HEAD LOSS IN SYMMETRICAL BIFURCATIONS

BY

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ABSTRACT

Five symmetrical wye branches of conventional and spherical types were tested for hydraulic losses under symmetrical and unsymmetrical flow conditions. Results are presented graphically. A wide variation in loss factor was observed depending on the type of wye and on flow condition. For a given wye the minimum wye loss coefficient does not necessarily occur under conditions of symmetrical flow.

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INTRODUCTION

In several recent hydro-electric power plants units of capacity up to 300,000 HP have been installed. Still larger units are proposed for future projects. In the penstocks which serve these plants both the diameter and water velocity have been increased beyond previous limits to match the increase in turbine discharge capacity.

A major portion of the total friction loss in penstocks of large diameter carrying water at high velocity is due to bends, outlets, wyes and valves. An accurate determination of hydraulic losses in these devices is necessary for an economical design of the penstock.

This thesis describes a model test program to determine hydraulic losses in large symmetrical wye branches. In three conventional type of wyes tested the influence of the magnitude of the angle between the branches of the wye was investigated. In two spherical wyes tested, the influences of the size of the sphere and the rounded pipe intersections were studied.

The investigation was primarily concerned with the hydraulic losses resulting from wyes. Therefore friction losses in the individual pipes were deducted from the total loss to obtain the form loss of the wye.

The flow in general was well within the turbulent range, the Reynolds number varying from 50,000 to 375,000. When the results of the experiments are applied to estimate the losses in a geometrically similar prototype, the Froude number is used as the criterion for dynamical similarity. For convenience the wye loss coefficients K are related to the velocity head in the main pipe.

PREVIOUS RESEARCH

Considerable research has been undertaken for the computation of hydraulic loss in bends, elbows, tees, branch outlets and symmetrical bifurcations, but most of it is confined to small pipes as part of losses in pipe fittings. Hinds, Thoma, Shoder, Weisbach and others[1] have shown in graphical form head loss in bends for various radius-diameter ratios. Model tests have been made on small tees and branch outlets at the Munich Hydraulic Institute.[2] Gardel[3] describes tests on water flow through eight tees with main pipe diameter of 150 mm joined by pipes ranging from 60 to 150 mm at angles ranging from 45° to 135°.

The theoretical basis has been developed by Favre[4] and McNown[5] for lateral bifurcations only. The characteristics of flow and pressure pulsations in lateral bifurcations have also been a subject of study at the University of Kansas (6), (7), (8).

Marchetti and Noseda[9] have made experiments on five bifurcations constructed by welding 70 mm diameter pipes with included angles between the downstream branches varying from 60° to 180°. The laboratory results were presented for different conditions of flow in graphical form enabling determination of hydraulic losses. For symmetrical bifurcations, the value of wye loss coefficient K varied from 0.27 for a 60° bifurcation to 0.96 for a 180° bifurcation. The Reynolds numbers varied from 97000 to 322000 for these experiments.

Gladwell and Tinney[10] conducted investigations on a trifurcation, the tests including measurement of head loss for different conditions of flow. With the centre pipe closed and flow equally divided, the value of K for a given discharge was 0.73 and 0.94 for right and left leg respectively. The large difference appears to be due to the bend upstream of the trifurcation.

CHAPTER I.

INSTRUMENTATION AND APPARATUS

1.1. LAYOUT: The research project was conducted in the Hydraulic Laboratory as shown in Figure 1 and Plate 3. The supply is from an overhead tank and hence no dynamic pressure fluctuations are introduced into the feeding system.

During the period in which the experiments were under way care was taken to ensure that there were no withdrawals at any other point in the laboratory and, thus, for each experiment a stable flow condition under constant head was established.

The general arrangement of the model is shown in Figures 2 and 3 and Plate 3. The supply to the model could be diverted to one or both of the branch pipes leading to left and right flumes (Figure 1) according to the requirements of the experiment.

The turbulence induced pressure fluctuations, introduced into the system due to the many elbows and tees between the overhead tank and the valve controlling flow to the wye, were dampened by providing two flow straighteners each 2 ft. long as shown in Figure 2. The first one was located downstream from the bend below the control valve, and the other downstream from the reducer near the first straightener. The straighteners consisted of thin aluminium tubing varying in diameter from one to two inches.

The length of the main pipe on the upstream side of the wye, comprised of steel and lucite sections, was 33 ft., the length-diameter ratio being 75. The length-diameter ratio equalled 30 for the branch pipes, which was considered adequate to eliminate flow disturbances caused by passage of water through the wye and thus assure observation of correct pressure heads at piezometric points on the branch pipes.

1.2. <u>APPARATUS</u>: Lucite was used throughout for all the wyes, a portion of the main pipe and the branch pipes. This set up allowed:

(i) to replace the different parts

(ii) to observe visually the portion in which hydraulic losses occurred, and

(iii) to see that there was no entrapment of air in any part which might affect the piezometric heads.

<u>DESCRIPTION OF WYES</u>: A total of five wyes, all of them symmetrical, were used for conducting the experiments. Three were 90° wyes and the remaining two were 60° wyes. The 90° wyes have been designated as (i) Large Spherical Wye, (ii) Small Spherical Wye and (iii) Tapered Wye; the 60° Wyes as (i) Tapered Wye (A) and (ii) Tapered Wye (B). For all wyes, the connecting main pipe and branch pipes had diameters of 5.25 and 3.75 inches respectively. The different wyes are shown

in Figure 4 and Plates 6, 7 and 8. Although dimensions of the wyes were chosen arbitrarily, the shapes follow a certain geometrical pattern as indicated in Figure 5.

90° Large Spherical Wye: As shown in Figure 4.(a), the sphere had a diameter of 7.5 inches equivalent to twice the diameter of the branch pipes. On the outlet side the intersection of sphere and pipe was rounded at a radius of 3/8 inch.

90° Small Spherical Wye: As shown in Figure 4.(b), the sphere had a diameter of 5.85 inches. The intersections were sharp.

90° Tapered Wye: As shown in Figures 4 and 5 the cone angle for the tapered wye was kept at 20°.

60° Tapered Wye (A): As shown in Figure 4.(d), the tapering was done at an angle of 10°.

60° Tapered Wye (B): As shown in Figure 4.(e), this wye contained a 3 inch long tapered portion. Otherwise it is similar to the 60° tapered wye (A) in all respects.

The theoretical centres of the wyes are shown in figure 4. Distances from the theoretical centres to the points of inlet and outlet of the wyes are given in Table 2.

Preparation of Wyes: In order to obtain dependable and accurate results, great care was taken in preparation of the models. Accuracy was carried to one-thousandth of an inch and internal surface of the wyes was made as smooth as possible.

During preparation of a wye, the faces were machined and the theoretical centre, angle of symmetrical bifurcation, length from the theoretical centre to points of inlet and outlet, and position of holes for connection with main and branch pipes were laid out. After turning the conical and cylindrical water passages on a milling machine, polishing of inner surface of wyes was done by emery paper first and then by crocus paper. Final polishing was done by polishing liquid. Two locating pins were installed on the main pipe to eliminate any offset between the wye and the main pipe.

Main and Branch Pipes: As shown in Figure 3, the Lucite section of the main pipe, approximately 13 ft. long, comprised of three sections. Flanges made from Lucite were fitted on both ends of each section of the main and branch pipes to connect the different sections of the main and branch pipes or the pipes with the wye. Each flange, with the end face machined and smoothened was then glued to the pipe with the face perpendicular to centre line of pipe. To stop leakage, annular rings 1/8 inch wide were machined on the connecting faces in which rubber rings 1/8 inch diameter were placed.

Setting up of Apparatus: For the final test setup the main pipe was aligned by means of a theodolite. The main pipe, branches and wye were levelled accurately with a carpenter's level. Measures were also adopted to eliminate discontinuity at all joints on the main and branch pipes, and particularly at joints with the wye.

1.3. INSTRUMENTATION: Primarily it consisted of means to measure pressure, discharge, temperature, and time.

Pressure Taps: The standard requirement for pressure taps is that the openings should be flush with the conduit wall and free from burrs, while the axis of the piezometric tube should be perpendicular to the centre line of pipe. The tap should be free from leakage.

The pressure tap used in these experiments is shown in Figure 6. The piezometer had an opening of 1/8 inch. The brass tube was held in position by a 1/8 inch NTP threaded screw in a 7/8 inch Lucite cube. The NTP in turn was connected to a 3/16 imperial threaded nut, with rubber ring at the junction to eliminate possibility of any leakage.

Piezometric Connections: Piezometers were installed in groups (Figure 3 and Plates 1 and 2) and connected to gage tanks. This arrangement was suitable because the water level in the manometric tubes could be observed simultaneously and any single pressure reading which appeared out of line could be checked immediately. The pressure taps were connected to manometers by flexible tubing with provision for removal of air bubbles trapped in the system. Numbers in Figure 3 indicate these connections on the piezometric rings, manometer tubes and gage tanks to main, left and right branch pipes respectively. The gage tanks 5.5 inches in diameter were fitted with hook gage rods and verniers to obtain reading of water surfaces. There were three gage tanks, (i) the upstream tank connected to the four pressure taps forming the piezometric ring and the corresponding manometers on the main pipe, (ii) the central tank connected to corresponding manometers and piezometric ring on the left branch pipe and (iii) the downstream gage tank connected to the manometers and piezometric ring on the right branch pipe. The board containing the manometer tubes along with the different gage tanks is shown in Plates 1 and 2.

The gage vernier in the upstream tank was set 0.210 ft. higher than the gage verniers in the centre and downstream tanks.

The range of pressure heads that could normally be observed by the gage rods was only 2 ft. and height of gage tanks was also about the same. With the aid of extension rods to the gage points it was possible to measure pressure head differences up to 3 ft. of water.

<u>Orifices for variation of discharge through Main and Branch Pipes</u>: The experiments were conducted for different conditions of flow; symmetrical, unsymmetrical and one leg, as explained subsequently in more detail. For symmetrical flow the total discharges used varied from 0.32 to 1.5 cfs;

for unsymmetrical flow, the total discharge was 0.75 and 0.92 cfs, whereas the discharge ratio in the two branches varied from zero to 1.0. For one leg flow the discharge variation was from 0.32 to 0.92 cfs.

The variation of discharge through the main pipe was accomplished partly by operating the control valve shown in Figure 1. For a particular experiment it was, at the same time, necessary to create conditions so that pressure differences could be obtained by observation of water levels in all the three gage tanks simultaneously. For this purpose orifices of different sizes, which are shown in Figure 7 and Plate 9, were placed in end pieces attached to the branch pipes. These orifices had different diameters and, depending on the desired particular discharge in each branch, orifices of certain diameters were placed in the end pieces attached to the branch pipes. If for a particular wye and a particular flow condition, water level in the gage tanks could not be observed simultaneously due to manomotric levels being lower or higher than the limits of observation imposed by the hook gages, diameter of the orifices in one or both the branches was changed until the desired result was achieved. These orifices were machined from one side to obtain a clean and sharp edge free from any burrs. In all experiments the orifices were placed in such a way that the sharp, undamaged edges of the orifices were facing the flow.

Measurement of Time: A degree of accuracy up to 0.1 second was obtained for determining time intervals in which a particular weight of water was collected in the weighing tank. For this purpose an electric clock reading directly up to 0.1 second was used.

Measurement of Temperature: To determine Reynold's numbers for the corresponding friction loss coefficients in the main and branch pipes, temperatures were recorded by using a thermometer, and readings obtained to the nearest half degree of Fahrenheit.

Measurement of Weight of Water: This was done by means of a weighing tank having a maximum capacity of 20,000 lbs., the scales of which were tested and found correct before starting the experiments.

Pressure Measurements: In spite of the fact that supply was from an overhead tank under constant head conditions in which no dynamic pressure fluctuations could have been possible, and that two sets of straighteners were provided at the upstream end of a long straight main pipe, some pressure fluctuations were observed in the manometric tubes connected to the different piezometric rings. It could be definitely established by process of elimination that these were turbulence induced pressure fluctuations. It was observed that maximum fluctuation in water level was of the order of 0.05 ft. The pressure fluctuations, as observed visually, were in the neighbourhood of 30 cycles per minute. The corrective measure adopted for obtaining pressure differences to the required degree of accuracy was to adjust* the water levels in the different gage tanks corresponding to average levels in the manometric tubes, the area ratio of the tube (diameter, ¼ inch) to the gage tank (diameter, 5½ inches) being approximately 1:480 and then allow 2 to 3 hours to elapse. By this procedure it was observed that water surfaces in the tanks assumed constant levels, automatically averaging out pressure fluctuations in the manometric tubes.

Discharge Measurements: As the degree of accuracy in obtaining velocity heads at points of piezometric rings was directly related to discharge, it was necessary to measure the different discharges accurately.

Combined discharge through the main pipe was obtained by allowing both the branch pipes to discharge into the weighing tank simultaneously. The discharge from each of the branch pipes was then obtained separately. It was observed that discrepancies occurred in measurement of discharges unless a sufficiently long time interval was provided. For combined

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* Note: This measure was adopted to reduce the period required for the water levels to become steady in the gage tanks. Water was either poured into or taken out from the tank until its level approximated the average water level indicated in the manometric tubes.

discharge and for the discharge from the right branch pipe the necessary time interval was found to be about 300 seconds, whereas for the left branch pipe the required time interval was 500 seconds. For all the experiments conducted, the time intervals mentioned above were adhered to, and Column 3 of Tables 10 to 14 show that the maximum difference in time intervals for weighing a particular quantity of water from the main, right, or left branch pipe did not exceed about 0.1%. The velocity head calculated on the basis of discharge so obtained was thus correct up to a thousandth of a foot, the degree of accuracy required.

CHAPTER II.

BASIC CONCEPTS RELATING TO HYDRAULIC LOSSES IN WYE

2.1. THEORY: It is assumed that the measurement of piezometric heads has been made after stable flow conditions have been established and after the water levels in the different gage tanks were steady.

For a horizontal piping, the energy losses can be expressed from the energy equation of Bernoulli as follows:

$$h_{pm} + h_{vm} = h_{pr} + h_{vr} + \Delta h + h_{fm} + h_{fr} \quad ..... (1)\ A$$

$$h_{pm} + h_{vm} = h_{pl} + h_{vl} + \Delta h + h_{fm} + h_{fl} \quad ..... (1)\ B$$

(See Page 16).

Defining Q as discharge; A, area; h_p, pressure head; h_v, velocity head; h_f, loss of head due to friction; V_1, mean velocity in the pipe; V_2, velocity at piezometric ring and designating subscripts m, r and l to main pipe, right and left branch respectively the following equations can be obtained.

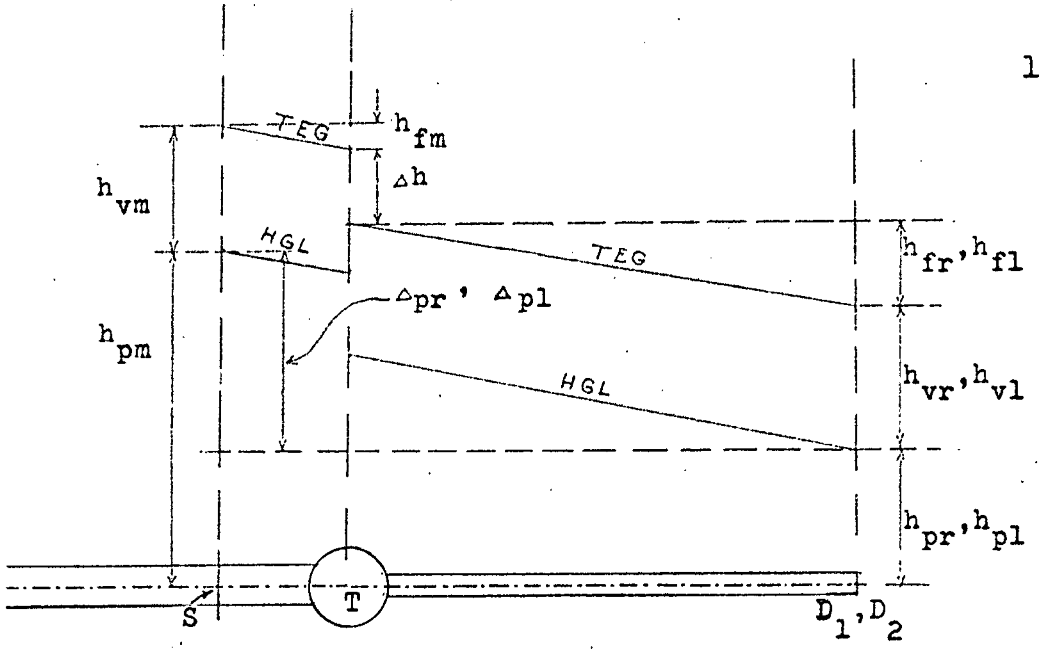
Continuity is given by:

$$Q_m = Q_r + Q_l \quad ..... (2)$$

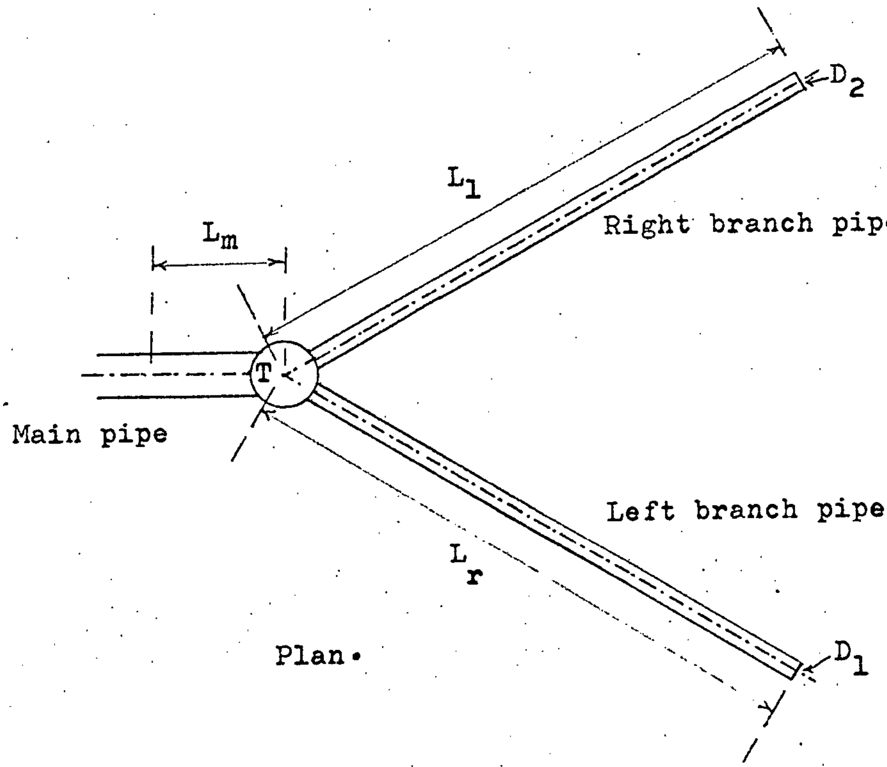
Average velocity in the main pipe is given by:

$$V_{m1} = \frac{Q_m}{A_{m1}} \quad ..... (3)$$

Similar expressions are valid for average velocity in the right or left branch; Q_r, Q_l, A_{r1}, A_{l1} being known. Velocity at the piezometric ring S on the main pipe is given by:



Elevation.



Plan.

$$V_{m2} = \frac{Q_m}{A_{m2}} \quad \ldots\ldots \quad (4)$$

Similar expressions for velocity at the piezometric rings D_1 or D_2 on the right or left branch can be obtained in terms of Q_r, Q_l, A_{r2} and A_{l2}. Equations (3) and (4) are required to distinguish the average velocity related to friction losses, and the average velocity at the piezometric rings which are related to velocity heads at these rings.

Velocity heads h_{vm}, h_{vr}, h_{vl} in the main, right and left branch pipes can be determined once velocities are obtained from equation (4).

The localized loss of wye can be expressed as:

$$\Delta h_r = (h_{pm} - h_{pr}) - (h_{fm} + h_{fr}) + (h_{vm} - h_{vr})$$

$$\Delta h_r = \Delta p_r - (h_{fm} + h_{fr}) + (h_{vm} - h_{vr}) \quad \ldots\ldots \quad (5)$$

Similarly

$$\Delta h_l = (h_{pm} - h_{pl}) - (h_{fm} + h_{fl}) + (h_{vm} - h_{vl}),$$

$$\Delta h_l = \Delta p_l - (h_{fm} + h_{fl}) + (h_{vm} - h_{vl}) \quad \ldots\ldots \quad (6)$$

Finally wye loss coefficient 'K' for the right or left branch pipe is given by:

$$K = \frac{\Delta h}{\frac{Vm^2}{2g}} \quad \ldots\ldots \quad (7)$$

Equations (5) and (6) have been used to determine localized wye loss at T, the theoretical centre of wye, and equation (7) for determination of K for the following flow conditions:

(a) Symmetrical Flow: The discharge in the main pipe is divided equally between the right and left branch pipes.

(b) Unsymmetrical flow: The discharge is divided unequally in the two branches with the discharge ratio δ ranging from 0 to 1.

(c) One Leg Flow: The discharge is wholly diverted to the right or left branch.

In the figure the hydraulic grade lines and the total energy grade lines have been shown from S to D_1, D_2, assuming that all wye losses are localized at the theoretical centre T. In addition to these localized wye losses, piezometric and velocity heads and loss of head due to friction at locations S, T, D_1, D_2 are also indicated.

The discharge passing from the main pipe through the wye into the branch pipes causes formation of vortices and turbulence in the wye. Mixing is carried a considerable distance and extinguished slowly while proceeding in the branch pipes. The effect of vortices and turbulence in the wye is extended into the main pipe for a very short distance only. The distance of S from T has, therefore, been kept much shorter than the distance of D_1 and D_2 from T.

CHAPTER III.

PRELIMINARY INVESTIGATIONS

3.1. PRELIMINARY EXPERIMENTS AND RESULTS: A complete set of experiments for symmetrical, unsymmetrical and one leg flow was conducted for the 90^o small spherical wye and the results tabulated in the way as shown in Tables 10 to 14. On examination of the results so obtained, it was found that (i) the head loss in the wye was different for the two branches, (ii) the piezometric readings of the central and downstream gage tanks differed considerably, (iii) there was variation in consecutive time intervals when a particular discharge was measured, (iv) discharge from the left branch pipe was consistently larger than that from the right branch pipe and (v) there was considerable turbulence induced pressure fluctuation (about 0.100 ft.) in the manometric tubes.

3.2. INVESTIGATIONS: These were undertaken with a view to determine the causes and to effect changes in the apparatus until the discrepancies were removed. A number of test runs were conducted to find factors responsible for the discrepancies observed.

While a particular experiment was in progress, it was found that air was trapped in the flexible tubing connected to the uppermost piezometric points on the different pipes and hence the top piezometric connections were pinched off to eliminate the source of this error.

By observation it was found that a relatively large quantity of air was necessary to obtain the condition "discharge into free atmosphere" and, hence, large wooden troughs were provided for both branch pipes. It was also noticed that the maximum variation occurred in measurement of discharge from the right branch pipe due to surge waves in the collecting system. When the wooden trough carrying water from the right branch pipe was extended so as to discharge in the right hand flume (Figure 1) an immediate improvement was found.

Velocity traverse: An unsymmetrical velocity distribution was found when a velocity traverse was made across the main pipe about 6 inches from the wye, the traverse station being shown in Figure 3. The resulting flow distribution is shown in Figure 8 based on observations recorded in Table 3 which conclusively proved that the velocity distribution was not symmetrical about the axis of the main pipe.

3.3. MODIFICATIONS: To improve the pattern of flow the following modifications were carried out in the main pipe section:

(i) The 4 inch standard steel pipe was replaced by a new section of 5 inch standard steel pipe (Figure 2).

(ii) Two sets of flow straighteners each 2 ft. long were provided in positions shown in Figure 2,

(iii) The controlling valve was rotated and made symmetrical with the direction of flow.

