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BUILDING MATERIALS AND STRUCTURES

REPORT BMS79

Water-Distributing Systems for Buildings

by

ROY B. HUNTER

NATIONAL BUREAU OF STANDARDS

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Foreword

One of the difficult design problems involved in the economical construction of water-supply systems in buildings is the selection of the smallest sizes of pipes for the various parts of the system that will assure an adequate supply of water at all outlets in the building under particular service conditions, such as the available service pressure and difference in elevation between the source of supply and the fixtures. The most difficult aspect of the problem arises from the fact that it is not sufficient to provide for an adequate supply when the pipes are new, but that a suitable allowance must be made for the decrease in capacity caused by the deterioration of the interior surface of the pipes with age. This involves the choice of materials for the pipes which will be best adapted to the characteristics of the particular water that will be used.

An earlier report in this series, BMS65, gives a method of estimating water demand loads, based on the number and kind of fixtures installed in the plumbing system. The present report gives a practical procedure for selecting the sizes of water pipes needed to supply the estimated demand under service conditions and contains much information that will assist in the selection of suitable materials for use in particular waters.

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Lyman J. Briggs, *Director.*

Water-Distributing Systems for Buildings

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ABSTRACT

This report gives information relating to the selection of pipe sizes and design of distributing systems for adequate supply of water in buildings. It contains flow charts showing the capacities of different commercial sizes of pipe in terms of friction loss in head for four degrees of roughness, depending on the pipe material and the character of water with which the pipe is used. A practical procedure is developed for the economical selection of pipe sizes for the different demands for each part, depending on the estimated demand and on the pressure available for friction loss as computed for particular service conditions. Suggested variations in the procedure provide convenient means of allowing for decrease in capacities of pipes in service.

I. INTRODUCTION

The results of the investigations of plumbing in connection with the National Bureau of Standards Research Program on Building Materials and Structures are being presented in a series of reports dealing with distinct phases of the problem. This paper, one of the series, deals with the problem of estimating the capacities of pipes of various kinds required for the water-supply services of buildings and with the selection of the proper sizes for satisfactory service for particular buildings. An earlier report [1][1] presented methods for estimating demand loads to be expected in buildings of different types, sizes, and occupancy. In a sense the two papers are concerned with the same general problem in that they deal with the two factors, load and capacity, upon which the selection of serviceable pipe sizes depends, and for this reason the two papers should be considered together.

The analysis of the experimental data obtained during this investigation and from other sources has proceeded concurrently with the preparation of a Plumbing Manual [2] which to a large extent summarizes the conclusions of the reports on different phases of the subject in a form suitable for the use of the engineer in designing plumbing systems. Additional illustrations of applications of the principles developed and explained in this Report may be found in the Plumbing Manual, Report BMS66.

II. SCOPE OF THE INVESTIGATION

No new experimental work was undertaken in connection with the investigation of water-supply pipes for buildings, because it was not believed that any material contribution to the already available information on the flow of water in pipes could be made by an experimental study in the time allotted for the investigation. There is an abundance of data on the flow of water in new pipes, and these data have been thoroughly analyzed by a number of investigators. There are very few correlated data available from which quantitative effects of the water carried on the capacities of pipes of different materials can be definitely predicted, although it is generally known that the effect of the water in some localities on the capacities of water-supply pipes of certain materials is enormous. The collection of data on the effects of waters of different characters and the analyses of these data in such a manner as to enable an engineer to predict with assurance the capacities of water-supply pipes after a few years' service would require years of intensive and correlated research in many localities. Consequently the investigation now reported was confined to a consideration of existing data and to a presentation of existing information in a form suitable for ready application to the problem. For the most part the data are presented in charts and tables from which the engineer may select the numerical values which are most applicable, in his judgment, to his particular problem.

[1] Figures in brackets indicate the literature references at the end of this report.

III. BASIS FOR ESTIMATES OF CAPACITY

1. Pipe Formulas

The basis for estimating flow in pipes is a pipe formula. Many empirical formulas have been proposed in the past, some of which have been extensively employed by engineers with varyingly satisfactory results. In the use of formulas for estimating pipe capacities, apparently it is not always appreciated that the friction factor is not a constant for any particular class of pipe but varies with diameter, roughness, and velocity, and that it is impossible from present knowledge to predict with a reasonable degree of accuracy what the diameter and roughness of any particular pipe will be after a period of service. The question of what quantitative allowances to make for decrease of capacity depends largely on the character of the water in each case and will be given consideration later.

2. The Rational Pipe Formula

The equation of equilibrium among the forces determining the rate of flow through a pipe is commonly known as a pipe formula. The rational formula for fluid flow in pipes may be written in the form

$$h/l=\lambda\frac{v^2}{2gd}, \tag{1}$$

in which, using English units,

h=the friction loss in head in feet of water,
l=the length of pipe in feet,
d=the diameter of the pipe in feet,
v=the mean velocity in feet per second,
g=the acceleration of gravity in feet per second per second, and
λ=a dimensionless friction factor whose value depends on the Reynolds number and the roughness of the pipe.

The Reynolds number, R_e, is a dimensionless number defined as

$$R_e=\frac{dv\rho}{\mu}=\frac{dv}{\nu}, \tag{2}$$

in which

ρ = the density of the water in pounds mass per cubic foot,

μ = the absolute viscosity of the water in pounds mass per foot per second, and

ν = the kinematic viscosity of the water ($=\mu/\rho$) in square feet per second.

For the flow of an incompressible fluid, such as water, in a smooth pipe, a unique relation exists between λ and R_e which may be expressed mathematically as

$$\lambda=\text{function}\frac{(dv)}{\nu}, \qquad (3)$$

and which for smooth pipe may be represented graphically as in figure 1 by curve 1.

to season in the same system. A high degree of accuracy is neither practical nor necessary in the proposed application, and hence eq 1 may be simplified by making two assumptions: (1) that the relation between λ and R_e is represented by an equation of the form

$$\lambda=bR_e^{-a} \qquad (4)$$

and (2) that the variations in ρ and μ with temperature are negligible in comparison with the accuracy required.

Equation 4 gives a straight line when plotted logarithmically. Hence, an approximate formula for application over a limited range of Reynolds numbers may be derived from the rational formula (eq 1) by drawing the straight

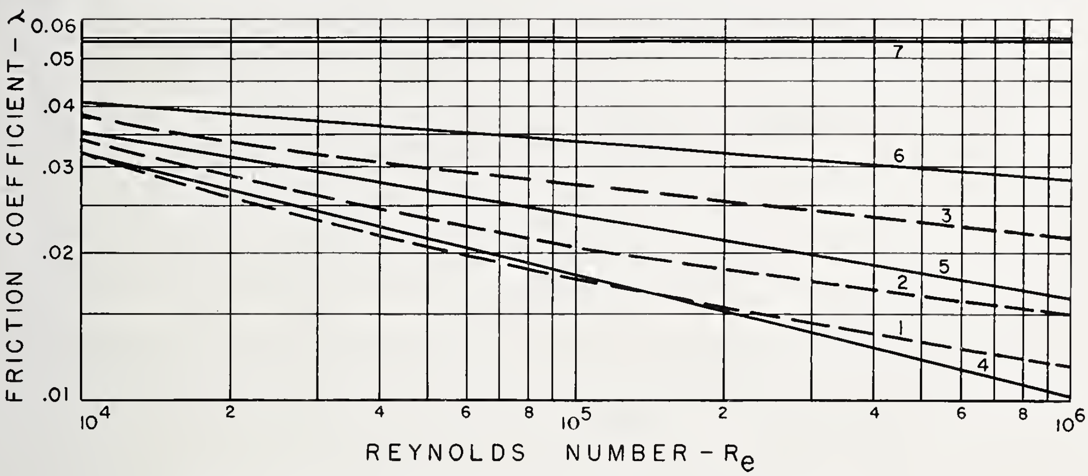

FIGURE 1.—Friction-coeffecient curve for smooth and rough pipes.

For pipes that are not smooth, the relation λ=function (dv/ν) gives a series of curves, one for each diameter, and each particular roughness, lying above the single curve for smooth pipe.

3. Approximate Formula for Smooth Pipe

Equation 1 is accurate for computing the mean velocity of flow under a given or allowable loss in head or for computing the loss in head for a given or required rate of delivery, provided the λ-R_e relation is known, as is the case for smooth pipe, and provided the density and viscosity are also known. However, the temperature and character of the water in water-distributing systems, on which the density and viscosity depend, will vary not only from system to system, but from day to day and from season

line best representing curve 1 in figure 1 over the selected range in Reynolds numbers and then in evaluating the Reynolds number, by substituting values of ρ and μ for the midrange in temperatures likely to be encountered in the application of the formula. Line 4 in figure 1, represented by the equation

$$\lambda=0.32R_e^{-1/4}, \qquad (4)$$

yields close approximations to the values of λ for smooth pipes over a range in Reynolds numbers from 3,000 to about 200,000. This range includes all velocities likely to be encountered in building water-supply lines of 6-inch diameter and smaller. (See later discussion of serviceable velocities.)

$R^e=vd/0.0000141$ for pure water at 50° F temperature, which is probably a fair average temperature for cold-water lines. By substituting this value of R_e in eq 4 and the resultant value of λ in eq 1, the latter reduces to

$$h/l = 0.000304\frac{v^{1.75}}{d^{1.25}}. \qquad (5)$$

This equation may be reduced to the following forms:

$$v = 102.0(h/l)^{0.571}d^{0.714} \qquad (6)$$

and

$$q = 80.2(h/l)^{0.571}d^{2.714}, \qquad (7)$$

in which v is in feet per second, q is in cubic feet per second, and h, l, and d are in feet.

If q_1 is in gallons per minute, p in pounds per square inch per 100 feet of pipe, and d_1 in inches, eq 7 reduces to

$$q_1 = 4.93p^{0.571}d_1^{2.714}. \qquad (8)$$

These formulas give close approximations for smooth straight copper tubing, copper pipe, and other straight pipes of similar smoothness, provided the actual inside diameters are used, but do not give as accurate results for Reynolds numbers above 200,000 as in the lower range.

4. Approximate Formulas for Rough Pipe

As pointed out in the discussion of the rational pipe formula, the relation between λ and R_e for rough pipe cannot be represented by a single curve for all diameters as can be done for smooth pipe. Hence a single formula for rough pipe will not give as accurate results as eq 5 does for smooth pipe. However, estimates made for a limited range in pipe diameters by means of a formula applying strictly to an intermediate diameter only in that range will be sufficiently close for practical purposes of selecting supply-pipe sizes for buildings, since the effects of different waters on capacity cannot ordinarily be estimated with as great an accuracy.

