LOSS OF HEAD IN ELBOWS AND TEES

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

MUNICIPAL AND SANITARY ENGINEERING

BY

SAMUEL LESLIE MILLER

AND IN

CIVIL ENGINEERING

BY

WILLIAM PAXTON WITT

COLLEGE OF ENGINEERING

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June 1, 1912

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

SAMUEL LESLIE MILLER

ENTITLED THE LOSS OF HEAD IN ELBOWS AND TEES

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Municipal and Sanitary Engineering.

Melvin L. Enger
Instructor in Charge

APPROVED: A N Talbot

HEAD OF DEPARTMENT OF MUNICIPAL AND SANITARY ENGINEERING

UNIVERSITY OF ILLINOIS

COLLEGE OF ENGINEERING.

May 24, 1912

This is to certify that the thesis of WILLIAM PAXTON WITT entitled THE LOSS OF HEAD IN ELBOWS AND TEES was prepared under my personal supervision; and I recommend that it be approved as meeting this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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INTRODUCTION.

For a number of years there has been considerable interest shown in experimenting upon the loss of head caused by the flow of water through elbows and tees. The interest has indeed been so keen that great expenditures have been made for apparatus, and great care has been exercised in their operation; notably in the cases of "Curve Resistance in Water Pipe" made by Mr. Earnest Schoder at the Cornell University Hydraulic Laboratory, and by Mr. George Jacob Davis in the Hydraulic Laboratory of the University of Wisconsin. There has been a great deal of discussion before the American Society of Civil Engineers, and much interest has been taken in the amount of loss in various forms of elbows and tees and the nature of the variation of this loss, when expressed in terms of the velocity head.

It has been generally believed, by those studying the subject, that the loss of head due to water flowing through elbows and tees does not all occur in the elbow or tee, but that a large proportion of it occurs in the pipe on the down stream side of the section considered. It is reasonable to expect no loss of head other than the loss due to friction of the straight pipe, on the up side of the elbow or tee, for here the water is flowing smoothly and uniformly and in an undisturbed manner.

It is believed, however, that the water does not flow smoothly and uniformly in the pipe after it leaves the elbow, but that owing to the disturbance of flow in the elbow, eddy currents are set up which continue for several diameters down the pipe. These eddy currents lose energy by dissapation and by causing the water to rub more vigorously on the sides of the pipe than it would in case of uniform flow.

It is the object of this thesis, therefore, first, to ascertain, if possible, the total head loss due to the elbows and tees, second, to determine the head actually lost within the elbow, and third to determine the value of K in the equation

$H = K\frac{V^2}{2g}$, where H is the head lost due to the elbow.

This naturally leads to two separate sets of experiments; first, to determine the total loss in a pipe containing the elbows or tees, and second, to determine the loss in the same pipe when extended in a straight line and uninfluenced by elbows, tees or other fixtures. Obviously the difference in loss between these two experiments would give the lost head resulting from the tee or elbow at the given velocity.

EXISTING LITERATURE.

There have been very few experiments performed to find the laws of the loss of head in either elbows or tees. Many text books contain formulas which are more or less complex and can seldom be used. Among these are the following.

Bovey.

For lost head in elbows Bovey gives

$$H = m\frac{V^2}{2g}$$

Where m 0.945 $\sin^2\frac{\phi}{2} + 2.047 \sin^4\frac{\phi}{2}$ and ϕ is the angle of the elbow. This formula was derived empirically from pipes 1.2 inches in diameter.

Navier.

$$H = (.0128 + 0.0186\,R)\frac{L}{R}\frac{V^2}{2g}$$

R radius of head and L, length of bend measured along its axis.

Mansfield Merriman.

$$H = f_1\frac{l}{d}\frac{V^2}{2g}$$

In this formula f_1 is an abstract number following the curve factor of the elbow.

f varies from 0.004 to 0.184 for $\frac{R}{d}$ from 20,0 to 1.0

R for radius of elbow.

d diameter of pipe.

Weisbach.

Hoskin's Hydraulics gives a formula from Weisbach.

$$H = m\frac{V^2}{2g}\frac{\phi}{180^\circ}$$

Where m = $0.131 + 1.1847\left(\frac{d}{2r}\right)^{\frac{7}{2}}$

r = radius.

d = diameter of pipe.

It can be seen that all these formulas are too complicated to remember and very complicated to work out, and that they are based on inadequate experiments.

Schoder.

Experiments have been made on 6 inch pipe by Mr. Schoder at the Cornell Hydraulic Laboratory. Since our experiments are

are all on 2 inch pipe, no direct comparison can be made with his experiments.

Davis.

A series of experiments by Mr. Davis at the University of Wisconsin were made upon 2 in. pipe. These experiments were carefully conducted. Mr. Davis plotted the results of his experiments on logarithmic paper with velocity as abscissae and lost head as ordinates, and found the points would lie on straight lines. The line representing the relation between loss of head and velocity for straight pipe was not parallel to the line representing the loss when there was an elbow in the line.

Mr. Davis assumes that the loss in the elbow varies as V^2 where V is the velocity, and gives the following law of variation for elbow No 3 in his test as,

$$H = 0.10113 \quad V^2$$

$$H = 0.0202 \quad V^2 \text{ for elbow, No 4.}$$

Mr. Davis used 2 in. lap steel pipe which was new at the beginning of his experiments. He found the loss per foot of pipe to be represented by the equation

$$H = 0.00240\,V^{1.85}$$

where H is the loss in feet of water and V the velocity in feet per second.

DESCRIPTION OF APPARATUS.

The elbows and tees which were used in these experiments were such as are used in every day plumbing work. They were common elbows and tees, a special long sweep elbow, a common Durham elbow and a long sweep Durham elbow.

The water was pumped from a sump by a 4 in. Worthington two stage centrifugal pump through suitable reducers into a 2 in. line consisting of pipe which had been in use in the laboratory for several years. About two feet from the lead of the pump was a gate valve used for primming purposes only. Connection was made through a tee into the standpipe for priming water. The elbows and tees were placed in the pipe line about 33 ft. from the pump in order that the water would become quieted before reaching the bend to be tested.

The volume of water was measured with a common fire nozzle and a play pipe. These were carefully calibrated against a Venturi meter, which had been previously calibrated. In order to get no disturbance at the nozzle and to get uniformity of results, twenty feet of the best rubber lined canvas hose was used. This made the distance from the elbow or tee to the nozzle about sixty feet.

The loss in head was measured by differential mercury gages connected to the pipe through two small holes. Two were used in order that their results could be checked and the mean or most probable value used in plotting the curves for the final results. The connections of these were placed, one three feet and the other seven feet above the elbow, while the down stream ends were 33 feet and 27 feet respectively below the elbow. This made the difference in reading in the two gages only the loss in 2 feet of 2 in. pipe. This was a sort of rough check in reading the two gages. It was assumed that there would be a disturbance in the pipe below the elbow and this is the reason for the long distance from the elbow to the piezometer tubes. That this distance was great enough is indicated by the consistency with which the gage readings checked.

The nozzle pressure was measured directly with a stationary,open air mercury gage in the laboratory, except in the case of the straight pipe experiments, when a differential gage was used and the readings reduced.

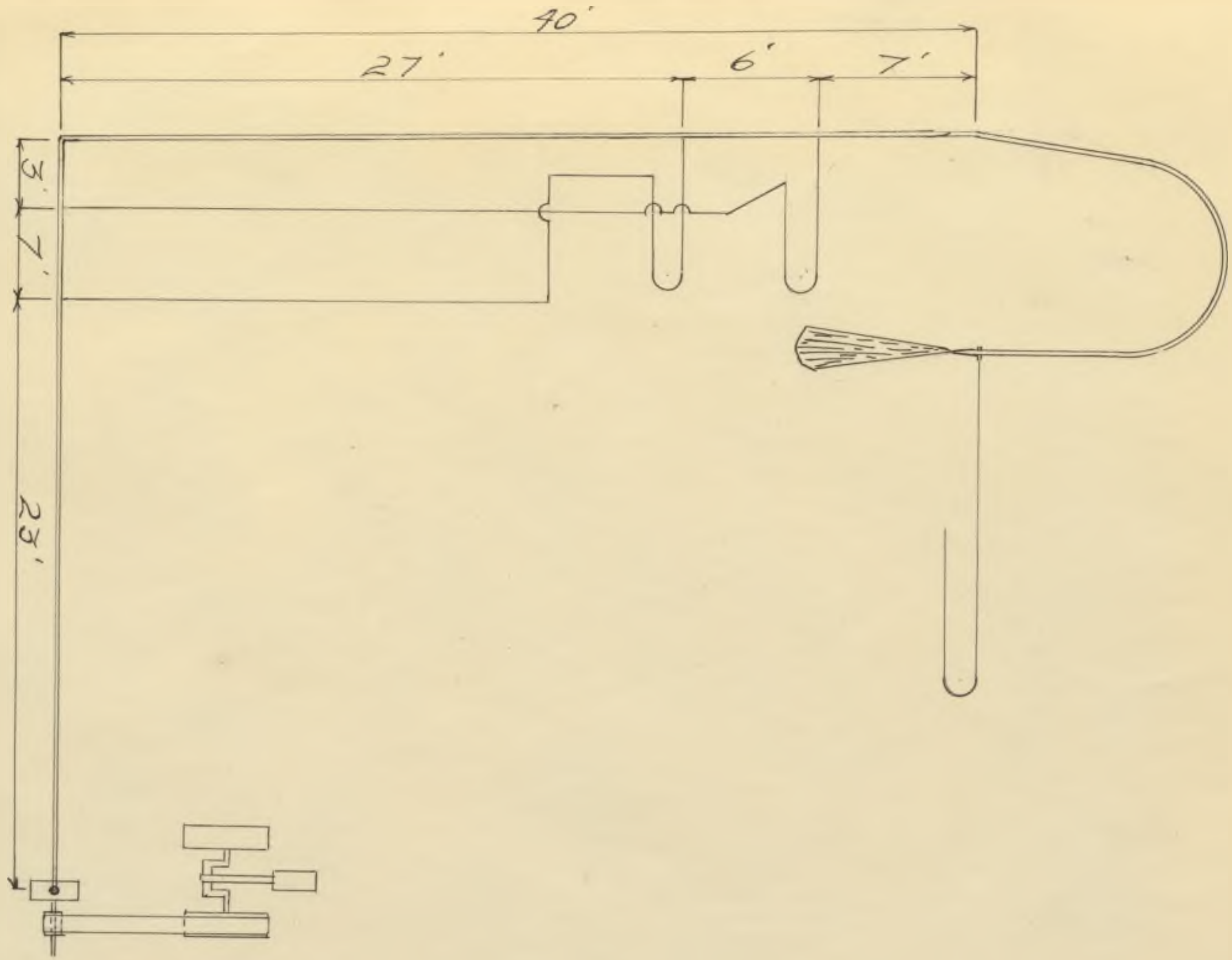
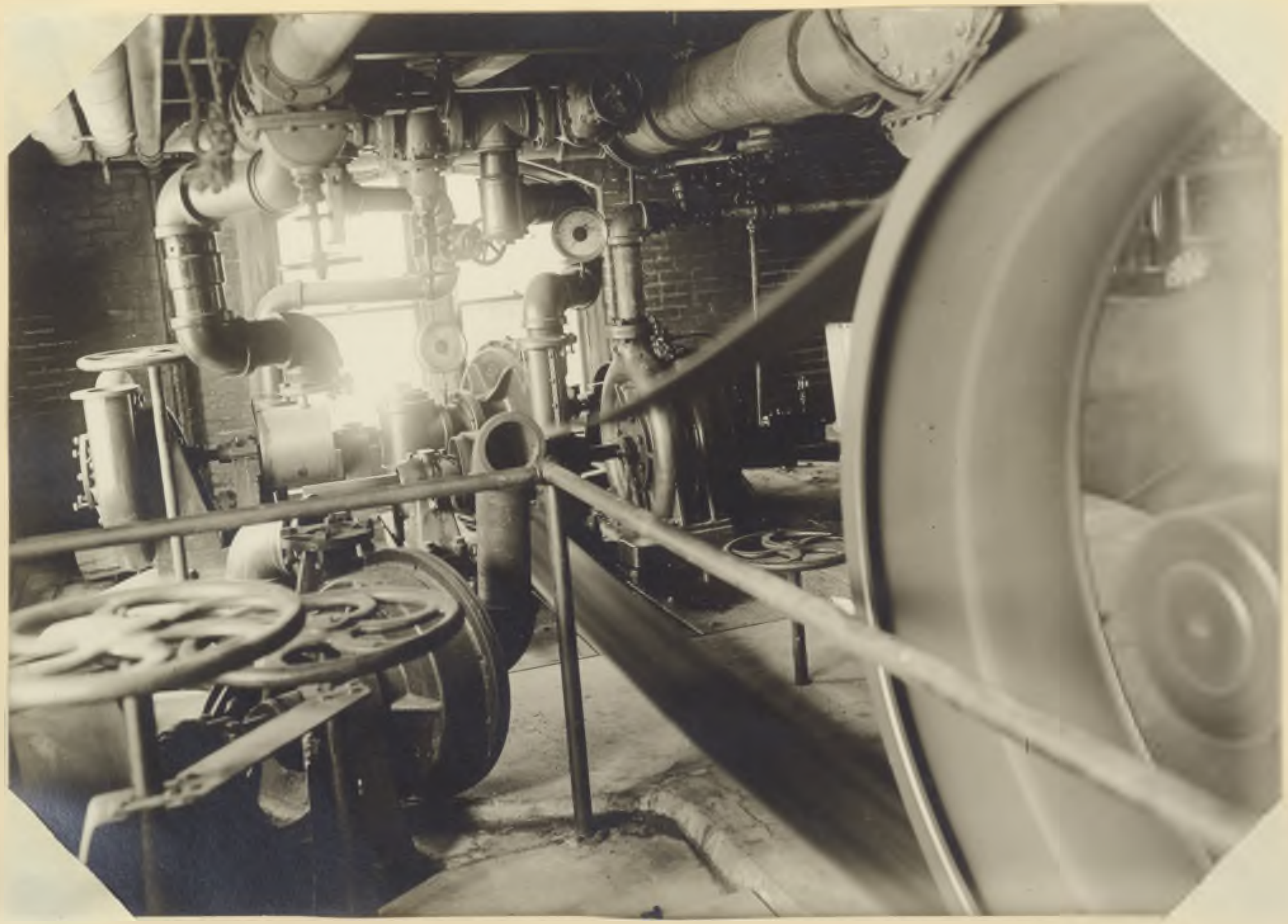


