.8
.6
.4
0
15
30
45
77'
VANE ANGLE IN DEGREES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DRAWN........ SUBMITTED
TRACED. O.R.S... RECOMMENDED
CHECKED G.J.H... APPROVED..
Sh. 20 of 50
DENVER, COLO.
232-D-1529

FIG. 25

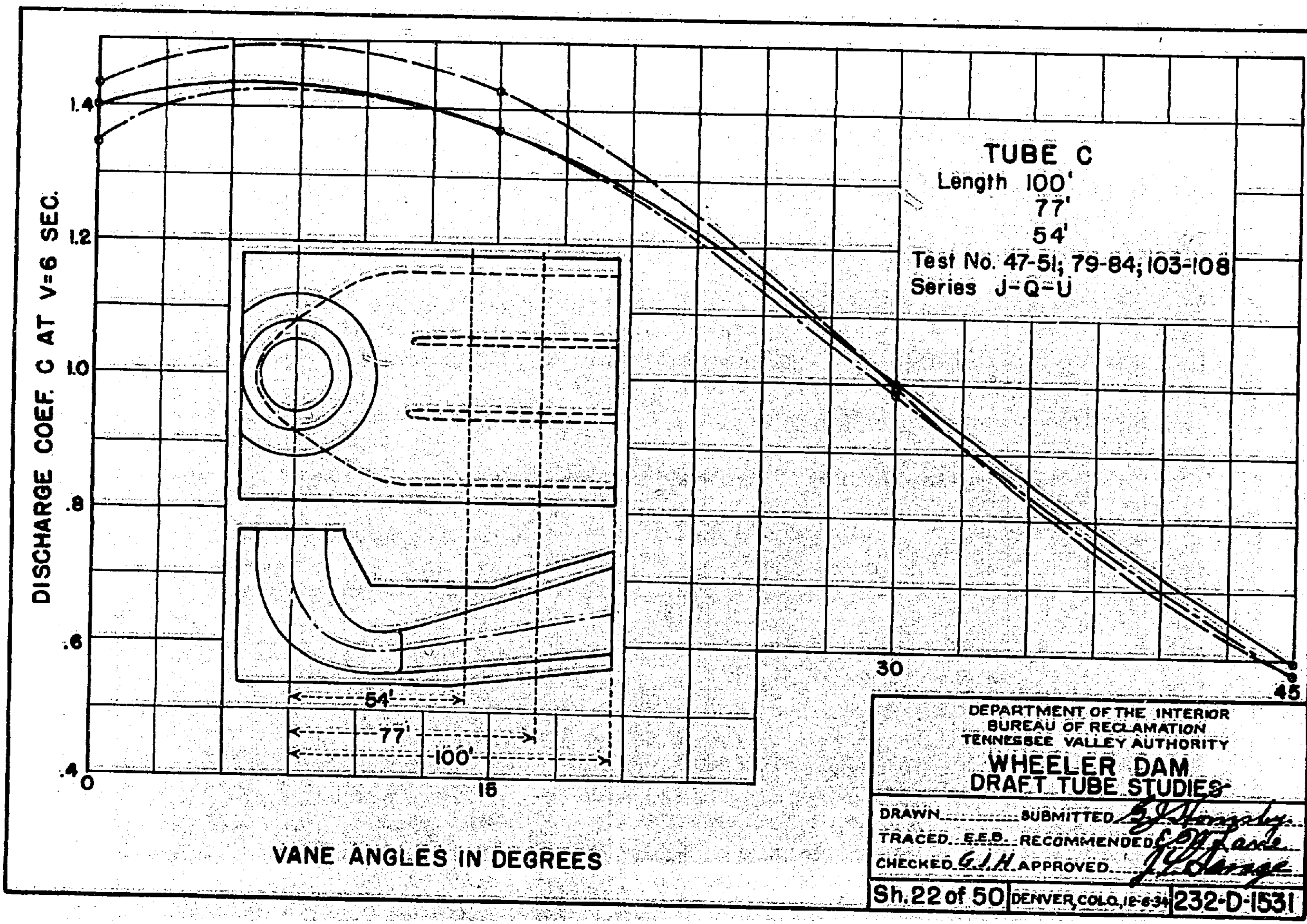



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

| | |
|---|---|
| DRAWN........... | SUBMITTED |
| TRACED. O.R.S.... | RECOMMENDED |
| CHECKED G.J.H.. | APPROVED |
| Sh. 21 of 50 | DENVER, COLO., 12-6-34 · 232-D-1530 |

FIG. 26


TUBE C
Length 100'
77'
54'
Test No. 47-51; 79-84; 103-108
Series J-Q-U
DISCHARGE COEF. C AT V=6 SEC.
VANE ANGLES IN DEGREES
1.4
1.2
1.0
.8
.6
.4
0
15
30
45
54'
77'
100'
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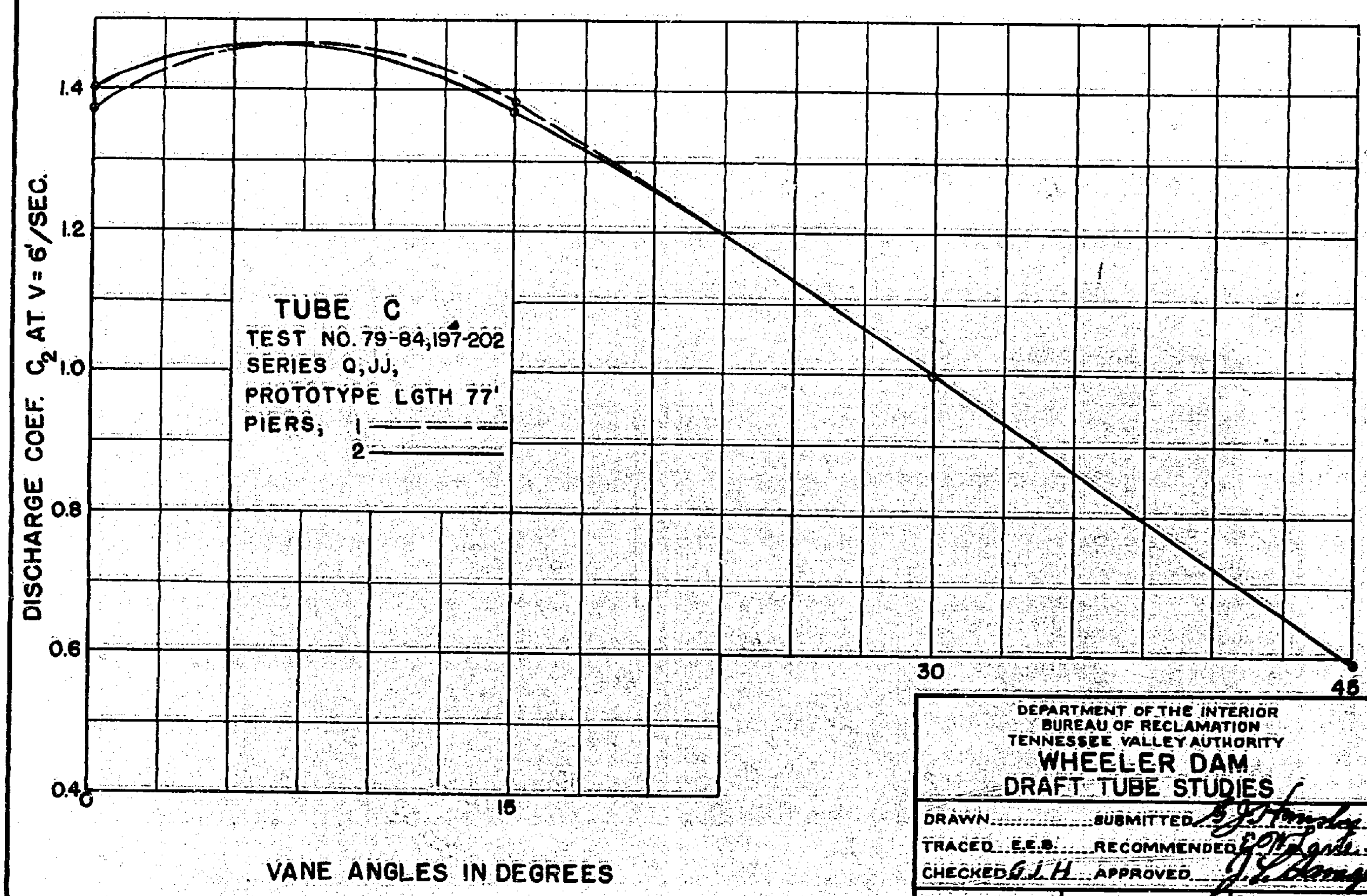
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES
DRAWN ........ SUBMITTED
TRACED E.E.B. RECOMMENDED
CHECKED G.I.H. APPROVED
Sh. 22 of 50
DENVER, COLO. 12-6-34
232-D-1531

FIG. 27

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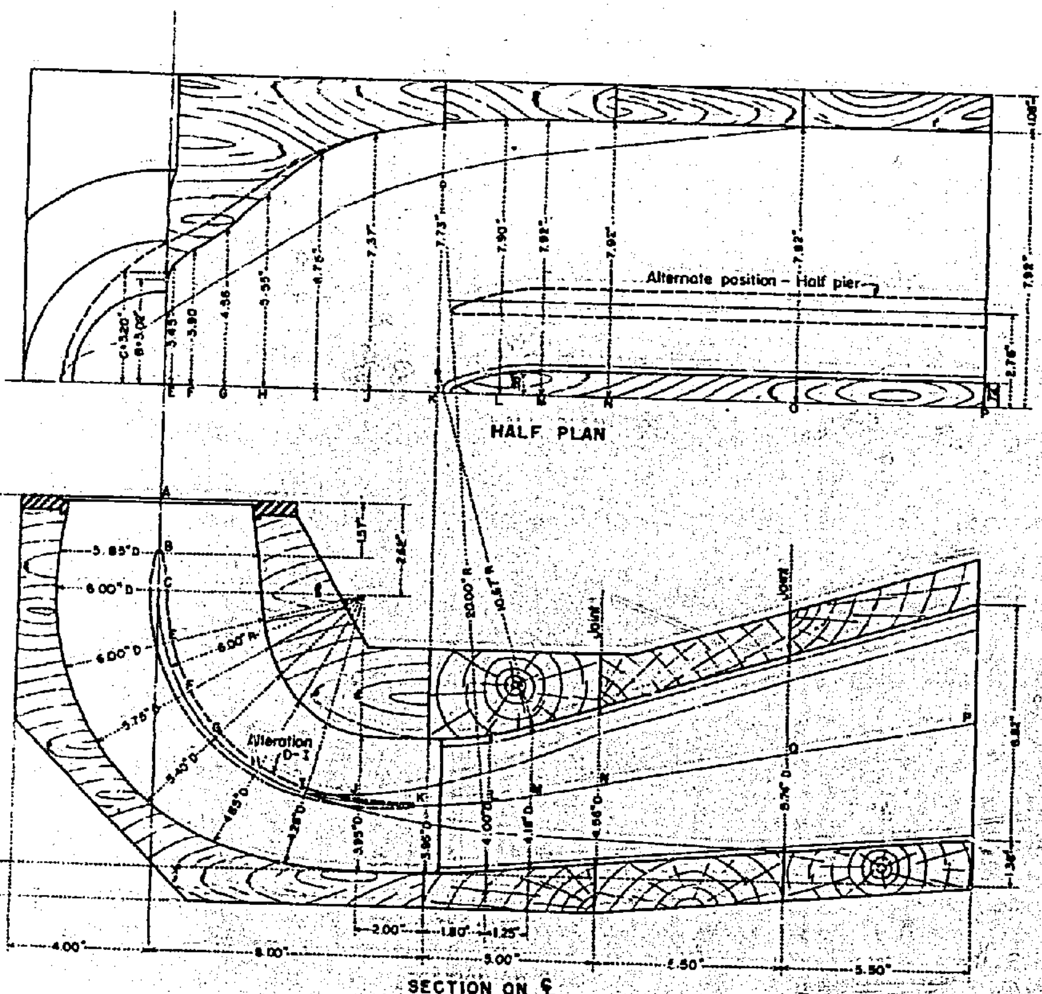
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

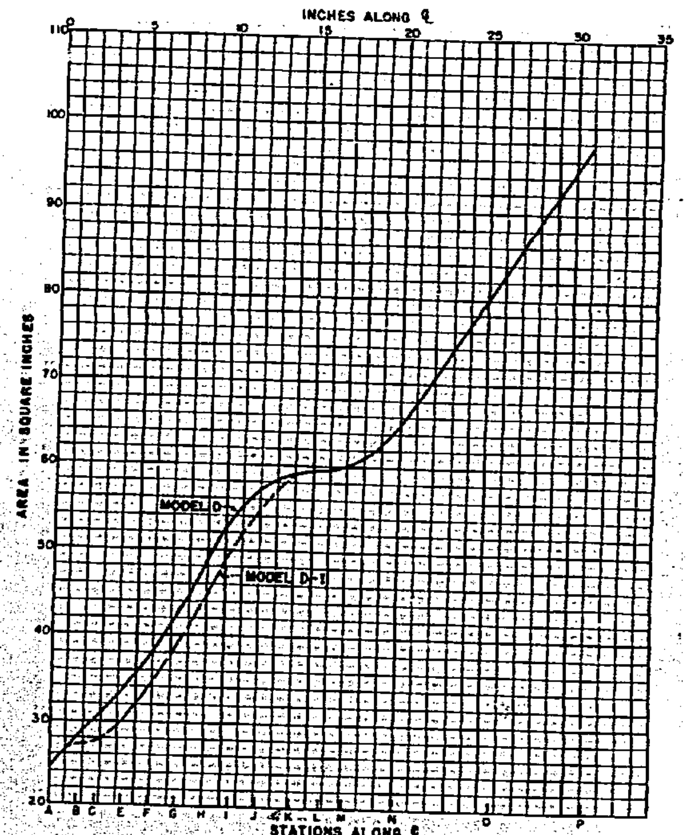
# WHEELER DAM
## DRAFT TUBE STUDIES

DRAWN ........ SUBMITTED [signature]
TRACED E.E.B. RECOMMENDED [signature]
CHECKED G.J.H. APPROVED [signature]

