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FIELD STUDY OF FRICTION LOSS IN ASBESTOS CEMENT PIPELINES

by

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Preface

The tests described in this report are part of a programme of basic research being undertaken by the Water Research Laboratory into friction losses in pipes. The work is financed through a research grant made available by James Hardie and Coy. Pty. Limited.

The study was undertaken by Mr. D. N. Foster, Senior Lecturer in Civil Engineering.

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Associate Professor of Civil Engineering,
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Abstract

Tests have been undertaken to determine friction loss in large asbestos-cement pipelines under typical field conditions encountered in water supply systems. The test results are compared with the flow resistance charts recommended for use in design by the manufacturers, James Hardie and Coy. Pty. Limited. The test results indicate that under conditions normally encountered in water supply systems the friction gradients given by the design charts should be increased by about 5 to 10 per cent to allow for ageing and variations in pipe characteristics during laying in the field.

Table of Symbols

C	Hazen Williams roughness parameter
D	Pipe diameter - (ft. except where specified as inches)
H	Friction head gradient (ft. per 100 ft.)
K	Coefficient for orifice meter (g. p. m. / ft.$^{\frac{1}{2}}$)
L	Pipe length - (ft.)
Q	Flow rate - (c.f.s., except where specified as g. p. m.)
R	Hydraulic radius (D/ 4 for a pipe) - (ft.)
$\mathbb{R}$	Reynolds Number (VD/ν)
S	Energy gradient - (ft. per ft.)
V	Mean velocity (ft. per sec.)
f	Darcy formula resistance coefficient
g	Gravitational acceleration (ft. / sec.^{2})
h_L	Head loss - (ft.)
k	Equivalent sand grain roughness - (ft.)
n	Manning formula resistance coefficient
ν	Kinematic viscosity (ft.^{2} per sec.)

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1. Introduction

Recent years have seen an increasing use of asbestos-cement pipelines in water supply, irrigation and sewerage schemes. Despite this, little information has been published on the friction characteristics of asbestos-cement pipelines under field conditions. Vallentine (1960), from laboratory tests on a short straight length of new 4 inch diameter pipe, developed an exponential equation relating discharge (g. p. m.) to pipe diameter (ins.) and friction gradient (ft. / 100 ft.)

$$Q = 2.80D^{2.65} H^{0.54} \tag{1}$$

to describe friction losses in new asbestos-cement pipes. This equation forms the basis of the design flow charts as recommended by the manufacturers, James Hardie and Coy. Pty. Limited. To date, the above equation and the related flow charts have not been checked under field conditions. The purpose of this study was therefore to undertake friction loss studies on pipelines typical of normal field installations, to ascertain the range of application of the flow charts. The locality selected for the study was at Warwick, Queensland, where 15-inch and 21-inch class C water supply pipelines were brought into service in 1960 and 1967 respectively. The tests should therefore be indicative of friction losses in new pipelines and of any increase in roughness with time. The results of these studies are described in this report.

2. Head Loss Equations - Previous Work

2.1 Modern Approach

Rational approaches to friction losses in pipes have most often been based on the Darcy-Weisbach relatioship

$$h_L = f \frac{L}{D} \frac{V^2}{2g} \tag{2}$$

In this equation the friction factor, f, is a variable and depends upon the Reynolds Number of the flow and the relative roughness, k/D, of the pipe.

Equation (2) has the advantages that it is dimensionally consistent and applies over a wider range of flow conditions and pipe roughness than most of the exponential formulae that have been developed.

For the range of flow velocities and pipe sizes encountered in engineering practice, flow in asbestos-cement pipelines is in the transitional turbulent region. In this region Colebrook and White (1937) from tests on commercial pipes have related the friction factor to the Reynolds Number of the flow and the relative roughness of the pipe by the equation

$$\frac{1}{f} = 2 \log \left(\frac{k}{3.7D} + \frac{2.51}{\mathbb{R}\sqrt{f}}\right) \tag{3}$$

This equation is generally regarded as the most accurate basis for hydraulic design and in this report will be taken as the standard against which other equations are compared.

To simplify the use of the Colebrook-White equation a number of design charts have been prepared. The best known are those of Moody, Rouse and Wallingford.

Use of these charts requires an estimate of the equivalent roughness, k, for the pipe. Little information on the values of k for asbestos-cement pipelines has been published. Vallentine (1960) from laboratory tests on a 4 inch pipeline recommends a value of k = 0.00005 ft. for new pipe. This value corresponds exactly with that recommended for use with the Wallingford charts (Ackers, 1958) although the details on which the latter is based are now known.

It should be noted that the form losses at pipe joints and minor deflections in the pipeline produced during construction are normally incorporated in the value of pipe roughness.

2.2 Exponential Formulae

2.21 General

The objections to the general use of exponential formulae in the calculation of energy loss in water supply pipelines has been described by Vallentine (1957). Exponential formulae are generally applicable only to the type of pipe and the range of flow conditions for which they were derived. Application of the formulae outside of this range can lead to significant error.

The continued widespread use of the exponential formulae of the Hazen-Williams and Manning type evolves from the fact that use of the older methods is facilitated by readily available and easily usable charts and tables and in many instances from a lack of appreciation of the inaccuracies inherent in the methods. The development of design charts based on the more general Colebrook-White equation, such as the Wallingford charts, has countered this advantage.

If the limitations in the general use of exponential formulae are recognized then their use for particular conditions of pipe roughness and flow range has some advantages. For a given pipe material and flow range it is usually possible to develop an exponential equation which gives results in close agreement with those predicted by the Colebrook-White equation. It is only in the application of the equations outside of this range that significant errors are introduced.

2.22 Manning Equation

The Manning equation can be written as

$$V = \frac{1.49}{n} R^{2/3} S^{\frac{1}{2}} \tag{4}$$

Application of this equation (with constant roughness parameter "n") to the estimate of head loss in pipelines is limited to flow in the rough turbulent region and pipes with relative roughness ($\frac{k}{D}$) between 0.05 and 0.001. (Vallentine 1957). These conditions are approximated in concrete pipelines of diameter less than 5 feet where the equation may yield approximate estimates of flow conditions. For the smoother surface of asbestos-cement, flow is in the transitional turbulent region and application of the equation to asbestos-cement without allowing for variation of the roughness parameter "n" with pipe size and flow velocity can lead to large errors.

Based on the Hardie Flow Chart for head losses with water at 60°F the variation of "equivalent" Mannings "n" with pipe diameter and flow velocity has been calculated and is shown in Figure 1. Because of the large variation in the roughness parameter "n", use of the Manning equation for asbestos cement pipes is not recommended and its use will not be discussed further.

2.23 Hazen-Williams Equation

The Hazen-Williams formula is

$$V = 1.318\, CR^{0.63}\, S^{0.54} \qquad (5)$$

The limitations (Vallentine 1959) to the general use of equation (5) are -

(i) The equation approximates flow conditions in the transitional turbulent region and is not applicable to rough-turbulent pipe flow.

(ii) The roughness coefficient C is not a constant, as normally assumed, but depends upon pipe diameter.

(iii) The formula does not allow for variation of viscosity. Hence it is not applicable to fluids other than water, nor to water at temperatures differing appreciably from the unstated values upon which the formula was based.

Flow in asbestos-cement, steel and cast-iron pipelines at normal velocities, pipe diameters and water temperatures encountered in water supply design is generally in the transitional turbulent region. The Hazen-William formula may therefore yield approximations for flow in these pipelines provided the designer can obtain from experience a satisfactory estimate of the roughness factor C.

Based on the laboratory tests of Vallentine (1960) the variation of C with pipe diameter for water pumped at 60°F in axbestos cement pipelines is shown in Figure 2.

2.24 Exponential Approximation to Darcy Equation for A-C Pipelines

As discussed earlier, given a particular pipe material and operating range of flow velocities and pipe diameters, it is usually possible to develop an exponential equation which approximates closely the more general Darcy equation over this operating range. Because of their mathematical simplicity such equations have merit.

Based on an experimentally determined value of equivalent roughness of 0.00005 ft. Vallentine (1960) has shown that flow of water (g.p.m.) at $60^{o}F$ through asbestos-cement pipes of diameter D (ins.) can be described by the equation

$$Q = 2.80D^{2.65} H^{0.54} \tag{6}$$

Within the velocity range 1 to 12 f.p.s. and pipe diameters 2 to 24 inch head loss predicted by equation (6) agrees to within $\pm$ 4 pc. with that obtained from the more general Darcy equation using the Colebrook-White estimate of friction factor f in the transitional turbulent region.

3. Design Charts for Asbestos-Cement Pipes

3.1 Introduction

Based on equation (6), Vallentine (1960) prepared a flow resistance chart (Figure 3) for water at 60°F in asbestos-cement pipelines. This chart is currently recommended for design purposes by the manufacturers, James Hardie and Coy. Pty. Limited.

3.2 Correction for Water Temperature

Exponential equations make no allowance for the variation in head loss with water temperature as a result of the change in viscosity. Charts and tables based on exponential formulae, are usually prepared for a standard water temperature and corrections made for flow conditions at other temperatures. In this report a standard temperature of 60°F is adopted. Corrections to head loss in asbestos-cement pipelines when operated at other temperatures are given in Figure 4 (Vallentine 1960).

3.3 Limitations to the Existing Flow Charts

The flow charts were prepared on the basis of results of laboratory experiments on a 92 ft. length of straight 4-inch diameter pipe. The general use of the chart for field installations has been criticised for the following reasons:-

(i) Joint loss may not scale up in the same manner as surface friction loss. Since all pipe lengths are nominally 13 feet the effective number of joints is increased as pipe diameter is increased. Opposed to this the surface disturbance at the joint is smaller with increasing diameter tending to offset the above factor.

(ii) The laboratory tests were conducted over straight pipe lengths and take no account of small displacements and deflections which occur during the laying of pipes in the field.

(iii) No account is taken of the possible increase in friction with age resulting from organic growth or the collection of slime on the walls of the pipe.

Because of these doubts, field studies have been undertaken to determine the magnitude of these effects and the application of the flow chart to field installations.

4. Field Friction Tests

4.1 Introduction

The city of Warwick in Queensland was selected as the locality of the study (Figure 5) for the following reasons:-

(i) Two large diameter A-C pipelines bring water over considerable distances from the Leslie and Connolly Dams into a storage reservoir at Bacon Hill from where it is fed into the town's distribution system. Draw-off from the supply line is limited to a small number of irrigation outlets which could be shut off during the tests.

(ii) The pipes were laid by Warwick City Council using day labour and should therefore be typical of installation under normal field conditions.

(iii) Vertical and horizontal curves were constructed by deflecting the pipe joints and test results would reflect the effect of such displacement on friction loss. Elevations and plans of the two pipelines are shown in Figures 6 and 7.

(iv) The 21 inch class C (internal diameter 19.92 in) pipeline from Leslie Dam was brought into service in 1967 just prior to the tests. Results on this line would therefore be indicative of friction loss in new pipe. The 15 inch class C pipeline (internal diameter 14.30 in.) from Connolly Dam was brought into service in 1960 and results should reflect any increase in roughness with time as a result of ageing.

(v) Flow range in the two pipelines, although not as high as would be liked, was sufficient to obtain variation of head loss over a reasonable velocity range.

4.2 Test Procedure

Water from the Leslie Dam is pumped up to an open 22 ft. diameter balance reservoir from where it gravitates through a 21 inch diameter class C A-C pipeline to the 100 ft. diameter Bacon Hill service reservoir. The total capacity of the three pumps provided is 3000 g.p.m.

The 15 inch class C pipeline gravitates water from Connolly Dam to the Bacon Hill Reservoir and has a maximum capacity of approximately 1000 g.p.m. This can be increased to about 1400 g.p.m. by a booster pump installed midway along the pipeline.

The water pumped through both pipelines is chlorinated at the source.

Discharge measurements were obtained from orifice meters installed in the pipelines. The 15 inch meter was calibrated at two flow rates by timing the rise of water level over approximately 3 feet in the Bacon Hill storage reservoir. The 21 inch meter was calibrated at three flow rates by timing the draw-down in the balance tank over 7 to 9 feet.

Pressure gauges were located at four positions along the 15 inch line. For the 21 inch line, 4 gauge points were used for the first test programme but it was found desirable, for reasons discussed later, to increase this to 7 locations for a repeat test. Gauge locations are shown on Figures 6 and 7. The distance between the gauges was obtained by chaining. Static level of the gauges was obtained by survey traverse and this was checked by gauge readings under static head.

