A5) “Hunter” Fixture Units Development

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Abstract

“Hunter Fixture Units” appear tabulated and referenced in worldwide variations for plumbing design for pipe sizing and capacity determinations. Dr. Hunter applied binomial probability theory in application to simultaneous events of water usages and drainage discharge events for design parameters of building plumbing systems. His publications presented graphs/tabulations for pipe sizing. The derived basis from binomial theory frequency analyses of usages resulted in tabulations that provided a means for selecting pipe sizes for adequacy/functions. From limited actual building usage patterns, data, and extended laboratory research the necessary piping requirements for both supply and discharge emerged in tabulations and design curves.

Dr. Hunter at National Bureau of Standards undertook plumbing research 1921 to his demise in 1943.
The planned identified future reports were not undertaken.

Keywords

Plumbing design, building drainage, potable water systems; building pipe sizing; plumbing codes; waste and water plumbing; plumbing detain methods; fixture units

1. Introduction

Plumbing systems actuations occur randomly and intermittently with variable magnitudes (probability for such events). Dr. Hunter introduced binomial probability theory for simultaneous events for water pipe supply and drainage systems that set sizing requirements. Improved procedures for loading tables were recognized as a need by the Coordinating Committee for a National Plumbing Code. Codification resulted from ‘**fixture units’** (dimensionless) for probable instances in building pipe sizing for water supply and drainage design. The water supply and drainage loading tables in plumbing design applications were based upon loads in ‘dimensionless fixture units’ as created from probability of simultaneous events introduced for water supply and drainage design as applied in model codes and handbooks. Prolonged illness and subsequent death of Dr. Hunter left barren the detailed descriptions applied in preparing the technical paper on pipe sizes determinations/computation.

Design to codes for water supply and drainage requirements follow procedures with tabulated “Hunter Fixture Units”. From mid-last century into this era, the uncertainty factors in engineered systems sizing requirements demand for variations inherent to design loading results from determinations for unknowns with variability determinations from probability principals**.** Recent engineered sizing by adaptation of probability determinations adapted from post-1940 plumbing systems loadings variability concepts by Dr. Hunter found application to central air operations for hood/air duct loads/power needs of station/plant loads with great uncertainty of demand functions (2). That probability application of uncertainties drew on a referral to Dr. Roy Hunters’ applications to plumbing systems’ fixtures user loadings (1). Similarities for random events probability theory to engineered systems for sizing water and waste piping systems relied on uncertainties from usage variations in applications that led to a probability basis a means of quantifying a probable ‘not to exceed’ failure rate. Uncertainty impacts from incalculable variables in many engineering methods require probability - as developed for plumbing systems system sizing parameters design approximations.

Dr. Hunter in BMS 65 stated:

"**INTRODUCTION" -** ***Simplification and standardization must comply with accepted health regulations and minimum requirements for plumbing, which in turn should be based on scientific principles,***
The report deals with one of the factors, on which minimum requirements should be based, the maximum load to be provided for in plumbing systems. Other reports are planned dealing with water supply and water distribution systems in buildings, principles of building drainage, and principles of venting.
"PURPOSE" - ***Purpose of this series of papers is to collect in organized manner information obtained by the author over a number of years (from 1921 to research of 1937-1940) on plumbing, together with results from research (1937 - 1940) on plumbing with intervening experiments and interpreting results in a form suitable for direct and practical applications. It hoped that this series of papers will supply logical answers to questions pertaining to pipe sizes and design of plumbing construction.***