A very complete analysis of available flow data on both new and old pipe is given in a paper by Kemler [3], which shows the variation of the friction constant with diameter that may be expected in new pipes not in the category of smooth pipe, and which also shows the wide variation in the friction factor for old pipe of nominally the same kind. Considering these variations and the fact that the actual friction coefficient and actual diameter of a pipe after it has been in service as a water conductor vary over rather wide ranges, it would appear that a few formulas representing different degrees of roughness are sufficient for estimating the capacities of water-supply pipes over a limited range of nominal diameters and a limited range in Reynolds numbers with a greater precision than the accuracy to which the diameters and roughness of pipes in service can be predicted from information now available. Accordingly, it is suggested that water-supply pipe be considered in four classes as to hydraulic roughness:

(1) *Smooth pipe*, in which class new copper or brass tubing with so-called streamlined fittings and brass pipe may be categorically placed;

(2) *Fairly smooth pipe*, in which class butt-welded steel and wrought-iron pipe with threaded fittings may be placed;

(3) *Fairly rough pipe*, which represents a roughness intermediate between fairly smooth and rough pipe; and

(4) *Rough pipe*, in which class any kind of badly corroded or badly caked pipe may be placed.

These are classifications made arbitrarily by the author for the purpose of presenting flow information in a concrete usable form, and except for smooth pipe, they are not based directly on experimental data on any particular kinds of pipe.

Kemler's analysis of the flow data relating to new welded-steel and wrought-iron pipe, which may be classified as fairly smooth pipe, shows λ-R_e curves ranging from curve 2 (fig. 1) for 6-inch pipe to curve 3 (fig. 1) for ½-inch pipe, with the curves for intermediate sizes lying in order of size between these limits. If a straight line (line 5, fig. 1) is now drawn intermediate between curves 2 and 3 and an approximate formula based on values of λ represented by that line, the capacities computed by that formula will be in error by varying amounts—except for particular diameters and particular values of the Reynolds number—ranging for ½-inch pipe from about +3.5 percent with a Reynolds number of 10,000 to about +5.5 percent with a Reynolds number of 250,000, and ranging for 6-inch pipe from about −2.0 percent with a Reynolds number of 10,000 to about

−7.0 percent with a Reynolds number of 250,000. The errors for intermediate sizes of pipe will be correspondingly less in the same range of Reynolds numbers, and the results will be approximately correct for diameters of 2 to 4 inches. These errors are negligible in comparison with the accuracy with which the load and the actual diameter and roughness of pipes in service can be predicted.

The equation of line 5 is $\lambda=0.17\ R_e^{-0.17}$. Proceeding in the same manner as for smooth pipe, by substituting this value of λ in eq 1, the corresponding formulas for fairly smooth pipe are as follows:

$$h/l=0.000396v^{1.83}/d^{1.17}, \tag{9}$$

$$v=72.0(h/l)^{0.546}d^{0.640}, \tag{10}$$

$$q=56.6(h/l)^{0.546}d^{2.64}, \tag{11}$$

and

$$q_1=4.57p^{0.546}d_1^{2.64}. \tag{12}$$

The experimental data [4, 5, 6, 7] for flow of water in rough pipe indicate that λ is approximately constant for each diameter of very rough pipe, not introducing contraction effects, over all ranges of the Reynolds number. Hence, the relation between λ and R_e for very rough pipe will be represented by a series of horizontal lines each applying to a particular diameter. The selection of the value of λ for use for application to this class of pipe is largely a matter of judgment. $\lambda=0.054R_e^{0.0}=0.054$, represented by line 7 in figure 1, seems to be a reasonable value for application in the range of diameters considered in deriving formulas for smooth and fairly smooth pipe.

Likewise, the selection of the value of λ for a class of pipe intermediate in roughness between fairly smooth and very rough is a matter of judgment. The relation $\lambda=0.085\ R_e^{-0.08}$, represented by line 6, was selected for the degree of roughness designated as fairly rough pipe.

Using these values of λ in the same manner as in deriving the formulas for smooth and fairly smooth pipe, the following formulas were obtained in which the same notation is employed.

Formulas for fairly rough pipe:

$$h/l=0.000540v^{1.92}/d^{1.08}, \tag{13}$$

$$v=50.4(h/l)^{0.521}d^{0.562}, \tag{14}$$

$$q=39.6(h/l)^{0.521}d^{2.562}, \tag{15}$$

$$q_1=4.29p^{0.521}d_1^{2.562}. \tag{16}$$

Formulas for rough pipe:

$$h/l=0.000838v^2/d, \tag{17}$$

$$v=34.5(h/l)^{0.5}d^{0.5}, \tag{18}$$

$$q=27.1(h/l)^{0.5}d^{2.5}, \tag{19}$$

$$q_1=3.70p^{0.5}d_1^{2.5}. \tag{20}$$

5. Graphical Presentation of Flow Formulas

If any two of the variables in the formulas given in three variables are plotted on logarithmic paper for a constant value of the third factor, the resulting curve is a straight line. Figures 2, 3, 4, and 5 give flow charts in gallons per minute, and friction loss in pounds per square inch per 100 feet of pipe, computed from equations 8, 12, 16, and 20, respectively, for different pipe diameters in inches. Velocities in feet per second are also shown in these charts by diagonal dotted lines.

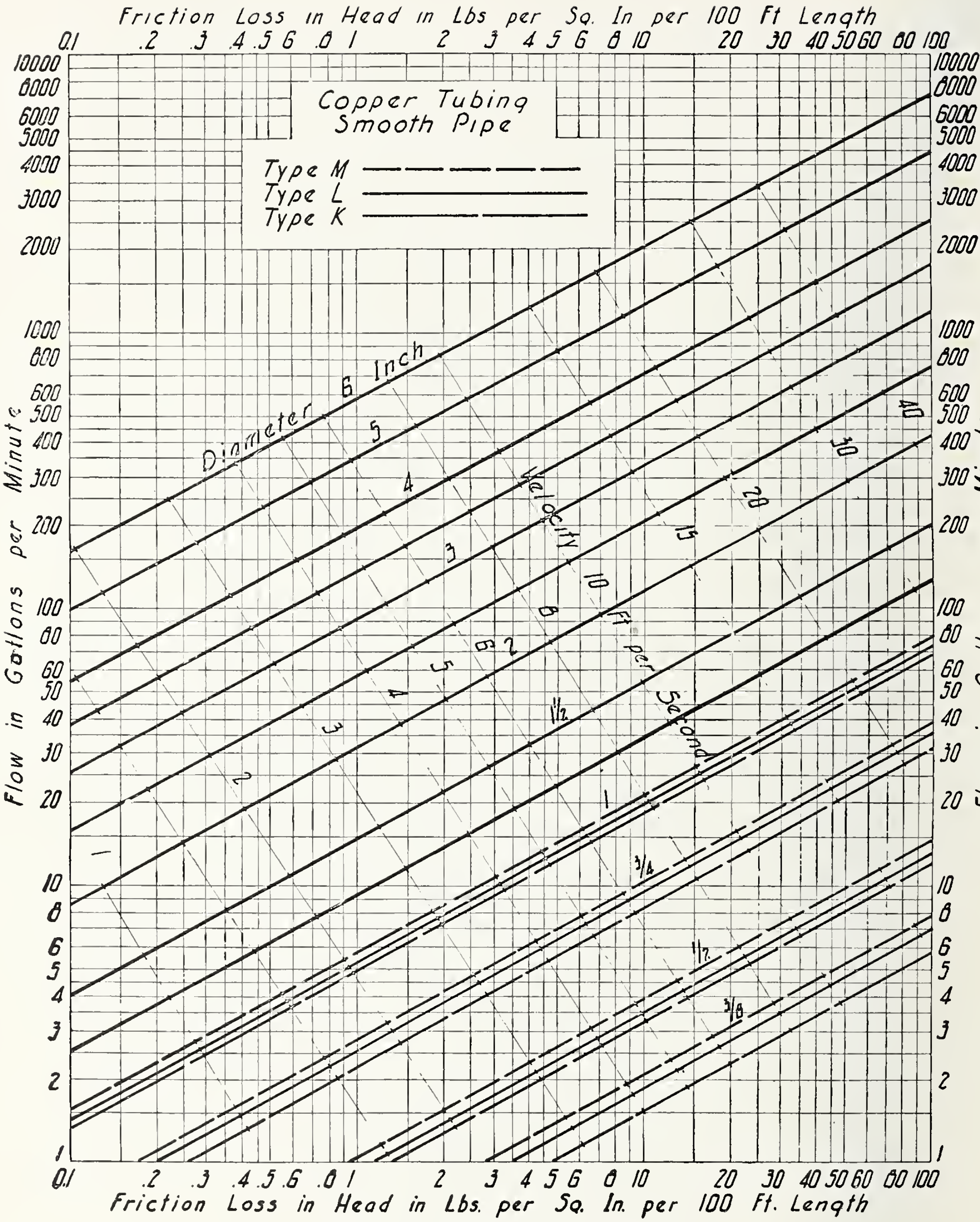

FIGURE 2.—*Flow chart for smooth pipe.*

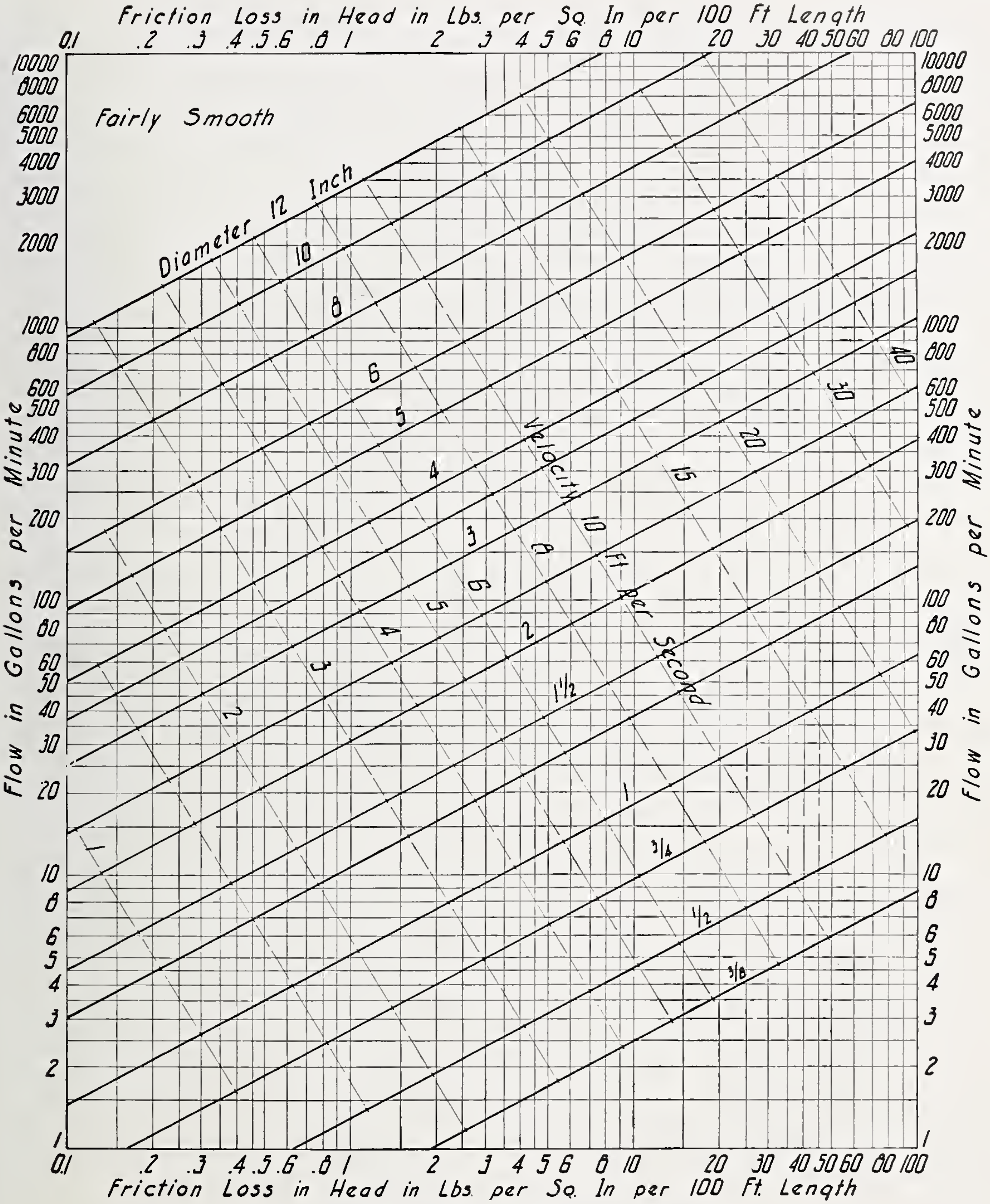

Figure 3.—Flow chart for fairly smooth pipe.