These modifications were proposed not only to improve the flow conditions in order to eliminate the discrepancy in discharge in the two branches but also to provide the maximum straight portion of the main pipe with a larger length-diameter ratio of approximately 75 to dampen turbulence induced pressure fluctuations.

After incorporating the changes in the main pipe section, the results of the velocity traverse, made at the same point at which the previous traverse was made, and shown in Table 4 and Figure 9, indicated an entirely symmetrical velocity distribution about the axis of the main pipe with the maximum velocity occurring at the centre.

Branch Pipes: Because the length of the branch pipes was only about 3.75 ft., giving a length-diameter ratio of about 12, it was considered necessary to increase the length so that most of the vortices and turbulence created in the wye would be extinguished by the time water reached the piezometric rings on the branch pipes. At the same time too large an increase in length of branch pipes would have resulted in magnifying the effect of friction losses, and thus would have reduced the degree of accuracy in obtaining the wye losses. The branch pipes were consequently replaced by two sections of pipe as shown in Figure 3. The length-diameter ratio was thus increased from 12 to approximately 30.

Location of Piezometric Ring on the Main Pipe: Some doubt was felt about the proximity and influence of the wye on the readings of the piezometers on the main pipe because of turbulence and formation of vortices in the wye. In order to check this situation, a velocity traverse was made under extreme conditions of maximum discharge of 0.92 cfs in the right branch with the left branch completely shut-off. The velocity profile so obtained, shown in Table 5 and Figure 10, indicates practically symmetrical flow about the axis of the main pipe, proving that the location point of the piezometric ring on the main pipe was outside the influence of the wye.

Friction Losses in Branch Pipes: As a result of preliminary investigations, it was also decided to measure friction losses at more or less a constant temperature which, in the present case, was 65° F and to keep the water temperature during the subsequent schedule of experiments on all the wyes close to this temperature. By adopting this procedure, friction losses in the branch pipes could be determined with a greater degree of accuracy.

CHAPTER IV.

EXPERIMENTAL PROCEDURE

The preliminary investigations having determined the pattern on which the experimental work was to be carried out, the procedure as described below was adopted with a view to obtain graphical representation of wye loss coefficients K for each of the five wyes for the cases of symmetrical, unsymmetrical and one leg flow.

4.1. FRICTION LOSSES: To obtain the different wye losses as per equations (5) and (6), it was first necessary to determine friction losses in the main pipe for the length S to T (Figure 3) and from T to D_1 and D_2 in the branch pipes.

Friction Losses in the Main Pipe: To obtain friction losses in the main pipe, two of the gage tanks were connected to piezometric rings at S and S_1 as shown in Figure 3. Friction losses were determined for different discharges ranging from 0.32 to 1.5 cfs and results thus obtained (Table 6) were plotted on log-log scale as shown in Figure 11. These friction losses are for the length SS_1 (Figure 3) which was 3.375 ft. For the length ST the friction loss that corresponded to any particular discharge was determined from the graph in Figure 11. The lengths SS_1 and ST for the different wyes are shown in Table 2.

Friction Losses in the Branch Pipes: The experimental set up for determination of friction losses in the branch pipes is shown in Figure 12. Four sections of pipes, designated with A, B, C, D, each having 3.75 inches nominal ID and 4.5 ft. long, were duly fitted with flanges and piezometric rings to form the right and left branches. Different combinations were tried so that friction losses for all discharges for these two legs would be equal. It was found that the two branch pipes could be formed by putting Sections A, C and B, D together which then would have almost identical friction losses. For the 90° wyes sections A and C formed the right branch pipe and B, D the left branch pipe. For 60° wyes it was found that more symmetrical discharges and pressure elevations were obtained by having Sections A, C as the left branch pipe and B, D as the right branch pipe.

Friction losses were determined for length B_1B_2 (= 9 ft.) for Sections A, C and B, D (Figure 12) as in the case of the main pipe for different discharges ranging from 0.32 to 0.75 cfs., and the results thus obtained (Tables 7 & 8) were plotted on log-log scale as shown in Figures 13 and 14. It may be seen from the two graphs that for high discharges, friction losses are almost the same; but for low discharges, the branch pipe formed by Sections A, C had somewhat less friction losses than the branch pipe formed by Sections B, D.

Friction losses from T to D_1, D_2 (Figure 3) for the two branch pipes were obtained in a similar way to that of the main pipe. The lengths S_2D_2, S_3D_1, TD_1 and TD_2 (Figure 3) for the different wyes being the same for the two branch pipes, are shown in Table 2.

Reynolds Numbers and Friction Factors for Main & Branch Pipes: For the different discharges for which friction losses were determined for the main and branch pipes, Reynold's numbers and the corresponding friction factors were determined (Table 9) and plotted on Moody's diagram in Figure 15. It may be observed that the points thus obtained for the branch pipes adhere very closely to the curve for smooth pipes. Some of the points on the main pipe are slightly shifted.

4.2. DETERMINATION OF AREAS OF MAIN AND BRANCH PIPES: Both for the main and branch pipes the following data were determined separately:

(a) Mean area of the pipe for correlation of friction loss to the mean velocity in the pipe,

(b) Area at piezometric rings to calculate the velocity heads used in equations (5) and (6).

For the main pipe the area was determined by measuring the diameter near the centre and at each end in four different positions and then taking the average of the 12 values. The nominal ID of the pipe was 5.25 inches but the mean diameter was found to be 5.252 inches. The same value of the diameter was also found at the piezometric ring.

For the branch pipes, the required areas were found by measuring diameters at both ends of each section in four different positions and taking the mean of the 16 values thus obtained. Table 1 indicates the mean diameters and mean areas and areas at piezometric rings for the main and branch pipes.

4.3. DISCHARGE AND PRESSURE MEASUREMENTS: Discharge was determined by measuring the time and weight of water. Care was taken to ensure that a steady condition was reached after any change in control valve position.

The extent of pressure fluctuations in the manometric tubes connected to the main and branch pipes was observed closely and water levels in respective gage tanks were adjusted to represent average pressure at each of the 3 piezometric rings. A period of not less than 2 hours was considered sufficient for the water level in the gage tanks to assume positions representing the actual pressures and only then gage readings were taken.

4.4. EXPERIMENTAL PROCEDURE: For each of the five wyes tested, hydraulic losses had to be obtained for three different conditions of flow, (i) symmetrical flow, (ii) unsymmetrical flow and (iii) one leg flow. For each wye, therefore, there were three series with a total number of twelve experiments to be performed. Again, for each condition of flow, losses had to be evaluated for specific discharges for comparison of results. For symmetrical flow, discharges for which observations were taken were 0.32, 0.5, 0.75, 0.92, 1.1 and 1.5 cfs: for one leg flow these discharges were 0.32, 0.5, 0.75 and 0.92 cfs. In the case of unsymmetrical flow, as already explained, with combined discharge maintained at 0.75 cfs for 90° wyes and 0.92 cfs for 60° wyes, the discharge ratio between the branch pipes was varied from 0 to 100% by placing orifices of different sizes into the two branch pipes.

4.4. <u>EXPERIMENTAL PROCEDURE</u>: The sequence of experiments with a particular wye was as follows:

(i) The wye was first bolted to the branch pipes. Connection between the wye and the branch pipes were checked by hand so that the joints were without offsets as far as possible. The connection of the wye was then made to the main pipe with the help of the locating pins.

(ii) Starting with symmetrical flow conditions, after placing orifice No. 1 in both the branches, the opening of the control valve was adjusted by trial and error so that the discharge was as near 1.5 cfs as possible. After observing each piezometric tube, water levels in the gage tanks were adjusted and the necessary time allowed for the water levels become constant. Observations were then made separately for combined discharge, discharge from right and left branch and for gage readings of water levels in tanks connected to the main and branch pipes.

The control valve was then closed and No. 1 orifices in the branch pipes were replaced by No. 2 orifices and the whole procedure repeated for discharge of 1.1 cfs. This procedure was continued until all the experiments under this flow condition were completed for the discharges 1.5, 1.1, 0.92, 0.75, 0.5 and 0.32 cfs.

(iii) The experiment for unsymmetrical flow condition was carried out next, after placing different orifices in the branch pipes and repeating the procedure, the series was completed for a variation of discharge ratio from 0 to 100%.

(iv) For one leg flow, one branch pipe was completely blocked and orifice numbers 1, 2 and 3 were placed one after the other to obtain discharges of 0.92, 0.75, 0.5 and 0.32 cfs. Similar observations as in the previous flow conditions were then made.

(v) After completing experiments on one wye another wye was tested and a similar procedure adopted to carry out the experiments.

The tabulation of results and graphical representation of points, details of which have been given in the following chapter, were proceeded with simultaneously. Any discrepancy in wye loss coefficient or discontinuity of curve joining the points on the graph was corrected immediately by repeating the experiment or by applying other remedial measures if required.

In particular, when it was found that for unsymmetrical flow, the curve was not well-defined for discharge ratio around zero, additional points were obtained in the vicinity by using orifices 7 and 8 in the branch pipe.

CHAPTER V.

RESULTS AND CONCLUSIONS

5.1. RESULTS OF EXPERIMENTS: The wye losses and wye loss coefficients have been obtained for all experiments on each of the five wyes. These have been shown from Tables 10 to 14.

Results of experiments conducted on the different wyes are shown graphically on Figures 16 to 29.

Two graphs have been drawn for each of the wye models. The first graph shows wye loss coefficient K against discharge in the main pipe. The second graph shows the wye loss coefficient K versus discharge ratio between the branch pipe and the main pipe. Again, the first graph comprises 3 curves for (i) symmetrical flow, (ii) open branch pipe and (iii) closed branch pipe.

5.2. CONCLUSIONS AND DISCUSSION:

Symmetrical Flow: For symmetrical flow (Figure 26), the wye loss coefficients for all the wyes show slightly larger values for low discharges. For high discharges the value becomes more or less constant as given below:

Particulars of wye	Value of K
90° large spherical	0.44
90° small spherical	0.30
90° tapered	0.16
60° tapered wye (A)	0.088
60° tapered wye (B)	0.080

The considerable variation in the value of K between the different wyes may be observed.

<u>K. for Open Branch</u>: In the case of 90° wyes the value of K falls with increase in discharge as shown in Figure 27, whereas for 60° wyes the value increases with increase in discharge, but for all wyes the values seem to become constant for high discharges. The value of K for large discharges for the different wyes is given below:

Particulars of wye	Value of K
90° large spherical	0.92
90° small spherical	0.86
90° tapered	0.47
60° tapered (A)	0.41
60° tapered (B)	0.41

For this condition of flow also there is a large variation in value of K for the different types of wyes.

<u>K for Closed Branch</u>: For the closed branch there is little change in the value of K for all wyes as seen from

Figure 28, the smallest value of K being 0.45 and the largest value, 0.60.

Unsymmetrical Flow: Figure 29 gives corresponding values of K for different discharge ratios for each of the five wyes.

A significant fact that emerges for unsymmetrical flow is that the minimum value of K need not necessarily occur for $\delta = 0.5$, i.e., when flow is equally divided between the two branches. The minimum value of K and the corresponding discharge ratio for each wye is given below:

Particulars of Wye	Minimum value of K	Corresponding discharge ratio
90° large spherical	0.41	0.14
90° small spherical	0.26	0.38
90° tapered	0.17	0.50
60° tapered (A)	0.085	0.54
60° tapered (B)	0.080	0.50

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Appendix

Notation: The following symbols have been used:

A_{m1} = internal average cross-sectional area of the main pipe in sq. ft.;

A_{r1} = internal average cross-sectional area of the right branch in sq. ft.;

A_{l_1} = internal average cross-sectional area of the left branch pipe in sq. ft.;

A_{m2} = internal area of the main pipe at piezometric ring in sq. ft.;

A_{r2} = internal area of the right branch pipe at piezometric ring in sq. ft.;

A_{l2} = internal area of the left branch pipe at piezometric ring in sq. ft.;

L_m = length of the main pipe in ft. from S to T, the theoretical centre of Wye, (Fig. 3);

L_r = length of the right branch pipe in ft. from T to D_1, (Fig. 3);

L_l = length of the left branch pipe in ft. from T to D , (Fig. 3);

Q_m = discharge in the main pipe in cfs;

Q_r = discharge in the right branch pipe in cfs;

Q_l = discharge in the left branch pipe in cfs;

= ratio of discharge in the right or left branch pipe to discharge in the main pipe;

V_{m1} = average velocity in the main pipe in fps;

V_{r1} = average velocity in the right branch pipe in fps;

V_{l1} = average velocity in the left branch pipe in fps;

V_{m2} = velocity in the main pipe in fps at the piezometric ring S, (Fig. 3);

V_{r2} = velocity in the right branch pipe in fps at the piezometric ring D_1, (Fig. 3);

V_{l2} = velocity in the left branch pipe in fps at the piezometric ring D_2, (Fig. 3);

h_{pm} = piezometric head in the main pipe in ft. at S, (Fig. 3);

h_{pr} = piezometric head in the right branch pipe in ft. at D_1, (Fig. 3);

h_{pl} = piezometric head in the left branch pipe in ft. at D_2, (Fig. 3);

h_{vm} = velocity head in the main pipe in ft. at S, (Fig. 3);

h_{vr} = velocity head in the right branch pipe in ft. at D_1, (Fig. 3);

h_{vl} = velocity head in the left branch pipe in ft. at D_2, (Fig. 3);

h_{fm} = friction losses in the main pipe in ft. from S to T, (Fig. 3);

h_{fr} = friction losses in the right branch pipe in ft. from T to D_1, (Fig. 3);

h_{fl} = friction losses in the left branch pipe in ft. from T to D_2, (Fig. 3);

Δ_{pr} = difference of piezometric heads in ft. at S and D_1, (Fig. 3);

Δ_{pl} = difference of piezometric heads in ft. at S and D_2, (Fig. 3);

Δ_{hr} = localized loss of head of wye at T between S and D_1, (Fig. 3);

Δ_{hl} = localized loss of head of wye at T between S and D_2, (Fig. 3);

K = Wye loss coefficient.

Table 1 Areas,
Main and Branch Pipes.

Description	Mean diameter (inches)	Mean area (sq.ft.)	Diameter at Piezometric ring (inches)	Area at Piezometric rings (sq.ft.)
Main pipe	5.252	0.1503	2.251	0.1503
Branch pipe (Sections A,C)	3.746	0.0764	3.750	0.0766
Branch pipe (Sections B,D)	3.750	0.0766	3.748	0.0766

Table 2 Distance from Theoretical Centre of Wye to Piezometric Ring,*
Main and Branch Pipes

Particulars of Wye	Distance from S to point of inlet S_4 (ft.)	Distance from point of inlet to T (ft.)	Distance ST (ft.)	Distance from T to point of (S_2,S_3) outlet (ft.)	Distance from point of outlet S_2,S_3 to D_1,D_2 (ft.)	Distance TD_1,TD_2 (ft.)
90° large spherical	0.500	0.243	0.743	0.355	8.833	9.188
90° small spherical	0.500	0.240	0.740	0.360	8.833	9.193
90° tapered	0.500	0.125	0.625	0.374	8.833	9.207
60° tapered (A)	0.500	0.083	0.583	0.497	8.833	9.330
60° tapered (B)	0.500	0.318	0.818	0.497	8.833	9.330

* See Fig. 3

Table 3 Velocity Traverse,
Symmetrical Flow, Preliminary Investigations.

Discharge 1.107 cfs

Temperature 70° F

Station No.	Calliper reading (inches)	Distance from Station 1 (inches)	Manometer readings (inches)	Velocity head (inches)
1	0.407	0	5.00 + 1.06	6.06
2	0.657	0.250	8.90 + 1.75	10.65
3	1.157	0.750	11.30 + 2.15	13.45
4	1.657	1.250	12.60 + 2.55	15.15
5	2.157	1.750	13.40 + 2.90	16.30
6	2.657	2.250	13.75 + 3.25	17.00
7	3.157	2.750	13.50 + 2.90	16.40
8	3.657	3.250	12.75 + 2.60	15.35
9	4.157	3.750	11.80 + 2.40	14.20
10	4.657	4.250	10.60 + 2.20	12.80
11	5.157	4.750	8.80 + 1.60	10.40
12	5.380	4.973	7.70 + 1.10	8.80
13	5.630	5.223	4.60 + 1.00	5.60

Table 4 Velocity Traverse,
Symmetrical flow, Final Test Set Up.

Discharge 1.10 cfs

Temperature 65° F

Station No.	Calliper reading (inches)	Distance from Station 1 (inches)	Manometer readings (inches)	Velocity head (inches)
1	5.611	0.00	4.70 + 0.95	5.65
2	5.361	0.250	7.80 + 1.20	9.00
3	4.861	0.750	10.00 + 1.85	11.85
4	4.361	1.250	11.35 + 2.25	13.60
5	3.861	1.750	12.40 + 2.50	14.90
6	3.361	2.250	13.20 + 2.80	16.00
7	2.861	2.750	13.70 + 3.15	16.85
8	2.361	3.250	13.65 + 3.30	16.95
9	1.861	3.750	13.05 + 2.85	15.90
10	1.361	4.250	11.95 + 2.40	14.35
11	0.861	4.750	10.15 + 2.10	12.25
12	0.611	5.000	8.80 + 1.80	10.60
13	0.420	5.191	5.10 + 1.00	6.10

Table 5 Velocity Traverse,
One Leg Flow, Final Test Set Up.

Discharge 0.917 cfs

Temperature 65° F

Station No.	Calliper reading (inches)	Distance from Station 1 (inches)	Manometer readings (inches)	Velocity head (inches)
1	0.410	0.00	5.45 - 1.25	4.20
2	0.660	0.25	7.75 - 0.85	6.90
3	1.160	0.75	9.25 - 0.55	8.70
4	1.660	1.25	10.30 - 0.45	9.85
5	2.160	1.75	10.95 - 0.25	10.70
6	2.660	2.25	11.30 - 0.12	11.18
7	3.160	2.75	11.30 - 0.10	11.20
8	3.660	3.25	10.95 - 0.10	10.85
9	4.160	3.75	10.35 - 0.20	10.15
10	4.660	4.25	9.45 - 0.25	9.20
11	5.160	4.75	8.15 - 0.55	7.60
12	5.410	5.00	7.20 - 0.90	6.30
13	5.620	5.20	5.15 - 0.95	4.20

Table 6 Friction Losses,
Main Pipe.

Discharge (cfs)	Temperature (°F)	Length (ft.)	Area (sq.ft.)	Friction Loss (ft.)
1.48	65	3.375	0.1503	0.170
1.11	64.5	3.375	0.1503	0.098
0.748	66	3.375	0.1503	0.048
0.498	65	3.375	0.1503	0.022
0.322	64	3.375	0.1503	0.010

Table 7 Friction Losses,
Branch pipe, Sections A and C.

Discharge (cfs)	Temperature (°F)	Length (ft.)	Area (sq.ft.)	Friction Loss (ft.)
0.744	64.5	9.00	0.0764	0.604
0.501	64	9.00	0.0764	0.300
0.321	64	9.00	0.0764	0.136
0.200	64.5	9.00	0.0764	0.059

Table 8 Friction Losses
Branch pipe, Sections B and D.

Discharge (cfs)	Temperature (F)	Length (ft.)	Area (sq.ft.)	Friction Loss (ft.)
0.746	65	9.00	0.0766	0.602
0.499	65.5	9.00	0.0766	0.297
0.321	64	9.00	0.0766	0.138
0.198	63.5	9.00	0.0766	0.062

Table 9 Friction Factors and Reynold Number
Main and Branch Pipes

Particulars	Discharge (cfs)	Velocity head (ft.)	Length / diameter	Friction factor	Reynold's Numbers (x10⁵)
Branch Pipe (Sections	0.744	1.473	28.7	.0142	2.71
A-C)	0.501	0.670	28.7	.0155	1.79
"	0.321	0.275	28.7	.0172	1.14
"	0.200	0.107	28.7	.0193	0.72
Branch Pipe (Sections	0.746	1.473	28.7	.0142	2.72
B-D)	0.499	0.657	28.7	.0156	1.81
"	0.321	0.273	28.7	.0174	1.14
"	0.198	0.103	28.7	.0207	0.72
Main Pipe	1.480	1.508	7.71	.0146	3.78
"	1.110	0.849	7.71	.0150	2.90
"	0.756	0.392	7.71	.0167	1.94
"	0.498	0.170	7.71	.0168	1.27
"	0.324	0.072	7.71	.0180	0.83
"	0.201	0.029	7.71	.0230	0.50

Table 10. Wye Loss Coefficients for 90° Large Spherical Wye (Symmetrical Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in °F and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft) in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient	Average wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1+1	M 19000	202.7 202.7	202.7	64.5 62.33	1.504	1.589	0.367	0.357	0.210			0.173	0.038				10.02	1.557					
		R 15000	319.8 319.4	319.6		0.7525					1.442				0.611	0.623	0.661			9.83	1.502	0.836	0.537	0.537
		L 19000	405.7 405.4	405.6		0.7515					1.432				0.605	0.619	0.657			9.81	1.496	0.836	0.537	
2	2+2	M 19000	276.6 276.4	276.5	64.5	1.103	0.890	0.300	0.295	0.210			0.098	0.022				7.34	0.836					
		R 10000	290.8 290.4	290.6	62.33	0.552					0.805				0.358	0.366	0.388			7.21	0.807	0.446	0.534	0.534
		L 15000	436.8 436.8	436.8		0.5515					0.800				0.356	0.363	0.385			7.20	0.805	0.446	0.534	
3	3+3	M 15000	320.0 319.7	319.9	65 62.33	0.752	1.021	0.831	0.832	0.210			0.048	0.011				5.01	0.390					
		R 7500	320.4 320.0	320.2		0.3758					0.389				0.179	0.183	0.194			4.91	0.374	0.211	0.541	0.539
		L 10000	425.8 425.4	425.6		0.3766					0.390				0.180	0.184	0.195			4.92	0.376	0.209	0.536	
4	4+4	M 10000	320.4 320.4	320.4	65 62.33	0.501	0.887	0.910	0.916	0.210			0.022	0.005				3.33	0.173					
		R 5000	323.9 323.3	323.6		0.248					0.181				0.086	0.088	0.093			3.25	0.167	0.094	0.542	0.549
		L 7500	476.7 476.4	476.6		0.253					0.187				0.088	0.090	0.095			3.30	0.169	0.096	0.555	
5	5+5	M 7000	347.2 346.9	347.1	65 62.33	0.3236	1.114	1.240	1.240	0.210			0.010	0.002				2.15	0.072					
		R 3500	348.1 348.3	348.2		0.1613					0.084				0.040	0.041	0.043			2.11	0.069	0.044	0.611	0.604
		L 4500	445.6 445.1	445.4		0.1623					0.084				0.040	0.041	0.043			2.12	0.070	0.043	0.597	