Sh. 23 of 50 DENVER, COLO., 12-6-34 232-D-1532

FIG. 28




**DRAFT TUBE MODEL D, WITH ALTERATION D-1**

MODEL RATIO 1:50

SCALE IN INCHES

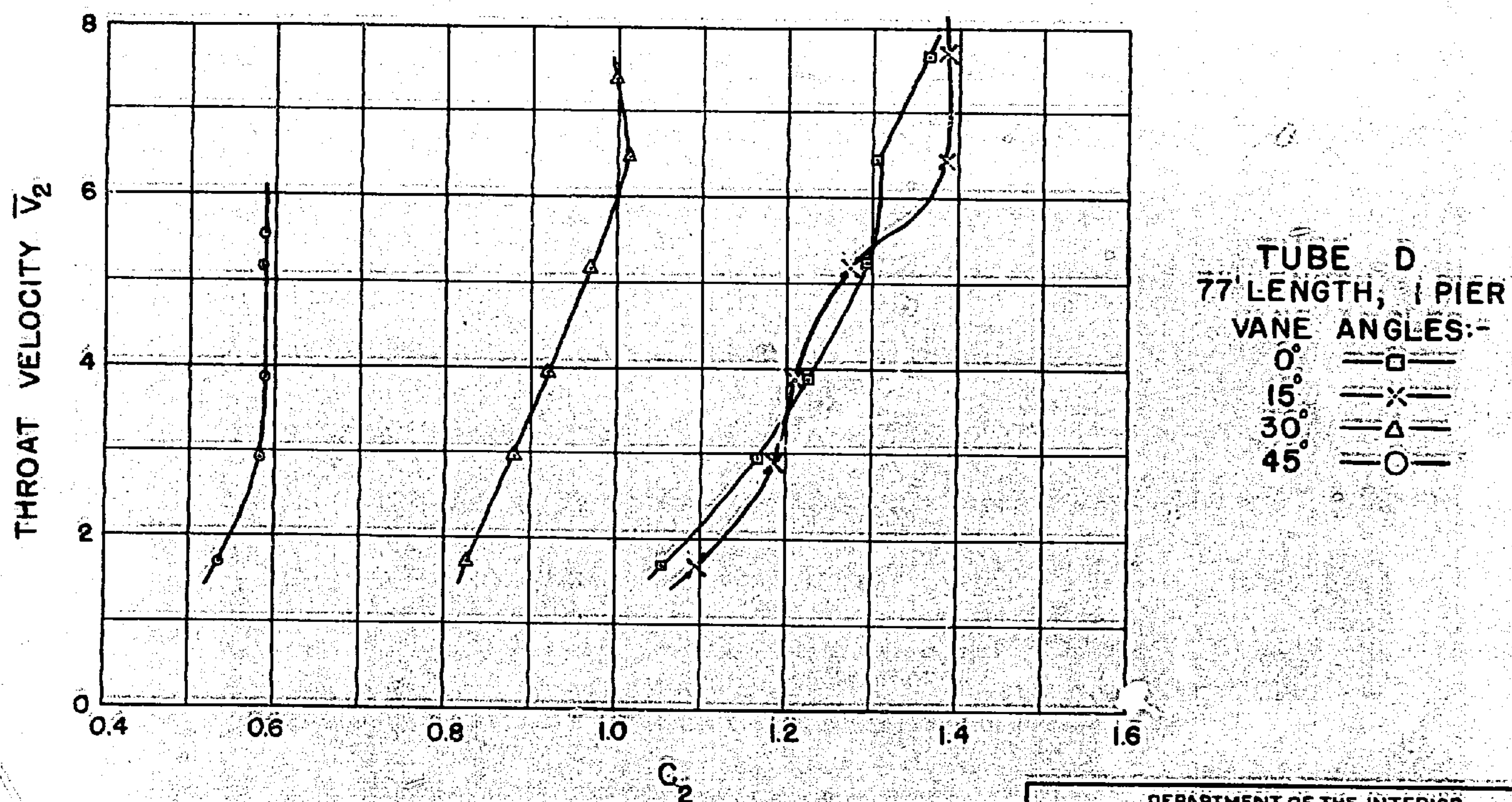
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

**WHEELER DAM**
**DRAFT TUBE STUDIES**

DRAWN E.C.P. SUBMITTED
TRACED R.H.S. RECOMMENDED
CHECKED E.J.H. APPROVED
Sheet 4 of 6 DENVER, COLO. MAR. 28, 1934 232-D-1563

FIG. 29

FIG. 30

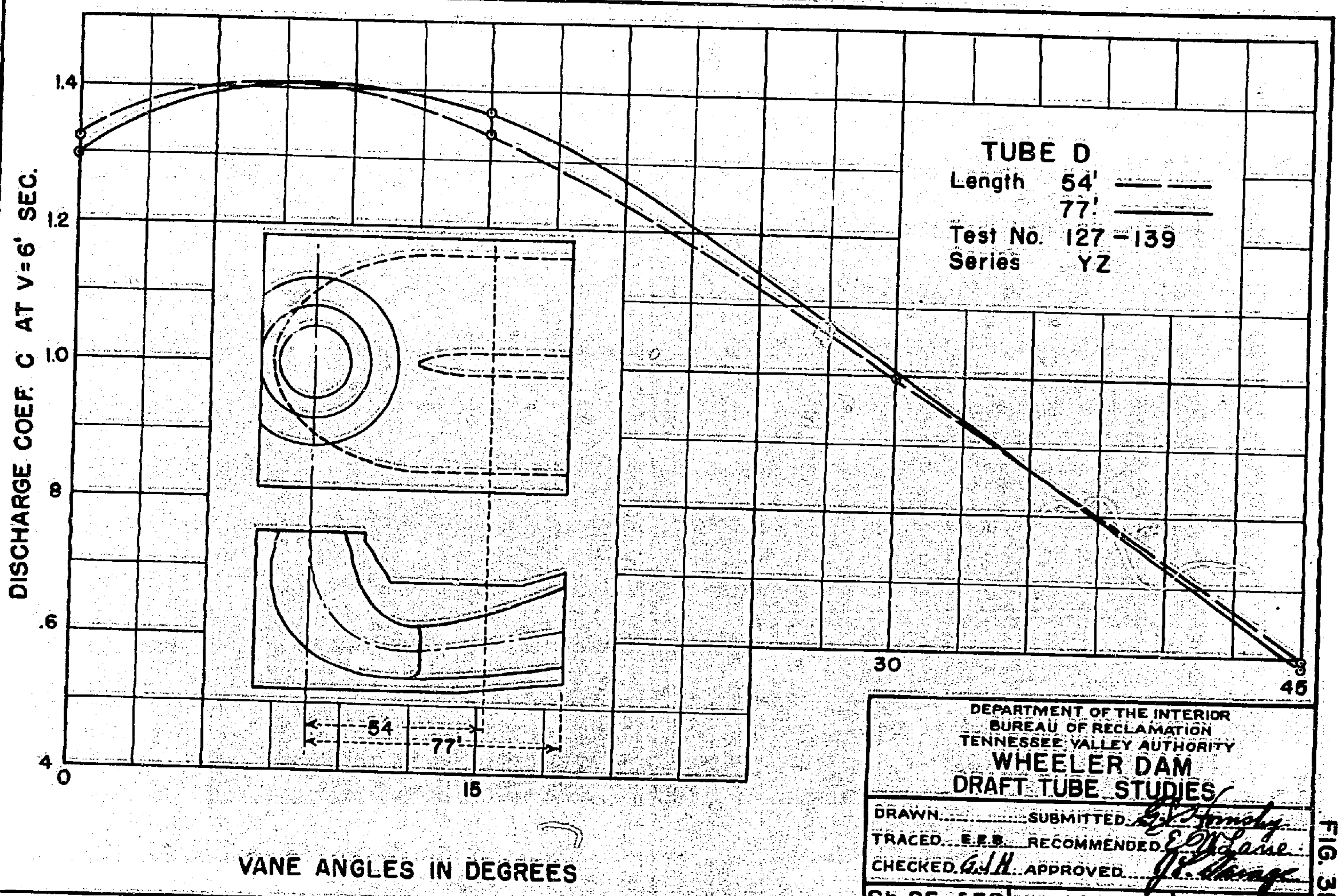



DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

WHEELER DAM
DRAFT TUBE STUDIES

DRAWN: ........ SUBMITTED E. J. Hornsby
TRACED: E.E.B. RECOMMENDED E. W. Lane
CHECKED G.J.H. APPROVED J. L. Savage

Sh. 24 of 50 | DENVER, COLO. 12-4-34 | 232-D-1533




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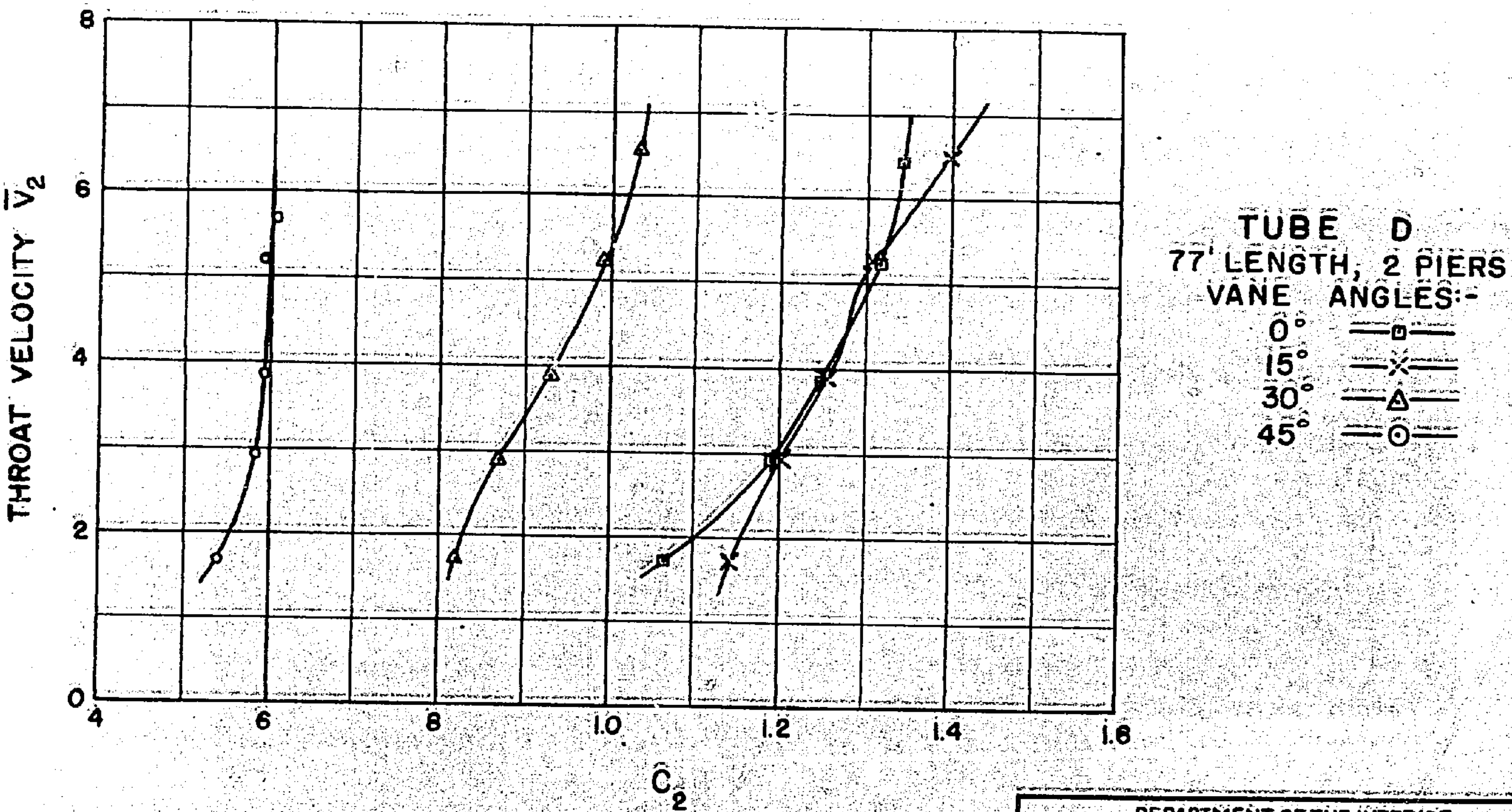
TENNESSEE VALLEY AUTHORITY
WHEELER DAM
DRAFT TUBE STUDIES

DRAWN ........ SUBMITTED ........
TRACED E.B.B. RECOMMENDED ........
CHECKED G.J.H. APPROVED ........

Sh. 25 of 50 DENVER, COLO., 12-6-34 232-D-1534

FIG. 31

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BUREAU OF RECLAMATION
TENNESSEE VALLEY AUTHORITY

**WHEELER DAM**
**DRAFT TUBE STUDIES**

DRAWN........ SUBMITTED [signature]
TRACED O.R.S. RECOMMENDED [signature]
CHECKED [initials] APPROVED [signature]