PLATE-I

LINE DIAGRAM

Showing Arrangement of Apparatus.



Photograph of Pump and Connections.

PRELIMINARY EXPERIMENTS.

Nozzles were used for measuring the discharge in all of the experiments, in order that deterimination of the discharge could be made instantaneous. Instantaneous readings were desirable for a two fold reason, first, because the steam pressure in the steam mains varied, owing to the variation in demand, consequently the engine would run at the slightly different velocities,producing a variation in the discharge. This was very undesirable, for the variations in discharge meant variations in loss of head, which of course, would introduce material error in the readings. Second, if the velocity was measured by volume displaced, a long period of time would be required to get a few readings. It was, therefore, decided to use the nozzle method of measuring the water.

It appeared that the Venturi meter was the most accurate and most economical for calibrating the nozzles. The Venturi meter was calibrated by displacement of water from constant stand pipe pressure,flowing through it into a six foot pit in the basement of the laboratory. Curves of the theoretical and actual discharge of the Venturi meter were plotted, page 11 and from these curves the coefficient of discharge was calculated to be 0.954.

One nozzle and the base of the play pipe were calibrated for discharge. The play pipe was used because we did not have a nozzle large enough to give us the discharge required under the pressure we could get from the pump. The nozzle was one inch in diameter and the opening of the play pipe was 1.79 inches in diameter. The pressure was measured at the base of the play pipe by piping from an equalizing chamber around the base of the play pipe to an open air mercury gage,graduated to read pressure in pounds per square inch. Four holes 1/16 inch in diameter led from the inside diameter of the nozzle to the equalizing chamber. The diameter of the play pipe at the point from which the pressure was taken is 2.5 inches. The theoretical discharge was calculated for the pressures for which readings were taken, and both theoretical and actual discharges were plotted upon logarithmic paper, page 12. The actual discharges were, of course, determined from the Venturi meter which had been previously calibrated for this purpose.

As the values of discharge vary as the square root of the head upon the nozzle, we had an easy method of checking the results. That is, when discharge in cubic feet per second is plotted as abscissae against head on base of nozzle in feet of water, the curve on logarithmic paper should be a straight line with a slope of 2. This method of calibration did give a series of points all of which fell on or close to a line which had a slope of 2. It was seen from the curves, page 11 , that the one inch nozzle has a coefficient of discharge of a little over one, while the play pipe has a coefficient of discharge of considerably less than one.

At the time we were ready to begin experimenting some of the apparatus had not arrived so that it was thought advisable to spend the time in becoming familiar with the operation of the apparatus. The pipe was hung from the ceiling of the laboratory, and wired into place, where it remained through the entire set of experiments on elbows and tees. The nozzle was fastened directly upon the pipe, and the series begun.

Tests were made by trying to read the gages simultaneously. This was found to be very inaccurate, due to the time which must necessarily pass while reading the gages. Next the open air mercury gage and the two differential gages were all turned off at the same time, holding whatever reading there was at that instant until all of the gages could be read.

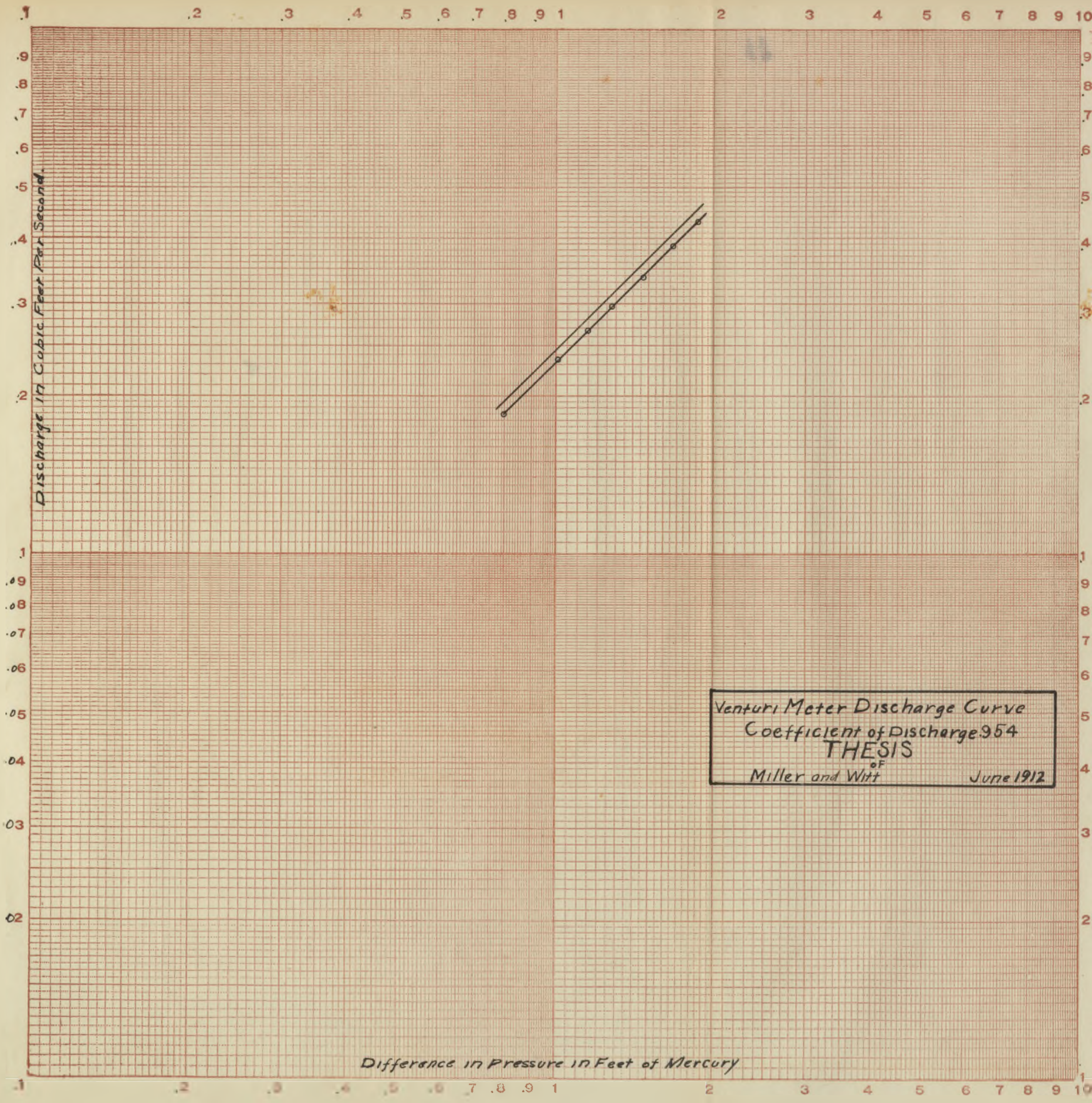
During the preliminary experimenting, possible sources of error were found. One, which was remedied as shown, was the variation of the speed of the pump,causing the head and losses to fall or rise, as the case might be. The gages were shut off and the engine speeded up or slowed down to see if the readings would change. The leaks in the valves were so small that it was found that the change would be only about 0.2 feet of water in one minute and, since the readings were taken in about one half minute, this error was disregarded.

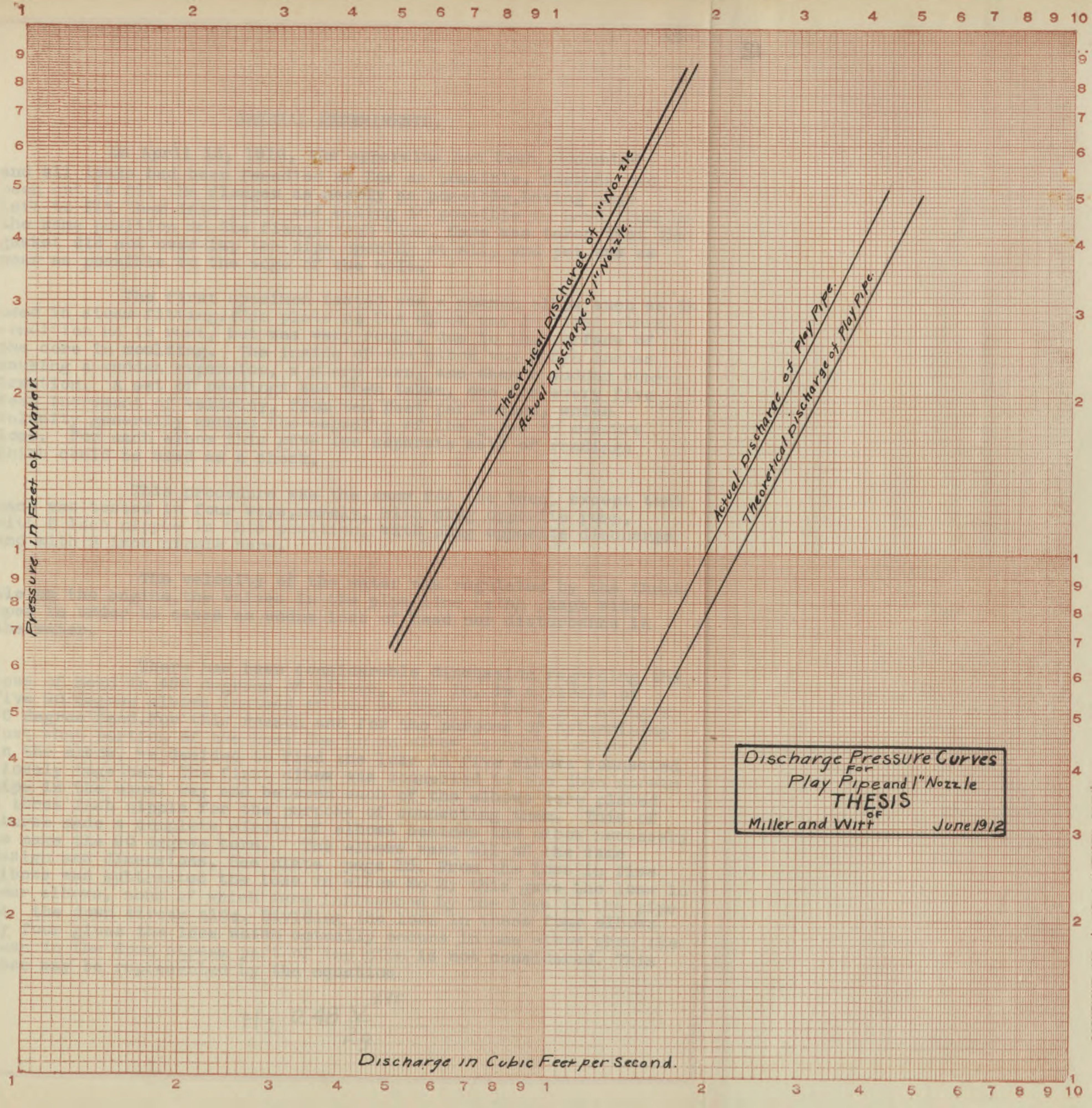
Another source of error was leaks in the piezometer tubes. The pressure in the pipe line was raised to 50 pounds per square inch and all leaks marked. These were then fixed and the pressure again raised, until there were no leaks greater than about ten drops a minute under this high pressure. The actual work was conducted under pressure lower than 25 pounds per square inch so that no appreciable leaks were to be found.