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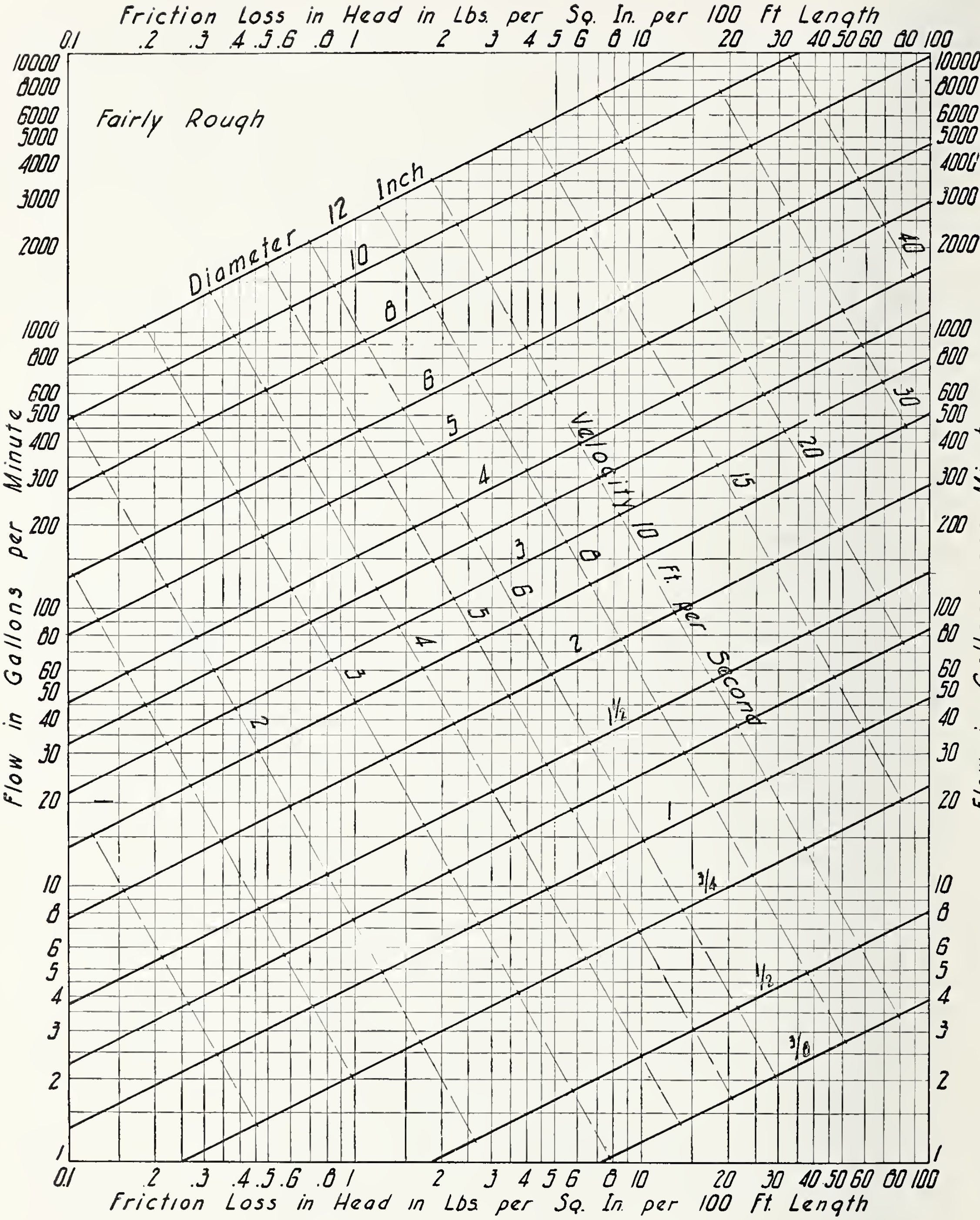

Figure 4.—*Flow chart for fairly rough pipe.*

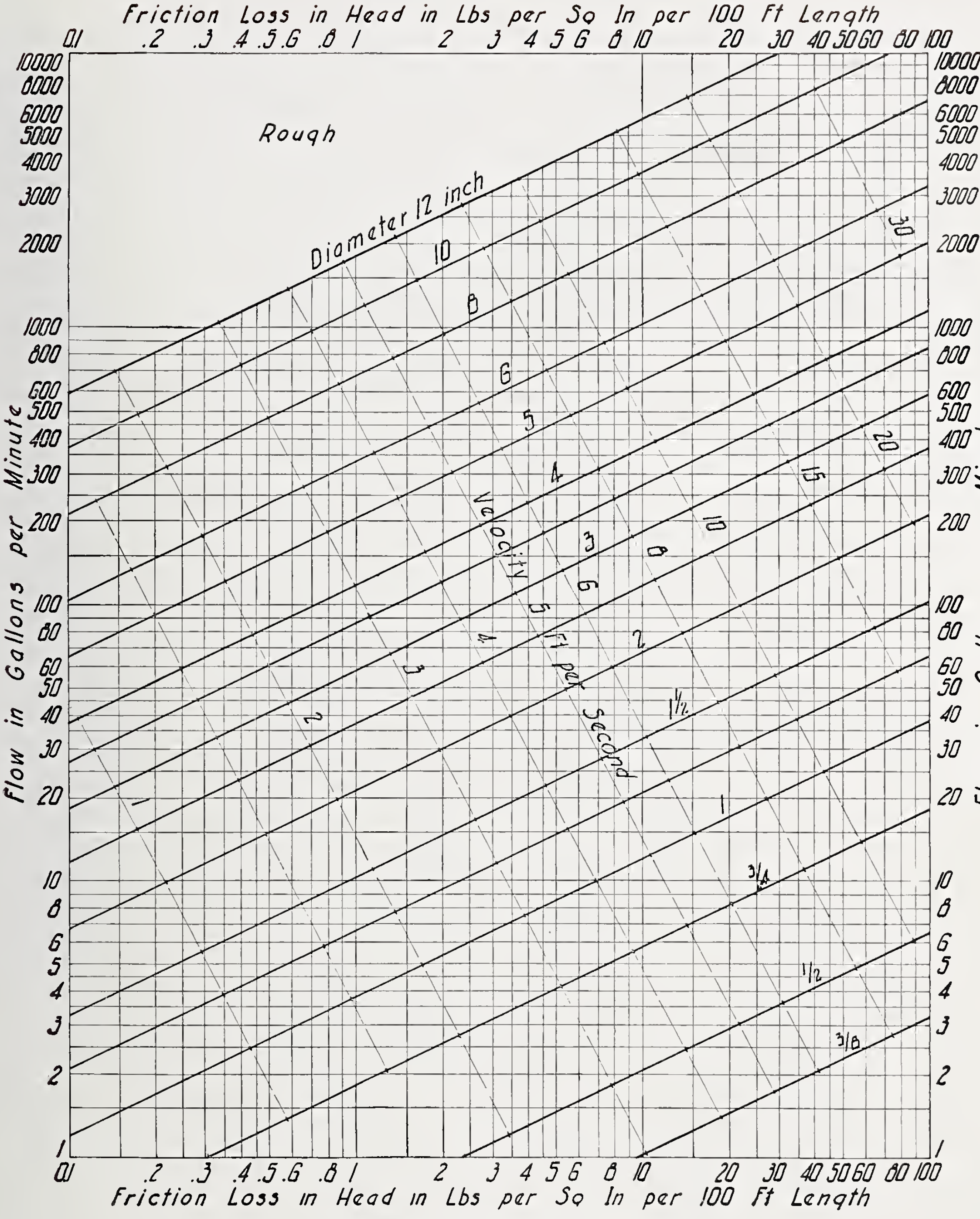

FIGURE 5.—*Flow chart for rough pipe.*

The flow for the actual diameters of copper tubing (smooth pipe) as computed by eq 8 is plotted against friction loss in figure 2, and sizes are given in nominal diameters (commercial designation). Three weights, types K, L, and M, are shown for ⅜- to 1-inch nominal diameters and the intermediate weight, type L only, for 1¼- to 6-inch diameters.

In figure 3 the flow for the actual diameters of standard-weight welded-steel pipe (fairly smooth pipe) as computed by eq 12 is plotted, and sizes are given in nominal diameters.

In figures 4 and 5 the flows as computed for the full nominal diameter by the given formulas are plotted for fairly rough and rough pipe, and the size designations are also nominal diameters.

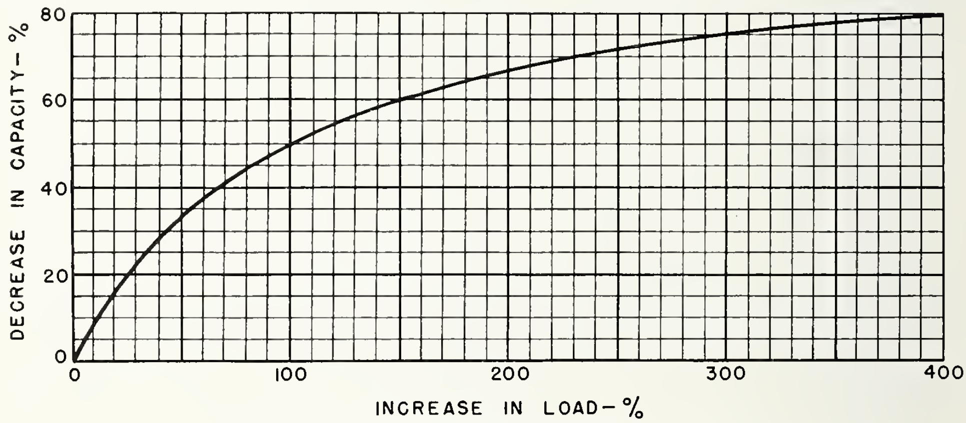

Figure 6.—*Relation between load and capacity allowances.*

In using these flow charts or any charts in similar form for estimating the capacity of pipes, it should be noted that they do not provide for estimating the effects of changes in diameter, and that likewise equations in the forms given do not provide a means of estimating the effects of changes in diameter unless the actual diameter resulting from the change is definitely known or can be predicted and is used in the equation.