The 15 inch line was tested in November 1967 at flow rates between 422 g. p. m. and 1411 g. p. m. The corresponding total head drops over the 16, 455 ft. test section were 4. 25 feet and 36. 50 feet respectively.

Two series of tests were run on the 21 inch line, the first in November 1967 and the second in February 1968. In the first series the flow was varied between 1250 and 2950 g. p. m. and computation of friction gradient given in this report is based on a test length of 16, 394 feet. The variation in total head over this length varied from 5. 88 ft. to 27. 12 ft.

For the second test series the test length was increased to 19, 618 feet and friction gradients were measured over a flow range from 1210 g. p. m. to 2950 g. p. m. The corresponding total head drops were 5. 8 and 33. 0 feet respectively.

4. 3 Test Results

4. 31 Calibration of 21 inch Flow Meter

Water flow through the 21 inch pipeline is measured on site by an orifice meter and a "Kent K. U. 0-3000 g. p. m. Flow Recorder". The flow recorder was used for measuring flow during the friction tests on the 21 inch line. Calibration of the meter was checked at three flow rates by drawing down the balance tank (see Appendix A for dimension of tank). The procedure was as follows:-

(i) One or more pumps were brought on to line and the flow through the pipeline adjusted until a small discharge occurred over the spillway of the balance tank.

(ii) When flow conditions were steady, the pumps were turned off and rate of drop in water level recorded using a direct reading "Stevens F61 float recorder". (The float of the recorder was contained in an open ended, 10 in. x 15 in. x 12 ft. long stilling tube. This damped out surface wave disturbances whilst still giving a rapid response to the drop of water level in the balance tank).

(iii) Flow readings indicated on the meter were recorded at 1 minute intervals for the duration of the test.

Test results are given in Table 1.

The variation of indicated discharge with time has been plotted in Figure 8. Within the accuracy of reading ($\pm$ 10 g. p. m.) the flow can be taken to vary linearly over the duration of the tests and calibration was therefore obtained using mean quantities as shown in Table 2.

The meter was calibrated at indicated flow rates of 905, 1900 and 2840 g. p. m. Correction factors of 0. 981, 0. 988 and 0. 985 respectively were obtained and for the analysis of the friction tests a mean value of 0. 985 was adopted.

4.32 Calibration of 15 inch Flow Meter

For flow measurement during the friction tests on the 15 inch line it was possible to use a differential water manometer connected directly to an orifice meter installed in the line. The discharge coefficient K for the meter in the equation

$$Q = K\sqrt{\Delta H}$$

where Q = flow rate g. p. m.
H = differential head across meter - ft.

was obtained by volume calibration at two flow rates, by timing the rise of water over the upper three feet of the Bacon Hill service reservoir (see Appendix B for dimensions of reservoir). The procedure was as follows:-

(i) Drawoff from the reservoir was stopped by turning off the outlet valves.

(ii) Flow through the 15 inch pipeline was turned into the reservoir and after steady conditions had been obtained the rise in water level with time was recorded using a direct reading "Stevens F61" float recorder. The float was contained in a 10 in. x 15 in. x 12 ft. long stilling tube to minimize surface wave disturbance.

(iii) Frequent readings were taken of the head difference on the water manometer for the duration of the test to ensure that conditions remained steady.

Test results are given in Table 3 and the computed coefficient of discharge in Table 4. The meter was calibrated at flow rates of 1,370 and 970 g. p. m. Coefficients of discharge of 1025 and 1023 were obtained and a mean value of 1024 was adopted for analysis of the test results.

4.4 Pressure Tappings

4.41 Installation

Pressure tappings were prepared by placing a tapping band around the pipe line with $\frac{1}{2}$" gate valve attached. The valve was opened and a 1/4" diameter hole drilled through the pipe. The pressure gauges were supported on a steel stand which rested on top of the pipe and connected to the tapping point by a 3 ft. flexible hose connection. This ensured that the gauges were at the same relative position at each location. The pressure tappings were located 1 ft. upstream of the collar and at an angle of approximately 60^{o} to the horizontal.

4.42 Location of Pressure Gauges

Location of the pressure gauges are shown on Figures 6 and 7. For the 21 inch tests, gauges located at A, B, C and D were used in the first test series in November 1967. These gauges were supplemented by gauges X, Y and Z for the test carried out in February 1968. In the latter test a gauge was also located between gauge points A and B but the pressure gauge was found to be sticking and this location was eliminated.

The distances between the gauges, as obtained by survey, and the identity numbers allocated to the gauges for the tests are shown in Table 5.

4.43 Calibration of Pressure Gauges

Pressure gauges used for the friction tests were "Lawrence" 12 inch Bourdan tube gauges. The gauges were calibrated before and after the tests with a "Barnet" dead load gauge tester. Gauge corrections are given in Figure 9.

During the tests the gauges were regularly compared with readings on an accurately calibrated standard 0-200 ft. gauge. With the exception of gauge No. 100 no significant variation in the calibrations was obtained before, during or after the tests and the mean corrections shown on Figure 9 were used for all calculations. For gauge No. 100 there was a noticeable change in calibration from before to after the tests. This was due to an accidental overloading of the gauge which occurred after the completion of the tests. For this reason, gauge corrections as obtained from the dead load tester and checked immediately prior to testing on the standard gauge were adopted in the calculations.

4.44 Static Level at Pressure Gauges

The static levels at the pressure tappings were obtained by :-

(i) survey level traverse to nearby bench marks;

(ii) reading of the pressure gauges with no flow in the line.

The results obtained from both methods are given in Table 6. For the 15 inch line, survey levels were taken at the pressure tappings and a small location correction had to be made to allow for the slight difference in elevation between this position and the location of the gauge. For the 21 inch line, levels were taken at the gauge location and no correction was necessary.

Within the accuracy of reading the pressure gauges, reasonable agreement was obtained between the two methods. All calculations are based on the survey traverse which should be the more accurate of the two.

4.45 Friction Gradients

4.451 15 Inch Pipeline: Test results for the 15 inch pipeline are given in Table 7, and the friction gradient over the entire line (corrected to a standard temperature of $60^{O}F$) is plotted on Figure 10. Agreement in friction gradients between individual pressure tappings was well within the experimental accuracy and points plotted in Figure 10 refer to the mean gradients over the entire pipeline.

4.452 <u>21 Inch Pipeline - November 1967 Test Results</u>: Results for the tests carried out in November 1967 on the 21 inch pipe line are given in Table 8. Within experimental accuracy, the friction gradients over the 13,257 foot length between gauges A and B (Figure 6) agreed with friction gradients over the 3,137 ft. length between gauges B and C. However, the gradient between gauges C and D (7418 ft.) was some 25 per cent higher. The reason for this high head loss was not known and it was decided to repeat the test run to try and isolate further the region of high head loss. Consequently, further gauges were located upstream, in the middle and downstream of the S-bend section in the pipeline (Gauges X, Y, Z, Figure 6) and the tests repeated.

4.453 21 <u>Inch Pipeline - February 1968, Test Results</u>: Results for the tests carried out in February 1968 are shown in Table 9. The measured gradients over the 19,618 ft. test section between gauges A and Y agree closely with the earlier test results. Within experimental error the friction gradients between the intermediate gauges A, B, C and Y were also consistent with the mean value, and the three gauges located at the S-bend showed nothing unusual, all showing close agreement with each other. Over the 3,694 ft. section Z-D (Figure 6) the friction gradient was some 40 per cent above the mean value and corresponds to an additional loss above friction of approximately 1.5 ft. The exact cause for this cannot be easily ascertained, but, as it is in a relatively straight section of the pipeline, it can only be the result of a partial blockage from air or some other obstruction, a faulty pressure gauge or an error in gauge datum at location D. For this reason, gradients over section Z-D have been excluded from the results.

Mean friction gradients (corrected to $60^{O}F$) for the pipeline are plotted in Figure 10.

5. Discussion of Test Results

5. 51 Comparison of Experimental Results with Flow Chart

The flow resistance chart (Figure 3) recommended by the manufacturers for new pipe is based on the exponential equation:-

$$Q = 2.80\ D^{2.65}\ H^{0.54}$$

where
Q = discharge g. p. m.
D = pipe dia. ins.
H = friction gradient ft/100 ft.

This relationship is plotted in Figure 10 where it can be directly compared with the experimental results. As it was not possible to measure pipe diameter directly, diameters used in the calculations were 19.92 and 14.30 inches which correspond to the size of the steel mandrils against which the pipe is formed during manufacture plus a small allowance for electrolytic expansion.

A random check of the diameters of 40 pipes at the factory gave mean diameters within 0.2 per cent of these values and maximum deviation from these diameters of less than 0.4 per cent.

Close agreement between the experimental and chart values was obtained. For the 21 inch (nominal) diameter line experimental head losses were 5 per cent higher than chart values. For the 15 inch (nominal) diameter line experimental head losses were 8 per cent higher than chart values.

The test results could be taken to indicate a small increase in roughness over that on which equation (1) is based. This could be the result of increased losses at joints due to pipe deflection during laying or the non-similarity in scaling up laboratory tests on 4 inch pipelines to larger diameter pipelines in the field. In the case of the 15 inch pipeline, which has been in service for 8 years, a small ageing factor may also be present. A small proportion of the increase (less than 1 per cent) can also be attributed to minor losses in the line which occurs at open stop valves, air valves and scour valves.

As the difference between experimental and chart values is only just outside the experimental accuracy (Appendix C) no firm conclusions can be drawn and modification to equation (1) would not be justified without undertaking a great deal of additional study. Meanwhile for design in water supply works, it may be desirable to increase head losses indicated by the flow charts by say 10 per cent to allow for ageing and unknown variations in the pipeline characteristics.

5.52 Equivalent Roughness

For the range of velocities and pipe sizes encountered in water supply schemes, friction losses obtained from equation (1) agree closely with that obtained by the more general Colebrook-White expression using an equivalent roughness of 0.00005 ft. If, as discussed in Section 5.51, an allowance of say 10 per cent in head loss is made for ageing and variation in pipe characteristics, the equivalent roughness should be increased to 0.00015 ft. These values can be used for the design of pipelines from charts based on the Colebrook-White equation such as the Moody, Rouse and Wallingford friction charts.

5.53 Hazen-Williams Coefficient

Despite its weaknesses, many design engineers continue to use the Hazen-Williams equation

$$V = 1.318\ CR^{0.63}\ S^{0.54}$$

The Hazen-Williams equation can be used satisfactorily for asbestos-cement pipelines provided it is recognized that the coefficient C varies with pipe diameter. Based on laboratory tests of Vallentine (1960) the variation of C with pipe diameter for water at 60°F in asbestos-cement pipelines is shown in Figure 2. Use of these values will give head losses in agreement with Equation 1 on which Hardie flow charts are based. The comparison between the experimental results described in this report and the above values is given in Table 10.

For the same reasons discussed in Section 5.51 no significant changes in the values of C as shown in Figure 2 can be justified. However, for conservative design practice it may be desirable to decrease the value of C as proposed by Vallentine (1960) to allow for any slight effects of ageing or variation in pipe characteristics. In the light of the tests undertaken at Warwick, use of a value of C in excess of 140 (or more precisely the values shown in Figure 2) should be satisfactory.

6. Comparison of Friction Loss in Asbestos-Cement Pipelines with that in other pipe materials

Surface roughness for various pipe materials for use in the Colebrook-White equation and charts based on this relationship have been listed by Ackers (1958) for good, normal or poor examples in their respective categories. These values are shown in Table 11.

As stated by Ackers (1958) this list is not intended to absolve the engineer of the responsibility for checking, by precise hydraulic tests whenever possible, the actual surface roughness achieved on particular projects. Where such direct evidence is available it should obviously take precedence over the general roughness values given in Table 11, which in practice may often be bettered but under adverse conditions may not be attained.

As roughness occurs within a logarithmic term in turbulent flow equations, the flow velocity is not sensitive to slight changes in the assumed values of k.

It is evident from Table 11 and the test results described in this report that asbestos-cement is one of the smoothest of the commercially available pipe materials. This is clearly illustrated in Figure 11 showing the head-discharge relationships for water at 60°F in a 12 inch diameter pipe of various pipe materials.