Care was taken that no air remained in the piezometer tubes. Each time that the water was turned on, all gage cocks were opened and remained so until readings were to be taken.

All piezometer readings were taken to the nearest one tenth of a foot of water. This is more accurate than could be plotted and was consistent with the nature of the experiments.

The line of pipe from the pump to the elbow tested was strung across the east end of the basement floor of the laboratory, directly below the other piping in that part of the laboratory, and was as near the ceiling as it could be placed. At the south side of the laboratory a turn was made by means of the elbows and tees tested; the pipe was then run for about forty feet to where the hose and nozzle connected with it. The above angle was measured by means of a transit and found to be about eighty nine degress and thirty minutes. The nozzle discharged into a channel from which the water ran back to the sump by gravity and was repumped. The play pipe and nozzle were fastened horizontally to an I beam in such a manner that the elevation of the nozzle would not change throughout the experiments. Levels were accurately taken by a wye level to determine the difference in elevation between the center line of the nozzle and the top of the mercury in the mercury well of the open air gage. This difference was 2.40 feet and was taken into account when calculating nozzle pressure.


Venturi Meter Discharge Curve
Coefficient of Discharge .954
THESIS
of
Miller and Witt
June 1912
Discharge in Cubic Feet Per Second.
Difference in Pressure in Feet of Mercury


Discharge Pressure Curves For Play Pipe and 1" Nozzle
THESIS OF Miller and Witt June 1912
Theoretical Discharge of 1" Nozzle
Actual Discharge of 1" Nozzle.
Actual Discharge of Play Pipe.
Theoretical Discharge of Play Pipe.
Pressure in Feet of Water.
Discharge in Cubic Feet per Second.

GENERAL EXPERIMENTS.

On April 13, 1912, the apparatus had been connected and all leaks had been remedied as far as possible. Gaskets had been cut to fit the flanges as nearly as possible, having lugs left to fit them into place and making it possible to have them in the same position on the flange each time. Care was taken that the gasket did not over-lap the pipe opening at all, and yet was as near as possible to the edge of the hole.

The first specimen tested was a common elbow such as is used in steam fitting. (See plate 2.) The elbow was in first class condition as to rust, but was very rough, due to the surface of the core in moulding. The inside of the elbow was 2 5/8 inches causing a sudden expansion, a sharp turn, and then a sudden contraction. A set of readings was then taken, one for every five feet increment of velocity, from ten feet per second, which velocity generally marked the capacity of the gages to measure loss. For each elbow this gave two separate sets of readings which could be used as a check.

This procedure was the same for the tees, except that each was tested in four ways, namely, with plug opposite pump, with 8 inch nipple in this position, with plug opposite discharge and with 8 inch nipple here.

The velocity of the water was regulated by the throttle on the engine, the valves in the pipe line being kept wide open in order to cause no undue loss of head nor disturbance in the water.

There has been considerable discussion regarding the loss of head in 450 degrees of elbows, that is, in a circle of five 90 degree elbows instead of one 90 degree elbow, in making a 90 degree bend. For this reason and for the purpose of determining just what portion of the loss due to an elbow actually occurred in the elbow, we decided to find the loss in five elbows connected closely together. The first elbow was connected to the down stream pipe in the usual way and between each of the elbows were placed a three inch nipple for the purpose of connecting them. This of course made a complete circle of elbows besides the elbow necessary to make the 90 degree turn. The elbows were all of the same design and dimensions, See plate page 15. From the loss in five elbows was subtracted the loss in elbow No 2; this gave the loss in four elbows, none of which were influenced by the loss in the pipe on the down stream side. Dividing the loss in these four elbows by four gives the loss which actually occurs in one elbow when the loss in the down stream part of the pipe is not considered. This loss may be represented by the equation

$$H = 0.48 \frac{V^{1.95}}{2g}$$

$$\text{or} \quad H = 0.00745\, V^{1.95}$$

where H is the loss of head in the elbow and V is the velocity in the pipe in feet per second. In the equation

$$H = K\frac{V^2}{2g},$$ K does not remain constant,

but values of it may be found for different velocities by referring to table page 27.

After all elbows and tees had been tested, the length of pipe along the south side of the laboratory was removed to the outside and preparations made for the straight pipe determination. Owing to the inaccessability of the mercury gage used in the previous experiments and because only two differential gages were available, only the loss of head between one set of piezometer tubes could be measured, the other gage being in use as an open air mercury gage to determine the pressure at base of play pipe. In this manner readings were taken for every five feet increment of velocity of water in the pipe. In all about twenty readings were taken for each length of pipe between piezometer tubes.

While the pipe was yet in position for the straight pipe experiment, the volume was determined by finding the weight of water at 60° F. which the pipe would hold. By this method the diameter was found to be 2.03 inches.While from a set of eight caliperings for four ends of the pipe, the diameter measures 2.07 inches. The mean of these was taken asthe actual diameter.

The loss per foot of straight pipe is expressed by the formula,

$$H = 0.0844\frac{V^{1.95}}{2g}$$

$$\text{or} \quad H = 0.00233\, V^{1.95}$$

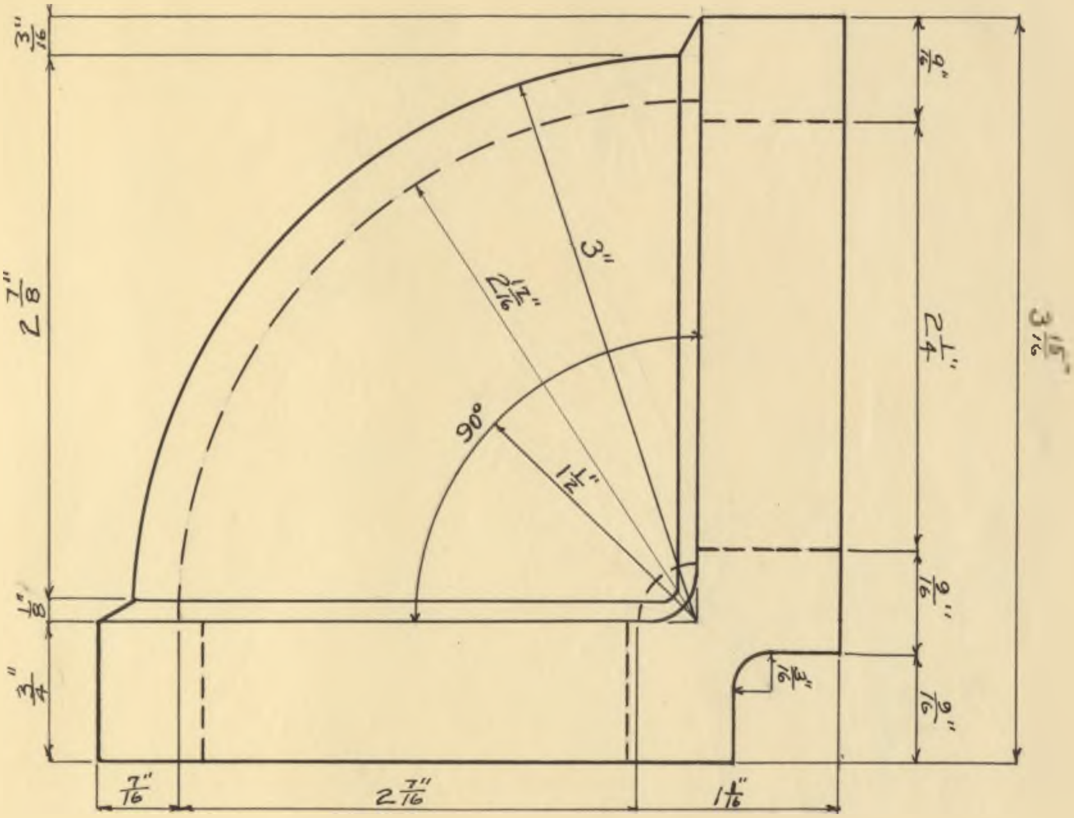


PLATE-II
Common Elbows No:s 2&3.