IV. ESTIMATES OF CAPACITIES OF PIPES IN SERVICE

It is not an uncommon experience to find that the water supply of a building, originally wholly adequate when the building and piping were new, has become inadequate after a number of years. Insofar as inadequate water supply is the result of changes in the building water-supply pipes due to aging, it is caused by one or both of the following: Corrosion and roughening of the pipes; or a decrease in diameter due to the adherence of the products of corrosion or deposits from the water (caking) on the walls of the pipes.

1. Methods of Allowing for Decrease in Capacity With Age

There are several methods that may be applied in allowing for decrease of capacity of pipes in service: (a) by increasing the friction factor in the formula for new pipe; (b) by decreasing the constant in the approximate capacity formula for new pipe; (c) by adding to the estimated load before referring to the flow formula, chart, or table applying to new pipe; or (d), roughly, by selecting a larger size than is indicated if the estimated load is referred to the capacities of new pipes under the pressure conditions encountered.

Recommendations for allowing for expected decrease in capacity of water-supply pipes have usually been in the form of a flat percentage allowance applied to the friction factor for new pipe, to the estimated capacities of new pipe, or to the estimate of the load to be carried.

Dawson and Bowman [8] recommend adding an allowance of 15 percent for additional friction loss to the formulas for new pipe to allow for increase of roughness with age. In the formulas which they give, this allows for only about 8-percent decrease in capacity.

Barnes [9] recommends adding 33 percent to the load for asphalted, screw-jointed, wrought-iron pipes. This is equivalent to allowing for about 25-percent decrease in capacity. In this connection it should be observed that a percentage allowance added to the load does not allow for the same percentage decrease in capacity. The curve of figure 6 shows the percentage allowances as an increase in load equivalent to given percentage allowances for decrease in capacity.

Probably the simplest method is that suggested by Barnes. However, the inconsistency of making a flat allowance for decrease in capacity applying either to the capacity or the load, without reference to the size of the pipe or to the character of the water it carries, becomes obvious from a study of the relative effects in different sizes of pipe.

2. Decrease in Capacity Relative to Changes in Roughness and Diameter

The data in table 1 are given to illustrate the effect of change in roughness alone, change in diameter alone, and the combined effect of both on two sizes of new (fairly smooth) pipe. The change in capacity is given for a friction loss of 10 pounds per square inch per 100 feet of 1- and 4-inch pipe for three assumed conditions of aging: (1) pipes roughened to fall in the category of fairly rough pipes, but no change in diameter; (2) no change in roughness, but a decrease of 0.1 inch in diameter; and (3) both changes combined. For the 1-inch pipe, the decreases in capacity for these assumed conditions are approximately 12, 24, and 33 percent, respectively. For the 4-inch pipe, the decreases in capacity are approximately 21, 6.5, and 26 percent, respectively.

Actually the reductions in capacities of small pipes due to increase in roughness will be relatively greater in water-supply pipes than is indicated by table 1, for, as previously pointed out, the formulas for pipes that are not smooth are most nearly accurate in the intermediate range from 2- to 3-inch diameters, and the use of these formulas overestimates the capacities of smaller pipes and underestimates the capacities of larger pipes.

Table 1.—*Effect of changes in diameter and roughness on capacity of 4-inch and 1-inch pipe*

[Pressure drop of 10 lb/in.² per 100 ft]

New pipe, fairly smooth	Diameter	in	4.0	1.0
	Capacity [1]	gpm	624	16.1
Used pipe, fairly rough. (Increase in roughness only)	Diameter	in	4.0	1.0
	Capacity [1]	gpm	493	14.2
	Decrease in capacity due to change in roughness only	gpm	131	1.9
		%	21.0	11.8
Used pipe, fairly smooth. (Decrease in diameter only)	Diameter	in	3.9	0.9
	Capacity [1]	gpm	584	12.2
	Decrease in capacity due to change in diameter only	gpm	40	3.9
		%	6.4	24.2
Used pipe, fairly rough. (Increase in roughness and decrease in diameter)	Diameter	in	3.9	0.9
	Capacity [1]	gpm	462	10.8
	Decrease in capacity due to changes in roughness and diameter	gpm	162	5.3
		%	26.0	32.9

[1] Capacities computed from eq 12 and 16.

Table 2 gives the flows computed by the formulas for pipes having nominal diameters ranging from ⅜ to 6 inches for several different assumed changes in roughness and diameter, corresponding to the changes that might occur in new, fairly smooth, ferrous pipe. The errors pointed out in the preceding paragraph in reference to the smaller diameters apply to this table also.

Table 3 gives a comparison of results computed from data by Freeman [10, p. 116–131] from extensive tests of new and old wrought-iron pipe ranging in diameter from 1 to 4 inches with flows computed by eq 12, 16, and 20 for the same diameters and friction loss. It will be observed that, assuming the new pipe tested by Freeman to have been fairly smooth, the agreement with the flows computed from eq 12 is within 6 percent, which is excellent. For the old pipe, the classifications *rough* and *fairly rough* were used, based on Freeman's detailed description of the interior surfaces of the specimens he tested (see below). Then eq 16 or 20, depending on the classification of the specimen, was used to compute the flows for the diameters measured by Freeman. Again the formulas are found to give results that compare very favorably with the measured flows, the differences ranging from +12.9 percent to −2.6 percent.

Table 2.—*Capacities under assumed conditions of aging for a friction loss of 10 lb/in.² per 100 feet*

Nominal diameter (*in.*)	New pipe, fairly smooth		Slightly corroded, no caking, fairly rough		Caked 0.0375-inch thick, fairly rough		Caked 0.075-inch thick, rough		Caked 0.15-inch thick, rough	
	Actual inside diameter	Flow q_1	Flow q	q/q_1	Flow q	q/q_1	Flow q	q/q_1	Flow q	q/q_1
	in.	*gpm*	*gpm*	%	*gpm*	%	*gpm*	%	*gpm*	%
3/8	0.493	2.49	2.32	93.0	1.52	61.0	0.81	32.5	0.19	7.5
1/2	.618	4.53	4.14	91.5	2.99	66.0	1.75	38.5	.67	15.0
3/4	.82	9.56	8.55	89.5	6.70	70.0	4.30	45.0	2.28	23.5
1	1.04	17.8	15.7	88.0	13.0	73.0	8.74	49.0	5.51	31.0
1 1/4	1.37	37.0	31.9	86.0	27.7	75.0	19.3	52.0	13.8	37.5
1 1/2	1.60	55.8	47.5	85.0	42.0	75.0	29.6	53.0	22.6	40.5
2	2.06	109	90.7	83.0	82.5	75.5	59.1	54.0	48.1	44.0
2 1/2	2.46	174	143	82.0	132	76.0	94.9	54.5	80.2	46.0
3	3.06	309	250	81.0	235	76.0	169	54.5	148	48.0
4	4.02	635	504	79.5	479	75.5	345	54.5	312	49.0
5	5.04	1,150	896	78.0	862	75.0	619	54.0	572	49.5
6	6.05	1,870	1,430	76.5	1,390	74.5	989	53.0	928	49.5

Table 3.—*Comparison of Freeman's data for new and old wrought-iron pipe with results from equations 12, 16, and 20 for the given diameters and roughness*

NEW, FAIRLY SMOOTH PIPE

Actual diameter	Observed flow, q	Computed flow, q_0	Difference, $q-q_0$	Percentage difference, $100\frac{q-q_0}{q_0}$	Equation used
in.	*gpm*	*gpm*	*gpm*	%	
1.061	19.4	18.9	+0.5	+2.6	12
2.093	120	113.5	+6.5	+5.7	12
3.115	343	324	+19	+5.9	12
4.123	715	679	+36	+5.3	12

OLD PIPE

Specimen	Actual diameter	Assumed [a] condition	Observed flow, q	Computed flow, q_0	Difference, $q-q_0$	Percentage difference, $100\frac{q-q_0}{q_0}$	Equation used
	in.		*gpm*	*gpm*	*gpm*	%	
A	2.054	Rough	75	71	+4.0	+5.6	20
B [b]	3.048	Fairly rough	280	248	+32	+12.9	16
C [b]	3.014	Rough	200	185	+15	+8.1	20
D	4.042	do	375	385	−10	−2.6	20

[a] The classifications given in this column were assigned on the basis of Freeman's description of the interior surfaces of these specimens [7, p. 128–130].
[b] Specimens *B* and *C* were taken from the same pipe line.

Freeman [10, p. 128–130] describes the specimens of old pipe as follows:

A. "This is so free from obstruction that one would at first glance say it was as smooth and clean as new pipe. On examining it closely its interior is nearly all reddened by rust and is somewhat scabby; and say half its internal area is covered by a very thin scale quite rough and scabby, about 1/64 inch thick."

B. "On a hasty look it would be called almost as smooth as new pipe. There are two bunches about 1/8 inch high in the whole section. In general the scales of corrosion are 1/32 inch high, or hollows and pits are 1/32 inch below a short straight-edge laid within the pipe."

C. "From looking into both ends of every piece of pipe with mirror at end reflecting sunlight, should say that every piece has whole interior surface rough, with its general hills and hollows varying from 1/32 to 1/16 inch in height above and below the average."

D. "Reflecting a sunbeam from end to end, I can see very plainly the whole interior. There is hardly a square inch of its surface that does not contain bunches 1/16 inch high, those being rough nodules of rust, of irregular shape and base but rounded section, though many with sharp perpendicular edges; these sharp-edged bunches being the remains of larger bunches which have been broken off while handling the pipe."

3. Allowances for Decrease in Capacity Under Particular Service Conditions

An examination of the data given in tables 2 and 3 strongly supports the following assumptions:

(1) That fairly close estimates of the capacities of new steel or wrought-iron pipes can be made by using eq 12 for fairly smooth pipe or by using the flow chart, figure 3, based on that formula.

(2) That change in diameter as well as change of roughness must be taken into account

in making accurate allowances for decrease in capacity of pipes used with corrosive or caking waters, especially in the smaller sizes of pipe.

(3) That, with the knowledge of the corrosion or caking effects of a particular water obtainable in advance of installation, estimates of future capacity cannot be made within better than about 10-percent accuracy for particular cases (See range in specimens *B* and *C*, table 3).

(4) That ample allowances for decrease in capacity of different sizes of ferrous pipe with waters of different character should range from about 20 percent for 6-inch and larger diameters with a favorable water to about 90 percent for ⅜-inch pipe with a corrosive or caking water.

From our general knowledge of the aging of pipes, it seems reasonable to assume also:

(5) That ferrous pipe, after a few years' service in a water supply with the best of waters in respect to corrosion and caking, will have passed from the category of fairly smooth to fairly rough pipe.

(6) That ferrous pipe, used with either a badly corrosive or badly caking water, will have passed from the category of fairly smooth to rough pipe after a few years in service.