7. Conclusions

(i) Friction tests on a 21 inch class C pipe line, installed at Warwick, Queensland, in 1967, indicate that the head discharge relationship for new pipe can be closely approximated by the exponential equation proposed by Vallentine (1960)

$$Q = 2.80 \, D^{2.65} \, H^{0.54}$$

where Q = flow rate g.p.m.
D = pipe dia. ins.
H = friction gradient ft/100 ft.

This equation has been used for the preparation of the flow resistance chart recommended for use in the design of asbestos-cement pipelines by the manufacturers, James Hardie and Coy. Pty. Limited.

Observed friction losses in the 15 inch (installed in 1960) and 21 inch (installed in 1967) pipelines, were 8 and 5 per cent respectively higher than that indicated by the chart values. This may indicate a slight increase in roughness as a result of non-similarity between laboratory and field tests and/or small additional losses at joints from deflection during construction and/or pipe ageing. As the increase is only just outside of the experimental accuracy, no firm conclusion can be given.

(ii) The 15 inch pipeline has been in service for a period of 8 years. The test results indicate that any effect of ageing over this period is small.

(iii) The test results indicate that bends of large radius, minor misalignments and pipe displacements that occur during laying have only a small effect on friction loss.

(iv) The Darcy equation

$$H_L = f \frac{L}{D} \frac{V^2}{2g}$$

using the Colebrook-White relationship for f is generally accepted as the most accurate for predicting head-discharge relationships for commercial pipes.

For the range of velocities and pipe sizes encountered in water supply schemes friction losses obtained by the exponential formula

$$Q = 2.80\, D^{2.65}\, H^{0.54}$$

agree within 4 pc. of those obtained by the Colebrook-White expression using an equivalent sand grain roughness of 0.00005 ft.

(v) The Hazen-Williams equation can be used for asbestos-cement pipes provided it is recognized that the roughness coefficient is a function of the pipe diameter as indicated in Figure 2. The experimentally obtained coefficients were 144 and 149 for the 15 inch and 21 inch pipeline respectively which agree (within experimental accuracy) reasonably well with the values of 150 and 152 proposed by Vallentine (1960).

(vi) Surface roughness for various pipe materials is given in Table 11 whilst a comparison of the head-discharge relationship is shown in Figure 11. It is clear from these figures and test results at Warwick that asbestos-cement is one of the smoothest of the commercially available pipe materials.

8. Recommendations

(i) To allow for ageing and variations in the pipe characteristics during placing in the field, it is recommended that friction losses indicated by the Hardie Flow Resistance Chart be increased by say 10 per cent. This should give an adequate factor of safety for normal water supply design.

(ii) For estimating friction losses from charts based on the Colebrook-White equation, it is recommended that an equivalent sand grain roughness of k = 0.00015 feet be used. Use of this value will result in estimates of head loss approximately 10 per cent higher than those obtained from the Hardie Flow Resistance Chart.

(iii) The Hazen-Williams equation can be used satisfactorily for estimates of head-loss in asbestos-cement pipelines provided it is recognized that the roughness coefficient varies with diameter. To allow for an increase in head loss of 10 per cent over values indicated by the Hardie Flow Chart, it is recommended that the lower values of the coefficient C shown in Figure 2 be used for design purposes.

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References

Ackers, P. (1958) "Charts for the Hydraulic Design of Channels and Pipes" D.S.I.R., Hyd. Res.Station, Hydr. Res. Papers Nos. 1 and 2, 1958.

Colebrook, C. F. and White, C. M. (1937) "Experiments with Fluid Friction in Roughened Pipes" Proc. Roy. Soc. A., 1937, 161.

Vallentine, H. R. (1957) "Friction losses in Water Supply Calculations" Commonwealth Eng. May 1951.

Vallentine, H. R. (1960) "Chart for Flow Resistance of Asbestos Cement Pipelines" Aust. Civil Eng. and Constr. Feb. 1960.

Appendix "A"

Dimensions of Balance Tank

The circumference of the balance tank was measured at three elevations above the floor of the tank using an odometer. Results are shown in Table 12. The mean circumference was 69.2 ft. and the corresponding mean diameter 22.02 ft.

Table 12

Circumference of Balance Tank

Height above Floor ft.	Circumference ft.
2	69.0
2	68.8
2	69.2
5	69.7
5	69.0
5	69.6
8	69.0
8	68.7
8	70.0
Sum	623.0
Mean	69.2

Readings from the odometer were checked by taping three diameters at four elevations above the floor of the balance tank. Readings are shown in Table 13. The mean diameter was found to be 21.96 ft. which agrees within 0.3 pc. of that obtained by the odometer. A diameter of 22.00 ft. has been used for all calculations.

Appendix "A" cont'd.

Table 13

Diameter of Balance Tank

Height above Floor ft.	Diameter ft.
2	22.00
2	22.00
2	21.92
5	21.90
5	22.02
5	22.02
8	21.88
8	22.00
8	22.00
11	22.02
11	21.98
11	21.94
Sum	263.48
Mean	21.96

Appendix "B"

Dimensions of Bacon Hill Service Reservoir

The circumference of the service reservoir at the top elevation and approximately 3 feet below the top, was measured using an odometer. Readings were checked by taping three diameters at each elevation. Measurements are shown in Table 14.

Table 14

Service Reservoir Dimensions

Elevation below top of reservoir ft.	Circumference ft.	Diameter ft.
0	313.1	99.98
0	313.6	99.88
0	313.4	99.98
3	315.1	100.00
3	315.6	99.88
3	314.5	99.88
Sum	1885.3	599.60
Mean	314.2	99.93

The diameter obtained from the mean of the circumference measurements is 100.0 ft. which is within 0.1 pc. of that obtained by taping. For calculations the diameter has been taken as 99.95 ft.

Appendix "C"

Estimated Accuracy of Friction Gradient Measurements

Although every endeavour was made during the tests to keep the experimental accuracy as high as possible, some error in the results cannot be avoided. The largest errors are in the measurement of head using Bourdon pressure gauges and these will be reflected in the results for mean head loss and friction gradients over the test length.

Mean head loss over the pipe line was calculated from the relationship:-

$$H_L = (H_{S_2} - H_2) - (H_{S_1} - H_1)$$

where H_L = head loss between end gauges 1 and 2 at start and finish of test section

H_S = static head at gauge as obtained by closed survey level traverse

H = pressure head at gauge as obtained from readings on Bourdon pressure gauges.

If ε_A, ε_B, ε_C and ε_D, are the errors associated with readings of H_{S_1}, H_{S_2}, H_1 and H_2 respectively then the error ε_H in total head loss is given by the relationship:-

$$\varepsilon_H = \sqrt{\varepsilon_A^2 + \varepsilon_B^2 + \varepsilon_C^2 + \varepsilon_D^2}$$

Static heads were obtained by closed survey traverse between established bench marks and the magnitudes of ε_A and ε_B are estimated at $\pm$ 0.05 ft.

For the 15 inch pipeline the end gauges had pressure ranges of 0-50 ft. and 0-200 ft. Estimated errors (ε_C and ε_D) are $\pm$ 0.4 ft. and $\pm$ 0.6 ft. respectively. It should be noted that these are higher than errors in calibration (Figure 9) and make an arbitary allowance for unknown errors in pressure tappings etc.

For the 21 inch pipeline the end gauges had pressure ranges of 0-50 ft. and 0-250 ft. Estimated errors (ε_C and ε_D) are $\pm$ 0.4 ft. and $\pm$ 0.7 ft. respectively.

Errors in head loss measurements over the test section are therefore estimated at $\pm$ 0.73 ft. for the 15 inch pipeline and $\pm$ 0.81 ft. for the 21 inch pipeline.

The percentage error in head loss depends on the magnitude of total loss. It will be highest at the lowest flow rate when head drop through the pipeline is a minimum and will decrease as the flow rate and head loss are increased. From Tables 7, 8 and 9 the head loss over the test sections at maximum flow was 36.50 ft. for the 15 inch pipeline and 27.12 ft. for the 21 inch pipelines. The corresponding percentage errors at maximum flow are therefore estimated at 2 per cent for the 15 inch line and 3 per cent for the 21 inch line.

The friction gradient is obtained by dividing the total head loss (H) over the test section by the measured test length (L). If ε_H and ε_L are the errors in head loss and length respectively the percentage error in the friction gradient, ε pc. is given by the relationship:-

$$\varepsilon \text{ pc.} = \sqrt{\left(\frac{\varepsilon H}{H}\right)^2 + \left(\frac{\varepsilon L}{L}\right)^2}$$

The lengths of the test sections were obtained by survey chaining, the percentage error ($\frac{\varepsilon L}{L}$) of which is estimated at $\pm$ 1 pc. The percentage errors in head loss ($\frac{\varepsilon H}{H}$) are given above and the percentage accuracy of the results for friction gradients at the maximum flow rates are therefore estimated at about 3 per cent.

Experimental errors increase in inverse proportion to the gradient as the flow rate, and measured head differences between gauges, become less. In assessing the results and drawing conclusions, greater weight has been given to the results at the higher flow rates.

Table 1

Calibration "KU" Kent Flow Meter 0-3000 g. p. m. Test Results

Time after start of test	Water level drop in balance tank - ft.			Flow readings Kent flow meter - g. p. m.		
	Test 1	Test 2	Test 3	Test 1	Test 2	Test 3
0	0.000	0.000	0.000	920	1940	2910
1	0.385	0.815	1.225	920	1940	2900
2	0.765	1.615	2.425	920	1930	2875
3	1.145	2.415	3.610	915	1920	2850
4	1.530	3.215	4.795	910	1910	2830
5	1.910	4.010	5.970	910	1905	2815
6	2.290	4.800	7.120	910	1895	2790
7	2.665	5.585	8.280	910	1880	2770
8	3.045	6.370	9.430	905	1870	2740
9	3.420	7.140		900	1860	
10	3.800	7.915		900	1850	
11	4.170			900		
12	4.545			900		
13	4.915			900		
14	5.285			895		
15	5.645			895		
16	6.020			890		
17	6.390			890		
18	6.755			890		
19	7.120			890		
20	7.490			890		

Table 2

Calibration of "Kent KU" 0-3000 gpm Flow Meter - 21 inch Pipe-line

Item	Test Number		
	1	2	3
1. Duration - mins.	20	10	8
2. Ht. change in balance tank - ft.	7.490	7.915	9.430
3. Volume change in balance tank - $ft.^3$	2847	3008	3584
4. Mean discharge - c.f.s.	2.37	5.01	7.47
5. Mean discharge - g.p.m.	888	1876	2797
6. Indicated mean discharge - g.p.m.	905	1900	2840
7. Correction factor	0.981	0.988	0.985

Table 3

Calibration of Orifice Meter 15 inch Line - Test Results

Test 1				Test 2			
Time after start of test secs.	Rise in water level in reser-foir ft.	Diff. head orifice meter ft.	Kent flow meter rdg. gpm	Time after start of test secs	Rise in water level in reser-voir ft.	Diff. head orifice meter ft.	Kent flow-meter rdg. gpm
0	0	1.81	1370	0	0	0.90	980
963	0.460	1.81	1370	1807	0.575	0.90	980
1984	0.935	1.81	1370	3667	1.220	0.90	980
3838	1.810	1.81	1370	5400	1.780	0.90	980
5770	2.730	1.81	1370	7200	2.380	0.90	980
6810	3.195	1.82	1370	9014	2.985	0.90	980
				10773	3.555	0.90	980

Table 4

Orifice Meter Coefficients 15" Pipe Line

Item	Test No. 1	Test No. 2
1. Water level rise - ft.	3.195	3.555
2. Duration - secs.	6,810	10,773
3. Volume change - $ft.^3$	25,100	27,900
4. Discharge - gpm	1,379	970
5. Head difference on manometer - ft.	1.81	0.90
6. Orifice coeff. K $Q = K\sqrt{\Delta H}$	1025	1023

Table 5.

Pressure Gauge Chainages and Locations

21" Dia. Pipeline				15" Dia. Pipeline		
Location	Chainage	Gauge No. Nov. 1967 test	Gauge No. Feb. 1968 test	Location	Chain-age	Gauge No. Nov. 1967 test
Balance tank outlet	0			Booster Pump	0	
A	333	4	1			
B	13590	3	3	E	3430.5	2
C	16727	2	2	F	10796.0	3
X	19451	-	102	G	15778.0	4
Y	19951	-	101	H	1988.5	1
Z	20451	-	100			
D	24145	5	5	Inlet to res-ervoir	19971.5	
Inlet to res-ervoir	24300					

Table 6

Static Levels at Pressure Gauges

15 inch Pipeline - November 1967.