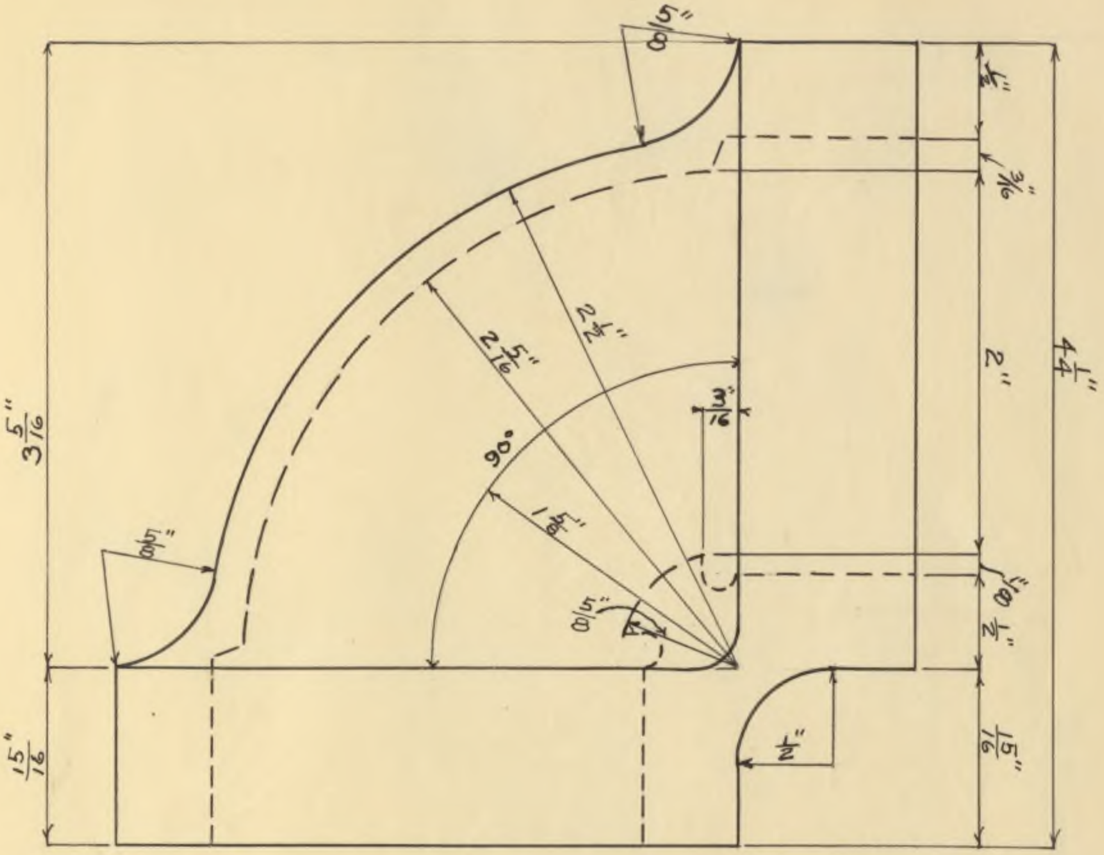


PLATE-III

Durham Elbow No. 4

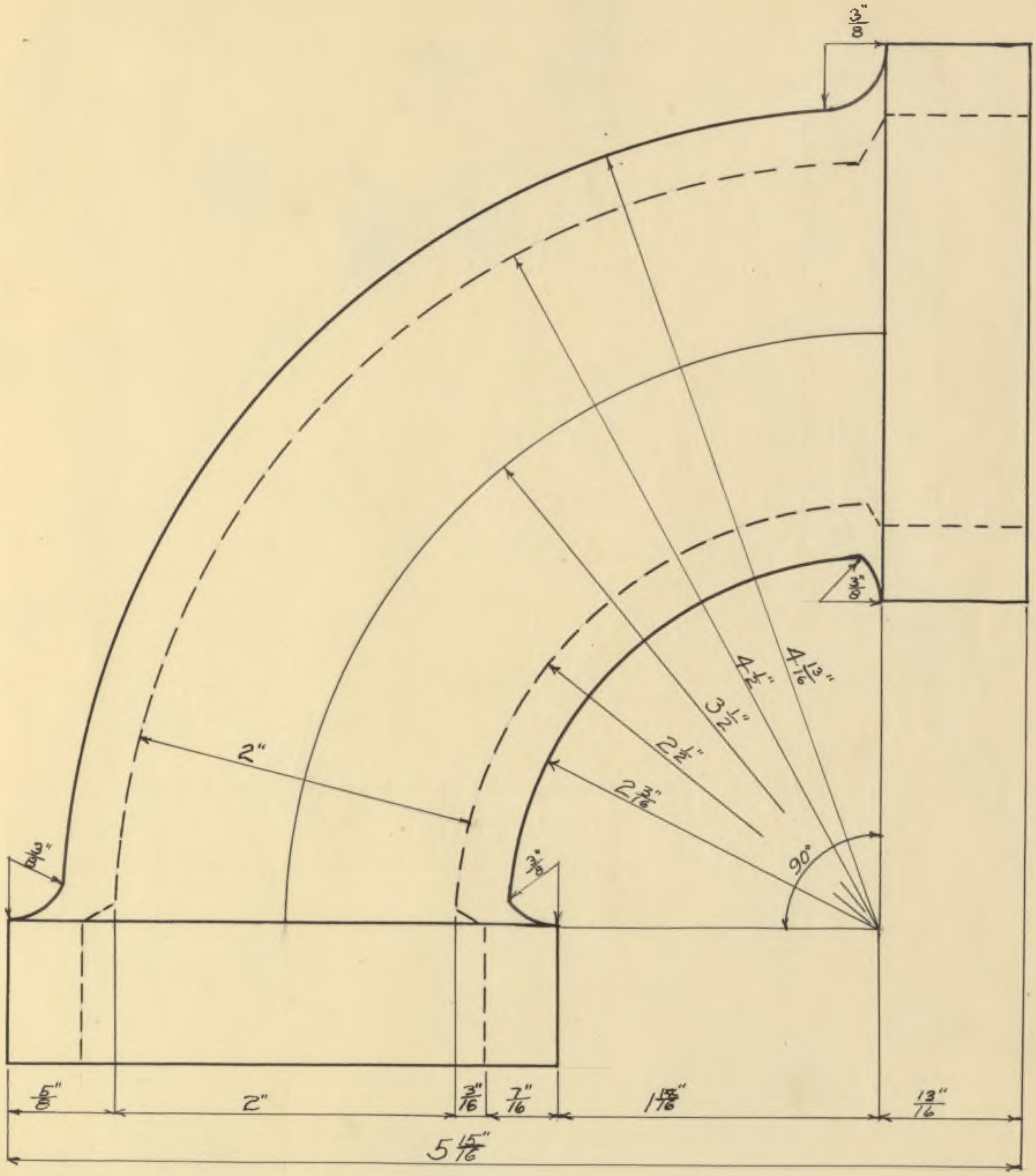


PLATE-IV

Long Sweep Durham Elbow No. 6

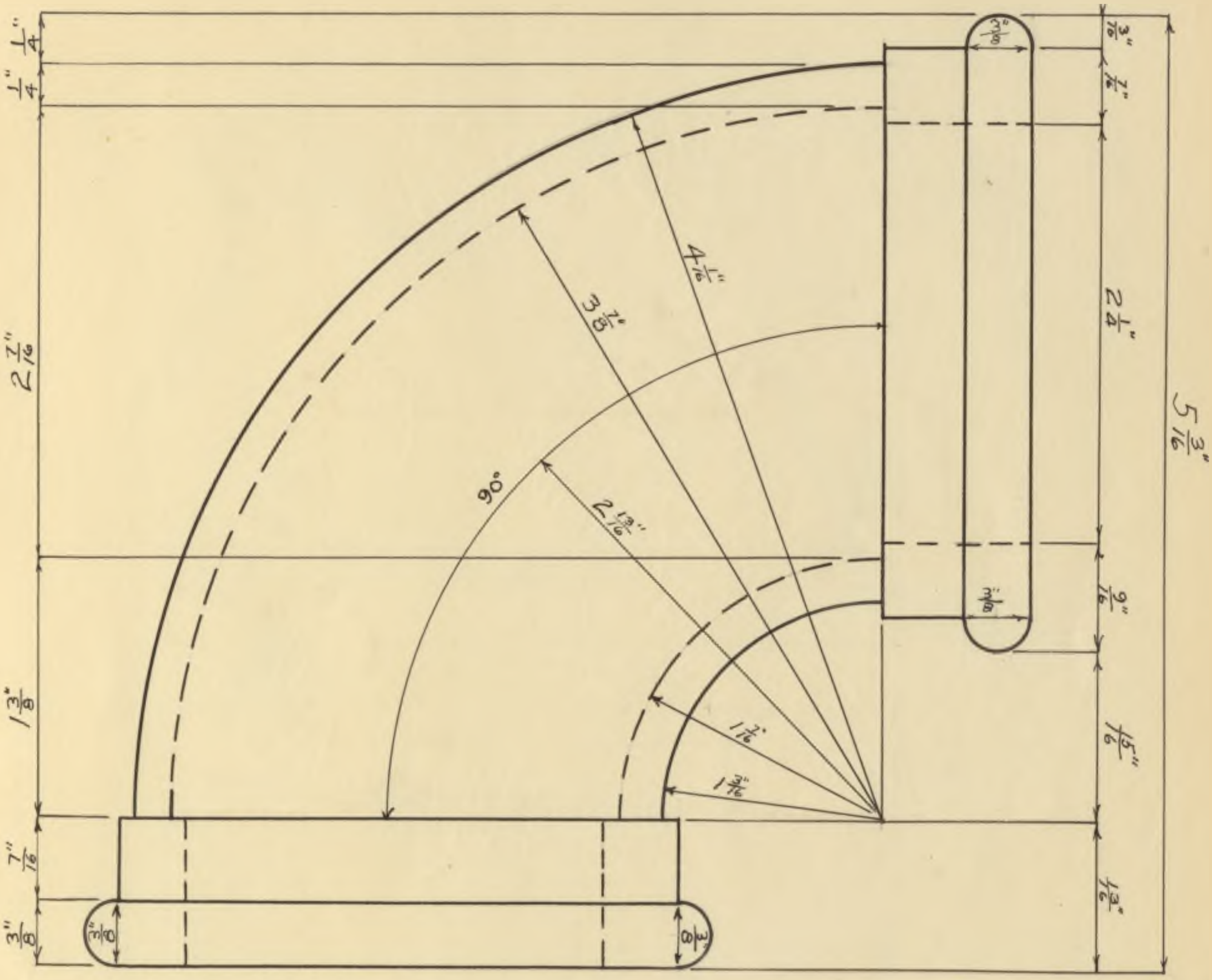


PLATE-V

Long Sweep Special Elbow No.5.

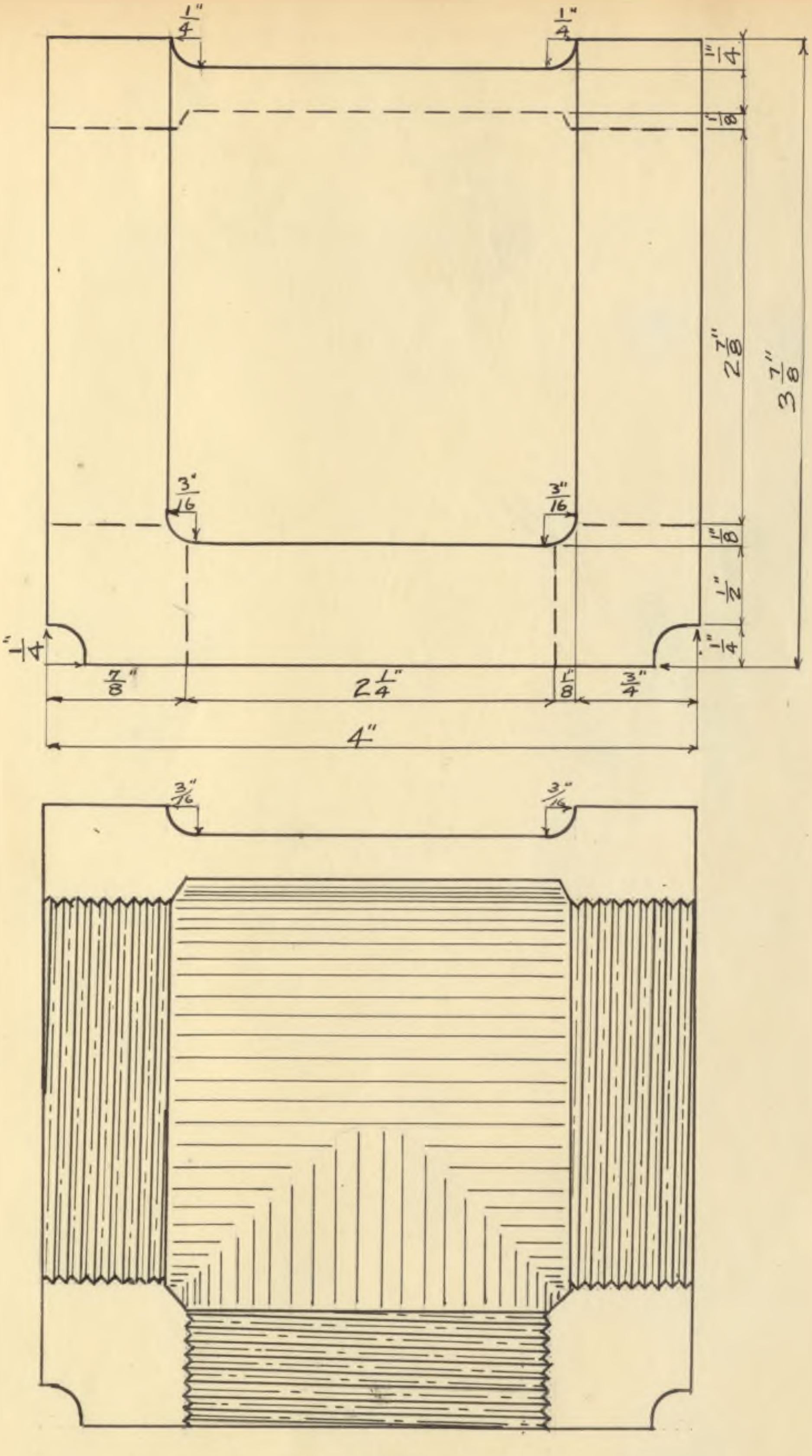
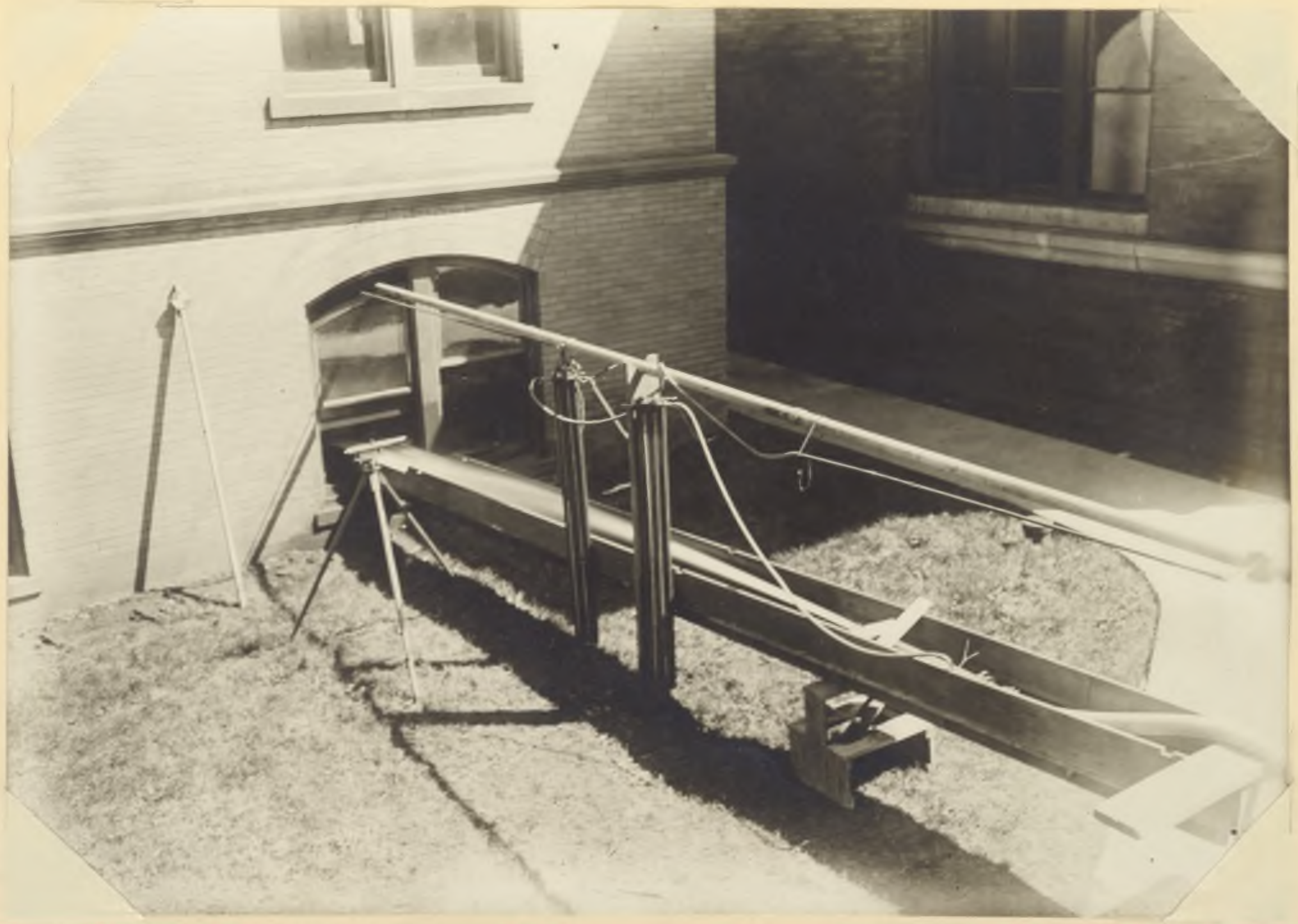


PLATE-VI

Tee No. 2



Straight Pipe Experiment.