It may be pointed out here that referring the estimated demand load to the chart for fairly rough pipe given in figure 4 or to the chart for rough pipe given in figure 5, instead of to the chart in figure 3 applying to new pipe, has the effect of allowing for a decrease in capacity. This is illustrated by table 4, in which the flows read from figures 4 and 5 are given, together with the flows for new fairly smooth pipe (from table 2), for diameters from ⅜ inch to 6 inches. The ratios of the flows obtained from figures 4 and 5 to the corresponding flows in new pipe are given in the table, and a comparison of the values obtained from figure 4 with the values given in table 2 shows that the use of figure 4 for diameters from 2 inches to 6 inches, inclusive, gives results that compare favorably with the results given in table 2 under the heading "slightly corroded, no caking, fairly rough." The discrepancies between the two sets of values for small diameters are largely due to the facts that the values in table 2 are computed for actual pipe diameters, while the curves in figure 4 are based on nominal diameters, and that the differences between nominal and actual diameters are disproportionately large for small diameters and vary irregularly from size to size. The use of this chart, however, gives results that are on the safe side for small diameters, as long as there is no caking.

Likewise, a similar comparison, shows that the results obtained from figure 5 for rough pipe compare favorably with the results given in table 2 under the heading "Caked 0.075-inch thick, rough." If anything, the use of figure 5 does not allow enough for the reduction in capacity of small pipes when used in caking waters.

TABLE 4.—*Comparison of flows in new pipe from table 2 with flows from figures 4 and 5 for fairly rough and rough pipe*

[Pressure loss of 10 lb./in.^{2} per 100 feet]

Nominal diameter (in.)	New pipe, fairly smooth	Used pipe, fairly rough			Used pipe, rough		
	Flow from table 2	Flow from figure 4	Percentage of flow when new	Reduction in flow	Flow from figure 5	Percentage of flow when new	Reduction in flow
	gpm	*gpm*	%	%	*gpm*	%	%
⅜	2.49	1.20	48	−52	1.00	40	−60
½	4.53	2.45	54	−46	2.07	46	−54
¾	9.56	6.9	72	−28	5.8	61	−39
1	17.8	14.5	81	−19	12.0	67	−33
1¼	37.0	.25.5	69	−31	21	57	−43
1½	55.8	41.	73	−27	33	59	−41
2	109	85.	78	−22	64	59	−41
2½	174	150.	86	−14	120	69	−31
3	309	240	78	−22	180	58	−42
4	635	510	80	−20	370	58	−42
5	1,150	890	77	−23	650	56	−44
6	1,870	1,450	77	−23	1,020	55	−45

Considering the differences and variations as illustrated by table 4, it appears that about as satisfactory allowances for decrease of capacity in service for pipes of from 2- to 6-inch diameters could be made by referring to figure 4 with the estimated demand load for favorable water conditions, and to figure 5 for unfavorable water conditions, as by deducting definite percentage allowances from the capacities for new pipe or by adding definite percentage allowances to the estimated demand load.

However, if sufficient information concerning the character of the water as to its corrosive effect and tendency to produce caking is available, or becomes available, for particular supplies, to justify making more definite allowances than can be obtained from a direct application of the flow charts, the data given in table 2 indicate that the allowances should vary with the diameter of pipe and with the degree of unfavorable character of water, somewhat as suggested by table 5. These suggested allowances are referred to limited ranges in estimated demand loads, which it is believed will be found easier to apply than allowances referred directly to pipe diameters.

In applying allowances for decrease in capacity, it should be remembered that ordinarily the decrease in capacity as a result of caking from hard waters will be relatively greater in hot-water lines than in cold-water lines, especially in the line between the heater and the hot-water distributing branches. Hence, for the same water supply, it may be advisable to make a greater allowance for decrease in capacity in hot-water than in cold-water pipes.

Table 5.—*Suggested allowances for decrease in capacity of ferrous pipes*

Estimated load (*gpm*)	Recommended allowances to be applied to estimated load or to capacity of new ferrous pipe to provide for aging							
	Noncaking		Slightly caking		Caking, moderately bad		Caking, very bad	
	To capacity	To load	To capacity	To load	To capacity	To load	To capacity	To load
	%	%	%	%	%	%	%	%
0.0 to 2.5	−20	+25	−40	+60	−60	+150	−80	+400
2.6 to 5.0	−20	+25	−35	+50	−55	+130	−75	+300
5.1 to 10	−20	+25	−30	+45	−55	+110	−65	+200
11 to 8	−20	+25	−30	+45	−50	+100	−65	+200
19 to 37	−20	+25	−30	+40	−45	+80	−60	+150
38 to 56	−20	+25	−30	+40	−40	+65	−60	+150
57 to 110	−20	+25	−25	+35	−35	+50	−55	+125
111 to 175	−20	+25	−25	+35	−35	+50	−55	+125
176 to 310	−20	+25	−25	+35	−30	+45	−50	+100
311 to 635	−20	+25	−25	+35	−30	+45	−50	+100
636 to 1,150	−20	+25	−25	+35	−30	+45	−50	+100
1,151 to 1,870	−20	+25	−25	+35	−30	+45	−50	+100

4. Decrease in Capacity of Small Galvanized-Steel and Nonferrous Pipes Due to Aging

A rough idea of the allowance to be made in estimating the capacity of small galvanized-steel, brass, and copper pipes after several years' use in cold and in hot water can be obtained from unpublished data at the National Bureau of Standards. These data were obtained from tests on ¾-inch pipe after 4 years of service in cold-water supply lines and 1¼-inch pipe in hot-water lines, using District of Columbia water, which is good in quality, both as regards caking and corrosion. For each specimen, the ratio of its capacity after 4-years' service to its capacity when new was first computed. Then the value thus obtained was compared with the ratios given in table 2 for pipe of the same nominal diameter. For example, the ratio for a ¾-inch red-brass pipe in cold-water service after 4 years' use was found to be a little less than the value of 89.5 percent given in table 2 for ¾-inch pipe in the column headed "slightly corroded, no caking, fairly rough." On this basis, this sample was designated as "fairly rough, light caking." The designations given below for the various pipes were obtained in a similar way.

Cold-water service, 4 years, ¾ inch

Galvanized steel	Fairly rough, moderate caking.
Red brass	Fairly rough, light caking.
Copper	Fairly rough, light caking.

Hot-water service, 4 years, 1¼ inch

Galvanized steel	Rough, heavy caking.
Yellow brass	Fairly rough, light caking.
Red brass	Slightly roughened, no caking.
Copper	Very slightly roughened, no caking.

Obviously the procedure used in assigning the classifications given above is very arbitrary, but at the same time the results constitute a useful guide in predicting the ultimate capacity of pipes of these materials in hot- and cold-water service.

It should be remembered, however, that these results are for a noncaking water and for only one size of pipe in each service.

5. Facts Regarding Corrosion and Caking

Obviously if data were available giving reliable quantitative information as to the effects of water of particular compositions on the roughness and diameters of pipes of different materials with respect to time in service, very close and reliable estimates of the capacities after any number of years of service could be made.

Some progress has been made toward a method of correlating the corrosion and coating effects of particular waters on the capacity of water-supply pipes of different materials. In 1936 Langelier presented a paper [11] in which he gave a method of computing the "calcium carbonate saturation index" from the water analysis and indicated its application to the aging of pipe. In 1938, De Martini presented a paper [12] giving data supporting the Langelier index as a possible means of predicting the corrosion of pipes. These studies are only a beginning toward the solution of the problem, and a great deal of correlated research on the effects of waters of different composition on pipes of different materials, both in regard to change in roughness and change in diameter with time in waters of different and known compositions, will be required before a reliable method of making quantitative allowances for decrease of capacity of water pipes in service can be developed. (See appendix for further discussion.)

In the meantime, builders and building owners will have to rely on general and usually inadequate information regarding the effects of the local waters in the selection of both the material and size of water pipes. In practically all cases the water supply undergoes a treatment before it is introduced to the mains for public use and in most cases an analysis of the local water, more or less complete, can be obtained from the waterworks officials. Geological Survey Water-Supply Paper 658 [13] gives the methods of treatment and the analyses of the water used in 670 cities distributed throughout the 48 States and the District of Columbia. The paper also contains much additional information on the composition of surface and ground waters. "Corrosion, Causes and Prevention," by Speller [14] gives a fairly complete treatment on the subject of corrosion. The last reference contains the following summary of "Facts established with respect to corrosion, especially of iron":

"1. At normal temperatures iron will not corrode appreciably in the absence of moisture.

"2. The presence of oxygen is also essential for corrosion to take place in ordinary water. Oxygen alone will cause considerable corrosion in acid, neutral, or slightly alkaline water. In natural waters, the rate of corrosion is almost directly proportional to oxygen concentration, if other factors do not change. Oxygen also accelerates corrosion in nonoxidizing acid solutions of moderate strength.

"3. Corrosion in acid solutions is much more rapid than in neutral solutions, and the latter is more rapid than in alkaline solutions.

"4. Hydrogen gas is usually evolved from the surface of the metal during corrosion in acid solutions and in concentrated solutions of alkalies; in nearly neutral solutions the evolution is usually very much less and may not be appreciable.

"5. The products of corrosion consist, mainly, of black or green ferrous oxide next to the metal, and reddish-brown ferric hydroxide (rust) which forms the outer layer, with graded mixtures of the two in between. When iron corrodes in the atmosphere the amount of ferrous rust produced is small, but when found under water the corrosion products often contain a large proportion of ferrous iron.

"6. In natural water, the precipitated rust usually carried down some compounds containing lime, magnesia, and silica together with other insoluble material from the water. These substances have considerable influence on the structure and density of the rust coating on the metal surface. A loose nonadherent coating under ordinary conditions may accelerate locally the rate of corrosion; a uniformly dense coating may cut down this rate very considerably.

"7. Surface films, sometimes invisible, often play an important part in controlling the rate of corrosion. These films have been made visible by separation from some metals and have been shown to raise the potential of these metals, making them more resistant in certain environments. In fact the superior resistance of metals like chromium and aluminum, for example, is undoubtedly due largely to the formation of such films.

"8. In most cases the initial rate of corrosion is much greater than the rate after a short period of time. This is particularly noticeable in film-forming solutions, such as the alkalies of chromates. It should be noted, however, that the initial rate of corrosion of a highly polished metal surface is abnormally low.

"9. Corrosion at normal temperature increases with increase of concentration in dilute solutions of many neutral salts, particularly chlorides, but decreases again in more concentrated solutions, other things being equal.

"10. In natural waters the rate of corrosion generally tends to increase with increase in velocity of motion of the water over the metal surface, with some exceptions where the film-forming tendency predominates.

"11. Dissimilarity in the chemical composition of metals in contact with each other in an electrically conducting solution sets up a difference in potential (precisely as in the galvanic cell) and thus accelerates corrosion locally. In corroding metals these variations in potential are found between a metal and other reactive materials, or between different metals in contact. This action is accompanied by an electric current which flows through the solution from anode to cathode; i. e., from the corrodible to the less corrodible metal in this particular solution.