Sh. 26 of 50 | DENVER, COLO. 12-6-34 | 232-D-1535

FIG. 32

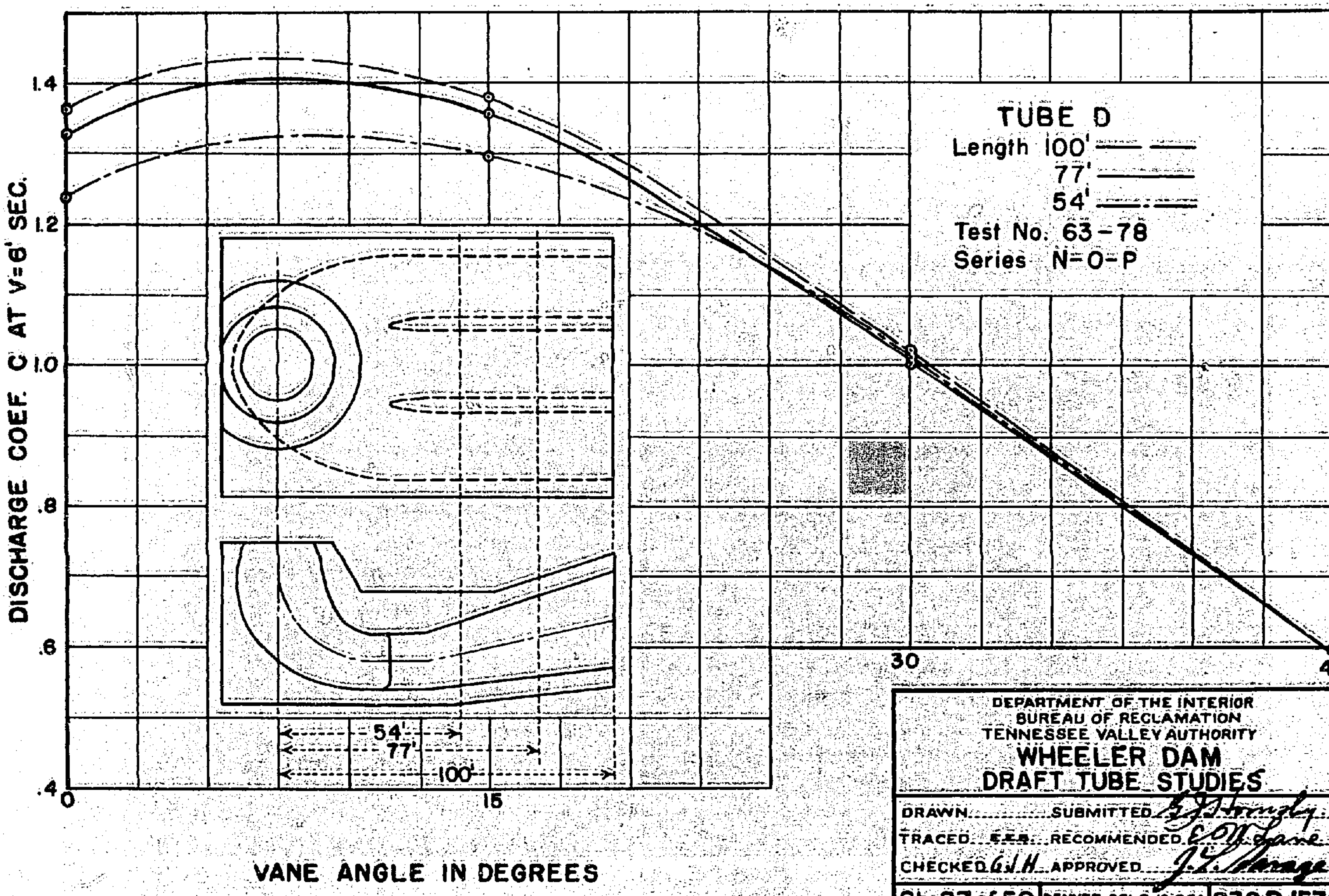


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FIG. 33

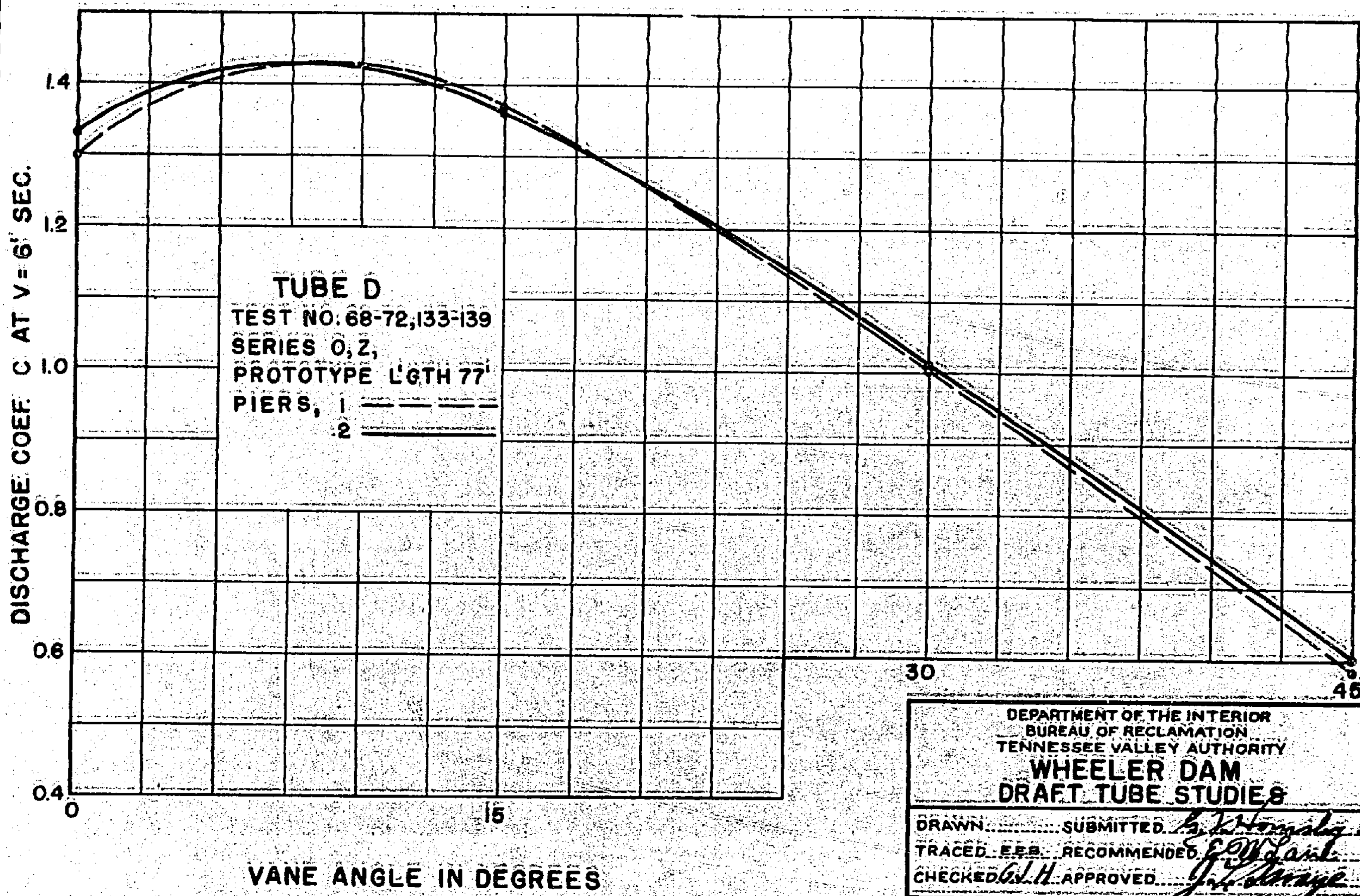


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FIG. 34

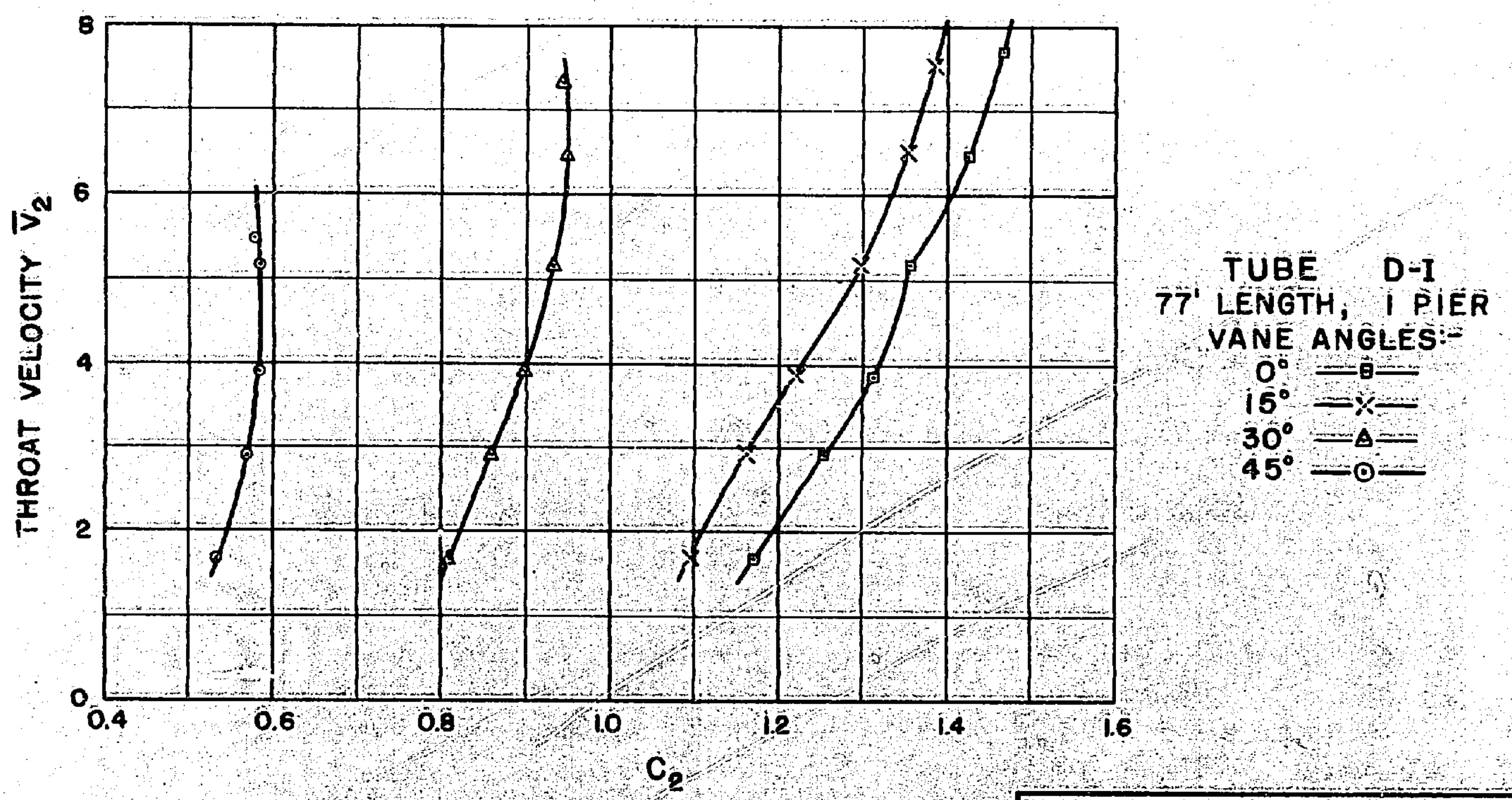


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FIG. 35

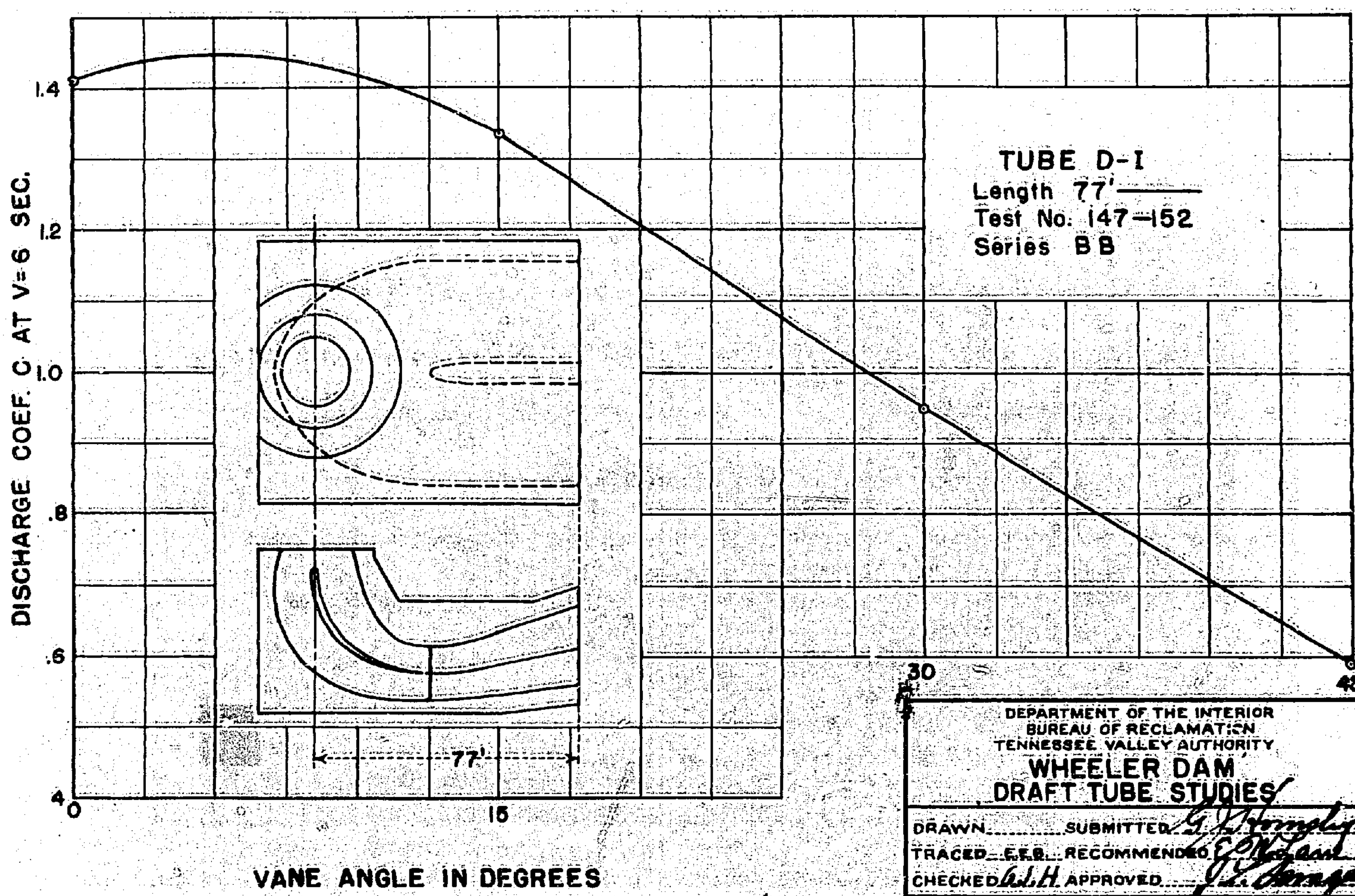


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FIG. 36