Table 10 (cont'd). Wye Loss Coefficients for 90 Large Spherical Wye (Unsymmetrical, and One Leg Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	L R	M 15000	320.2 320.1	320.2	65.5 62.33	0.751	1.365	1.659	0.390	0.210			0.048	0.011				5.00	0.388				
	5+2	R 14500	404.4 404.0	404.2		0.575					1.185	0.763			0.380	0.390	0.401			7.51	0.876	0.296	0.763
		L 5000	451.6 452.0	451.8		0.177					-0.084	0.237			0.044	0.045	0.056			2.32	0.084	0.164	0.423
2	L R	M 15000	321.8 321.7	321.8	65 62.33	0.749	1.822	1.831	1.421	0.210			0.048	0.011				4.98	0.385				
	4+3	R 9500	349.3 349.2	349.2		0.081					0.611	0.584			0.237	0.242	0.253			5.70	0.505	0.238	0.618
		L 8000	412.9 412.5	412.7		0.668					0.207	0.416			0.128	0.131	0.142			4.06	0.257	0.193	0.486
3	L R 1+6	M 10000	321.4 321.0	321.2	65 62.33	0.749	1.563	0.133	1.954	0.210			0.048	0.011				4.98	0.386				
		R 2000	395.4 395.9	395.7		0.081					-0.181	0.108			0.012	0.012	0.023			1.06	0.019	0.163	0.422
		L 19000	456.0 456.6	456.3		0.668					1.640	0.892			0.494	0.504	0.515			8.72	1.182	0.329	0.853
4	L R	M 15000	321.6 321.2	321.4	65 62.33	0.748	1.928	0.250	2.305	0.210			0.048	0.011				4.98	0.385				
	1+7	R 1000	486.8 486.7	486.8		0.033					-0.167	0.044			0.002	0.002	0.013			0.44	0.003	0.202	0.523
		L 19000	426.5 426.1	426.3		0.715					1.893	0.956			0.556	0.567	0.578			9.33	1.355	0.345	0.895
5	L R	M 15000	321.8 321.7	321.8	65 62.33	0.748	2.085	0.295	2.457	0.210			0.048	0.011				4.98	0.385				
	1+8	R 500	569.8 568.2	569.0		0.014					-0.162	0.019			0.001	0.001	0.012			0.19	0.001	0.210	0.546
		L 19000	415.5 414.9	415.2		0.734					2.000	0.981			0.583	0.595	0.606			9.58	1.428	0.351	0.913
1	R L	M 15000	321.2 321.2	321.2	65.5 62.33	0.749	2.357	2.734	0.480	0.210			0.048	0.011				4.98	0.386				
	1+x	R 15000	-	-		-					2.087	1.00			0.607	0.620	0.631			9.78	1.485	0.357	0.924
		L -	-			-					-0.167	0.00			-	-	0.011			-	-	0.208	0.539
2	R L	M 10000	348.4 348.4	348.4	65.5 62.33	0.460	2.228	2.500	1.619	0.210			0.019	0.004				2.99	0.139				
	2+x	R 10000	-	-		-					0.819				0.256	0.261	0.265			6.01	0.562	0.131	0.942
		L -	-	-		-					-0.062				-	-	0.004			-	-	0.073	0.525
3	R L	M 10250	512.4 512.8	512.6	65.5 62.33	0.321	1.772	2.014	1.570	0.210			0.010	0.002				2.13	0.071				
	3+x	R 10250	-	-		-					0.412				0.137	0.140	0.142			4.19	0.274	0.072	1.018
		L -	-	-		-					-0.032				-	-	0.002			-	-	0.037	0.519

Table 11. Wye Loss Coefficients for 90° Small Spherical Wye (Symmetrical Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient	Average wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1+1	M 19000	200.0 200.4	200.2	65.0 62.33	1.522	1.262	0.389	0.374	0.210			0.177	0.039				10.13	1.593					
		R 10000	211.0 210.8	210.9		0.760					1.098				0.615	0.628	0.667			9.92	1.532	0.492	0.309	0.302
		L 19000	400.5 400.5	400.5		0.761					1.083				0.616	0.629	0.668			9.94	1.537	0.471	0.295	
2	2+2	M 19000	275.6 275.5	275.55	65.0 62.33	1.107	0.692	0.303	0.297	0.210			0.098	0.021				7.36	0.842					
		R 10000	290.6 290.2	290.40		0.552					0.605				0.357	0.365	0.386			7.22	0.811	0.250	0.297	0.294
		L 15000	435.1 434.9	435.00		0.553					0.599				0.358	0.366	0.387			7.22	0.810	0.244	0.290	
3	3+3	M 15000	319.2 319.3	319.5	65.0 62.33	0.753	0.914	0.826	0.829	0.210			0.048	0.011				5.01	0.390					
		R 7500	320.8 320.6	320.7		0.3755					0.295				0.182	0.187	0.198			4.90	0.374	0.113	0.290	0.293
		L 10500	446.3 445.9	446.1		0.3775					0.298				0.183	0.187	0.198			4.92	0.377	0.115	0.295	
4	4+4	M 10000	320.5 320.0	320.25	65.5 62.33	0.501	0.836	0.899	0.903	0.210			0.022	0.005				3.33	0.173					
		R 5000	323.6 323.2	323.40		0.248					0.133				0.086	0.088	0.093			3.23	0.163	0.050	0.289	0.290
		L 7500	476.0 476.4	476.20		0.253					0.147				0.092	0.094	0.099			3.30	0.169	0.052	0.301	
5	5+5	M 7500	375.0 375.0	375.0	65.0 62.33	0.321	1.085	1.230	1.232	0.210			0.010	0.002				2.13	0.071					
		R 3750	374.0 373.6	373.8		0.161					0.063				0.040	0.041	0.043			2.10	0.068	0.023	0.324	0.307
		L 5000	497.8 497.4	496.6		0.161					0.065				0.042	0.043	0.045			2.11	0.069	0.022	0.310	

Table 11 (cont'd). Wye Loss Coefficients for 90 Small Spherical Wye (Unsymmetrical and One Leg Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft) in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	L R	M 15000	321.0 320.6	320.8	65.0 62.33	0.750	1.262	1.610	0.394	0.210			0.048	0.011				4.99	0.387				
	5+2	R 12500	348.9 349.1	349.0		0.574					1.078	0.765			0.380	0.387	0.398			7.52	0.872	0.195	0.504
		L 5500	502.0 501.2	501.6		0.176					-0.132	0.235			0.049	0.050	0.061			2.30	0.085	0.109	0.282
2	L R	M 15000	320.0 320.0	320.0	66.0 62.33	0.752	1.703	1.796	1.409	0.210			0.048	0.011				5.01	0.390				
	4+3	R 10250	376.8 376.4	376.6		0.437					0.504	0.582			0.240	0.245	0.256			5.71	0.506	0.132	0.338
		L 8000	412.0 412.6	412.3		0.312					0.117	0.416			0.133	0.136	0.147			4.07	0.257	0.103	0.264
3	L R	M 15000	321.9 321.6	321.8	65.0 62.33	0.748	1.472	1.874	0.107	0.210			0.048	0.011				4.98	0.385				
	6+1	R 15000	360.8 360.4	360.6		0.667					1.575	0.893			0.499	0.510	0.521			8.71	1.178	0.261	0.678
		L 2000	401.9 401.4	401.7		0.079					-0.192	0.106			0.011	0.011	0.022			1.04	0.017	0.154	0.400
4	L R	M 15000	322.4 322.2	322.3	65.0 62.33	0.746	1.883	0.247	2.272	0.210			0.048	0.011				4.96	0.383				
	1+7	R 2000	979.8 978.6	979.2		0.033					-0.179	0.044			0.002	0.002	0.013			0.429	0.003	0.188	0.490
		L 19000	426.8 427.2	427.0		0.713					1.846	0.955			0.562	0.574	0.585			9.31	1.348	0.296	0.773
5	L R	M 15000	321.8 321.6	321.7	65.5 62.33	0.748	2.065	0.295	2.457	0.210			0.048	0.011				4.98	0.385				
	1+8	R 500	569.0 569.8	569.4		0.014					-0.172	0.019			0.001	0.001	0.012			0.185	0.001	0.200	0.519
		L 19000	415.3 414.7	415.0		0.734					1.968	0.981			0.583	0.595	0.606			9.58	1.428	0.319	0.828
1	R L	M 15000	321.9 321.6	321.8	65.0 62.33	0.745	2.179	2.570	0.344	0.210			0.048	0.011				4.96	0.382				
	1+x	R 15000	-			-					2.045	1.000			0.606	0.619	0.630			9.72	1.468	0.329	0.861
		L -	-	-		-					-0.181	0.000			-	-	0.011			-	-	0.190	0.497
2	R L	M 10000	319.4 318.9	319.2	65.0 62.33	0.502	0.853	1.140	0.103	0.210			0.022	0.005				3.34	0.174				
	2+x	R 10000	-	-		-					0.960				0.302	0.309	0.314			6.56	0.669	0.151	0.866
		L -	-	-		-					-0.077				-	-	0.005			-	-	0.086	0.495
3	R L	M 7500	371.9 371.9	371.9	65.0 62.33	0.324	0.588	0.830	0.384	0.210			0.010	0.002				2.15	0.072				
	3+x	R 7500	-	-		-					0.414				0.137	0.140	0.142			4.23	0.278	0.065	0.917
		L -	-	-		-					-0.032				-	-	0.002			-	-	0.038	0.528

Table 12. Wye Loss Coefficients for 90° Tapered Wye (Symmetrical Flow)

Test No.	Orifice No.	Weight of water (lbs) from M,main pipe; R,right leg; L,left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient	Average wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1+1	M 19000	204.0 203.6	203.8	63.5 62.34	1.497	0.960	0.343	0.338	0.210			0.150	0.028				9.95	1.530					
		R 15000	322.3 322.1	322.2		0.746					0.832				0.599	0.613	0.641			9.74	1.475	0.246	0.161	0.156
		L 19000	408.1 407.3	407.7		0.748					0.827				0.601	0.604	0.632			9.77	1.483	0.232	0.152	
2	2+2	M 19000	301.9 301.3	301.6	63.5 62.34	1.011	0.203	0.114	0.112	0.210			0.082	0.015				7.32	0.833					
		R 10000	318.4 317.9	318.15		.504					0.401				0.306	0.313	0.328			6.58	0.673	0.133	0.160	0.159
		L 10000	317.6 318.4	318.0		.504					0.399				0.306	0.313	0.328			6.58	0.672	0.132	0.158	
3	3+3	M 15000	322.0 322.4	322.2	64 62.34	0.746	0.829	0.798	0.800	0.210			0.048	0.009				4.97	0.383					
		R 7500	323.6 323.3	323.45		0.372					0.239				0.176	0.180	0.189			4.86	0.367	0.066	0.172	0.168
		L 10000	428.7 428.0	428.35		0.374					0.241				0.178	0.182	0.191			4.88	0.371	0.062	0.164	
4	4+4	M 10000	321.6 321.3	321.45	64 62.34	0.499	0.800	0.890	0.895	0.210			0.022	0.004				3.32	0.171					
		R 5000	324.6 325.1	324.85		0.247					0.115				0.085	0.087	0.091			3.22	0.162	0.032	0.187	0.181
		L 7500	478.3 477.5	477.90		0.251					0.120				0.088	0.090	0.094			3.28	0.167	0.030	0.175	
5	5+5	M 7500	373.4 373.6	373.5	64 62.34	0.322	1.061	1.216	1.215	0.210			0.010	0.002				2.15	0.072					
		R 3750	375.2 374.8	375.0		0.1603					0.056				0.040	0.041	0.043			2.10	0.068	0.017	0.236	0.214
		L 5000	497.4 495.1	497.7		0.1613					0.055				0.042	0.043	0.045			2.11	0.069	0.013	0.181	

Table 12 (cont'd). Wye Loss Coefficients for 90° Tapered Wye (Unsymmetrical and One Leg Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	R L	M 15000	320.5 320.4	320.7	64 62.34	0.750	1.179	1.530	0.400	0.210			0.048	0.009				4.99	0.387				
	2+5	R 12500	347.4 347.2	347.3		0.577					0.989	0.769			0.385	0.394	0.403			7.53	0.881	0.092	0.236
		L 4750	441.5 440.7	441.2		0.173					-0.141	0.231			0.047	0.048	0.057			2.26	0.079	0.110	0.284
2	R L	M 15000	325.4 324.9	325.15	64 62.34	0.739	1.592	1.724	1.371	0.210			0.048	0.009				4.92	0.376				
	3+4	R 10000	370.5 370.1	370.30		0.433					0.431	0.586			0.231	0.236	0.245			5.65	0.496	0.066	0.176
		L 10000	523.8 523.4	523.60		0.306					0.078	0.414			0.128	0.131	0.140			3.99	0.248	0.069	0.184
3	R L	M 15000	322.5 323.0	322.75	64 62.34	0.746	1.335	0.111	1.718	0.210			0.048	0.009				4.97	0.383				
	1+6	R 10000	351.7 351.4	351.55		0.078					-0.173	0.105			0.011	0.011	0.020			1.02	0.016	0.174	0.454
		L 19000	455.5 456.1	455.80		0.668					1.434	0.895			0.488	0.499	0.508			8.72	1.183	0.126	0.329
4	L R	M 15000	320.7 320.3	320.4	66 62.33	0.7508	1.752	0.258	2.133	0.210			0.048	0.009				4.99	0.388				
	1+7	R 1200	601.0 602.2	601.6		0.032					-0.171	0.043			0.002	0.002	0.011			0.42	0.003	0.203	0.523
		L 19000	423.6 424.0	423.8		0.719					1.714	0.957			0.564	0.577	0.586			9.38	1.369	0.137	0.353
5	L R	M 15000	321.45 321.00	321.22	66 62.33	0.749	1.900	0.306	2.279	0.210			0.048	0.009				4.98	0.386				
	1+8	R 500	578.50 579.30	578.90		0.0139					-0.169	0.019			0.001	0.001	0.010			0.18	0.001	0.206	0.534
		L 19000	414.50 415.00	414.75		0.735					1.804	0.981			0.585	0.597	0.606			9.60	1.432	0.152	0.399
1		M 15000	324.6 325.0	324.8	63.5 62.34	0.741	1.981	0.325	2.356	0.210			0.047	0.009				4.93	0.378				
	L R	R -	-	-		-					-0.165	0.000			-	-	0.009			-	-	0.204	0.530
	1+x	L -	-	-		-					1.866	1.000			0.583	0.597	0.606			9.67	1.455	0.183	0.484
2	L R	M 15000	482.8 482.0	482.4	64 62.34	0.498	0.754	0.087	1.035	0.210			0.023	0.004				3.31	0.171				
	2+x	R -	-	-		-					-0.071				-	-	0.004			-	-	0.096	0.562
		L -	-	-		-					0.383				0.297	0.304	0.308			6.50	0.657	0.083	0.485
3	L R	M 10000	497.3 497.0	497.15	65 62.33	0.322	0.554	0.381	0.790	0.210			0.010	0.002				2.14	0.071				
	3+x	R -	-	-		-					-0.026				-	-	0.002			-	-	0.043	0.605
		L -	-	-		-					0.383				0.139	0.142	0.144			4.20	0.275	0.035	0.493

Table 13. Wye Loss Coefficients for 60° Tapered Wye (A), (Symmetrical Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient	Average wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1		M 19000	201.9 202.3	202.1	65 62.33	1.508	0.877	0.348	0.348	0.210			0.174	0.030				10.03	1.564					
	1+1	R 15000	319.0 319.5	319.3		0.753					0.739				0.603	0.625	0.655			9.83	1.503	0.145	0.093	0.091
		L 19000	404.1 403.9	404.0		0.755					0.739				0.603	0.625	0.655			9.85	1.509	0.139	0.089	
2		M 19000	277.5 277.7	277.6	64.5 62.33	1.098	0.482	0.269	0.269	0.210			0.098	0.017				7.30	0.829					
	2+2	R 10000	292.5 292.9	292.7		0.548					0.423				0.350	0.363	0.380			7.15	0.797	0.075	0.090	0.088
		L 19000	522.2 521.8	522.0		0.550					0.423				0.350	0.363	0.380			7.17	0.802	0.070	0.085	
3		M 19000	330.0 329.9	330.0	64 62.34	0.924	1.743	1.653	1.652	0.210			0.070	0.012				6.15	0.596					
	3+3	R 10000	347.5 347.2	347.3		0.462					0.301				0.258	0.268	0.280			6.03	0.564	0.053	0.089	0.088
		L 15000	521.0 521.6	521.3		0.462					0.300				0.257	0.266	0.278			6.03	0.566	0.052	0.087	
4		M 15000	320.2 320.1	320.2	65 62.33	0.7510	0.819	0.817	0.811	0.210			0.048	0.022				5.00	0.388					
	3+3	R 7500	320.1 320.2	320.2		0.3755					0.218				0.182	0.190	0.198			4.90	0.373	0.035	0.090	0.088
		L 10000	427.1 427.4	427.3		0.3755					0.212				0.180	0.187	0.195			4.90	0.373	0.032	0.084	
5		M 10000	319.5 319.5	319.5	65.5 62.33	0.502	0.807	0.915	0.906	0.210			0.022	0.004				3.34	0.173					
	4+4	R 5000	317.8 317.6	317.7		0.253					0.111				0.091	0.094	0.098			3.30	0.169	0.017	0.110	0.104
		L 7500	481.6 482.0	481.8		0.250					0.102				0.087	0.090	0.094			3.26	0.166	0.015	0.097	

Table 13 (cont'd). Wye Loss Coefficients for 60° Tapered Wye (A), (Unsymmetrical and One Leg Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft) in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1		M 19000	330.7 330.5	330.6	65 62.33	0.922	1.793	2.197	0.810	0.210			0.070	0.012				6.13	0.594				
	R L	R 15000	360.2 360.2	360.2		0.667					1.193	0.724			0.492	0.510	0.522			8.71	1.182	0.083	0.140
	2+6	L 7500	472.5 473.0	472.3		0.255					-0.194	0.276			0.093	0.096	0.108			3.32	0.172	0.110	0.185
2	R L	M 19000	330.1 329.9	330.0	64 62.34	0.923	1.479	1.626	1.086	0.210			0.070	0.012				6.14	0.596				
	4+3	R 15000	444.7 444.7	444.7		0.541					0.603	0.586			0.343	0.356	0.368			7.06	0.775	0.056	0.094
		L 10000	420.0 420.4	420.2		0.382					0.063	0.414			0.187	0.193	0.205			4.99	0.387	0.067	0.112
3	R L	M 19000	330.9 330.8	330.9	64.5 62.33	0.921	2.704	3.189	0.727	0.210			0.070	0.012				6.13	0.593				
	6+1*	R 19000	364.3 364.1	364.2		0.836					2.187	0.908			0.728	0.754	0.768			10.92	1.853	0.159	0.268
		L 2000	377.5 376.8	377.2		0.085					-0.275	0.092			0.013	0.013	0.025			1.10	0.019	0.274	0.462
4	R L	M 19000	332.1 332.1	332.1	65 62.33	0.918	3.101	3.566	0.786	0.210			0.070	0.012				6.10	0.579				
	1*+7	R 19000	345.2 344.8	345.0		0.883					2.525	0.962			0.802	0.830	0.842			11.53	2.068	0.194	0.335
		L 1500	691.7 691.1	691.4		0.035					-0.255	0.038			0.002	0.002	0.014			0.46	0.003	0.307	0.530
5	R L	M 19000	332.3 331.9	332.1	65 62.33	0.918	3.270	3.736	0.810	0.210			0.070	0.012				6.10	0.579				
	1*+8	R 19000	337.9 337.5	337.7		0.902					2.670	0.983			0.832	0.862	0.874			11.78	2.160	0.215	0.371
		L 500	501.6 502.4	502.0		0.016					-0.256	0.017			0.001	0.001	0.013			0.21	0.001	0.308	0.532
1		M 19000	332.5 332.2	332.4	64.5 62.33	0.917	3.404	3.877	0.830	0.210			0.070	0.012				6.10	0.577				
	R L 1*+x	R 19000 L -	- -	-		- -					2.784 -0.263	1.00 0.00			0.855 -	0.886 -	0.898 0.012			11.98 -	2.231 -	0.236 0.302	0.410 0.522
2		M 19000	407.4 407.0	407.2	64.5 62.33	0.749	2.017	2.403	0.342	0.210			0.048	0.008				4.98	0.385				
	R L 1+x	R 19000 L -	- -	- -		- -					1.885 -0.176				0.600 -	0.622 -	0.630 0.008			9.77 -	1.484 -	0.157 0.203	0.408 0.527
3		M 10000	319.8 319.8	319.8	65 62.33	0.502	0.764	1.050	0.100	0.210			0.022	0.004				3.34	0.173				
	R L 2+x	R 10000 L -	- -	- -		- -					0.874 -0.076				0.301 -	0.312 -	0.316 0.004			6.55 -	0.666 -	0.065 0.093	0.376 0.537
4		M 7000	347.5 347.1	347.3	65 62.33	0.323	0.561	0.802	0.393	0.210			0.010	0.002				2.15	0.072				
	R L 3+x	R 7000 L -	- -	- -		- -					0.378 -0.031				0.141 -	0.146 -	0.148 0.002			4.22 -	0.277 -	0.025 0.039	0.347 0.542

Table 14. Wye Loss Coefficients for 60° Tapered Wye (B), (Symmetrical Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient	Average wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1+1	M 19000	204.2 204.3	204.3	65 62.33	1.492	0.851	0.322	0.311	0.210			0.171	0.042				9.92	1.530					
		R 15000	323.1 323.0	323.1		0.745					0.740				0.596	0.619	0.661			9.72	1.469	0.140	0.091	0.087
		L 19000	407.9 408.1	408.0		0.747					0.739				0.599	0.622	0.664			9.75	1.478	0.127	0.083	
2	2+2	M 19000	277.3 277.1	277.2	65 62.33	1.099	0.486	0.270	0.273	0.210			0.098	0.024				7.30	0.829					
		R 10500	306.8 306.6	306.7		0.549					0.423				0.352	0.365	0.389			7.17	0.798	0.067	0.081	0.080
		L 19000	522.2 521.4	521.8		0.550					0.426				0.354	0.367	0.391			7.18	0.801	0.065	0.078	
3	2+2	M 19000	324.8 324.7	324.8	65 62.33	0.938	10.078	9.967	9.971	0.210			0.072	0.017				6.24	0.605					
		R 10000	342.8 342.7	342.8		0.468					0.317				0.267	0.277	0.294			6.11	0.580	0.048	0.079	0.079
		L 19000	511.8 512.2	512.0		0.470					0.321				0.267	0.277	0.294			6.13	0.584	0.048	0.079	
4	3+3	M 15000	317.7 317.8	317.8	64.5 62.33	0.757	0.832	0.823	0.825	0.210			0.049	0.012				5.04	0.394					
		R 8000	340.0 340.0	340.0		0.378					0.217				0.184	0.191	0.203			4.93	0.378	0.030	0.076	0.079
		L 10000	423.5 423.9	423.7		0.379					0.219				0.182	0.189	0.201			4.95	0.380	0.032	0.081	
5	4+4	M 10500	337.0 337.1	337.1	64.5 62.33	0.499	0.792	0.900	0.890	0.210			0.022	0.005				3.32	0.170					
		R 5000	318.7 318.9	318.8		0.250					0.112				0.091	0.094	0.099			3.28	0.167	0.016	0.094	0.094
		L 7500	486.2 486.8	486.5		0.248					0.102				0.086	0.089	0.094			3.23	0.162	0.016	0.094	

Table 14 (cont'd). Wye Loss Coefficients for 60 Tapered Wye (B), (Unsymmetrical and One Leg Flow)