"12. Composition of ordinary iron or steel, within the common variations found commercially, has little effect on corrosion under water or underground, but sometimes it has a marked effect in atmospheric or acid corrosion. From the standpoint of corrosion, homogeneity of a metal is not usually so important as external conditions.

"13. The condition of the metal surface in submerged corrosion may not affect the total corrosion, although it may have a marked tendency to localize the action. Corrosion of iron is rarely uniform over its surface.

"14. Variation in composition or concentration of a solution in contact with a metal tends to localize corrosion at certain areas and retard action at other areas of the surface. A portion of the metal surface which is protected from diffusion of oxygen inward becomes anodic to other areas which are in contact with a solution richer in oxygen, i. e., corrosion is more active at such protected areas.

"15. The smaller the anodic areas in relation to the associated cathodic areas, the greater is the rate of penetration of corrosion at the anodic points. The polarity of a certain area often reverses during the process of natural corrosion."

There is another fact that should be emphasized in connection with the problem of estimating capacities of water pipes in service. In waters having "carbonate hardness" or other "temporary hardness," the precipitation of calcium carbonate or other salts (see fact 6 above) on the wall of the pipe is very likely to continue until the diameter is materially reduced, and with very hard waters may result in the complete closing of small hot-water pipes.

V. SELECTION OF SIZES OF WATER-SUPPLY PIPES

1. Essential Steps in Selecting Serviceable Pipe Sizes

In general, the process of selecting serviceable pipe sizes for any particular building will include the following steps, which, however, are not necessarily made in the exact order given:

(a) Estimation of the demand load on the system;

(b) Determination of the required piping lay-out from the building plans and determination therefrom of the developed length of the different parts of the system, including the building main and risers;

(c) Estimation of the pressure available for friction loss in the system from the minimum service pressure in the street main or other source of supply, the difference in static pressure between the street main and the highest fixture or group of fixtures, the minimum pressure at the highest fixture or group of fixtures for satisfactory operation, and the friction loss through the meter if one is installed;

(d) Selection of the kind of pipe (galvanized steel, brass, copper, lead, etc.) to use, a choice which will ordinarily be made from considerations of the effects of the water on the life and capacity of the different kinds of pipe in service, and of the relative costs of the initial installation of each kind;

(e) Selection of the flow chart or formula considered most applicable to the kind of pipe chosen for use with the particular water;

(f) The selection of the size of pipe to be installed in each part of the water-supply system, beginning with the building main and progressing through the principal branches and risers of the system. This selection should be based on the estimated demand load on each part of the system (main, branch, or riser) and on the pressure available for friction loss, using the flow chart that has been selected as the suitable one for the conditions of the problem. See section V–3 following.

There are certain details in this suggested procedure, the amplification of which will aid in clarifying the reasons for the different steps.

2. Method of Making Demand Estimates

An earlier paper in this series [1] gave a suggested method of estimating the demand load in building water-supply systems, based on the number and kind of fixtures installed and on the probable simultaneous use of those fixtures. The essentials for making these estimates consist principally of a table of demand weights in terms of fixture units for different plumbing fixtures under different conditions of service (table 6), and curves (fig. 7) from which the estimated demand in gallons per minute corresponding to any total number of fixture units may be obtained. Figure 8 gives the curves of figure 7 on an enlarged scale for a range up to 250 fixture units.

The estimated demand load for fixtures used intermittently on any supply pipe will be obtained by multiplying the number of each kind of fixture supplied through that pipe by its weight from table 6, adding the products, and then referring to the appropriate curve of figure 7 or 8 with this sum. In using this method it should be noted that the demand for fixture or supply outlets other than those listed in the table of fixture units is not yet included in the estimate. The demands for outlets—such as hose connections, air-conditioning apparatus, etc.—which are likely to impose continuous demand during times of heavy use of the weighted fixtures should be estimated separately and added to the demand for fixtures used intermittently, in order to obtain an estimate of the total demand.

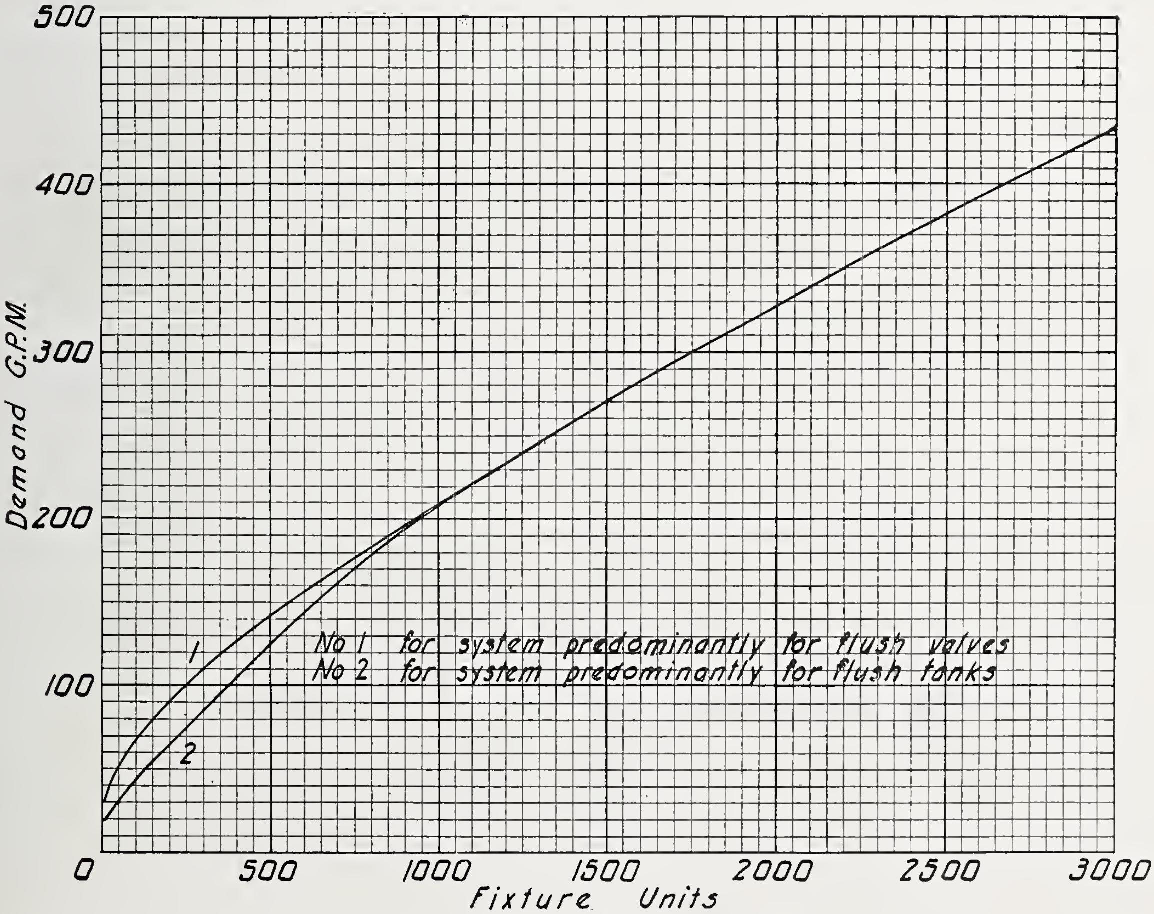

Figure 7.—*Estimate curves for demand load.*

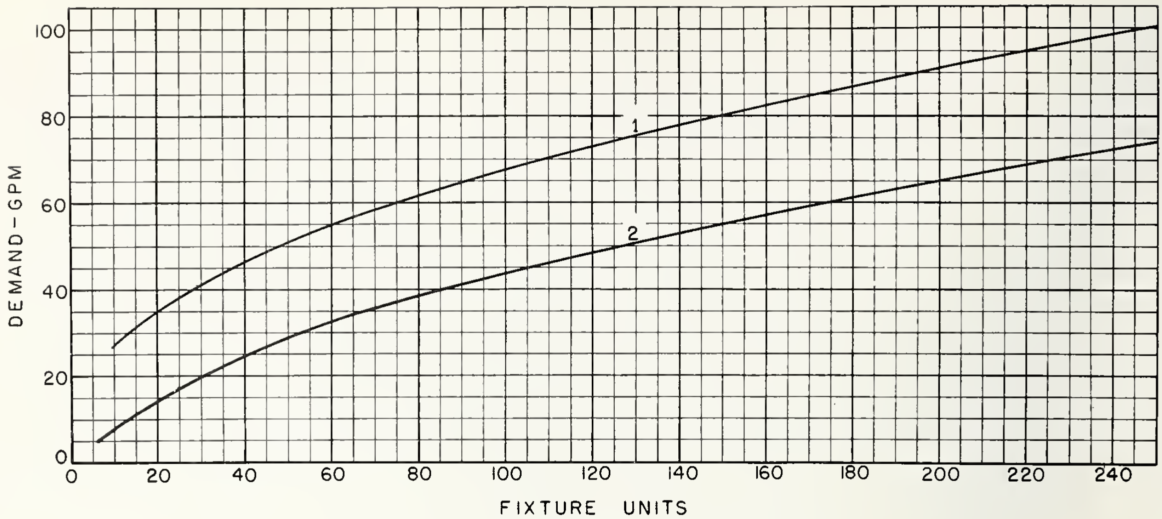

Figure 8.—*Section of figure 7 on enlarged scale.*

Table 6.—*Demand weights of fixtures in fixture units* [1]

Fixture or group [2]	Occupancy	Type of supply control	Weight in fixture units [3]
Water closet	Public	Flush valve	10
Do	do	Flush tank	5
Pedestal urinal	do	Flush valve	10
Stall or wall urinal	do	do	5
Do	do	Flush tank	3
Lavatory	do	Faucet	2
Bathtub	do	do	4
Shower head	do	Mixing valve	4
Service sink	Office, etc	Faucet	3
Kitchen sink	Hotel or restaurant.	do	4
Water closet	Private	Flush valve	6
Do	do	Flush tank	3
Lavatory	do	Faucet	1
Bathtub	do	do	2
Shower head	do	Mixing valve	2
Bathroom group	do	Flush valve for closet	8
Do	do	Flush tank for closet	6
Separate shower	do	Mixing valve	2
Kitchen sink	do	Faucet	2
Laundry trays (1–3)	do	do	3
Combination fixture	do	do	3

[1] For supply outlets likely to impose continuous demands, estimate continuous supply separately and add to total demand for fixtures.

[2] For fixtures not listed, weights may be assumed by comparing the fixture to a listed one using water in similar quantities and at similar rates.

[3] The given weights are for total demand. For fixtures with both hot- and cold-water supplies, the weights for maximum separate demands may be taken as ¾ the listed demand for the supply.

A more detailed discussion of the proposed method of estimating load demands is given in the paper [1] just referred to, and illustrations of its practical application are given in the Plumbing Manual [2].

3. Estimation of Pressure Available for Friction Loss in Pipes

Obtain, as nearly as possible, an estimate of the minimum daily service pressure in the water main. This can usually be obtained from the water department for a particular area.

Determine the difference in elevation in feet between the water main and the highest fixture or group of fixtures in the particular building. Multiply this difference in elevation in feet by 0.434 to reduce it to difference in static head in pounds per square inch.

