NBS MONOGRAPH 86

# Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems





U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

## THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

**Institute for Basic Standards.** Electricity. Metrology. Heat. Radiation Physics. Mechanics. Applied Mathematics. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radio Standards Laboratory: Radio Standards Physics; Radio Standards Engineering.** Office of Standard Reference Data.

**Institute for Materials Research.** Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.** Office of Standard Reference Materials.

**Central Radio Propagation Laboratory.**** Ionosphere Research and Propagation. Troposphere and Space Telecommunications. Radio Systems. Upper Atmosphere and Space Physics.

**Institute for Applied Technology.** Textiles and Apparel Technology Center. Building Research. Industrial Equipment. Information Technology. Performance Test Development. Instrumentation. Transport Systems. Office of Technical Services. Office of Weights and Measures. Office of Engineering Standards. Office of Industrial Services.

---

*NBS Group, Joint Institute for Laboratory Astrophysics at the University of Colorado.

**Located at Boulder, Colorado.

UNITED STATES DEPARTMENT OF COMMERCE • Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

# Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems

Robert S. Wyly

National Bureau of Standards Monograph 86

Issued December 18, 1964

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C., 20402 - Price 35 cents

Library of Congress Catalog Card Number: 64-60067

# Contents

# Investigation of the Hydraulics of Horizontal Drains in Plumbing Systems

**Robert S. Wyly**

Results are reported from an investigation of the hydraulics of flow in experimental apparatus simulating nominally horizontal simple and branching drains of plumbing systems. The data are correlated with limited findings in an earlier, unpublished NBS study the results of which have been utilized in current plumbing codes. The need for further research is pointed out, particularly in relation to hydraulic performance of drain systems as affected by steep slopes, drain storage volume, energy losses at stack bases, attenuation of water depths and discharge rates in long drains, and large drain diameters.

Analysis yielded equations useful in estimating hydraulic capacities for surge flow or for surge flow superimposed on steady flow over a range of conditions. Capacity estimates for the large drains are substantially greater than formerly assumed. The experimental findings suggest that through careful design it may be possible to reduce the number of conventional vents extending above plumbing fixtures in small systems such as those in one- and two-family houses. The results, of interest to writers of plumbing codes and handbooks, have important applications in computation of optimum plumbing loads on building drains and building sewers, in terms of actual plumbing fixtures.

## 1. Introduction

Knowledge of the hydraulics of nominally horizontal drains under conditions similar to those occurring in service in building sanitary drainage systems is essential to the rational computation of minimum pipe sizes for such systems. This paper provides some of this needed information, particularly that concerning the hydraulics of sanitary building drains and building sewers. Investigations of some of the factors which affect hydraulic capacities of such drains are reported.

The typical discharge into a drainage system produced by plumbing fixtures is intermittent in occurrence and variable in magnitude; and on many occasions there is discharge due to concurrent operation of two or more fixtures. A method of estimating discharge for design purposes under these conditions is required in order to compute drainpipe sizes. A method which has gained widespread acceptance in the United States has been described in some detail [1, 2].[1]

In early plumbing codes the computation of minimum sizes of horizontal drains was based on the assumption of steady, uniform flow. This basis is still employed in some codes, but many modern codes employ design criteria based on heretofore unpublished experimental data on unsteady or "surge" flow and on flow interference at drain junctions. These criteria were developed by the late Dr. R. B. Hunter, who was in charge of plumbing research at the National Bureau of Standards from 1921 to 1943. Hunter's experimental data provided an improved basis for the determination of drain loadings as given by BMS66, Plumbing Manual [3]. Design requirements for horizontal drains derived from BMS66 have been utilized by model codes and handbooks [4, 5, 6, 7, 8] and by numerous State and municipal plumbing codes.

Prolonged illness and subsequent death prevented Dr. Hunter from preparing a technical paper on his investigation of flow in horizontal drains and on the computation of pipe sizes from the data. Without the information this paper would have provided it has been difficult to evaluate, or to make improvements in the procedures for selecting sizes of horizontal drains presently based on his data. This was recognized particularly by the Coordinating Committee for a National Plumbing Code [5]. This committee made some improvements in the loading tables originally developed by Hunter [3], but found the lack of documentation of Hunter's work on horizontal drains seriously handicapped its review of loading tables. Although experience had indicated that adequately large pipe sizes apparently resulted from drain design in accordance with BMS66, the committee realized that since the time at which Hunter's recommendations were made, there had been some significant changes in available types and hydraulic properties of plumbing equipment and in the typical use of this equipment. Furthermore, some members of the committee felt that drain design in accordance with BMS66 or with some of the state and municipal codes actually resulted in pipe sizes larger than necessary in many systems, and that the design procedures lacked desirable flexibility. These considerations by the Coordinating Committee indicated that further research on horizontal drains was needed.

In this paper, data obtained by Hunter and by the author are reported from laboratory investigations of (1) surge flow introduced into empty simple drains, (2) attenuation of surges in simple drains, (3) continuous full-section flow in simple drains under substantially steady, uniform conditions, (4) steady flow in compound drains, and (5) surge flow introduced through a branch drain

[1] Figures in brackets indicate the literature references on pages 35–36.

into the side or top of a main drain carrying steady flow. In addition to the laboratory data, some of Hunter's field observations on flow in building drains are reported.

Code writers and design engineers may find the equations developed for estimating hydraulic capacities over a range of conditions useful in computing permissible plumbing loads on building drains and building sewers. These equations should contribute to increased flexibility and rationality in the design of such drains. The relations should be particularly useful in design computations in the event that further research should prove the feasibility of achieving adequate venting of fixture drains in plumbing systems for houses through maintenance of a continuous air-space above the water surface in horizontal branches, building drains and building sewers so as to minimize or eliminate the need for conventional dry vents extending above fixture flood level rim height.

## 2. Symbols and Definitions

Insofar as practicable, the terminology used in this paper is in agreement with American Standard ASA Y10.2—1958, Letter Symbols for Hydraulics, and with American Standard ASA A40.8—1955, National Plumbing Code. The following explanation of terms is given for the convenience of the reader. Definitions marked with an asterisk are not defined in the above standards.

Symbols:

| | |
|---|---|
| $A$ | cross-sectional area |
| $C$ | the Chezy coefficient of roughness |
| $D$ | diameter |
| $e$ | the base of the natural system of logarithms (numerically, 2.718) |
| $f$ | the Darcy-Weisbach coefficient of friction |
| $F$ | force |
| $g$ | acceleration of gravity (numerically, 32.2 ft/sec$^2$) |
| $h$ | head |
| $k_d$ | Nikuradse roughness magnitude for drain |
| $k_s$ | Nikuradse roughness magnitude for stack |
| $K$ | a dimensionless coefficient |
| $L$ | length |
| $N_R$ | Reynolds number |
| $n$ | the Manning coefficient of roughness |
| $\nu$ | kinematic viscosity |
| $p$ | pressure |
| $\pi$-terms | ($\pi_1$, $\pi_2$, $\pi_3$, etc.) groups of dimensionless parameters derived from dimensional analysis |
| $Q$ | volume rate of flow (discharge rate) |
| $r_h$ | hydraulic radius |
| $R$ | ratio of water section to cross section of drain or stack |
| $\rho$ | density (mass per unit volume) |
| $S$ | drain slope |
| $t$ | time |
| $\phi$ | functional symbol |
| $\theta$ | angle of inclination from the horizontal (equivalent to $S$) |
| $V$ | mean velocity |
| $z$ | vertical distance from drain invert to center of gravity of cross section of water stream |

Subscripts:

| | |
|---|---|
| $c$ | confluence of steady flow and surge flow at junction in compound drain system |
| $d$ | drain |
| $i$ | initial conditions |
| $j$ | jet |
| $s$ | stack |
| sfc | steady flow capacity |
| sg | surge |
| st | pertaining to steady flow introduced into drain entrance as a jet of water of given cross section at a rate sufficient to equal the steady flow capacity of the drain |
| $t$ | terminal conditions |
| 1 | main drain |
| 2 | branch drain |

Definitions:

**Attenuation* refers to diminution of depth, velocity, and/or discharge rate with time or length.

The *building* (*house*) *drain* is that part of the lowest piping of a drainage system which receives the discharge from soil, waste, and other drainage pipes inside the walls of the building and conveys it to the building (house) sewer beginning 3 ft outside the building wall.

The *building* (*house*) *sewer* is that part of the horizontal piping of a drainge system which extends from the end of the building drain and which receives the discharge of the building drain and conveys it to a public sewer, private sewer, individual sewage-disposal system, or other point of disposal.

**Capacity* is synononous with hydraulic capacity or flow capacity (see *flow capacity*).

The **capacity surge* refers to a surge, specifically described by volume rate of input flow and time duration, which results in the hydraulic capacity of the drain being attained.

A **compound drain* is a system of connected conduits in which the main drain is nominally horizontal, and in which there are one or more branch drains.

The **crown* of a horizontal drain is the topmost point on a cross section of the bore.

A *drain* is any pipe which carries waste water or water-borne wastes in a building drainage system.

A *drainage system* (drainage piping) includes all the piping within public or private premises, which conveys sewage, rain water, or other liquid wastes to a legal point of disposal, but does not include the mains of a public sewer system or private or public sewage-treatment or disposal plant.

A *fixture drain* is the drain from the trap of a fixture to the junction of that drain with any other drain pipe.

The **flow capacity* or **hydraulic capacity*, of a drain is the maximum volume rate of input flow which can be received without producing hydrostatic pressure at the crown of the drain somewhere along its length.

A *horizontal branch* is a drain pipe extending laterally from a soil or waste stack or building drain, with or without vertical sections or branches, which receives the discharge from one or more fixture drains and conducts it to the soil or waste stack or to the building (house) drain.

**Hydraulic capacity*, see **flow capacity*.

The term **hydraulic elements*, as applied to a given cross section in a horizontal drain, refers to hydraulic radius, depth, mean velocity, discharge rate, wetted perimeter, and cross-sectional area of water stream.

**Initial* area, velocity, or cross section of surge refers to the surge as it approaches the stack-base fitting and before it enters a horizontal test drain. The **invert* of a horizontal drain is the lowest point on a cross section of the drain.

The **local attenuating force* as used in this paper refers to the gravity induced accelerative forces near the ends of a surge of limited length which tend to "flatten" the surge and hence to inhibit it from fully occupying the cross section of the drain.

A **primary branch* (of the building drain) is the sloping drain extending from the base of a soil or waste stack to its junction with the main building drain or with another branch thereof.

**Relative capacity* is the ratio of the hydraulic capacity of a simple drain for surge flow to the capacity of the drain for steady flow.

**Relative discharge rate*, with reference to a compound drain, is the ratio of the rate of discharge in either the main or a branch drain to the steady flow capacity of the main.

A **secondary branch* (of the building drain) is any branch of the building drain other than a primary branch.

A **simple drain* is a single conduit without branches, is used as a drain, is in uniform alinement, and has uniform slope and diameter.

A *soil pipe* is a pipe which conveys the discharge of water closets or fixtures having similar functions, with or without the discharge from other fixtures.

**Steady flow* is a type of flow in which the hydraulic elements at any cross section in the stream are constant with time.

**Steady flow capacity* refers to the hydraulic capacity of a drain in which steady flow is maintained.

**Surge flow* refers to a type of flow produced by discharging water into a drainage system at a substantially constant volume rate for a limited period of time.

**Surge-flow capacity* is the hydraulic capacity associated with a capacity surge.

**Time duration of surge* is the length of time for which a jet of water was allowed to discharge into a test drain at a substantially constant volume rate of flow.

**Uniform flow* is a type of flow in which the hydraulic elements are constant from section to section along the stream at any given time.

A *vent pipe* (or system) is a pipe (or pipes) installed to provide a flow of air to or from a drainage system or to provide a circulation of air within such system to protect trap seals from siphonage and back pressure.

A *waste pipe* is a pipe which conveys only liquid waste, free of fecal matter.

## 3. General Characteristics of Hydraulic Phenomena

The nature of fluid flow in sanitary drainage systems is described briefly to acquaint the reader with the general characteristics of the phenomena dealt with in these investigations; and to indicate the basis for methods of computing hydraulic capacities of nominally horizontal drains derived from the experimental data.

The flow at any point in a horizontal drain serving a number of plumbing fixtures will fluctuate with time. The drain is in general only partially filled or empty, and the stream varies in depth and velocity. It seems reasonable to consider the flow as comprising either surges introduced into an empty drain, or as comprising a combination of surges superimposed on antecedent flow.

Minimum time duration of surge is associated with the discharge of a single plumbing fixture into the drain to which it is connected. If several fixtures are connected to a horizontal branch, random overlap of the individual discharges will form composite surges characterized by average volume rates of flow and time durations greater than in the case for a single fixture. As these discharges move through the vertical and horizontal members of the drainage system, the gravitational and frictional forces produce significant changes in the hydraulic characteristics. In large systems, particularly at considerable distances from the origin of hydraulic loading, the surges tend to coalesce and to produce a condition approaching steady flow. However, it is generally recognized that in most drainage systems, particularly in those of small or moderate size, the flow is definitely unsteady and nonuniform, and at times is nonexistent.

In many instances, the velocity at which water is discharged into a sloping drain of a plumbing system is greater than can be maintained in that drain by gravity. This is particularly true for a building drain at the base of a tall stack. However, the excessive velocity is reduced because initially frictional forces are large in relation to gravitational forces acting parallel to the invert of the drain. During this early stage of movement through the drain, the surge depth actually increases. The distance from the drain entrance at which a maximum surge depth occurs appears to be influenced by the velocity and cross section of the stream at entrance; by the diameter, slope, and roughness of the drain; and by water already flowing in the drain when the surge is introduced. After maximum depth is produced, gravitational forces become predominant. Subsequently, the surge depth gradually decreases and its length increases. Downstream from the section of maximum depth the hydraulic elements undergo continuous change. For this reason, some attention was given to surge attenuation.

Characteristic behavior of a surge in a simple drain, observed at the station at which maximum depth was produced in a laboratory experiment, is shown in figures 1 to 3. The drain was vented by holes along the top of the drain spaced at intervals of approximately 4 ft. This assured pneumatic pressures near atmospheric and eliminated the necessity for considering possible effects of pneumatic pressures substantially different from atmospheric. This type of venting produced essentially the same venting effects as are attained in actual building drains by other means.

The surge shown in the photographs was introduced into the drain at essentially a constant volume rate for a limited time and at a velocity in excess of that which could be maintained in the drain at the particular slope used. Three successive stages are shown in the development of the surge at intervals of a few seconds. In figure 1, the surge approaches from the right. Figure 2 shows the existence of full-conduit flow at the observation station as indicated by a slight spurt of water thrown upward from the observation hole. The flow at the drain entrance had been stopped by suddenly closing a control valve before the maximum depth occurred. The surge did not fill the drain at other stations along the length of the drain. Figure 3 shows rapidly decreasing depth. Subsequent to the time of maximum depth at any station along the length of the drain, attenuation of depth at that station continued until the drain was empty. Observations showed that the hydraulic capacity of the drain for surge flow, as indicated by a full section without hydrostatic pressure at the crown of the drain, exceeded its steady flow capacity.

The mutual interference of two streams of water which meet at the junction of a compound drain causes a local increase in water depth near the junction. If the interference is excessive, the drain may become full under pressure for some distance upstream and downstream from the junction. If this happens, low-set fixtures may be flooded and trap seals may be lost because of excessive pneumatic pressures. Most building drainage systems exhibit at least one example of a compound drain, particularly below grade where primary and secondary branches of the building drain are joined.

FIGURE 1. *Surge approaching observation station from right.*

FIGURE 2. *Surge fills drain for short distances upstream and downstream from this station.*

Figures 4 to 7 show flow interference at the junction of a compound drain carrying flow in both the branch and the main. The main drain was vented as described above for the simple drain. Figures 4 and 5 show a full section (capacity condition) in the vicinity of the junction, produced by steady flow in the branch and the main. Measurements showed that the sum of the two flow rates was less than the steady flow capacity of the main.

Figures 6 and 7 are the first and last photographs, respectively, in a sequence not shown completely here. They indicate the development of a full section at the junction due to flow interference between surge flow in the branch and steady flow in the main. The main drain was not filled either upstream or downstream from the junction. The hydraulic capacity of the system for steady flow, as indicated by a full section at the junction and by the absence of hydrostatic pressure at the crown of the drain, was in general less than the steady flow capacity of the main alone. The hydraulic capacity of the system for combined surge and steady flow was greater than the system capacity for steady flow in both the branch and the main.

FIGURE 3. *Water depth decreases rapidly after maximum depth is produced.*

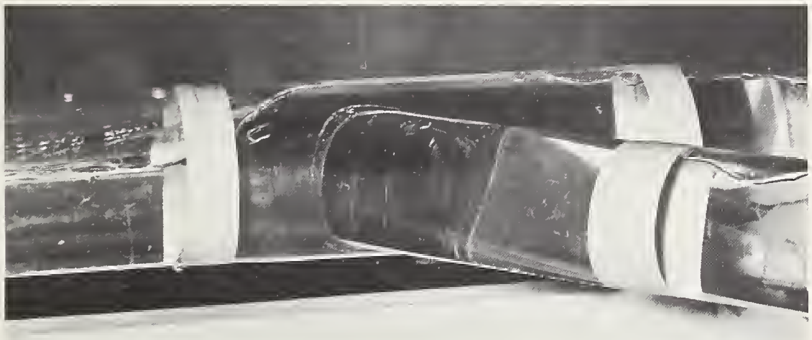

FIGURE 4. *Elevation view of full-section condition at junction in compound drain (steady flow in main and in branch).*



738-631 O - 64 - 2

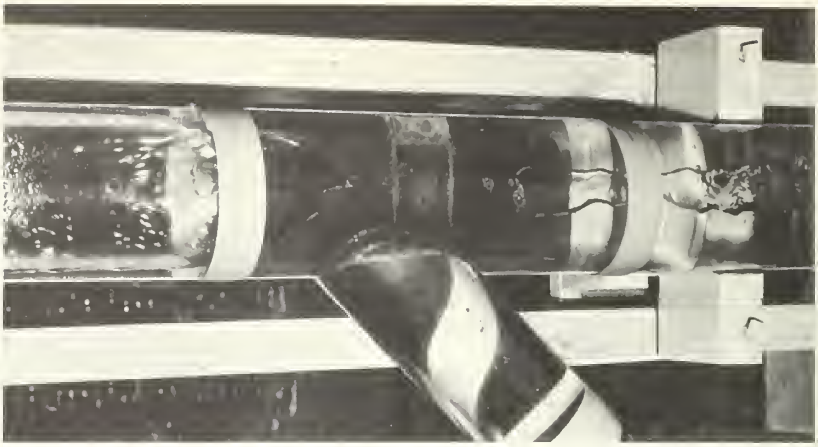

FIGURE 5. *Plan view of condition at junction in compound drain shown in figure 4.*

FIGURE 6. *Elevation view showing surge from branch entering main which is carrying a small steady flow.*
Main is not completely filled upstream or downstream from junction.

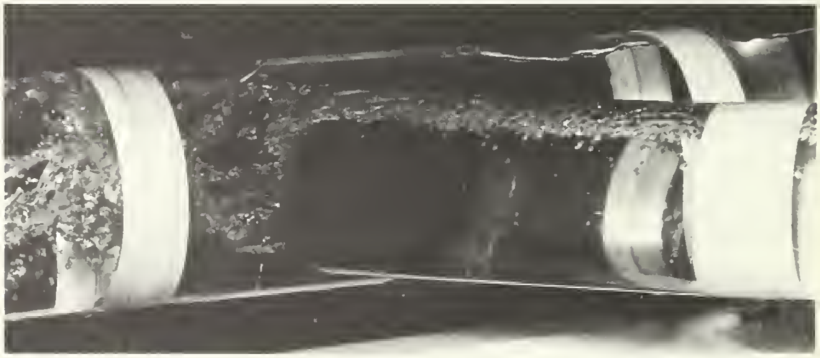

FIGURE 7. *Continuation of surge in branch soon produces a full section at junction.*

## 4. Field Study

### 4.1. Test methods and Apparatus

Hunter installed gages on the building drains of several large buildings by tapping the top and bottom of each drain. Two types of gage were used. The first was an external glass tube connected to the top and the bottom of the drain, and the second was a simple piezometer tube connected to the bottom of the drain near the same point as was the first gage, the upper end being open to the atmosphere. Under conditions of steady flow, the elevation of the water surface in the closed gage was the same as that within the drain, and the elevation of the water surface in the open gage indicated the sum of the pneumatic and hydrostatic pressures at the drain invert. The difference between the indications of the two gages was the penumatic pressure within the drain.

A modified form of the closed gage was used for determining maximum water depths in building drains over a period of days. Small water traps were connected to the gage tube at vertical intervals of ½ in. The elevation of the inlet connection of the highest trap in which water was collected indicated the highest elevation, within ½ in., reached by the water in the tube.

Observations were made by the use of the gages both in occupied buildings with normal use of fixtures and in unoccupied buildings with manual test flushing of fixtures. Descriptive information on the buildings in which observations were made is given in table 1.

TABLE 1. *Buildings investigated in field study of flow in building drains*

| Building No. | Location | Type | Height | Occupancy | Drains observed |
|---|---|---|---|---|---|
| 1 | Washington, D.C | Office and laboratory | 4-story and basement | Occupied | 4-in. primary and 6-in. secondary branches. |
| 2 | Washington D.C | Office | 6-story and basement | Unoccupied (new) | 6-in. branch. |
| 3 | New York, N.Y | Office, storage, and laboratory. | 12-story and basement | Occupied | Two 5-in. main drains [a]. |
| 4, 5 | New York, N.Y | Apartment | 16-story | Unoccupied (new) | Various primary and secondary branches. |
| 6 | New York, N.Y | Hotel-apartment | | Unoccupied (new) | 6-in. and 10-in. primary branches. |
| 7 | New York, N.Y | Office | 22-story | Occupied | 6-in. secondary branch [b] (combined storm and sanitary). |

[a] One of the 5-in. drains served 51 water closets, 43 wash basins, 19 urinals, and 12 slop sinks. These fixtures were used by 450 resident workers and an unestimated number of transients. The other 5-in. drain served 52 water closets, 54 wash basins, 18 urinals, 12 slop sinks, being used by 680 resident workers and an unestimated number of transients.

[b] The 6-in. combined drain served 180 water closets, 75 wash basins, 39 urinals, 22 slop sinks, and 2,500 ft² of storm-drainage area. Fixtures in basement were drained into a sump which was emptied into the building drain by an ejector. It was estimated that 5,700 resident workers and 3,300 transients had daily access to the toilets.

### 4.2. Results

A brief summary of the field observations will be given, since this information was later utilized in the design of apparatus and in establishing hydraulic conditions for laboratory experimentation.

The results of flushing a single water closet, as observed from gages attached to the drains in the manner described in section 4.1, were as follows: (1) the water level in open and closed gages rose rapidly to the same height in both, then gradually receded with fluctuations to approximately the same level in both gages; and (2) the time interval required for the stream to pass an observation point varied from two to twelve times the duration of flow at the fixture. In general, the interval increased with length of drain between the fixture and the observation point.

The results of flushing a number of water closets either in rapid succession or simultaneously were: (1) for moderate rates of flow, the water levels in the open and the closed gages rose with fluctuations to approximately the same elevation in both and receded as described for the flow from a single closet, with the exception that time durations of flow and maximum indicated water depths were greater; (2) for rates of flow sufficient to fill the drain greater than approximately one-fourth the drain diameter at the observation point, the gages indicated the existence of fluctuating positive pneumatic pressures the magnitude of which increased with water depth; and (3) for rates of flow sufficient to produce indicated water depths in excess of half the drain diameter, large pneumatic-pressure fluctuations were observed, indicating that intermittently the crests of surges of water may have filled the drain at one or more cross sections and produced excessive pneumatic pressures.

The gages equipped with miniature traps indicated that normal use of fixtures during the periods of observation did not cause the drains to flow full at the stations where the gages were located.

Flushing of fixtures in buildings, either manually or through normal use, proved to be an unsatisfactory method of producing hydraulic loadings for test purposes. Satisfactory methods for measuring volume rates of flow in the drains could not be developed in the time allotted to the field observations. Under the fluctuating conditions produced by sewage flowing in the building drains of occupied buildings, the gages did not always give accurate indications of pressures and water levels because of lag or overthrow of the gages. Therefore, in some cases the peak pressures and water depths actually may have been either somewhat less or greater than indicated by the gages. For these and other reasons, the field study was discontinued. Experimentation was continued in the laboratory, where rates of flow could be controlled and measured, and where drain slope, length, and diameter could be varied in a systematic order.

The field study indicated to Hunter the need for laboratory study of (1) surge discharge in an initially empty drain, and (2) surge discharge superimposed on antecedent flow, such as may occur at the junction of a primary and a secondary branch of a building drain.

## 5. Laboratory Experiments

### 5.1. Surge Flow in Initially Empty Simple Drains

#### a. Hydraulic Capacities

##### (1) Test Methods and Apparatus

Hunter measured surge-flow capacities in a simple drain approximately 70 ft in length. His apparatus is shown schematically in figure 8. The drain was constructed of 5-ft lengths of uncoated cast-iron soil pipe. Diameters of 3 and 4 in., each at successive slopes of 1/16, 1/8, and 1/4 in./ft, were used. A longitudinal slot about 1/4 in. wide and several inches long was cut in the crown of each length of soil pipe in order to relieve pneumatic pressures and to provide a visual indication of a full drain.

Water was introduced into the drain through a long-sweep quarter bend in a vertical plane. The water entered the quarter bend from a 3-in. pipe equipped with a gate valve for regulating the rate of discharge and a quick-opening gate valve for initiating and terminating the flow.