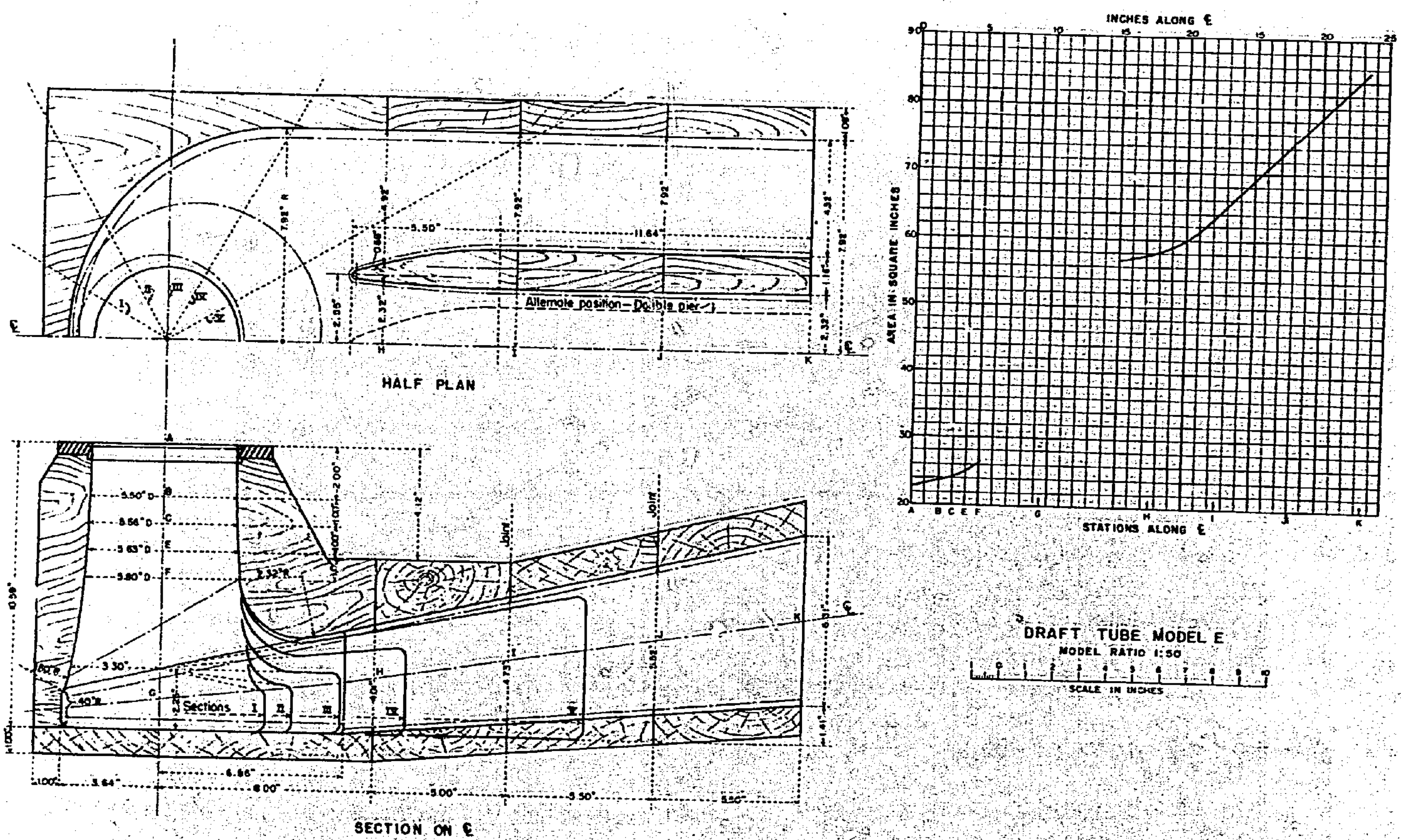


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FIG. 37

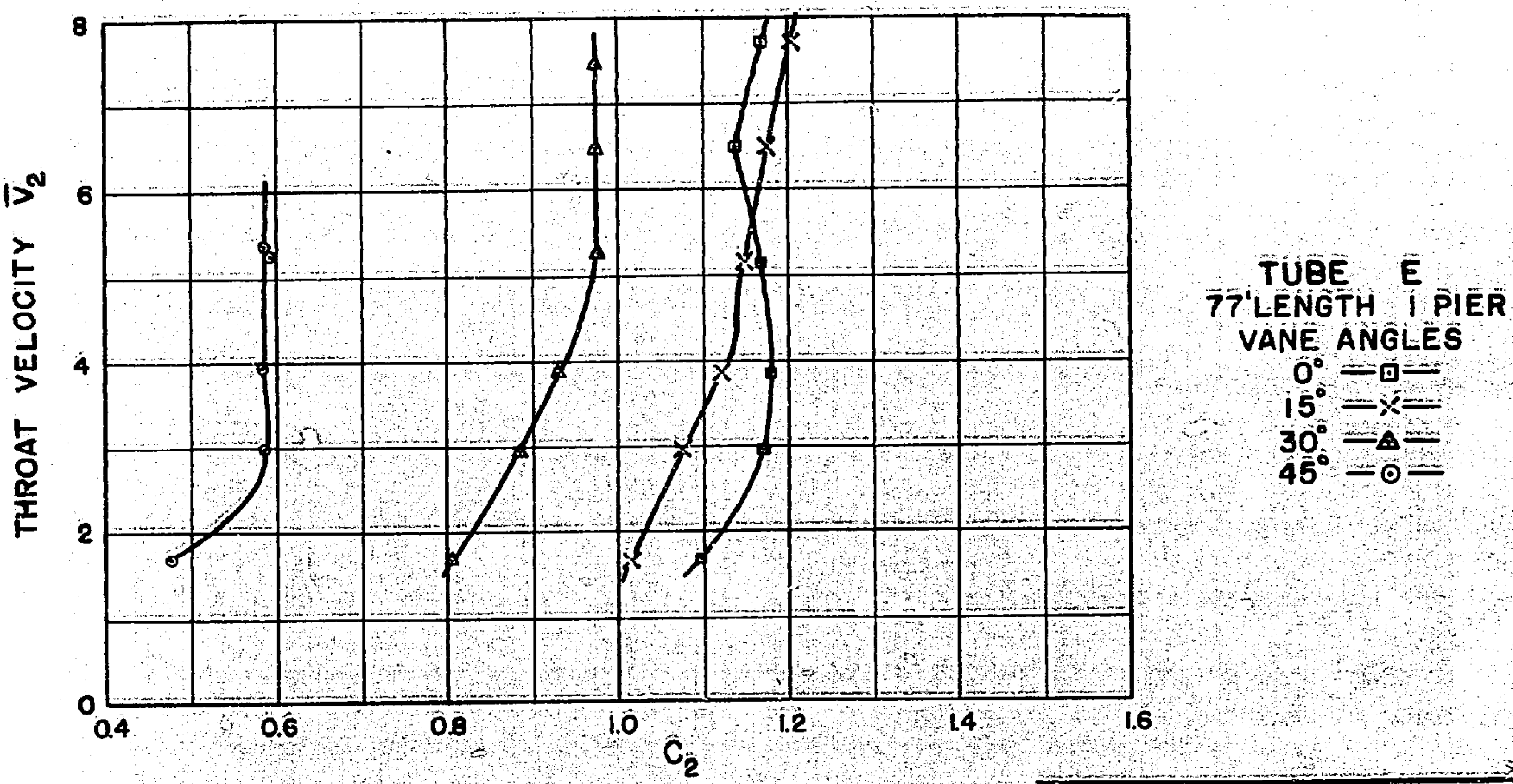


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FIG. 38

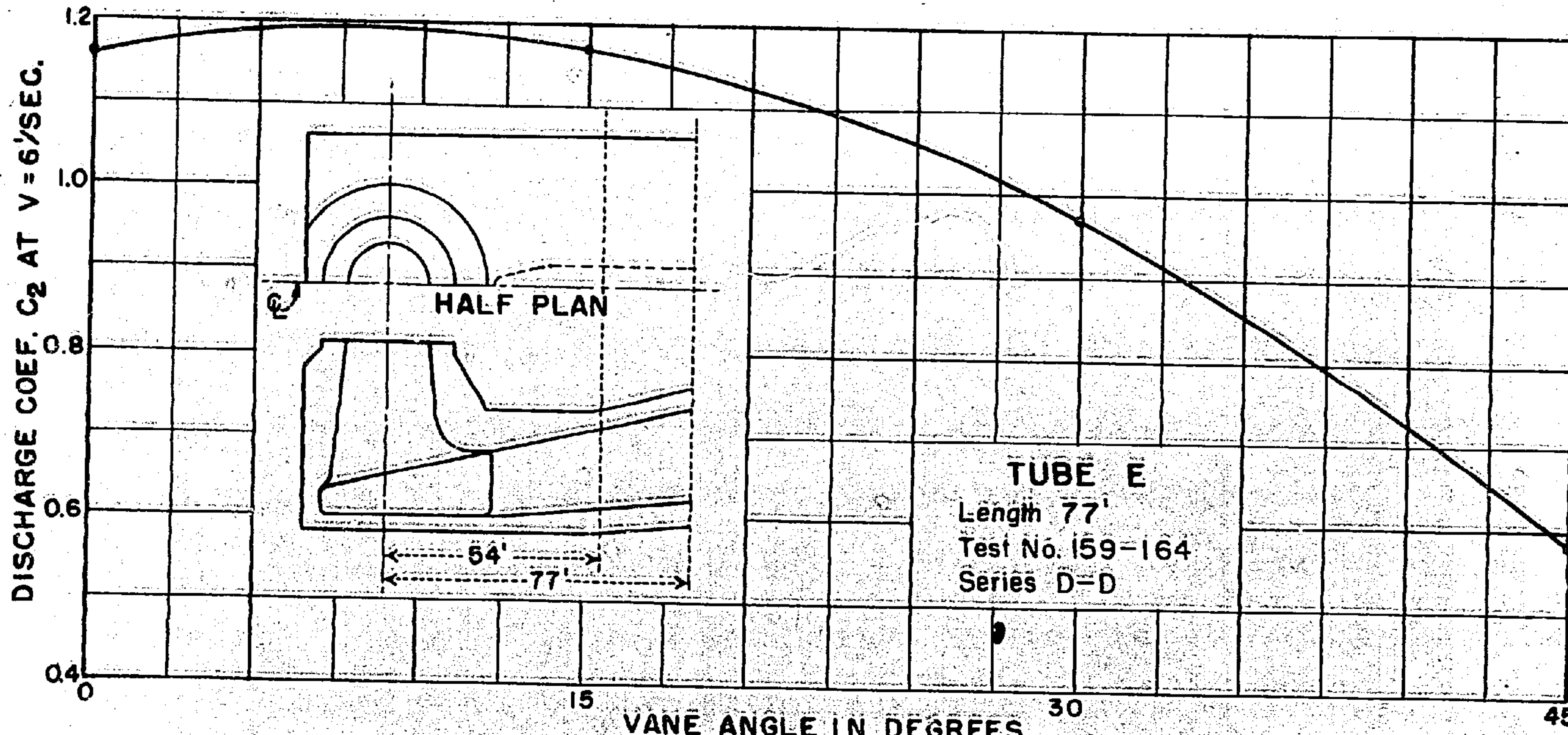


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FIG. 39

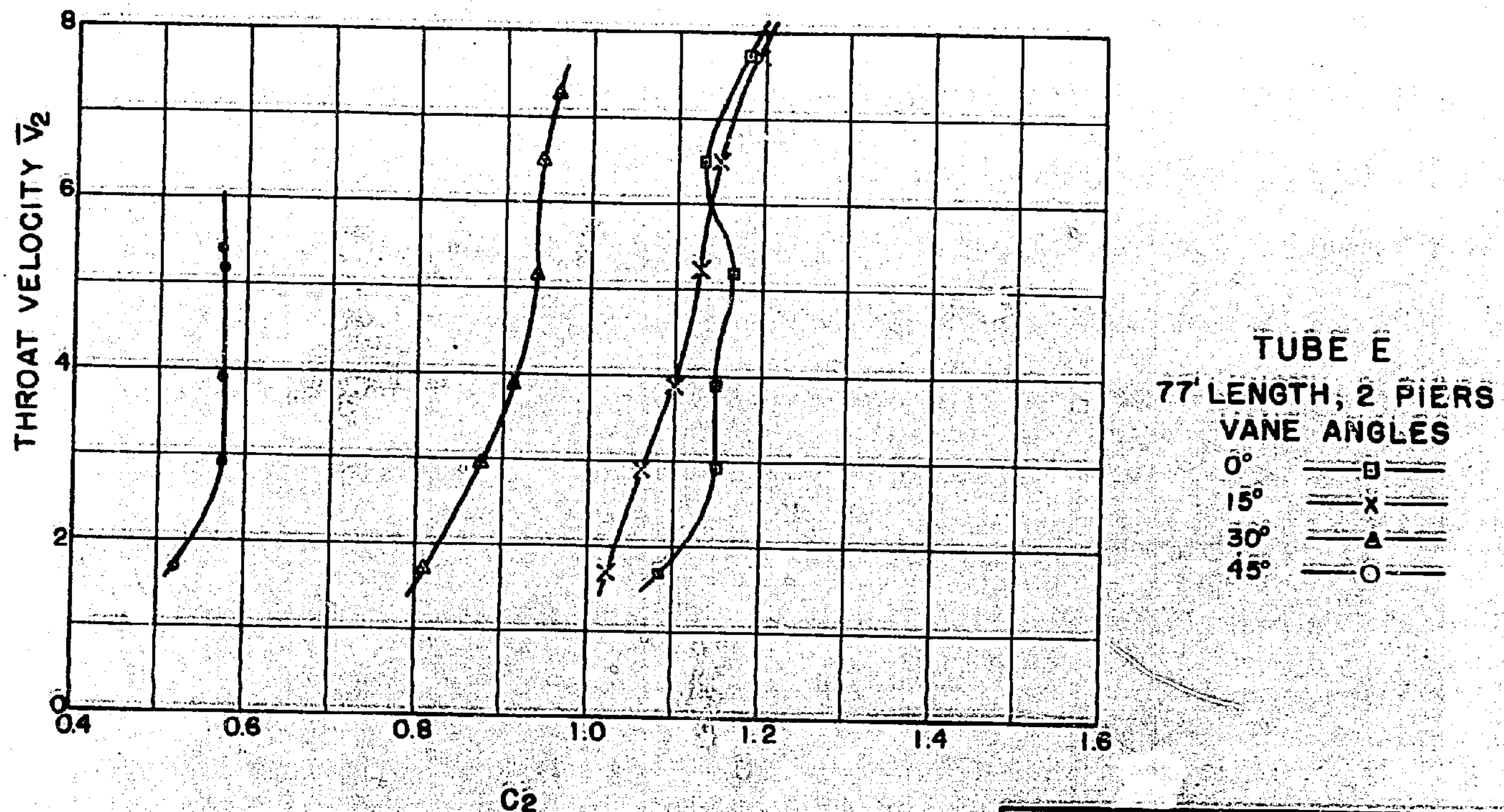


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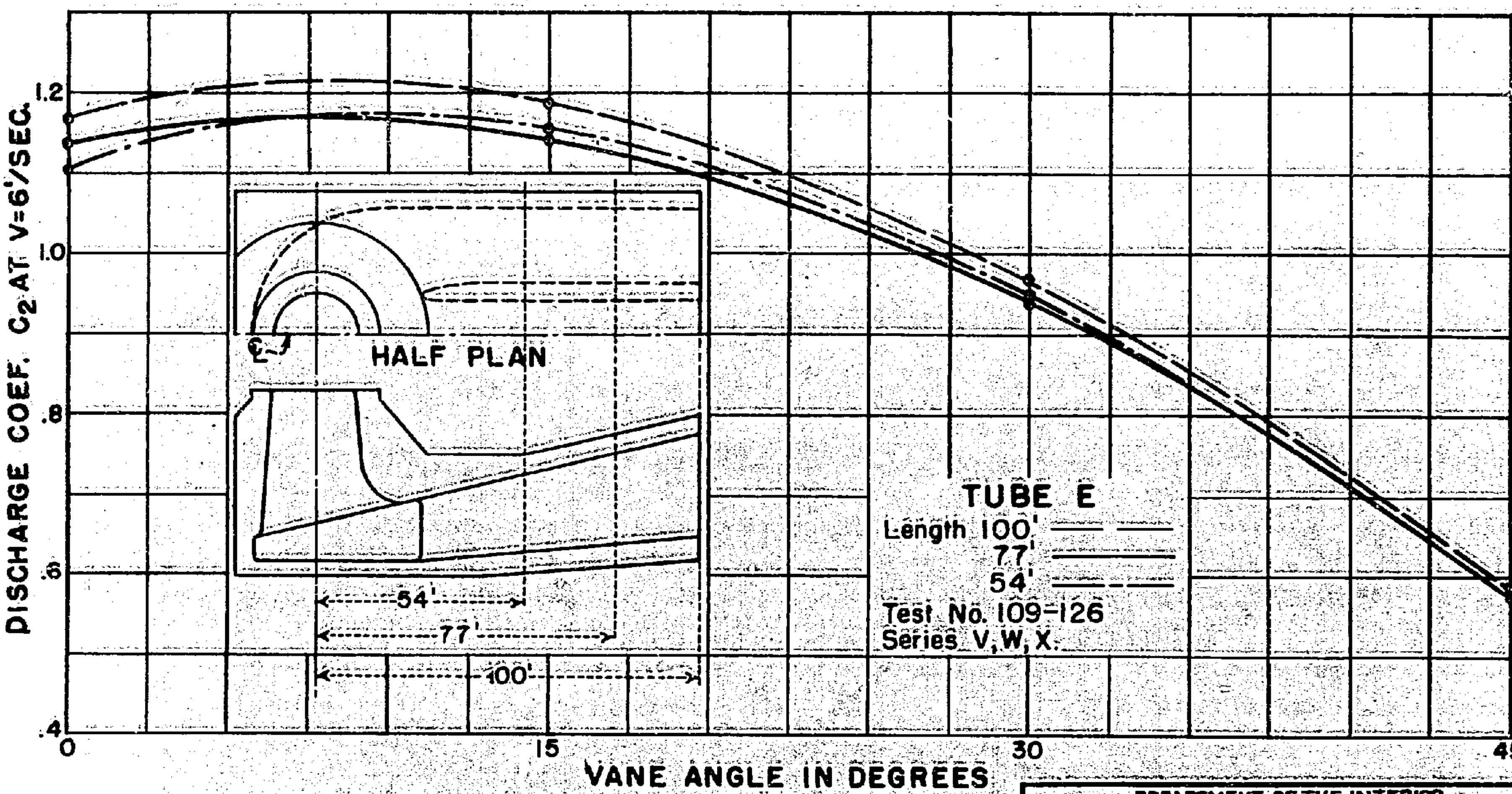
FIG. 40