Obtain an estimate of the friction loss of the water meter in pounds per square inch, if one is to be installed, for the total demand rate of flow. See section V–4 following for data on loss in head caused by water meters and information regarding selection of size of meter.

Decide what the minimum pressure at the highest fixture or group of fixtures should be for satisfactory operation. This pressure should not be less than 15 lb/in.^{2} for flush valves, and not less than 8 to 10 lb/in.^{2} for fixtures with faucets or flush-tank supplies.

Add the difference in static head, the pressure for satisfactory operation of the highest group of fixtures, and the estimated pressure loss through the meter, and subtract the sum from the service pressure. Divide this difference by the developed length of pipe from the water main to the highest group of fixtures, and multiply the quotient by 100. The result will be the maximum allowable friction loss for pipes in the system in pounds per square inch per 100 feet of pipe. With this factor and the estimated demand carried by any particular part of the system, as for example the building main, refer to the appropriate flow chart and select the pipe size passing through or just above the point of intersection of the coordinate lines representing the estimated demand in gallons per minute and the allowable friction loss in pounds per square inch per 100 feet of pipe. Using the same allowable friction loss and the estimated demand load carried by the particular branch, proceed to branches of the system.

4. Pressure Loss in Water Meters

The following paragraphs based on "Standard Specifications for Cold Water Meters—Disk Type" [15] give information useful in selecting suitable sizes of water meters for particular installations and in estimating the loss in head caused by them.

Tables 7 and 8 are extracts from above-mentioned Standard Specifications.

Table 7 gives the "normal test flow limits," for disk-type water meters for sizes from ⅝ to 6 inches, which may be regarded as the limits of recommended ranges in capacities.

Table 8 gives the maximum allowable pressure loss for the different sizes of meters, 25 lb/in.^{2}, at the upper limit of normal test flow. Since the friction loss in a water meter depends on its size as well as on the rate of flow, table 8 contains insufficient data for estimating the head loss for different supply demands. Figure 9, from which an estimated loss of head for any rate of flow can be obtained, is based on the maximum allowable head loss, as given in table 8, and on the assumption that the head loss varies directly as the square of the rate of flow, an assumption which appears to be verified by experimental data [16].

Since disk-type meters are usually required by the purchasers to comply with the Standard Specification cited, new meters generally show a lower loss under test over the normal test-flow ranges than is given by figure 9, which is based on the maximum permissible head loss. Therefore, values for head loss taken from figure 9 for any given demand load and size of meter will be adequate and hence safe to use in computing the available pressure for friction loss in pipes. However, if data more nearly applicable to a particular make of water meter are desired, the manufacturers of water meters are prepared to furnish on the request of purchasers the needed information regarding their own meters, as is indicated by the following quotation, also from the Standard Specification: "* * * The manufacturer shall state in his bid the type of meter he proposes to furnish as listed in his catalogue. The actual capacity of each size of meter called for is to be given graphically from 0 pounds up to 25 pounds loss in pressure * * *." This information will probably be given in the form shown in figure 9.

Service water meters are usually purchased by the water department and installed for the customer on a service charge or rental basis, and are kept in order by the department; and probably most local water departments can supply information regarding capacity and head loss of the make or makes of meters used by them.

It will be observed that the serviceable ranges of capacities (normal test ranges) of meters of different sizes overlap to a large extent. Hence there is the possibility of a wide selection in size if it is made purely on the basis of the demand. For example, a demand of 20 gpm might lead to the selection of any size from ⅝ to 3 inches, inclusive, or a demand of 48 gpm might lead to the selection of any size from 1 to 6 inches, inclusive. Practically, however, the choice will be limited to two or three sizes at most.

The accepted practice, except in special cases, seems to be to install a meter of the same size as, or not more than one size less than, the building main or service connection. However, there is an inclination toward smaller meters for two reasons: (1) The initial cost of meters, and therefore the service charge, mounts rapidly with increase in size; and (2) the larger the meter is in any given installation, the greater part of the time it will operate below its lower limit of accurate measuring (see specification requirement), and therefore the less accurately the total water consumed will be metered. The practice of installing small meters may, and frequently does, result in inadequate pressure during periods of peak use, unless the excessive loss of head in the meter is balanced by a smaller friction loss in the building main, which means the selection of a larger size of pipe for the building main than would be required if a larger meter had been installed. The logical procedure is to examine all conditions pertaining to the particular building and to make the selection of both meter and pipe sizes from the standpoint of satisfactory service, that is, maintaining a satisfactory pressure at the fixtures under the estimated peak demand. See illustrative example under the following section 5.

The data in tables 7 and 8 and in figure 9 apply only to disk-type meters, which is the type used as service meters in the majority of cases. In case another type is installed, the corresponding capacity and head-loss data should be obtained and used in the manner described.

TABLE 7.—*Performance requirements of water meters*

["Registration. The registration on the meter dial shall indicate the quantity recorded to be not less than 98 percent nor more than 102 percent of the water actually passed through the meter while it is being tested at rates of flow within the specified limits herein under normal test flow limits: There shall be not less than 90 percent of the actual flow recorded when a test is made at the rate of flow set forth under 'minimum test flow'."]

Size	Normal test-flow limits	Minimum test flow
in.	*gpm*	*gpm*
5/8	1 to 20	1/4
3/4	2 to 34	1/2
1	3 to 53	3/4
1 1/2	5 to 100	1 1/2
2	8 to 160	2
3	16 to 315	4
4	28 to 500	7
6	48 to 1,000	12

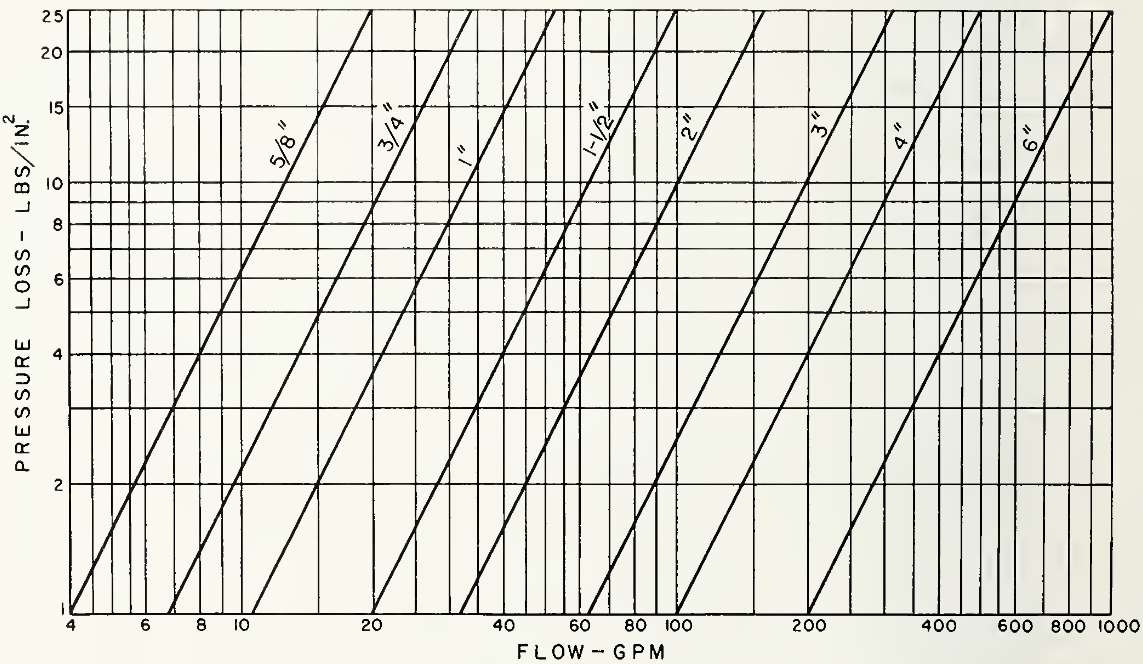

FIGURE 9.—*Pressure losses in water meters.*

TABLE 8.—*Maximum permissible loss of head in disk-type water meters*

["Capacity. New meters shall show a loss of head not exceeding 25 lb/.in.², when rate of flow is that given in the following table."]

Size	Rate of flow
in.	*gpm*
⅝	20
¾	34
1	53
1½	100
2	160
3	315
4	500
6	1,000

5. Example Illustrating Steps in Selecting Sizes of Water-Supply Pipes

The preceding steps may be presented in a more concrete form by assuming the data, which would ordinarily depend on local conditions and a particular building. For example, assume that: (1) A building is two stories in height and has two bathrooms, an additional water closet and lavatory, with flush tanks for all water closets, a kitchen sink, a two-compartment laundry tray, and a hose outlet for which a demand of 5 gpm is allowed; (2) the elevation of the highest fixture above the water main is 20 feet; (3) the developed length of pipe from the water main to the highest fixture, obtained from the building plans, is 120 feet; (4) the minimum daily service pressure is 45 lb./in.²; (5) galvanized-steel pipe has been chosen for use in the water-supply system; (6) information regarding the effects of the local water on galvanized steel indicates that the pipe will become fairly rough with no appreciable caking, so that figure 4 is the most suitable flow chart for estimating capacities; and (7) a service meter of the disk type is to be installed.

By reference to table 6, the total fixture units supplied through the building main are obtained as follows:

Kind of fixture or group	Number	Fixture units
Bathrooms	2	12
Water closet	1	3
Lavatory	1	1
Kitchen sink	1	2
Laundry trays	1	3
Total		21

Referring to curve 2 of figure 8, with 21 fixture units, it is found that the estimated peak demand for fixtures is approximately 15 gpm, to which 5 gpm for the hose outlet must be added, giving a total estimated demand for the building main of 20 gpm.

The allowable friction loss may now be computed, if we assume further that it is necessary to maintain a pressure at the highest fixture of at least 8 lb./in.² for satisfactory supply under peak demand. The loss in static pressure because of elevation is found to be $20 \times 0.434 = 8.68$ lb./in.² or approximately 8.7 lb./in.². Reference to table 7 shows that at least a ¾-inch meter should be used, since the estimated demand, 20 gpm, is at the upper limit of the recommended range for a ⅝-inch meter. Reference to figure 9 shows that the loss in head in a ¾-inch meter for a rate of flow of 20 gpm is about 8.7 lb./in.² Using approximate values for friction losses, the pressure available for friction loss in pipes may be computed as follows: $100[45 \text{ lb./in.}^2 - (8+8.7+8.7) \text{ lb/in.}^2] \div 120 = 16.3$ lb./in.² per 100 feet of pipe. Reference to figure 4 shows that the capacity of a 1-inch pipe for that estimated pressure available for friction loss in pipes is about 18 gpm, or a little less than the estimated demand.

If as an alternative to installing a 1¼-inch building main, which would obviously be more than ample, a 1-inch meter in installed, in which the head loss for a flow of 20 gpm is about 3.6 lb./in.², the pressure available for friction loss will become $100[45 \text{ lb/in.}^2 - (8.0 + 8.7 \div 3.6) \text{ lb./in.}^2] \div 120 = 22.5$ lb./in.². Reference again to figure 4 shows that the capacity of the 1-inch pipe for this friction loss is about 22.0 gpm, which is a little higher than the requirement.