Test No.	Orifice No.	Weight of water (lbs) from M, main pipe; R, right leg; L, left leg	Time interval (secs)	Average time interval (secs)	Temperature in F° and specific weight of water (lbs/cu.ft.)	Discharge (cfs)	Hook gage reading in upstream tank (ft)	Hook gage reading in central tank (ft)	Hook gage reading in downstream tank (ft)	Vernier correction (ft)	Pressure head difference (ft) between main pipe and right leg or main pipe and left leg	Discharge ratio, Discharge in branch / Discharge in main pipe	Friction loss (ft) in main pipe for length 3.375'	Friction loss (ft), in main pipe for length ST	Friction loss (ft) in right or left leg, for length 9.0'	Friction loss (ft), in right or left leg, for length TD_1 or TD_2	Total friction loss (ft)	Velocity in main pipe (ft/sec)	Velocity head in main pipe (ft)	Velocity in right or left leg (ft/sec)	Velocity head in right or left leg (ft)	Wye loss (ft)	Wye loss coefficient
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1		M 19000	331.4 331.2	331.3	64.5 62.33	0.919	1.764	0.779	2.185	0.210			0.070	0.017				6.11	0.583				
	R L	R 5000	316.4 316.2	316.3		0.255					-0.211	0.277			0.092	0.096	0.113			3.32	0.171	0.098	0.168
	5+2	L 19000	459.2 458.8	459.0		0.664					1.195	0.723			0.494	0.512	0.529			8.67	1.168	0.081	0.139
2	R L	M 19000	330.3 329.9	330.1	64.5 62.33	0.922	1.484	1.087	1.626	0.210			0.070	0.017				6.14	0.586				
	4+3	R 10000	419.0 419.0	419.0		0.383					0.068	0.415			0.188	0.195	0.212			5.00	0.388	0.054	0.092
		L 15000	414.9 414.3	414.6		0.539					0.607	0.585			0.341	0.354	0.371			7.04	0.770	0.052	0.089
3	R L	M 19000	330.9 331.0	331.0	64.5 62.33	0.920	2.705	3.232	0.718	0.210			0.070	0.017				6.12	0.582				
	1*+6	R 15000	288.0 287.9	288.0		0.835					2.197	0.961			0.727	0.744	0.761			10.91	1.849	0.169	0.290
		L 2000	377.6 377.0	377.3		0.085					-0.317	0.039			0.013	0.013	0.030			1.10	0.019	0.216	0.371
4	R L	M 19000	331.9 332.0	332.0	64.5 62.33	0.918	2.607	3.112	0.280	0.210			0.070	0.017				6.11	0.580				
	1*+7	R 19000	345.2 345.0	345.1		0.882					2.537	0.961			0.798	0.827	0.844			11.52	2.063	0.210	0.362
		L 1000	445.9 445.3	445.6		0.036					-0.295	0.039			0.001	0.001	0.018			0.47	0.003	0.264	0.455
5	R L	M 19000	332.9 332.6	332.8	64.5 62.33	0.916	2.760	3.264	0.301	0.210			0.070	0.017				6.09	0.576				
	1*+8	R 19000	338.6 338.2	338.4		0.900					2.669	0.983			0.827	0.858	0.875			11.77	2.152	0.218	0.379
		L 500	501.5 502.1	501.8		0.016					-0.294	0.017			0.002	0.002	0.019			0.21	0.001	0.262	0.455
1		M 19000	332.0 332.0	332.0	64.5 62.33	0.918	2.906	3.420	0.319	0.210			0.070	0.017				6.11	0.580				
		R 19000	-	-		-					2.797	1.000			0.857	0.889	0.906			11.98	2.233	0.238	0.410
	R L 1*+x	L -	-	-		-					-0.304	0.000			-	-	0.017			-	-	0.259	0.447
2	R L	M 15000	320.9 320.9	320.9	64.5 62.33	0.750	2.036	2.440	0.358	0.210			0.048	0.012				4.98	0.385				
		R 15000	-	-		-					1.888				0.603	0.626	0.638			9.66	1.475	0.160	0.415
	1+x	L -	-	-		-					-0.194				-	-	0.012			-	-	0.179	0.466
3		M 10000	319.2 319.2	319.2	64.5 62.33	0.502	0.765	1.060	0.092	0.210			0.022	0.005				3.33	0.173				
	R L	R 10000	-	-		-					0.883				0.301	0.312	0.317			6.56	0.667	0.072	0.417
	2+x	L -	-	-		-					-0.085				-	-	0.005			-	-	0.083	0.480
4		M 7000	344.5 344.5	344.5	65 62.33	0.326	0.585	0.831	0.408	0.210			0.010	0.002				2.17	0.073				
	R L	R 7000	-	-		-					0.387				0.142	0.148	0.150			4.26	0.282	0.028	0.384
	3+x	L -	-	-		-					-0.036				-	-	0.002			-	-	0.035	0.480

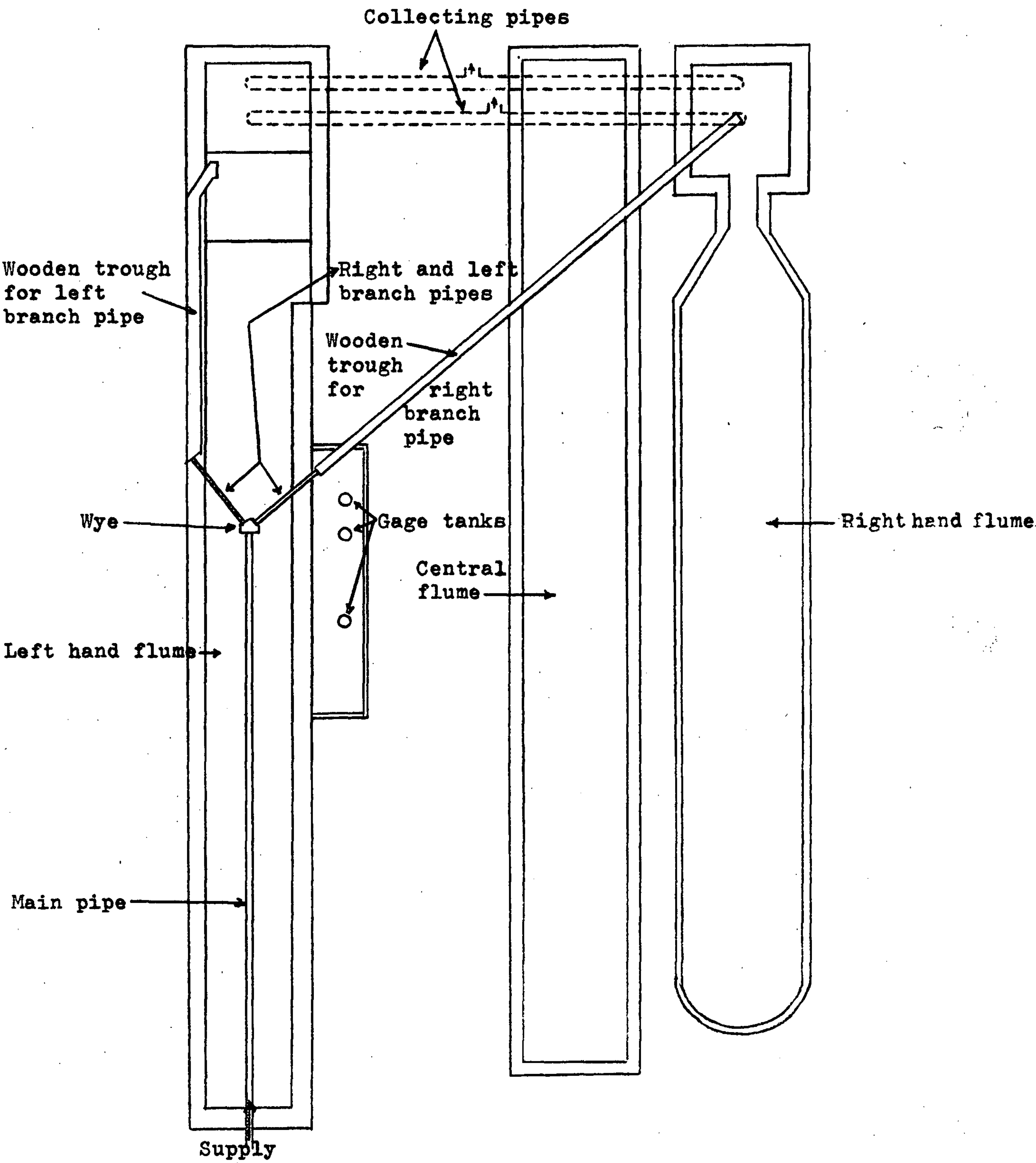


Fig. 1. General arrangement.

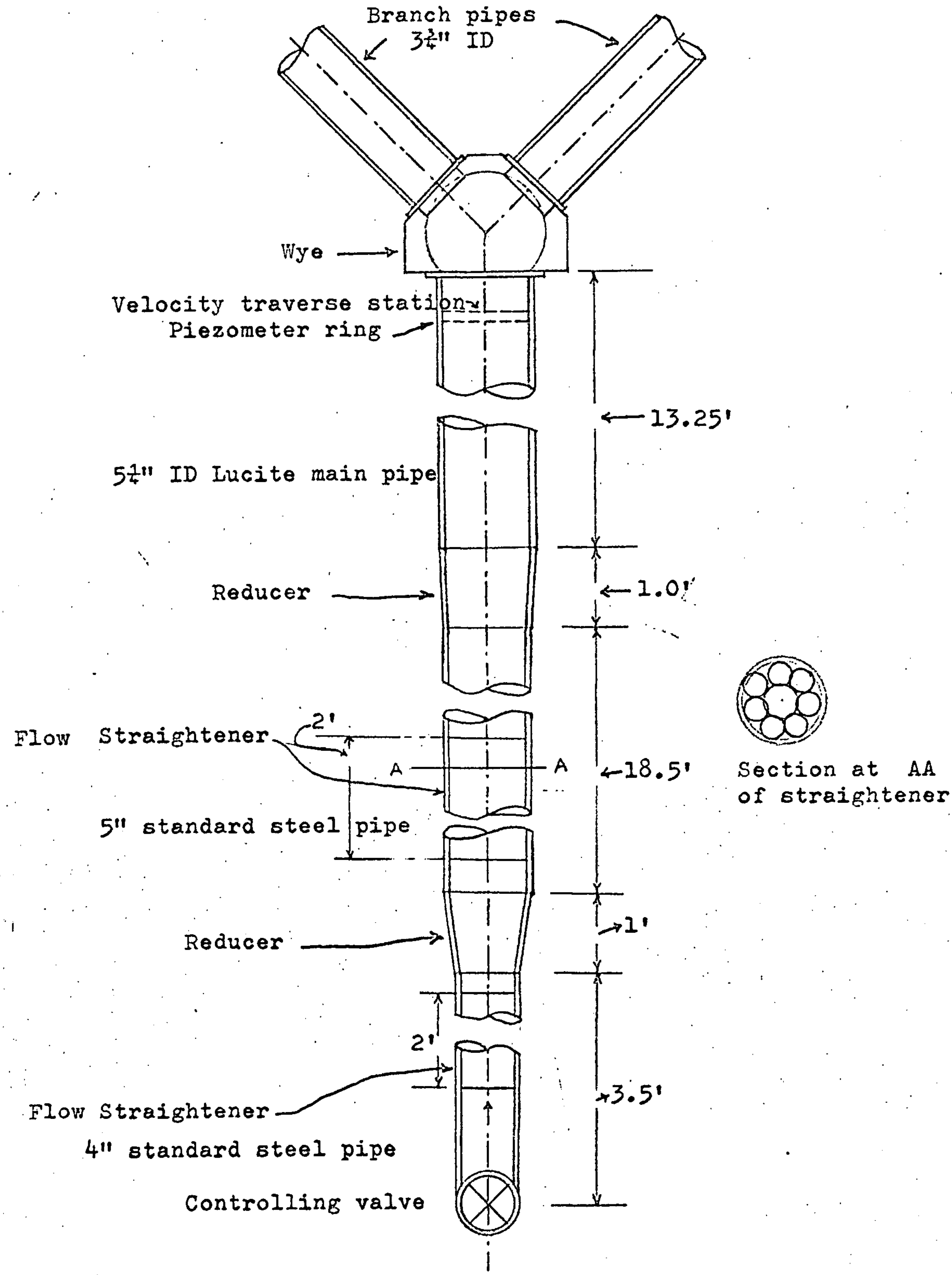


Fig. 2. Details of main pipe from controlling valve to wye.

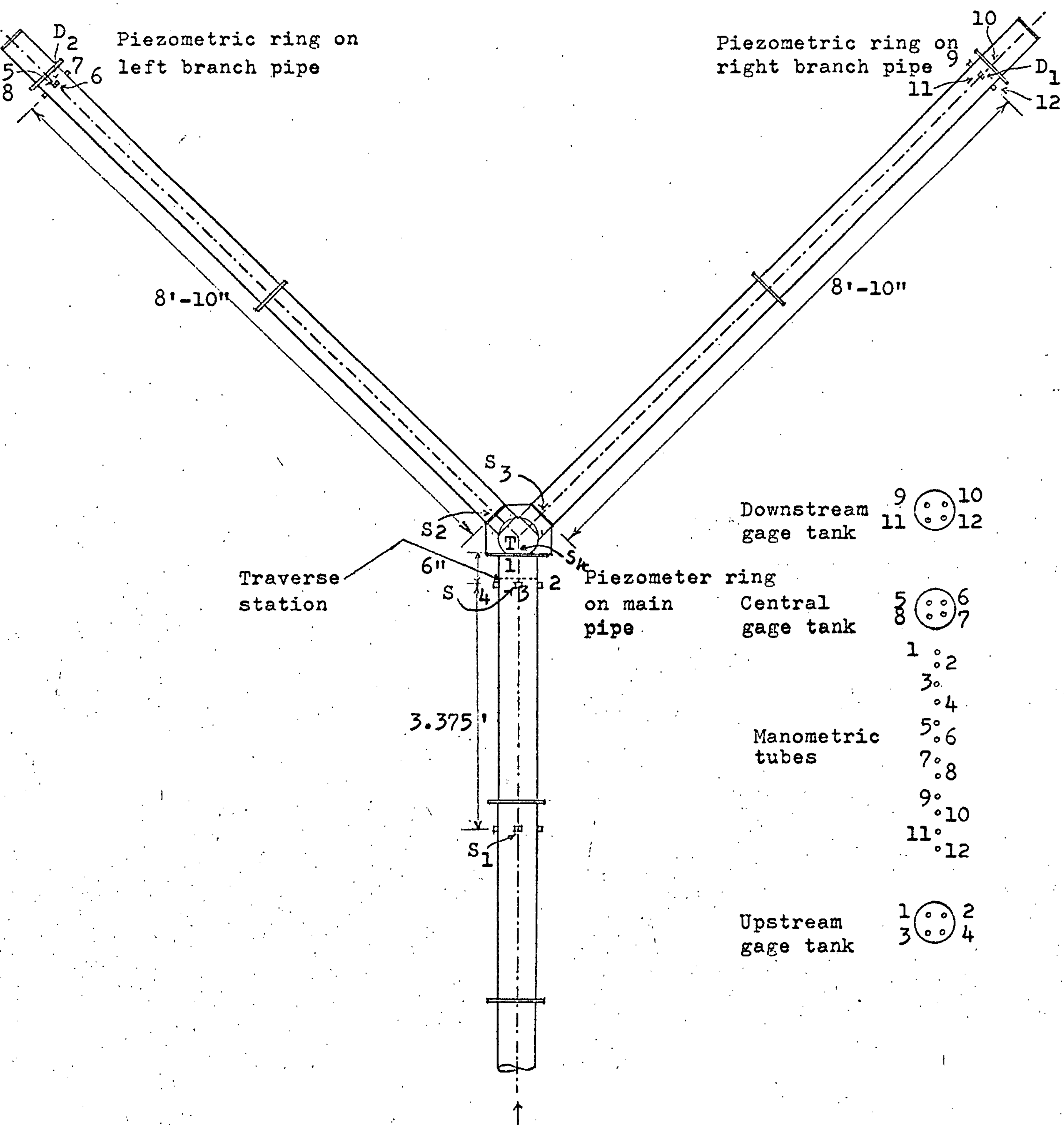


Fig. 3. Model lay out and manometric arrangement.

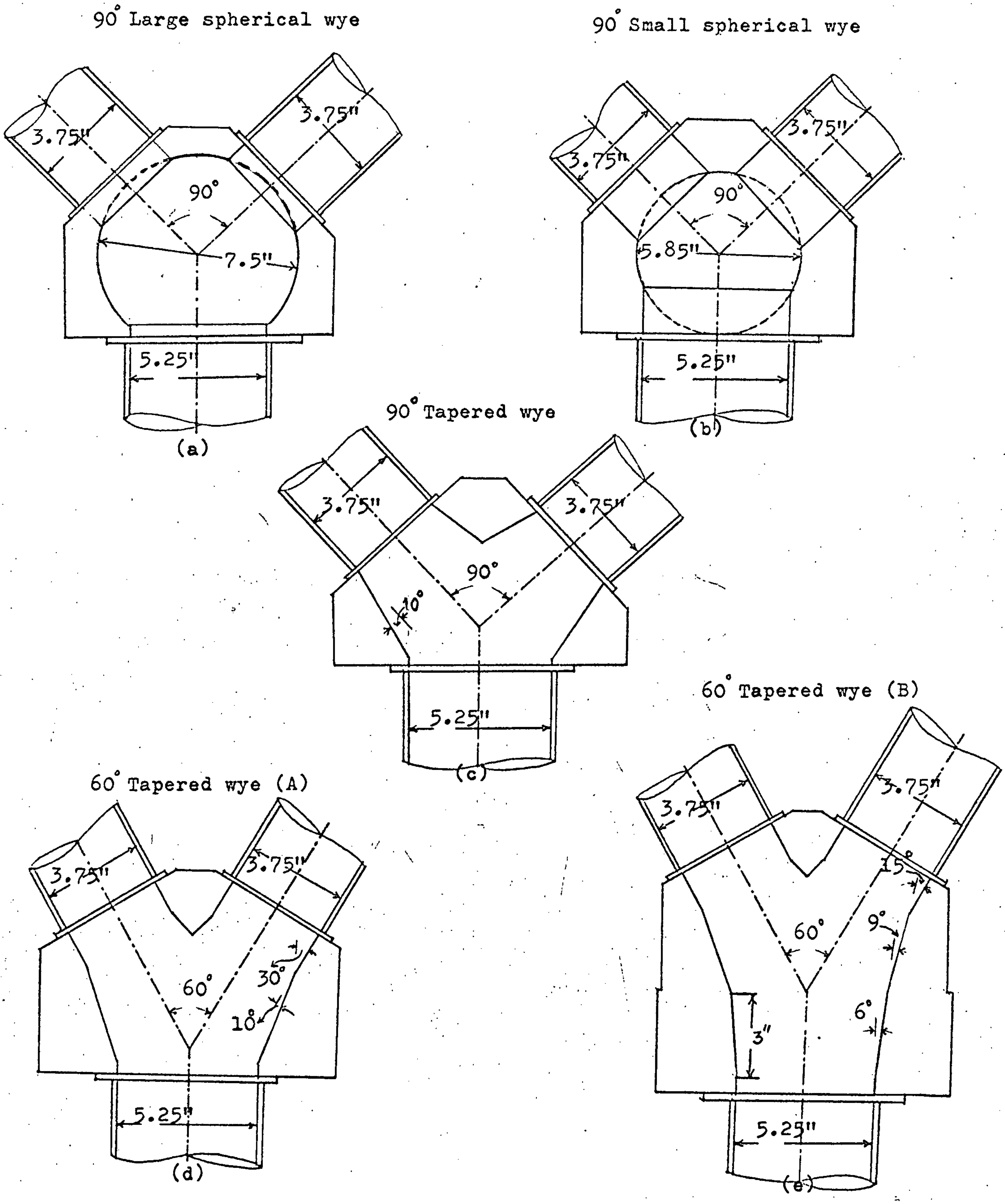


Fig. 4. Details of wyes.

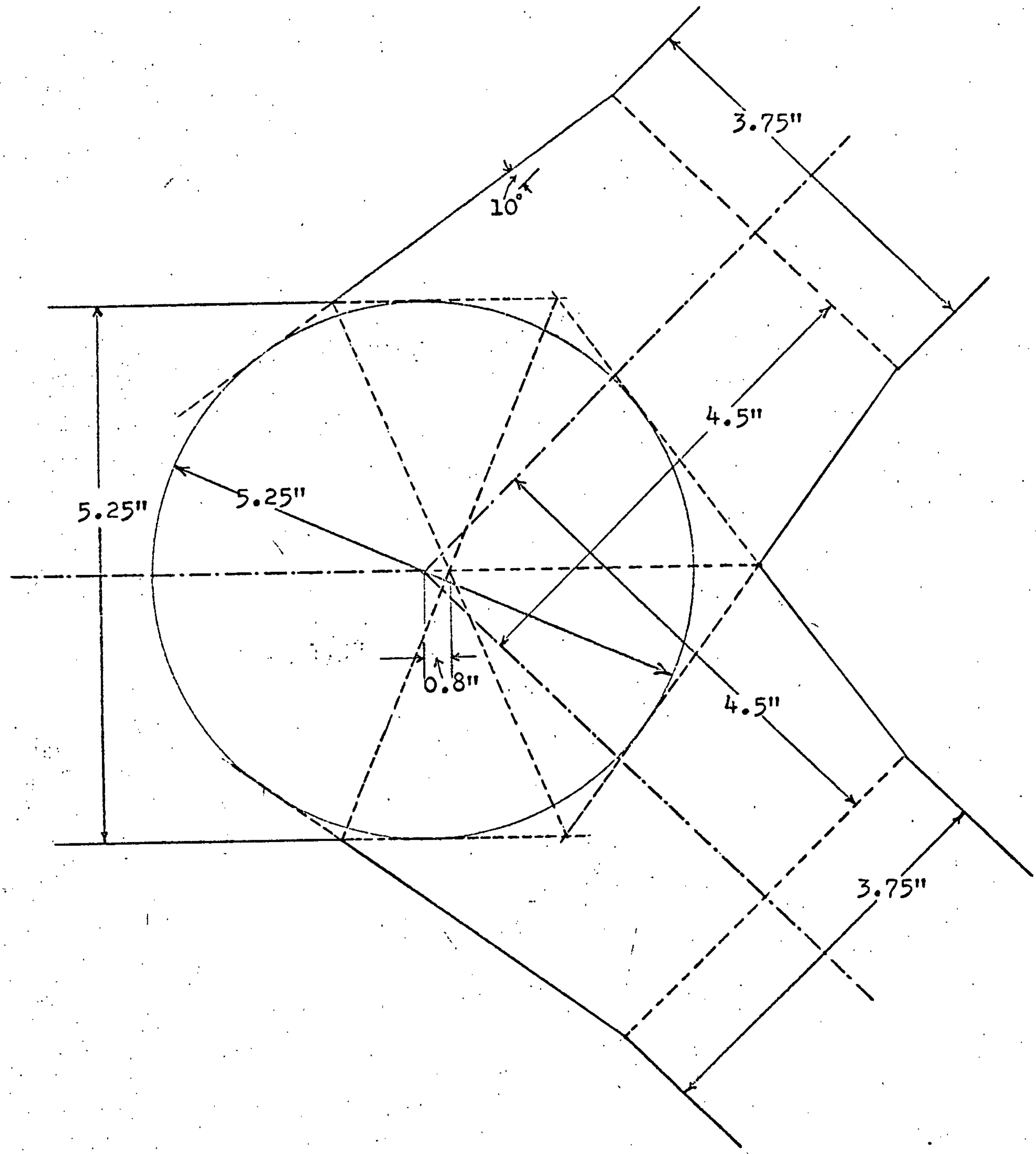


Fig.5. Geometric details of 90° tapered wye.