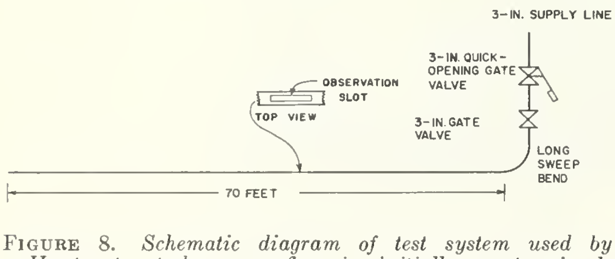


FIGURE 8. *Schematic diagram of test system used by Hunter to study surge flow in initially empty simple drains.*

Test surges were produced manually by suddenly opening the quick-opening valve, allowing the flow thus produced to discharge into the test drain at a substantially constant volume rate of flow for a selected interval of time, and then suddenly closing the valve. The cross-sectional form of the water jet produced is shown schematically in figure 9E. For each time interval, repeated trials were made until a rate of discharge was obtained such that the drain was barely filled for some small part of its length. The interval of time during which water discharged into the drain was taken as the surge duration, and the corresponding discharge rate was taken as the hydraulic capacity. The drain capacity was determined for steady, uniform flow without end restriction and without hydrostatic pressure at the crown of the drain in order to establish the extent to which surge-flow capacity exceeded steady flow capacity. The method used for adjustment of these values to simulate the condition of long drains is given in section 9.2 of the appendix.

More recently, the author investigated surge flow in simple drains approximately 98 ft long over an expanded range of test conditions. This apparatus is shown schematically in figure 10. The drain materials utilized were methyl methacrylate plastic tubing, galvanized-steel pipe, and cast-iron soil pipe. In general, drain slopes of 1/16, 1/8, and 1/4 in./ft were used. Plastic was used for 4- and 6½-in., steel for 3- and 4-in., and cast iron for 3- and 4-in. drains. Holes 5/8 in. in diameter were drilled in the crown of the drains at intervals (4.3 ft for the plastic, 5.0 ft for the cast-iron, and 5.3 ft for the galvanized-steel drains) to serve as air vents and as visual indicators of the existence of a full-conduit condition without hydrostatic pressure at the crown line.

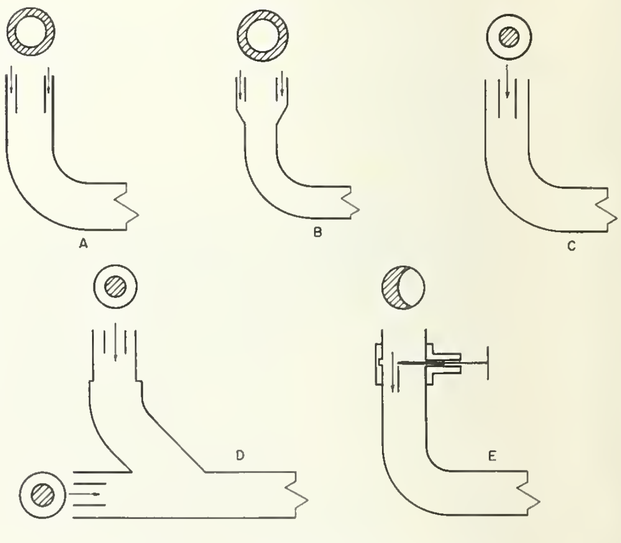


FIGURE 9. *Cross-sectional forms of jets.*

A. Annular
B. Modified annular
C. Single circular
D. Multiple circular
E. Crescent

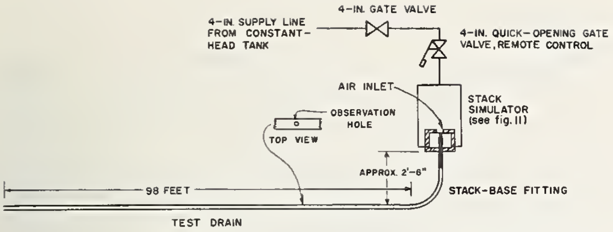


FIGURE 10. *Schematic diagram of test system used by author to study surge flow in initially empty simple drains.*

The quick-opening valve which initiated and terminated the surges introduced into the test drains was controlled by a pneumatic system actuated by a push-button electrical circuit. Surge duration time was measured with an electric stop clock. The clock was started by a microswitch actuated by a small paddle projecting into the cross section of the drain entrance, and stopped by another microswitch actuated by the handle of the quick-opening valve as it approached the closed position.

Initial velocities and cross sections of the test surges at a level about 2 ft above the center line elevation of the entrance to the test drain were predetermined by means of the stack simulator shown in figure 11 for an annular jet form. Inserts were provided such that jet forms of either solid cylindrical or annular shapes could be produced, as shown in figures 9A to 9D. Control of velocity and cross section was necessary to produce conditions at the base of the stack similar to those believed to occur in service [9]. Several cross-sectional forms of jets were used because the shape may vary in service depending on the geometry and dimensions of the installation. The form shown in figure 9D is an uncommon one, actually comprising two separate jets. This was necessary in some of the tests on the 6½-in. drain in order to introduce sufficient water to produce a capacity surge.

For each of various predetermined combinations of initial velocity and cross section, successive trials were made to determine the time duration of surge which caused the drains to flow full for the smallest possible portion of their length without producing hydrostatic pressure at the crown. Hydraulic capacities were determined both for surge flow, and for steady flow in the same drains for purposes of comparison. The determination of capacities for steady flow is explained in some detail in sections 9.1 and 9.2 of the appendix.

Volume rates of flow were measured with a calibrated orifice meter and a calibrated gate valve. The orifice meter was calibrated by volumetric measurement of steady discharge as a function of pressure drop across the orifice. The gate valve was calibrated by volumetric measurement of steady discharge produced by the available head from a constant head tank as a function of degree

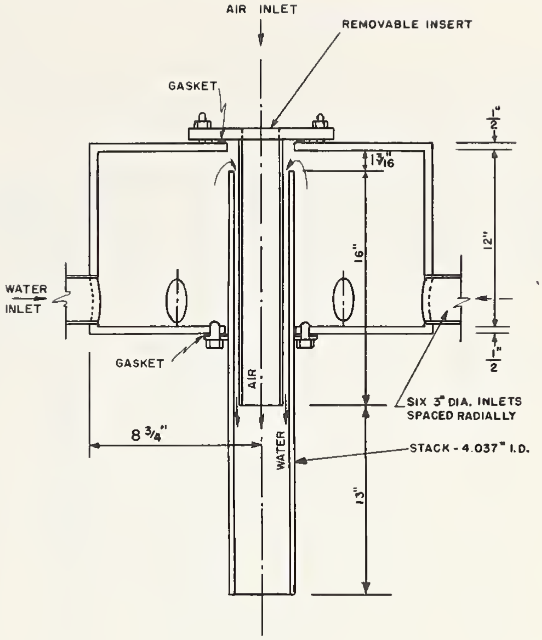


FIGURE 11. *Stack-flow simulator for producing jet of water having annular cross section.*

of opening of the valve wheel. The average rate of flow through the valve at a given degree of opening was not affected significantly by the time duration of flow for durations greater than 5 sec.

#### (2) Results

Characteristic performance of a surge in a simple drain has been described in section 3 and illustrated in figures 1 to 3. Tables 2 and 3 give experimentally determined drain capacities for surge flow in initially empty drains, using the apparatus described in (1) and illustrated in figures 8 to 11. Table 2 gives Hunter's data and table 3 gives the author's data. The ratio of initial jet velocity to theoretical stack terminal velocity was varied over a range. In this ratio, the terminal velocity is for a cast-iron stack of the same diameter as the drain, computed from eq (A–7) of section 9.4, assuming a value of $k_s$ of 0.00083 ft. Initial jet velocities at the bases of the test stacks may be computed from table 3 by dividing the column 10 value by the product of the corresponding column 8 value times the cross-sectional area of the drain, using dimensionally consistent units. Velocities for the data in table 2 may be obtained in the same way from column 4 and column 6 values.

Initial experimental velocities for Hunter's data ranged from about 2.2 to 5.2 times the maximum that should occur at the bases of multistory stacks in the field loaded with water-occupied

Table 2. *Surge capacities of initially empty, sloping, simple drains*

(Data on cast-iron soil pipe obtained under Hunter's direction, using crescent-shaped jet, long-sweep stack-base fitting, and open condition at lower end of drain)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|
| Drain diameter | Drain slope | Capacity [a] for steady flow | Ratio of initial area of stream [b] to area of drain | Time duration of surge | Capacity [c] for surge flow | Ratio of initial velocity to stack terminal velocity [d] | Ratio of capacity for surge flow to capacity for steady flow |
| *in.* | *in./ft* | *gpm* | | *sec* | *gpm* | | |
| [e] 3.00 | 1/16 | 32.8 | 0.042 | 30 | 42.0 | 5.22 | 1.28 |
| | | | .042 | 30 | 42.0 | 5.22 | 1.28 |
| | | | .042 | 20 | 42.0 | 5.22 | 1.28 |
| | | | .042 | 20 | 42.0 | 5.22 | 1.28 |
| | | | .042 | 20 | 42.0 | 5.22 | 1.28 |
| | | | .055 | 15 | 51.8 | 4.55 | 1.58 |
| | | | .055 | 15 | 51.8 | 4.55 | 1.58 |
| | | | .055 | 15 | 51.8 | 4.55 | 1.58 |
| | | | .075 | 10 | 66.8 | 3.90 | 2.04 |
| | | | .075 | 10 | 66.8 | 3.90 | 2.04 |
| | | | .075 | 10 | 66.8 | 3.90 | 2.04 |
| | | | .116 | 5 | 99.5 | 3.20 | 3.03 |
| | | | .116 | 5 | 99.5 | 3.20 | 3.03 |
| | | | .116 | 5 | 99.5 | 3.20 | 3.03 |
| | 1/8 | 46.8 | 0.061 | 40 | 54.5 | 4.25 | 1.17 |
| | | | .061 | 30 | 54.5 | 4.25 | 1.17 |
| | | | .064 | 20 | 59.3 | 4.27 | 1.27 |
| | | | .071 | 15 | 63.4 | 4.00 | 1.36 |
| | | | .086 | 10 | 74.3 | 3.61 | 1.59 |
| | | | .124 | 5 | 104 | 3.06 | 2.22 |
| | 1/4 | 66.7 | 0.083 | 40 | 72.5 | 3.68 | 1.09 |
| | | | .086 | 30 | 74.3 | 3.61 | 1.11 |
| | | | .089 | 20 | 76.7 | 3.57 | 1.15 |
| | | | .091 | 15 | 77.6 | 3.54 | 1.16 |
| | | | .095 | 10 | 81.8 | 3.49 | 1.23 |
| | | | .134 | 5 | 112 | 2.97 | 1.68 |
| 3.90 | 1/16 | 64.1 | 0.054 | 40 | 79.5 | 3.98 | 1.24 |
| | | | .054 | 30 | 79.5 | 3.98 | 1.24 |
| | | | .055 | 20 | 80.9 | 3.90 | 1.26 |
| | | | .068 | 15 | 97.0 | 3.54 | 1.51 |
| | | | .095 | 10 | 132 | 3.03 | 2.06 |
| | | | .149 | 5 | 193 | 2.44 | 3.01 |
| | 1/8 | 91.2 | 0.071 | 30 | 102 | 3.48 | 1.12 |
| | | | .075 | 25 | 107 | 3.38 | 1.17 |
| | | | .079 | 20 | 111 | 3.31 | 1.22 |
| | | | .094 | 15 | 130 | 3.05 | 1.43 |
| | | | .110 | 10 | 151 | 2.86 | 1.66 |
| | | | .165 | 5 | 207 | 2.29 | 2.27 |
| | 1/4 | 130 | 0.103 | 30 | 142 | 2.93 | 1.09 |
| | | | .106 | 30 | 146 | 2.89 | 1.12 |
| | | | .109 | 30 | 146 | 2.82 | 1.12 |
| | | | .108 | 20 | 149 | 2.88 | 1.15 |
| | | | .109 | 20 | 149 | 2.86 | 1.15 |
| | | | .109 | 15 | 150 | 2.86 | 1.15 |
| | | | .110 | 15 | 152 | 2.85 | 1.17 |
| | | | .125 | 10 | 167 | 2.67 | 1.29 |
| | | | .126 | 10 | 169 | 2.67 | 1.30 |
| | | | .175 | 5 | 215 | 2.21 | 1.65 |
| | | | .176 | 5 | 216 | 2.21 | 1.66 |

[a] Values given for steady flow capacity were derived by applying corrections in accordance with the rational pipe-flow formula to laboratory measurements of apparent steady flow capacities in drains 70 ft long discharging to atmosphere at the lower, open end (see sec. 9.2).

[b] Based on area of opening through gate valve which was used to control stream introduced through sweep fitting at drain entrance.

[c] Values given for surge flow capacity were derived from laboratory data giving degree of opening of control valve and a calibration curve showing rate of discharge as a function of degree of opening.

[d] Computed from eq (A-7) and from values in columns 1, 4, and 6. Equal stack and drain diameters were assumed. A value of absolute roughness of 0.00083 ft for the stack was used in the computations. This value was derived from resistance measurements on cast-iron soil pipe [9].

[e] Nominal diameter. The laboratory notes do not indicate the exact diameter of this drain.

cross sections indicated by the values in column 4 of table 2 assuming stack and drain diameter to be the same. The initial experimental velocities used in the author's tests reported in table 3 covered a more restricted range from a little less than 0.5 to about 1.3 times theoretical stack terminal velocity. This range of velocities is reasonable at the bases of drainage stacks in service.

Table 3 gives, among other information, the distances along the drains at which the full-conduit condition was observed. In the case of Hunter's data, shown in table 2, this distance is is not given, but was less than 20 ft from the drain entrance in all cases. The capacities of the test drains under conditions approaching steady, uniform flow are given in table 4.

Perhaps the most significant observations with reference to surge flow were:

1. For a given time duration of surge, actual surge-flow capacity increased with drain slope but relative capacity decreased,

2. for a given drain, capacity decreased with increasing surge-duration time, approaching as a lower limit the steady flow capacity of the drain, and

3. entrance velocity, initial area and shape of surge cross section, and drain roughness appeared to have small effect on relative capacity.

Detailed discussion of the experimental results appears in section 6.1.

### b. Surge Attenuation

#### (1) Test Methods and Apparatus

The attenuation of discharge rates of surges was investigated by Hunter. He first utilized a 4-in. drainage stack 10 stories in height with a building drain extending laterally 40 ft from the base of the stack. Building-drain diameters of 4, 5, and 6 in. at slopes of ⅛ and ¼ in./ft were used. For the 5-in. drain, a slope of 7/16 in./ft was also used. The drains were constructed of 5-ft lengths of cast-iron soil pipe. Single water closets were discharged into 4-in. branch drains at either the fourth or the tenth floor. The average rates at which the water closets discharged water into the branch drains were measured, and the cumulative discharges from the end of the building drain were measured volumetrically in a collecting tank for three consecutive 5-sec intervals after the water reached the end of the drain.

At another time, Hunter used the apparatus shown in figure 12 to measure instantaneous rate of flow at the discharge end of a horizontal drain produced by a water closet discharged directly into the upstream end without the use of an intervening vertical drain. The 60 radial compartments moved transversely beneath the discharge end of the drain at a constant angular velocity adjusted so that the full volume of a single operation of the water closet was discharged from the end of the drain in one revolution. The approximate instantaneous rate of discharge was computed as a function of time from the measurements of volume of water caught in successive compartments and of angular velocity. Drain diameters of 3 and 4 in., and lengths of 0, 1, 6, 11, 21, and 41 ft at a slope of ¼ in./ft were used successively. The drains were constructed of 5-ft lengths of cast-iron soil pipe.

TABLE 3. *Surge capacities of initially empty, sloping, simple drains*

(Author's data)

| (1) Drain diameter | (2) Drain slope | (3) Drain material | (4) Capacity for steady flow [a] | (5) Type of stack-base fitting | (6) Condition at lower end of drain | (7) Form of initial cross section of stream | (8) Ratio of initial area of stream to area of drain | (9) Time duration of surge | (10) Capacity for surge flow | (11) Ratio of initial velocity to stack terminal velocity [b] | (12) Distance from drain entrance to point at which surge filled drain | (13) Ratio of capacity for surge flow to capacity for steady flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| 2.985 | 1/16 | Plastic | 42.1 | Long sweep | Open | Modified annular. | 0.30 | 31.5 | 50.7 | 0.85 | 30.8 | 1.20 |
| | | | | | | | | 21.2 | 57.0 | .91 | 30.8 | 1.35 |
| | | | | | | | | 13.9 | 63.3 | .97 | 30.8 | 1.50 |
| | | | | | | | | 9.4 | 78.6 | 1.11 | 26.5 | 1.87 |
| | | | | | | | .37 | 9.0 | 77.7 | .86 | 26.5 | 1.85 |
| | | | | | | | | 4.7 | 97.1 | .98 | 22.1 | 2.31 |
| | | | | | | | | 3.1 | 116 | 1.10 | 17.7 | 2.76 |
| | | | | | | | .46 | 4.2 | 111 | .87 | 22.1 | 2.64 |
| | | | | | | Single circular | .21 | 31.5 | 54.1 | 1.23 | 39.7 | 1.28 |
| | | | | | | | | 22.8 | 58.7 | 1.29 | 35.2 | 1.39 |
| | | | | | | | .34 | 27.5 | 55.8 | .77 | 35.2 | 1.32 |
| | | | | | | | | 19.4 | 59.1 | .79 | 30.8 | 1.40 |
| | | | | | | | | 13.4 | 68.7 | .87 | 30.8 | 1.63 |
| | | | | | | | | 7.2 | 83.1 | .98 | 26.5 | 1.97 |
| | | | | | | | | 5.4 | 102 | 1.11 | 26.5 | 2.42 |
| | | | | | | | .40 | 8.0 | 84.6 | .86 | 26.5 | 2.01 |
| | | | | | | | | 5.3 | 107 | .99 | 26.5 | 2.54 |
| | | | | | | | | 3.6 | 128 | 1.10 | 13.3 | 3.04 |
| | | | | | | | .50 | 3.7 | 127 | .86 | 17.7 | 3.02 |
| 2.985 | 1/4 | Plastic | 90.8 | Long sweep | Open | Modified annular. | .37 | 25.1 | 97.1 | .98 | 66.1 | 1.07 |
| | | | | | | | | 20.5 | 97.1 | .98 | 66.1 | 1.07 |
| | | | | | | | | 5.0 | 116 | 1.10 | 30.8 | 1.28 |
| | | | | | | | | 5.2 | 116 | 1.10 | 30.8 | 1.28 |
| | | | | | | | .46 | 10.2 | 111 | .87 | 44.1 | 1.22 |
| | | | | | | | | 10.3 | 111 | .87 | 44.1 | 1.22 |
| | | | | | | | | 4.0 | 140 | 1.00 | 26.5 | 1.54 |
| | | | | | | | | 3.9 | 140 | 1.00 | 26.5 | 1.54 |
| | | | | | | | .53 | 3.2 | 142 | .87 | 22.1 | 1.56 |
| | | | | | | | | 3.9 | 142 | .87 | 26.5 | 1.56 |
| | | | | | | Single circular | .34 | 18.8 | 102 | 1.10 | 61.7 | 1.12 |
| | | | | | | | | 18.8 | 102 | 1.10 | 61.7 | 1.12 |
| | | | | | | | .40 | 14.5 | 107 | .99 | 57.3 | 1.18 |
| | | | | | | | | 14.2 | 107 | .99 | 57.3 | 1.18 |
| | | | | | | | | 5.3 | 128 | 1.10 | 35.2 | 1.41 |
| | | | | | | | | 6.0 | 128 | 1.10 | 35.2 | 1.41 |
| | | | | | | | .50 | 6.6 | 127 | .86 | 35.2 | 1.40 |
| | | | | | | | | 7.1 | 127 | .86 | 37.4 | 1.40 |
| 3.068 | 1/16 | Galv. steel | 40.7 | Long sweep | Open | Modified annular. | 0.28 | 21.4 | 57.0 | 0.92 | 28.1 | 1.40 |
| | | | | | | | | 14.2 | 63.3 | .99 | 25.5 | 1.56 |
| | | | | | | | | 10.3 | 78.6 | 1.12 | 25.5 | 1.93 |
| | | | | | | | 0.35 | 10.0 | 77.7 | 0.87 | 25.5 | 1.91 |
| | | | | | | | | 4.5 | 97.1 | 1.00 | 20.2 | 2.39 |
| | | | | | | | | 3.8 | 116 | 1.11 | 20.2 | 2.85 |
| | | | | | | | 0.43 | 3.8 | 111 | 0.88 | 20.2 | 2.73 |
| | | | | | | Single circular. | 0.20 | 29.8 | 54.1 | 1.24 | 30.8 | 1.33 |
| | | | | | | | | 19.6 | 58.7 | 1.30 | 30.8 | 1.44 |
| | | | | | | | 0.33 | 27.4 | 55.8 | 0.78 | 28.1 | 1.37 |
| | | | | | | | | 20.5 | 59.1 | .80 | 28.1 | 1.45 |
| | | | | | | | | 14.0 | 68.7 | .88 | 28.1 | 1.69 |
| | | | | | | | | 7.2 | 83.1 | .99 | 25.5 | 2.04 |
| | | | | | | | | 5.5 | 102 | 1.12 | 25.5 | 2.51 |
| | | | | | | | 0.38 | 7.9 | 84.6 | 0.87 | 25.5 | 2.08 |
| | | | | | | | | 5.5 | 107 | 1.00 | 22.9 | 2.63 |
| | | | | | | | | 3.6 | 128 | 1.12 | 20.2 | 3.14 |
| | | | | | | | 0.47 | 3.4 | 127 | 0.87 | 20.2 | 3.12 |
| 3.068 | 1/4 | Galv. steel | 84.0 | Long sweep | Open | Modified annular. | 0.35 | 11.7 | 97.1 | 1.00 | 36.0 | 1.16 |
| | | | | | | | | 7.2 | 116 | 1.11 | 33.4 | 1.38 |
| | | | | | | | 0.43 | 8.2 | 111 | 0.88 | 36.0 | 1.32 |
| | | | | | | | | 3.5 | 140 | 1.01 | 20.2 | 1.67 |
| | | | | | | | 0.50 | 3.6 | 142 | 0.88 | 20.2 | 1.69 |

See footnotes at end of table.

TABLE 3. *Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) Drain diameter | (2) Drain slope | (3) Drain material | (4) Capacity for steady flow [a] | (5) Type of stack-base fitting | (6) Condition at lower end of drain | (7) Form of initial cross section of stream | (8) Ratio of initial area of stream to area of drain | (9) Time duration of surge | (10) Capacity for surge flow | (11) Ratio of initial velocity to stack terminal velocity [b] | (12) Distance from drain entrance to point at which surge filled drain | (13) Ratio of capacity for surge flow to capacity for steady flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| | | | | | | Single circular. | 0.33 | 12.9 | 102 | 1.12 | 36.0 | 1.21 |
| | | | | | | | 0.38 | 10.7 | 107 | 1.00 | 33.4 | 1.27 |
| | | | | | | | | 5.4 | 128 | 1.12 | 28.1 | 1.52 |
| | | | | | | | 0.47 | 8.0 | 127 | 0.87 | 25.5 | 1.51 |
| 2.913 | 1/16 | Uncoated cast iron soil pipe. | 35.5 | Long sweep | Open | Modified annular. | 0.32 | 18.5 | 50.3.3 | 0.84 | 22.9 | 1.43 |
| | | | | | | | | 10.8 | 6 7 | .96 | 20.4 | 1.78 |
| | | | | | | | 0.39 | 6.7 | 77.7 | 0.85 | 17.9 | 2.19 |
| | | | | | | | | 4.5 | 97.1 | .98 | 15.4 | 2.74 |
| | | | | | | | 0.48 | 4.1 | 111 | 0.86 | 15.4 | 3.13 |
| | | | | | | Single circular. | 0.23 | 8.8 | 68.7 | 1.40 | 20.4 | 1.94 |
| | | | | | | | | 5.6 | 83.1 | 1.57 | 15.4 | 2.34 |
| | | | | | | | 0.42 | 5.3 | 84.6 | 0.85 | 15.4 | 2.38 |
| | | | | | | | | 4.5 | 107 | .98 | 15.4 | 3.01 |
| | | | | | Restricted | Modified anlar. | 0.32 | 25.8 | 46.9 | 0.81 | 22.9 | 1.32 |
| | | | | | | | | 18.7 | 50.7 | .84 | 22.9 | 1.43 |
| | | | | | | | | 12.6 | 58.5 | .92 | 20.4 | 1.65 |
| | | | | | | | | 9.5 | 63.3 | .96 | 20.4 | 1.78 |
| | | | | | | | | 7.8 | 78.6 | 1.10 | 17.9 | 2.21 |
| | | | | | | | 0.39 | 12.8 | 55.8 | 0.70 | 20.4 | 1.57 |
| | | | | | | | | 6.8 | 77.7 | .85 | 17.9 | 2.19 |
| | | | | | | | | 4.4 | 97.1 | .98 | 15.4 | 2.74 |
| | | | | | | | 0.48 | 3.0 | 111 | 0.86 | 10.4 | 3.13 |
| | | | | | | Single circular. | 0.23 | 31.8 | 44.8 | 1.09 | 25.4 | 1.26 |
| | | | | | | | | 17.2 | 54.1 | 1.22 | 22.9 | 1.52 |
| | | | | | | | | 12.6 | 58.7 | 1.28 | 20.4 | 1.65 |
| | | | | | | | 0.36 | 16.8 | 55.8 | 0.76 | 22.9 | 1.57 |
| | | | | | | | | 12.9 | 59.1 | .79 | 20.4 | 1.66 |
| | | | | | | | | 8.9 | 68.7 | .86 | 20.4 | 1.94 |
| | | | | | | | | 5.6 | 83.1 | .97 | 15.4 | 2.34 |
| | | | | | | | | 3.9 | 102 | 1.09 | 15.4 | 2.87 |
| | | | | | | | 0.42 | 30.0 | 45.4 | 0.59 | 25.4 | 1.28 |
| | | | | | | | | 13.0 | 55.8 | .66 | 17.9 | 1.57 |
| | | | | | | | | 5.2 | 84.6 | .85 | 15.4 | 2.38 |
| | | | | | | | | 4.4 | 107 | .98 | 15.4 | 3.01 |
| | | | | | | | 0.53 | 12.2 | 56.0 | 0.52 | 17.9 | 1.58 |
| | | | | | | | | 4.9 | 91.7 | .70 | 15.4 | 2.58 |
| 2.913 | 1/4 | Uncoated cast iron soil pipe. | 73.7 | Long sweep | Restricted | Modified annular | 0.32 | 11.4 | 89.2 | 1.18 | 30.4 | 1.21 |
| | | | | | | | 0.39 | 11.9 | 90.5 | 0.93 | 27.9 | 1.23 |
| | | | | | | | | 6.6 | 97.1 | .98 | 20.4 | 1.32 |
| | | | | | | | | 4.4 | 116 | 1.09 | 20.4 | 1.57 |
| | | | | | | | 0.48 | 8.0 | 94.2 | 0.78 | 27.9 | 1.28 |
| | | | | | | | | 4.2 | 111 | .86 | 15.4 | 1.51 |
| | | | | | | Single circular | 0.36 | 18.0 | 83.1 | 0.97 | 32.9 | 1.13 |
| | | | | | | | | 8.6 | 92.3 | 1.03 | 25.4 | 1.25 |
| | | | | | | | | 6.8 | 102 | 1.09 | 25.4 | 1.38 |
| | | | | | | | 0.42 | 16.0 | 84.6 | 0.85 | 32.9 | 1.15 |
| | | | | | | | | 9.1 | 93.6 | .91 | 27.9 | 1.27 |
| | | | | | | | | 5.5 | 107 | .98 | 20.4 | 1.45 |
| | | | | | | | | 3.8 | 128 | 1.09 | 15.4 | 1.74 |
| | | | | | | | 0.53 | 7.2 | 103 | 0.75 | 22.9 | 1.40 |
| | | | | | | | | 4.0 | 127 | .85 | 15.4 | 1.72 |
| 3.978 | 1/16 | Plastic | 91.9 | Long sweep | Open | Annular | 0.26 | 25.4 | 116 | 1.00 | 54.2 | 1.26 |
| | | | | | | | | 20.9 | 130 | 1.07 | 47.6 | 1.42 |
| | | | | | | | | 15.4 | 143 | 1.13 | 54.2 | 1.56 |
| | | | | | | | 0.30 | 27.6 | 115 | 0.86 | 54.2 | 1.25 |
| | | | | | | | | 14.9 | 147 | 1.00 | 43.2 | 1.60 |
| | | | | | | | | 14.4 | 147 | 1.00 | 52.0 | 1.60 |
| | | | | | | | | 8.4 | 179 | 1.13 | 49.8 | 1.95 |