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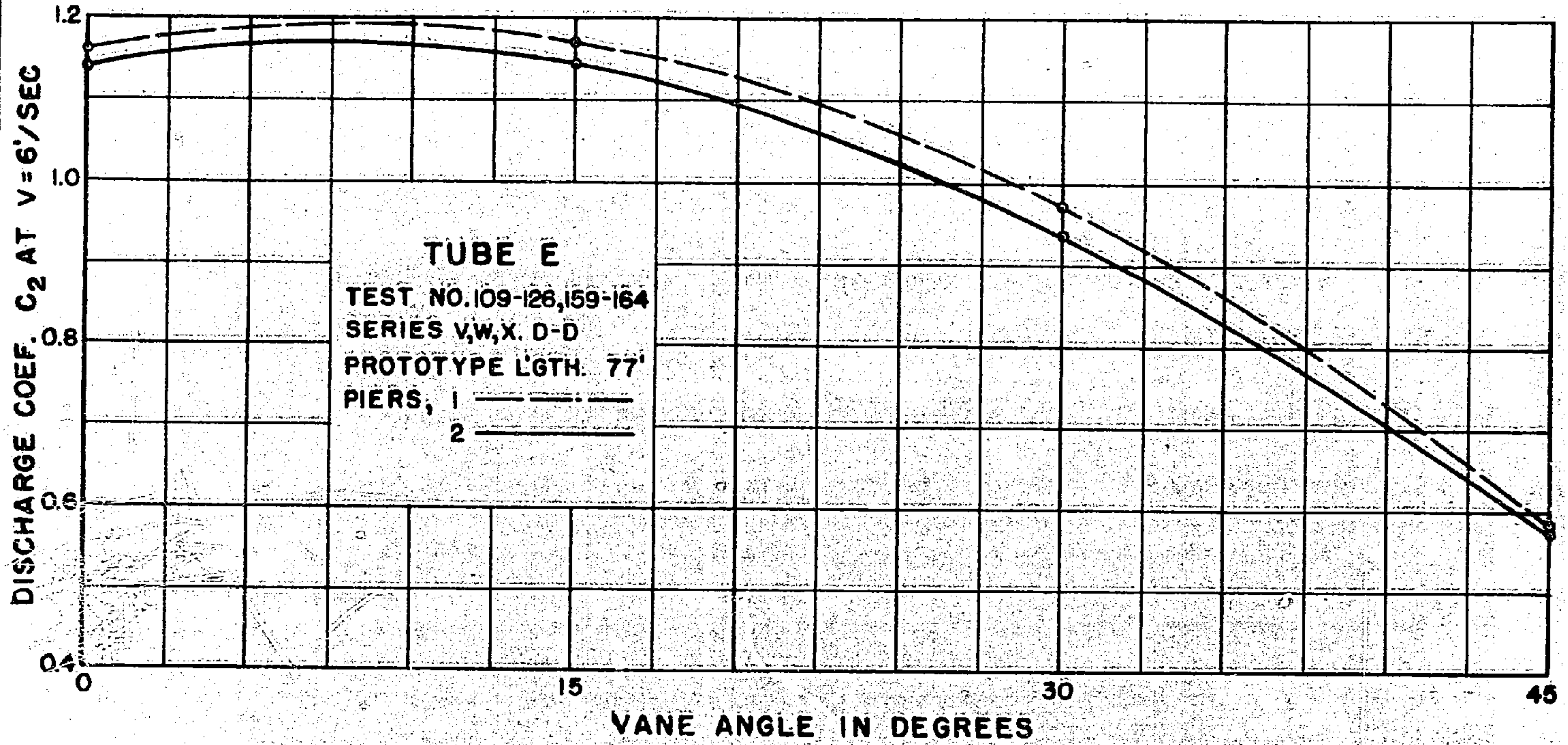
Sh. 34 of 50 DENVER, COLO., 12-6-34 232-D-1543

FIG. 41

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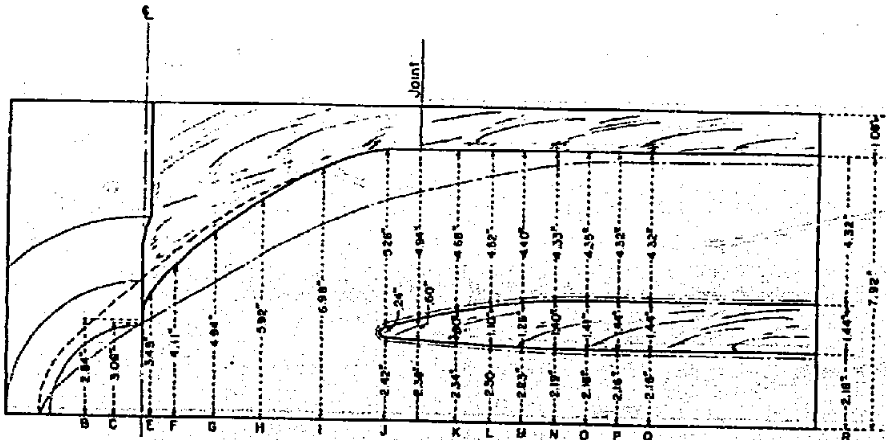
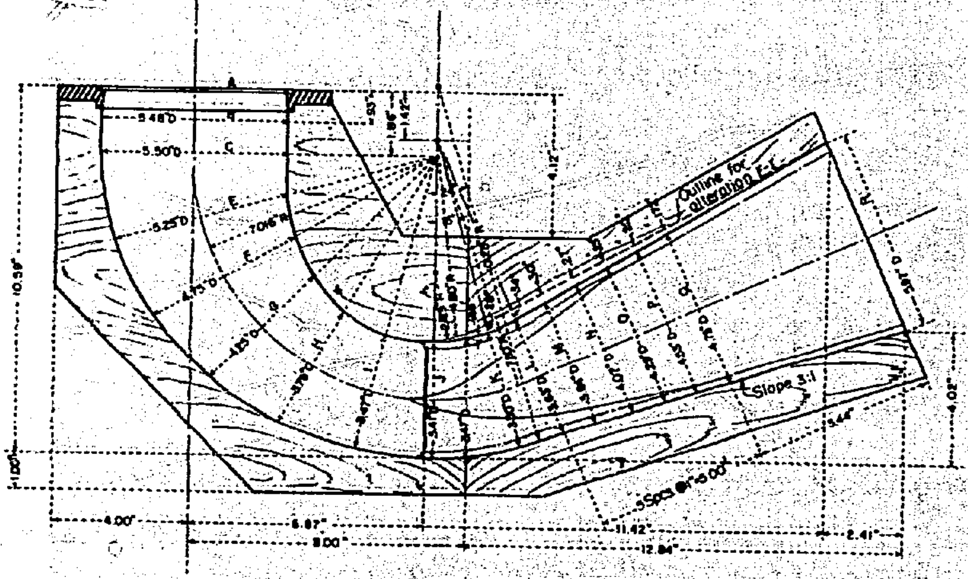
| Sh 35 of 50 | DENVER, COLO. 12-6-34 |
| 232-D-1544 | |

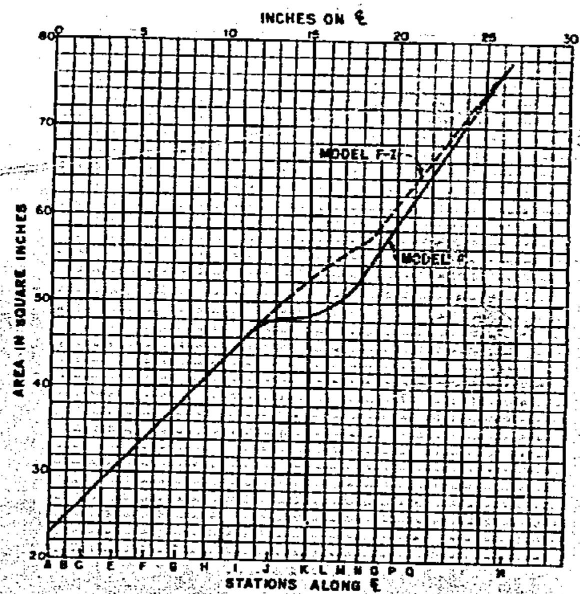
FIG. 42




HALF PLAN




SECTION ALONG ℄




# DRAFT TUBE MODEL F WITH ALTERATION F-1

MODEL RATIO 1:50

SCALE IN INCHES

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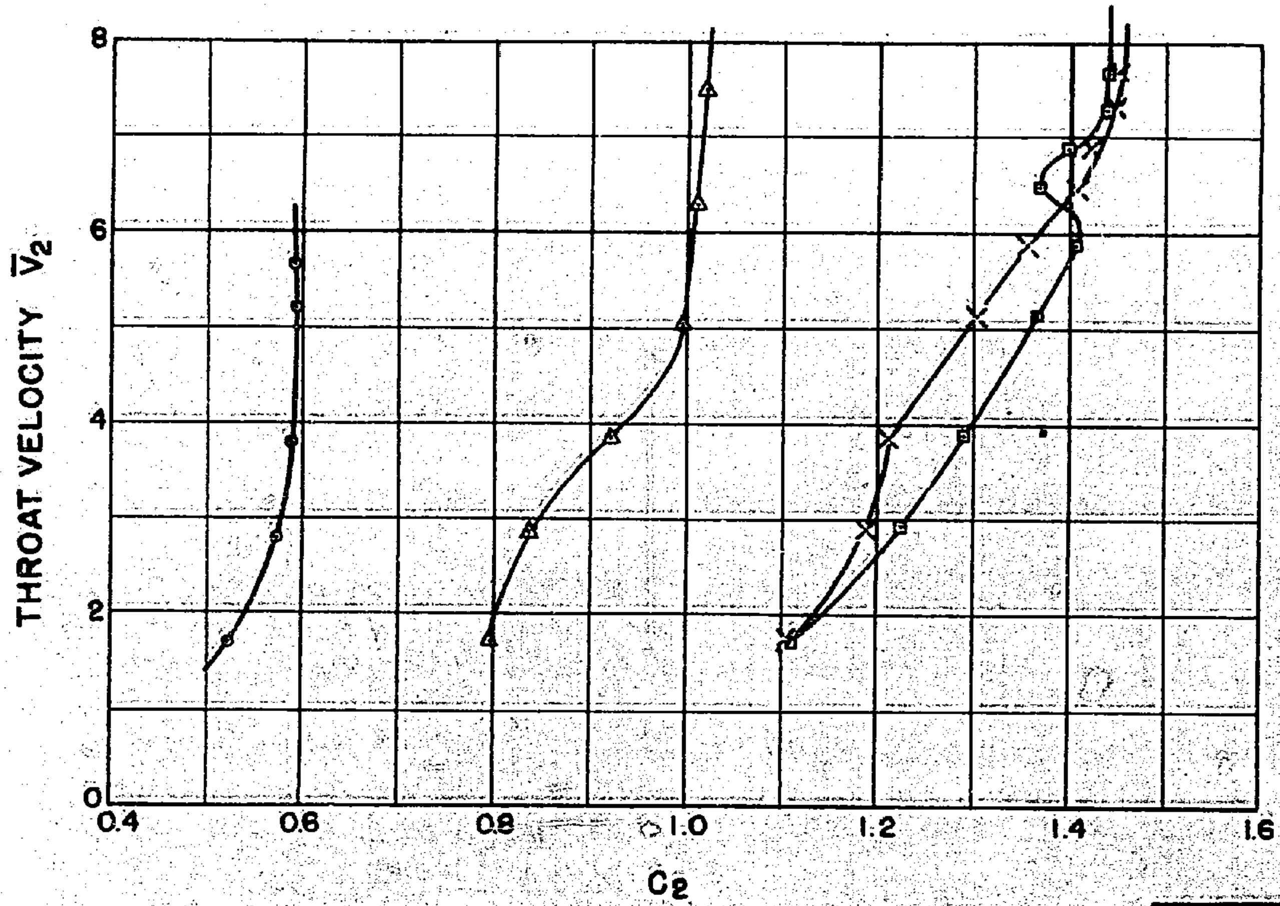
FIG. 43

FIG. 44




TUBE-F
77' LENGTH 2 PIERS
VANE ANGLES
0° —□—
15° —x—
30° —Δ—
45° —⊙—

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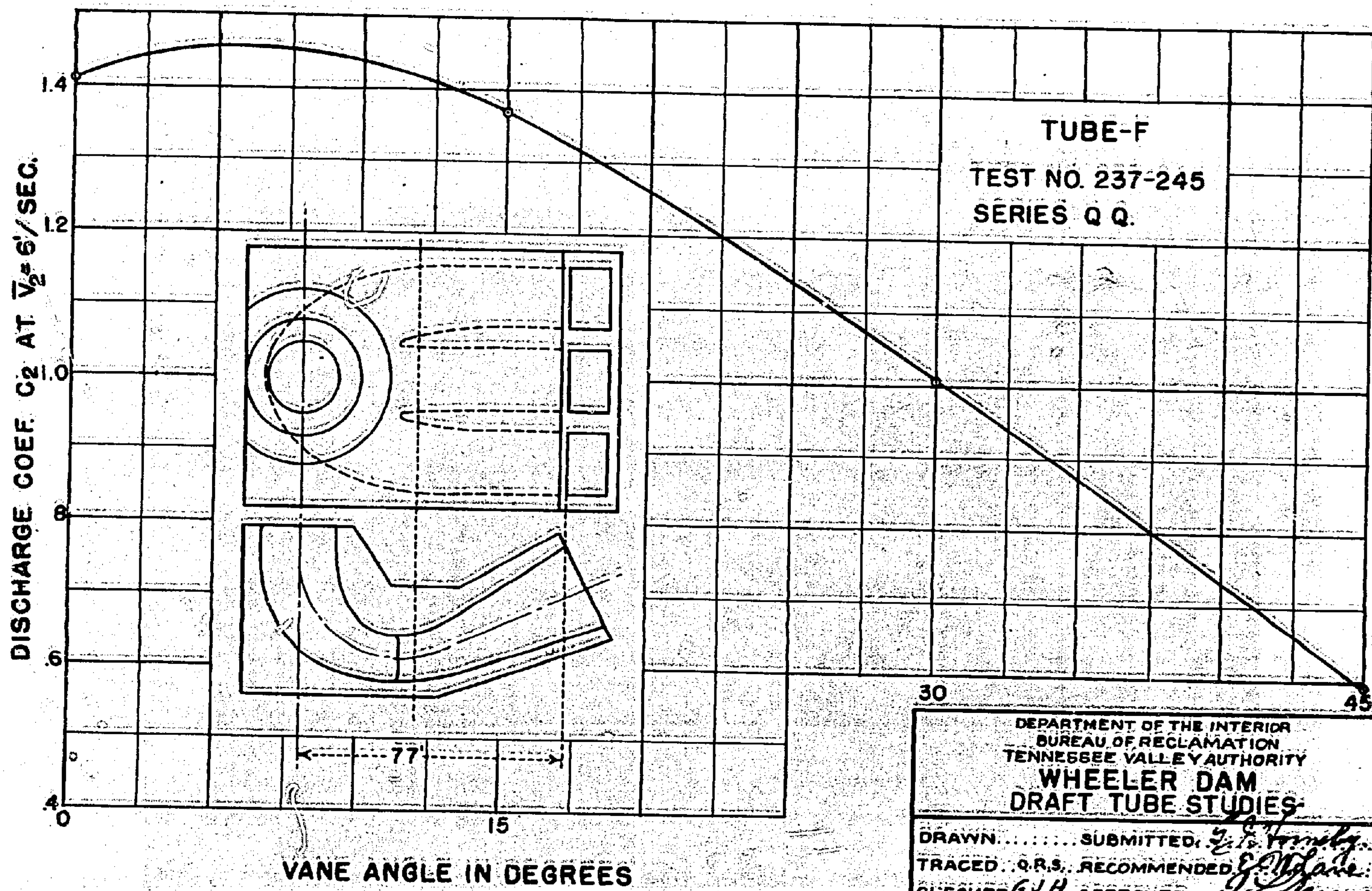