Gauge Location	Static Head-Pressure Gauge Readings				Survey Traverse	
	Gauge Rdg.	Gauge Corr.	Location Corr.	Corr. Rdg.	RL. at pressure Tapping	Static Head(1)
E	157.8	-3.9	-0.02	153.88	1606.22	153.78
F	139.1	+1.65	-0.05	140.70	1619.44	140.56
G	92.2	+0.9	-0.11	92.99	1666.82	93.18
H	93.7	+0.9	-0.28	94.32	1664.93	95.07

(1) Static Head is based on an assumed water level at RL. 1760.

21 inch Pipeline- November 1967

Gauge Location	Static Head-Pressure Gauge Readings			Survey Traverse	
	Gauge Rdg.	Gauge Corr.	Corr. Reading	RL. at Pressure Gauge	Static Head(2)
A	30.1	-0.05	30.05	1739.79	30.21
B	141.5	+1.7	143.2	1626.66	143.34
C	161.5	-3.9	157.6	1611.72	158.28
D	92.1	+1.3	93.4	1676.29	93.71

(2) Static head is based on an assumed water level at RL. 1770.

21 inch Pipeline - February 1968

Gauge Location	Static Head-Pressure Gauge Readings			Survey Traverse	
	Gauge Rdg.	Gauge Corr.	Corr. Reading	RL. at Pressure Gauge	Static Head(3)
A	28.9	+0.2	29.1	1739.79	30.21
B	141.5	+1.7	143.2	1626.66	143.34
C	161.7	-3.9	157.8	1611.72	158.28
X	224.0	-3.4	220.6	1549.28	220.72
Y	225.7	-0.7	225.0	1545.45	224.55
Z	223.5	+0.9	224.4	1546.11	223.89
D	92.0	+1.3	93.3	1676.29	93.71

(3) Static head is based on an assumed water level at RL. 1770

Orifice Meter					Gauge Readings														
High Pressure Reading	Low Pressure Reading	ΔP	Discharge	Gauge Location	Chainage	Gauge No.	Gauge Reading	Gauge Correction	Location Correction	Correction Reading	Static Head at Gauge	Head Drop at Gauge	Head Loss between Gauges	Distance	Friction Gradient per 100 ft.	Total Head Drop	Total Distance	Mean Friction Gradient over Pipeline	Water Temperature °F
ft.	ft.	ft.	g.p.m.		ft.		ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft./100ft.	ft.	ft.	ft./100ft.	
5·92	5·01	0·91	976	E	3430·5	2	108·1	−4·2	−0·02	103·88	153·78	49·90	8·06	7365·5	0·109	18·25	16455	0·111	68
				F	10796	3	81·8	+0·85	−0·05	82·60	140·56	57·96	5·68	4982·0	0·114				
				G	15778	4	29·7	−0·05	−0·11	29·54	93·18	63·64	4·51	4107·5	0·110				
				H	19885·5	1	27·0	+0·2	−0·28	26·92	95·07	68·15							
5·02	4·60	0·42	654	E	3430·5	2	94·5	−4·0	−0·02	90·48	153·78	63·30	3·91	7365·5	0·053	9·15	16455	0·056	68
				F	10796	3	72·7	+0·7	−0·05	73·35	140·56	67·21	2·98	4982·0	0·060				
				G	15778	4	23·25	−0·15	−0·11	22·99	93·18	70·19	2·26	4107·5	0·055				
				H	19885·5	1	22·7	+0·2	−0·28	22·62	95·07	72·45							
4·66	4·49	0·17	422	E	3430·5	2	87·9	−3·7	−0·02	84·18	153·78	69·60	1·91	7365·5	0·026	4·25	16455	0·026	68
				F	10796	3	68·4	+0·7	−0·05	69·05	140·56	71·51	1·18	4982·0	0·024				
				G	15778	4	20·75	−0·15	−0·11	20·49	93·18	72·69	1·16	4107·5	0·028				
				H	19885·5	1	21·3	+0·2	−0·28	21·22	95·07	73·85							
5·355	4·765	0·59	786	E	3430·5	2	99·1	−3·95	−0·02	95·13	153·78	58·65	5·56	7365·5	0·075	12·40	16455	0·075	68
				F	10796	3	75·7	+0·7	−0·05	76·35	140·56	64·21	3·48	4982·0	0·070				
				G	15778	4	25·75	−0·15	−0·11	25·49	93·18	67·69	3·36	4107·5	0·082				
				H	19885·5	1	24·1	+0·2	−0·28	24·02	95·07	71·05							
4·78	4·51	0·27	532	E	3430·5	2	90·4	−3·65	−0·02	86·73	153·78	67·05	2·86	7365·5	0·039	6·40	16455	0·039	68
				F	10796	3	70·0	+0·7	−0·05	70·65	140·56	69·91	1·78	4982·0	0·036				
				G	15778	4	21·75	−0·15	−0·11	21·49	93·18	71·69	1·76	4107·5	0·043				
				H	19885·5	1	21·7	+0·2	−0·28	21·62	95·07	73·45							
7·61	5·71	1·90	1411	E	3430·5	2	134·6	−4·0	−0·02	130·58	153·78	23·2	16·36	7365·5	0·220	36·50	16455	0·220	68
				F	10796	3	100·0	+1·05	−0·05	101·00	140·56	39·56	10·98	4982·0	0·220				
				G	15778	4	42·8	−0·05	−0·11	42·64	93·18	50·54	9·16	4107·5	0·226				
				H	19885·5	1	35·5	+0·15	−0·28	35·37	95·07	59·70							
6·93	5·46	1·47	1243	E	3430·5	2	122·8	−3·9	−0·02	118·88	153·78	34·90	12·81	7365·5	0·174	28·45	16455	0·173	68
				F	10796	3	91·9	+1·0	−0·05	92·85	140·56	47·71	8·53	4982·0	0·171				
				G	15778	4	37·1	−0·05	−0·11	36·94	93·18	56·24	7·11	4107·5	0·173				
				H	19885·5	1	31·8	+0·2	−0·28	31·72	95·07	63·35							
6·32	5·22	1·10	1074	E	3430·5	2	113·0	−4·0	−0·02	108·98	153·78	44·80	9·71	7365·5	0·132	21·75	16455	0·132	68
				F	10796	3	85·2	+0·9	−0·05	86·05	140·56	54·51	6·23	4982·0	0·125				
				G	15778	4	32·6	−0·05	−0·11	32·44	93·18	60·74	5·81	4107·5	0·141				
				H	19885·5	1	28·6	+0·2	−0·28	28·52	95·07	66·55							
		0·90	973	E	3430·5	2	107·5	−4·1	−0·02	103·38	153·78	50·40	8·01	7365·5	0·109	18·00	16455	0·109	68
				F	10796	3	81·0	+1·2	−0·05	82·15	140·56	58·41	5·23	4982·0	0·105				
				G	15778	4	29·7	−0·05	−0·11	29·54	93·18	63·64	4·76	4107·5	0·116				
				H	19885·5	1	26·75	+0·2	−0·28	26·67	95·07	68·40							

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Table 7
Pipe Friction Test Results - 15" Class "C"
A. C. Pipes

Discharge			Gauge Location	Gauge Readings					Static Head at Gauge	Head Drop at Gauge	Head Loss between Gauges	Distance	Friction Gradient per 100 ft.	Head Drop between Gauges Nos. 4 and 2	Total Distance	Friction Gradient over Pipeline between Gauges No. 4 and 2.	Water Temperature °F.
Flow Meter Rdg.	Correction Factor	Discharge		Chainage	Gauge Number	Gauge Reading	Gauge Correction	Correction Reading									
g.p.m.		g.p.m.		ft.		ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft/100 ft.	ft.	ft.	ft/100 ft.	
1940	0·985	1911	A	333	4	29·8	−0·1	29·70	30·21	0·51	10·43	13257	0·079	12·57	16394	0·077	70
			B	13590	3	131·0	+1·4	132·40	143·34	10·94	2·14	3137	0·068				
			C	16727	2	149·0	−3·8	145·20	158·28	13·08	7·38	7418	0·100				
			D	24145	5	72·0	+1·25	73·25	93·71	20·46							
1450	0·985	1428	A	333	4	30·1	−0·1	30·00	30·21	0·21	6·23	13257	0·047	7·37	16394	0·045	70
			B	13590	3	135·5	+1·4	136·90	143·34	6·44	1·14	3137	0·036				
			C	16727	2	154·5	−3·8	150·70	158·28	7·58	4·58	7418	0·062				
			D	24145	5	80·3	+1·25	81·55	93·71	12·16							
2590	0·985	2551	A	333	4	29·5	−0·1	29·40	30·21	0·81	17·68	13257	0·133	21·37	16394	0·130	70
			B	13590	3	123·5	+1·35	124·85	143·34	18·49	3·69	3137	0·118				
			C	16727	2	140·0	−3·9	136·10	158·28	22·18	12·03	7418	0·162				
			D	24145	5	58·5	+1·0	59·50	93·71	34·21							
2950	0·985	2906	A	333	4	29·2	−0·1	29·10	30·21	1·11	22·43	13257	0·169	27·12	16394	0·165	70
			B	13590	3	118·5	+1·3	119·80	143·34	23·54	4·69	3137	0·150				
			C	16727	2	134·0	−3·95	130·05	158·28	28·23	14·48	7418	0·195				
			D	24145	5	50·0	+1·0	51·00	93·71	42·71							
2300	0·985	2266	A	333	4	29·7	−0·1	29·60	30·21	0·61	13·83	13257	0·104	16·87	16394	0·103	70
			B	13590	3	127·5	+1·4	128·90	143·34	14·44	3·04	3137	0·097				
			C	16727	2	144·6	−3·8	140·80	158·28	17·48	9·73	7418	0·131				
			D	24145	5	65·5	+1·0	66·50	93·71	27·21							
1800	0·985	1773	A	333	4	29·9	−0·1	29·80	30·21	0·41	9·03	13257	0·068	10·87	16394	0·066	70
			B	13590	3	132·5	+1·4	133·90	143·34	9·44	1·84	3137	0·059				
			C	16727	2	150·8	−3·8	147·00	158·28	11·28	6·13	7418	0·083				
			D	24145	5	75·0	+1·3	76·30	93·71	17·41							
1250	0·985	1231	A	333	4	30·2	−0·1	30·10	30·21	0·11	4·83	13257	0·036	Obvious Error in Reading			70
			B	13590	3	137·0	+1·4	138·40	143·34	4·94	~~9·06~~	~~3137~~	~~0·289~~				
			C	~~16727~~	~~2~~	~~166·2~~	~~−3·8~~	~~162·40~~	~~158·28~~	~~4·12~~	4·07	10555	0·039				
			D	24145	5	83·4	+1·3	84·70	93·71	9·01							

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Table 8

Pipe Friction Test Results - 21" Class "C" A. C. Pipes, Nov. 1967.