TABLE 3. *Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drain diameter | Drain slope | Drain material | Capacity for steady flow [a] | Type of stack-base fitting | Condition at lower end of drain | Form of initial cross section of stream | Ratio of initial area of stream to area of drain | Time duration of surge | Capacity for surge flow | Ratio of initial velocity to stack terminal velocity [b] | Distance from drain entrance to point at which surge filled drain | Ratio of capacity for surge flow to capacity for steady flow |
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| | | | | | | | 0.34 | 14.6 | 145 | 0.87 | 49.8 | 1.58 |
| | | | | | | | | 7.8 | 182 | 1.00 | 41.0 | 1.98 |
| | | | | | | | | 7.7 | 182 | 1.00 | 45.4 | 1.98 |
| | | | | | | | | 5.1 | 218 | 1.11 | 45.4 | 2.37 |
| | | | | | | | 0.39 | 8.3 | 176 | 0.87 | 45.4 | 1.92 |
| | | | | | | | | 6.0 | 220 | .99 | 38.8 | 2.39 |
| | | | | | | | | 5.3 | 220 | .99 | 45.4 | 2.39 |
| | | | | | | | | 3.2 | 269 | 1.12 | 36.6 | 2.93 |
| | | | | | | | 0.43 | 5.7 | 210 | 0.88 | 43.2 | 2.28 |
| | | | | | | | | 4.4 | 260 | 1.00 | 32.2 | 2.83 |
| | | | | | | | | 4.8 | 260 | 1.00 | 36.6 | 2.83 |
| | | | | | | | | 3.9 | 260 | 1.00 | 36.6 | 2.83 |
| | | | | | Restricted | Annular | 0.26 | 26.5 | 116 | 1.00 | 49.8 | 1.26 |
| | | | | | | | | 26.5 | 116 | 1.00 | 49.8 | 1.26 |
| | | | | | | | | 30.4 | 116 | 1.00 | 49.8 | 1.26 |
| | | | | | | | | 20.7 | 130 | 1.07 | 47.6 | 1.42 |
| | | | | | | | | 15.1 | 143 | 1.13 | 47.6 | 1.56 |
| | | | | | | | 0.30 | 31.2 | 115 | 0.86 | 49.8 | 1.25 |
| | | | | | | | | 19.9 | 131 | .93 | 45.4 | 1.42 |
| | | | | | | | | 14.5 | 147 | 1.00 | 43.2 | 1.60 |
| | | | | | | | | 8.0 | 179 | 1.13 | 41.0 | 1.95 |
| | | | | | | | 0.34 | 15.0 | 145 | 0.87 | 45.4 | 1.58 |
| | | | | | | | | 8.0 | 182 | 1.00 | 41.0 | 1.98 |
| | | | | | | | | 5.4 | 218 | 1.11 | 38.8 | 2.37 |
| | | | | | | | 0.39 | 9.2 | 176 | 0.87 | 41.0 | 1.92 |
| | | | | | | | | 6.0 | 220 | .99 | 36.6 | 2.39 |
| | | | | | | | | 4.1 | 269 | 1.12 | 32.2 | 2.93 |
| | | | | | | | 0.43 | 6.5 | 210 | 0.88 | 36.6 | 2.28 |
| | | | | | | | | 4.3 | 260 | 1.00 | 32.2 | 2.83 |
| | | | | | | Single circular | 1.0 | 19.8 | 137 | 0.28 | 41.0 | 1.49 |
| | | | | | | | | 11.5 | 164 | .31 | 27.8 | 1.78 |
| | | | | | | | | 7.7 | 189 | .34 | 19.2 | 2.06 |
| | | | | | | | | 6.4 | 210 | .36 | 14.8 | 2.28 |
| | | | | | | | | 5.4 | 241 | .39 | 14.8 | 2.62 |
| | | | | | | | | 3.6 | 291 | .44 | 7.3 | 3.17 |
| | ⅛ | Plastic | 134 | Long sweep | Open | Annular | 0.30 | 13.0 | 179 | 1.13 | 58.4 | 1.34 |
| | | | | | | | | 13.0 | 179 | 1.13 | 58.4 | 1.34 |
| | | | | | | | 0.34 | 12.1 | 182 | 1.00 | 56.3 | 1.36 |
| | | | | | | | | 12.0 | 182 | 1.00 | 56.3 | 1.36 |
| | | | | | | | | 7.9 | 218 | 1.11 | 52.0 | 1.63 |
| | | | | | | | 0.39 | 12.4 | 176 | 0.87 | 60.6 | 1.31 |
| | | | | | | | | 12.2 | 176 | .87 | 60.6 | 1.31 |
| | | | | | | | | 7.1 | 220 | .99 | 52.0 | 1.64 |
| | | | | | | | | 6.2 | 269 | 1.12 | 56.3 | 2.01 |
| | | | | | | | | 5.2 | 269 | 1.12 | 43.2 | 2.01 |
| | | | | | | | 0.43 | 9.3 | 210 | 0.88 | 56.3 | 1.57 |
| | | | | | | | | 4.9 | 260 | 1.00 | 45.4 | 1.94 |
| | | | | | | | | 3.3 | 329 | 1.15 | 36.6 | 2.46 |
| | | | | Y-&-⅛ bend | Open | Annular | 0.26 | 26.1 | 151 | 1.17 | 54.2 | 1.13 |
| | | | | | | | | 26.1 | 151 | 1.17 | 54.2 | 1.13 |
| | | | | | | | 0.30 | 32.4 | 147 | 1.00 | 54.2 | 1.10 |
| | | | | | | | | 32.4 | 147 | 1.00 | 54.2 | 1.10 |
| | | | | | | | | 17.1 | 163 | 1.06 | 47.6 | 1.22 |
| | | | | | | | | 17.1 | 163 | 1.06 | 47.6 | 1.22 |
| | | | | | | | | 12.3 | 179 | 1.13 | 45.4 | 1.34 |
| | | | | | | | | 12.3 | 179 | 1.13 | 45.4 | 1.34 |
| | | | | | | | 0.34 | 31.9 | 145 | 0.87 | 56.3 | 1.08 |
| | | | | | | | | 20.5 | 156 | .91 | 54.2 | 1.16 |
| | | | | | | | | 15.7 | 164 | .93 | 47.6 | 1.22 |
| | | | | | | | | 10.7 | 182 | 1.00 | 43.2 | 1.36 |
| | | | | | | | | 6.8 | 218 | 1.11 | 36.6 | 1.63 |
| | | | | | | | 0.39 | 11.5 | 176 | 0.87 | 38.8 | 1.31 |
| | | | | | | | | 6.4 | 220 | .99 | 36.6 | 1.64 |
| | | | | | | | | 4.8 | 269 | 1.12 | 32.2 | 2.01 |
| | | | | | | | 0.43 | 7.9 | 210 | 0.88 | 32.2 | 1.57 |
| | | | | | | | | 4.7 | 260 | 1.00 | 30.0 | 1.94 |
| | | | | | | | | 3.5 | 329 | 1.15 | 27.8 | 2.46 |



738-631 O - 64 - 3

Table 3. *Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drain diameter | Drain slope | Drain material | Capacity for steady flow [a] | Type of stack-base fitting | Condition at lower end of drain | Form of initial cross section of stream | Ratio of initial area of stream to area of drain | Time duration of surge | Capacity for surge flow | Ratio of initial velocity to stack terminal velocity [b] | Distance from drain entrance to point at which surge filled drain | Ratio of capacity for surge flow to capacity for steady flow |
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| | ¼ | Plastic | 195 | Long sweep | Open | Annular | 0.34 | 15.4 | 218 | 1.11 | 73.6 | 1.12 |
| | | | | | | | | 9.2 | 240 | 1.17 | 67.2 | 1.23 |
| | | | | | | | 0.39 | 16.0 | 220 | 0.99 | 73.8 | 1.13 |
| | | | | | | | | 5.0 | 269 | 1.12 | 49.8 | 1.38 |
| | | | | | | | 0.43 | 7.0 | 260 | 1.00 | 52.0 | 1.33 |
| | | | | | | | | 3.5 | 329 | 1.15 | 32.2 | 1.69 |
| | | | | | | Single circular | 1.0 | 9.0 | 230 | 0.38 | 27.8 | 1.18 |
| | | | | | | | | 4.9 | 291 | .44 | 14.8 | 1.49 |
| | | | | | Restricted | Annular | 0.30 | 20.6 | 209 | 1.24 | 84.6 | 1.07 |
| | | | | | | | 0.34 | 20.5 | 207 | 1.08 | 80.2 | 1.06 |
| | | | | | | | | 12.4 | 218 | 1.11 | 71.4 | 1.12 |
| | | | | | | | | 7.8 | 240 | 1.17 | 58.4 | 1.23 |
| | | | | | | | 0.39 | 22.5 | 208 | 0.96 | 80.2 | 1.07 |
| | | | | | | | | 13.2 | 220 | .99 | 67.2 | 1.13 |
| | | | | | | | | 5.6 | 269 | 1.12 | 49.8 | 1.38 |
| | | | | | | | 0.43 | 25.0 | 210 | 0.88 | 82.4 | 1.08 |
| | | | | | | | | 6.6 | 260 | 1.00 | 49.8 | 1.33 |
| | | | | | | | | 3.3 | 329 | 1.15 | 32.2 | 1.69 |
| | | | | | | Single circular | 1.0 | 21.6 | 210 | 0.36 | 54.2 | 1.08 |
| | | | | | | | | 8.2 | 241 | .39 | 23.7 | 1.24 |
| | | | | | | | | 3.6 | 291 | .44 | 7.3 | 1.49 |
| 4.026 | 1/16 | Galv. steel | 90.6 | Long sweep | Open | Annular | 0.25 | 28.5 | 116 | 1.00 | 41.2 | 1.28 |
| | | | | | | | | 23.1 | 116 | 1.00 | 41.2 | 1.28 |
| | | | | | | | | 23.0 | 130 | 1.07 | 41.2 | 1.44 |
| | | | | | | | | 12.3 | 143 | 1.14 | 41.2 | 1.58 |
| | | | | | | | 0.29 | 30.2 | 115 | 0.87 | 41.2 | 1.27 |
| | | | | | | | | 26.0 | 115 | .87 | 41.2 | 1.27 |
| | | | | | | | | 21.4 | 131 | .94 | 41.2 | 1.45 |
| | | | | | | | | 10.5 | 147 | 1.01 | 41.2 | 1.62 |
| | | | | | | | | 7.5 | 179 | 1.13 | 41.2 | 1.98 |
| | | | | | | | 0.33 | 12.6 | 145 | 0.87 | 41.2 | 1.60 |
| | | | | | | | | 7.6 | 182 | 1.00 | 41.2 | 2.01 |
| | | | | | | | | 5.1 | 218 | 1.11 | 36.0 | 2.41 |
| | | | | | | | 0.38 | 8.6 | 176 | 0.87 | 41.2 | 1.94 |
| | | | | | | | | 5.7 | 220 | 1.00 | 36.0 | 2.43 |
| | | | | | | | | 3.5 | 269 | 1.13 | 30.6 | 2.97 |
| | | | | | | | | 3.5 | 269 | 1.13 | 30.6 | 2.97 |
| | | | | | | | 0.42 | 6.2 | 210 | 0.88 | 41.2 | 2.32 |
| | | | | | | | | 4.0 | 260 | 1.00 | 30.6 | 2.87 |
| | | | | | | Single circular | 1.0 | 23.9 | 107 | 0.24 | 41.2 | 1.18 |
| | | | | | | | | 16.5 | 137 | .28 | 38.6 | 1.51 |
| | | | | | | | | 12.5 | 164 | .31 | 15.0 | 1.81 |
| | | | | | | | | 12.1 | 164 | .31 | 25.5 | 1.81 |
| | | | | | | | | 8.5 | 189 | .34 | 9.7 | 2.09 |
| | | | | | | | | 9.1 | 189 | .34 | 15.0 | 2.09 |
| | | | | | | | | 7.4 | 210 | .36 | 9.7 | 2.32 |
| | | | | | | | | 8.1 | 210 | .36 | 15.0 | 2.32 |
| | | | | | | | | 6.1 | 230 | .38 | 9.7 | 2.54 |
| | | | | | | | | 5.5 | 241 | .39 | 9.7 | 2.66 |
| | ¼ | Galv. steel | 191 | Long sweep | Open | Annular | 0.29 | 15.7 | 209 | 1.24 | 62.2 | 1.09 |
| | | | | | | | 0.33 | 10.2 | 218 | 1.11 | 51.7 | 1.14 |
| | | | | | | | | 6.6 | 240 | 1.18 | 46.5 | 1.26 |
| | | | | | | | 0.38 | 10.8 | 220 | 1.00 | 57.0 | 1.15 |
| | | | | | | | | 4.7 | 269 | 1.13 | 41.2 | 1.41 |
| | | | | | | | | 3.7 | 295 | 1.19 | 30.6 | 1.54 |
| | | | | | | | 0.42 | 16.3 | 210 | 0.88 | 62.2 | 1.10 |
| | | | | | | | | 4.8 | 260 | 1.00 | 46.5 | 1.36 |
| | | | | | | Single circular | 1.0 | 19.0 | 210 | 0.36 | 57.0 | 1.10 |
| | | | | | | | | 9.7 | 230 | .38 | 46.5 | 1.20 |
| | | | | | | | | 9.0 | 241 | .39 | 30.6 | 1.26 |
| | | | | | | | | 6.9 | 263 | .41 | 25.5 | 1.38 |
| | | | | | | | | 5.4 | 291 | .44 | 25.5 | 1.52 |

TABLE 3. *Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Drain diameter | Drain slope | Drain material | Capacity for steady flow [a] | Type of stack-base fitting | Condition at lower end of drain | Form of initial cross section of stream | Ratio of initial area of stream to area of drain | Time duration of surge | Capacity for surge flow | Ratio of initial velocity to stack terminal velocity [b] | Distance from drain entrance to point at which surge filled drain | Ratio of capacity for surge flow to capacity for steady flow |
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| 3.983 | 1/16 | Coated cast iron soil pipe. | 89.0 | Long sweep | Restricted | Annular | 0.26 | 20.8 | 116 | 1.00 | 45.2 | 1.30 |
| | | | | | | | | 13.9 | 130 | 1.07 | 45.2 | 1.46 |
| | | | | | | | | 11.9 | 143 | 1.13 | 42.7 | 1.61 |
| | | | | | | | 0.30 | 24.2 | 115 | 0.86 | 45.3 | 1.29 |
| | | | | | | | | 15.2 | 131 | .93 | 45.2 | 1.47 |
| | | | | | | | | 11.7 | 147 | 1.00 | 45.2 | 1.65 |
| | | | | | | | | 8.1 | 179 | 1.13 | 45.2 | 2.01 |
| | | | | | | | | 4.9 | 209 | 1.24 | 35.2 | 2.35 |
| | | | | | | | 0.34 | 12.4 | 145 | 0.87 | 45.2 | 1.63 |
| | | | | | | | | 6.4 | 182 | 1.00 | 35.2 | 2.04 |
| | | | | | | | | 5.1 | 207 | 1.08 | 35.2 | 2.33 |
| | | | | | | | | 4.3 | 218 | 1.11 | 35.2 | 2.45 |
| | | | | | | | | 3.8 | 240 | 1.18 | 35.2 | 2.70 |
| | | | | | | | 0.38 | 7.2 | 176 | 0.87 | 35.2 | 19.8 |
| | | | | | | | | 4.9 | 208 | .96 | 35.2 | 2.34 |
| | | | | | | | | 4.4 | 220 | .99 | 35.2 | 2.47 |
| | | | | | | | | 3.4 | 269 | 1.12 | 35.2 | 3.02 |
| | | | | | | | 0.43 | 5.3 | 210 | 0.88 | 35.2 | 2.36 |
| | | | | | | | | 4.2 | 260 | 1.00 | 35.2 | 2.92 |
| | 1/4 | Coated cast iron soil pipe. | 188 | Long sweep | Restricted | Annular | 0.30 | 12.1 | 209 | 1.24 | 75.2 | 1.11 |
| | | | | | | | 0.34 | 12.4 | 207 | 1.08 | 75.2 | 1.10 |
| | | | | | | | | 9.6 | 218 | 1.11 | 65.2 | 1.16 |
| | | | | | | | | 6.4 | 240 | 1.18 | 55.2 | 1.28 |
| | | | | | | | 0.38 | 13.4 | 208 | 0.96 | 70.2 | 1.11 |
| | | | | | | | | 10.1 | 220 | .99 | 65.2 | 1.17 |
| | | | | | | | | 4.6 | 269 | 1.12 | 45.2 | 1.43 |
| | | | | | | | 0.43 | 12.6 | 210 | 0.88 | 75.2 | 1.12 |
| | | | | | | | | 5.1 | 260 | 1.00 | 45.2 | 1.38 |
| 6.484 | 1/8 | Plastic | 342 | Long sweep | Open | Single circular. | 0.25 | 28.6 | 482 | 1.10 | 95.6 | 1.41 |
| | | | | | | | | 16.5 | 574 | 1.22 | 78.1 | 1.68 |
| | | | | | | | 0.28 | 25.0 | 482 | 1.01 | 78.1 | 1.41 |
| | | | | | | | | 22.0 | 507 | 1.04 | 78.1 | 1.48 |
| | | | | | | | | 14.8 | 573 | 1.12 | 78.1 | 1.68 |
| | | | | | | | | 13.8 | 576 | 1.12 | 78.1 | 1.68 |
| | | | | | | | 0.30 | 35.7 | 431 | 0.86 | 91.2 | 1.26 |
| | | | | | | | | 19.5 | 506 | .95 | 78.1 | 1.48 |
| | | | | | | | | 19.2 | 532 | .98 | 78.1 | 1.56 |
| | | | | | | | | 16.0 | 553 | 1.00 | 78.1 | 1.62 |
| | | | | | | | | 14.0 | 577 | 1.03 | 78.1 | 1.69 |
| | | | | | | | | 14.0 | 579 | 1.03 | 78.1 | 1.69 |
| | | | | | | | | 12.5 | 615 | 1.07 | 78.1 | 1.80 |
| | | | | | | | | 11.5 | 651 | 1.10 | 78.1 | 1.90 |
| | | | | | | | | 10.4 | 656 | 1.11 | 73.7 | 1.92 |
| | | | | | | | 0.32 | 26.0 | 460 | 0.84 | 78.1 | 1.34 |
| | | | | | | | | 21.0 | 497 | .88 | 78.1 | 1.45 |
| | | | | | | | | 19.0 | 503 | .88 | 78.1 | 1.47 |
| | | | | | | | | 15.4 | 561 | .94 | 78.1 | 1.64 |
| | | | | | | | | 13.5 | 584 | .97 | 78.1 | 1.71 |
| | | | | | | | | 13.7 | 584 | .97 | 73.7 | 1.71 |
| | | | | | | | | 11.9 | 608 | .99 | 73.7 | 1.78 |
| | | | | | | | | 11.6 | 625 | 1.00 | 75.9 | 1.83 |
| | | | | | | | | 10.0 | 664 | 1.04 | 73.7 | 1.94 |
| | | | | | | | | 9.8 | 684 | 1.06 | 75.9 | 2.00 |
| | | | | | | | | 9.8 | 690 | 1.07 | 75.9 | 2.02 |
| | | | | | | | | 7.6 | 727 | 1.10 | 64.9 | 2.13 |
| | | | | | | | 0.35 | 26.0 | 461 | 0.79 | 78.1 | 1.35 |
| | | | | | | | | 18.4 | 510 | .84 | 78.1 | 1.49 |
| | | | | | | | | 16.4 | 545 | .87 | 78.1 | 1.59 |
| | | | | | | | | 15.5 | 562 | .89 | 78.1 | 1.64 |
| | | | | | | | | 13.0 | 586 | .91 | 73.7 | 1.71 |
| | | | | | | | | 13.7 | 586 | .91 | 78.1 | 1.71 |
| | | | | | | | | 11.5 | 624 | .94 | 73.7 | 1.82 |
| | | | | | | | | 9.8 | 659 | .97 | 75.9 | 1.93 |
| | | | | | | | | 9.8 | 689 | 1.00 | 75.9 | 2.02 |
| | | | | | | | | 8.7 | 690 | 1.00 | 69.3 | 2.02 |
| | | | | | | | | 9.8 | 692 | 1.00 | 75.9 | 2.02 |
| | | | | | | | | 6.6 | 754 | 1.06 | 60.5 | 2.20 |