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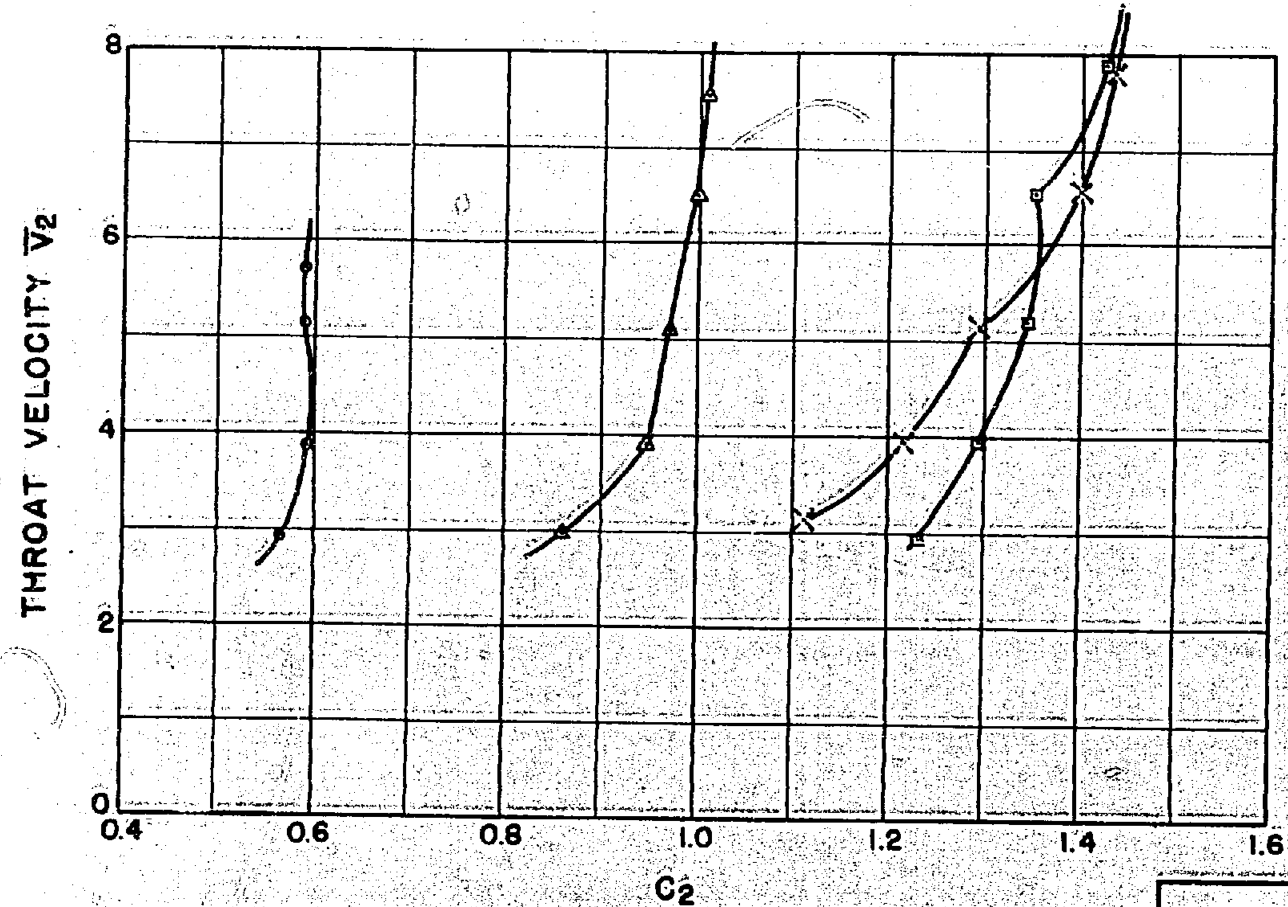
FIG. 45




TUBE F-1

77' LENGTH 2 PIERS

VANE ANGLES

| | |
|---|---|
| 0° | —⊡— |
| 15° | —×— |
| 30° | —△— |
| 45° | —⊙— |

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FIG. 46

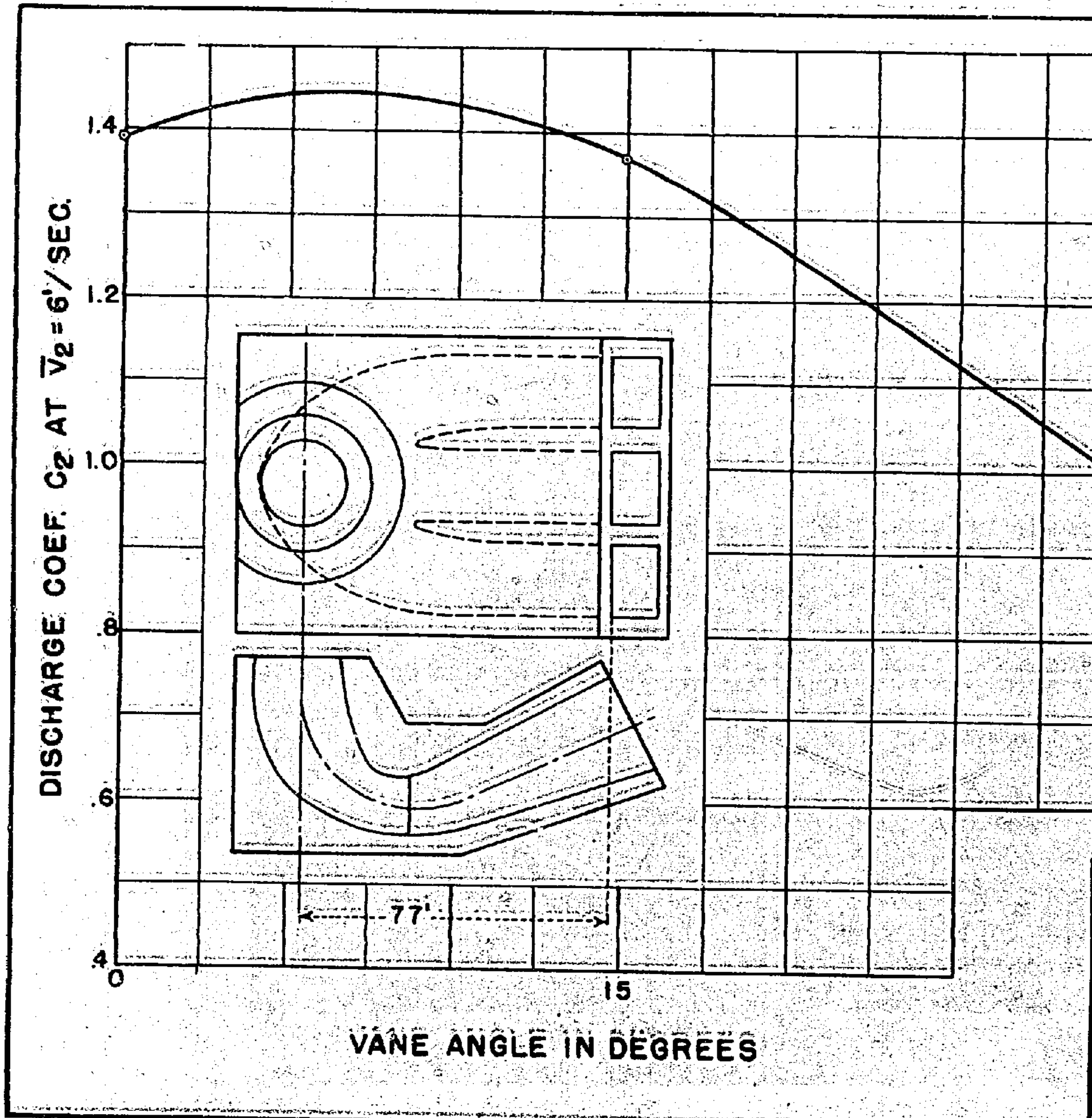


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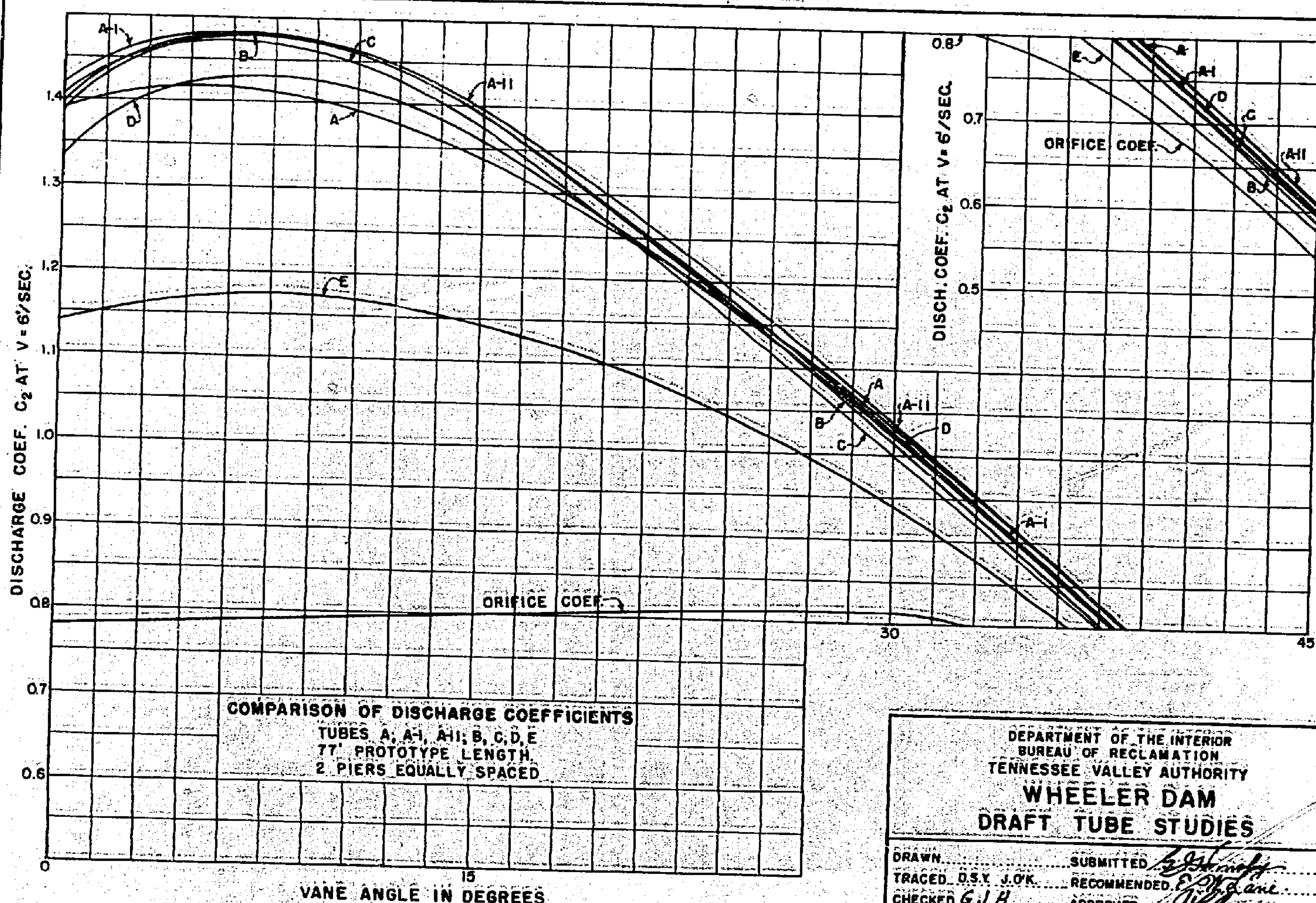
FIG. 48

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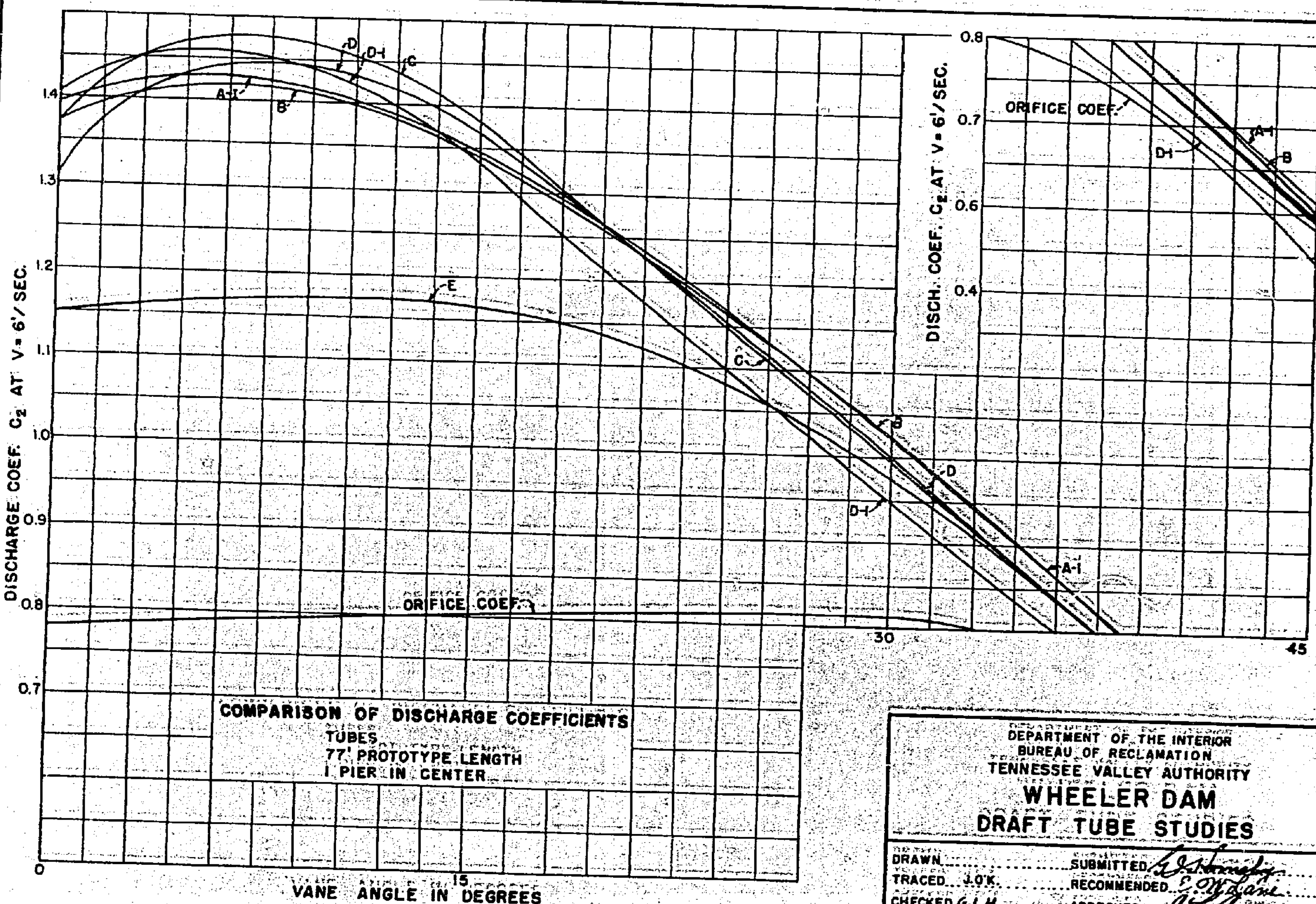
Sheet 44 of 50 | DENVER, COLO. DEC. 6, 1934 | 232-D-1553