Discharge			Gauge Location	Gauge Readings					Static Head at Gauge	Head Drop at Gauge		Head Loss between Gauges	Distance	Friction Gradient per 100 ft.	Total Head Drop 60 - 6101	Total Distance	Mean Friction Gradient over Pipeline Gauges 1-101	Water Temperature °F
Flow Meter Rdg.	Correction Factor	Discharge		Chainage	Gauge Number	Gauge Reading	Gauge Correction	Correction Reading		Reading	Mean							
g.p.m.		g.p.m.		ft.		ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft.	ft/100 ft.	ft.	ft.	ft/100 ft.	
			A	333	1	30·3	+0·2	30·50	30·21	−0·29	−0·29	4·53	13257	0·034				
			B	13590	3	137·5	+1·6	139·10	143·34	4·24	4·24	0·84	3137	0·027				
			C	16727	2	157·1	−3·9	153·20	158·28	5·08	5·08	0·44	3224	0·014	5·81	19618	0·030	75
1230	0·985	1210	X	19451	102	218·0	−3·0	215·00	220·72	5·72								
			Y	19951	101	219·5	−0·5	219·00	224·55	5·55	5·52							
			Z	20451	100	217·5	+1·1	218·60	223·89	5·29		2·69	4194	0·064	Gauge Disregarded in Taking Mean			
			D	24145	5	84·2	+1·3	85·50	93·71	8·21	8·21							
			A	333	1	30·2	+0·2	30·40	30·21	−0·19	−0·19	6·83	13257	0·052				
			B	13590	3	135·3	+1·4	136·70	143·34	6·64	6·64	1·24	3137	0·040				
			C	16727	2	154·2	−3·8	150·40	158·28	7·88	7·88				9·31	19618	0·047	75
1520	0·985	1500	X	19451	102	214·5	−2·9	211·60	220·72	9·12		1·24	3224	0·038				
			Y	19951	101	216·0	−0·6	215·40	224·55	9·15	9·12							
			Z	20451	100	213·5	+1·3	214·80	223·89	9·09		3·29	4194	0·078	Gauge Disregarded in Taking Mean			
			D	24145	5	80·1	+1·2	81·30	93·71	12·41	12·41							
			A	333	1	29·9	+0·2	30·10	30·21	0·11	0·11	9·13	13257	0·069				
			B	13590	3	132·7	+1·4	134·10	143·34	9·24	9·24	1·74	3137	0·055				
			C	16727	2	151·1	−3·8	147·30	157·28	10·98	10·98				12·61	19618	0·064	75
1790	0·985	1760	X	19451	102	211·0	−2·6	208·40	220·72	12·32		1·74	3224	0·054				
			Y	19951	101	212·5	−0·8	211·70	224·55	12·85	12·72							
			Z	20451	100	209·5	+1·4	210·90	223·89	12·99		4·09	4194	0·097	Gauge Disregarded in Taking Mean			
			D	24145	5	75·6	+1·3	76·90	93·71	16·81	16·81							
			A	333	1	29·6	+0·2	29·80	30·21	0·41	0·41	10·63	13257	0·080				
			B	13590	3	130·9	+1·4	132·30	143·34	11·04	11·04	2·64	3137	0·084				
			C	16727	2	148·4	−3·8	144·60	158·28	13·68	13·68				15·34	19618	0·078	75
1990	0·985	1960	X	19451	102	207·5	−2·5	205·00	220·72	15·72		2·07	3224	0·064				
			Y	19951	101	209·5	−0·6	208·90	224·55	15·65	15·75							
			Z	20451	100	206·5	+1·5	208·00	223·89	15·89		5·06	4194	0·121	Gauge Disregarded in Taking Mean			
			D	24145	5	71·7	+1·2	72·90	93·71	20·81	20·81							
			A	333	1	29·4	+0·2	29·60	30·21	0·61	0·61	13·53	13257	0·102				
			B	13590	3	127·8	+1·4	129·20	143·34	14·14	14·14	3·24	3137	0·103				
			C	16727	2	144·7	−3·8	140·90	158·28	17·38	17·38				20·14	19618	0·103	75
2270	0·985	2240	X	19451	102	203·0	−2·5	200·50	220·72	20·22		3·37	3224	0·104				
			Y	19951	101	204·0	−0·5	203·50	224·55	21·05	20·75							
			Z	20451	100	201·0	+1·9	202·90	223·89	20·99		5·46	4194	0·130	Gauge Disregarded in Taking Mean			
			D	24145	5	66·5	+1·0	67·50	93·71	26·21	26·21							
			A	333	1	29·1	+0·2	29·30	30·21	0·91	0·91	16·63	13257	0·125				
			B	13590	3	124·4	+1·4	125·80	143·34	17·54	17·54	3·94	3137	0·126				
			C	16727	2	140·7	−3·9	136·80	158·28	21·48	21·48				24·68	19618	0·126	75
2530	0·985	2490	X	19451	102	198·5	−2·6	195·90	220·72	24·82		4·01	3224	0·124				
			Y	19951	101	199·0	−0·4	198·60	224·55	25·95	25·59							
			Z	20451	100	196·0	+1·9	197·90	223·89	25·99		6·52	4194	0·155	Gauge Disregarded in Taking Mean			
			D	24145	5	60·6	+1·0	61·60	93·71	32·11	32·11							
			A	333	1	28·7	+0·2	28·90	30·21	1·31	1·31	19·13	13257	0·144				
			B	13590	3	121·6	+1·3	122·90	143·34	20·44	20·44	4·24	3137	0·135				
			C	16727	2	137·5	−3·9	133·60	158·28	24·68	24·68				27·88	19618	0·142	75
2725	0·985	2680	X	19451	102	194·5	−2·6	191·90	220·72	28·82		4·51	3224	0·140				
			Y	19951	101	196·0	−0·8	195·20	224·55	29·35	29·19							
			Z	20451	100	192·5	+2·0	194·50	223·89	29·39		7·02	4194	0·167	Gauge Disregarded in Taking Mean			
			D	24145	5	56·5	+1·0	57·50	93·71	36·21	36·21							
			A	333	1	28·2	+0·2	28·40	30·21	1·81	1·81	22·63	13257	0·171				
			B	13590	3	117·6	+1·3	118·90	143·34	24·44	24·44	5·54	3137	0·177				
			C	16727	2	132·3	−4·0	128·30	158·28	29·98	29·98				33·01	19618	0·168	75
3000	0·985	2950	X	19451	102	189·5	−2·5	187·00	220·72	33·72		4·84	3224	0·150				
			Y	19951	101	190·5	−1·0	189·50	224·55	35·05	34·82							
			Z	20451	100	186·5	+1·7	188·20	223·89	35·69		8·39	4194	0·200	Gauge Disregarded in Taking Mean			
			D	24145	5	49·5	+1·0	50·50	23·70	43·21	43·21							

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Table 9.

Pipe Friction Test Results - 21" Class "C" A. C. Pipes, February 1968.

Table 10

Comparison of Hazen-Williams Coefficients

Pipe Diameter	Hazen-Williams Coefficient after Vallentine (1960)	Warwick Experimental Values
15" Class C	150	144
21" Class C	152	149

Classification	Suitable design chart values of k (ft.)		
	Good	Normal	Poor
Smooth			
Drawn non-ferrous pipes of aluminium, brass, copper, lead, etc. and non-metallic pipes of Alkathene glass, Saran, etc.	-	0.00001	-
Asbestos Cement	-	0.00005	
Metal			
Spun bitumen lined	-	0.0001	-
Spun concrete lined	-	0.0001	-
Uncoated steel	0.00005	0.0001	0.0002
Coated steel	0.0001	0.0002	0.0005
Galvanised iron	0.0002	0.0005	0.001
Coated cast-iron	0.0002	0.0005	0.001
Uncoated cast-iron	0.0005	0.001	0.002
Old turberculated water mains with the following degrees of attack:			
Slight	0.002	0.005	0.01
Moderate	0.005	0.01	0.02
Appreciable	0.02	0.05	0.1
Severe	0.05	0.1	0.2
(Good - up to 20 years' use; normal: - 40-50 years' use; poor: 80-100 years' use)			
Concrete (as classified by Scobey)			
Class 4. Monolithic construction against oiled steel forms with no surface irregularities, precast pipe lines with no shoulders or depressions at the joints.	0.0002	0.0005	-
Class 3. Monolithic construction against steel forms, wet-mix or spun precast pipes, or with cement or asphalt coating.	0.001	0.002	0.005
Class 2. Monolithic construction against rough forms, rough texture precast pipes, or cement gun surface.	0.002	0.005	-
Class 1. Precast pipes with mortar squeeze at joints	-	0.01	0.02
Smooth trowelled surfaces	0.001	0.002	0.005
Clayware etc.			
Glazed sewer pipe	0.001	0.002	0.005
Butt jointed drain tile	0.002	0.005	0.01

Table 11: Recommended Values of k in feet
(after Ackers 1958)

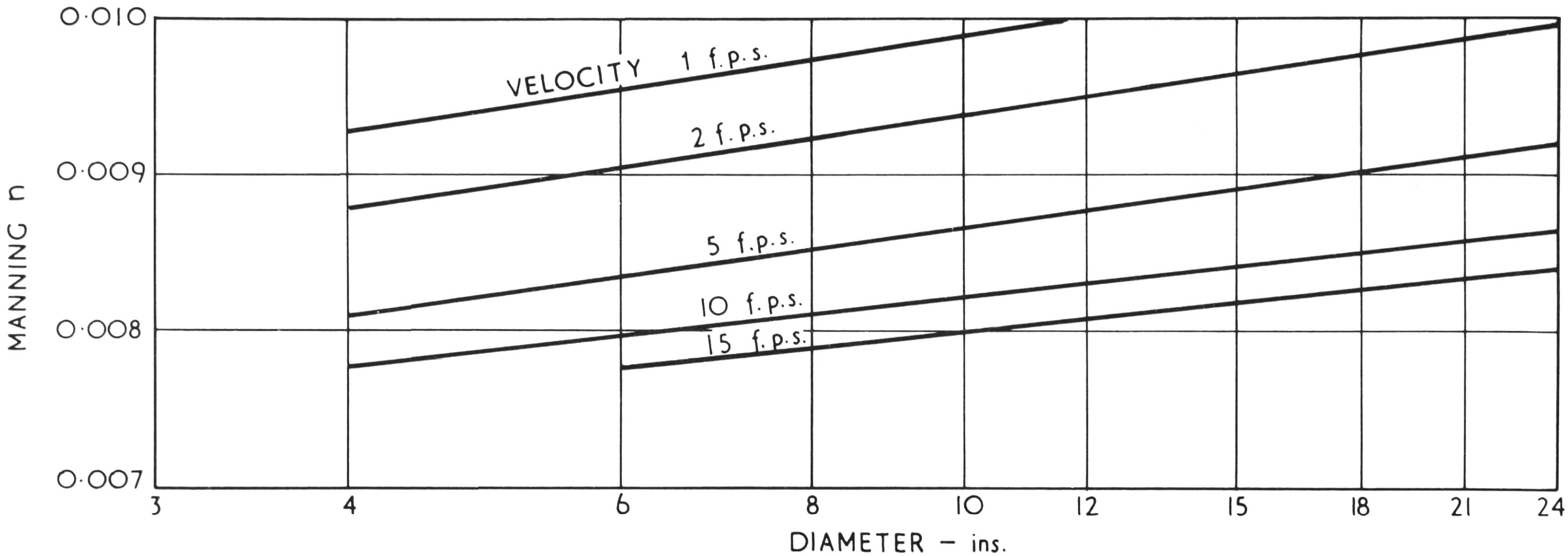


Figure 1: Fibrolite Pipes - Variation of Manning Rouchness, n, with Pipe Size and Flow Velocity.