TABLE 3.—*Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) Drain diameter | (2) Drain slope | (3) Drain material | (4) Capacity for steady flow [a] | (5) Type of stack-base fitting | (6) Condition at lower end of drain | (7) Form of initial cross section of stream | (8) Ratio of initial area of stream to area of drain | (9) Time duration of surge | (10) Capacity for surge flow | (11) Ratio of initial velocity to stack terminal velocity [b] | (12) Distance from drain entrance to point at which surge filled drain | (13) Ratio of capacity for surge flow to capacity for steady flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| | | | | | | | 0.39 | 25.5 | 458 | 0.70 | 78.1 | 1.34 |
| | | | | | | | | 18.5 | 510 | .74 | 78.1 | 1.49 |
| | | | | | | | | 15.0 | 559 | .79 | 78.1 | 1.64 |
| | | | | | | | | 12.5 | 594 | .82 | 73.7 | 1.74 |
| | | | | | | | | 13.7 | 594 | .82 | 78.1 | 1.74 |
| | | | | | | | | 13.7 | 594 | .82 | 78.1 | 1.74 |
| | | | | | | | | 10.5 | 658 | .87 | 73.7 | 1.92 |
| | | | | | | | | 10.0 | 682 | .89 | 73.7 | 1.99 |
| | | | | | | | | 8.0 | 709 | .91 | 69.3 | 2.07 |
| | | | | | | | | 8.0 | 709 | .91 | 69.3 | 2.07 |
| | | | | | | | | 8.0 | 717 | .91 | 69.3 | 2.10 |
| | | | | | | | | 8.0 | 720 | .91 | 69.3 | 2.10 |
| | | | | | | | | 8.0 | 720 | .91 | 69.3 | 2.10 |
| | | | | | | | | 7.1 | 773 | .96 | 64.9 | 2.26 |
| | | | | | | | | 5.8 | 808 | .98 | 60.5 | 2.36 |
| 6.484 | 1/16 | Plastic | 342 | Long sweep | Restricted | Single circular. | 0.25 | 24.8 | 482 | 1.10 | 95.6 | 1.41 |
| | | | | | | | | 15.1 | 574 | 1.22 | 78.1 | 1.68 |
| | | | | | | | 0.28 | 29.5 | 469 | 0.99 | 91.2 | 1.37 |
| | | | | | | | | 13.6 | 576 | 1.12 | 78.1 | 1.6 |
| | | | | | | | 0.30 | 34.2 | 431 | 0.86 | 91.2 | 1.26 |
| | | | | | | | | 17.9 | 532 | .98 | 78.1 | 1.56 |
| | | | | | | | | 10.1 | 656 | 1.11 | 73.7 | 1.92 |
| | | | | | | | 0.32 | 20.0 | 497 | 0.88 | 78.1 | 1.45 |
| | | | | | | | | 11.1 | 608 | .99 | 73.7 | 1.78 |
| | | | | | | | | 7.2 | 727 | 1.10 | 62.7 | 2.13 |
| | | | | | | | 0.35 | 15.6 | 545 | 0.87 | 78.1 | 1.59 |
| | | | | | | | | 8.5 | 690 | 1.00 | 69.3 | 2.02 |
| | | | | | | | | 6.2 | 754 | 1.06 | 60.5 | 2.20 |
| | | | | | | | 0.39 | 8.8 | 658 | 0.87 | 69.3 | 1.92 |
| | | | | | | | | 6.3 | 773 | .96 | 60.5 | 2.26 |
| | | | | | | | | 4.9 | 808 | .98 | 51.7 | 2.36 |
| | | | | Y-&-1/8 bend | Open | Single circular. | 0.39 | 30.6 | 437 | 0.68 | 45.2 | 1.28 |
| | | | | | | | | 23.0 | 488 | .72 | 40.8 | 1.43 |
| | | | | | | | | 19.8 | 521 | .75 | 40.8 | 1.52 |
| | | | | | | | | 15.3 | 584 | .81 | 36.4 | 1.71 |
| | | | | | | | | 16.2 | 594 | .82 | 32.0 | 1.74 |
| | | | | | | | | 14.9 | 604 | .82 | 36.4 | 1.77 |
| | | | | | | | | 12.2 | 652 | .86 | 34.2 | 1.91 |
| | | | | | | | | 10.7 | 675 | .88 | 34.2 | 1.97 |
| | | | | | | | | 9.9 | 705 | .90 | 34.2 | 2.06 |
| | | | | | | Multiple circular. | 0.48 | 18.8 | [c] 561 | 0.64 | 64.9 | 1.64 |
| | | | | | | | | 10.2 | [c] 662 | .71 | 49.5 | 1.94 |
| | | | | | | | | 9.4 | [c] 720 | .75 | 49.5 | 2.10 |
| | | | | | | | | 7.5 | [c] 804 | .80 | 45.2 | 2.35 |
| | | | | | | | | 6.9 | [c] 871 | .84 | 43.0 | 2.55 |
| | | | | | | | | 6.4 | [c] 911 | .86 | 40.8 | 2.66 |
| | | | | | | | 0.55 | 17.8 | [c] 555 | 0.55 | 58.3 | 1.62 |
| | | | | | | | | 12.0 | [c] 655 | .61 | 47.3 | 1.92 |
| | | | | | | | | 9.1 | [c] 726 | .65 | 40.8 | 2.12 |
| | | | | | | | | 6.3 | [c] 838 | .71 | 27.6 | 2.45 |
| | | | | | | | | 5.9 | [c] 897 | .74 | 27.6 | 2.62 |
| | | | | | | | | 6.0 | [c] 906 | .74 | 27.6 | 2.65 |
| | | | | | | | 0.61 | 30.6 | [c] 437 | 0.43 | 45.2 | 1.28 |
| | | | | | | | | 19.8 | [c] 521 | .48 | 43.0 | 1.52 |
| | | | | | | | | 17.9 | [c] 554 | .50 | 58.3 | 1.62 |
| | | | | | | | | 15.3 | [c] 584 | .51 | 38.6 | 1.71 |
| | | | | | | | | 14.9 | [c] 604 | .52 | 38.6 | 1.77 |
| | | | | | | | | 12.6 | [d] 648 | .54 | 29.8 | 1.90 |
| | | | | | | | | 12.2 | [c] 652 | .55 | 34.2 | 1.91 |
| | | | | | | | | 10.4 | [c] 664 | .55 | 40.8 | 1.94 |
| | | | | | | | | 10.7 | [c] 675 | .56 | 34.2 | 1.97 |
| | | | | | | | | 9.9 | [c] 705 | .57 | 34.2 | 2.06 |
| | | | | | | | | 8.7 | [c] 754 | .60 | 40.8 | 2.20 |
| | | | | | | | | 8.6 | [d] 773 | .61 | 27.6 | 2.26 |
| | | | | | | | | 7.1 | [c] 842 | .64 | 25.4 | 2.46 |
| | | | | | | | | 7.0 | [d] 850 | .64 | 27.6 | 2.48 |
| | | | | | | | | 6.0 | [d] 888 | .66 | 25.4 | 2.60 |
| | | | | | | | | 6.2 | [c] 915 | .67 | 25.4 | 2.68 |
| | | | | | | | | 4.9 | [c] 925 | .67 | 21.0 | 2.70 |
| | | | | | | | | 5.2 | [d] 930 | .68 | 25.4 | 2.72 |

TABLE 3.—*Surge capacities of initially empty, sloping, simple drains*—Continued

(Author's data)

| (1) Drain diameter | (2) Drain slope | (3) Drain material | (4) Capacity for steady flow [a] | (5) Type of stack-base fitting | (6) Condition at lower end of drain | (7) Form of initial cross section of stream | (8) Ratio of initial area of stream to area of drain | (9) Time duration of surge | (10) Capacity for surge flow | (11) Ratio of initial velocity to stack terminal velocity [b] | (12) Distance from drain entrance to point at which surge filled drain | (13) Ratio of capacity for surge flow to capacity for steady flow |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *in.* | *in./ft* | | *gpm* | | | | | *sec* | *gpm* | | *ft* | |
| | ⅛ | Plastic | 500 | Long sweep | Open | Single circular | 0.32 | 8.2 | 755 | 1.13 | 80.2 | 1.51 |
| | | | | | | | | 8.9 | 769 | 1.14 | 80.2 | 1.54 |
| | | | | | | | 0.35 | 8.4 | 782 | 1.08 | 75.9 | 1.56 |
| | | | | | | | 0.39 | 8.4 | 790 | 0.97 | 80.2 | 1.58 |
| | | | | | | | | 8.2 | 808 | .98 | 80.2 | 1.62 |
| | | | | | Restricted | Single circular | 0.30 | 8.4 | 738 | 1.19 | 78.1 | 1.48 |
| | | | | | | | | 7.9 | 753 | 1.20 | 78.1 | 1.51 |
| | | | | | | | 0.32 | 8.5 | 727 | 1.10 | 82.4 | 1.45 |
| | | | | | | | | 7.6 | 769 | 1.14 | 73.7 | 1.54 |
| | | | | | | | 0.35 | 8.4 | 754 | 1.06 | 78.1 | 1.51 |
| | | | | | | | | 7.5 | 782 | 1.08 | 69.3 | 1.56 |
| | | | | | | | 0.39 | 7.5 | 776 | 0.96 | 73.7 | 1.55 |
| | | | | | | | | 7.0 | 808 | .98 | 73.7 | 1.62 |
| 6.484 | ⅛ | Plastic | 500 | Y-&-1/8 bend | Open | Single circular | 0.39 | 32.0 | 584 | 0.81 | 71.5 | 1.17 |
| | | | | | | | | 23.8 | 604 | .82 | 53.9 | 1.21 |
| | | | | | | | | 16.4 | 652 | .86 | 47.3 | 1.30 |
| | | | | | | | | 12.4 | 675 | .88 | 43.0 | 1.35 |
| | | | | | | | | 11.1 | 700 | .90 | 38.6 | 1.40 |
| | | | | | | | | 10.2 | 720 | .91 | 38.6 | 1.44 |
| | | | | | | Multiple circular. | 0.48 | 18.0 | 662 | 0.71 | 78.1 | 1.32 |
| | | | | | | | | 18.0 | 662 | .71 | 78.1 | 1.32 |
| | | | | | | | | 12.3 | 720 | .75 | 64.9 | 1.44 |
| | | | | | | | | 8.2 | 804 | .80 | 60.5 | 1.61 |
| | | | | | | | | 8.3 | 871 | .84 | 56.1 | 1.74 |
| | | | | | | | | 8.0 | 871 | .84 | 56.1 | 1.74 |
| | | | | | | | | 5.6 | 911 | .86 | 34.2 | 1.82 |
| | | | | | | | 0.55 | 15.9 | 655 | 0.61 | 67.1 | 1.31 |
| | | | | | | | | 11.0 | 655 | .61 | 56.1 | 1.31 |
| | | | | | | | | 7.8 | 726 | .65 | 38.6 | 1.45 |
| | | | | | | | | 7.3 | 838 | .71 | 25.4 | 1.68 |
| | | | | | | | | 5.3 | 838 | .71 | 29.8 | 1.68 |
| | | | | | | | | 7.0 | 897 | .74 | 34.2 | 1.79 |
| | | | | | | | | 6.2 | 906 | .74 | 29.8 | 1.81 |
| | | | | | | | 0.61 | 29.4 | [d] 594 | 0.52 | 67.1 | 1.19 |
| | | | | | | | | 21.2 | [c] 606 | .52 | 80.2 | 1.21 |
| | | | | | | | | 18.0 | [d] 648 | .54 | 51.7 | 1.30 |
| | | | | | | | | 15.5 | [c] 664 | .55 | 64.9 | 1.33 |
| | | | | | | | | 10.2 | [c] 754 | .60 | 49.5 | 1.51 |
| | | | | | | | | 10.5 | [d] 773 | .61 | 38.6 | 1.55 |
| | | | | | | | | 5.4 | [c] 842 | .64 | 25.4 | 1.68 |
| | | | | | | | | 5.3 | [c] 842 | .64 | 16.7 | 1.68 |
| | | | | | | | | 7.5 | [d] 850 | .64 | 29.8 | 1.70 |
| | | | | | | | | 6.7 | [d] 888 | .66 | 27.6 | 1.78 |
| | | | | | | | | 4.7 | [c] 915 | .67 | 25.4 | 1.83 |
| | | | | | | | | 5.8 | [d] 920 | .67 | 25.4 | 1.84 |
| | | | | | | | | 4.0 | [c] 925 | .67 | 21.0 | 1.85 |
| | | | | | | | | 5.8 | [d] 930 | .68 | 25.4 | 1.86 |
| 6.484 | ¼ | Plastic | 727 | Y-&-1/8 bend | Open | Multiple circular. | 0.48 | 14.5 | [c] 871 | 0.84 | 73.7 | 1.20 |
| | | | | | | | | 13.2 | [c] 911 | .86 | 71.5 | 1.25 |
| | | | | | | | 0.55 | 18.9 | [c] 838 | 0.71 | 75.9 | 1.15 |
| | | | | | | | | 13.5 | [c] 897 | .74 | 58.3 | 1.23 |
| | | | | | | | | 11.4 | [c] 906 | .74 | 53.9 | 1.25 |
| | | | | | | | 0.61 | 18.5 | [c] 842 | 0.64 | 75.9 | 1.16 |
| | | | | | | | | 21.0 | [d] 850 | .64 | 80.2 | 1.17 |
| | | | | | | | | 11.0 | [d] 888 | .66 | 53.9 | 1.22 |
| | | | | | | | | 13.3 | [c] 915 | .67 | 53.9 | 1.26 |
| | | | | | | | | 11.2 | [c] 925 | .67 | 53.9 | 1.27 |
| | | | | | | | | 10.1 | [d] 930 | .68 | 51.7 | 1.28 |

[a] See table 4.
[b] Computed from eq (A-7) and from values in columns 1, 8, and 10. Equal stack and drain diameters were assumed. A value of absolute roughness of 0.00083 ft for the stack was used in the computations (see [9]).
[c] Horizontal-jct supply valve wide open. Flow controlled by vertical-jct supply valve.
[d] Vertical-jct supply valve wide open. Flow controlled by horizontal-jct supply valve.

The author utilized an electrical depth-sensing device and a recorder to measure changes in water depth in a 4 in. plastic drain at a slope of ¼-in./ft. during the passage of a capacity surge. The length of the drain was approximately 98 ft. The sensing element comprised two parallel flat stain-

**Table 4.** *Capacity flow rates and coefficients of roughness for sloping simple drains under conditions approaching steady uniform flow*

(Downstream ends restricted so as to simulate conditions in very long drains completely filled but not under pressure)

| (1) Drain diameter | (2) Drain material | (3) Drain slope | (4) Capacity-flow rate, Experimental | (5) Capacity-flow rate, Rationalized [a] | (6) Darcy-Weisbach "f", Experimental [b] | (7) Darcy-Weisbach "f", Rationalized [c] | (8) Nikuradse "k" x $10^4$, experimental [d] | (9) Chezy "C" rationalized [e] | (10) Manning "n", rationalized [f] |
|---|---|---|---|---|---|---|---|---|---|
| in. | | in./ft | gpm | gpm | | | ft | $ft^{1/2}/sec$ | $ft^{1/6}$ |
| 2.985 | Plastic [g] (methacrylate) | 1/16 | 41.6 | 42.1 | 0.0229 | 0.0226 | 0.99 | 107 | 0.00874 |
| | | 1/4 | 93.1 | 90.8 | .0183 | .0193 | .13 | 115 | .00810 |
| | | | | | | Averages | 0.56 | 111 | 0.00842 |
| 3.068 | Steel [g] (galvanized) | 1/16 | 39.8 | 40.7 | 0.0287 | 0.0275 | 7.6 | 96.7 | 0.00972 |
| | | 1/4 | 86.1 | 84.0 | .0245 | .0259 | 4.3 | 99.7 | .00943 |
| | | | | | | Averages | 6.0 | 98.2 | 0.00958 |
| 2.914 | Cast iron [g] (plain) | 1/16 | 35.5 | 35.5 | 0.0278 | 0.0278 | 5.3 | 96.1 | 0.00969 |
| | | 1/4 | 73.6 | 73.7 | .0259 | .0259 | 5.3 | 99.7 | .00934 |
| | | | | | | Averages | 5.3 | 97.4 | 0.00952 |
| [h] 3.00 | Cast iron [i] (plain) | 1/16 | [j] 32.1 | 32.8 | 0.0394 | 0.0380 | 24 | 82.3 | 0.0114 |
| | | 1/8 | [j] 45.6 | 46.8 | .0391 | .0374 | 25 | 83.1 | .0113 |
| | | 1/4 | [j] 69.8 | 66.7 | .0334 | .0367 | 16 | 83.6 | .0112 |
| | | | | | | Averages | 22 | 83.0 | 0.0113 |
| 3.978 | Plastic [g] (methacrylate) | 1/16 | 92.0 | 91.9 | 0.0197 | 0.0200 | 0.46 | 114 | 0.00862 |
| | | 1/4 | 192 | 195 | .0181 | .0176 | .73 | 121 | .00812 |
| | | | | | | Averages | 0.60 | 118 | 0.00837 |
| 4.026 | Steel [g] (galvanized) | 1/16 | 90.4 | 90.6 | 0.0216 | 0.0216 | 1.7 | 109 | 0.00901 |
| | | 1/4 | 191 | 191 | .0195 | .0195 | 1.7 | 115 | .00856 |
| | | | | | | Averages | 1.7 | 112 | 0.00878 |
| 3.983 | Cast iron [g] (bitumen-coated) | 1/16 | 90.2 | 89.0 | 0.0206 | 0.0212 | 1.0 | 110 | 0.00892 |
| | | 1/4 | 186 | 188 | .0195 | .0191 | 1.7 | 116 | .00845 |
| | | | | | | Averages | 1.4 | 113 | 0.00868 |
| 3.90 | Cast iron [i] (plain) | 1/16 | [j] 66.8 | 64.1 | 0.0338 | 0.0369 | 20 | 83.5 | 0.0117 |
| | | 1/8 | [j] 89.0 | 91.2 | .0381 | .0364 | 31 | 84.0 | .0116 |
| | | 1/4 | [j] 128 | 130 | .0368 | .0361 | 29 | 84.5 | .0116 |
| | | | | | | Averages | 27 | 84.0 | 0.0116 |
| 6.484 | Plastic [g] (methacrylate) | 1/16 | 340 | 342 | 0.0166 | 0.0165 | 0.27 | 126 | 0.00850 |
| | | 1/8 | 500 | 500 | .0153 | .0146 | .05 | 133 | .00801 |
| | | | | | | Averages | 0.16 | 130 | 0.00826 |

[a] Computed from the rational pipe-flow equation, using values of "f" given in column 7.
[b] Computed from the rational pipe-flow equation, using experimental values of flow rate.
[c] Computed by adjusting column 6 values in accordance with the rational pipe-flow equation, using experimental values of Reynolds number, column 8 average values of "k," and the relationship between "f," "k," and Reynolds number (see sec. 9.1).
[d] Computed by use of chart showing relationship between "f," "k," and Reynolds number (see sec. 9.1).
[e] Computed from the relationship between "C" and "f," using column 7 values of "f" (see eq (A–3)).
[f] Computed from the relationship between "n" and "f," using column 7 values of "f" (see eq (A–3)).
[g] Drain-pipe materials manufactured about 1958.
[h] Nominal diameter. Laboratory notes do not state whether diameter was acutally measured.
[i] Drain-pipe materials manufactured prior to 1939.
[j] Estimated from measurements of flow rates in drains 70 ft long without end restrictions, by use of an equation which relates capacity-flow rates in short drains and in long drains (see sec. 9.2).

**Table 5.** *Flow from water closet through 4-in. stack and 40 ft of 4-in. building drain*

| Slope of drain | Height of stack | Flush: Duration | Flush: Average rate [a] | Average flow rate at end of drain during indicated period: 1st 5 sec | 2d 5 sec | 1st 10 sec | 1st 15 sec | Max. recorded 5-sec rate of discharge at end of drain | Ratio of max. recorded 5-sec rate at end of drain to estimated max. 5-sec rate at water closet [a] |
|---|---|---|---|---|---|---|---|---|---|
| in./ft | ft | sec | gpm | gpm | gpm | gpm | gpm | gpm | |
| 1/8 | 30 | 10 | 31.8 | 13.5 | 16.5 | 15.0 | 14.0 | 16.5 | 0.389 |
| 1/8 | 90 | 10 | 27.0 | 12.0 | 12.0 | 12.0 | 10.0 | 12.0 | .333 |
| 1/4 | 30 | 10 | 30.6 | 18.0 | 18.0 | 18.0 | 16.5 | 18.0 | .441 |
| 1/4 | 90 | 9.5 | 31.6 | 15.0 | 13.5 | 14.2 | 12.2 | 15.0 | .356 |

[a] Estimated maximum 5-sec rate at water closet obtained by multiplying average rate by 1.33. This factor is based on a review of numerous water closet discharge patterns shown in NBS Reports 1131 and 1633.

**Table 6.** *Flow from water closet through 4-in. stack and 40 ft of 5-in. building drain*

| Slope of drain | Height of stack | Flush: Duration | Flush: Average rate [a] | Average flow rate at end of drain during indicated period: 1st 5 sec | 2d 5 sec | 1st 10 sec | 1st 15 sec | Max. recorded 5-sec rate of discharge at end of drain | Ratio of max. recorded 5-sec rate at end of drain to estimated max. 5-sec rate at water closet [a] |
|---|---|---|---|---|---|---|---|---|---|
| in./ft | ft | sec | gpm | gpm | gpm | gpm | gpm | gpm | |
| 1/8 | 30 | 9 | 32.0 | 18.0 | 12.0 | 15.0 | 14.5 | 18.0 | 0.422 |
| 1/8 | 90 | 10 | 32.4 | 12.7 | 15.7 | 14.2 | 11.5 | 15.7 | .363 |
| 1/4 | 30 | 10 | 30.6 | 20.0 | 20.0 | 20.0 | 17.0 | 20.0 | .490 |
| 1/4 | 90 | 10 | 30.0 | 16.6 | 15.5 | 16.0 | 14.0 | 16.6 | .415 |
| 7/16 | 30 | 9 | 32.7 | 21.0 | 17.2 | 19.1 | 16.0 | 21.0 | .482 |
| 7/16 | 90 | 9 | 32.7 | 18.0 | 13.5 | 15.8 | 14.0 | 18.0 | .413 |

[a] Estimated maximum 5-sec rate at water closet obtained by multiplying average rate by 1.33. This factor is based on a review of numerous water closet discharge patterns shown in NBS Reports 1131 and 1633.

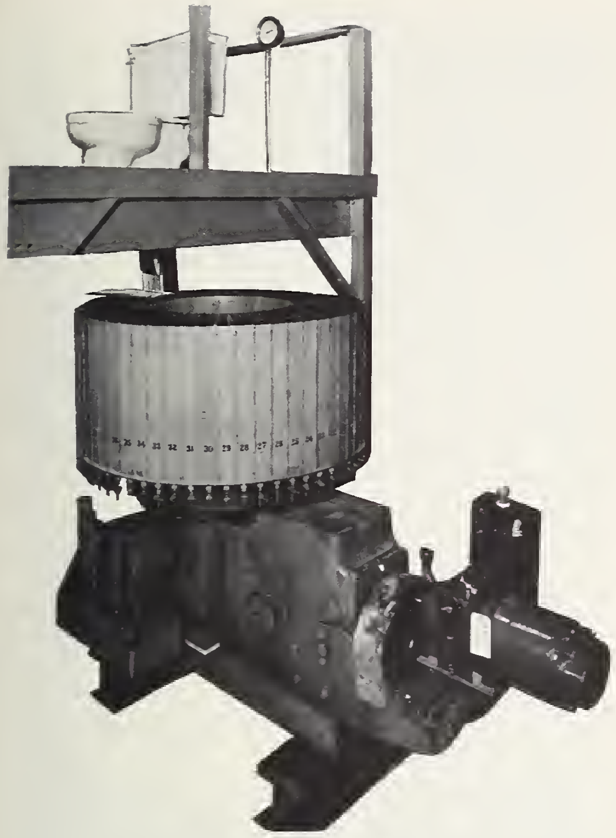

FIGURE 12. *Discharge-rate meter.*

TABLE 7. *Flow from water closet through 4-in. stack and 40 ft of 6-in. building drain*

| Slope of drain | Height of stack | Flush: Duration | Flush: Average rate [a] | Average flow rate at end of drain during indicated period: 1st 5 sec | 2d 5 sec | 1st 10 sec | 1st 15 sec | Max. recorded 5-sec rate of discharge at end of drain | Ratio of max. recorded 5-sec rate at end of drain to estimated max. 5-sec rate at water closet [a] |
|---|---|---|---|---|---|---|---|---|---|
| *in./ft* | *ft* | *sec* | *gpm* | *gpm* | *gpm* | *gpm* | *gpm* | *gpm* | |
| 1/8 | 30 | 9 | 32.0 | 18.0 | 14.0 | 16.0 | 14.0 | 18.0 | 0.422 |
| 1/8 | 90 | 8 | 37.5 | 15.0 | 15.0 | 15.0 | 12.2 | 15.0 | .300 |
| 1/4 | 30 | 9 | 31.7 | 21.0 | 15.0 | 18.0 | 15.5 | 21.0 | .496 |
| 1/4 | 90 | 9 | 32.7 | 16.0 | 16.0 | 16.0 | 13.3 | 16.0 | .367 |

[a] Estimated maximum 5-sec rate at water closet obtained by multiplying average rate by 1.33. This factor is based on a review of numerous water closet discharge patterns shown in NBS Reports 1131 and 1633.

less-steel probes positioned vertically in a cross section of the drain. The instrument system was calibrated by measuring the current flowing through the water between the probes over a range of water depth in a plastic vessel. The water used for calibration was taken from the same source as that used in the test drain. The salts in the water resulted in sufficient electrical conductivity to make this method of measuring depths feasible. The test surge was produced as described in section 5.1a(1) so that the velocity at the base of the simulated stack was approximately the same as terminal velocity for the same rate of discharge computed through the use of eq (44) of NBS Monograph 31 [9] or for the same cross-sectional area computed through the use of eq (A–7).

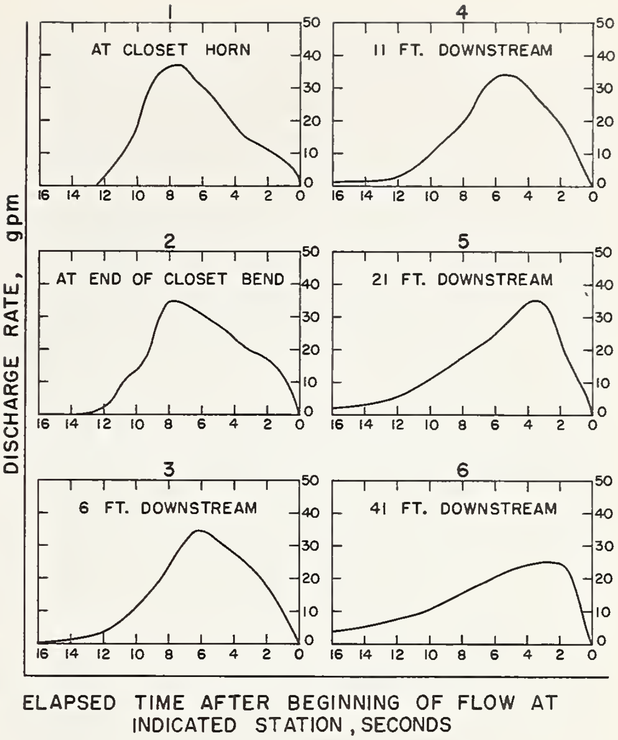


FIGURE 13. *Rate of discharge from water closet as a function of time and distance from the fixture.*

Discharge rates measured with rate meter at end of a 4-in. drain which was extended successively to the indicated lengths. Reverse horizontal scale simulates surge profile for left-to-right movement.

TABLE 8. *Attenuation of maximum 5-sec discharge rate from single water closet discharged directly into drain*

| Drain diameter | Drain slope | Distance from water closet to end of drain | Peak rate of discharge at end of drain [a] | Estimated max. 5-sec rate at end of drain [b] | Ratio of estimated max. 5-sec rate at end of drain to max. 5-sec rate at drain entrance, 1–δ |
|---|---|---|---|---|---|
| *in.* | *in./ft* | *ft* | *gpm* | *gpm* | |
| 3 | 1/4 | 6 | 36.6 | [b] 31.1 | 0.99 |
| | | 11 | 34.5 | [b] 29.3 | .93 |
| | | 21 | 31.7 | [b] 26.9 | .86 |
| | | 41 | 23.6 | [b] 20.1 | .64 |
| 3 | 1/8 | 6 | 37.5 | [b] 31.9 | 1.01 |
| | | 11 | 36.8 | [b] 31.3 | 0.99 |
| | | 21 | 26.4 | [b] 22.4 | .71 |
| | | 41 | 17.4 | [b] 14.8 | .47 |
| 4 | 1/4 | 6 | 36.8 | 29.6 | 0.94 |
| | | 11 | 33.7 | 29.5 | .94 |
| | | 21 | 36.0 | 28.8 | .92 |
| | | 41 | 25.3 | 23.5 | .75 |
| 4 | 1/8 | 6 | 37.1 | [b] 31.5 | 1.00 |
| | | 11 | 36.9 | [b] 31.4 | 1.00 |
| | | 21 | 34.4 | [b] 29.2 | 0.93 |
| | | 41 | 24.2 | [b] 20.6 | .65 |

[a] Peak rate at water closet was 37.0 gpm. The data of figure 13, for a 4-in. drain at a slope of 1/4 in./ft, show that the max. 5-sec rate at the water closet was approx. 85% of the peak rate, or 31.4 gpm.