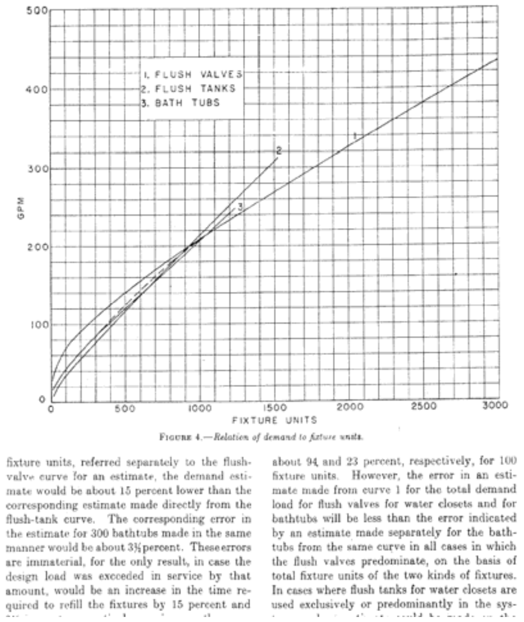

FIGURE 4.—*Relation of demand to fixture units.*

fixture units, referred separately to the flush-valve curve for an estimate, the demand estimate would be about 15 percent lower than the corresponding estimate made directly from the flush-tank curve. The corresponding error in the estimate for 300 bathtubs made in the same manner would be about 3½ percent. These errors are immaterial, for the only result, in case the design load was exceeded in service by that amount, would be an increase in the time required to refill the fixtures by 15 percent and

about 94 and 23 percent, respectively, for 100 fixture units. However, the error in an estimate made from curve 1 for the total demand load for flush valves for water closets and for bathtubs will be less than the error indicated by an estimate made separately for the bathtubs from the same curve in all cases in which the flush valves predominate, on the basis of total fixture units of the two kinds of fixtures. In cases where flush tanks for water closets are used exclusively or predominantly in the sys-

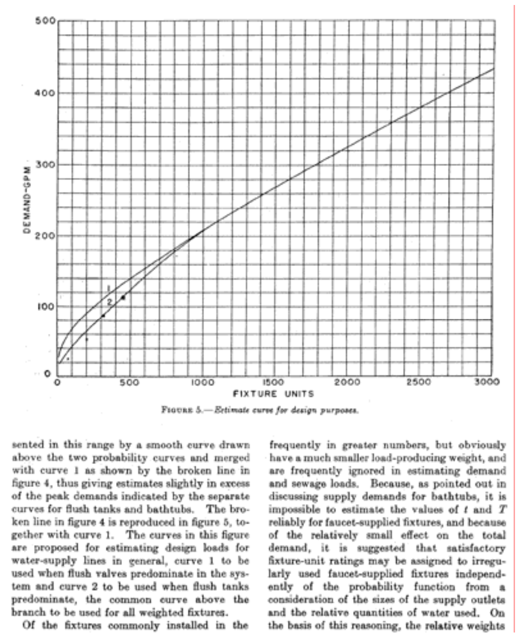

FIGURE 5.—*Estimate curve for design purposes.*

sented in this range by a smooth curve drawn above the two probability curves and merged with curve 1 as shown by the broken line in figure 4, thus giving estimates slightly in excess of the peak demands indicated by the separate curves for flush tanks and bathtubs. The broken line in figure 4 is reproduced in figure 5, together with curve 1. The curves in this figure are proposed for estimating design loads for water-supply lines in general, curve 1 to be used when flush valves predominate in the system and curve 2 to be used when flush tanks predominate, the common curve above the branch to be used for all weighted fixtures.

Of the fixtures commonly installed in the frequently in greater numbers, but obviously have a much smaller load-producing weight, and are frequently ignored in estimating demand and sewage loads. Because, as pointed out in discussing supply demands for bathtubs, it is impossible to estimate the values of t and T reliably for faucet-supplied fixtures, and because of the relatively small effect on the total demand, it is suggested that satisfactory fixture-unit ratings may be assigned to irregularly used faucet-supplied fixtures independently of the probability function from a consideration of the sizes of the supply outlets and the relative quantities of water used. On the basis of this reasoning, the relative weights

Primary source documents (1, 3) present graphical (illustrated) and tabulated loads results from probability theory applied to plumbing systems design requirements by

Dr. Roy Hunter. His research extended over more than two decades. His detailed research/analyses and introduction from binomial probability theory applied to specific fixtures functions/user demands. Currently details developed for pipe sizing in plumbing remains applicable with modified details.