FIG. 49




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

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FIG. 50

FIG. 51

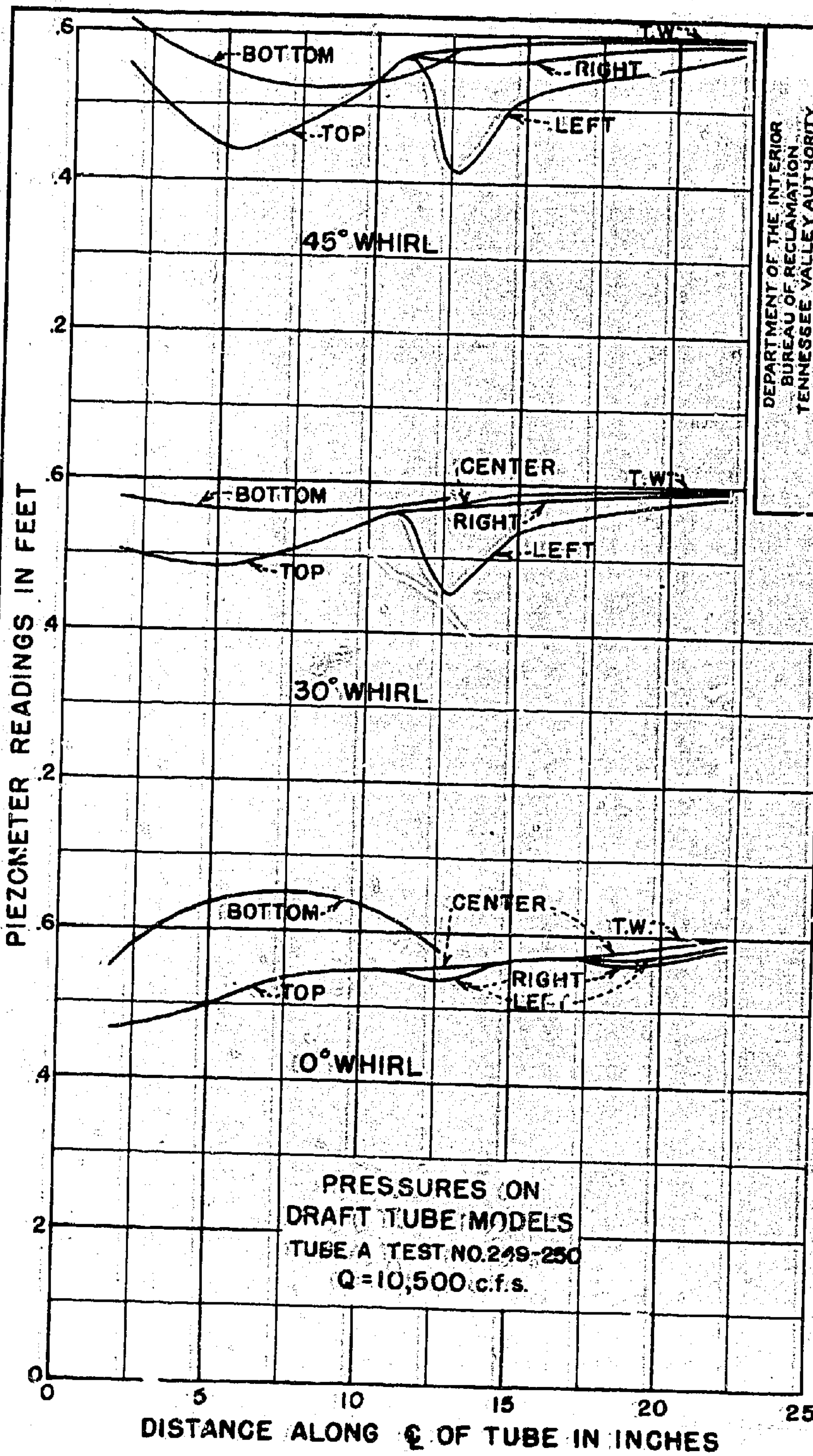


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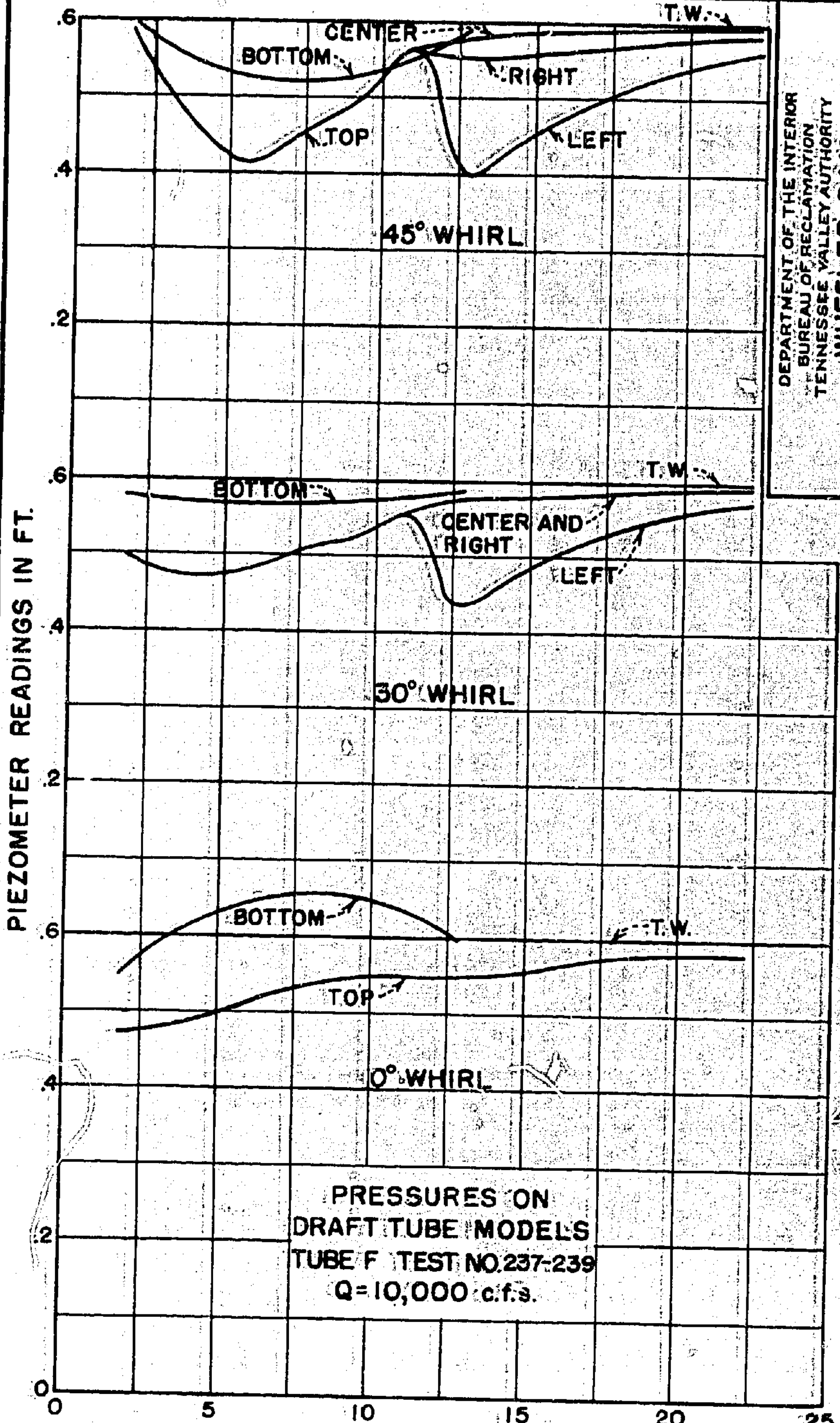
FIG. 52




PRESSURES ON
DRAFT TUBE MODELS
TUBE F TEST NO. 237-239
Q=10,000 c.f.s.

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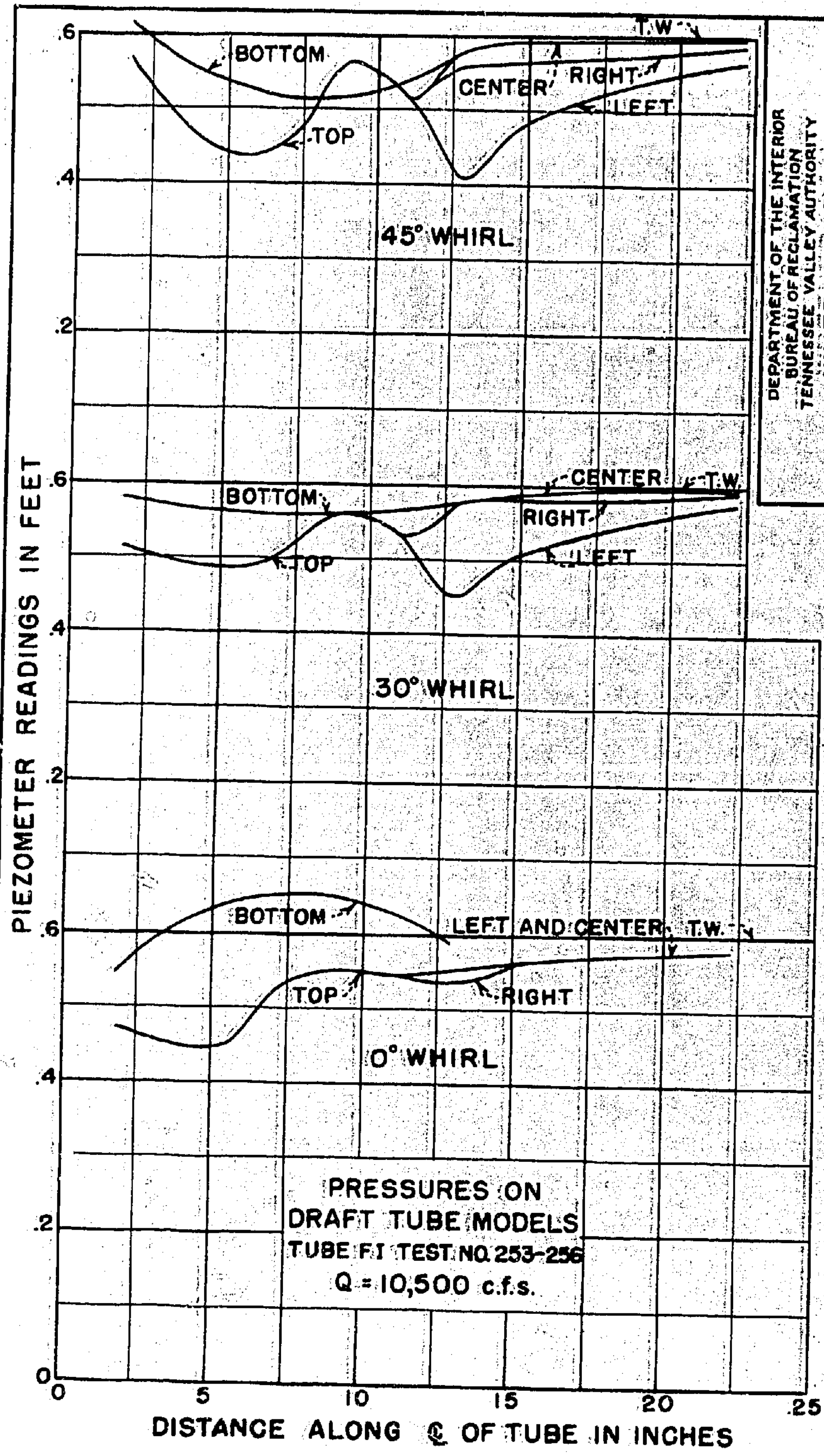
FIG. 53

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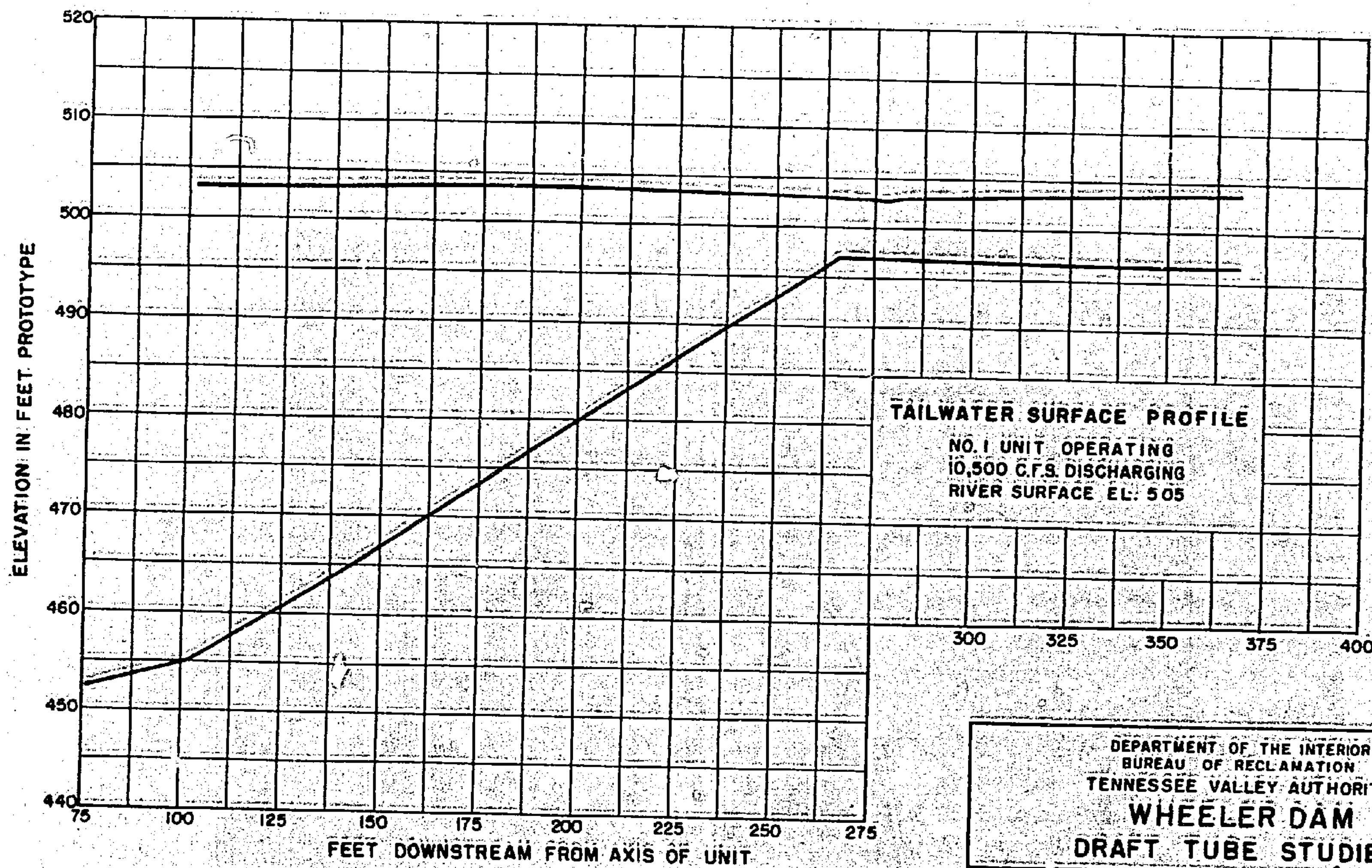
232-D-1551