[b] Data of figure 13, for the 4-in. drain at slope of 1/4 in./ft show that the max. 5-sec rate at the end of the drain averaged approx. 85% of the peak rate at the end of the drain. Accordingly, values identified *b* were obtained by multiplying the peak rates by 0.85.

#### (2) Results

The data in tables 5, 6, and 7 were obtained from the 10-story test system. These data relate to attenuation of discharge rate in a simple drain carrying a small surge, such as the discharge of a single water closet, which does not fill the drain. The water discharged from the end of the building drain for the first 15 sec accounted for 60 to 70 percent of the total discharge. Thereafter, the flow gradually receded, and was reduced to a trickle from the end of the drain in about 45 sec for the 4-in. and in about 60 sec for the 6-in. drain. The flush duration at the water closets ranged from 8 to 10 sec.

The instantaneous discharge rate from the end of a 4-in. drain resulting from the flushing of a water closet directly connected to the drain, measured with the apparatus shown in figure 12 and expressed as a function of time, is shown in figure 13. The purpose of using an abscissa scale reading from right to left is to create the impression of surge movement from station 1 to 2 to 3, etc. Table 8 gives data on peak discharge rate for 3- and 4-in. drains.

Data from tables 5, 6, and 7, on the attenuation of discharge rates from single water closet flushes in the 10-story system are summarized in table 9. The data in the fourth column indicate the extent of attenuation of discharge rate in the stack and 40 ft of building drain; and that in the fifth column, attenuation in the drain only.

In order to compare the attenuation data from the 10-story system with that from the horizontal drain with a directly connected water closet, adjustments were made to some of the recorded data. Maximum 5-sec rates were recorded at the end of the drain for the 10-story system, while peak instantaneous rates were recorded for the other test system. Average rate of discharge at the water closet was recorded for the 10-story

Table 9. *Attenuation of maximum 5-sec discharge rate from single water closet with passage through 4-in. soil stack and 40 ft of building drain*

| Drain diameter | Drain slope | Height of stack | Ratio of max. recorded 5-sec rate at end of drain to estimated max. 5-sec rate at water closet [a] | Ratio of max. recorded 5-sec rate at end of drain to estimated max. 5-sec rate [b] at drain entrance, $1-\delta$ |
|---|---|---|---|---|
| *in.* | *in/ft* | *ft* | | |
| 4 | 1/8 | 30 | 0.39 | 0.41 |
| | | 90 | .33 | .38 |
| | 1/4 | 30 | .44 | .46 |
| | | 90 | .36 | .41 |
| 5 | 1/8 | 30 | .42 | .44 |
| | | 90 | .36 | .42 |
| | 1/4 | 30 | .49 | .51 |
| | | 90 | .42 | .47 |
| | 7/16 | 30 | .48 | .50 |
| | | 90 | .41 | .47 |
| 6 | 1/8 | 30 | .42 | .44 |
| | | 90 | .30 | .34 |
| | 1/4 | 30 | .50 | .52 |
| | | 90 | .37 | .42 |

[a] These data are from tables 5, 6, and 7.
[b] Max. 5-sec rate at entrance of building drain estimated by reducing the max. 5-sec rate at the water closet 1.4 percent for each 10 ft of stack height. This reduction factor was derived from data in the third and fourth columns of this table.

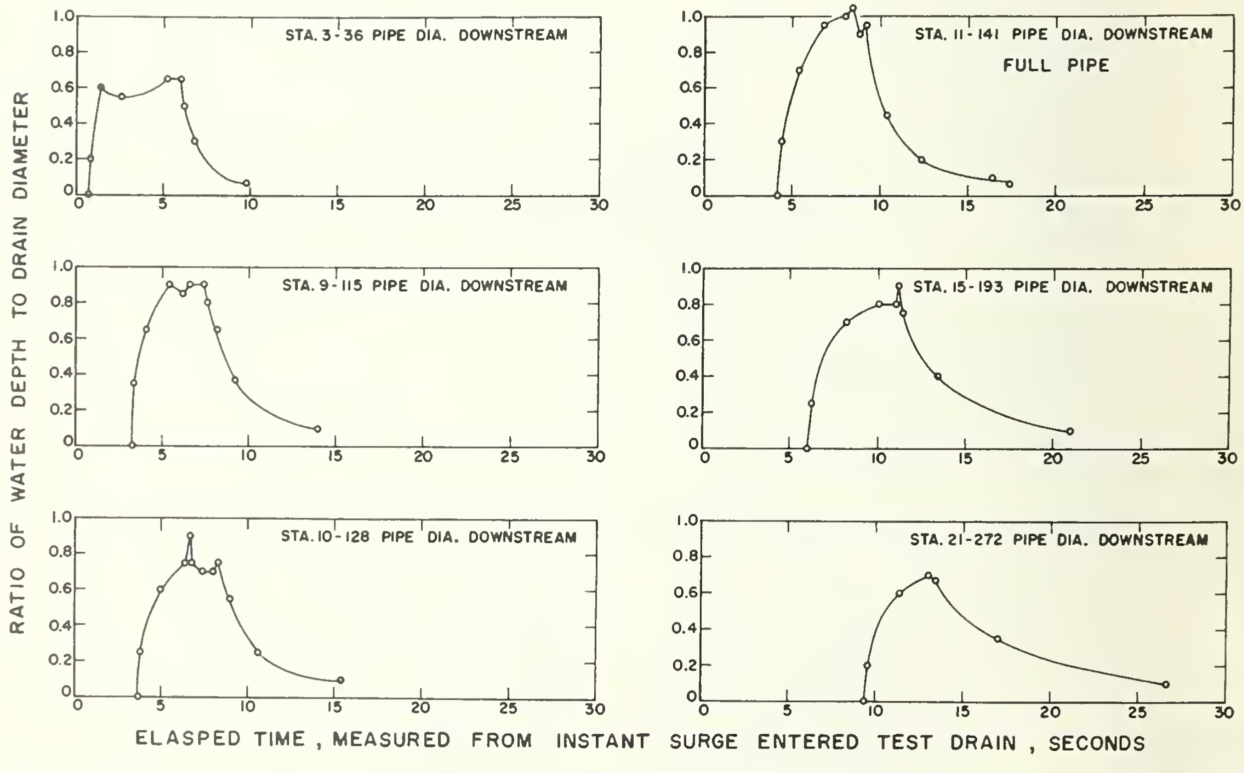


Figure 14. *Water depth produced by surge in 4-in. plastic drain, as a function of time and distance from drain entrance. (Measured with electrical depth gage.)*

system, while instantaneous peak rate was recorded for the other system. It seems reasonable to compare the data on the basis of the same type of peak rate, i.e., attenuation of either instantaneous peaks or 5-sec peaks. For various reasons it was decided to make the comparison on the basis of attentuation of 5-sec peaks. The method used for estimating maximum 5-sec rates, where not originally measured, is explained in the footnotes to tables 5 through 9.

Typical data obtained by the author with the electrical depth gage on the attenuation of water depth in a plastic drain as a function of time and position are shown in figure 14. The measured variables and the test conditions for these data differ from those for Hunter's data in two important ways: first, the data are for water depths while Hunter's data are for discharge rates; and second, the data are for capacity surges while Hunter's data are for surges which did not fill the drains. The surge from which the data in figure 14 were derived occupied about one-third of the cross-sectional area of the drain entrance and had an initial velocity of about 16 fps. The time duration of the surge at the drain entrance was 6.5 sec and the discharge rate was 265 gpm, or about 35 percent greater than the steady flow capacity of the drain. Figure 14 shows that the length of time for passage of the surge at any given station increased with distance downstream. The water depth increased at first, completely filling the drain cross section at a distance of 47 ft from the entrance. Beyond this station, depth decreased and passage time increased.

Attenuation was inversely related to drain slope, and directly to drain length according to the data of tables 8 and 9. The effect of drain diameter was less clearly indicated. For drain lengths of 40 and 41 ft. and diameters of 3, 4, and 5 in., attenuation decreased as diameter increased, other conditions being the same. However, attenuation in the 6-in. drain did not conform to this trend.

The possible effect of gravity on discharge rate of surges through deflection of the surface profile near the unobstructed end of a drain was not considered in these measurements. It does not seem likely that this would affect comparative indications appreciably, but might affect actual values. Hence it should be taken into account in any further work on attenuation.

The data in tables 8 and 9 were utilized as the basis for approximate equations for predicting attenuation of discharge rate as a function of drain length and slope, as explained in section 6.2.

## 5.2. Flow in Compound Drains

### a. Test Methods and Apparatus

Hunter made a preliminary study of the effects of introducing either steady or surge flow through a branch drain while maintaining a steady discharge into the entrance of the main drain which was less than the steady flow capacity of the main.

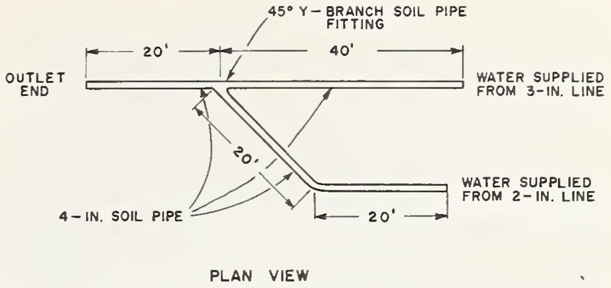


Figure 15. *Schematic diagram of test system used by Hunter to study flow conditions at junction in compound drain.*

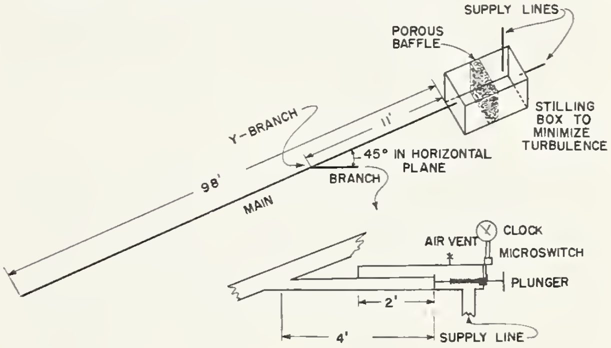


Figure 16. *Schematic diagram of test system used by author to study flow conditions at junction in compound drain.*

He used a 4-in. diam main drain of cast-iron soil pipe approximately 60 ft in length at slopes of 1/16 and 1/8-in./ft. Branch diameter was 4-in., and lengths were 20 ft and 40 ft. The branch and the main were in a common nominally horizontal plane, with the same slope. This apparatus is shown schematically in figure 15.

The author continued Hunter's study over an expanded range of conditions, utilizing the apparatus shown schematically in figure 16. The main drain was 98 ft in length. Main diameters were 4 and 6½-in., and slopes were 1/16, 1/8, and 1/4 in./ft. Several different sizes of branch drain were used. The drains were constructed of transparent methyl methacrylate plastic. The effective length of the branch drain was either 2 or 4 ft as indicated in the tables of data (see sec. 5.2b).

Two conditions were studied with this apparatus: (1) the condition resulting from steady flow in both main and branch; and (2) the condition resulting from surge flow in the branch and steady flow in the main. In these tests, an arbitrary steady rate of discharge not sufficient to fill the main drain was introduced into the upstream end of the main through a stilling box. After substantially steady, uniform flow was attained throughout the length of the main, discharge was introduced through the branch. Adjustments were made of the flow rate in the branch in order to just fill the main drain completely at its junction with the branch. For tests with surge flow in the branch, a selected surge duration time was maintained in successive trials to determine capacity discharge rate for the branch. Surge flow into the branch was initiated and terminated by a quick-opening valve in the supply line to the branch drain. Manual opening and closing of the plunger valve shown in figure 16 was timed to coincide approximately with push-button operation of the quick-opening valve in order to record surge duration time at the branch. The surge duration was recorded by an electric stop clock controlled by a microswitch actuated by movement of the plunger shaft. In the tests with steady flow in the branch, the plunger valve was locked in a partially open position. For steady flow in the main drain and either steady or surge flow in a branch in a common horizontal plane, the criterion of hydraulic capacity was the existence of a full section of minimum length within the main at its junction with the branch.

The author also studied the condition produced by superimposing surge flow through a vertical branch on steady flow in a main horizontal drain, utilizing the apparatus shown in figure 10 as modified by replacing the long-sweep stack-base fitting with a Y- and ⅛-bend fitting with a heel inlet. Steady flow was introduced into the main through a short length of 3-in. pipe caulked into the heel of the base fitting. Surge flow with an annular cross section was introduced through a simulated 4-in. stack from the vertical at velocities approximately equal to stack terminal velocities computed by a method given in an earlier paper [9] (see also eqs (A–6) and A–7 of sec. 9.4). A 4-in. main, approximately 98 ft long, was constructed of transparent methyl-methacrylate plastic. Drain slopes of ⅛ and ¼ in./ft were used. For a given surge which by itself did not produce a full-conduit condition anywhere along the drain, steady flow through the heel inlet to the stack-base fitting was increased by increments in successive runs until the superimposition of the surge produced a full section of minimum length downstream of the stack. This was the criterion of hydraulic capacity. The capacity could be described by the volume rates of steady and surge flow and by the time duration of surge.

Venting of the test drains was provided at intervals as described in section 3.

### b. Results

A description of flow at the junctions of main and branch drains was given in section 3 and illustrated in figures 4 to 7. Hydraulic capacities of compound drains, measured over a range of test parameters are given in tables 10, 11, and 12. Table 10 gives data for steady flow in both main and branch in a common horizontal plane. Table 11 gives data for flow in the same test system except that surge flow, instead of steady flow, was introduced through the branch. Table 12 gives data for steady flow in a main and surge flow through a vertical branch. The data given for cast-iron drains were obtained by Hunter and

TABLE 10. *Capacity of drain system for steady flow at junction of main and 45° branch*

(Main drain and branch in same nominally horizontal plane. Full section at junction.)

| Diameter of main | Diameter of branch | Drain slope | Drain material | Length of branch | Capacity flow rates | | |
|---|---|---|---|---|---|---|---|
| | | | | | Main | Branch | Total |
| *in.* | *in.* | *in./ft* | | *ft* | *gpm* | *gpm* | *gpm* |
| 4 | 4 | 1/16 | Cast iron | 20 | 18.6 | 41.8 | 60.4 |
| | | | | | 21.2 | 44.2 | 65.4 |
| | | | | | 23.9 | 41.5 | 65.4 |
| | | | | | 26.5 | 38.4 | 64.9 |
| | | | | | 30.0 | 36.7 | 66.7 |
| | | | | | 30.9 | 34.6 | 65.5 |
| | | | | | 37.2 | 28.3 | 65.5 |
| | | | | | 37.5 | 26.6 | 64.1 |
| | | | | | 53.2 | 14.6 | 67.8 |
| | | | | | 53.5 | 15.9 | 69.4 |
| | | | | | 76.5 | 0 | |
| | | | | | 77.1 | 0 | |
| | | | | | 85.2 | 0 | |
| | | | | 40 | 25.6 | 39.4 | 65.0 |
| | | | | | 32.6 | 33.3 | 65.9 |
| | | | | | 80.4 | 0 | |
| | | ⅛ | Cast iron | 20 | 30.9 | 37.9 | 68.8 |
| | | | | | 46.2 | 24.2 | 70.4 |
| | | | | | 114 | 0 | |
| | | | | | 114 | 0 | |
| | | | | 40 | 31.0 | 40.1 | 71.1 |
| | | | | | 45.6 | 28.0 | 73.6 |
| | | | | | 63.9 | 13.8 | 77.7 |
| | | | | | 81.2 | 7.2 | 88.4 |
| | | | | | 115 | 0 | |
| | | | | | 115 | 0 | |
| 4 | 3 | 1/16 | Plastic | 4 | 28.4 | 49.3 | 77.7 |
| | | | | | 30.0 | 44.2 | 74.2 |
| | | | | | 32.5 | 45.0 | 77.5 |
| | | | | | 34.9 | 39.5 | 74.4 |
| | | | | | 39.6 | 35.4 | 75.0 |
| | | | | | 39.7 | 32.4 | 72.1 |
| | | | | | 44.4 | 27.8 | 72.2 |
| | | | | | 48.9 | 23.4 | 72.3 |
| | | | | | 53.6 | 20.7 | 74.3 |
| | | | | | 50.6 | 16.1 | 66.7 |
| | | | | | 61.6 | 14.9 | 76.5 |
| | | | | | 63.6 | 12.2 | 75.8 |
| | | | | | 68.4 | 11.4 | 79.8 |
| | | ⅛ | Plastic | 2 | 39.2 | 39.0 | 78.2 |
| | | | | | 39.8 | 40.5 | 80.3 |
| | | | | | 40.6 | 39.4 | 80.0 |
| | | | | | 42.6 | 39.0 | 81.6 |
| | | | | | 45.5 | 33.7 | 79.2 |
| | | | | | 48.4 | 33.0 | 81.4 |
| | | | | | 48.4 | 32.2 | 80.6 |
| | | | | | 50.0 | 31.8 | 81.8 |
| | | | | | 74.0 | 16.1 | 90.1 |
| | | | | | 73.5 | 15.0 | 88.5 |
| | | | | | 74.3 | 16.2 | 90.5 |
| | | | | | 88.4 | 8.6 | 97.0 |
| | | | | | 95.5 | 6.1 | 102 |
| 6½ | 6½ | 1/16 | Plastic | 4 | 94.2 | 134 | 228 |
| | | | | | 94.1 | 137 | 231 |
| | | | | | 123 | 109 | 232 |
| | | | | | 149 | 86.8 | 236 |
| | | | | | 172 | 72.6 | 245 |
| | | | | | 193 | 60.4 | 253 |
| | | | | | 212 | 48.5 | 261 |
| | | | | | 229 | 42.4 | 271 |
| | | | | | 243 | 34.6 | 278 |
| | | | | | 254 | 29.6 | 284 |
| | | ⅛ | Plastic | 4 | 137 | 110 | 247 |
| | | | | | 175 | 84.0 | 259 |
| | | | | | 207 | 63.0 | 270 |
| | | | | | 232 | 52.6 | 285 |
| | | | | | 253 | 47.1 | 300 |
| | | | | | 280 | 38.5 | 319 |
| | | | | | 316 | 31.8 | 348 |
| 6½ | 4 | 1/16 | Plastic | 2 | 145 | 114 | 259 |
| | | | | | 179 | 80.2 | 259 |
| | | | | | 199 | 64.5 | 264 |
| | | | | | 219 | 49.8 | 269 |
| | | | | | 238 | 45.2 | 283 |
| | | | | | 260 | 34.1 | 294 |
| | | | | | 278 | 29.5 | 308 |
| | | ⅛ | Plastic | 2 | 172 | 111 | 283 |
| | | | | | 189 | 85.1 | 274 |
| | | | | | 205 | 80.6 | 286 |
| | | | | | 233 | 74.5 | 308 |

**Table 10.** *Capacity of drain system for steady flow at junction of main and 45° branch*—Continued

(Main drain and branch in same nominally horizontal plane. Full section at junction.)

| Diameter of main | Diameter of branch | Drain slope | Drain material | Length of branch | Capacity flow rates | | |
|---|---|---|---|---|---|---|---|
| | | | | | Main | Branch | Total |
| *in.* | *in.* | *in./ft* | | *ft* | *gpm* | *gpm* | *gpm* |
| | | | | | 264 | 50.7 | 315 |
| | | | | | 273 | 46.1 | 319 |
| 6½ | 3 | 1/16 | Plastic | 4 | 219 | 63.6 | 283 |
| | | | | | 236 | 45.1 | 281 |
| | | | | | 271 | 30.1 | 301 |
| | | | | | 310 | 22.6 | 333 |
| | | | | | 312 | 22.6 | 335 |
| | | | | | 352 | 14.8 | 367 |
| | | 1/8 | Plastic | 2 | 223 | 104 | 327 |
| | | | | | 232 | 81.1 | 313 |
| | | | | | 236 | 73.0 | 309 |
| | | | | | 243 | 71.5 | 315 |
| | | | | | 244 | 66.1 | 310 |
| | | | | | 254 | 67.9 | 322 |
| | | | | | 263 | 63.2 | 326 |
| | | | | | 264 | 63.0 | 327 |
| | | | | | 281 | 61.5 | 343 |
| | | | | | 292 | 53.6 | 346 |
| | | | | | 307 | 49.0 | 356 |

those for plastic drains were obtained by the author.

The maximum and minimum limits on the ranges of discharge used in the tests were determined in some cases by limitations imposed by the water-supply or flow-measuring apparatus and in other cases by inability to attain a clear indication that the criterion of hydraulic capacity had been satisfied. In most cases of the latter type, it appeared that hydraulic capacities were actually somewhat greater than indicated by the equations developed from the data in tables 10, 11, and 12, for which reasonably clear indications of a capacity condition were attained; but this point was not investigated in a systematic manner.

**Table 11.** *Capacity of drain system for steady flow in main and surge flow in branch*

(Main drain and branch in same nominally horizontal plane. Full section at junction of main and 45° branch.)

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|
| Diameter of main | Diameter of branch | Drain slope | Drain material | Diameter of jet at upper end of branch | Time duration of surge | Capacity flow rates: Main | Branch | Total |
| *in.* | *in.* | *in./ft* | | *in.* | *sec* | *gpm* | *gpm* | *gpm* |
| 4 | 3 | 1/8 | Plastic [a] | 1¾ | 5 | 38.9 | 84.6 | 124 |
| | | | | | | 40.6 | 68.4 | 109 |
| | | | | | | 49.0 | 51.6 | 101 |
| | | | | | | 50.0 | 41.9 | 91.9 |
| | | | | | 10 | 33.6 | 84.6 | 118 |
| | | | | | | 34.8 | 68.1 | 103 |
| | | | | | | 43.1 | 51.6 | 94.7 |
| | | | | | | 46.0 | 41.9 | 87.9 |
| | | | | | 15 | 27.0 | 84.8 | 112 |
| | | | | | | 31.8 | 68.4 | 100 |
| | | | | | | 37.6 | 51.6 | 89.2 |
| | | | | | | 46.0 | 41.9 | 87.9 |
| | | | | | 20 | 22.9 | 84.3 | 107 |
| | | | | | | 28.4 | 68.1 | 96.5 |
| | | | | | | 34.8 | 51.6 | 86.4 |
| | | | | | | 43.3 | 41.4 | 84.7 |

**Table 11.** *Capacity of drain system for steady flow in main and surge flow in branch*—Continued

| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|
| Diameter of main | Diameter of branch | Drain slope | Drain material | Diameter of jet at upper end of branch | Time duration of surge | Capacity flow rates: Main | Branch | Total |
| *in.* | *in.* | *in./ft* | | *in.* | *sec* | *gpm* | *gpm* | *gpm* |
| | | | | | 30 | 19.6 | 84.3 | 104 |
| | | | | | | 23.4 | 68.1 | 91.5 |
| | | | | | | 31.1 | 51.6 | 82.7 |
| | | | | | | 38.9 | 41.9 | 80.8 |
| | | | Plastic [a] | 2 | 5 | 40.2 | 78.8 | 119 |
| | | | | | | 41.7 | 79.7 | 121 |
| | | | | | | 46.2 | 63.5 | 110 |
| | | | | | 10 | 34.5 | 79.7 | 114 |
| | | | | | | 35.1 | 79.3 | 114 |
| | | | | | | 37.6 | 63.5 | 101 |
| | | | | | 15 | 30.2 | 80.0 | 110 |
| | | | | | | 30.8 | 79.3 | 110 |
| | | | | | | 35.3 | 63.2 | 98.5 |
| | | | | | 20 | 25.0 | 78.8 | 104 |
| | | | | | | 25.8 | 81.4 | 107 |
| | | | | | | 26.2 | 80.0 | 106 |
| | | | | | | 31.5 | 62.9 | 94.4 |
| | | | | | 30 | 20.1 | 78.8 | 98.9 |
| | | | | | | 21.6 | 80.2 | 102 |
| | | | | | | 27.3 | 63.2 | 90.5 |
| | | | Plastic [a] | 2½ | 5 | 36.8 | 116 | 153 |
| | | | | | | 48.4 | 57.9 | 106 |
| | | | | | | 54.0 | 39.5 | 93.5 |
| | | | | | 10 | 26.2 | 116 | 142 |
| | | | | | | 40.9 | 57.9 | 98.8 |
| | | | | | | 52.0 | 39.5 | 91.5 |
| | | | | | 15 | 22.0 | 116 | 138 |
| | | | | | | 35.1 | 57.9 | 93.0 |
| | | | | | | 48.4 | 39.5 | 87.9 |
| | | | | | 20 | 17.4 | 129 | 146 |
| | | | | | | 19.0 | 116 | 135 |
| | | | | | | 19.6 | 92.8 | 112 |
| | | | | | | 33.0 | 57.2 | 90.2 |
| | | | | | | 47.1 | 40.0 | 87.1 |
| | | | | | 30 | 11.0 | 129 | 140 |
| | | | | | | 14.2 | 116 | 130 |
| | | | | | | 15.6 | 92.1 | 108 |
| | | | | | | 29.5 | 57.2 | 86.7 |
| | | | | | | 44.3 | 40.0 | 84.3 |
| | 4 | 1/16 | Cast iron [b] | 2 | 5 | 16.4 | 101 | 117 |
| | | | | | | 25.5 | 104 | 130 |
| | | | | | | 38.4 | 54.4 | 92.8 |
| | | | | | | 54.2 | 35.2 | 89.4 |
| | | | | | 10 | 16.4 | 103 | 119 |
| | | | | | 15 | 16.2 | 86.7 | 103 |
| | | | | | | 25.5 | 68.5 | 94.0 |
| | | | | | | 38.4 | 43.1 | 81.5 |
| | | | | | | 54.2 | 31.6 | 85.8 |
| | | | | | 20 | 16.2 | 82.0 | 98.2 |
| | | | | | 25 | 16.2 | 76.7 | 92.9 |
| | | | | | | 25.5 | 51.5 | 77.0 |
| | | | | | | 38.4 | 39.9 | 78.3 |
| | | | | | | 54.2 | 26.6 | 80.8 |
| | | | | | 35 | 16.2 | 54.5 | 70.7 |
| | | | | | | 25.5 | 51.5 | 77.0 |
| | | | | | | 38.4 | 37.8 | 76.2 |
| | | | | | | 54.2 | 23.3 | 77.5 |
| | | | Cast iron [c] | 2 | 10 | 13.9 | 99.3 | 113 |
| | | | | | | 20.2 | 93.6 | 114 |
| | | | | | | 28.1 | 89.5 | 118 |
| | | | | | | 30.9 | 78.3 | 109 |
| | | | | | | 39.5 | 61.7 | 101 |
| | | | | | | 46.8 | 41.0 | 87.8 |
| | | | | | | 56.3 | 27.4 | 83.7 |
| | | | | | 20 | 13.9 | 84.5 | 98.4 |
| | | | | | | 20.2 | 87.9 | 108 |
| | | | | | | 28.1 | 80.9 | 109 |
| | | | | | | 30.9 | 63.0 | 93.9 |
| | | | | | | 39.5 | 41.9 | 81.4 |
| | | | | | | 46.8 | 31.2 | 78.0 |
| | | | | | | 56.3 | 22.9 | 79.2 |