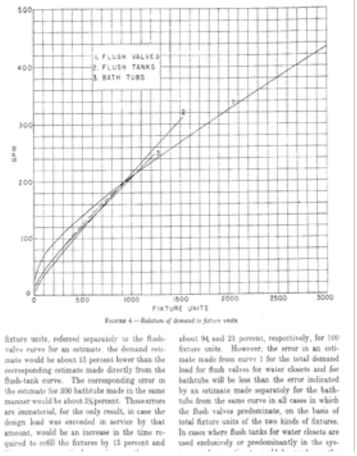

Figure 4.—Relation of demand to fixture units.

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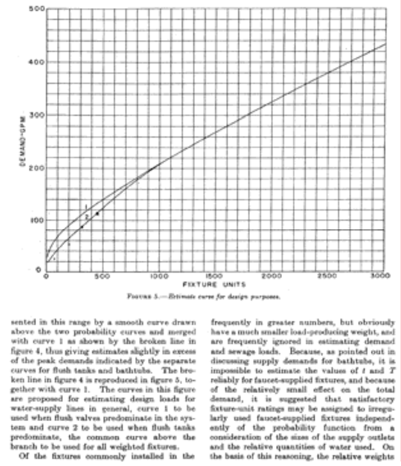
The “fixture units” terminology appears for pipe sizing of plumbing systems design and regulatory information in “Hoover Code(s)” (5, 6, 7) with different definition from the 1940 probability concept. Use of the terminology applied to both design and regulatory requirements.



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Observations (members of the committee) regarding use of water closets in public places resulted in definition “… *intent established rate of discharge of ordinary wash basin at* ***..about 7.5 gpm, so near to one cubic foot minute that it was taken as the definition of one fixture unit...***in the initial usages**.** Terminology code changes occurred after the research applications adopted from probability principles analyses based upon actual fixture usages (supply or discharge) from defined user functions.

1.2 Secretary of Commerce - Herbert Hoover Recognition - 1924 (4)

Three sequenced reports (4, 5, 6) - recommendation of Dept. of Commerce Building Code Committee. Reports - BH2, BH 13 – (same title – ‘24, ‘28, ’32 - known as “Hoover Codes”) were initially requested by Secretary of Commerce Herbert Hoover (later 31st President). Statement from the 1924 code “…*Actual practice has been*

U. S. DEPARTMENT OF COMMERCE
R. P. LAMONT, Secretary
BUREAU OF STANDARDS
GEORGE K. BURGESS, Director

Elimination of Waste Series

RECOMMENDED
MINIMUM REQUIREMENTS
FOR PLUMBING

(With Supplement Containing Progress Revision
to May, 1931)

REPORT OF
SUBCOMMITTEE ON PLUMBING OF THE
BUILDING CODE COMMITTEE
REVISED AUGUST 30, 1928
[Supplementary revision issued March 5, 1932]

GEORGE C. WHIPPLE, Chairman
HARRY Y. CARSON
WILLIAM C. GROENIGER
AUGUST E. HANSEN
J. L. MURPHY

JOHN M. GRIES, Chief, Division of Building and Housing
GEORGE N. THOMPSON, Secretary
R. B. HUNTER, In Charge of Tests

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON: 1932

For sale by the Superintendent of Documents, U. S. Government Printing Office
Washington 25, D. C. - Price $1.25

48 RECOMMENDED PLUMBING REQUIREMENTS

In view of the importance of corrosion as an element in the longevity of plumbing systems, one of the members of the committee has prepared a memorandum on this subject, which will be found in the appendix. Another experimental study bearing on the subject of corrosion was made in the Sanitary Engineering Laboratory of Harvard University, under the direction of the chairman of the committee, by Dana E. Kepner and Warren E. Howland. It concerned the movements of air and gases in horizontal branch waste-pipes, especially long branches. Mr. Howland's memorandum, to be found in the appendix, describes only a few of the many experiments conducted during a period of about six months.