OBSERVED AND CALCULATED DATA.

GAGE 1			GAGE 2			
Gage 1 Ft. of Water	Correction Ft. of Water	Corrected Gage 1 Ft. of Water	Ft. of Water	Nozzle Pressure. Ft. of Water: Play Pipe	Nozzle Pressure. Ft. of Water: Nozzle	Velocity in Pipe in Ft. per Sec.
		Elbow No 2.				
54.9	2.6	57.6	60.6	18.30		26.0
44.3	2.1	46.4	48.2	14.43		23.1
27.6	1.3	28.9	28.0	8.84		18.1
17.1	0.9	18.0	19.5		57.6	15.0
7.0	0.4	7.4	8.3		23.6	9.6
		Elbow No 3.				
56.9	2.6	59.5	60.4	18.15		26.0
46.4	2.1	48.5	49.3	14.65		23.3
29.7	1.4	31.1	31.5	9.05		18.4
18.7	0.9	19.6	19.8		54.2	14.6
8.9	0.4	9.3	10.1		26.8	10.2
		Elbow No 4 Short Durham.				
55.8	2.5	58.3	60.0	17.30		25.3
49.5	2.2	51.7	52.8	15.05		23.6
30.5	1.4	31.9	32.4	8.93		18.3
18.5	0.9	19.4	20.9		55.9	14.8
8.6	0.4	9.0	9.6		25.1	9.9
		Elbow No 5 Long Sweep Special.				
55.0	2.6	57.7	59.2	18.43		26.1
45.5	2.3	47.8	48.8	15.00		23.6
26.9	1.3	28.2	28.6	8.61		18.0
15.2	0.8	16.0	17.1		49.1	13.8
9.1	0.4	9.5	9.8		28.7	10.5
		Elbow No 6 Long Sweep Durham.				
58.1	2.8	60.9	60.7	19.35		26.8
44.4	2.1	46.5	46.5	14.50		23.2
28.7	1.4	30.1	30.2	9.16		18.5
16.2	0.8	17.0	17.7		52.3	14.3
8.3	0.4	8.7	9.8		28.0	10.05
		Tee No 2 Plug Opposite Pump.				
56.9	2.4	59.3	59.7	16.10		24.4
53.0	2.2	55.2	55.9	14.80		23.5
34.4	1.4	35.8	36.4	9.30		18.5
20.5	0.9	21.4	21.9		55.9	14.7
8.6	0.4	9.0	9.5		24.0	9.7
		Tee No 2 Plug Opposite Discharge.				
57.4	2.4	59.8	60.1	16.20		24.5
52.5	2.2	54.7	55.7	14.75		23.4
32,2	1.3	33.5	34.4	8.84		18.1
19.0	0.8	19.8	20.9		52.5	14.3
9.8	0.4	10.2	10.8		25.6	10.0
		Five Common Elbows Similar to Elbow No 3.				
55.9	1.8	57,7	59.1	12.50		21.6
39.3	1.3	40.6	41.1	8.58		17.9
25.0	0.9	25.9	26.9		53.6	14.45
11.4	0.4	11.8	12.1		23.9	9.7

OBSERVED AND CALCULATED DATA.

GAGE 1			GAGE 2			
Gage 1	Correction	Corrected Gage 1		Nozzle Pressure. Ft. of Water.		Velocity in Pipe in Ft. per Sec.
Ft. of Water	Ft. of Water	Ft. of Water	Ft. of Water	Play Pipe	Nozzle	
Straight Pipe Experiment.						
59.5	3.5	63.00		24.17		29.9
58.1	3.4	61.50		23.38		29.5
56.65	3.0	59.65		22.59		29.0
48.05	2.7	50.75		18.94		26.4
47.7	2.8	50.70		19.21		26.7
47.55	2.7	50.25		19.10		26.6
43.2	2.5	45.70		17.22		25.3
25.0	1.6	26.60		9.86		19.1
24.75	1.6	26.35		9.71		19.0
16.06	0.9	16.96			59.87	15.3
16.05	0.9	16.95			59.87	15.3
15.85	0.9	16.75			60.72	15.5
15.85	0.9	16.75			60.39	15.4
8.40	0.5	8.90			30.70	10.95
8.35	0.4	8.75			30.53	10.9
7.45	0.4	7.85			26.72	10.2
			59.95	22.32		28.8
			58.72	21.87		28.6
			42.25	14.42		23.1
			41.24	14.37		23.1
			28.35	10.60		19.9
			28.25	11.10		20.4
			16.95		60.42	15.4
			16.90		60.77	15.45
			9.40		32.67	11.25
			8.60		29.37	10.7

GENERAL DISCUSSION.

In order that the curves could be made exceptionally plain and to avoid confusion, a reduction curve, Page 28, was drawn. This curve shows the loss in feet of water in 2 feet of pipe for any velocity. By means of this the difference of readings which should exist between the two gages can be read. By this method, only one line is plotted with two points which should coincide. In this manner all curves were plotted for the loss in 36.12 feet of pipe plus the loss in the specimen tested.

The scope of this data is unusually wide when the range of velocity in a two inch pipe is considered . In the beginning of these experiments it was believed that high velocities were desirable because by using high velocities the loss of head in the tees and elbows becomes very much larger and is therefore less affected by errors of measurment.

The upper limit of the velocities was practically fixed by the limit of loss which could be measured by the differential gages. This maximum velocity was usually from 25 to 26 feet per second in the case of elbows and tees but reached as high as 29 feet per second in the case of the straight pipe. Higher velocities might have been obtained had we used two differential gages connected in series, but we did not have the extra fittings on hand required for this, the time was limited, and there was danger of introducing material error by this method on account of the large number of readings that must be taken when two differential mercury gages are used in series.

Discussion of Results.

The results shown by the curves seem to disprove some of Mr. Davis's statements and yet the curves generally seem to have the same slope as those which he plotted.

In the formula $H = K\frac{V^2}{2g}$, Mr. Davis simply gives one value and does not state whether the values of K decrease or increase with the increase of the velocity. Each one of our curves has a slope which lies between 1.9 and 2.1, only one being greater than 2.0. For the straight pipe used, the slope was 1.95. All plotting was done on logarithmic paper. Take a case where the slope of the loss curve for an elbow is 1.96. In the two equations

for V = 26 feet per second

$$K = K'\frac{V^{1.96}}{V^{2.00}} = K'\frac{1}{V^{\frac{1}{25}}}$$

or $$K = 0.86\ K.$$

This is a greater difference than there would be at usual velocities and gives an error of 14%. This certainly should be taken into account. For this reason we have given a table which gives the values of K in $K\frac{V^2}{2g}$ for velocities of 10, 15, 20, and 25 feet per second. See page 27.

From plotting on logarithmic paper, the equation for loss may be expressed in terms of velocity in the form of

(1) $y = K_1 x^m$ in the case od loss in elbow plus straight pipe.

and

(2) $y' = K_2 x^n$ in the case of straight pipe alone.

In getting the loss in the elbow alone, we subtract 1 from 2 and get

$$y - y' = K_1 x^m - K_2 x^n$$

$$= x^n(K_1 x^{m-n} - K_2)$$

This is not the equation of a straight line unless $m = n$.

The segment of the curve which is plotted here is so short that it hardly shows the curvature, though as the values approach the point of crossing, the curve becomes steeper until at that point it is vertical. At the point where the two curves cross, the curve representing the loss of head in the elbow would become asymtotic to a vertical line passing through the velocity at such point. Of course if $m = n$, as should be, the two curves would no longer cross and the curve representing the loss of head in the elbow would be a straight line and would have the same slope as the other curves.

Although it was found to be true by plotting the points it leads to an absurdity whenever the lines are converging with increase of velocity. At the point where they would cross, the loss of head in the elbow would be zero and beyond this point the loss would be less in straight pipe and elbow than in straight pipe alone. In plotting, the curves were made as nearly parallel as possible, to conform to the points plotted. Some of these curves would cross if prolonged but it is not known if both curves would be a straight line between such limits. However, most of the curves are very nearly parallel.

For instance take loss curve for elbow No 2, page 29. This is only an instance of what was explained before. Here the segment of the curve is more vertical than the straight pipe loss curve, which only means that it is nearer to the zero than the others.

By averaging the constants found for each curve for elbows of short radius, we get approximately $H = 0.015\,V^{1.95}$ for the equation of the loss. The three values were 0.0137 and 0.0147 for common elbows and 0.0170 for short turn Durham. In the case of the long sweep elbows, the equation is $H = 0.0115\,V^{1.95}$.

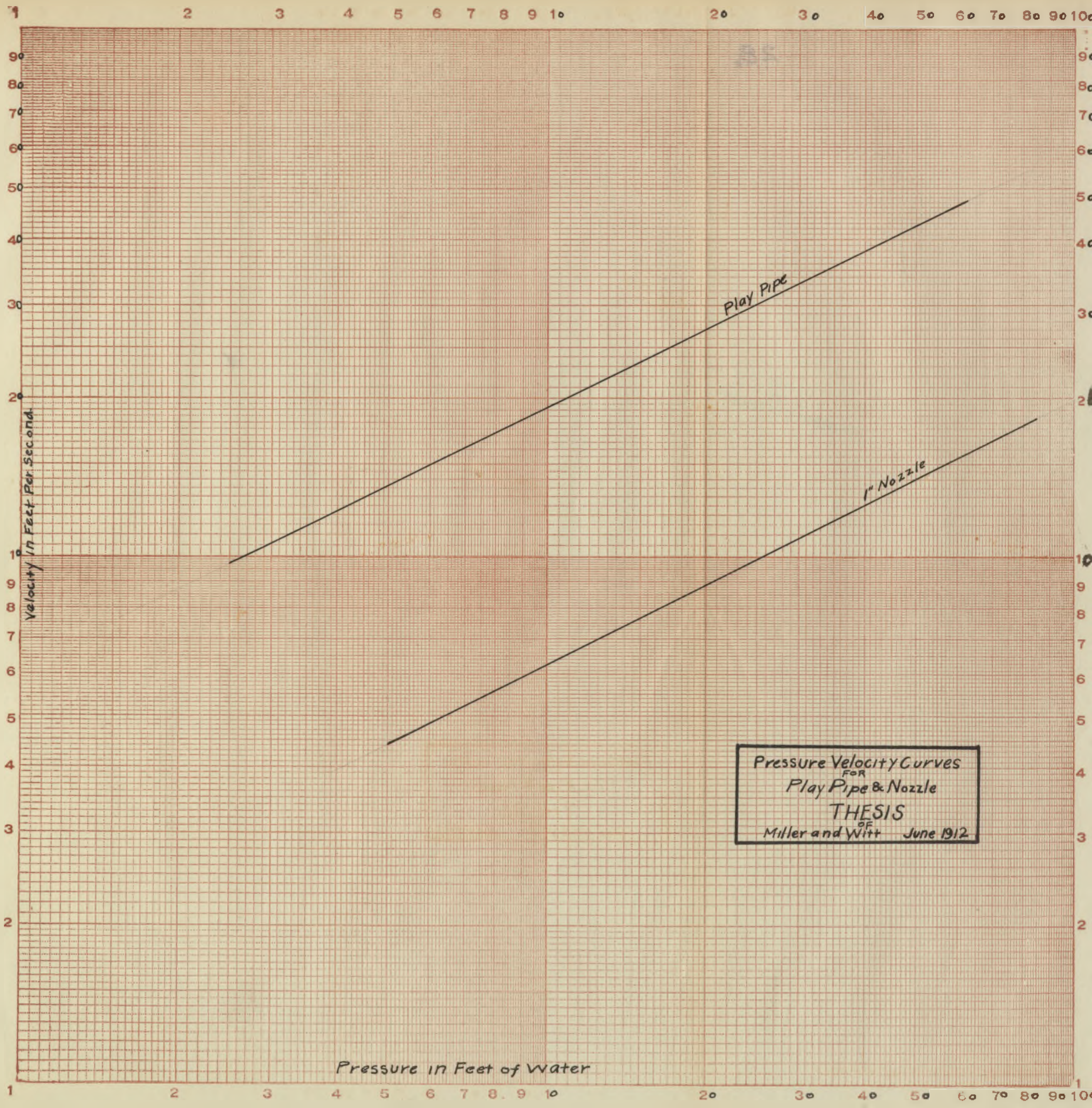
In the case of tees, the values found for the constant were 0.024 and 0.0236. The slope of these curves is the same as the straight pipe, being 1.95. This gives the equation $H = 0.024\,V^{1.95}$ for the loss in a common steam fitting tee.