TABLE 11. *Capacity of drain system for steady flow in main and surge flow in branch*—Continued

| (1) Diameter of main | (2) Diameter of branch | (3) Drain slope | (4) Drain material | (5) Diameter of jet at upper end of branch | (6) Time duration of surge | (7) Capacity flow rates: Main | (8) Capacity flow rates: Branch | (9) Capacity flow rates: Total |
|---|---|---|---|---|---|---|---|---|
| *in.* | *in.* | *in./ft* | | *in.* | *sec* | *gpm* | *gpm* | *gpm* |
| | | | | | 30 | 13.9 | 78.7 | 92.6 |
| | | | | | | 20.2 | 70.8 | 91.0 |
| | | | | | | 28.1 | 62.0 | 90.1 |
| | | | | | | 30.9 | 53.6 | 84.5 |
| | | | | | | 39.5 | 37.1 | 76.6 |
| | | | | | | 46.8 | 21.8 | 68.6 |
| | | | | | | 56.3 | 21.1 | 77.4 |
| | | 1/8 | Cast iron [b] | 2 | 10 | 16.7 | 142 | 159 |
| | | | | | | 23.9 | 106 | 130 |
| | | | | | | 37.6 | 54.0 | 91.6 |
| | | | | | | 55.5 | 35.6 | 91.1 |
| | | | | | | 73.7 | 34.1 | 108 |
| | | | | | | 90.5 | 30.1 | 121 |
| | | | | | 20 | 16.7 | 100 | 117 |
| | | | | | | 23.9 | 78.6 | 102 |
| | | | | | | 37.6 | 37.1 | 74.7 |
| | | | | | | 55.5 | 30.2 | 85.7 |
| | | | | | | 73.7 | 29.9 | 104 |
| | | | | | | 90.5 | 28.7 | 119 |
| | | | | | 30 | 16.7 | 85.8 | 102 |
| | | | | | | 23.9 | 60.0 | 83.9 |
| | | | | | | 37.6 | 34.8 | 72.4 |
| | | | | | | 55.5 | 26.7 | 82.2 |
| | | | | | | 73.7 | 26.1 | 99.8 |
| | | | | | | 90.5 | 25.9 | 116 |
| | | | Cast iron [c] | 2 | 5 | 53.8 | 57.2 | 111 |
| | | | | | 10 | 16.4 | 138 | 154 |
| | | | | | | 25.5 | 144 | 170 |
| | | | | | | 39.9 | 55.7 | 95.6 |
| | | | | | | 55.5 | 35.6 | 91.1 |
| | | | | | | 74.1 | 26.3 | 100 |
| | | | | | 15 | 53.8 | 34.9 | 88.7 |
| | | | | | 20 | 16.4 | 110 | 126 |
| | | | | | | 25.5 | 64.4 | 89.9 |
| | | | | | | 39.9 | 43.2 | 83.1 |
| | | | | | | 55.5 | 31.2 | 86.7 |
| | | | | | | 74.1 | 22.0 | 96.1 |
| | | | | | 25 | 53.8 | 32.3 | 86.1 |
| | | | | | 30 | 16.4 | 77.0 | 93.4 |
| | | | | | | 25.5 | 54.0 | 79.5 |
| | | | | | | 39.9 | 39.5 | 79.4 |
| | | | | | | 55.5 | 27.4 | 82.9 |
| | | | | | | 74.1 | 18.2 | 92.3 |
| | | | | | 40 | 53.8 | 25.7 | 79.5 |
| 6½ | 3 | 1/16 | Plastic [d] | 3 | 5 | 225 | 107 | 332 |
| | | | | | | 227 | 123 | 350 |
| | | | | | | 236 | 89.5 | 326 |
| | | | | | 10 | 208 | 123 | 331 |
| | | | | | | 213 | 107 | 320 |
| | | | | | | 221 | 89.2 | 310 |
| | | | | | 20 | 198 | 123 | 321 |
| | | | | | | 199 | 107 | 306 |
| | | | | | | 208 | 89.5 | 298 |
| | 4 | 1/16 | Plastic [d] | 4 | 5 | 204 | 109 | 313 |
| | | | | | | 214 | 87.8 | 302 |
| | | | | | | 236 | 64.1 | 300 |
| | | | | | 10 | 189 | 109 | 298 |
| | | | | | | 202 | 87.8 | 290 |
| | | | | | | 221 | 64.1 | 285 |
| | | | | | 20 | 165 | 109 | 274 |
| | | | | | | 181 | 87.8 | 269 |
| | | | | | | 205 | 64.1 | 269 |

[a] Branch length 2 ft.
[b] Branch length 20 ft.
[c] Branch length 40 ft.
[d] Branch length 4 ft.

Hydraulic capacity was affected by velocities in main and branch drains, the ratio of the diameters, the division of discharge between main and branch, and other factors. Where surge flow in the branch was involved, time duration of surge also affected capacity. These and other factors are included in the equations developed in section 6. Perhaps the most significant observations were:

1. A relatively small amount of steady discharge in a branch drain resulted in a substantial decrease in system capacity due to mutual interference at the junction of the main and branch, and
2. surge discharge in a branch drain resulted in an increase in system capacity over that obtained for steady discharge.

Detailed discussion of the results appears in section 6.3.

TABLE 12. *Capacity of 4-in. plastic drain system for steady flow in main and surge flow in branch*

(Main drain in nominally horizontal plane; branch, in vertical plane, connected to main through Y-&-1/8 bend fitting near upstream end of main. Full section at some distance downstream from junction.)

| Drain slope | Time duration of surge | Initial area [a] of surge stream | Distance from branch to point at which surge filled drain | Capacity flow rates: Main | Capacity flow rates: Branch | Capacity flow rates: Total |
|---|---|---|---|---|---|---|
| *in./ft* | *sec* | *in.²* | *ft* | *gpm* | *gpm* | *gpm* |
| ⅛ | 5 | 4.76 | 23.8 | 4.6 | 220 | 225 |
| | | 4.23 | 25.9 | 9.8 | 182 | 192 |
| | | 4.23 | 23.8 | 10.9 | 182 | 193 |
| | | 4.23 | 23.8 | 15.1 | 182 | 197 |
| | | 3.71 | 19.4 | 27.7 | 147 | 175 |
| | | 3.24 | 21.6 | 45.8 | 116 | 162 |
| | | 2.62 | 23.8 | 92.4 | 76.5 | 169 |
| | | 2.05 | 23.8 | 108 | 52.0 | 160 |
| | 10 | 4.23 | 30.3 | 1.3 | 182 | 183 |
| | | 4.23 | 36.8 | 1.9 | 182 | 184 |
| | | 3.71 | 34.6 | 16.2 | 147 | 163 |
| | | 3.24 | 30.2 | 34.2 | 116 | 150 |
| | | 2.62 | 28.1 | 75.7 | 76.5 | 152 |
| | | 2.05 | 28.1 | 104 | 52.0 | 156 |
| | 15 | 3.71 | 43.4 | 8.1 | 147 | 155 |
| | | 3.24 | 34.6 | 31.1 | 116 | 147 |
| | | 2.62 | 34.6 | 69.5 | 76.5 | 146 |
| | | 2.05 | 32.4 | 90.4 | 52.0 | 142 |
| | 20 | 3.71 | 52.2 | 5.0 | 147 | 152 |
| | | 3.24 | 43.4 | 25.8 | 116 | 142 |
| | | 2.62 | 43.4 | 64.4 | 76.5 | 141 |
| | | 2.05 | 34.6 | 88.4 | 52.0 | 140 |
| ¼ | 5 | 5.23 | 34.6 | 6.3 | 260 | 266 |
| | | 4.76 | 30.2 | 14.2 | 220 | 234 |
| | | 4.23 | 21.6 | 34.8 | 182 | 217 |
| | | 2.62 | 12.8 | 107 | 78.5 | 186 |
| | 10 | 4.76 | 56.6 | 9.0 | 220 | 229 |
| | | 4.23 | 47.8 | 27.8 | 182 | 210 |
| | | 3.71 | 43.4 | 53.4 | 147 | 200 |
| | | 3.24 | 21.6 | 73.8 | 116 | 190 |
| | | 3.24 | 21.6 | 66.2 | 116 | 182 |
| | 15 | 4.76 | 60.9 | 4.5 | 220 | 224 |
| | | 4.23 | 60.9 | 24.6 | 182 | 207 |
| | | 3.71 | 60.9 | 51.8 | 147 | 199 |

[a] Surges were annular in initial cross section. Initial velocities were approximately in accordance with terminal velocities for a 4-in. stack as computed from eq (A–7) for a value of $k_s = 0.00083$ ft.

# 6. Analysis of Experimental Results

## 6.1. Surge Flow in Initially Empty Simple Drains

The analysis begins with a consideration of the forces acting on the water, followed by an application of the principles of dimensional analysis. The primary object of this analysis is to obtain a solution which can be used for predicting hydraulic capacities over a range of conditions. Definitions and symbols used in the analysis are explained in section 2.

For steady, uniform gravity flow in a long, sloping drain of uniform slope and cross section, the hydraulic elements are constant throughout the length of the drain, and constant with time at any particular cross section.

On the other hand, for surge flow, the hydraulic elements vary both with distance along the drain at any given time and with time at any given cross section. Therefore, a knowledge of the hydraulics of steady flow is of limited value in the solution of problems of surge flow.

A simple method is desired for predicting relative capacity, defined as the ratio of surge-flow capacity to steady flow capacity. This knowledge is needed for design of plumbing drains in service. The steady flow capacity of a conduit for full-bore gravity flow without pressure at the crown can be determined from established formulas with reasonable accuracy or by direct measurement. Experimental observations have indicated that the predominant parameters affecting surge-flow capacity are time duration of surge and drain slope. The combined effect of roughness and drain diameter was less clearly indicated.

A consideration of the forces acting on the fluid indicates that relative capacity will be greatest when the local attenuating force is at a maximum, thus making it possible for the drain to carry a substantially greater rate of surge flow than steady flow without creating hydrostatic pressure at the crown of the drain. Local attenuating force is defined in section 2. Since such forces are most predominant in short-duration surges, relative capacity should be inversely related to the length of time that water is allowed to discharge into the drain. The experimental data confirmed this.

The data showed clearly that, for any given time duration of surge, relative capacity decreased with increasing drain slope. Although actual hydraulic capacities increased with slope for both steady and surge flow, the increase for a given increase in slope was relatively less for surge flow than for steady flow.

Surface roughness of the drain material introduces a shearing force in opposition to the longitudinal component of gravity which tends to empty the drain. For any given slope, increased roughness decreases actual drain capacity, both for surge flow and for steady flow. However, local attenuating force is a significant factor in surge flow, tending to prevent the drain from filling up. This is not a factor in steady flow. Therefore, a given change in roughness should affect surge-flow capacity relatively less than steady flow capacity. Hence, relative capacity for surge flow should increase with surface roughness. A slight trend in this direction was observed in the experimental data.

Dimensional analysis [10] was used in obtaining groupings of pertinent variables that satisfy the qualitative requirements discussed above. The variables considered in the analysis are in general those associated with the water stream near the drain entrance, since no measurements were made of dynamic quantities as the surge moved through the test drain between the entrance and the cross section at which the drain was filled. Among the variables considered are the following: (1) velocity $V_d$, of the water stream (jet) at the drain entrance; (2) equivalent diameter, $D_j$, of the jet at the drain entrance; (3) time duration of surge, $t$; (4) drain slope, $\theta$; (5) drain diameter, $D_d$; (6) drain length, $L_d$; (7) absolute roughness, $k_d$, of drain material; (8) fluid density, $\rho$; (9) fluid viscosity, $\nu$; and (10) acceleration due to gravity, $g$. If the problem is to be analyzed from the standpoint of *relative* capacity, another variable must be added to the list; namely (11) the velocity, $V_{st}$, which, if multiplied by the cross-sectional area of the stream at the drain entrance, $0.785D_j^2$, would produce a rate of discharge equal to that required to cause the drain under consideration to flow barely full without pressure under steady flow conditions. These variables can be collected into dimensionless terms as follows:

$$\pi_1=\frac{V_d}{\sqrt{D_d g}};\ \pi_2=\frac{V_{st}}{\sqrt{D_d g}};\ \pi_3=\frac{D_j}{D_d}$$

$$\pi_4=t\sqrt{\frac{g}{D_d}};\ \pi_5=\frac{V_d D_d}{\nu};$$

$$\pi_6=\frac{k_d}{D_d};\ \pi_7=\theta \text{ and } \pi_8=\frac{L_d}{D_d}.$$

Dimensional analysis does not give the functional relationships which may exist between the indicated terms but it does reduce the number of potentially significant variables to be studied.

The term $L_d/D_d$ can have no effect on the phenomenon under consideration so long as none of the discharge reaches the lower end of the drain before the maximum depth is produced. That is in very long drains $L_d/D_d$, or $\pi_8$, is not a pertinent variable. This term is significant only when the drain is so short that the characteristic surface profile in the region of maximum depth is affected appreciably by the proximity of the downstream or outlet end. The analysis will be developed to apply to drains that are quite long, so that $\pi_8$ can be omitted from consideration. Actually, this omission will lead to the prediction of capacities tending to include a safety factor when applied to practical conditions where drains may be short, since short drains tend to have surge capacities somewhat greater than long ones, other factors being the same.

Experimental data showed no significant effect on relative capacity attributable to $\pi_3$ or $\pi_5$ over the range of experimentation, hence these parameters will not be included further in the analysis. The fact that variation in Reynolds number did not affect relative capacity significantly indicates that the experimentation with surge flow was in the hydraulically "rough" range where frictional resistance is independent of Reynolds number. Therefore, the relationship

$$\phi(\pi_1, \pi_2, \pi_4, \pi_6, \pi_7)=0 \tag{1}$$

follows. It is desired to predict the relative capacity for surge flow, or the relative increase in hydraulic capacity for surge flow as compared to that for steady flow. For any given cross-sectional area of jet and time duration of surge, the relative increase in capacity can be represented by

$$\frac{\Delta Q}{Q_{sfc}}=\frac{\pi_1-\pi_2}{\pi_2}. \tag{2}$$

Plotting of experimental data on logarithmic paper showed that this convenient grouping of the variables brought order from the data. Therefore, the relationship

$$\frac{\Delta Q}{Q_{sfc}}=\phi(\pi_4, \pi_6, \pi_7) \tag{3}$$

was utilized in further consideration of the experimental data. That is,

$$\frac{\Delta Q}{Q_{sfc}}=\phi\left(t\sqrt{\frac{g}{D_d}}, \frac{k_d}{D_d}, \theta\right). \tag{4}$$

The term $\Delta Q/Q_{sfc}$, the relative increase in capacity for surge flow over that for steady flow, will be looked upon as the dependent variable.

Data for any particular drain at a given slope showed that $\Delta Q/Q_{sfc}$ was approximately an inverse linear function of the time duration of surge. This indicated that

$$\frac{\Delta Q}{Q_{sfc}}\propto\frac{1}{\pi_4}=\frac{\sqrt{D_d}}{t\sqrt{g}}. \tag{5}$$

The data for different degrees of drain roughness indicated that $\Delta Q/Q_{sfc}$ increased slightly with roughness, other factors being the same. Computations based on the experimental data indicated the relationship between $\Delta Q/Q_{sfc}$ and $k_d/D_d$ as exhibited by the data cannot be represented satisfactorily by a simple power function of $k_d/D_d$. Since the Reynolds numbers associated with the relatively high velocities of the surges introduced into the experimental drains indicate the flow to be within or near the hydraulically rough regime, it seems reasonable that the roughness effect might have been related to the roughness coefficients associated with the "rough" regime. Using values of $k_d$ given in table 4, corresponding values of $f$, $C$, or $n$ for the rough regime may be computed from the usual relationships [11]

$$\frac{1}{\sqrt{f_r}}=2\log\frac{D_d}{k_d}+1.14 \tag{6}$$

and

$$\frac{1}{\sqrt{f_r}}=\frac{C_r}{\sqrt{8g}}=\frac{1.18(D_d)^{1/6}}{\sqrt{8g}n_r}. \tag{7}$$

The subscript $r$ denotes the rough regime. It was found that the resistance coefficient was related to the observed effect of roughness on $\Delta Q/Q_{sfc}$ by the simple relation

$$\frac{\Delta Q}{Q_{sfc}}\propto\pi_6\propto\sqrt{f_r}. \tag{8}$$

By use of eq (7) the roughness effect could have been expressed equally well in terms of $C_r$ or $n_r$.

Data for any particular drain for different slopes showed that $\Delta Q/Q_{sfc}$ was approximately an inverse linear function of the drain slope, or

$$\frac{\Delta Q}{Q_{sfc}}\propto\frac{1}{\pi_7}\propto\frac{1}{\tan\theta}. \tag{9}$$

The experimental results of tables 2, 3, and 4 and figures 17, 18, and 19 indicate that the left-hand member of eq (3) is approximately a linear function of the product of the terms in the right-hand member as given by eqs (5), (8), and (9). This provides the basis for a convenient simplification in which the dependent variable is expressed as a function of the independent variables which could be computed easily from the experimental measurements. The curves shown in figures 17, 18, and 19 were computed from this function expressed as

$$\frac{\Delta Q}{Q_{sfc}}=\frac{K}{t}\sqrt{\frac{D_d}{g}}\frac{\sqrt{f_r}}{\tan\theta}. \tag{10}$$

In eq (10) $K$ is a dimensionless coefficient dependent on the geometry of the jet form. This simple function of the principal variables may not be applicable far outside the range of the experimentation. However, the agreement is satisfactory over the practical working range investigated.

The quantities $1+\Delta Q/Q_{sfc}$, $t$, and $k_d$ were measured for several values of $\theta$ and $D_d$, the values of which are given in tables 2, 3 and 4. Corresponding values of $1/\sqrt{f_r}$ (and hence $\sqrt{f_r}$) were computed from eq (6). From eq (10) values of $K$ were computed for the various jet forms used. Possibly the explanation of the difference in $K$-values for different jet forms is that the energy losses associated with the passage of the water through the stack-base fittings are affected by the jet form. However, this effect was not incorporated in eq (10) as a function of other variables, since in a typical plumbing system the flow at the base of the stack tends to approach the annular jet form which yielded the lowest capacity in the experimentation. Thus the use of the coefficient derived for the annular jet form should be safe for design.

With a few exceptions, the data in table 3 are in satisfactory agreement with eq (10). This is

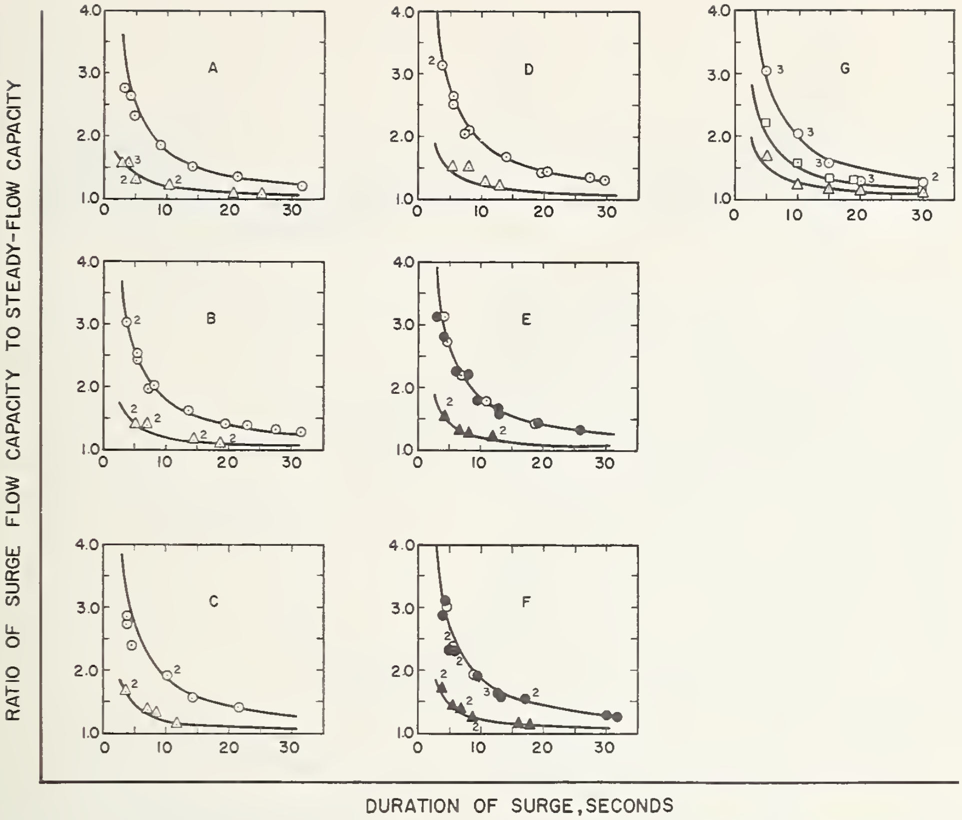


FIGURE 17. *Comparison of eq(10) and experimental measurements on drain systems shown in figures 8 and 10 (surge flow in initially empty 3-in. drains, long-sweep stack-base fitting).*

| End of drain open | End of drain restricted | Slope in./ft |
|---|---|---|
| ○ | ● | 1/16 |
| □ | ■ | 1/8 |
| △ | ▲ | 1/4 |

(Numbers adjacent to symbols indicate duplicate values.)

| Chart | Jet form (see fig. 9) | Drain material |
|---|---|---|
| A | B | Plastic. |
| B | C | Plastic. |
| C | B | Steel, galvanized. |
| D | C | Steel, galvanized. |
| E | B | Cast iron, uncoated. |
| F | C | Cast iron, uncoated. |
| G | E | Cast iron, uncoated. |

demonstrated in figures 17, 18, and 19. The curves in these figures represent eq (10), using values of $K$ as indicated in the following table computed from data in tables 3 and 4. The plotted points in the figures are experimentally determined values.

| Jet form | $K$ |
|---|---|
| Annular | 9.86 |
| Modified annular | 10.5 |
| Single circular | 11.4 |

These values of $K$ were determined from the data where long drains were simulated. Values of $K=10.5$ for Hunter's crescent jets and $K=12.3$ for the multiple-circular jets were used in plotting the curves for these data. The basis for the latter two values is discussed in section 9.3 of the appendix.

It had been expected that the type of stack-base fitting used might affect surge-flow capacities, and hence the value of $K$. However, the data in table 3 on this effect appear to be inconclusive. Data on a 4-in. drain show that, for the Y and ⅛ bend, $Q/\Delta Q_{stc}$ was of the order of 3 percent less

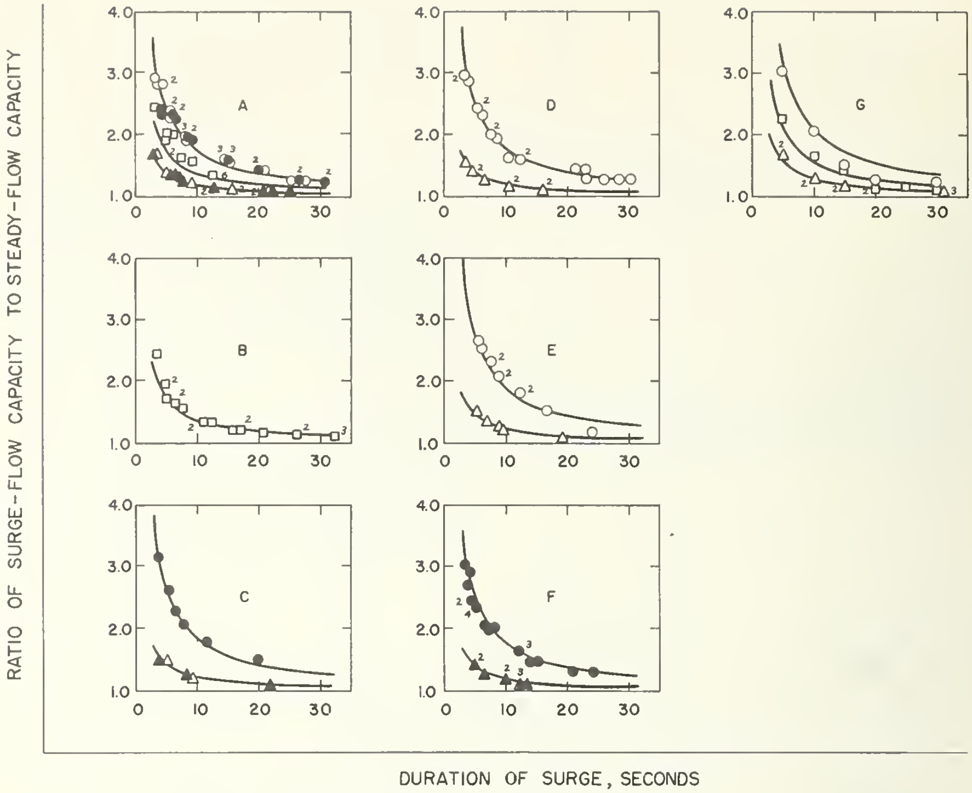


FIGURE 18. *Comparison of eq(10) and experimental measurements on drain systems shown in figures 8 and 10 (surge flow in initially empty 4-in. drains, long-sweep stack-base fitting except where otherwise indicated).*

| End of drain open | End of drain restricted | Slope in./ft |
|---|---|---|
| ○ | ● | 1/16 |
| □ | ■ | 1/8 |
| △ | ▲ | 1/4 |

(Numbers adjacent to symbols indicate duplicate values.)

| Chart | Jet form (see fig. 9) | Drain material |
|---|---|---|
| A | A | Plastic. |
| B* | A | Plastic. |
| C | C | Plastic. |
| D | A | Steel, galvanized. |
| E | C | Steel, galvanized. |
| F | A | Cast iron, coated. |
| G | E | Cast iron, uncoated. |

*Y- and 1/8-bend stack-base fitting.

than for the long sweep. Similar data on the 6½-in. drain show a value of the order of 4 percent greater. Therefore, no allowance has been made for the type of stack-base fitting in estimating surge-flow capacities. The experimental data with a Y and ⅛ bend are too limited in scope to permit a satisfactory evaluation of the effect of type of stack-base fitting.