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232-D-1555

FIG. 54

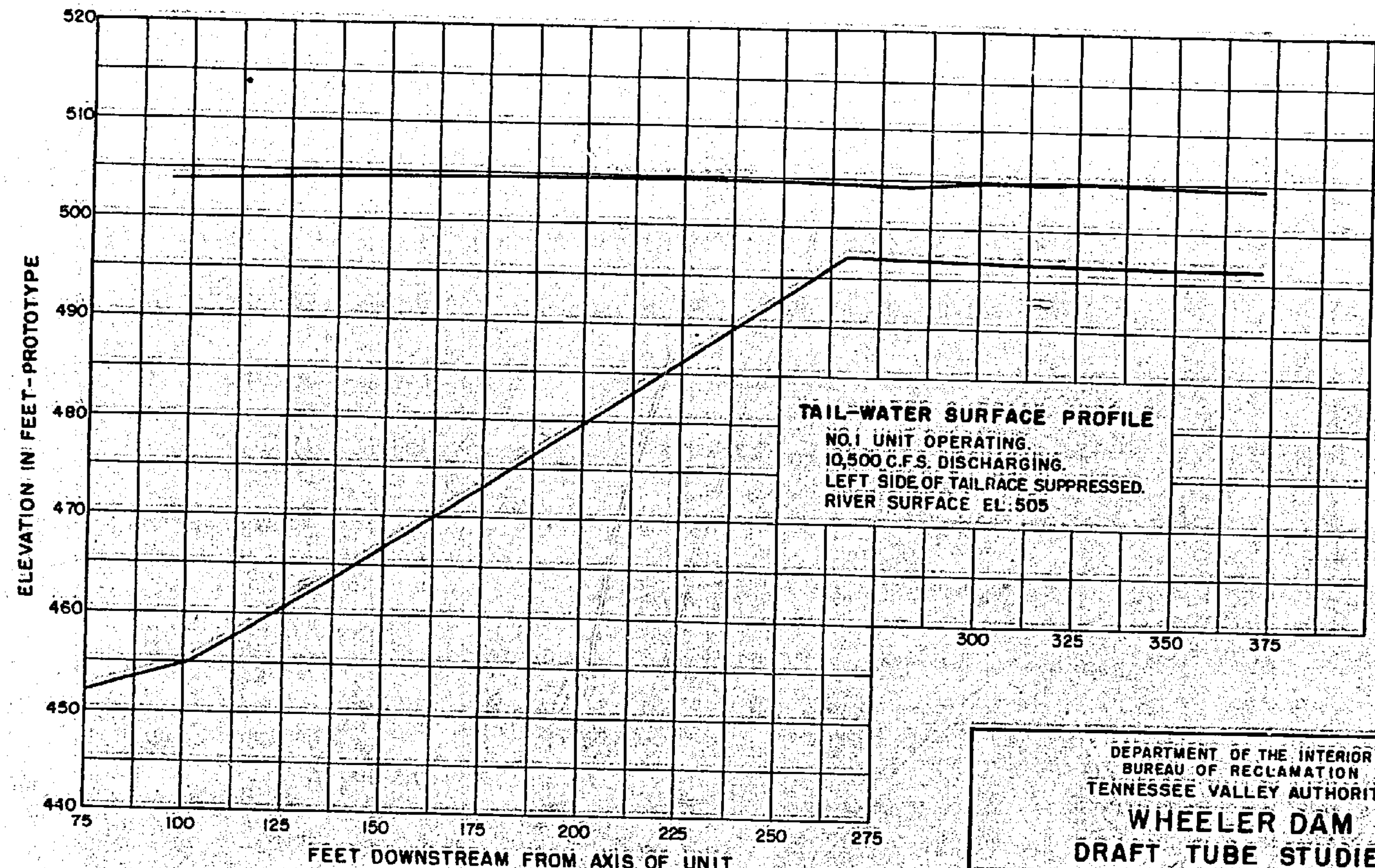


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FIG. 55

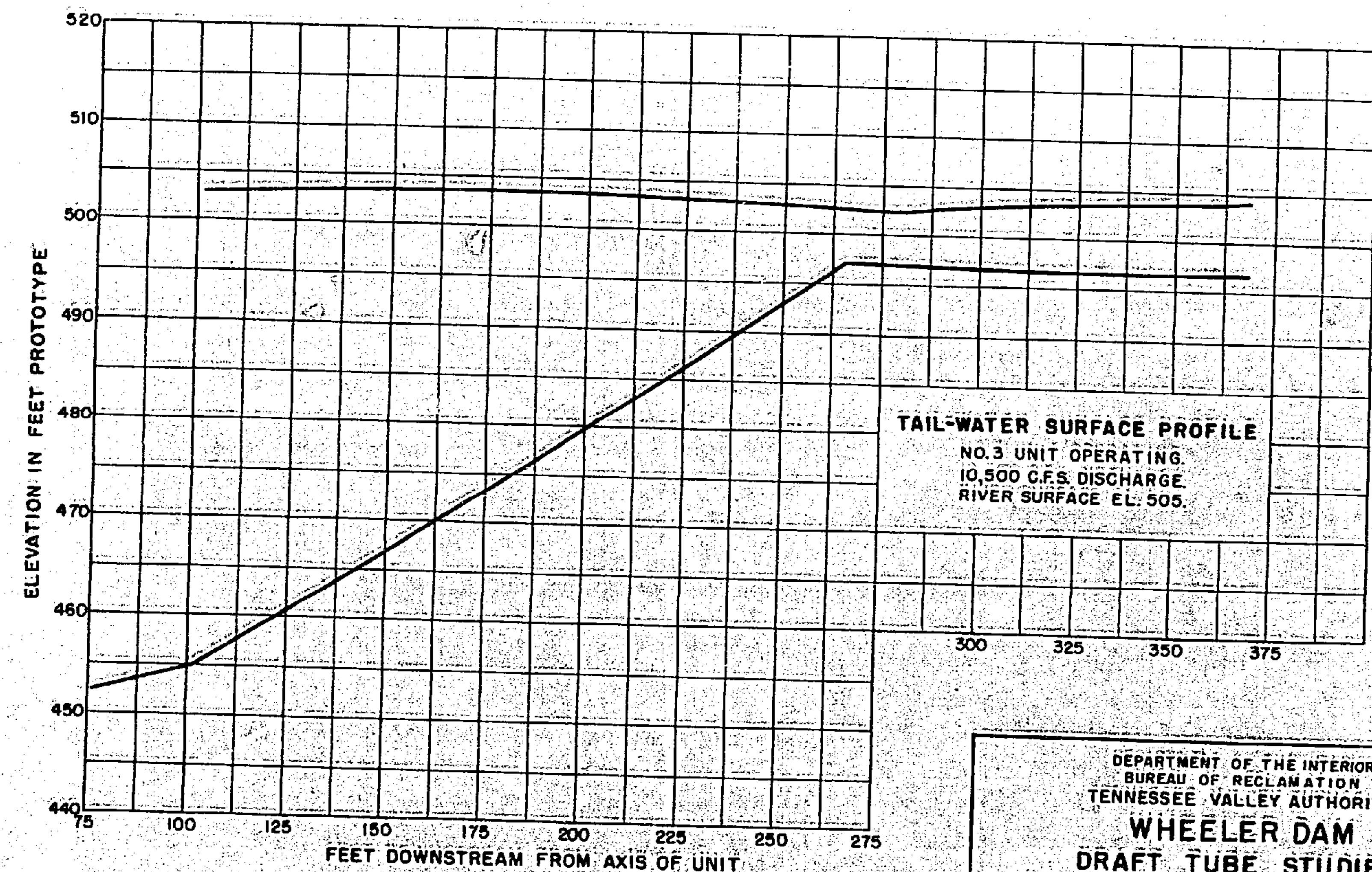


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FIG. 56

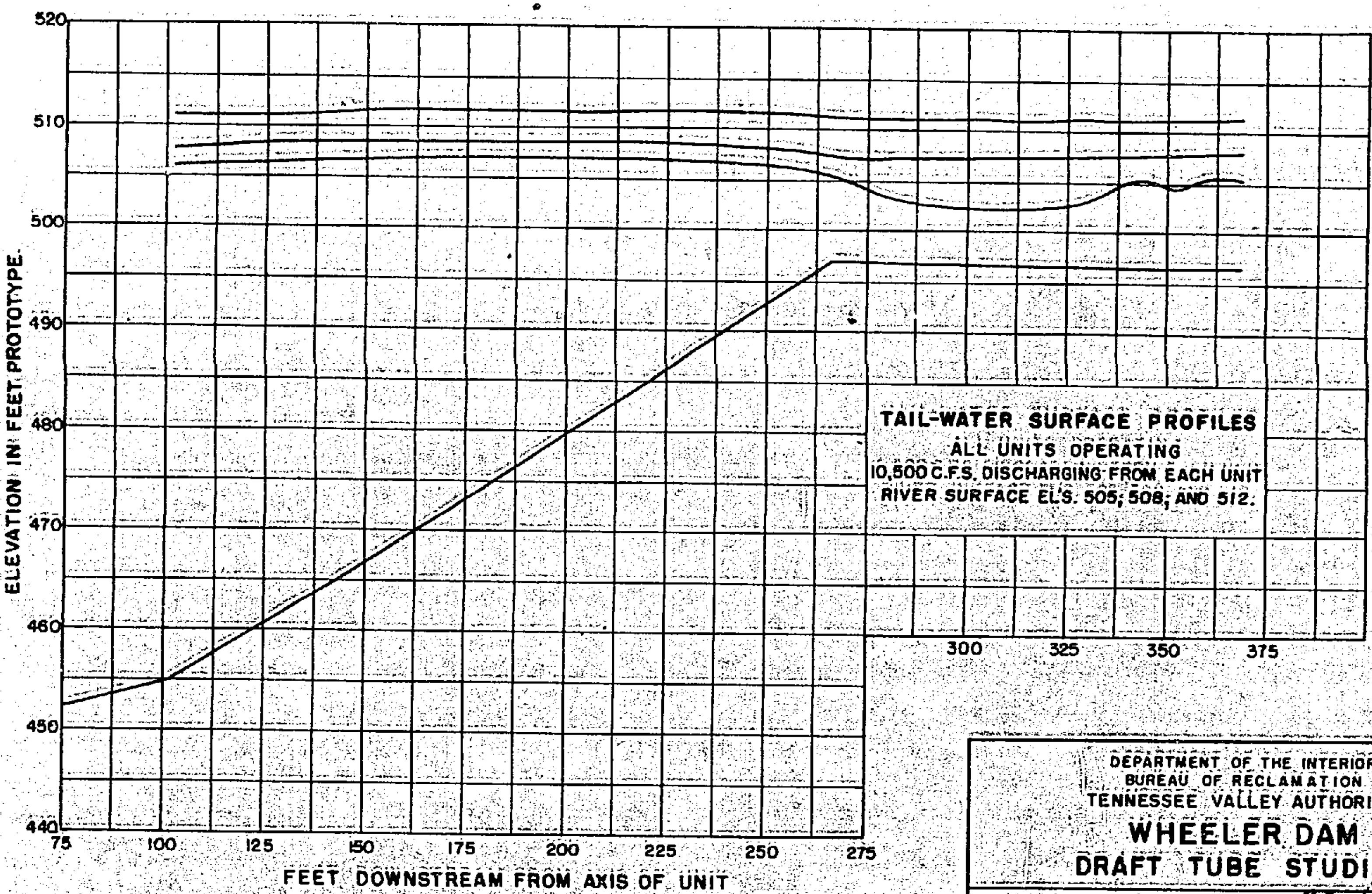


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FIG. 57

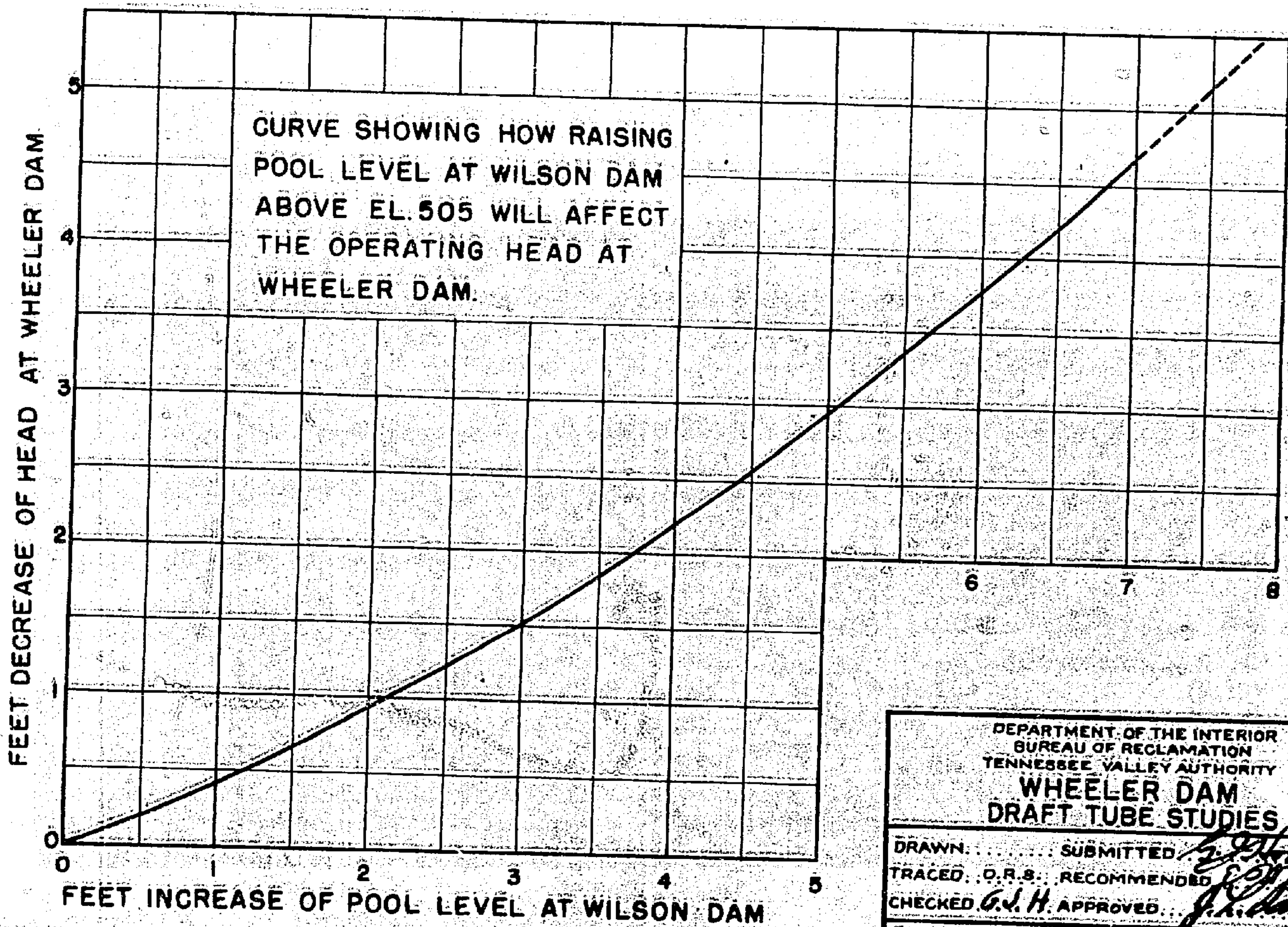


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FIG. 58

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

$\alpha$ = velocity distribution coefficient for the orifice with draft tube attached

$\alpha_1$ = velocity distribution coefficient for the orifice without draft tube attached

$\alpha_3$ = 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

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

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

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

where $\alpha$ 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

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

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

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

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. $\alpha$, 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

$$A w \overline{V}_2 \left( \alpha \frac{\overline{V}_2^2}{2g} - \alpha_3 \frac{\overline{V}_3^2}{2g} - E_{2-3} \right). \qquad (4)$$

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

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

Substituting (5) in (4)

$$A w \overline{V}_2 \left( \alpha \frac{\overline{V}_2^2}{2g} + E_{1-2} - h_1 \right)$$

As the kinetic energy available at the orifice is

$$\alpha \frac{\overline{V}_2^2}{2g} A w \overline{V}_2$$

the efficiency is

$$e = \frac{A w \overline{V}_2 \left( \alpha \frac{\overline{V}_2^2}{2g} + E_{1-2} - h_1 \right)}{A w \overline{V}_2 \, \alpha \frac{\overline{V}_2^2}{2g}}$$

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, $\alpha$, $\overline{V}_2$, 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 $\alpha$

Without the draft tube attached

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

with the draft tube attached

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

subtracting the second from the first

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

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

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

by substituting 4R for d, the diameter. A mean value of tion factor, for the draft-tube surface is estimated. Th tions throughout the draft tube, the quantity $\frac{fv^2}{8Rg}$ is pl ordinate against L, the distance of the section from the measured along the centerline of the tube, as abscissa. under this curve is an estimate of the loss due to fricti draft tube. As flow conditions are very irregular within this may safely be taken as the minimum loss due to frict 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 $\alpha_3$ equals 1, its minimum value. From this Equation a value of $\alpha_1$ may be obtained which is reasonably sure to be a minimum. As $E'' - E'$ is negative, although undoubtedly small, it cannot be stated that $\alpha_1$ 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 $\alpha$ may be estimated. This value of will result in a maximum value of $1/\alpha$. 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 $\alpha$ of 1.52 as a minimum for the vane angle 0°. For the 15° vane angle, $\alpha$ 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, $\alpha_3$, 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, $\alpha_3$ would be at least 9.

As the factors $\alpha$, $\alpha_1$, $\alpha_3$, $C_1$, $E_{1-2}$, 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 $\alpha$, 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, $\alpha_1$, would also have to be determined by the same method as the determination of $\alpha$. The experimental equipment would have to be altered, however, so that the orifice would discharge into a large reservoir before $\alpha_1$ could be measured. If the time and expense were taken to obtain $\alpha$, $\alpha_1$, $C_1$, 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 $\alpha$, $\alpha_1$, $C_1$, 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.