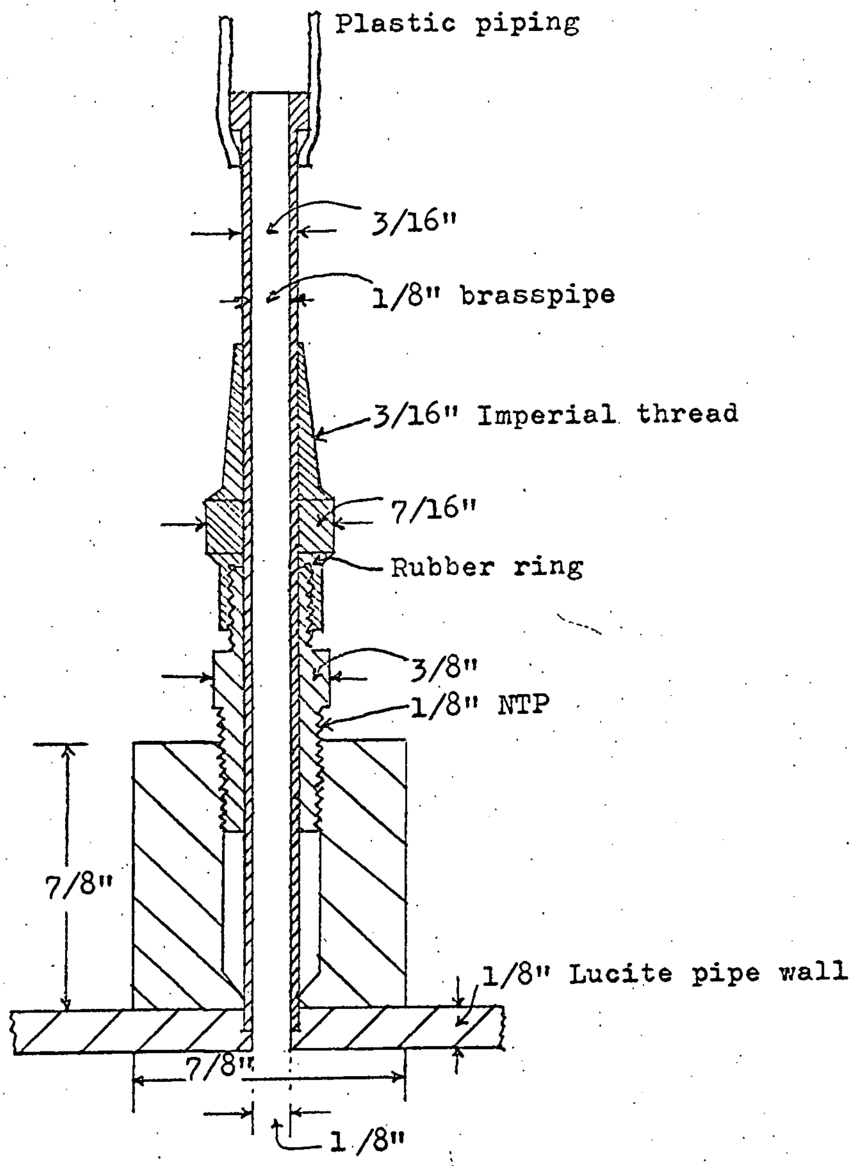
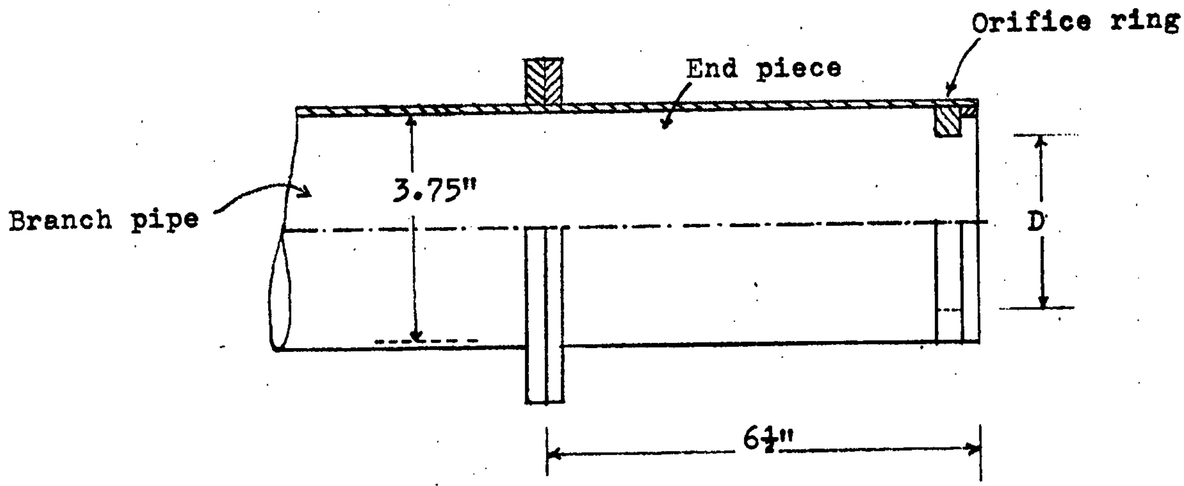


Fig. 6. Pressure tap.



Numerical designation of orifice	External diameter (inches)	Internal diameter (inches)	Remarks
1*	3.720	3.622	Rounded orifices
1	"	3.300	Rounded orifices
2	"	3.375	
3	"	2.913	
4	"	2.490	
5	"	2.000	
6	"	1.342	
7	"	0.840	
8	"	0.534	
x	-	-	no orifice

Fig. 7. Orifice arrangement.

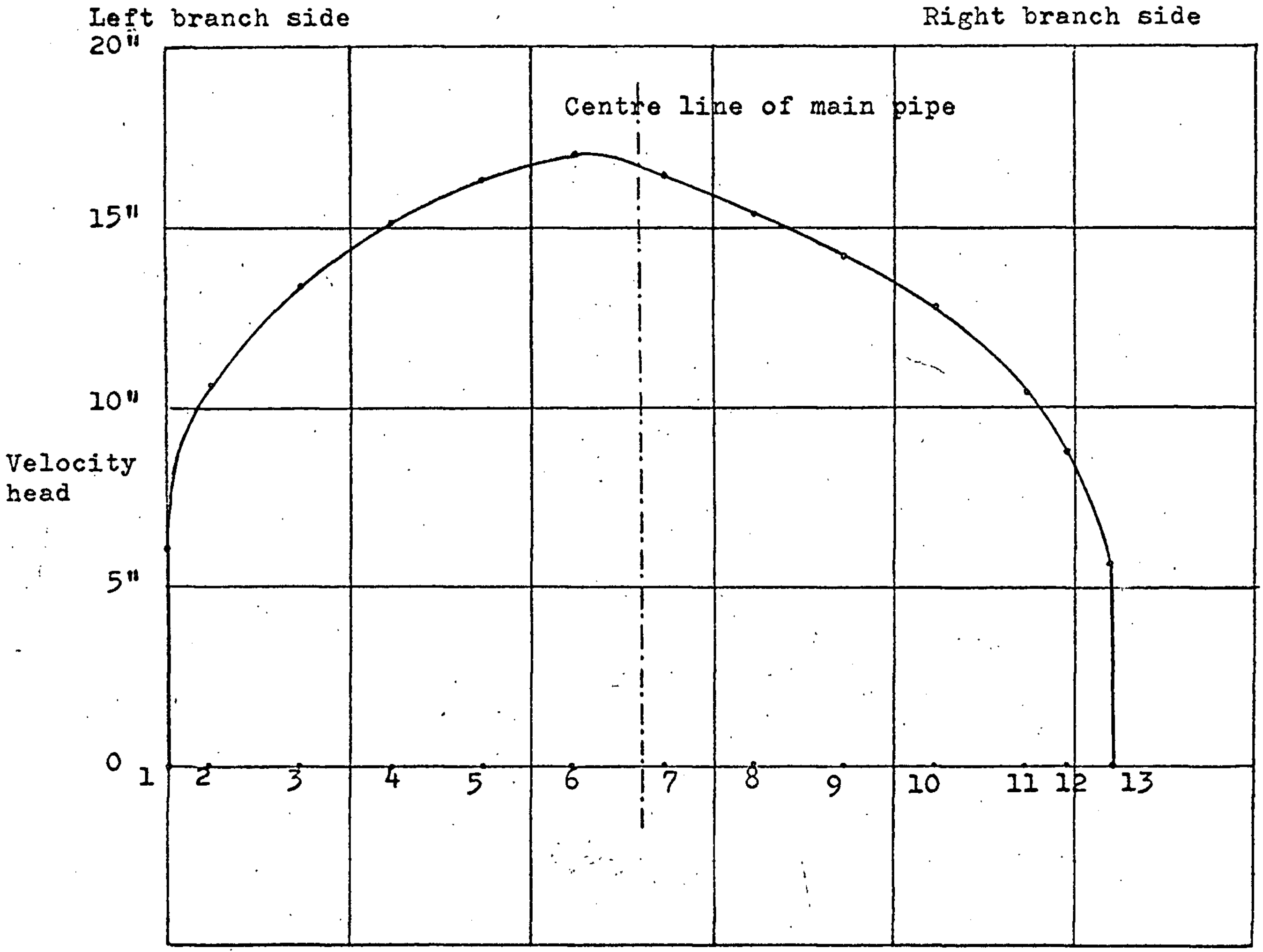


Fig. 8. Velocity traverse across main pipe near wye during preliminary investigations.

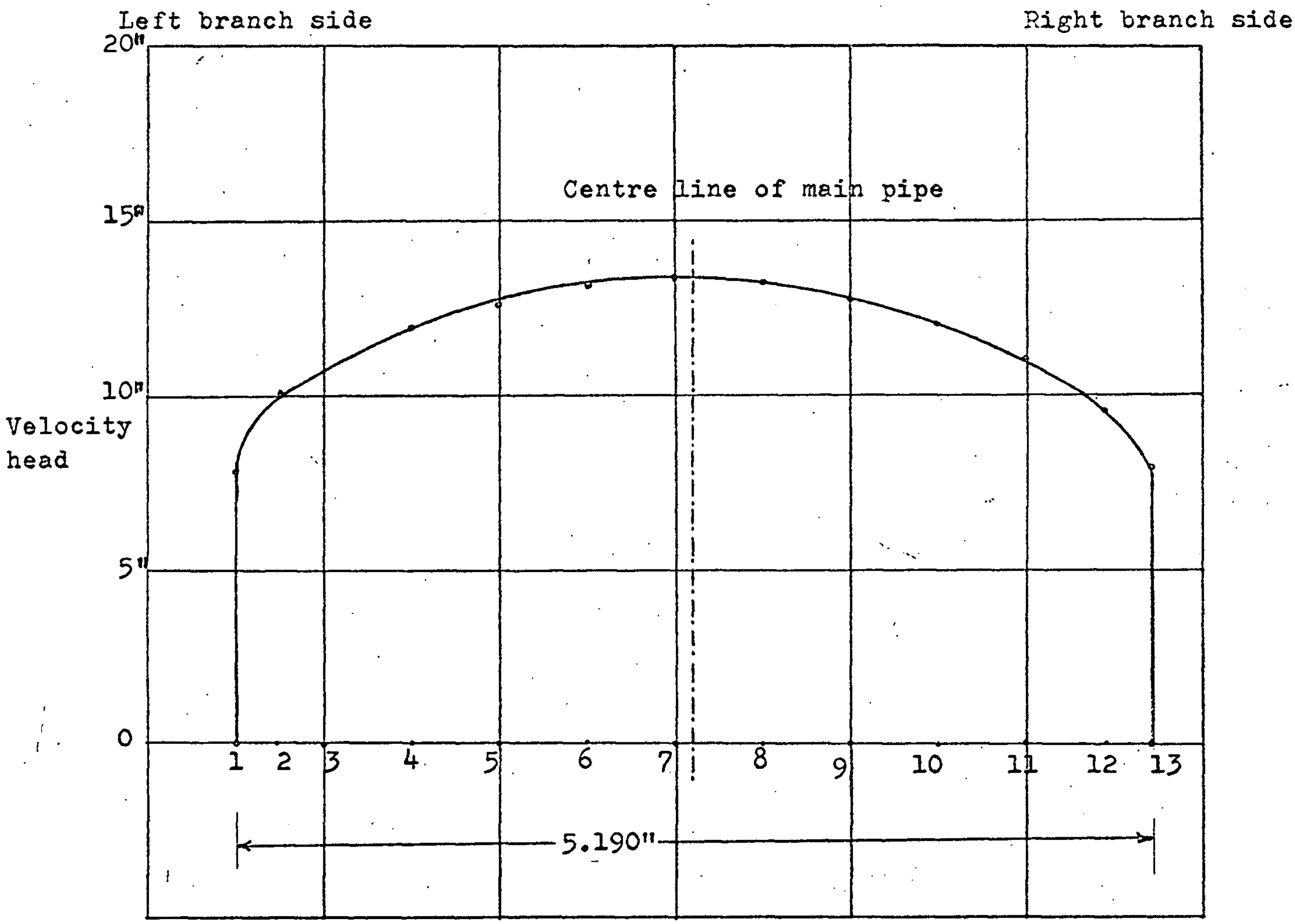


Fig. 9. Velocity traverse across main pipe near wye after modifications in the main pipe section.

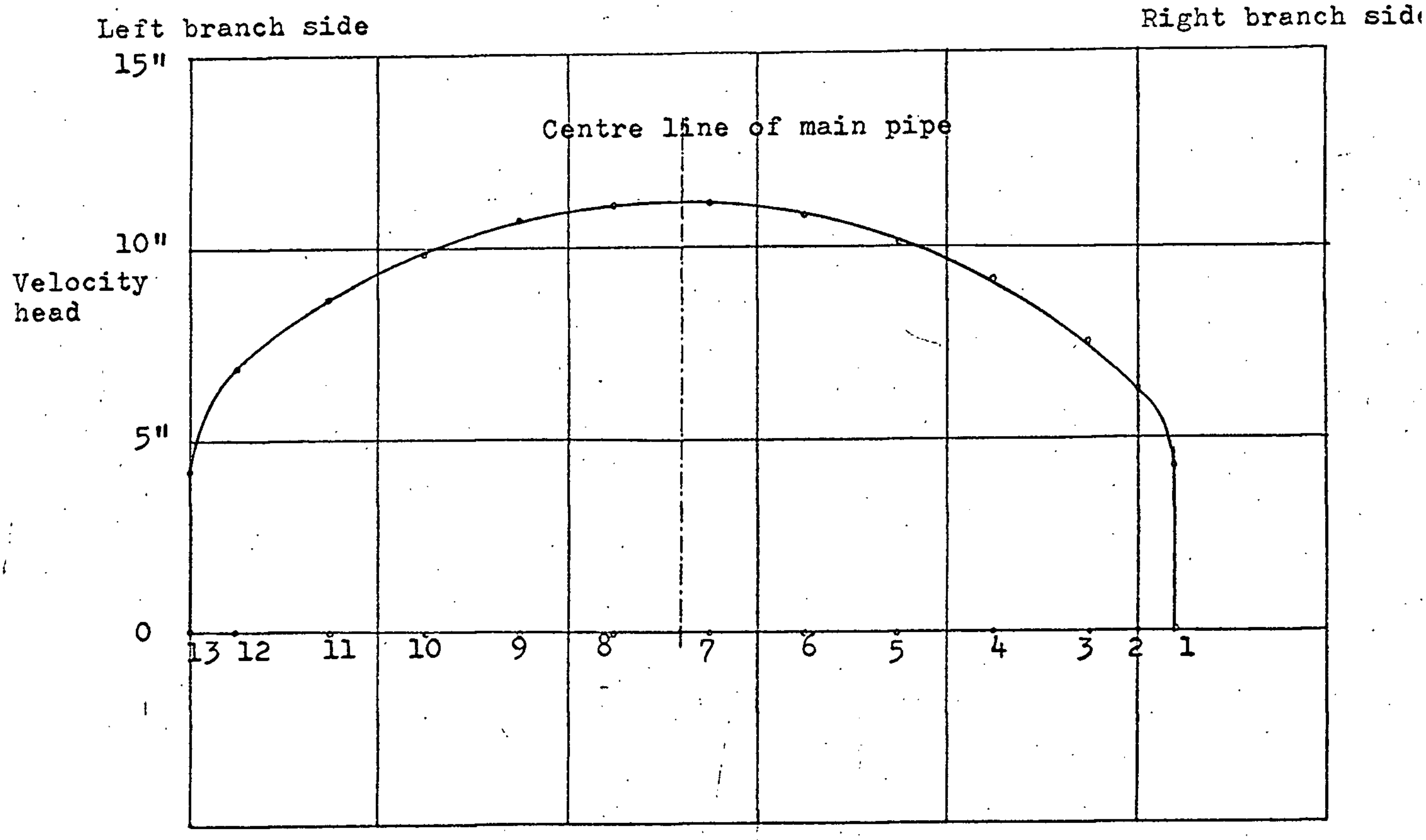


Fig 10. Velocity traverse with one leg flow with discharge of 0.92 cfs.

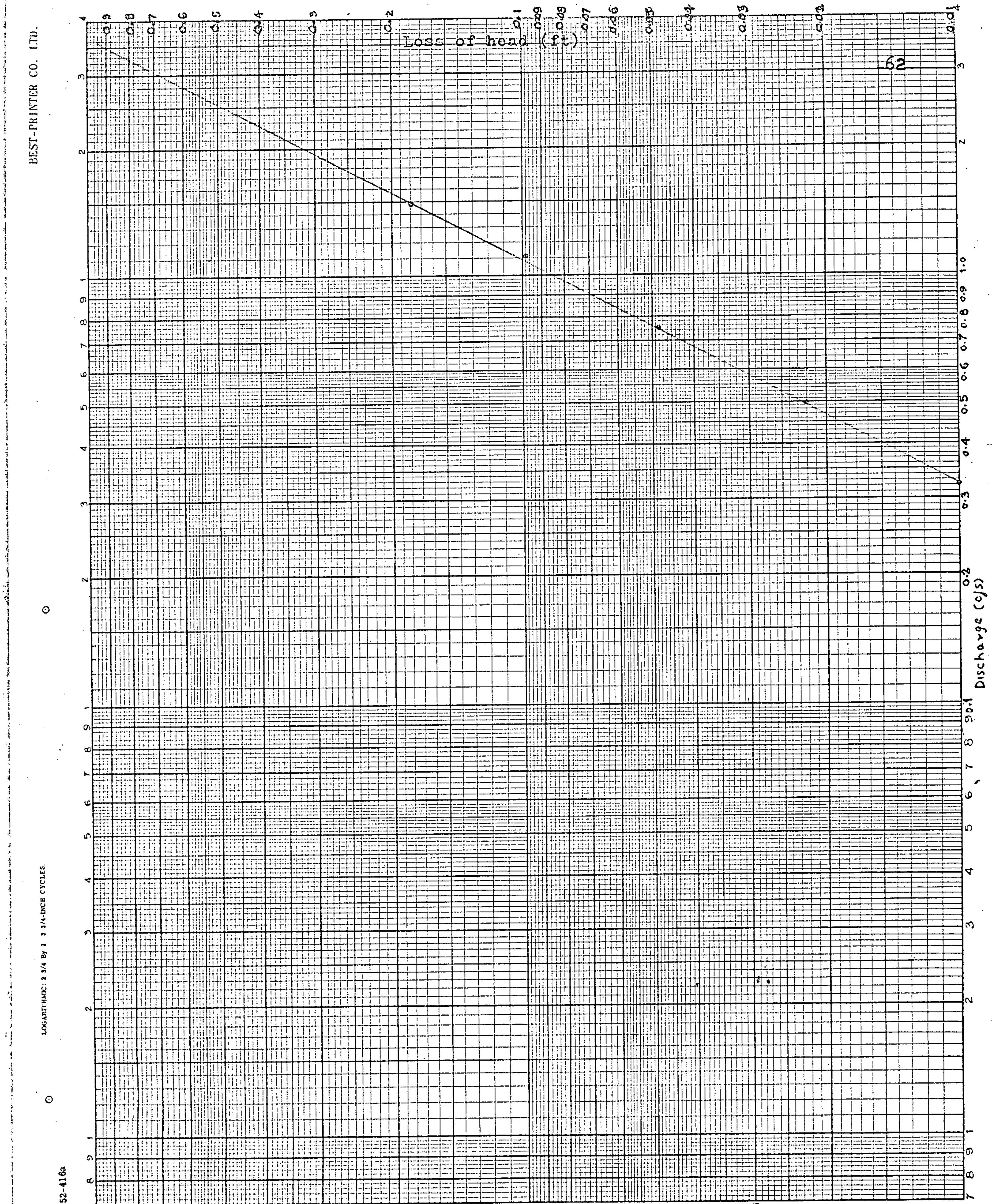


Fig. 11. Friction losses in main pipe

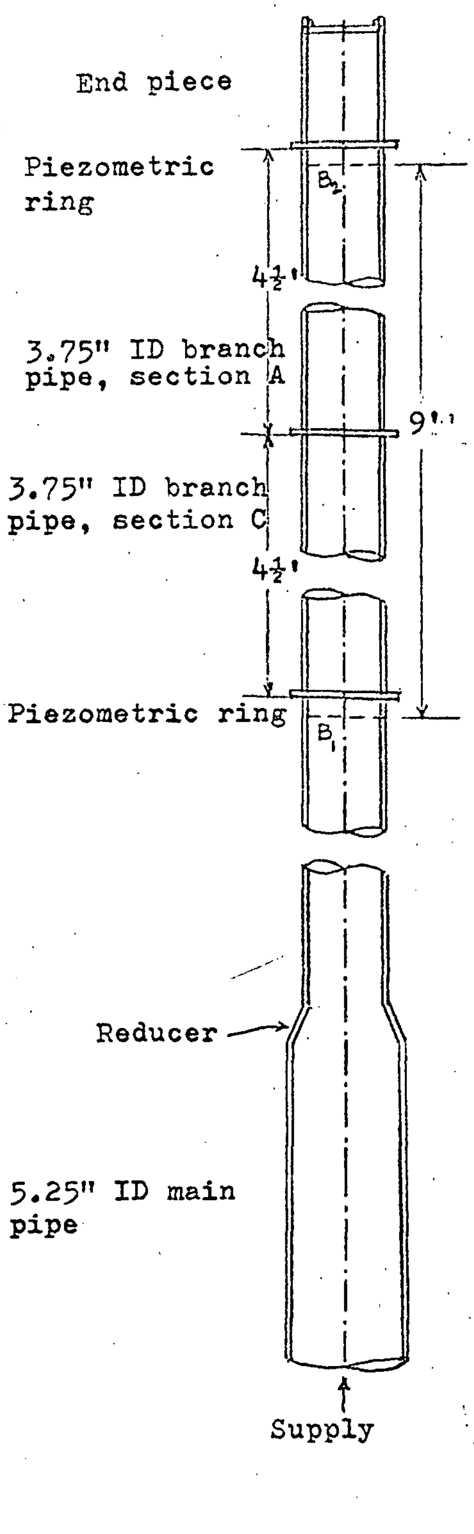


Fig. 12. Experimental set up for measurement of friction losses in branch pipes.