## 6.2. Attenuation of Discharge Rates in Long, Initially Empty Drains

When a surge is introduced into a sloping drain, a maximum depth is produced at some cross section, which may or may not be in the vicinity of the drain entrance. Both the depth and discharge rate of the surge decrease continuously after it passes the section where maximum depth occurs.

A precise, physical evaluation of the phenomenon of surge attenuation might indicate some effect due to initial entrance velocity, drain roughness, drain diameter, and other factors. The data summarized in tables 8 and 9 are not believed adequate for a rigorous evaluation. However, the data are presented because they are informative and because they were utilized by Hunter in making certain recommendations as to permissible

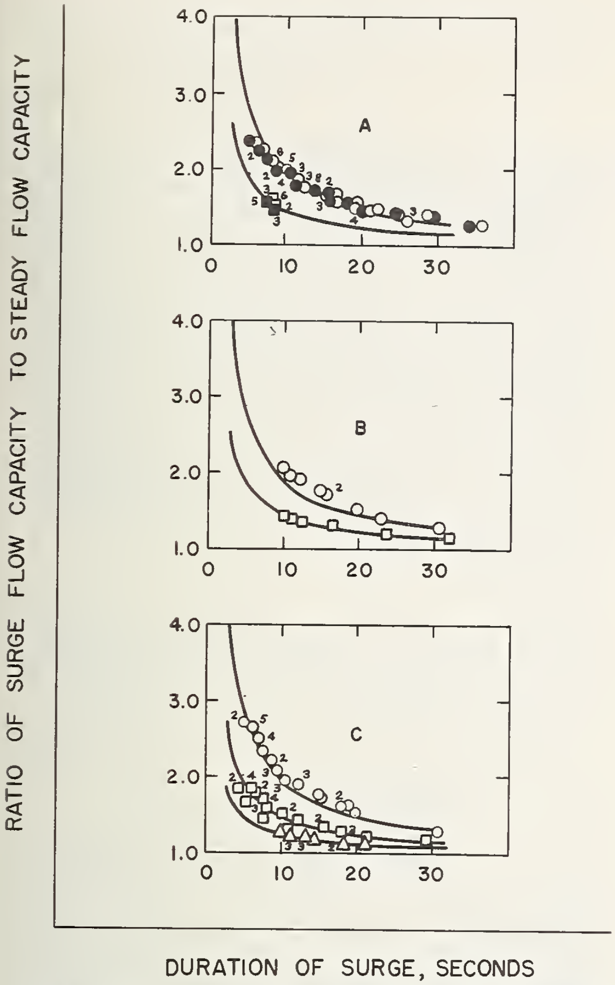


FIGURE 19. *Comparison of eq(10) and experimental measurements on drain system shown in figure 10 (surge flow in initially empty 6½-in. plastic drain, long-sweep stack-base fitting except where otherwise indicated).*

| End of drain open | End of drain restricted | Slope in./ft |
|---|---|---|
| ○ | ● | 1/16 |
| □ | ■ | 1/8 |
| ▲ | ▲ | 1/4 |

(Numbers adjacent to symbols indicate duplicate values.)

| Chart | Jet form (see fig. 9) |
|---|---|
| A | C |
| B* | C |
| C* | D |

*Y- and 1/8-bend stack-base fitting.

loads on secondary branches of long building drains and building sewers [3].

The data in tables 8 and 9 are somewhat erratic, but inspection indicates that the predominant factors affecting the attenuation of discharge rate between the drain entrance and outlets were (1) the length, $L$, measured between these two sections, and (2) the slope, $S$. The empirical equations

$$\delta=\frac{K_1L}{\sqrt{S}} \tag{11}$$

and

$$\delta=e^{-K_2\sqrt{S}/L} \tag{12}$$

have been derived from the data, where $L$ is expressed in feet, and $S$ in in./ft. The term

$$\delta=\frac{Q_u-Q_d}{Q_u} \tag{13}$$

is the attenuation factor, where $Q_u$ is the discharge rate at the upstream cross section, and $Q_d$ is the rate at the downstream cross section. Equation (12) is proposed as being more reasonable than eq (11), since it yields a more reasonable result, $\delta\rightarrow 1.0$, for a very long drain than eq (11). The values for discharge ratio in the right-hand column of tables 8 and 9 are actually values of $1-\delta$.

Hunter utilized eq (11) with a value of $K_1=0.005$ in computing permissible loads on drains located at considerable distances from the load origin [3]. An upper-envelope fit to the data of tables 8 and 9 can be obtained through the use of eq (12) with a value of $K_2$ of about 50, where $\delta$ is expressed as a function of $L/\sqrt{S}$. However, the data do not provide as conclusive a basis for the derivation of a design equation as might be desired. Further work appears to be needed on this aspect of attenuation.

### 6.3. Flow of Junction at Main and Branch in Compound Drains

Two types of flow were considered: steady flow in both the main and branch, and surge flow in the branch with steady flow in the main. The criterion of capacity was the occurrence of a full-section condition at the junction of the main and the branch similar to that illustrated in figures 4 to 7.

In practically all of the experimental determinations of flow capacities at drain junctions, the combined capacity of the main and the branch was appreciably greater when the branch carried surge flow and the main steady flow, than when both carried steady flow.

When surges of short duration were discharged through a branch into a main carrying steady flow, the unfilled portions of the drains upstream from their junction appeared to affect the flow capacity of the system. This effect was not investigated systematically, but the experimental evidence indicated that system capacity increased with this "storage" volume.

When surge flow was superimposed on steady flow in a nominally horizontal main through a vertical branch (stack) at a velocity comparable to terminal velocity in a soil or waste stack under service conditions, a full section was produced downstream from the junction, somewhat as shown in figure 2. This was taken as the criterion of capacity. The data indicated that under these conditions system capacity was roughly in agreement with an equation of the same form as that derived from data on full-section flow at the junction of compound drains with both the branch and the main in a common nominally horizontal plane and with surge flow in the branch and steady flow in the main.

### a. Steady Flow in Branch and Main in a Common Horizontal Plane

Referring to figure 20, case 1 represents conditions in a horizontal drain system for which a given rate of flow, $Q_3$, is carried in the main without the addition of any flow from the branch. The center of gravity of this stream is at a distance $\bar{z}_3$, above the invert. Case 2 represents conditions for which the same rate of flow is divided between the branch, $Q_2$, and the main $Q_1$. Thus,

$$Q_3=Q_1+Q_2.$$

The system is filled at section *a-a* without creating appreciable hydrostatic pressure at the crown of the main in the vicinity of the junction. It is evident that the upstream velocity near the junction (section *a-a*) is less and the depth greater in case 2 than in case 1. It is also evident that, at sufficient distance downstream from section *a-a*, the hydraulic elements are the same in the two cases. In case 2, the average elevation of section *a-a* above the invert is $\bar{z}_1'$, or $D_1/2$. The difference between $\bar{z}_3$ and $\bar{z}_1'$, $\Delta\bar{z}$, is the result of the confluence of the two streams at the Y-branch. The observed effect is intimately related to energy and momentum changes occurring in the vicinity of the junction of the two drains.

An analysis of the data was first made on the thesis that the difference in water depth with reference to the drain invert at the junction of the main and the branch and at a section far downstream was caused by the centrifugal force generated by mutual deflection of streamlines in the vicinity of the junction. This analysis followed the approach given in the NBS Monograph 31 [9] regarding interference of flows at the junction of a vertical drain (soil or waste stack) and a horizontal branch.

However, a precise evaluation of the factors involved in this complex phenomenon did not seem to be justified on the basis of the data obtained, because several gross simplifying assumptions were necessary in developing the analysis for practical application and certain constants had to be determined from the experimental data. Nevertheless, in reviewing the data in accordance with the centrifugal force thesis, it was found that the equation:

$$X^{5/8}Y^{3/8}=0.250\left(\frac{D_1}{D_2}\right)^2 \qquad (14)$$

fitted the data in table 10 reasonably well. In eq

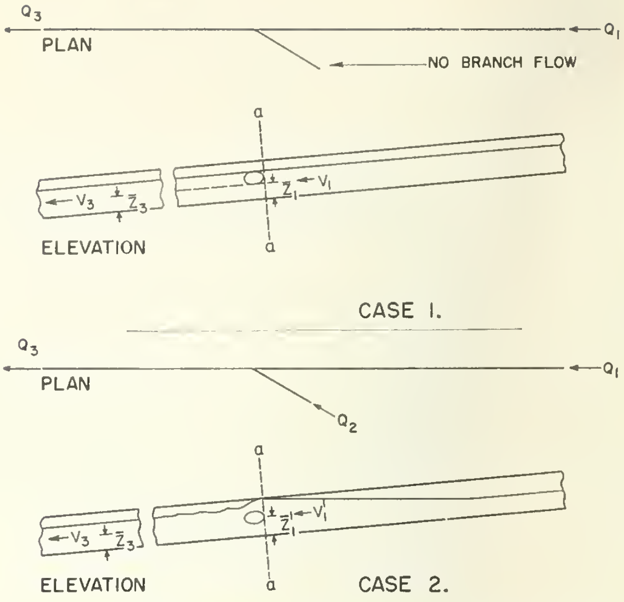


FIGURE 20. *Diagram illustrating terms used in discussion of flow interference at junction of main and branch.*

Case 1: Elevation of center of gravity of section a-a above invert $=\bar{z}_3=\bar{z}_1$,
$V_1=V_3$,
$Q_1=Q_3$, and
$Q_2=0$.

Case 2: Elevation of center of gravity of section a-a above invert $=\bar{z}_1'=\frac{D_1}{2}\neq\bar{z}_3$,
$V_1'\neq V_3$,
$Q_1+Q_2=Q_3$
$Q_1\neq 0$,
$Q_2\neq 0$, and
main and branch are full but not under hydrostatic pressure at junction (sec. a-a).

(14) $X=\frac{(V_1)^2}{2g\Delta\bar{z}}$, and $Y=\frac{(V_2)^2}{2g\Delta\bar{z}}$ where full-section flow is assumed at the main-branch junction as indicated in case 2 of figure 20. An equally good fit was found by replacing the diameter ratio function in eq (14) with a more complex function involving the volume common to the intersestion of main and branch. This function was also expressed in terms of the diameters but was not a simple power function.

It can be shown by the methods of dimensional analysis that the variables that are most apparent can be grouped in a form similar to that of eq (14). Let the applicable variables be $Q_1$, $Q_2$, $D_1$, $D_2$, $S$, and $C$. In addition, the acceleration of gravity, $g$, will be introduced as an experimental constant. One possible grouping of these quantities is:

$$\phi\left(\frac{Q_1}{(D_1)^{5/2}\sqrt{g}}, \frac{Q_2}{(D_2)^{5/2}\sqrt{g}}, \frac{D_2}{D_1}, S, C\right)=0. \qquad (15)$$

It is permissible to introduce $\frac{\Delta\bar{z}}{D_1}$ in place of $S$ on the basis of the relationship between $S$ and $r_h$ by the Chezy formula and between $r_h$ and $\Delta\bar{z}$ by the geometry of segments of circular sections. Thus,

$$\phi\left(\frac{Q_1}{(D_1)^{5/2}\sqrt{g}}, \frac{Q_2}{(D_2)^{5/2}\sqrt{g}}, \frac{D_2}{D_1}, \frac{\Delta\bar{z}}{D_1}, C\right)=0 \qquad (16)$$

which can be placed in an equivalent form

$$\phi\left(\frac{(V_1)^2}{g\Delta\bar{z}}, \frac{(V_2)^2}{g\Delta\bar{z}}, \frac{D_2}{D_1}, \frac{\Delta\bar{z}}{D_1}, C\right)=0. \qquad (17)$$

The first three variables in eq (17) are identical in form to those appearing in eq (14) which is in reasonable agreement with the data of table 10.

The fact that the experimental data showed no apparent consistent effects due to variation in $\Delta\bar{z}/D_1$ and $C$ over the range of the experimentation indicates that these terms can be neglected in regard to the analysis of these particular data. Thus on the basis of dimensional analysis it is permissible to utilize the function shown in eq (14) for application to the data shown in table 10.

Equation (14) can be expressed in terms of discharge rates, rather than velocities. This can be done through use of the relationship

$$Q=AV=\frac{\pi D^2 V}{4}. \qquad (18)$$

This results in the equation,

$$\left(\frac{(Q_1)^2}{(D_1)^4 g\Delta\bar{z}}\right)^{5/8}\left(\frac{(Q_2)^2}{(D_2)^4 g\Delta\bar{z}}\right)^{3/8}=0.309\left(\frac{D_1}{D_2}\right)^2 \qquad (19)$$

or

$$(Q_1)^{5/2}(Q_2)^{3/2}=0.0955\,\frac{(D_1)^9(g\Delta\bar{z})^2}{D_2}, \qquad (20)$$

in which $Q_1$ and $Q_2$ are expressed in cubic feet per second; $D_1$, $D_2$, and $\Delta\bar{z}$ are in feet; and $g$ is in feet per second per second. The latter equation is in a more convenient form for solution than eq (19). Equation (20) can be solved to give corresponding values of $Q_1$ and $Q_2$ which caused the compound drains to flow full at their junctions without creating hydrostatic pressure at the crown of the main, applicable over the range of the experimentation. The solution can be achieved for a drain system for which the steady flow capacity of the main flowing full is known.

The relationship between vertical distance from invert to center of gravity of water cross section, $\bar{z}_3$, and water depth for free-surface flow was determined from King's tabulation of vertical distance below water surface to center of gravity of water cross section for circular conduits flowing partly full [12]. The relationship between total rate of discharge for the drain system ($Q_1+Q_2$ in the terminology of this paper) and water depth in the main downstream of the junction was computed from the Manning formula wherein the hydraulic radius was expressed as a function of water depth. This made it possible to relate rate of discharge, $Q_1+Q_2$, to difference in vertical distance between center of gravity of water cross section and center of gravity of conduit cross section, ($\Delta\bar{z}$), where $\Delta\bar{z}=\bar{z}_1'-\bar{z}_3$, or $\Delta\bar{z}=\frac{D_1}{2}-\bar{z}_3$ as shown in figure 20.

Values of $D_1$ and $D_2$ were known for the experimental drains. The number of unknowns in eq (20) was reduced to two through use of the relationship between $\Delta\bar{z}$ and $(Q_1+Q_2)$ described above. Curves were computed by assuming

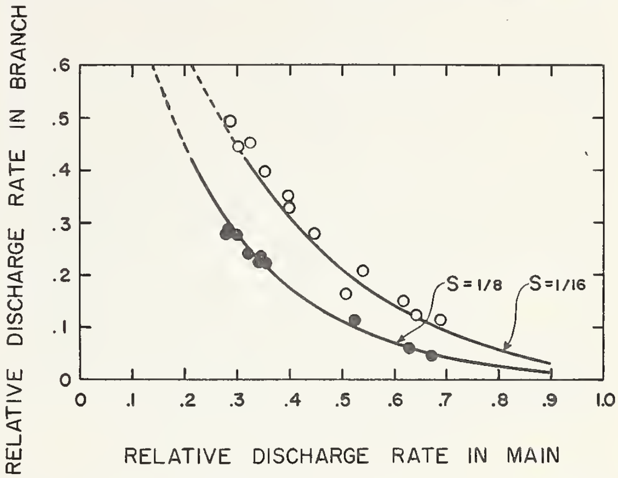


FIGURE 21. *Comparison of eq (20) and experimental measurements on plastic drain system shown in figure 16 (for 4-in. main and 3-in. branch, steady flow).*

| Drain slope | Steady flow capacity of main as a simple drain (see table A-1) |
|---|---|
| *in./ft* | *gpm* |
| 1/16 | 100 |
| 1/8 | 139 |

Curves dashed for values of branch discharge in excess of steady flow capacity of branch as a simple drain.

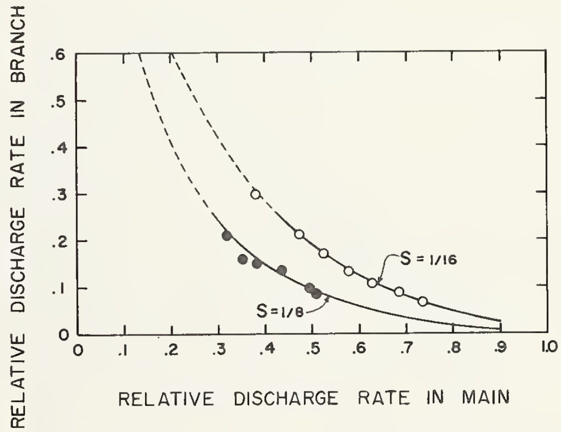


FIGURE 22. *Comparison of eq (20) and experimental measurements on plastic drain system shown in figure 16 (for 6½-in. main and 4-in. branch, steady flow).*

| Drain slope | Steady flow capacity of main as a simple drain (see table A-1) |
|---|---|
| *in./ft* | *gpm* |
| 1/16 | 380 |
| 1/8 | 535 |

Curves dashed for values of branch discharge in excess of steady flow capacity of branch as a simple drain.

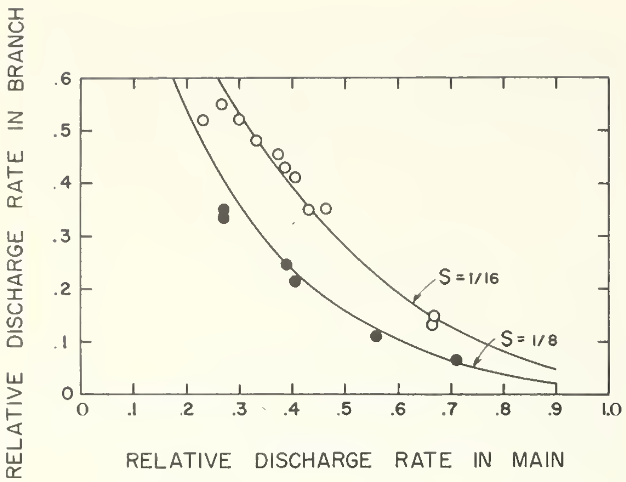


FIGURE 23. *Comparison of eq (20) and experimental measurements on cast-iron drain system shown in figure 15 (for 4-in. main and 4-in. branch, steady flow).*

| Drain slope | Steady flow capacity of main as a simple drain (see table 10) |
|---|---|
| *in./ft* | *gpm* |
| 1/16 | 79 8 |
| 1/8 | 114 |

numerical values of $\Delta\bar{z}$ and solving eq (20) for corresponding values of $Q_1$ and $Q_2$.

This procedure has been carried out for several of the experimental drains. Results from some of the tests are shown in figures 21 to 23. Actual measurements from table 10 are shown for comparison with the computed curves. In these figures equal slopes are assumed for main and branch drains. The ordinates and abscissas are expressed as "relative discharge rates," obtained by dividing the actual rates by the steady flow capacity of the main determined experimentally. Therefore, the ordinate and abscissa values represent factors which, if multiplied by the known steady flow capacity of the main, give the actual capacities of the branch and the main, respectively. This method of representing ordinate and abscissa values is useful in showing the magnitudes of permissible flow rate in relation to the steady flow capacity of the main, over the range of the experimentation. Also it clearly shows that the relative discharge rate decreases as slope is increased, evidently because of greater energy losses in the vicinity of the junction.

The computed curves in the figures are dashed for ordinate values greater than the approximate steady flow capacities of the branch drains at the indicated slopes. Rates of steady flow in branch drains in excess of these limits should never be permitted to occur in sanitary systems in service.

The agreement between observed values and values computed from eq (20) is considered satisfactory for drain slopes of 1/16 and 1/8 in./ft. However, measurements in a 4-in. drain with 2-, 3-, and 4-in. branches at a slope of 1/4 in./ft (not given in table 10) differed erratically from those computed from eq (20). This difference may have been influenced by the excessive turbulence characteristic of the 1/4-in./ft slope. Further investigation of junction flow at slopes greater than 1/8 in./ft is needed.

#### b. Surge Flow in Branch, Steady Flow in Main

Table 11 gives data obtained for surge flow discharged through a branch drain into a main carrying steady flow. The main and the branch were both nominally horizontal, and were joined by a 45°-Y-branch fitting as shown in figure 16. System capacity, $(Q_1+Q_2)$, was somewhat greater under this condition than under the conditions described in section 6.3a where steady flow was carried in both the main and the branch. An empirical equation was developed from the experimental data which gives hydraulic capacity for combined surge and steady flow based on distribution of flow between main and branch, and on hydraulic capacities for the two separate types of flow as given by eqs (10) and (20), respectively. The equation

$$Q_c = Q_{st}[1+\gamma(1-e^{-kQ_2/Q_1})] \tag{21}$$

conformed to the experimental findings more closely than did several others considered. The terms have the following significance:

$Q_2/Q_1$ = ratio of branch discharge to main discharge, to be considered as an independent variable,

$Q_c$ = system capacity for combined surge and steady flow,

$Q_{st}$ = system capacity for steady flow in both branch and main, as given by eq (20),

$\gamma$ = relative increase in capacity for surge flow of a given time duration over that for steady flow in a simple drain of the same diameter and slope as the main, as obtained from eq (10), and

$k$ = an experimental constant.

Rates of discharge and surge-duration times apply to conditions at the entrances to the test drains. The accuracy of eq (21) should be greatest for very small and very large values of $Q_2/Q_1$, since full-pipe, steady flow in the main is approached as $Q_2/Q_1$ becomes small, and surge flow into the empty main is approached as $Q_2/Q_1$ becomes large. At intermediate values of $Q_2/Q_1$, agreement of eq (21) with observed capacity depends on the value of $k$ used. This constant may depend to some extent on drain length upstream from the main-branch junction, on drain slope, and possibly on other factors not yet investigated.

Figures 24 and 25 show experimental data from table 11 for the test system in which both the main and branch were nominally horizontal. Data

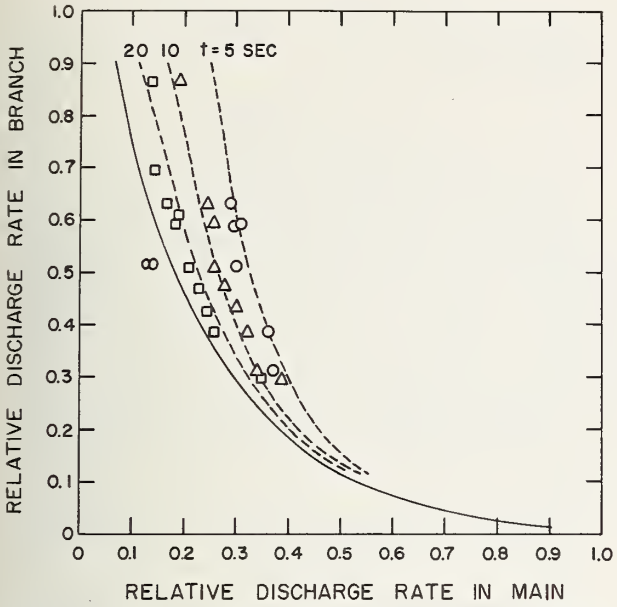


FIGURE 24. *Comparison of eq (21) and experimental measurements on plastic drain system shown in figure 16 (for 4-in. main and 3-in. branch on a slope of 1/8 in./ft, steady flow in main, surge flow in branch, steady flow capacity of main=134 gpm based on data of table 4).*

○ 5-sec surges.
△ 10-sec surges.
□ 20-sec surges.

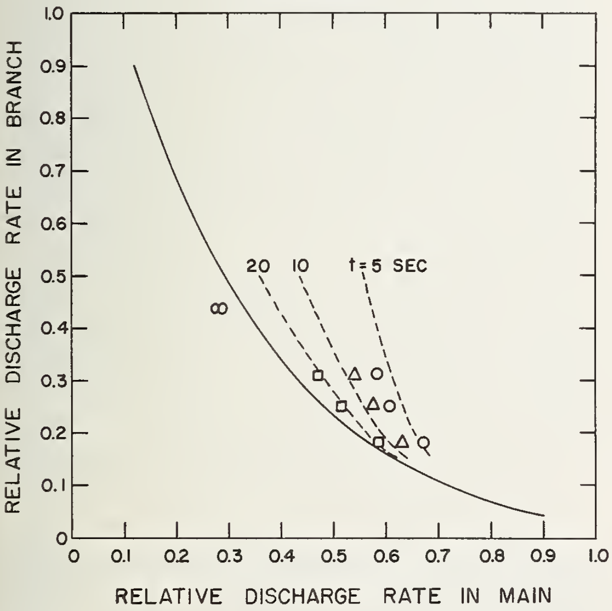


FIGURE 25. *Comparison of eq (21) and experimental measurements on plastic drain system shown in figure 16 (for 6½-in. main and 4-in. branch on a slope of 1/16 in./ft, steady flow in main, surge flow in branch, steady flow capacity of main=352 gpm based on data of table 4).*

○ 5-sec surges.
△ 10-sec surges.
□ 20-sec surges.

are shown for 5-, 10-, and 20-sec surges in the branch, with steady flow in the main. For comparison, dashed curves are shown, computed from eq (21) with a value of $k=0.41$. The term $\gamma$ is the same as $\Delta Q/Q_{stc}$ in eq (10). Values of $\gamma$ were based on an annular jet form and on drain diameter, slope, and roughness applicable to the main in the particular test system under consideration. The solid curve represents eq (21) where the surge duration time is infinity. In this case, $\gamma$ becomes zero according to eq (10), and $Q_c=Q_{sf}$ according to eq (21); hence eq (20) for steady flow in both main and branch is applicable. The agreement between eq (21) and the data is considered satisfactory. However, more work is needed to establish the limits of the range where satisfactory agreement can be expected; particularly as to ratio of branch diameter to main diameter, ratio of branch discharge to main discharge, and slope.