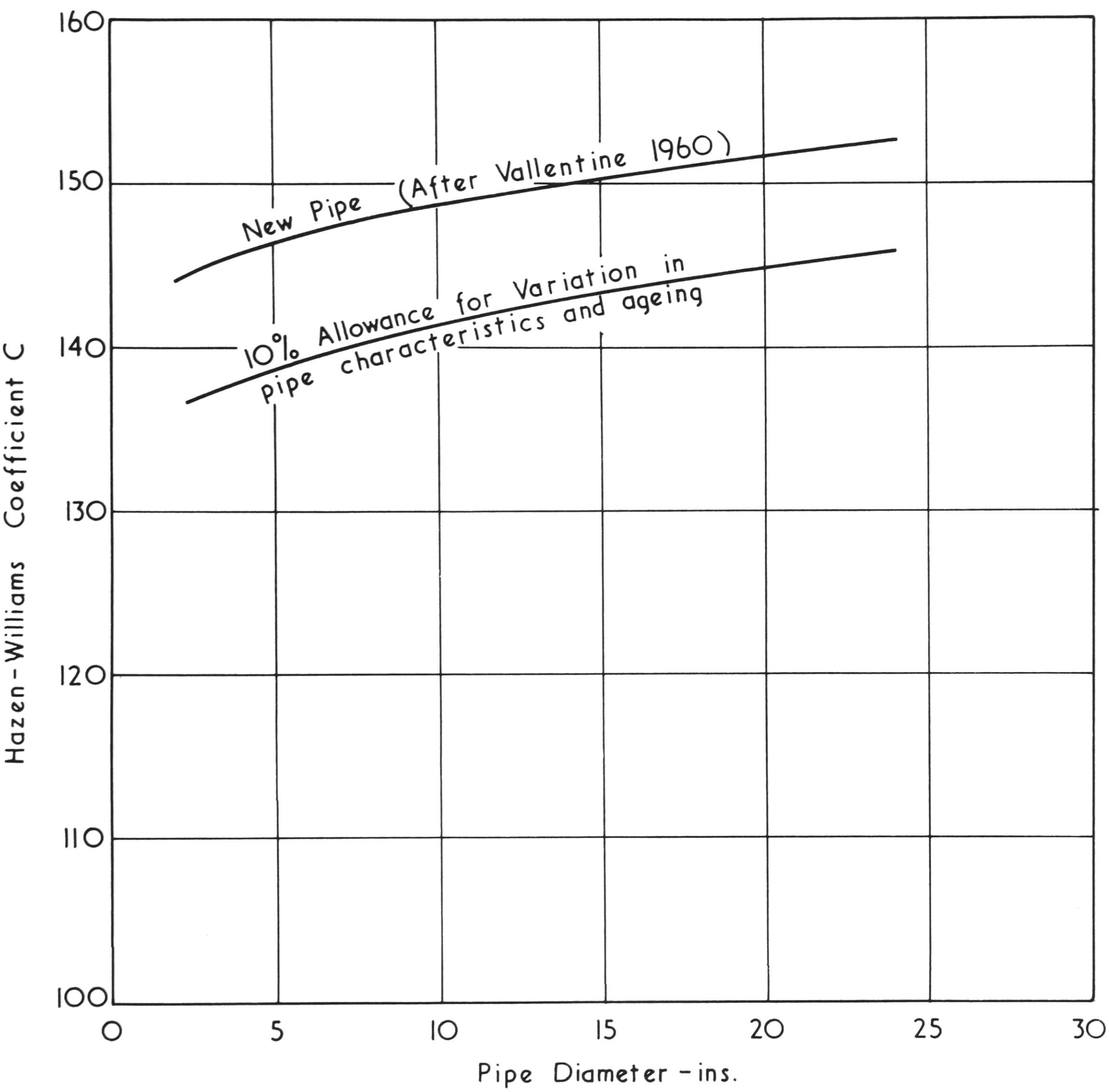


Figure 2: Variation of Hazen-Williams C in A. C. Pipes for Water at 60°F.

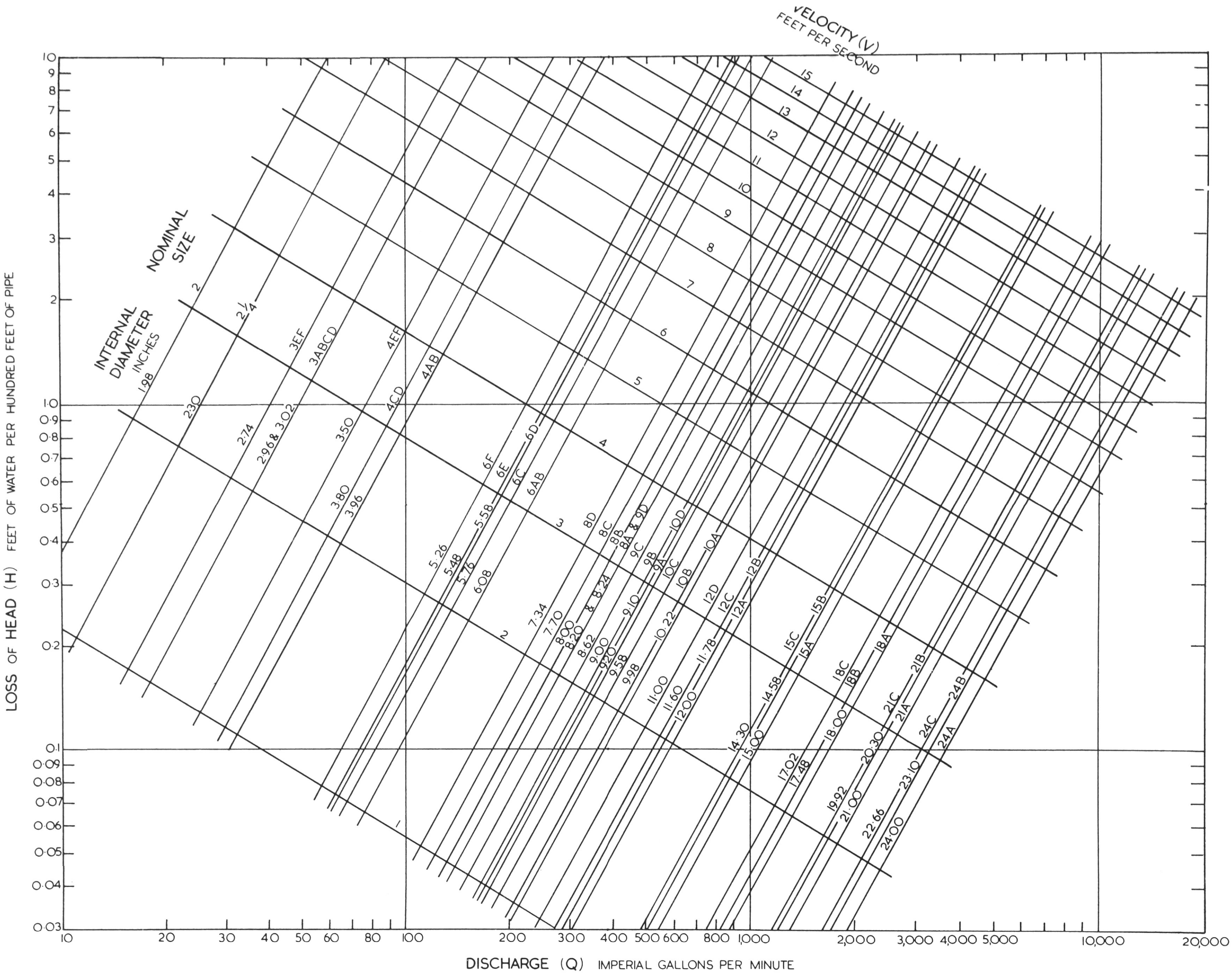


Figure 3: Fibrolite Pipes - Flow Resistance Chart
for Water at 60°F.

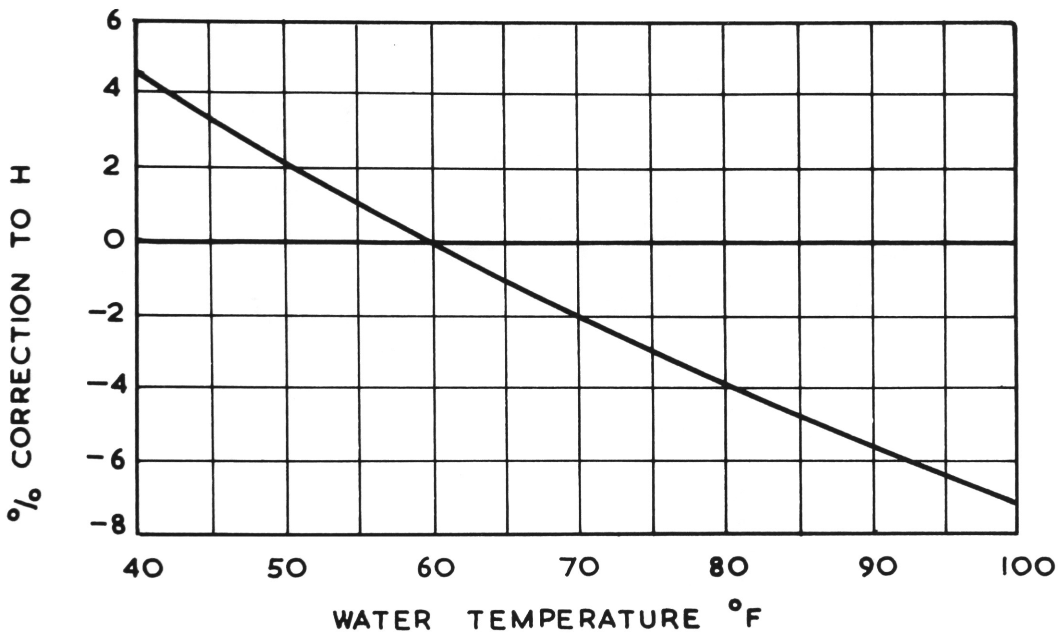


Figure 4: Correction for Temperature to be Applied to the Head Loss H calculated by the Formula $Q = 2.80D^{2.65} H^{0.54}$.

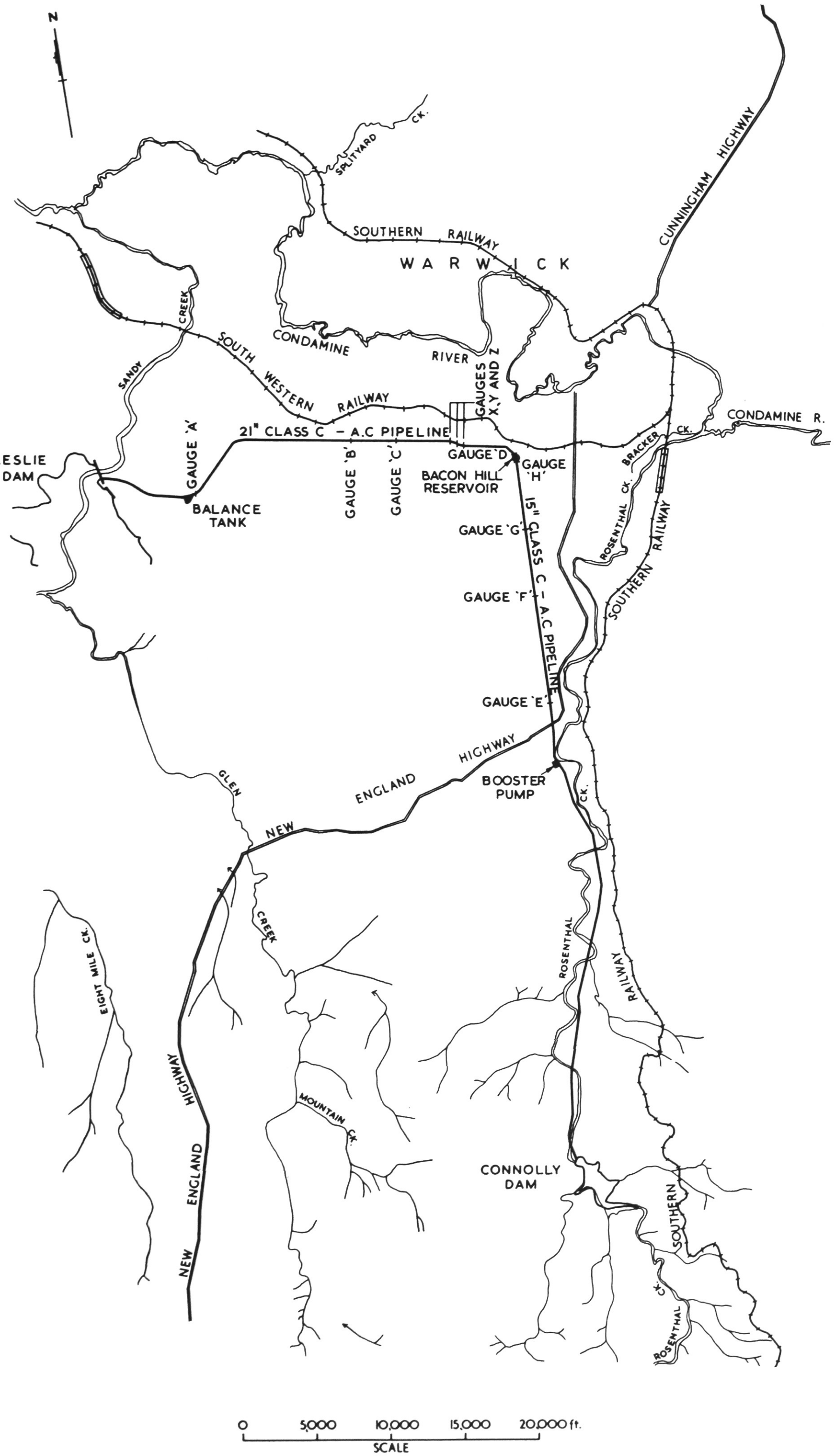


Figure 5: Warwick Pipe Friction Tests
Locality Plan.