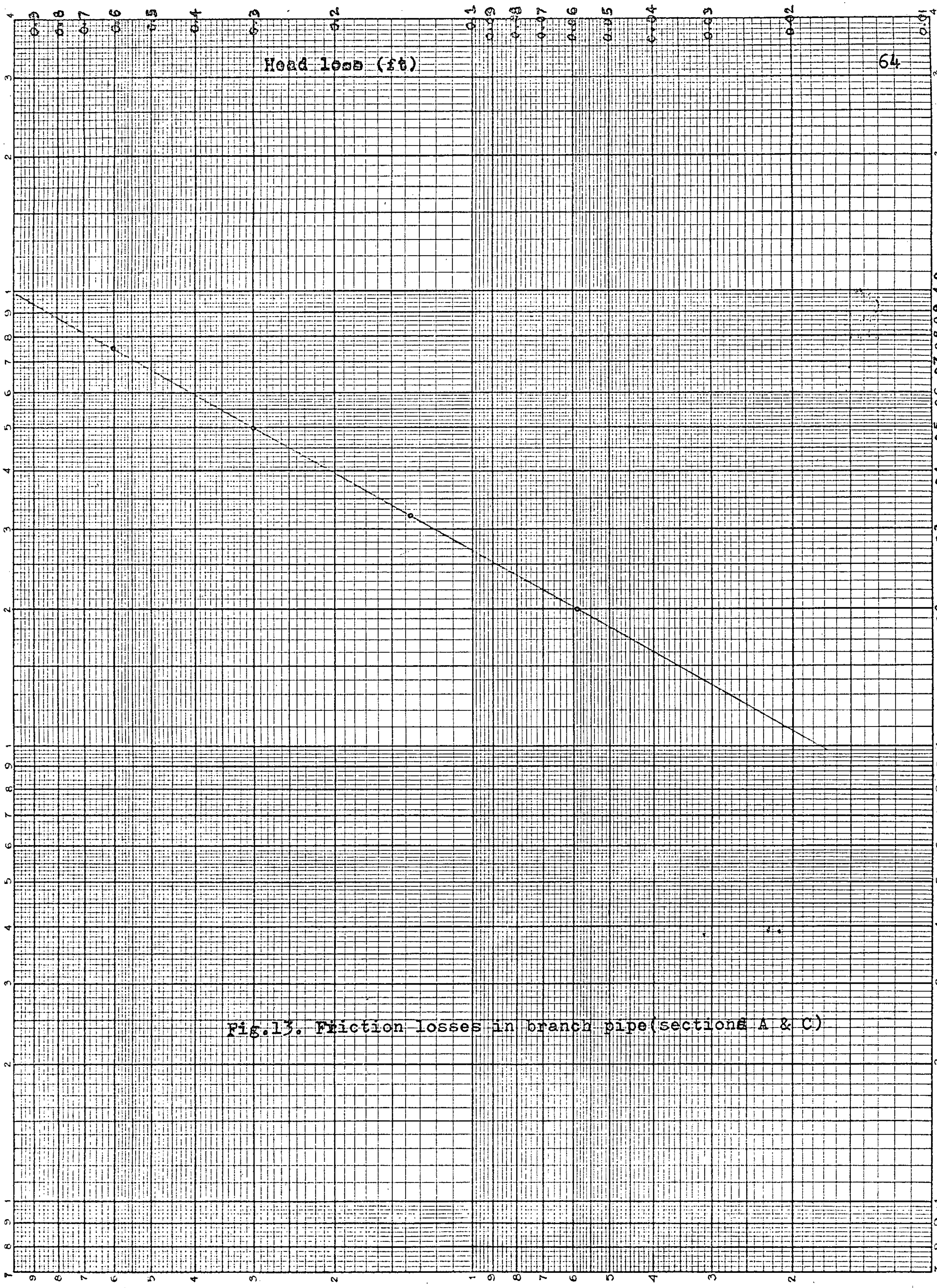


Fig.13. Friction losses in branch pipe(sections A & C)

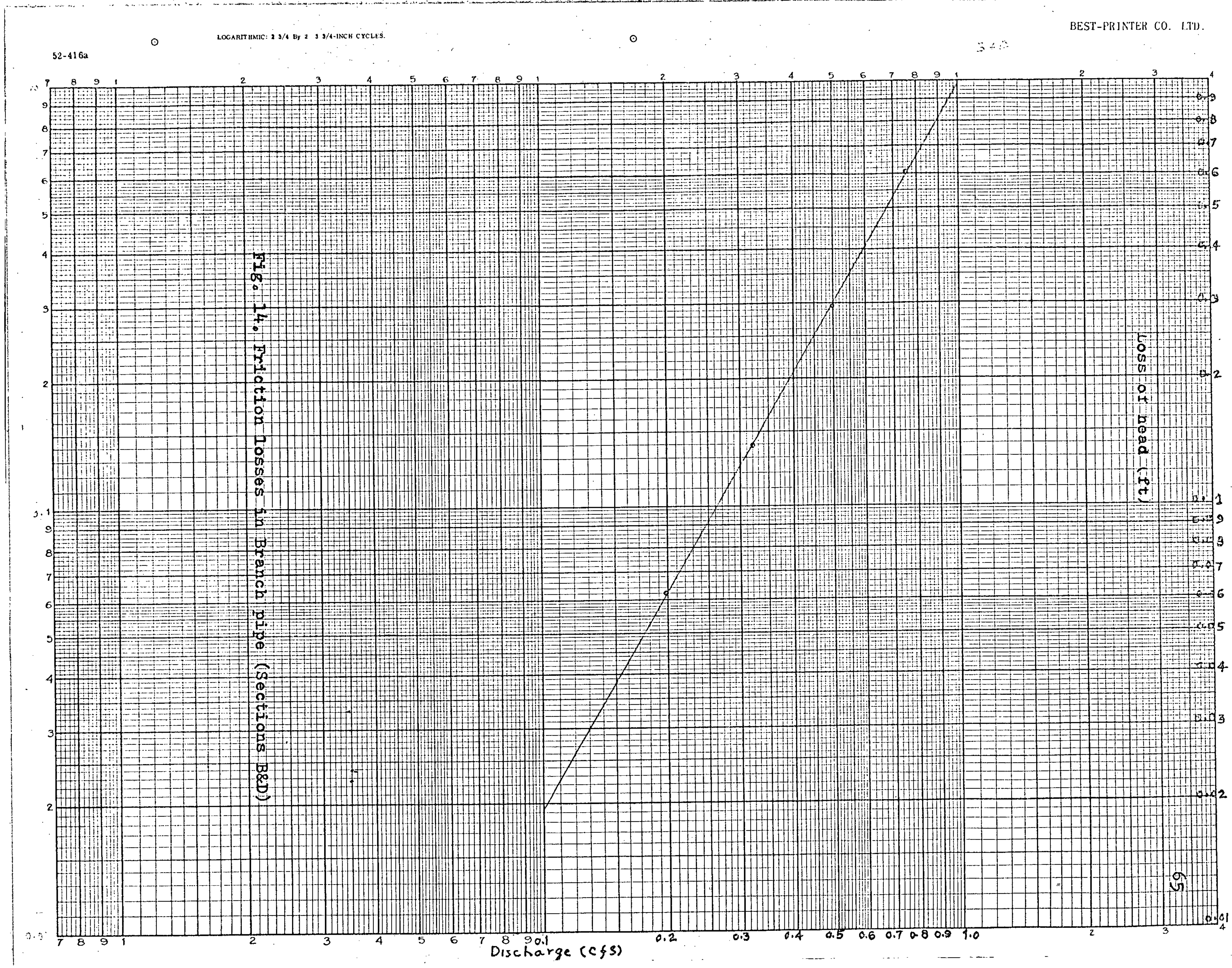
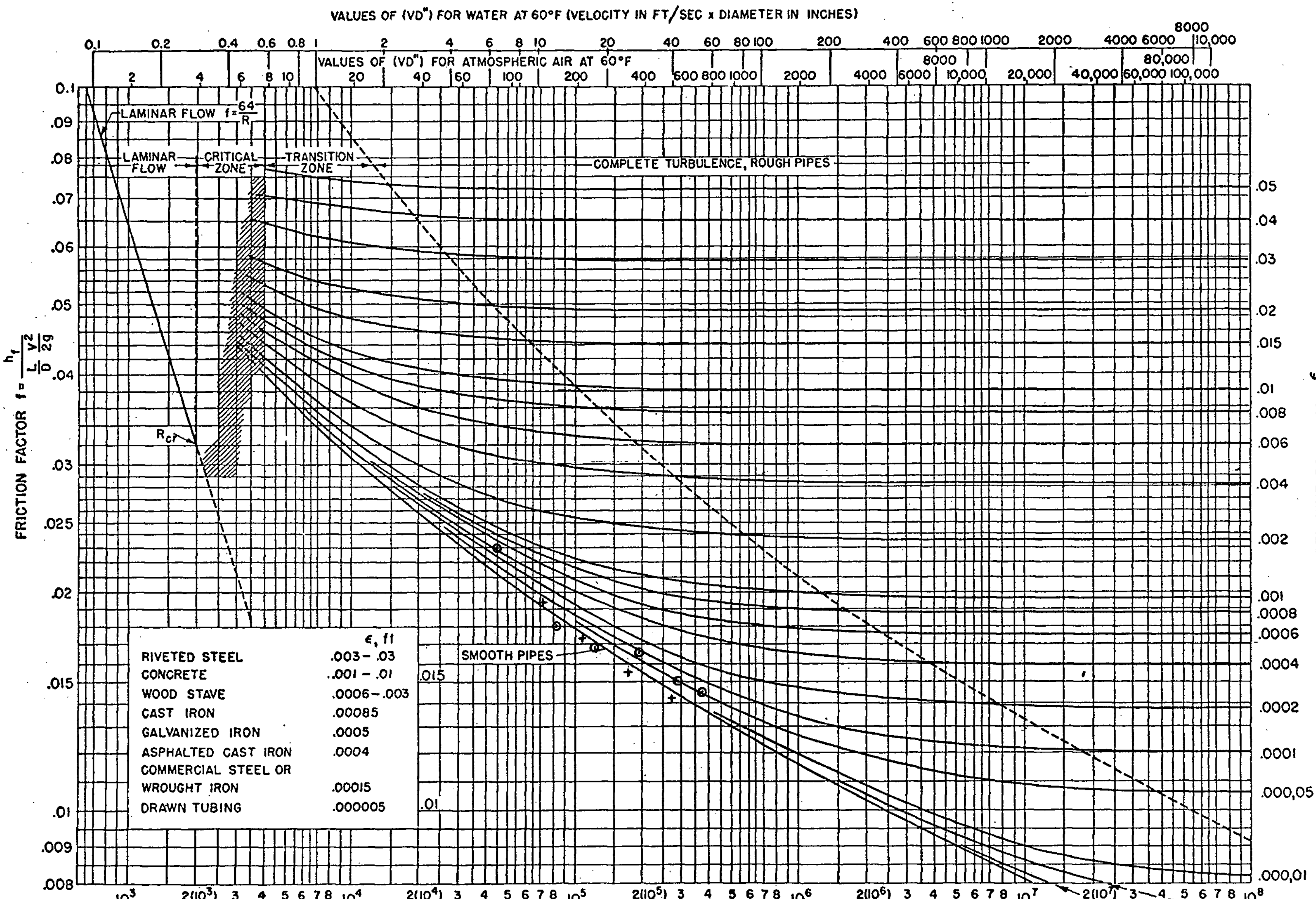


Fig. 14. Friction Losses in Branch pipe (Sections B&D)



+ *Branch Pipes* ⊙ *Main Pipe*

Fig. 15, Friction Factors vs. Reynold Numbers for Main & Branch Pipes.

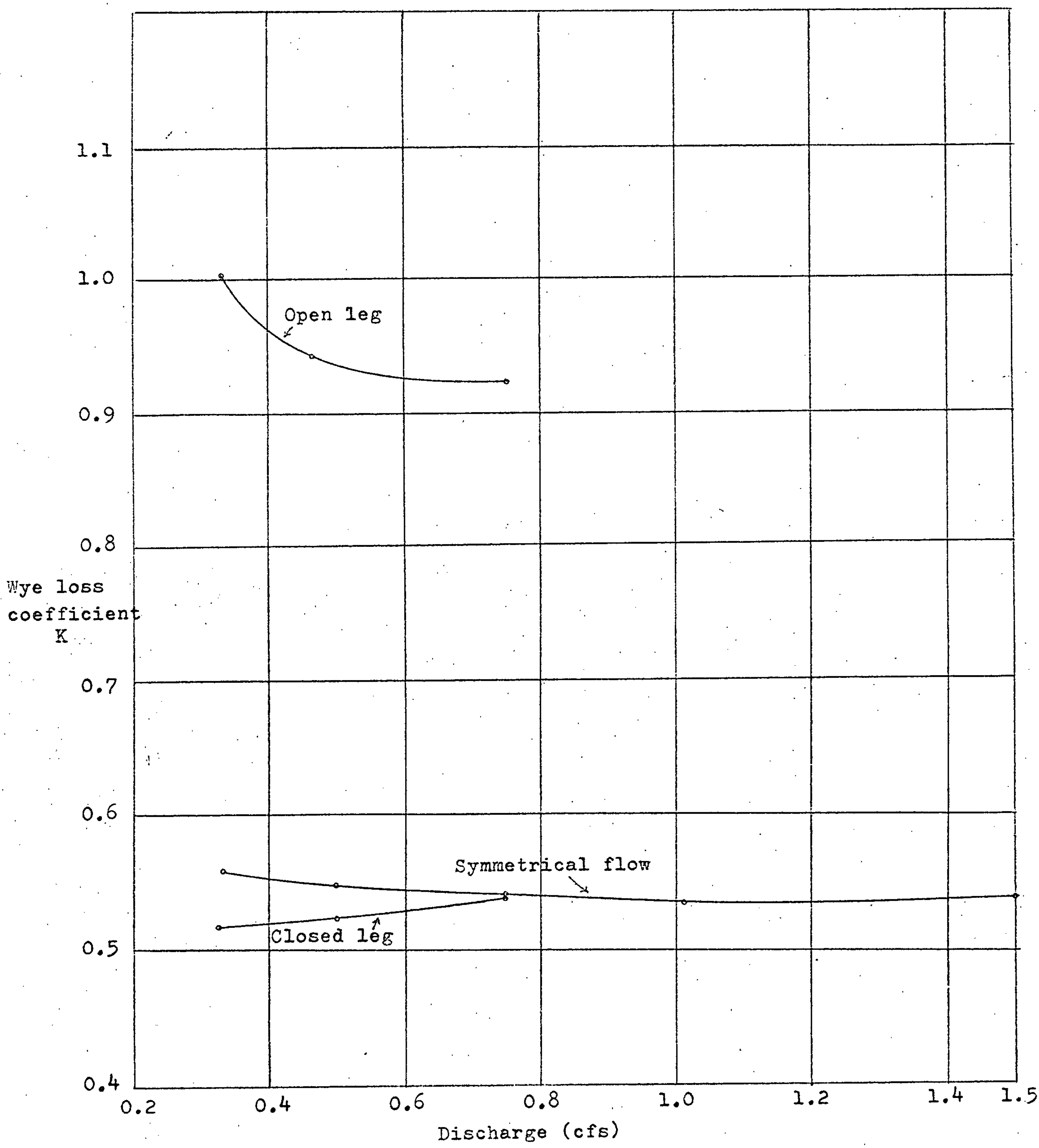


Fig. 16. 90° Large spherical wye, symmetrical & one leg flow.

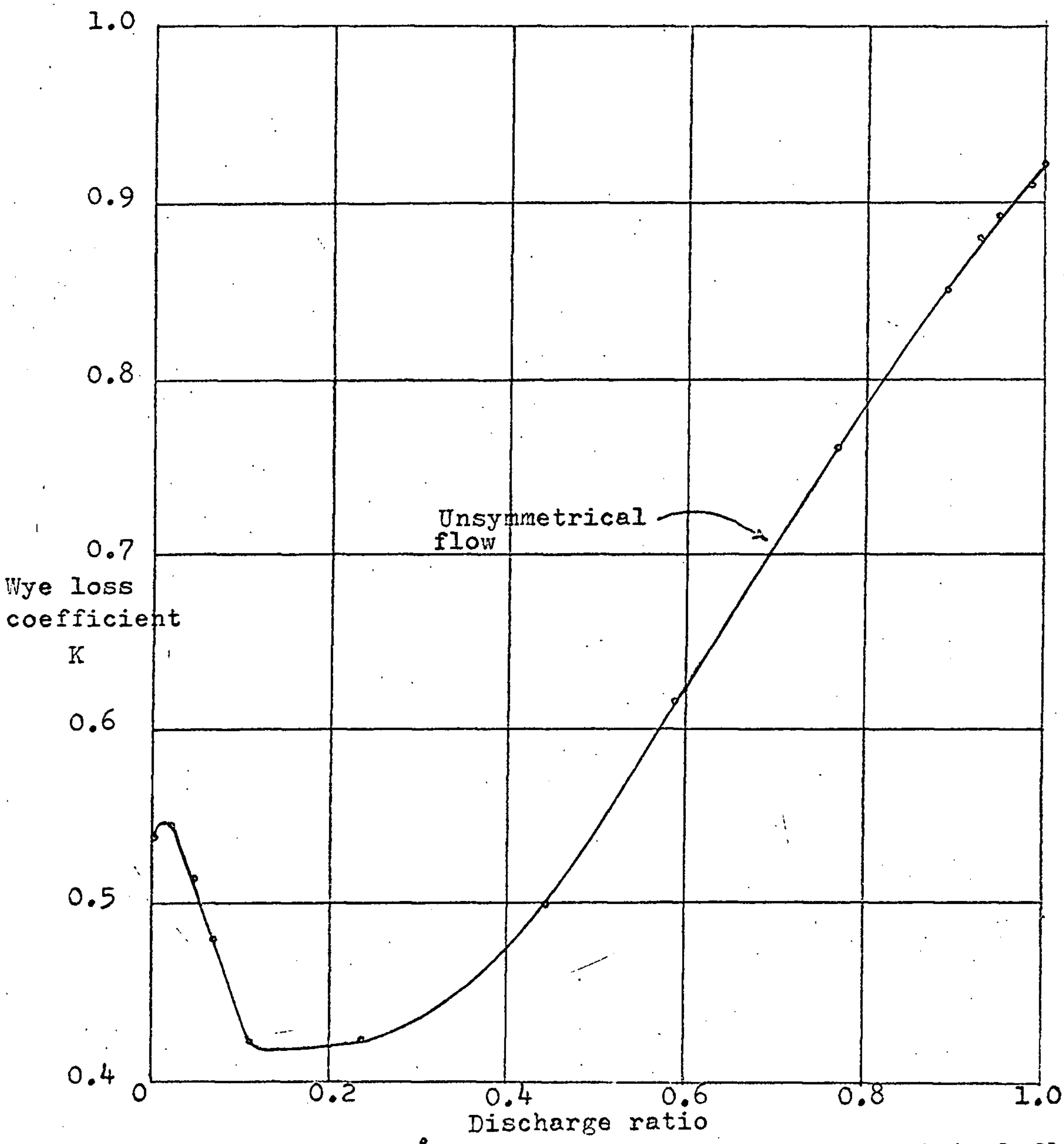


Fig. 17. 90° Large spherical wye, unsymmetrical flow

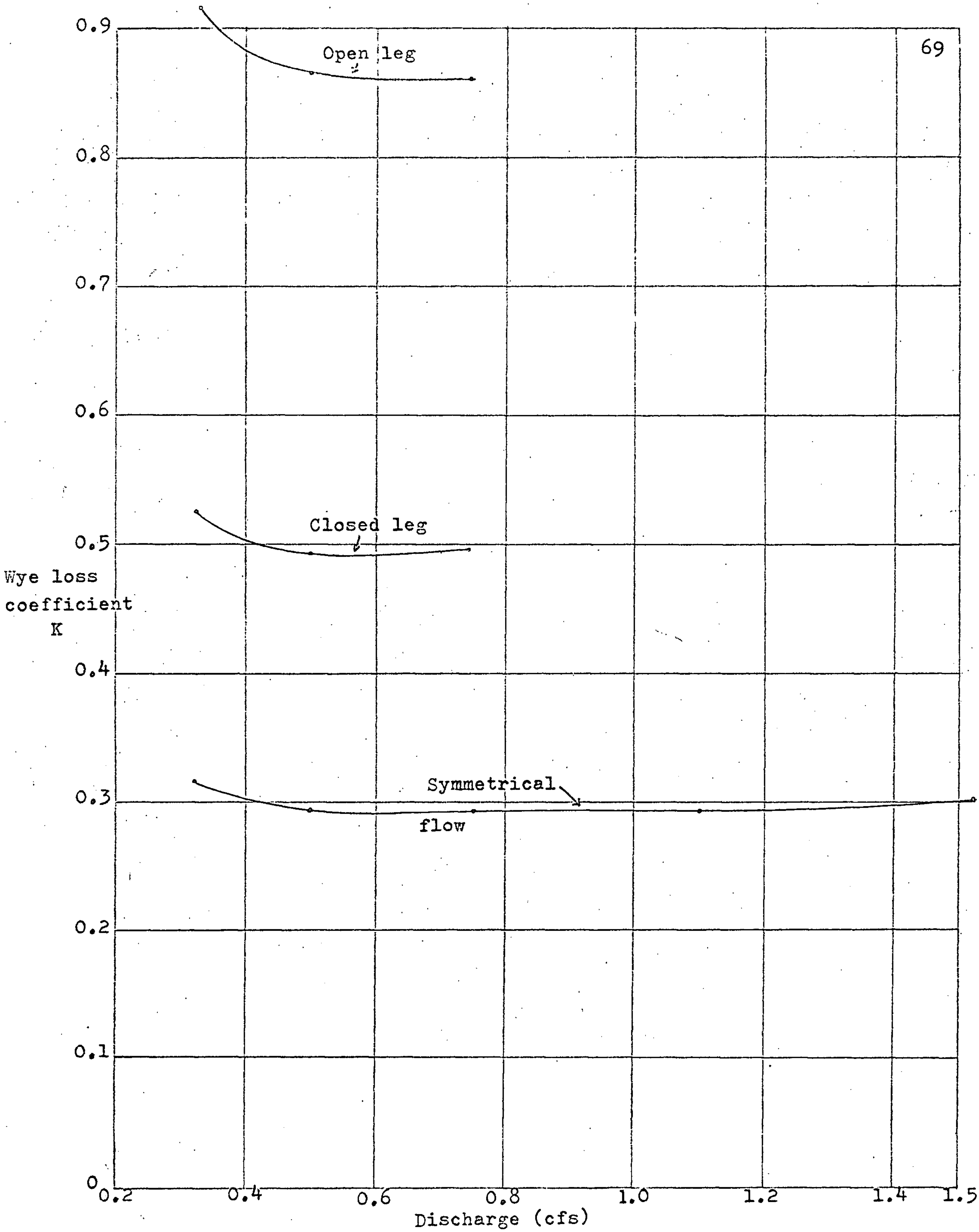


Fig. 18. 90° Small spherical wye, symmetrical and one leg flow

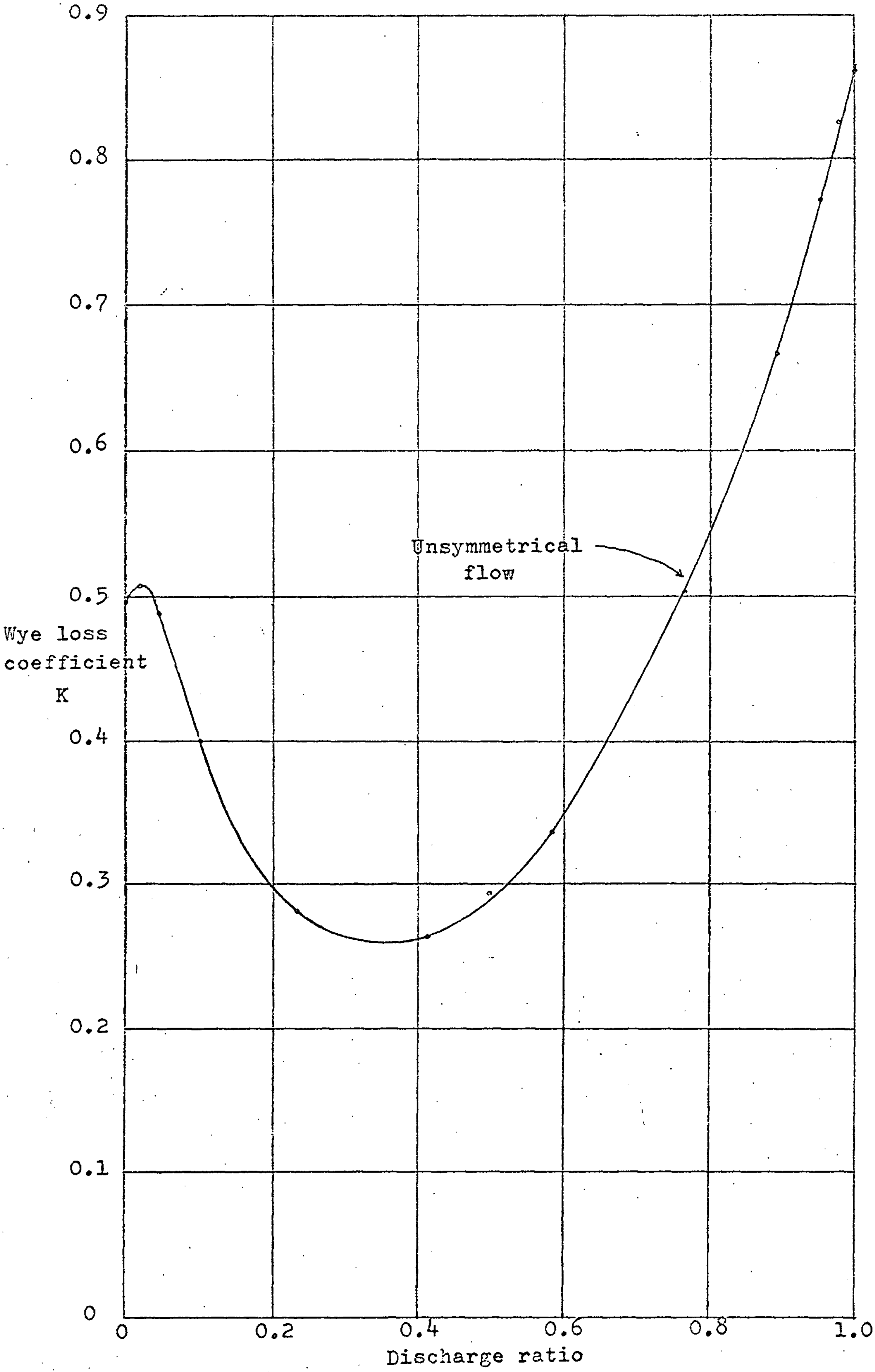


Fig. 19. 90° Small spherical wye, unsymmetrical flow.