Figure 26 shows data from table 12 for combined

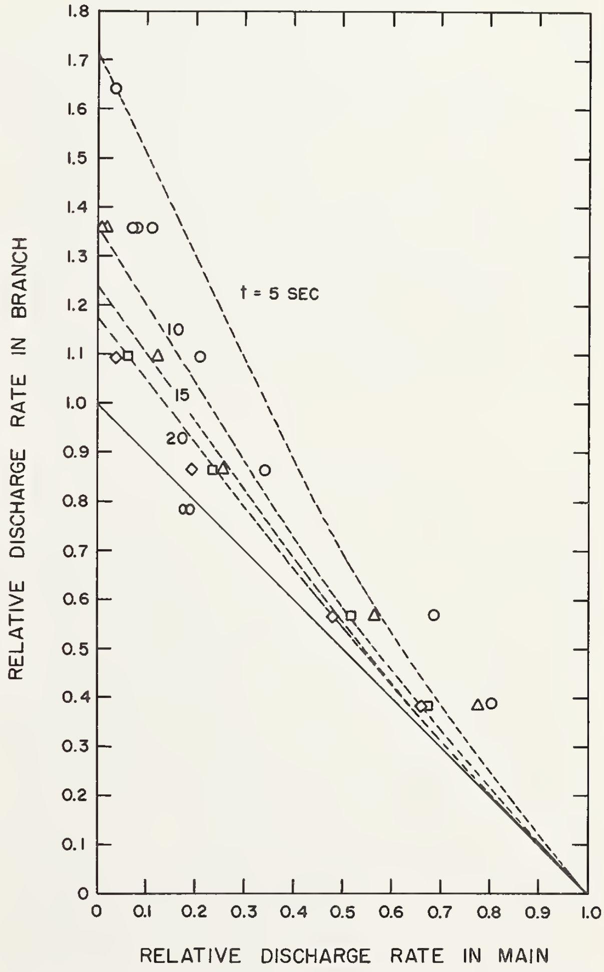


FIGURE 26. *Comparison of eq (21) and experimental measurements on drain system comprising a vertical branch and a 4-in. plastic main drain on a slope of 1/8 in./ft (steady flow in main, surge flow in branch, steady flow capacity of main=134 gpm based on data of table 4).*

○ 5-sec surges.
△ 10-sec surges.
□ 15-sec surges.
◇ 20-sec surges.

surge and steady flow in the test system described in section 5.2a, where the main carried steady flow and the surges were introduced through a stack (vertical branch) connected to the main with a Y- and ⅛-bend fitting about 2 ft from the upstream end of the main. Steady flow was delivered at the upstream end of the main, and surge flow was delivered through the branch at velocities comparable to terminal velocity in soil or waste stacks under service conditions as given by eq (A–6). Pressure conditions were not investigated in the main immediately upstream from the junction nor within the junction itself. As indicated in section 5.2a, the criterion of capacity was the occurrence of a full section of minimum length downstream from the junction. The dashed curves in figure 26 were computed from eq (21), based on a value of $k=0.22$, in a way similar to that described for figures 24 and 25. System capacity for steady flow, $Q_{st}$, as given by the solid curve, was assumed equal to the steady flow capacity of the main rather than being computed from eq (20). Although the agreement between the data and the computed curves is considered acceptable, more work is needed on this aspect of junction flow. In particular, more information is needed as to what the criterion of hydraulic capacity should be for a system comprising a stack discharging surge flow into the top of a horizontal drain carrying steady flow.

Preliminary measurements, utilizing the test system in figure 16, showed that for a slope of 1/16 in./ft increasing upstream storage volume by increasing the size of the stilling box resulted in increased system capacity for combined surge and steady flow, other conditions being the same. Hunter observed capacities for combined flow which were relatively somewhat greater than the capacities observed by the author. This difference may have been caused by the greater upstream storage volumes associated with his test system, particularly in the long branch drains. In addition to performing a storage function, such drains may, under certain conditions, also permit "cresting" of high velocity surges and possibly their subsequent attenuation upstream from the main-branch junction. In the author's tests on the system in which both the main and the branch were horizontal, the branch storage volume was practically eliminated by making the branches quite short, and the main storage volume was limited to that due to 11 lineal ft of main and approximately 3 ft² of surface area in the stilling box. In the test system in which the branch was vertical, there was no effective upstream storage volume in either the branch or the main. Under service conditions where the building drain is connected to one or more branch drains, upstream storage volume may well be greater than in the author's tests. The values of $k$ in eq (21) derived from the tests would probably be conservative as applied to such service conditions, insofar as the effect of storage volume is concerned. Equation (21) does not provide for evaluation of storage volume except empirically through the value assigned to $k$.

## 7. Conclusions

### 7.1. Estimating Hydraulic Capacity

Methods for estimating hydraulic capacity, as reflected in eqs (10), (12), (20), and (21), should be useful as improved criteria for sizing horizontal drains in sanitary drainage systems for buildings. Horizontal drains of interest to engineers, plumbing-code writers, and plumbing officials include fixture drains, horizontal fixture branches, primary and secondary branches of building drains, and building sewers. The equations are particularly applicable to building drains and building sewers.

### 7.2. Design of Plumbing Systems With Minimum Venting

Equations (10), (12), (20), and (21) should be especially useful in selecting safe economic pipe sizes for sanitary drainage system designs in which adequate venting of fixture drains depends on the existence of a continuous air space or absence of excessive surge cresting above the mean water surface in horizontal branches, building drains, or other horizontal drains. Presently, this type of venting is permitted to a limited degree under the provisions of some plumbing codes, as for example under the provisions of paragraph *12.22 Combination Waste and Vent System* of ASA A40.8—1955 limited to sinks and floor drains. Guidance in the design of such systems, as provided in part by eqs (10), (12), (20), and (21), should make it possible, at least on the basis of hydraulics and pneumatics, to further minimize the number of vent pipes and the total quantity of vent piping required in systems where surge flow of relatively short duration is typical such as in one- and two-family houses. Possibly this approach could result in the elimination of *all* conventional vents in the simpler drainage systems. However, some further research on this matter may be needed.

### 7.3. Utilization of Field Data and of Data on Surge Attenuation

Attenuation of surge discharge rates in long drains (see sec. 6.2) may be a significant factor in the determination of hydraulic capacities of secondary branches of building drains, and of building sewers. Hunter's data on this phenomenon, given in tables 5 through 9, were utilized in the computation of recommended fixture-unit loads on secondary branches by the committee which developed the Plumbing Manual [3]. Hunter's field data from the buildings described in table 1 furnished general information on typical flow conditions which was later utilized in the design of experimental apparatus and development of test procedures.

### 7.4. Effect of Surge-Duration Time, Drain Slope, and Other Factors on Hydraulic Capacity

Flow capacities were greatest for short-duration surge flow and least for steady flow. Actual capacities increased with drain slope and diameter. Relative capacities decreased with drain slope. Other factors, including roughness of pipe material and geometry of fittings, evidently affected capacity to some extent, but to a lesser degree than did surge-duration time, drain slope, and drain diameter.

### 7.5. Surge-Flow Capacities of Simple Drains

Equation (10) agrees reasonably well with measured values of surge-flow capacity in a number of simple drains initially empty. The most significant variables were surge-duration time, drain diameter, and drain slope. The equation is based on data for drain slopes of $\frac{1}{16}$, $\frac{1}{8}$, and $\frac{1}{4}$ in./ft; hence it may not apply to slopes greater than $\frac{1}{4}$ in./ft.

### 7.6. Steady Flow Capacities of Compound Drains

Equation (20) is in satisfactory agreement with measured values of steady flow capacity in several nominally horizontal compound-drain systems each of which comprised a main drain and a branch drain intersecting the main at an angle of 45°. The equation predicts a minimum capacity for the system when a relatively small part of the flow is carried by the branch, and somewhat greater capacities when the branch flow is increased or decreased from this critical value. Evidently eq (20) is not suitable for application to drain slopes of 1/4 in./ft or more.

### 7.7. Capacities for Surge Flow Superimposed on Steady Flow

Equation (21), which is an arbitrary combination of eqs (10) and (20), is roughly in agreement with measured values of flow capacity in compound drains carrying surge flow in the branches and steady flow in the mains.

### 7.8. Need for Further Investigation

Adequate safety factors should be used in the application of the equations to conditions very much outside the range covered in the experiments reported. Reduction of these safety factors to a desirable minimum cannot be accomplished without further information as to the effects, on hydraulic capacity, of the following factors under controlled experimental conditions:

1. Partial or complete elimination of conventional venting of horizontal drains,
2. drain storage volume upstream from junctions in compound drains for the case of steady flow in main and surge flow in branch, eq (21),
3. very small discharge in either main or branch of compound drains, and correspondingly large discharge in the other component, eqs (20) and (21),
4. energy losses at the bottom of drainage stacks resulting from turbulence and friction in stack-base fittings, eq (10),
5. drain slopes greater than $\frac{1}{8}$ in./ft in the case of compound drains (see particularly eq (20)),
6. hydrodynamic pressures upstream in main from junction of main and vertical branch, eq (21),
7. attenuation of depth and discharge rates for surge flow in long drains, eqs (11) and (12), and
8. drain diameters greater than employed in the experiments reported herein.

### 7.9. Computation of Allowable Fixture-Unit Loads

For design purposes it is desirable to express allowable sanitary loads in terms of plumbing fixtures (fixture-unit loads) rather than in terms of hydraulic capacity. This procedure involves the simultaneous solution of two types of equations—one relating to hydraulic capacity and the other to probable discharge from mixed groups of fixtures.

The computation of fixture-unit loads for nominally horizontal drains in plumbing systems is an appropriate subject for a later paper. Such a paper should give in some detail methods by which the computations may be made on the basis of hydraulic data such as reported herein, of data on typical use and discharge of plumbing fixtures, and of the mathematics of probability.

---

Acknowledgment is made to a number of persons at the National Bureau of Standards who contributed significantly to the success of the investigation. The late Dr. Roy B. Hunter left unpublished data in his files on an early study of some of the problems discussed in this paper. John L. French made an informative analysis (unpublished) of Hunter's data, which pointed out the need for further research and stimulated the author's interest in the subject. Herbert B. Banks, Douglas E. Gasterland, Daniel R. Tolliver, and Carl W. Brumfield gave careful attention to construction of equipment, to making of measurements, and to analysis of data under the direction of the author. Editorial assistance by Theodora C. Bailey and constructive technical suggestions by John L. French, Bradley A. Peavy, Jr., and Joseph C. Davis contributed notably to the presentation.

## 8. References

[1] R. B. Hunter, Methods of estimating loads in plumbing systems, NBS Building Materials and Structures Report BMS 65, 1940.

[2] H. N. Eaton and J. L. French, Fixture-unit ratings as used in plumbing system design, Housing Research Paper 15, Housing and Home Finance Agency, 1951.

[3] Plumbing Manual, NBS Building Materials and Structures Report BMS 66, Report of the Subcommittee on Plumbing of the Central Housing Committee on Research, Design, and Construction, 1940.
[4] Report of the coordinating committee for a national plumbing code, U.S. Department of Commerce and Housing and Home Finance Agency, Domestic Commerce Series No. 28, 1951.
[5] American standard national plumbing code, ASA A40.8—1955, American Society of Mechanical Engineers and American Public Health Association.
[6] V. T. Manas, National plumbing code handbook (McGraw-Hill Book Co., New York, 1957).
[7] H. E. Babbitt, Plumbing, 3d ed. (McGraw-Hill Book Co., New York, 1960).
[8] V. T. Manas, National plumbing code illustrated, 3d ed. (Manas Publications, 1962).
[9] R. S. Wyly and H. N. Eaton, Capacities of stacks in sanitary drainage systems for buildings, NBS Monograph 31, 1961.
[10] E. Buckingham, Notes on the method of dimensions, Phil. Mag. **V42**, No. 251, Nov., 1921.
[11] H. Rouse, Elementary mechanics of fluids (John Wiley & Sons, Inc., New York, N.Y., 1946).
[12] H. W. King, Handbook of Hydraulics, 4th ed. (McGraw-Hill Book Co., New York, 1954).
[13] L. F. Moody, Friction factors for pipe flow, A.S.M.E. Transactions, V66, 1944.
[14] F. M. Dawson and A. A. Kalinske, Report on hydraulics and pneumatics of plumbing drainage systems—I, University of Iowa Studies in Engineering, Bulletin 10 (1937).
[15] F. M. Dawson and A. A. Kalinske, Report on the hydraulics and pneumatics of the plumbing drainage system, Technical Bulletin 2 of the National Association of Master Plumbers of the United States, Inc. (1939).
[16] F. Sommer, Studies made on vertical drains at 100 mm diameter, Trade School, Bern, Switzerland, 1963.
[17] Sovent, a new vertical stack system, Oderlin and Co. Limited—metal works, Baden, Switzerland, 1961.
[18] H. E. Voegeli, Drainage without vent stacks, Air Conditioning Heating and Ventilating, V60, No. 8, August, 1963.

## 9. Appendix

### 9.1. Computation of Roughness Coefficients

Table 4 gives the results of computations of roughness coefficients for the drains used in the experiments. The method for computation is summarized below.

The capacity flow rate for steady flow was determined for each drain under conditions which simulated a very long drain (see sec. 9.2). A continuous flow at a constant volume rate was discharged into the drain entrance. The supply rate was adjusted carefully so that the hydraulic gradient, or surface profile, coincided with the crown of the drain downstream from the point at which substantially steady, uniform flow was attained, this point being somewhat less than 50 drain diameters from the entrance in most cases. The full-conduit condition was determined visually by means of the vent holes in the crown of the drain.

A value of the Darcy-Weisbach friction factor was computed for each combination of drain slope, diameter, and material from the relationship

$$f=1.23g\left[\frac{(D_d)^5S}{(Q_{stc})^2}\right], \tag{A–1}$$

in which dimensionally consistent units are used. Equation (A–1) was derived from the Darcy-Weisbach formula by expressing velocity in terms of discharge rate and setting hydraulic gradient equal to the drain slope.

In order to obtain the Nikuradse roughness magnitude, the Reynolds number,

$$N_R=\frac{VD}{\nu}, \tag{A–2}$$

corresponding to each experimental value of $f$ was computed. Values of the roughness magnitude, $k_d$, were then determined approximately by inspection of the conventional graph showing the relationship between $f$, $N_R$, and $k_d/D$ [13]. According to the theory on which this relationship is based, the roughness magnitude for a given pipe is not affected by Reynolds number. However, because of small errors in measurement and possible systematic differences occurring when drain lines were disassembled and reassembled in changing slope, the experimental values of $k_d$ determined for a given drain as described actually were somewhat different for the Reynolds numbers associated with different slopes. Since no predominant trend was observed, the values of $k_d$ obtained for the different slopes were averaged. For each combination of drain diameter, material, and slope the graph was again consulted to obtain a value of $f$ corresponding to this average value of $k_d$, based on the experimental value of $N_R$. These values of $f$ are referred to as "rationalized" values, from which rationalized values of capacity flow rate were computed through the use of eq (A–1). The word "rationalized" is used here in the sense that the quantities referred to are in conformance with the Darcy-Weisbach formula and the Nikuradse roughness magnitude concept ("rational" pipe flow theory).

Values of Chezy's $C$ and Manning's $n$, corresponding to the rationalized values of $f$, were computed from the relationship obtained by equating the conventional expressions for discharge rate as given by Chezy, Darcy-Weisbach, and Manning, i.e.,

$$\frac{1}{\sqrt{f}}=\frac{1.49}{\sqrt{8g}}\frac{(r_h)^{1/6}}{n}=\frac{C}{\sqrt{8g}} \tag{A–3}$$

in which the hydraulic radius is expressed in feet and $r_h$ is equal to $D_d/4$ for a circular drain completely filled.

### 9.2. Effect of Drain Length on Measured Steady Flow Capacity

Evidently the steady flow capacities recorded in Hunter's notes for drains 70 ft long were obtained without end restriction. For comparison with the author's measurements with end restriction, it was necessary to estimate the steady flow capacities that probably would have been obtained by Hunter had very long drains been used or simulated by end restriction.

The slope of the free surface of the water flowing at a constant volume rate in a channel or conduit of uniform slope and cross section without end restriction is greater near the discharge end than upstream. This makes it difficult to determine steady flow capacity for such a conduit if the ratio of length to diameter is small. In attempting to bring the water surface into contact with the crown very close to the end of the drain under this condition, somewhat too large a discharge rate is likely to be used. Consequently some slight internal hydrostatic pressure and overflowing occurs farther upstream. Under this condition there is some uncertainty as to how an experimenter is to decide that the drain is "full." The end restriction utilized in the new work consisted of a wood block ¾ in. thick clamped into place across one side of the discharge end of the drain. The top of the block was inclined outward from the vertical by about 5 deg, and the inside edge projected across the bore of the drain just enough (a maximum of the order of ¾ in. or a little more) to bring the water surface up to the crown uniformly along the drain from the discharge end upstream to the point at which entrance disturbances had been substantially dissipated.

Experimental data are given in tables A–1 and A–2 for steady flow capacities with and without end restriction. Inspection of the values in table A–1 shows that capacities were less when long drains were simulated, and the effect of end restriction was greatest for small slopes. The relationship is a complex one, and the data reported here are not sufficient to yield a fully satisfactory solution of the problem. However, they provide enough information to develop a rough empirical method for estimating the effect of slope and drain length on observed values. The empirical relationship

$$Q'/Q=1+e^{-\beta c} \qquad \text{(A–4)}$$

is in satisfactory agreement with the data in table A–1. The term $Q'$ represents the measured capacity for a drain of finite length, $L$, and unrestricted end; $Q$ represents the capacity for a drain of great length; and $\beta$ is represented approximately as

$$\beta=\sqrt{S^{1/2}L/D}. \qquad \text{(A–5)}$$

Actually, the roughness of the drain material may affect $\beta$ slightly, but this effect was neglected. Insertion of values from table A–1 in eqs (A–4) and (A–5) yielded the values of $c$ shown in table A–3.

Finally, eq (A–4) was applied to the flow rates recorded by Hunter for drains 70 ft long as indicated in table A–2 in order to make a rough estimate of the rates which probably would have been obtained if very long drains had been simulated. A value of $c$=0.21 was used in these computations. The estimated flow rates are shown in the fifth column of table A–2. The values thus obtained were then rationalized by the method described in section 9.1. That is, rationalized values of $f$ were determined, and rationalized values of steady flow capacities were computed from eq (A–1). The results are given in the last column of table A–2.

Table A–1. *Steady flow capacities as a function of drain length*

| Drain | | | Capacity flow rates | | |
|---|---|---|---|---|---|
| Diameter and material | Slope | Length | Drains approx. 98 ft long, without end restriction | Very long drains simulated by end restriction | |
| | *in./ft* | *L/D* | *gpm* (measured) | *gpm* (measured) | *gpm* (rationalized) |
| 3-in., plastic | 1/16 | 404 | 45.6 | 41.6 | 42.1 |
| | 1/4 | 404 | 94.3 | 93.1 | 90.8 |
| 3-in., galv.-steel | 1/16 | 385 | 43.5 | 39.8 | 40.7 |
| 4-in., plastic | 1/16 | 296 | 100 | 92.0 | 91.9 |
| | 1/4 | 296 | 200 | 192 | 195 |
| 4-in., cast-iron (coated) | 1/16 | 294 | 92.8 | 90.2 | 89.0 |
| | 1/4 | 294 | 189 | 186 | 188 |
| 6½-in., plastic | 1/16 | 179 | 380 | 340 | 342 |
| | 1/8 | 179 | 535 | 500 | 500 |

Table A–2. *Steady flow capacities for test drains used in Hunter's investigation of surge flow in simple drains*

| Drain | | | Capacity flow rates | | |
|---|---|---|---|---|---|
| | | | Measured with ends of 70 ft drains unrestricted and discharging to atmosphere | Estimated for very long drains | |
| Diameter and material | Slope | Length | | Measured rates corrected for end effect [a] | Corrected rates rationalized [b] |
| | *in./ft* | *L/D* | *gpm* | *gpm* | *gpm* |
| 3-in., cast-iron (uncoated) | 1/16 | 280 | 35.6 | 32.1 | 32.8 |
| | 1/8 | 280 | 49.0 | 45.6 | 46.8 |
| | 1/4 | 280 | 72.7 | 69.8 | 66.7 |
| 4-in., cast-iron (uncoated) | 1/16 | 215 | 76.1 | 66.8 | 64.1 |
| | 1/8 | 215 | 98.5 | 89.0 | 91.2 |
| | 1/4 | 215 | 137 | 128 | 130 |

[a] Measured rates corrected for "end effect" through use of eq (A–4) with a value of $c$=0.21.
[b] Corrected rates rationalized by method outlined in section 9.1.

Table A–3. *Computation of* c*-values in eq (A–4)*

| Drain | | | c-value |
|---|---|---|---|
| Diameter and material | Slope | Length | |
| | *in./ft* | *L/D* | |
| 3-in., plastic | 1/16 | 404 | 0.17 |
| | 1/4 | 404 | .21 |
| 3-in., galv.-steel | 1/16 | 385 | .18 |
| 4-in., plastic | 1/16 | 296 | .20 |
| | 1/4 | 296 | .18 |
| 4-in., cast-iron (coated) | 1/16 | 294 | .29 |
| | 1/4 | 294 | .24 |
| 6½-in., plastic | 1/16 | 179 | .21 |
| | 1/8 | 179 | .22 |
| Averages: | | | |
| For 1/16-in. slope | | | 0.21 |
| For 1/8-in. slope | | | .22 |
| For 1/4-in. slope | | | .21 |
| Grand average | | | .21 |

Equation (A–4) gives the theoretically correct result, $Q'=Q$, when $L/D$ becomes very large, and is in satisfactory agreement with data from experimental drains over a range of $L/D$ from approximately 180 to 400.

### 9.3. Determination of *K*-Values for Unusual Jet Forms

In computing the curves in figures 17 and 18 for Hunter's crescent jets, (data shown in table 2), a value of $K=10.5$ was used, this being the same as was determined for the modified annular jets. It was ascertained by inspection that this value resulted in satisfactory agreement between Hunter's data and the computed curves. Possibly the value of $K=11.4$ derived for single circular jets could have been chosen with comparable justification.

As indicated in table 3, surge-flow capacities for the 6½-in. drain with the multiple-circular jet were determined only with the end of the drain fully open. Measurements on the same drain with the single circular jet showed that the value of $K$ was reduced about 10 percent by simulating a long drain through the use of an end restriction. For this reason, $K$ determined experimentally for the multiple circular jet without end restriction was reduced accordingly to a value of 12.3 for application to long drains.

### 9.4. Terminal Velocities in Soil and Waste Stacks

Terminal velocities can be estimated as a function of water discharge rate ($Q_w$), stack diameter, and stack roughness by the method given in NBS Monograph 31 [9], in which the equation

$$V_t=2.22\left(\frac{g^3}{k_s}\right)^{1/10}\left(\frac{Q_w}{D_s}\right)^{2/5} \qquad \text{(A–6)}$$

was derived. Dimensionally consistent units must be used in eq (A–6).

Substitution of the expression $\frac{\pi}{4}R_sD_s^2V_t$ for $Q_w$ in eq (A–6) gives the relation

$$V_t=3.21(R_s)^{2/3}\left(\frac{D_s}{k_s}\right)^{1/6}\sqrt{gD_s} \qquad \text{(A–7)}$$

in which $R_s$ is the ratio of the area of the water section in the stack to the cross section of the stack where terminal velocity exists. Equation (A–7) is convenient for estimating terminal velocities as a function of water cross section, stack diameter, and stack roughness without knowing the water discharge rate.

Since terminal lengths characteristic of soil and waste stacks carrying substantial loads range from less than one branch interval of height for a 3-in. stack to about 2 branch intervals for an 8-in. stack [9], it is not unreasonable to assume near-terminal velocities at the bases of soil and waste stacks for design purposes.

Equation (A–7) was utilized in the predetermination of cross-sectional areas and velocities of the surges which were introduced into the experimental drains, and in relating test-surge velocities to computed service terminal velocities, as shown in tables 2 and 3.

In the use of eqs (A–6) and (A–7) it should be recognized that these equations are based on the concept of an annular sheet of water flowing down the wall of a soil or waste stack enclosing a central air "core," as presented by Dawson and Kalinske [14, 15] and by Wyly and Eaton [9].

Recent European data [16, 17, 18] suggest that through the use of specially designed "mixing" fittings at the junctions of a multi-story stack with its horizontal branches an air-water mixture can be created which has a velocity and an effective density less than water. This appears to be desirable from the standpoint of minimizing pneumatic pressure fluctuations in the horizontal branches, thus permitting the elimination of some conventional vent piping. The European data do not appear to cover the possible effect of the proposed fittings on total load allowable on a stack, but are limited to a comparison of air flow rates, pressures, and velocities with and without the special fittings at loads well below the upper limits normally permitted under plumbing codes in this country. However, this type of construction has not been investigated as it might relate to American plumbing practice, and hence has not been considered in the derivation of eqs (A–6) and (A–7).



U.S. GOVERNMENT PRINTING OFFICE: 1964 O—738-631