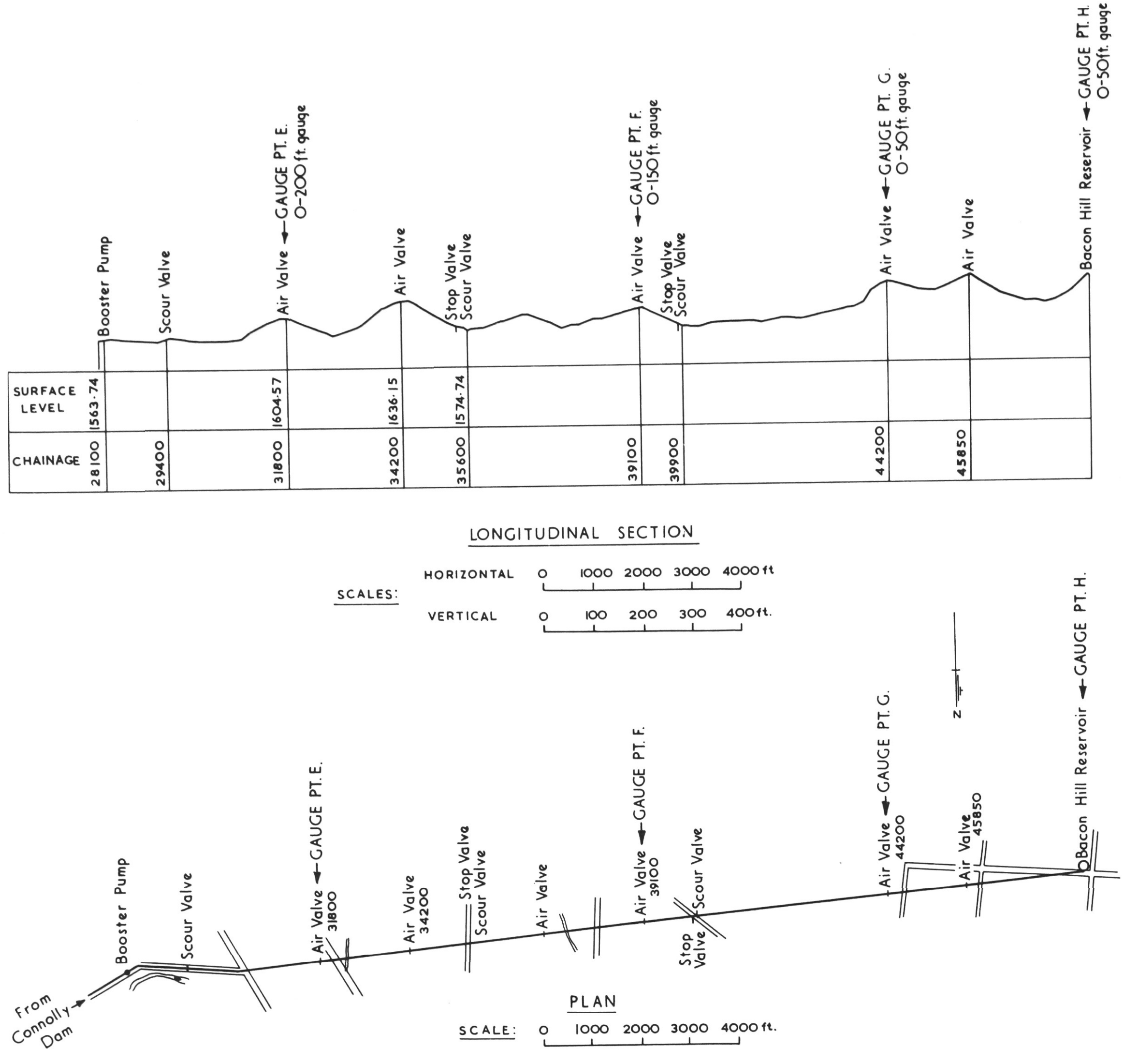


Figure 6: Warwick Pipe Friction Tests - Pipe Details - 15" Pipeline.

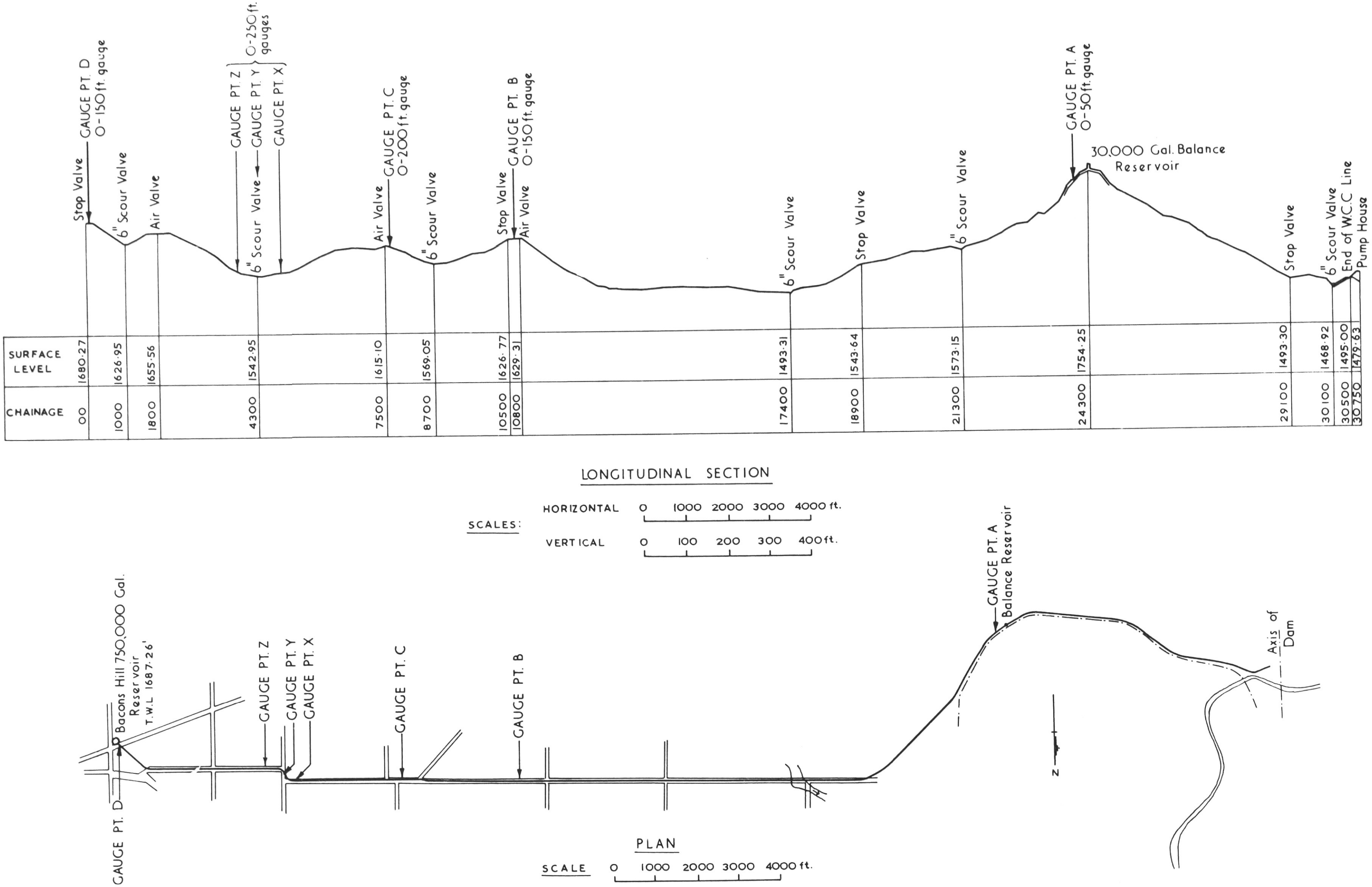


Figure 7: Warwick Pipe Friction Tests - Pipe Details
21'' Pipeline.

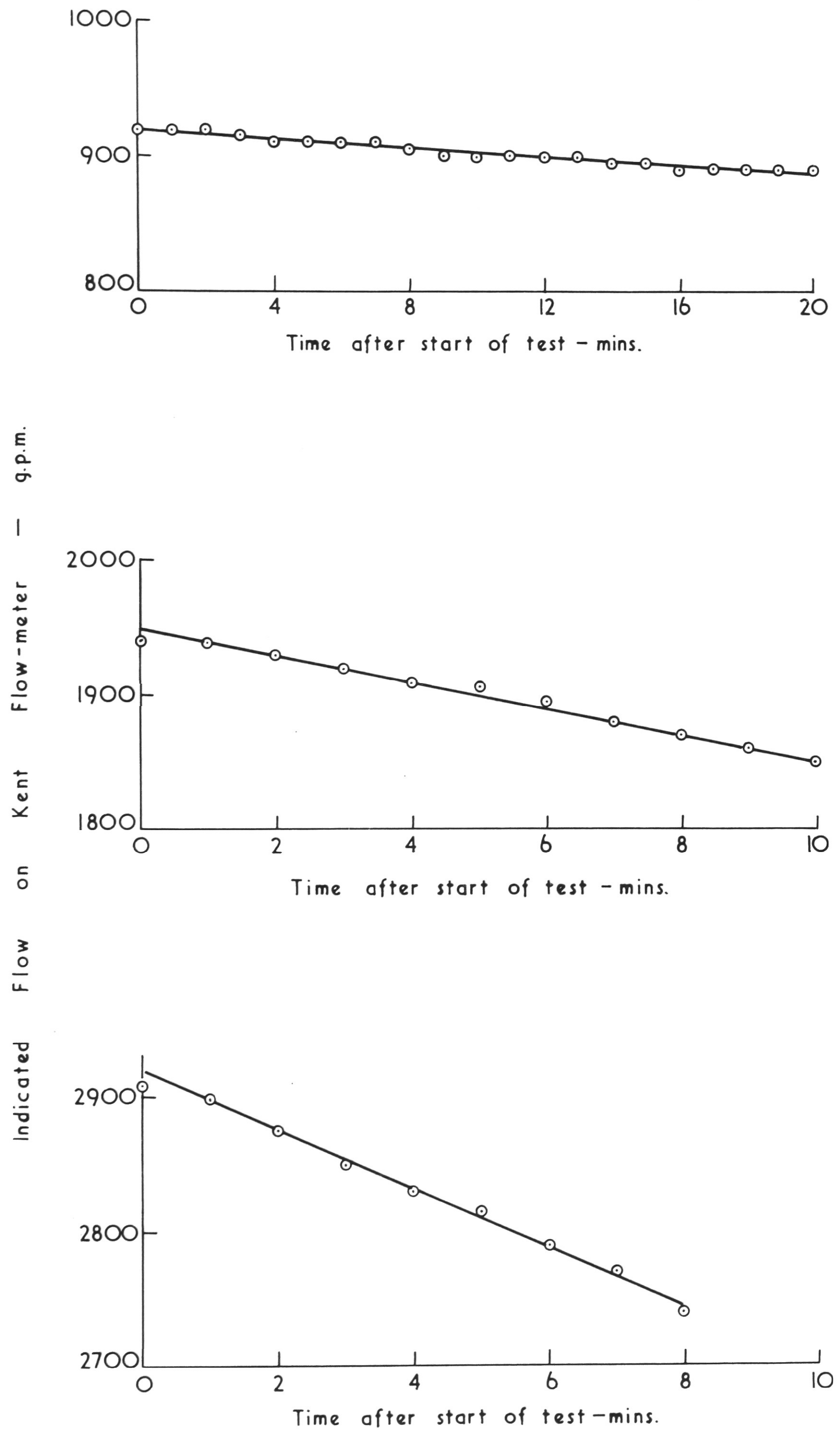


Figure 8: Calibration Test - 21" Flowmeter
Variation of Discharge with time.