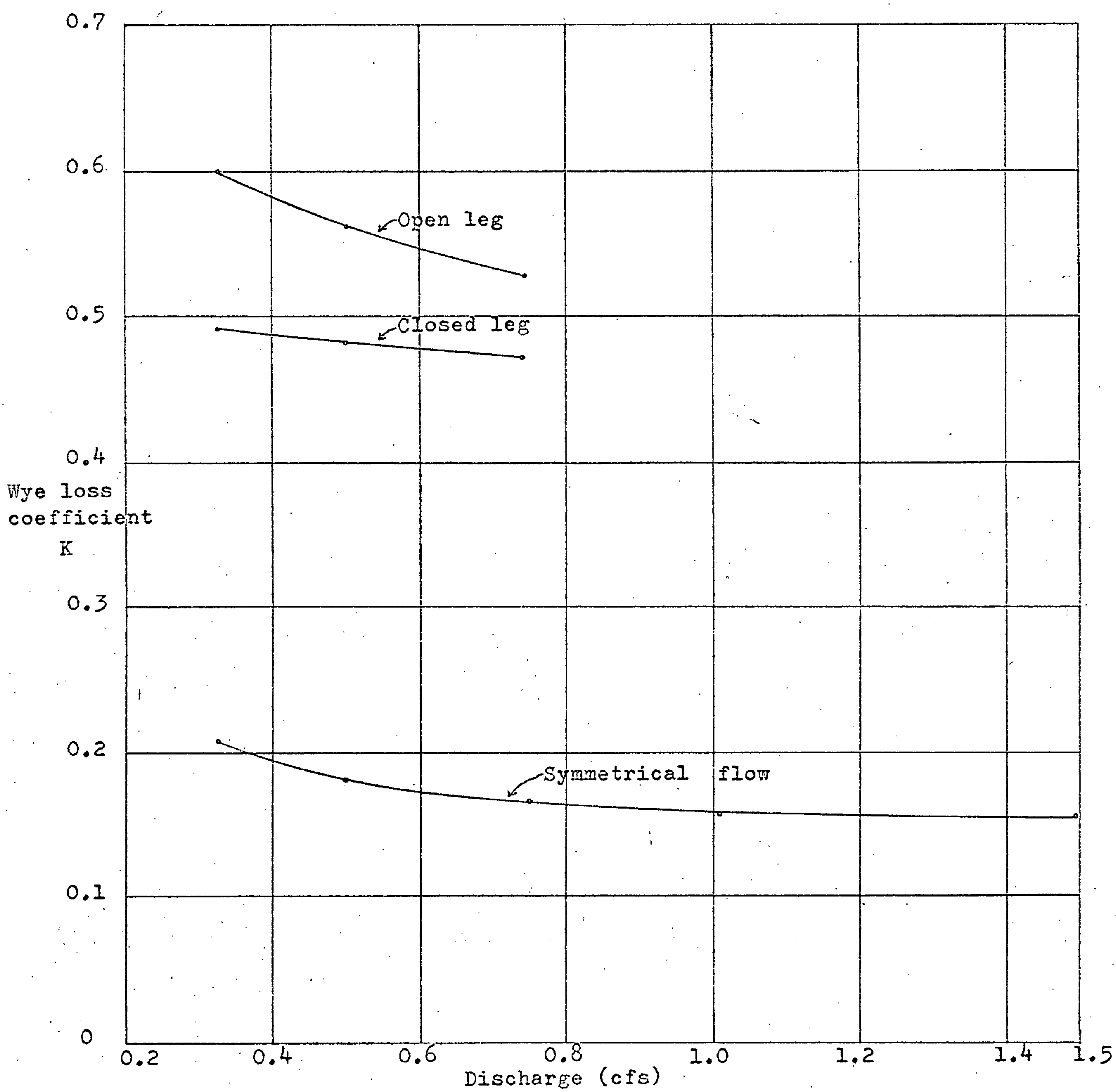


Fig. 20. 90° Tapered wye, symmetrical and one leg flow.

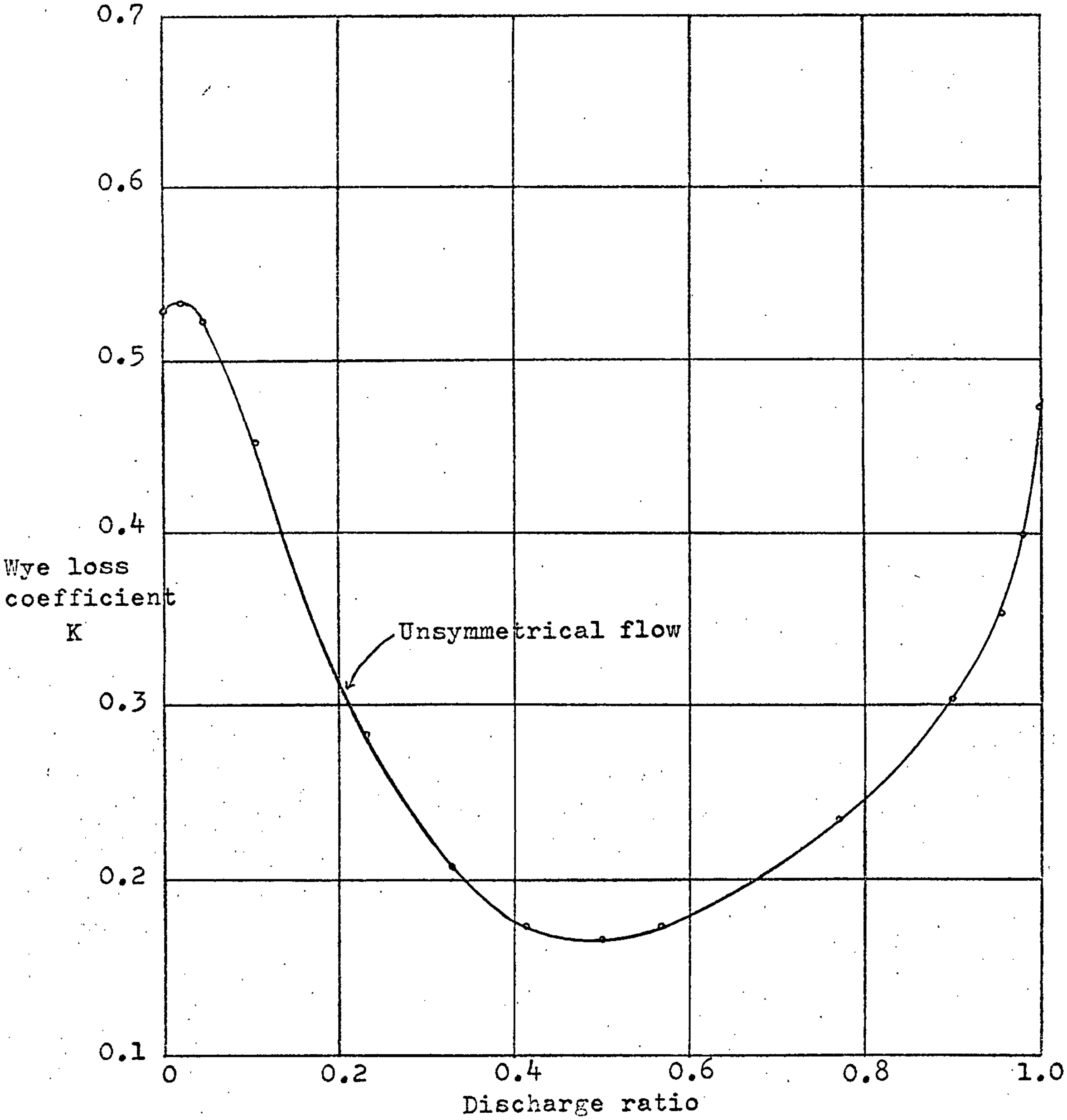


Fig.21. 90° Tapered wye, unsymmetrical flow.

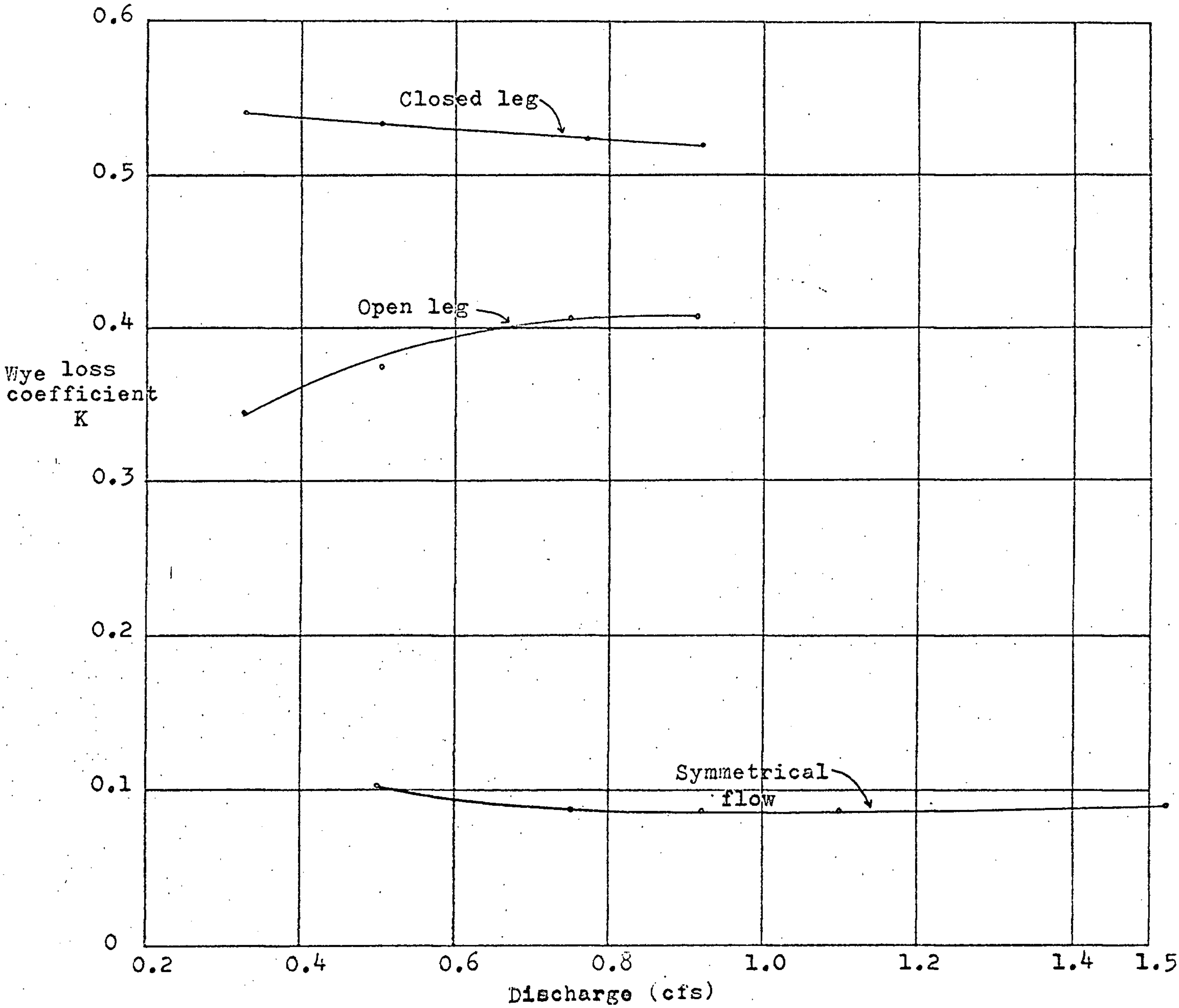


Fig. 22. 60° Tapered wye (A), symmetrical and one leg flow.

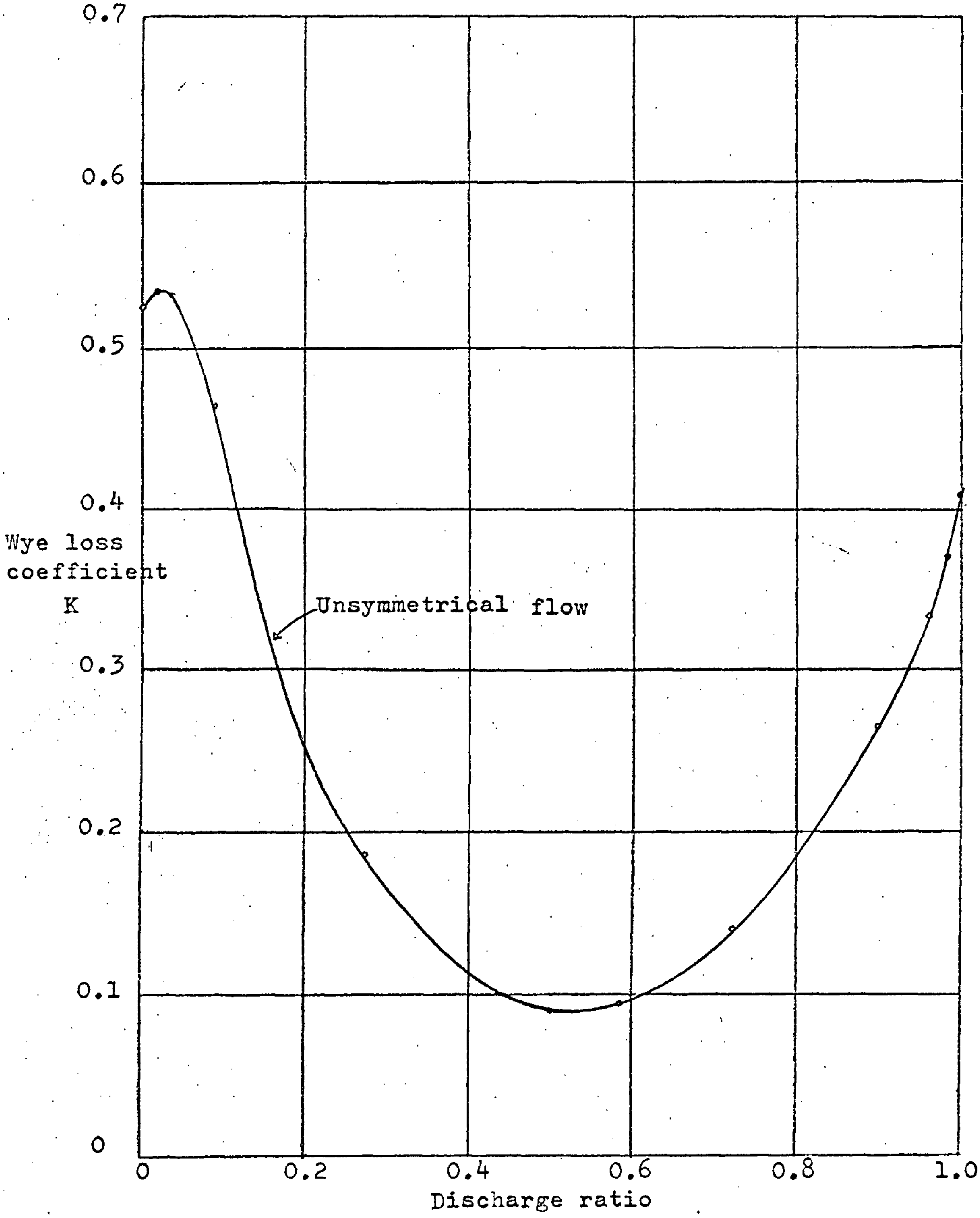


Fig. 23. 60° Tapered wye(A),unsymmetrical flow.

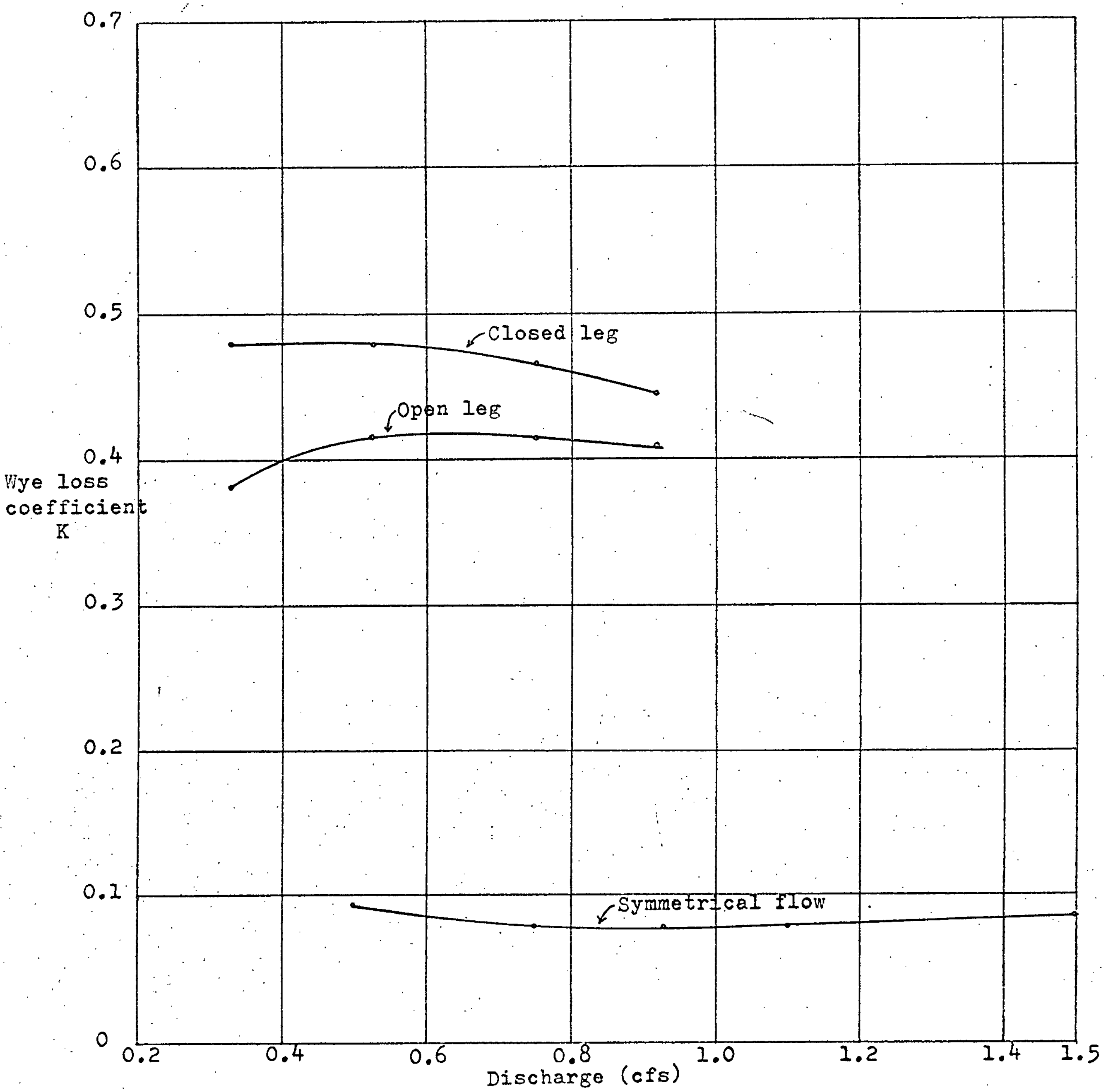


Fig. 24. 60° Tapered wye(B),symmetrical and one leg flow.

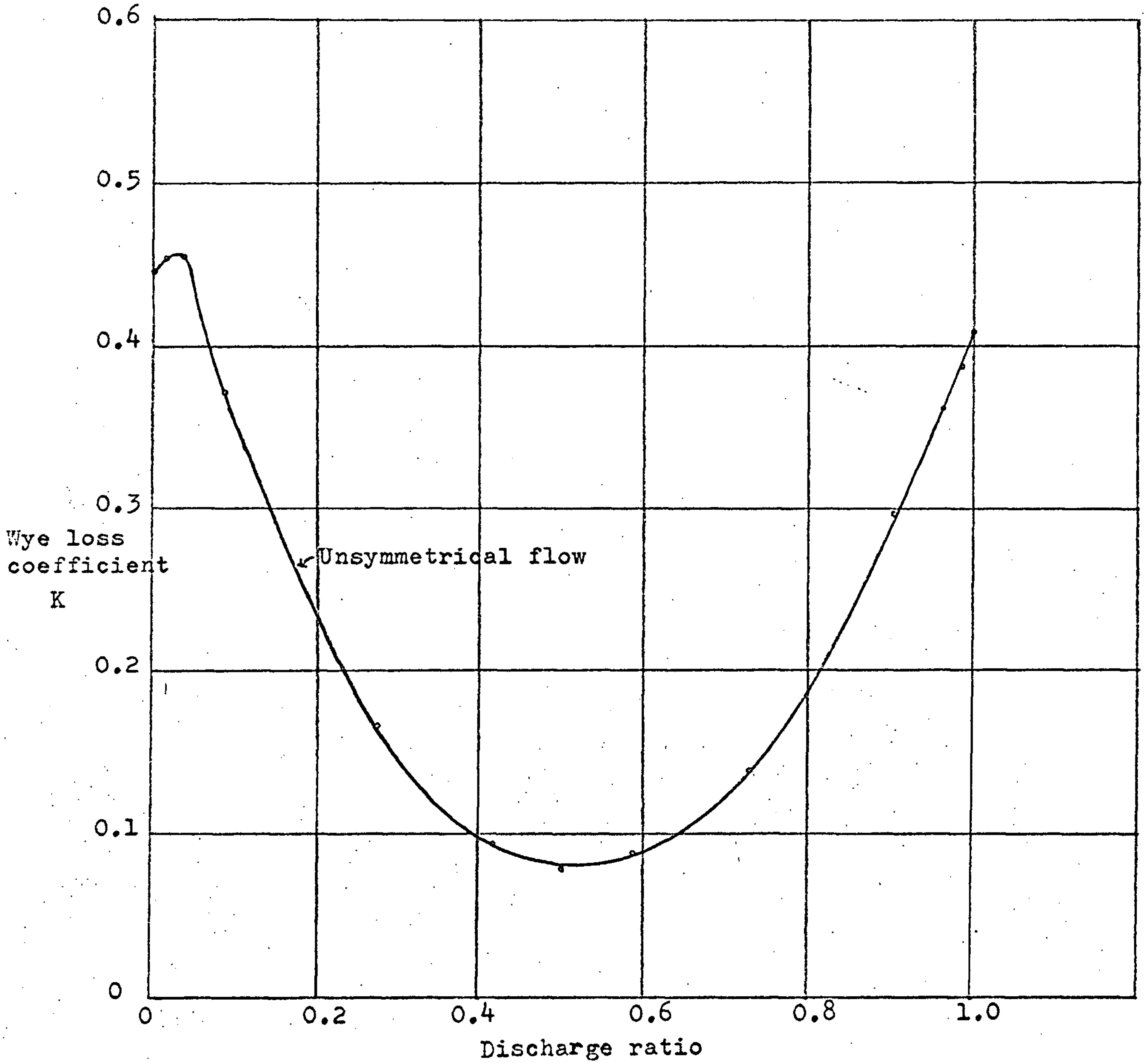


Fig. 25. 60° Tapered wye (B), unsymmetrical flow.