In the final results the assumption made at first was found to be correct; that is, that the loss due to an elbow or a tee does not all occur in that elbow or tee, but was distributed down along the pipe for several diameters. Just how far this disturbance extended below the elbow, was not found, but that it is less than 150 diameters is certain, because no disturbance was shown in the piezometer readings.

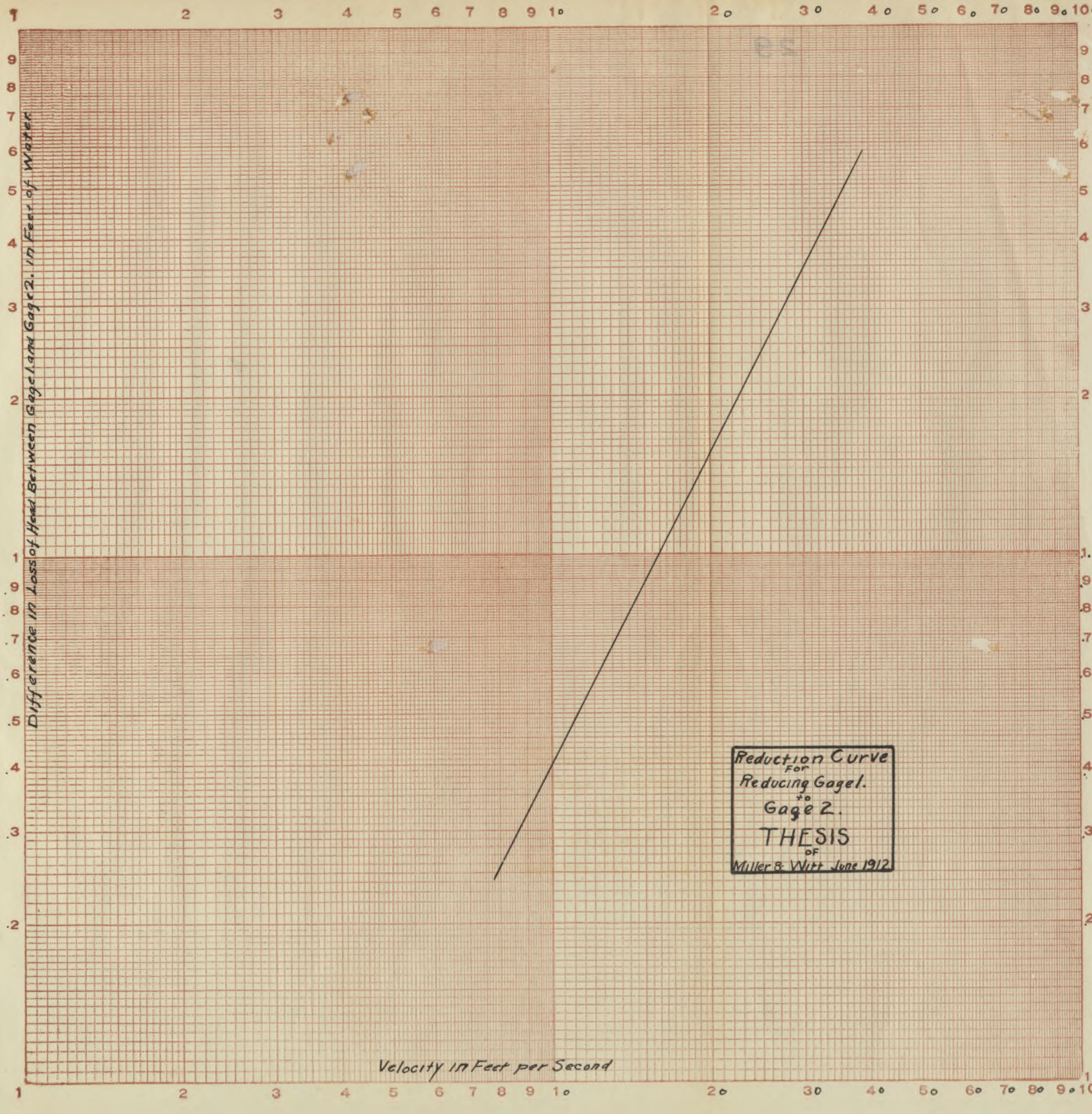
The method of determining the loss in the elbow alone has already been described in the 5 elbows experiment. This shows that any experiment which is performed in this manner finds only about one half of the total loss due to the elbow.

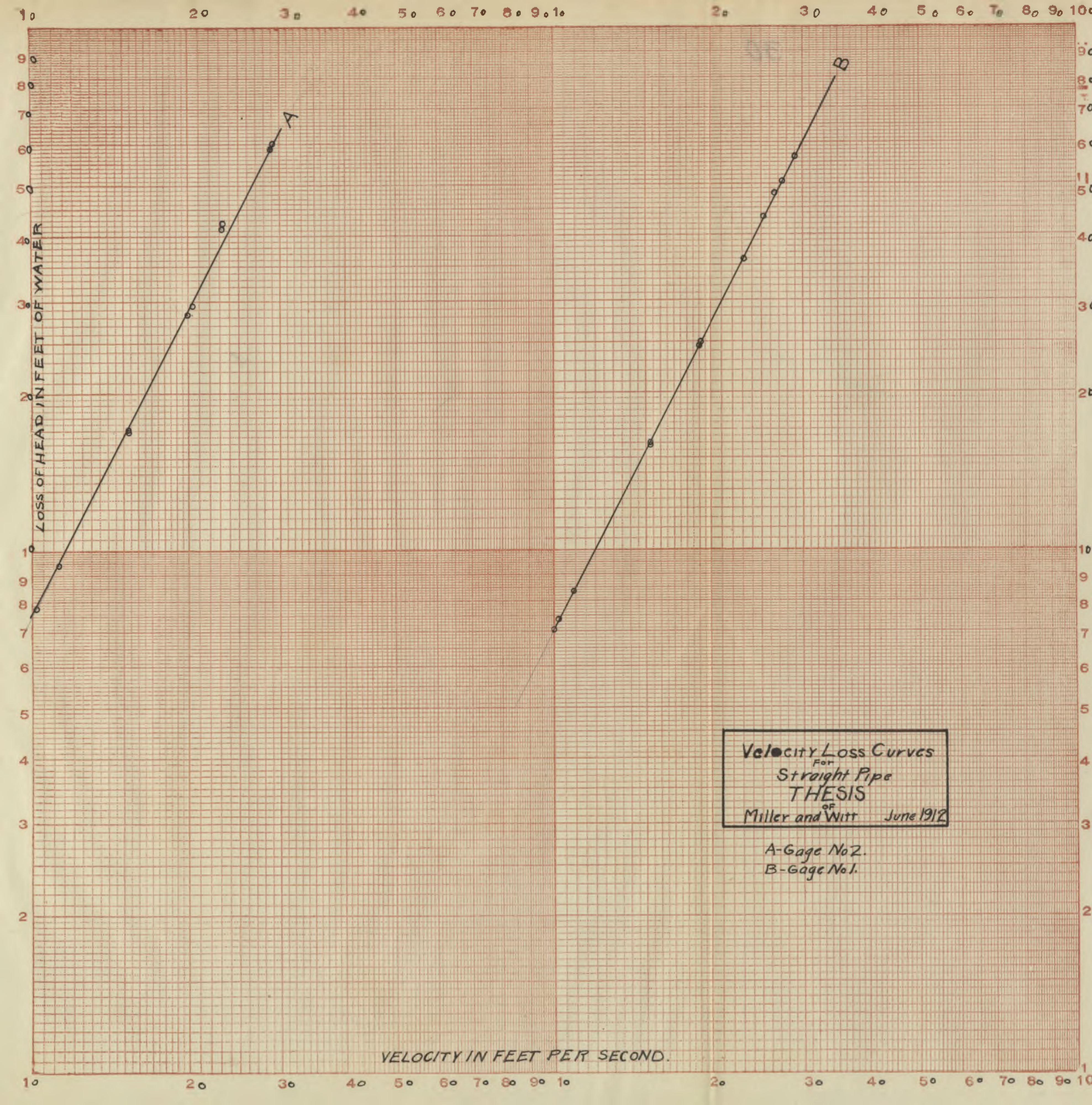
TABLE SHOWING LOSS OF HEAD IN ELBOWS AND TEES IN TERMS OF THE VELOCITY HEAD.

Description of Elbow or Tee.	Radius in.	Inside Diam. in.	Fig. on Page	Plate on Page	Velocity in ft. per sec.	K in Loss = $\frac{KV^2}{2g}$	K in Loss = $\frac{KV^{1.95}}{2g}$
Elbow No 2	1.5	2.5	15	31	10 15 20 25	0.772 0.887 0.966 1.030	0.88
Elbow No 3	1.5	2.5	15	32	10 15 20 25	1.190 1.145 1.135 1.110	Rusty and Pitted 0.95
Elbow No 4	1.625	2	16	32	10 15 20 25	1.307 1.290 1.290 1.290	1.1
Elbow No 5	3.5	2	18	33	10 15 20 25	0.825 0.858 0.88 0.90	0.76
Elbow No 6	2.625	2.5	17	33	10 15 20 25	.901 .886 .870 .865	0.735
Tee No 2	Plug opp. Nozzle	2.44	19	35	10 15 20 25	1.93 1.89 1.85 1.82	1.55
Tee No 2	Plug opp. Pump		19	35	10 15 20 25	1.48 1.63 1.73 1.78	1.53
Tee No 2	With 8" Nipple		19	36	10 15 20 25	1.45 1.43 1.41 1.39	1.19
Tee No 2	No Nipple		19	36	10 15 20 25	1.45 1.43 1.4. 1.39	1.19
Five Elbows	1.5	2.5	15	34	10 15 20 25	3.47 3.43 3.38 3.35	2.85
Four Elbows	1.5	2.5	15	34	10 15 20 25	2.25 2.25 2.25 2.25	1.90
One of the Four Elbows	1.5	2.5	15	34	10 15 20 25	0.564 0.564 0.664 0.564	0.48