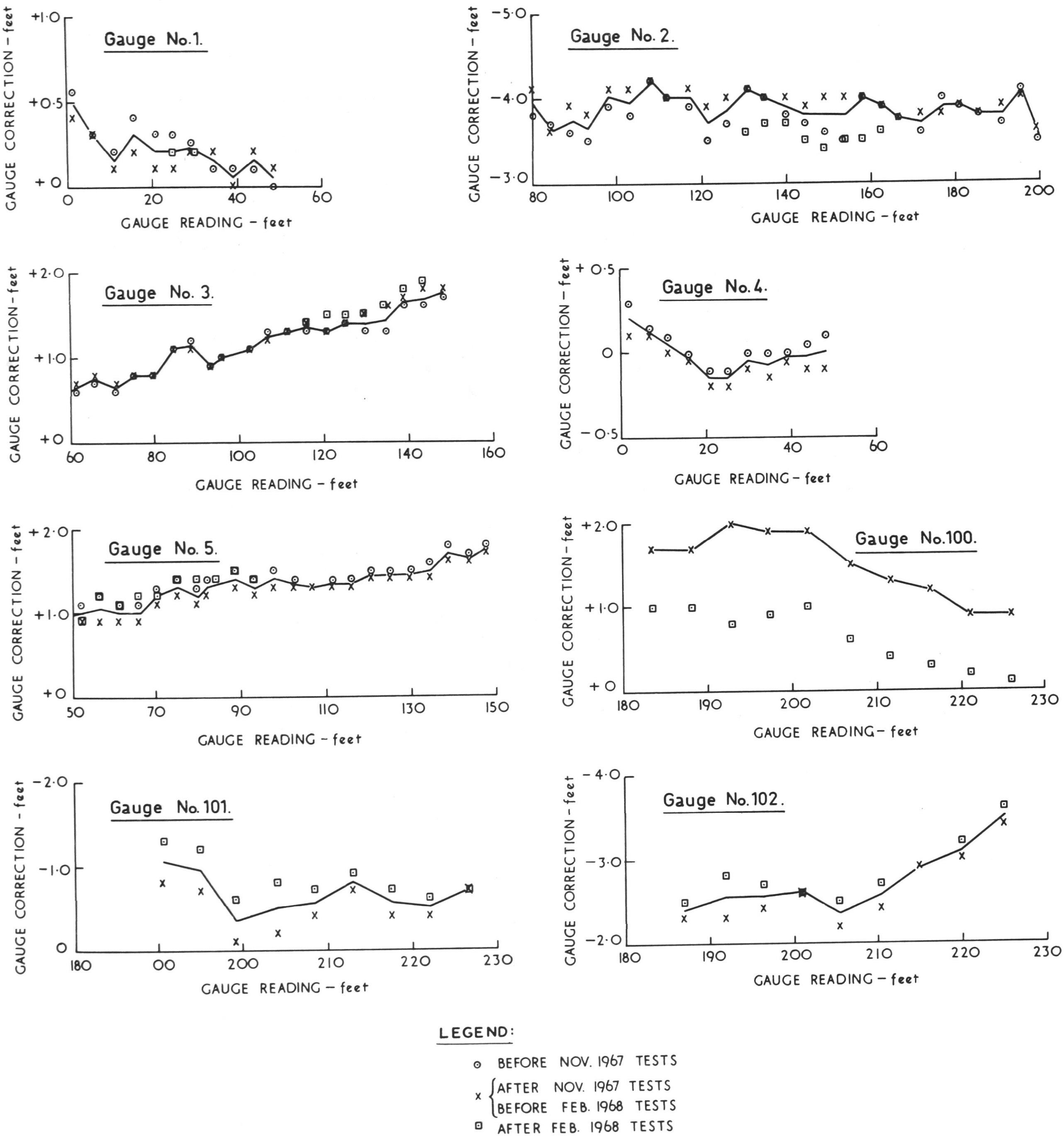


Figure 9: Pressure Gauge Calibrations

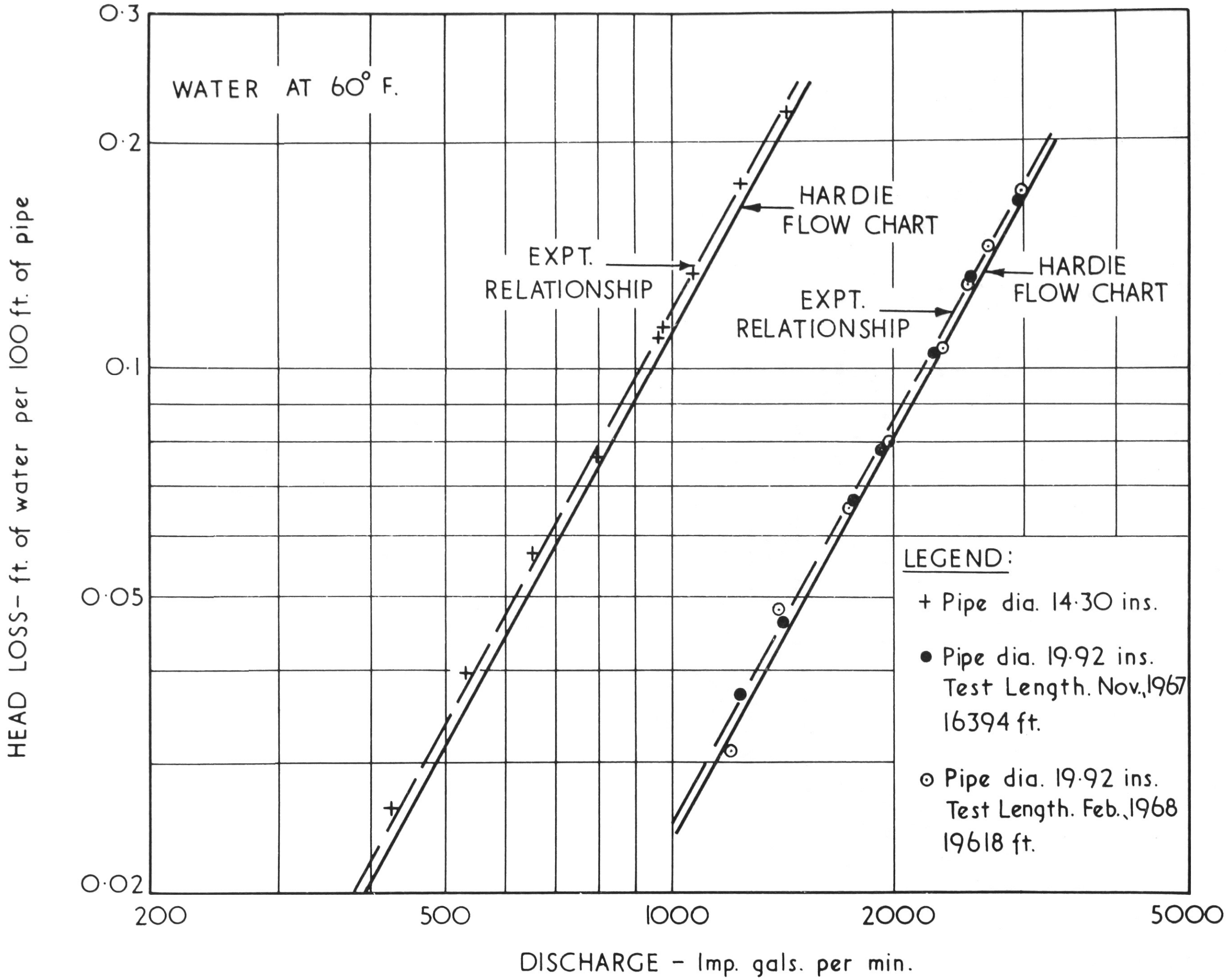
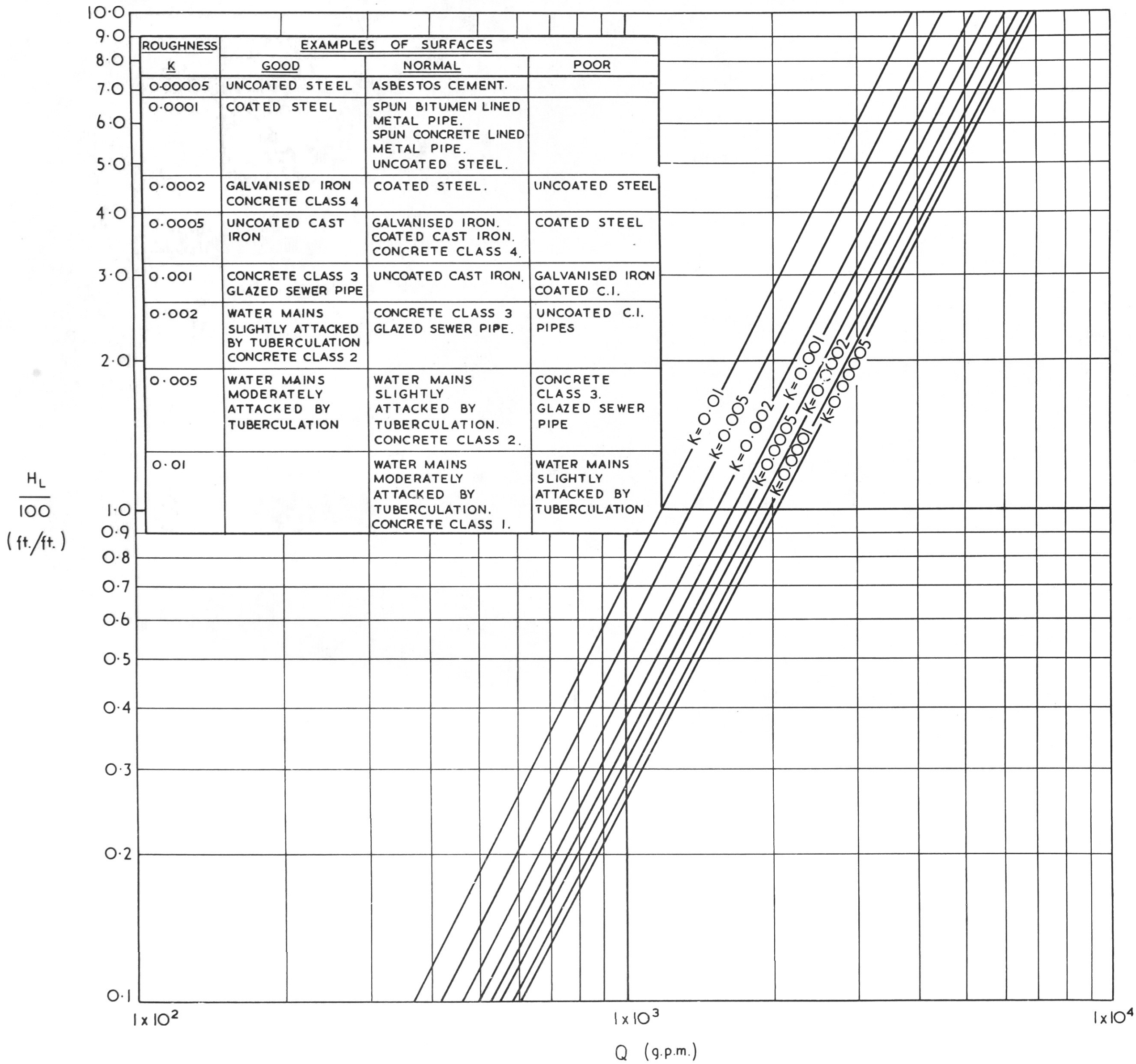


Figure 10: Comparison of Experimental Results with Hardie Flow Chart as based on Equation $Q = 2.80\ H^{0.54} D^{2.65}$



ROUGHNESS	EXAMPLES OF SURFACES		
K	GOOD	NORMAL	POOR
0·00005	UNCOATED STEEL	ASBESTOS CEMENT.	
0·0001	COATED STEEL	SPUN BITUMEN LINED METAL PIPE. SPUN CONCRETE LINED METAL PIPE. UNCOATED STEEL.	
0·0002	GALVANISED IRON CONCRETE CLASS 4	COATED STEEL.	UNCOATED STEEL
0·0005	UNCOATED CAST IRON	GALVANISED IRON. COATED CAST IRON. CONCRETE CLASS 4.	COATED STEEL
0·001	CONCRETE CLASS 3 GLAZED SEWER PIPE	UNCOATED CAST IRON.	GALVANISED IRON COATED C.I.
0·002	WATER MAINS SLIGHTLY ATTACKED BY TUBERCULATION CONCRETE CLASS 2	CONCRETE CLASS 3 GLAZED SEWER PIPE.	UNCOATED C.I. PIPES
0·005	WATER MAINS MODERATELY ATTACKED BY TUBERCULATION	WATER MAINS SLIGHTLY ATTACKED BY TUBERCULATION. CONCRETE CLASS 2.	CONCRETE CLASS 3. GLAZED SEWER PIPE
0·01		WATER MAINS MODERATELY ATTACKED BY TUBERCULATION. CONCRETE CLASS 1.	WATER MAINS SLIGHTLY ATTACKED BY TUBERCULATION

Figure 11: Comparison of Head-Discharge Relationship for Various Pipe Materials
Pipe Diameter 1 ft. - Water Temp. 60°F
(After Ackers 1958)