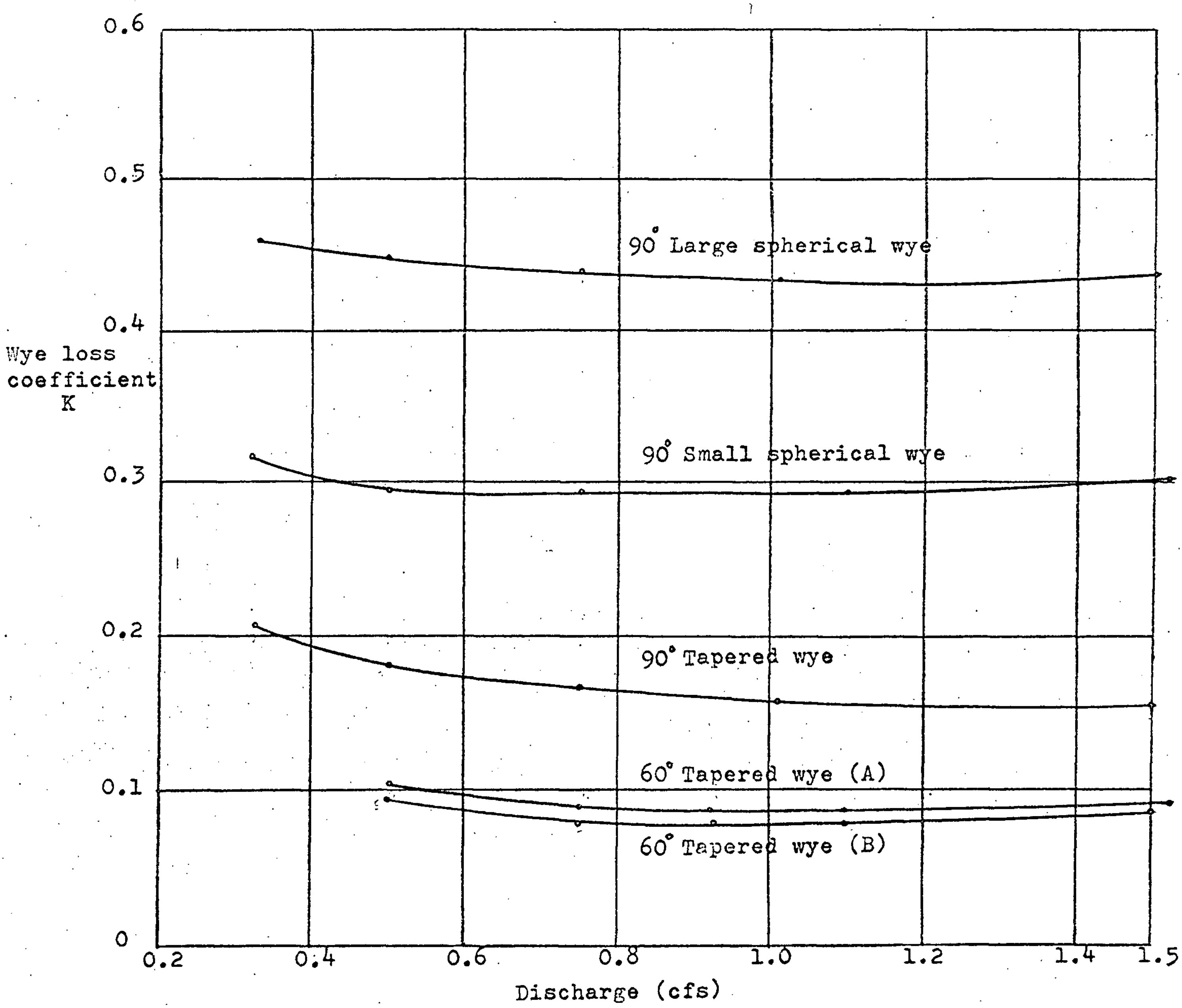


Fig. 26. Wye loss coefficients for all wyes, symmetrical flow.

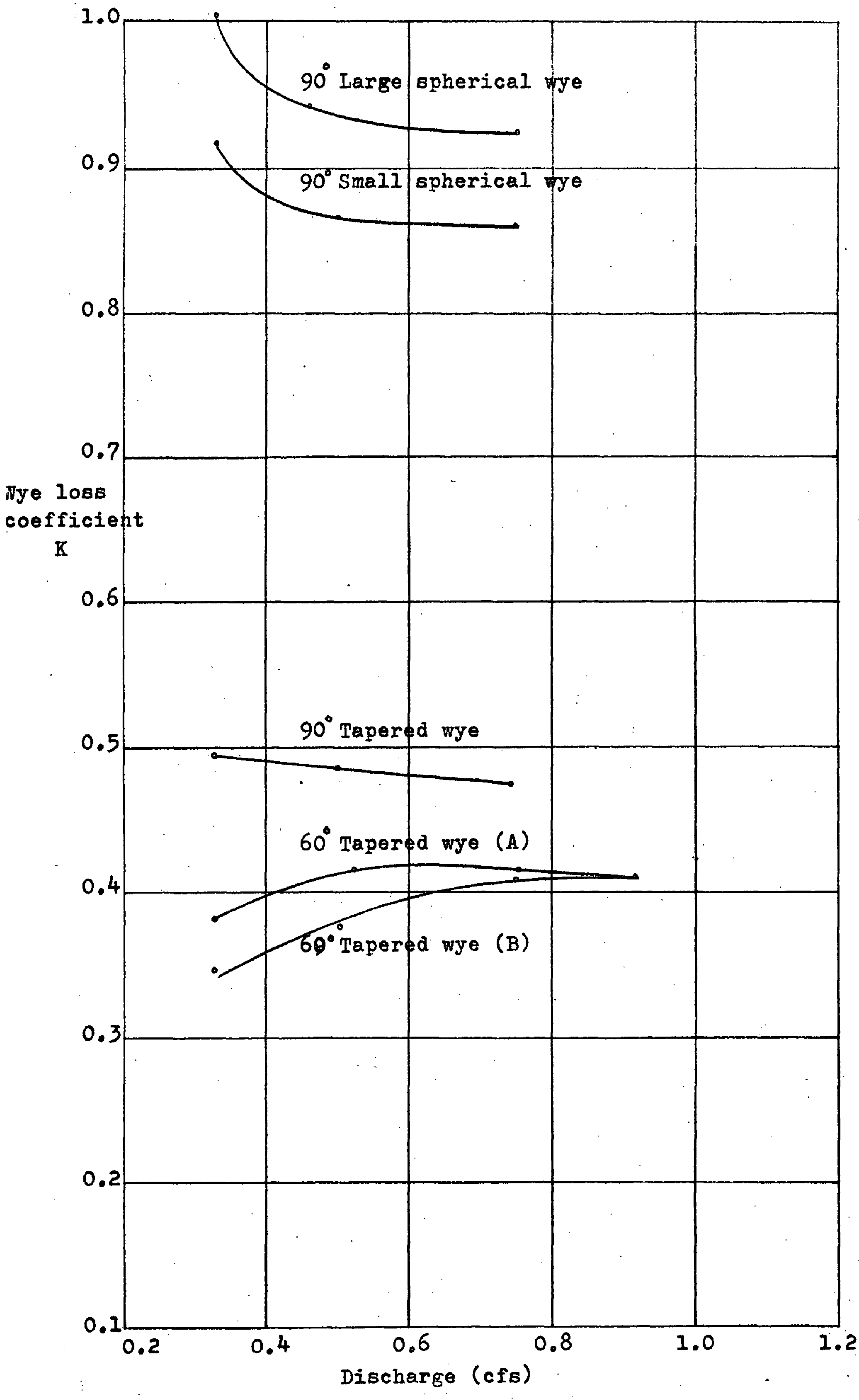


Fig. 27. Wye loss coefficients for all wyes, one leg flow (open branch).

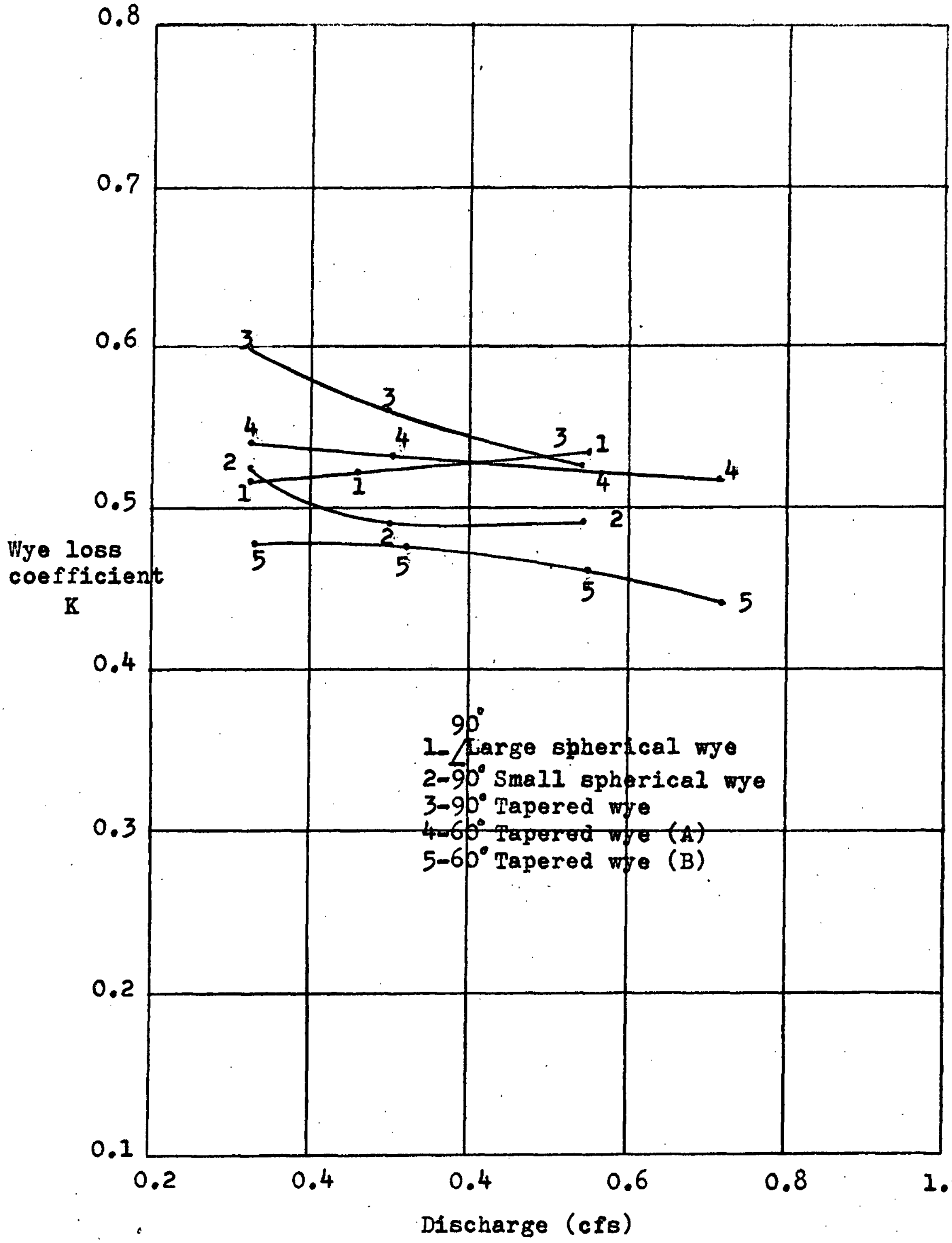


Fig. 28. Wye loss coefficients for all wyes,one leg flow(closed branch).

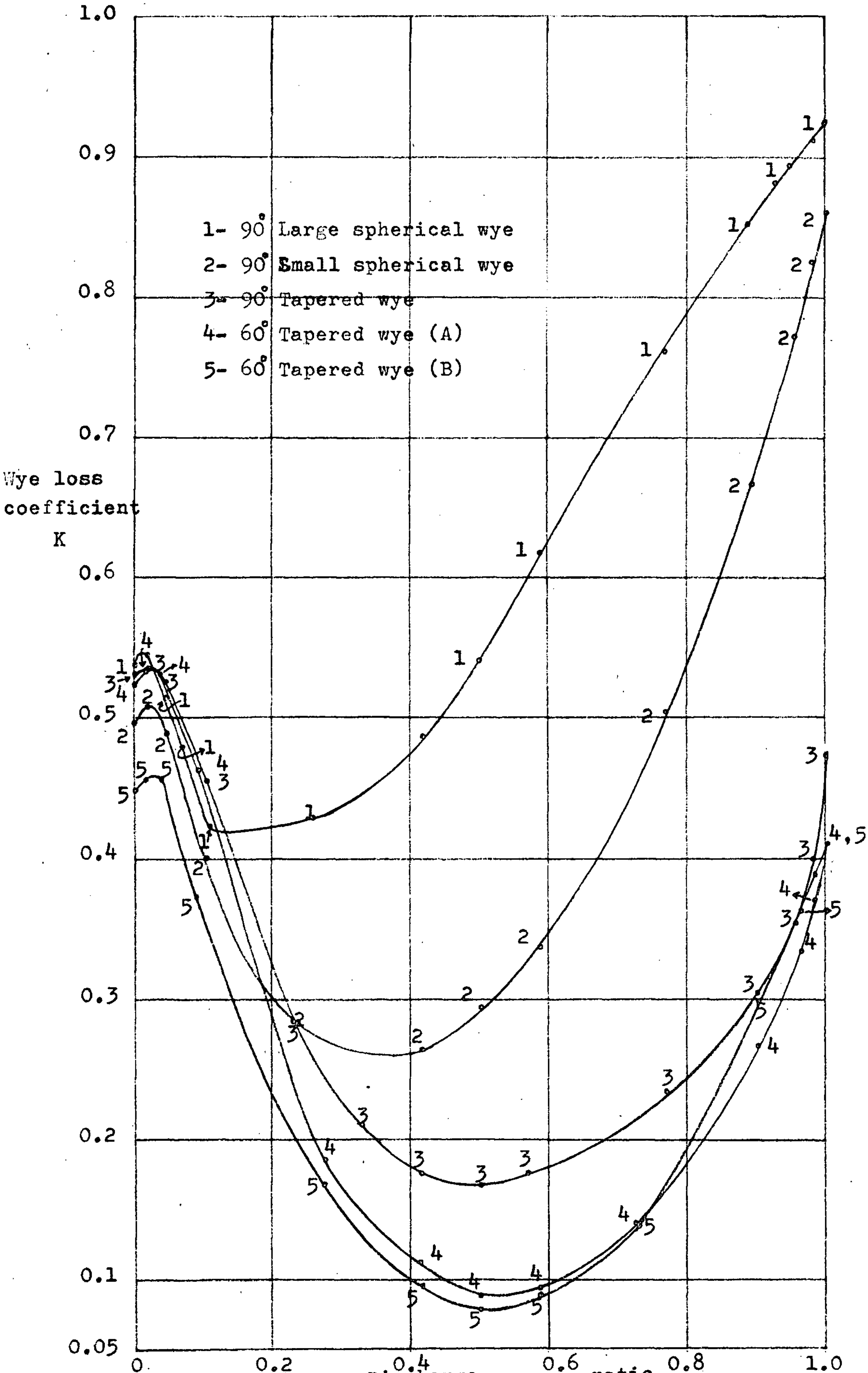


Fig. 29. Wye loss coefficients for all wyes, unsymmetrical flow.

Plate 1. Manometric board with gage tanks

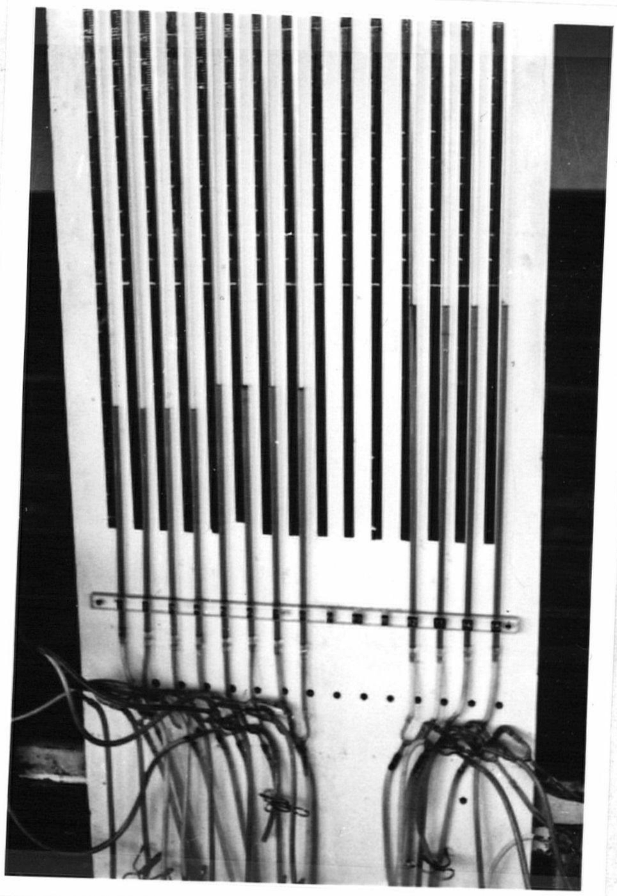


Plate 2. Manometric board

Plate 3. Lay out of model looking downstream.

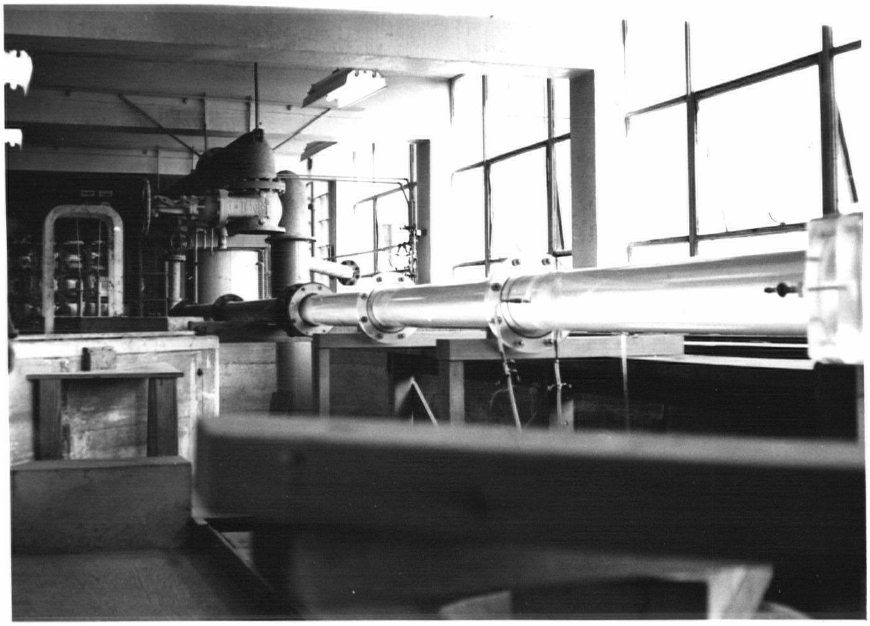


Plate 4. Main pipe and control valve

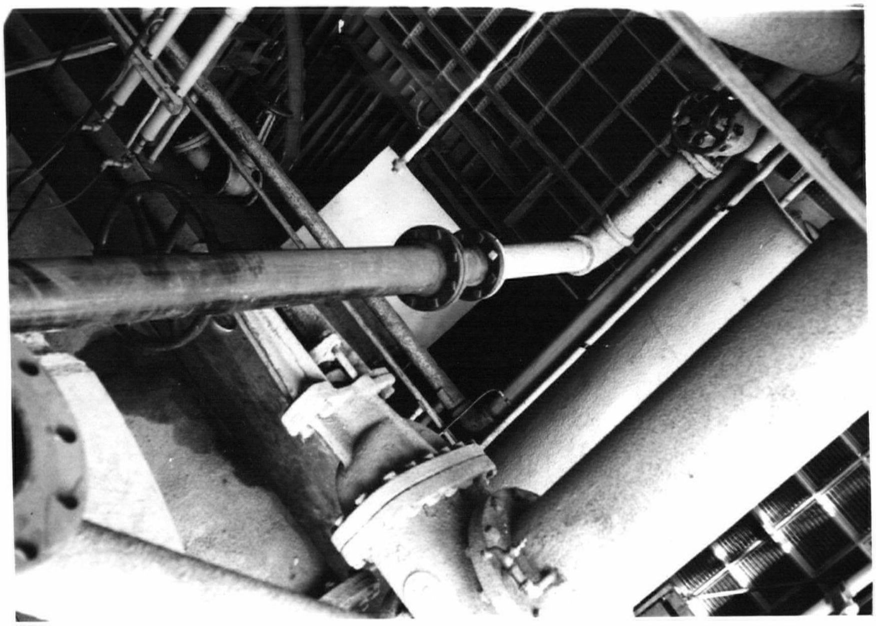


Plate 5. Control valve

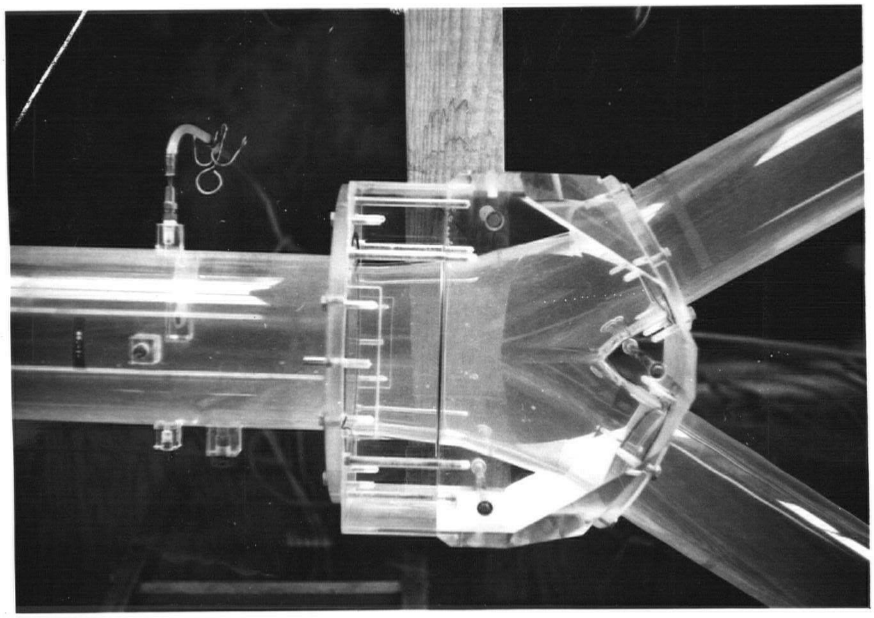


Plate 6. Wye in place

Plate 7. 90° tapered and 90° small spherical wye.

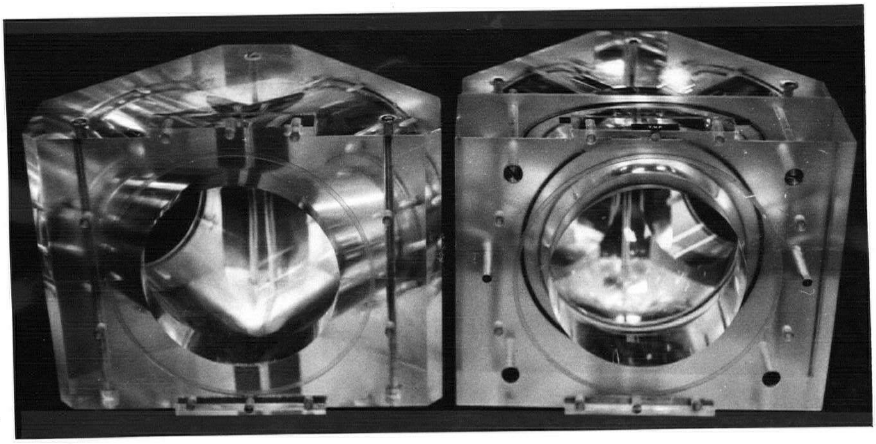


Plate 8. 90° tapered and 90° small spherical wye.

Plate 9. Orifices and end piece