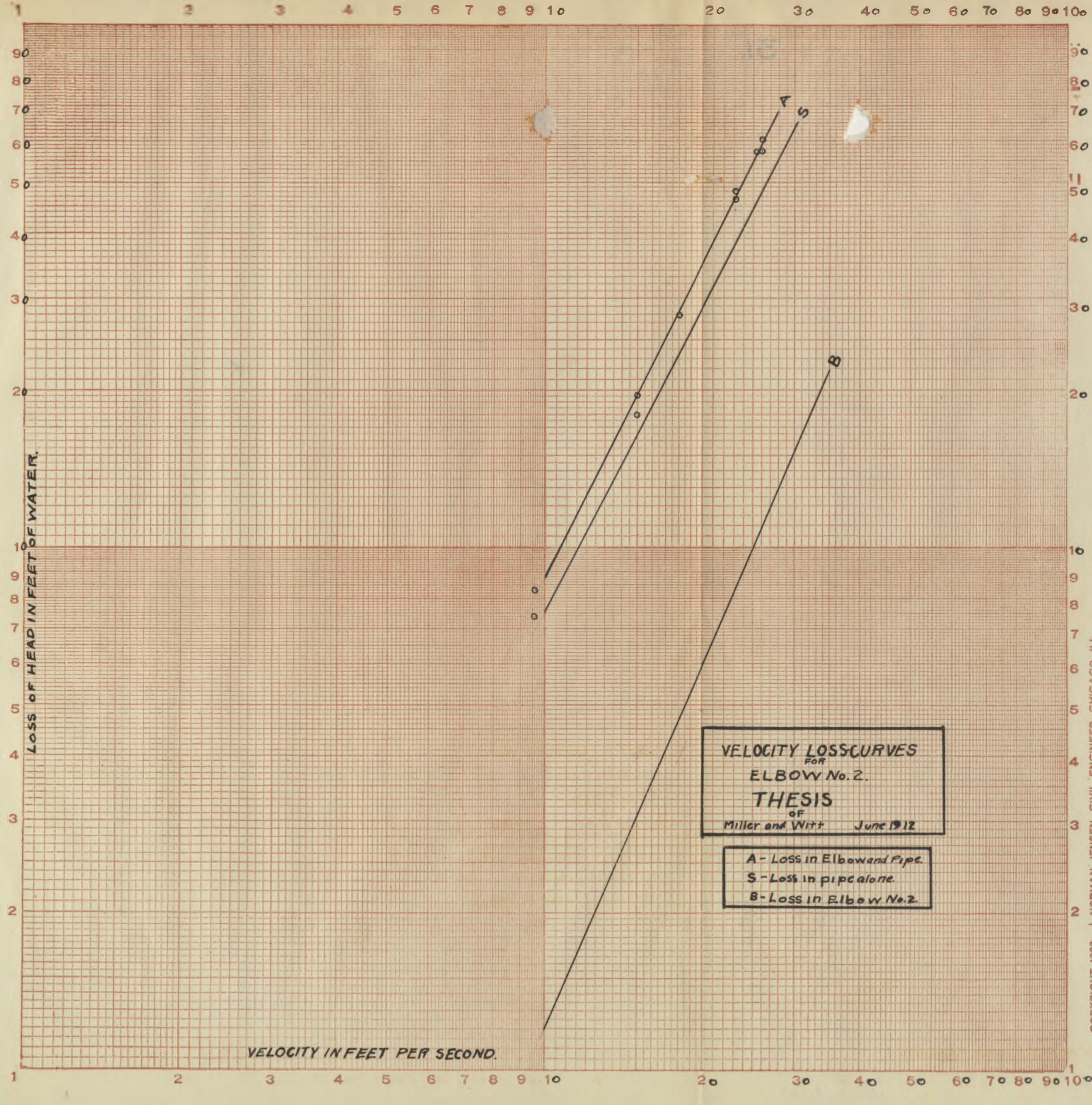


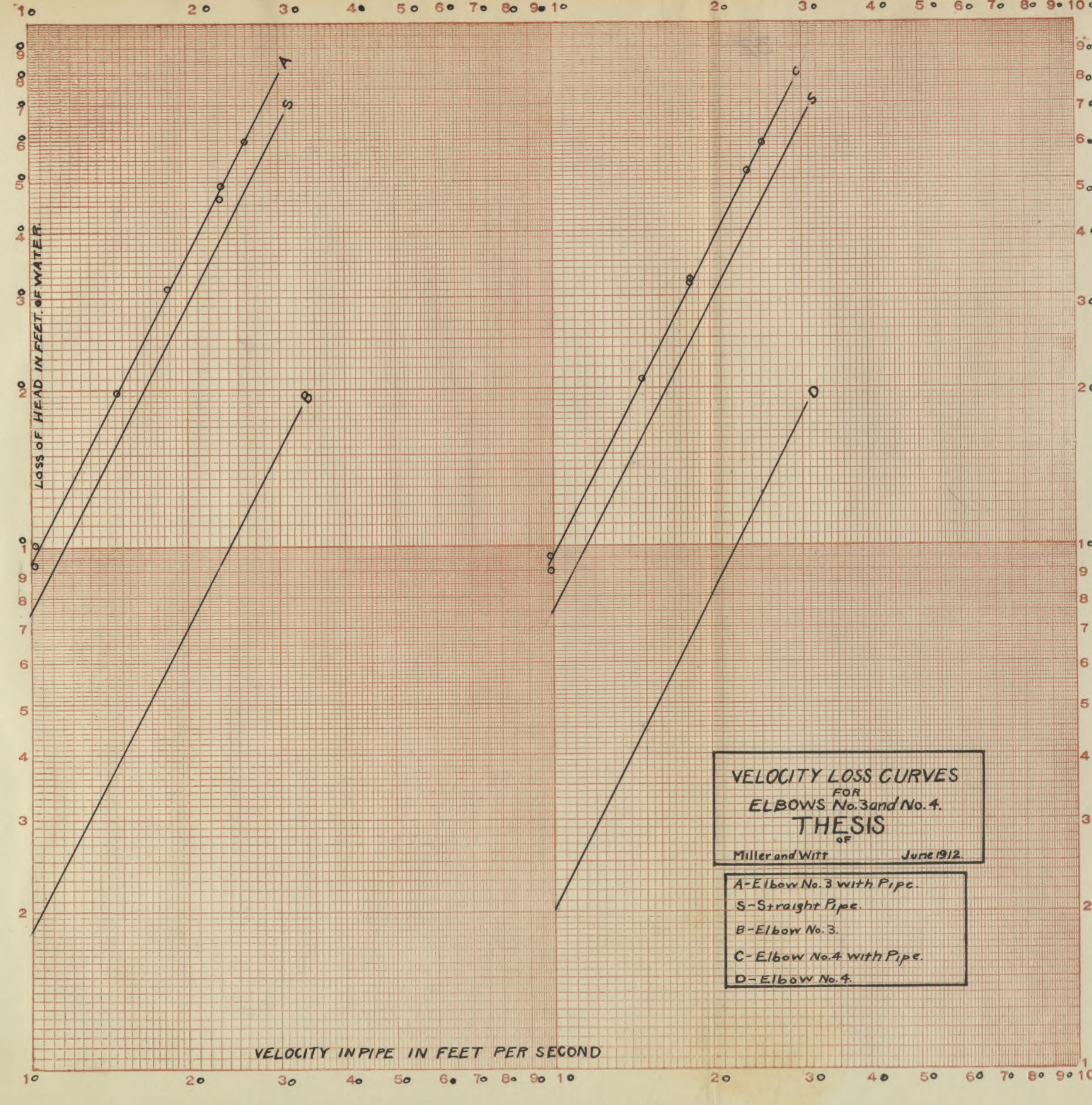
Play Pipe
1" Nozzle
Velocity in Feet Per Second.
Pressure in Feet of Water
Pressure Velocity Curves FOR Play Pipe & Nozzle
THESIS OF
Miller and Witt June 1912


Difference in Loss of Head Between Gage 1. and Gage 2. in Feet of Water
Velocity in Feet per Second
Reduction Curve
For
Reducing Gage 1.
to
Gage 2.
THESIS
OF
Miller & Witt June 1912

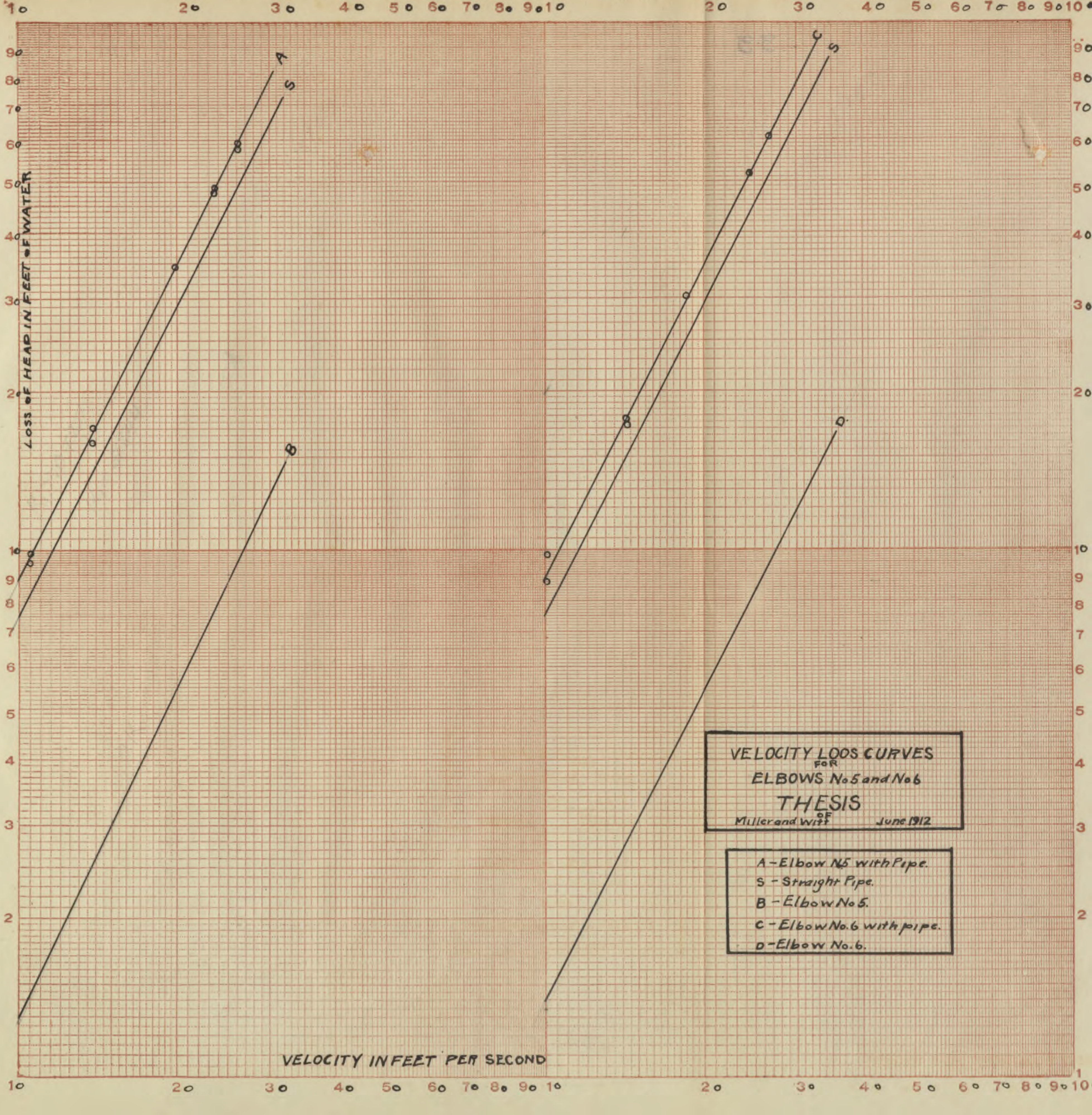


LOSS OF HEAD IN FEET OF WATER
VELOCITY IN FEET PER SECOND.
A
B
Velocity Loss Curves
For
Straight Pipe
THESIS
of
Miller and Witt
June 1912
A-Gage No 2.
B-Gage No 1.