It will be observed from this illustration that the builder has a possibility of three choices: (1) To install a 1-inch building main and a 1-inch service meter, which is a logical choice in relation to sizes; (2) to install a 1¼-inch building main with a ¾-inch service meter, which would result in more expensive pipe installation and a lower service charge on the meter than in the first alternative; or (3) to install a 1-inch building main with a ¾-inch service meter with the risk that the pressure at the highest fixture is likely to drop to 5 or 6 lb./in.² under peak demands, which are likely to occur only occasionally and for relatively short intervals. The third alternative will probably be wholly satisfactory, if the character of the water is favorable to maintenance of pipe capacities in service.

Having decided on the size of the building main and the size of the service meter, if one is installed, the pressure available for friction loss in the pipes, as determined for the building main, is also applicable to the principal branches of the water distributing system in the building, provided the distribution of the fixtures among the branches is known and the demand for each branch has been estimated.

For illustration, assume in this example that there are three principal branches to be considered: (1) A branch through which all cold water is supplied to the two bathrooms and the additional water closet and lavatory; (2) a branch leading to the hot-water heater from which the cold-water supply to the kitchen sink and set of laundry tubs is taken; and (3) the principal hot-water branch leading from the heater. Using the pressure available for friction loss in pipes as determined for a 1-inch building main with a 1-inch service meter, 22.5 lb/in.^{2} per hundred feet of pipe, the computations resulting from the use of table 6 and figures 8 and 4 may be compiled for convenience as illustrated in table 9.

TABLE 9.—*Results of applying table 6 and figures 8 and 4 for a particular service*

Fixture	Fixture units (table 6 and note 3)	Demand (fig. 8)	Pipe size (fig. 4)
BRANCH 1, COLD WATER ONLY			
		gpm	*in.*
3 flush tanks	3×3=9		
2 bathtubs	¾(2×2)=3		
3 lavatories	¾(3×1)=2.25		
Total	14.25	11	1
BRANCH 2, COLD-WATER LINE TO HEATER			
1 set laundry trays	1×3=3		
1 kitchen sink	1×2=2		
2 bathtubs	¾(2×2)=3		
3 lavatories	¾(3×1)=2.25		
Total	10.25	8	¾
BRANCH 3, MAIN HOT-WATER LINE			
1 set laundry trays	¾(1×3)=2.25		
1 kitchen sink	¾(1×2)=1.5		
2 bathtubs	¾(2×2)=3.0		
3 lavatories	¾(3×1)=2.25		
Total	9	7	¾

In the preceding illustrations, the allowance for decrease in capacities in service was made by referring to the flow chart for fairly rough pipe. If in any locality definite data for decrease in capacity with age of different kinds of pipe with the particular local water are available, a more appropriate allowance for corrosion and caking effects may be possible by subtracting the allowance from the capacities of new pipe of the kind to be used or by adding a corresponding allowance to the estimated load before referring to the flow chart for new pipe of that kind. Obviously, whatever methods are used, much depends on a knowledge of local conditions and the judgment of the engineer, especially in large or complicated water-distributing systems.

6. DEMAND ESTIMATES AND PIPE SIZES FOR PARTICULAR TYPES OF BUILDINGS

It is clear from the preceding discussion that the problem of estimating the peak water demand for buildings in general becomes more complex as the buildings increase in size and as the ratios of number of fixtures of different kinds vary with the occupancy of the building. For buildings in which the occupancy is solely residential, the same kinds of fixtures are ordinarily installed and in numbers of each kind that enable classifying as to peak demand. Thus, a small residence which has one bathroom and one combination fixture may be considered as one of a class or type which may be designated as type *A*. A residence which has one bathroom, one kitchen sink, and one set of from one to three laundry trays may be designated as type *B*. Two bathrooms, one kitchen sink, and one set of laundry trays may be designated as type *C*. In this manner it is possible to divide residences and small apartment buildings into a limited number of types for which demand estimates may be made and tabulated which will be applicable to these types for any locality, as illustrated in table 10. If desired, a corresponding tabulation of the pipe sizes needed to meet these demands, which will be applicable for the same types of buildings in localities where the minimum service pressure and the developed length of pipe are approximately the same, may be made, thus avoiding detailed computations for particular buildings of a given type.

TABLE 10.— *Water-demand estimates for typical buildings*

Type of building as to number and kind of fixtures	Kinds of fixtures			Total fixture units [1]		Total demand [2]	
	Bathrooms	Kitchen sinks or combination fixtures	Groups of 1 to 3 laundry trays	With flush valves for water closets	With flush tanks for water closets	With flush valves for water closets	With flush tanks for water closets
	Number	*Number*	*Number*	*Number*	*Number*	*gpm*	*gpm*
A	1	1	0	10	8	27	6
B	1	1	1	13	11	30	8
C	2	1	1	21	17	36	12
D	3	2	1	31	25	42	17
E	4	4	2	46	38	49	24
F	8	8	3	89	73	64	36
G	16	16	4	172	140	84	52

[1] Total fixture units from table 5.
[2] Total demand from figures 7 or 8.

For large buildings, such as apartment houses and office buildings, the procedure in selecting serviceable sizes of water-supply pipes will not differ essentially, except in magnitude, from that described in detail for residential types. However, buildings of this category are not so susceptible as detached residences to classification into types in respect to the number, kind, and distribution of plumbing fixtures; and because of this, each building will present a distinct problem that should be handled by a competent engineer experienced in the field of water supply for buildings.

Likewise the procedure for selecting serviceable sizes of supply pipes in a down-feed system from a storage tank will not be essentially different from that described, except that the supply to the storage tank may be safely based on the estimated average demand during the period of heaviest use of water, provided the tank is of sufficient capacity to take care of the excess of temporary peak demands over the average demand, and that the sizes of down-feed pipes are so selected that the gain or difference in static head from the tank to any lower level is equal to or greater than the friction loss under the estimated peak demand.

7. Networks of Pipes in Water-Distributing Systems

The procedure described in the preceding sections in considerable detail is applicable to small buildings and to larger buildings in which the water-distributing system consists of a single building main with simple branches and risers. However, as supply systems increase in size and complexity, the problem becomes one for an engineer experienced in this field and cannot be adequately treated in a brief discussion, except as to the general method of procedure. Networks of pipes, sometimes used in water-distributing systems, require special consideration as to methods employed.

If a building has two or more interconnected building mains from the same or different street mains, thus forming a network of pipes, or has two or more supply risers interconnected by headers, thus forming a network of pipes in the water-distributing system of the building, the problem becomes much more complicated than for the conventional case in which the building main, risers, and branches are in series. In the case of a network of pipes, the total flow (load) will be distributed among the branches of the network in relation to the relative resistances of the different branches, that is, in relation to the diameters and lengths of the branches. It is not the purpose of this report to go into the details of the solution of this problem but merely to point out the possibility of its occurrence in the water supply of buildings and the necessity of considering the distribution of the demand load in such cases.

A general method of considering the distribution of flow in pipe networks is given by Cross [17]. A method for solving the problem of pipe networks by a series of approximations based on the Cross method has been given by Fair [18, 19]. A knowledge of the principles of pipe flow is necessary in applying these methods.

VI. CONCLUSIONS

(1) Because of the many factors involved in determining the minimum serviceable sizes of supply pipes for buildings, which vary for different buildings, it is not feasible in general to set up minimum requirements for water-supply pipes in terms of diameters.

(2) Except for fixture branches, the sizes of water-supply pipes for any particular building should be determined from the estimated peak or maximum demand for the building, and the

estimated pipe capacities should be based on the particular conditions encountered, including available service pressure, elevation of the highest fixtures above the street main, and the estimated effects of the water on the capacity of pipes in service.

(3) The minimum sizes of fixture supplies for different fixtures are standardized for Federal use (Federal Specification WWP–541a), and these minimums logically apply to the fixture branch connecting to the fixture supply.

(4) Estimates of total maximum water demand for any number of fixtures of the same or different kinds can be made by applying relative load-producing values (fixture-unit values) for different fixtures and occupancies and computing the probability of overlapping demands, apparently with greater accuracy than the capacity of building supply systems after they have been in use a number of years can be estimated.

(5) For complicated building water-supply systems the design or piping layout and the selection of material and pipe sizes should be delegated to an engineer experienced in this field.

(6) More information than is now available regarding the effects of waters of different character on the capacities of pipes in service is needed to enable the engineer to make more accurate estimates of capacities of building water-supply systems. (See appendix).

VII. APPENDIX

Frequent reference has been made in the body of this report to the lack of data on the effects of water supplies of different characters on the capacities of water-supply pipes in service. This further discussion, briefly outlining the author's conception of the scope of a research program for obtaining these data and suggesting a possible means of instituting it, is offered in the hope of stimulating interest in a cooperative organization of such a research program. Although a great volume of research has been done on the corrosion of pipes and flow in pipes corroded in service, these researches have been largely of a sporadic nature, have not extended over long periods of time, have not included any great variety of materials or variety in waters of known composition, and have not been correlated as to purpose and methods of procedure. When an attempt is made to analyze and correlate these data in some systematic manner, it is usually found that essential measurements and information regarding conditions under which the data were obtained are lacking.

In order to supply the greatest amount of correlated information, any research program undertaken for the purpose suggested should include an investigation of all materials commonly used as water pipes in a sufficient number of public water supplies to be representative of all public water supplies of the country, should be correlated in advance as to methods, measurements to be taken, conditions to be recorded, and form of reports to be rendered, and should extend over a period of 20 years or more.

The program suggested is probably prohibitive as an undertaking for any single or small group of laboratories, both in respect to its cost and its demand for research personnel. However, it would not seem to be prohibitive in either respect, if such a research program were sponsored and financed to a limited extent by several national organizations interested in a project of this nature. The undertaking could be directed by a research and correlating committee representative of engineering societies, universities and engineering colleges, trade associations dealing with pipes, fittings, and plumbing materials, Federal, State, and municipal organizations, and building associations. It seems probable that many engineering schools could and would assume the responsibility for carrying out the program in its relation to one particular public water supply. The actual research work involved in any one year in one laboratory might appropriately be made the subject of a senior or graduate student thesis, the thesis constituting the partial or annual report of the research. If this last system proved feasible, except for the initial cost of material the expense of carrying the work would probably not exceed that of the usual thesis research work.

No extensive financing should be necessary to carry out this proposed program. In fact, the general financing probably would not need to extend beyond the expenses of the committee.

The preceding discussion merely suggests the problem and roughly outlines a possible method of attack. The questions of what material to use and what allowance to make for decrease in capacities of pipes of different materials with a particular water are the most difficult to decide in designing for satisfactory water supply for a building. The results of a well-conducted research along the lines suggested would be of great value, not only in this field but in others concerned with the conduction of water. If the proposal were carried no further than the setting up of a research committee and promulgating a statement of the problem with a complete outline of experimental procedure, it would have an educational value and would act as an incentive to those who might take up research independently along similar lines to include data of general value in addition to those required for their particular purposes.

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