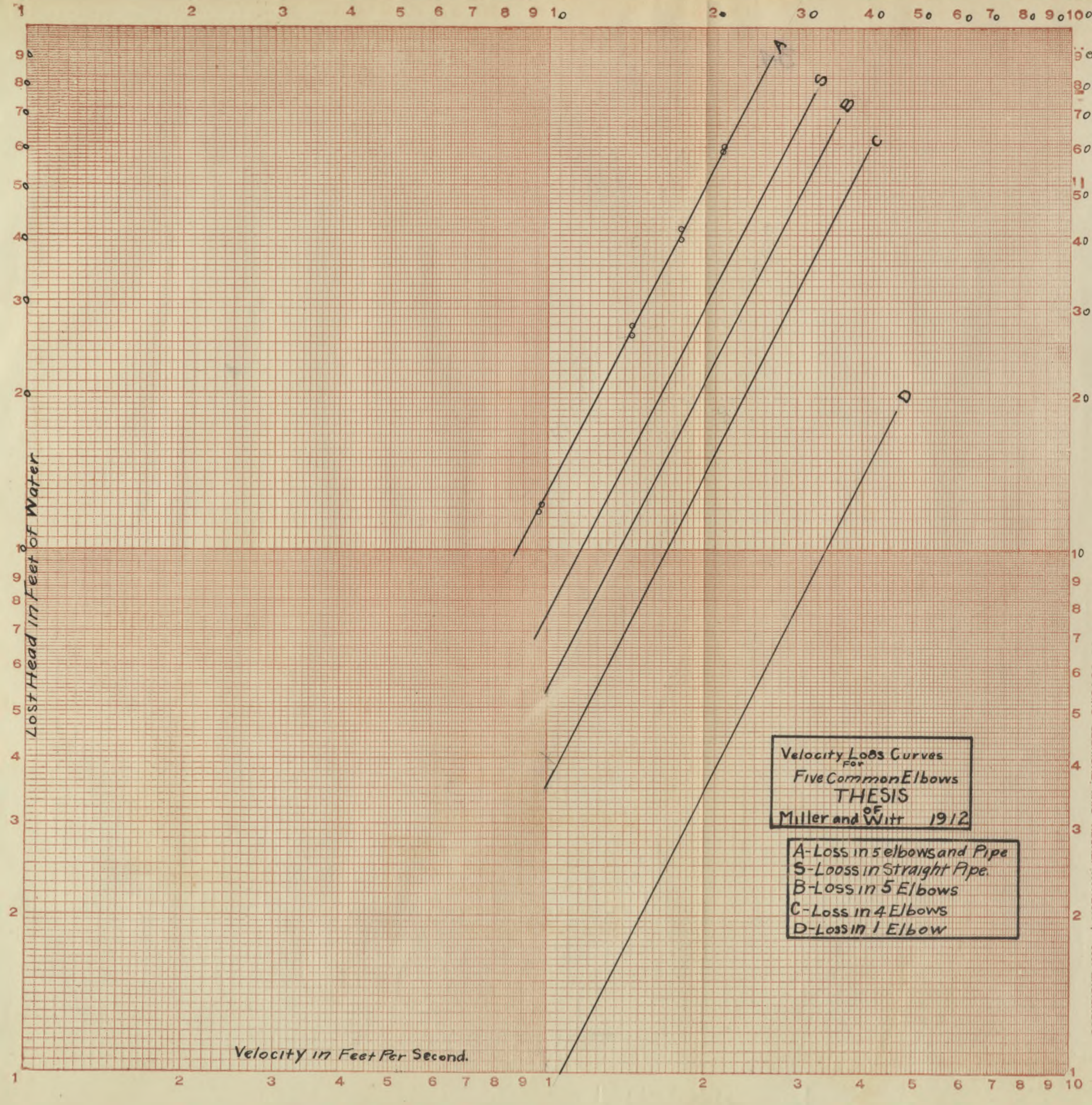

VELOCITY LOSS CURVES
FOR
ELBOW No. 2.
THESIS
OF
Miller and Witt
June 1912
A - Loss in Elbow and Pipe.
S - Loss in pipe alone.
B - Loss in Elbow No. 2.
LOSS OF HEAD IN FEET OF WATER.
VELOCITY IN FEET PER SECOND.
A
S
B



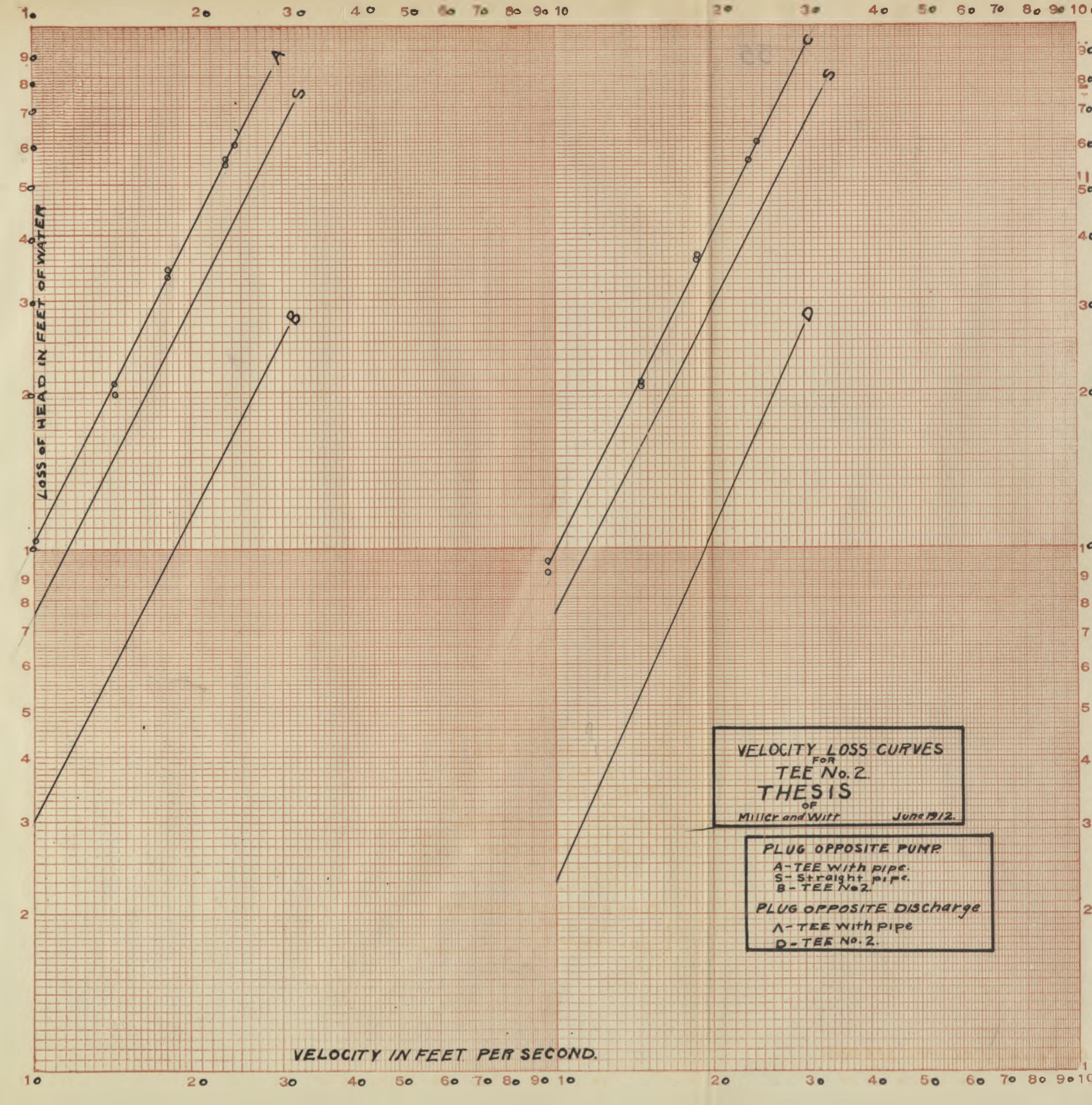
VELOCITY LOSS CURVES
FOR
ELBOWS No. 3 and No. 4.
THESIS
OF
Miller and Witt
June 1912.
A-Elbow No. 3 with Pipe.
S-Straight Pipe.
B-Elbow No. 3.
C-Elbow No. 4 with Pipe.
D-Elbow No. 4.
LOSS OF HEAD IN FEET. OF WATER.
VELOCITY IN PIPE IN FEET PER SECOND
A
S
B
C
S
D



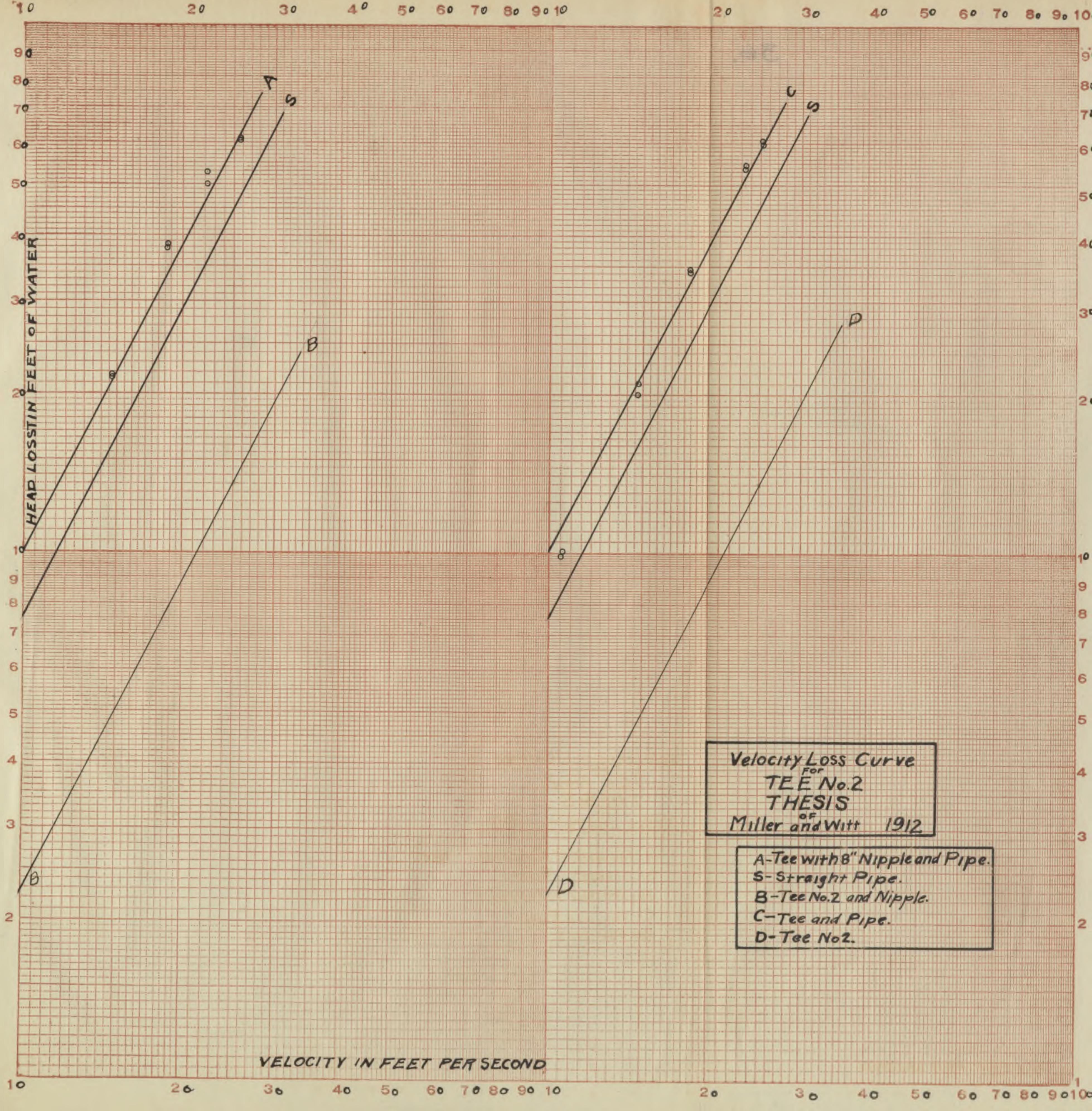
VELOCITY LOOS CURVES FOR ELBOWS No 5 and No 6
THESIS OF
Miller and Witt
June 1912
A - Elbow No 5 with Pipe.
S - Straight Pipe.
B - Elbow No 5.
C - Elbow No. 6 with pipe.
D - Elbow No. 6.
LOSS OF HEAD IN FEET OF WATER
VELOCITY IN FEET PER SECOND
A
S
B
C
S
D



Velocity Loss Curves for Five Common Elbows
THESIS of Miller and Witt 1912
A-Loss in 5 elbows and Pipe
S-Looss in Straight Pipe.
B-Loss in 5 Elbows
C-Loss in 4 Elbows
D-Loss in 1 Elbow
A
S
B
C
D
Lost Head in Feet of Water
Velocity in Feet Per Second.



LOSS OF HEAD IN FEET OF WATER
VELOCITY IN FEET PER SECOND.
A
S
B
C
S
D
VELOCITY LOSS CURVES
FOR
TEE No. 2.
THESIS
OF
Miller and Witt
June 1912.
PLUG OPPOSITE PUMP.
A-TEE with pipe.
S-Straight pipe.
B-TEE No 2.
PLUG OPPOSITE DISCharge
A-TEE with pipe
D-TEE No. 2.



HEAD LOSS IN FEET OF WATER
VELOCITY IN FEET PER SECOND
A
S
B
C
S
D
D
B
Velocity Loss Curve
FOR
TEE No.2
THESIS
OF
Miller and Witt 1912
A-Tee with 8" Nipple and Pipe.
S-Straight Pipe.
B-Tee No.2 and Nipple.
C-Tee and Pipe.
D-Tee No2.

CONCLUSIONS.

As the results of these experiments, we arrive at the following conclusions:-

First, That only about 0.5 of the entire loss due to an elbow occurs in the elbow itself.

Second, That Mr. Davis has curves which are correct, but that the form in which he put his general formula does not agree with our conclusions. Mr. Davis states that the loss varies as shown by the equation: $H = K\frac{V^2}{2g}$.

From our experiments we find that the exponent of V should not be 2, but should be the slope of the curve for loss in the straight pipe, plotted on logarithmic paper, to make this law hold good.

Third, That there can be a law formulated for any elbow under any given set of conditions. The loss which occurs in any fitting follows the general formula, $H = KV^m$,

where m is the slope of the line plotted on logarithmic paper. In our experiments m was 1.95

The Values of K for Various Fittings.

Specimen	Page of Drawing	Values of K in $H=KV^m$
Common short turn elbows	15	0.014
Short turn Durham elbows	16	0.017
Long sweep Durham	17	0.012
Long sweep special fitting	18	0.0114
Common tee, either direction	19	0.024