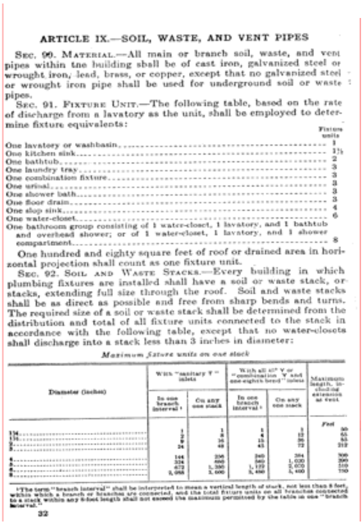
Doctor Hunter's original report (see ch. 6) will speak for itself, but because of its length and its technical character the committee wishes to call attention to some of its salient features and to express its own views on certain matters pertinent to the investigation.

UNIT OF FIXTURE DISCHARGE

In order to study the capacity of house drainage systems, it was found desirable to establish a unit of fixture discharge—a unit involving both volume and time; that is, rate. The rate of discharge of an ordinary washbasin having a nominal 1¼-inch outlet, trap, and waste was found to be about 7.5 gallons per minute, a figure so near to 1 cubic foot per minute that the latter was taken as the definition of one fixture unit. The maximum rate of discharge of other fixtures may be expressed in terms of this unit. For example, it will be seen from Table 1 that a sink with a 1½-inch outlet is equivalent to 1½ units; a bathtub with a 1½-inch outlet, to 2 units; and a water-closet, to 6 units. Fixtures differ a great deal, however, and minor details of design may considerably affect the rate of discharge. It would be useful in designing plumbing systems to know the unit value of each of the common fixtures on the market. No attempt was made to collect this information, although a dozen or more fixtures were studied with reference to their rates of discharge.

WATER-CLOSETS

Doctor Hunter devised an ingenious apparatus for determining the rates of discharge of water-closets by means of an autographic record. This showed the advantage of siphonic action in flushing. While no attempt was made to set definite limits for the rate of flush or for the volume of water required, it may be said that for "wash-down closets" efficient flushing was obtained by using rates of 27 to 33 gallons per minute, or 3.6 to 4.4 units; for siphon-jet closets, 3.2 to 4.8 units, the average value being about 30 gallons per minute, or 4 fixture units. If the rate of discharge is too low, the closet may not be properly cleansed; if it is too high, flushing will be less efficient



ARTICLE IX.—SOIL, WASTE, AND VENT PIPES

Sec. 90. Material.—All main or branch soil, waste, and vent pipes within the building shall be of cast iron, galvanized steel or wrought iron, lead, brass, or copper, except that no galvanized steel or wrought iron pipe shall be used for underground soil or waste pipes.

Sec. 91. Fixture Unit.—The following table, based on the rate of discharge from a lavatory as the unit, shall be employed to determine fixture equivalents:

	Fixture units
One lavatory or washbasin	1
One kitchen sink	1½
One bathtub	2
One laundry tray	3
One combination fixture	3
One urinal	3
One shower bath	3
One floor drain	3
One slop sink	4
One water-closet	6
One bathroom group consisting of 1 water-closet, 1 lavatory, and 1 bathtub and overhead shower; or of 1 water-closet, 1 lavatory, and 1 shower compartment	8

One hundred and eighty square feet of roof or drained area in horizontal projection shall count as one fixture unit.

Sec. 92. Soil and Waste Stacks.—Every building in which plumbing fixtures are installed shall have a soil or waste stack, or stacks, extending full size through the roof. Soil and waste stacks shall be as direct as possible and free from sharp bends and turns. The required size of a soil or waste stack shall be determined from the distribution and total of all fixture units connected to the stack in accordance with the following table, except that no water-closets shall discharge into a stack less than 3 inches in diameter:

Maximum fixture units on one stack

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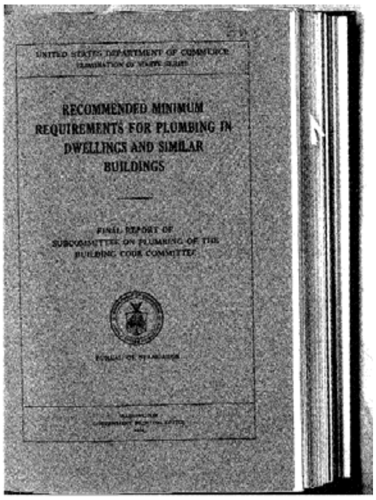
governed by opinions and guesswork, often involving needless costly precautions which many families could ill afford. The lack of generalized principles is responsible to a certain extent for the contradictory plumbing regulations in different localities …”. Illustrations are shown (1931) and cited elements made for continued research at NBS were noted with identification for the historically significance from NBS plumbing research by Dr. R. B. Hunter (he was a leader in plumbing research at National Bureau of Standards from 1921 to 1943). The acknowledgment stated ***“Especial commendation should be given to Dr. R. B. Hunter for his ingenious and accurate physical investigations of the hydraulics and pneumatics of drainage systems under various conditions of use***” (Chapter 7 extended contents on “Sizes of Soil, Vent and Waste”).

1.2 Earlier Competence - Back to 1924

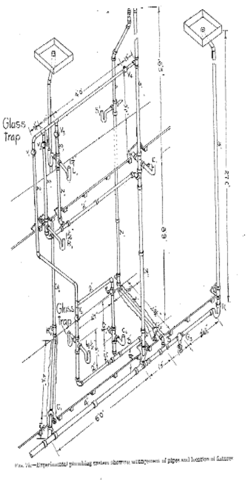
Initial documentation published in 1924 from developments of team efforts established a new Plumbing Code; examples form that initial report are illustrated.

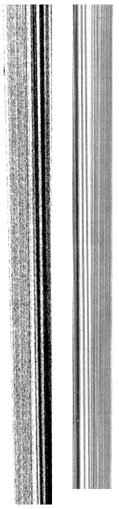


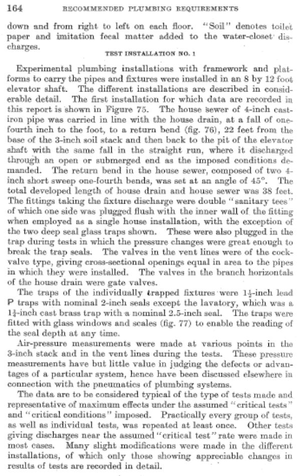
UNITED STATES DEPARTMENT OF COMMERCE

RECOMMENDED MINIMUM REQUIREMENTS FOR PLUMBING IN DWELLINGS AND SIMILAR BUILDINGS

FINAL REPORT OF SUBCOMMITTEE ON PLUMBING OF THE BUILDING CODE COMMITTEE







164 RECOMMENDED PLUMBING REQUIREMENTS

down and from right to left on each floor. “Soil” denotes toilet paper and imitation fecal matter added to the water-closet discharges.

TEST INSTALLATION NO. 1

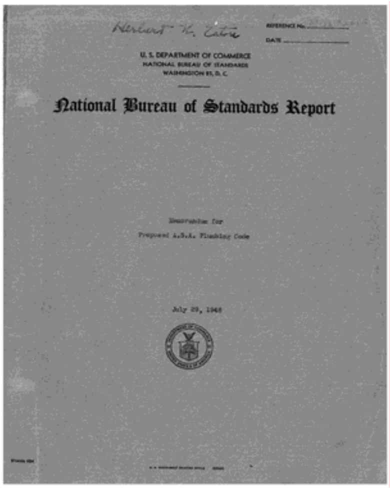
Experimental plumbing installations with framework and platforms to carry the pipes and fixtures were installed in an 8 by 12 foot elevator shaft. The different installations are described in considerable detail. The first installation for which data are recorded in this report is shown in Figure 75. The house sewer of 4-inch cast-iron pipe was carried in line with the house drain, at a fall of one-fourth inch to the foot, to a return bend (fig. 76), 22 feet from the base of the 3-inch soil stack and then back to the pit of the elevator shaft with the same fall in the straight run, where it discharged through an open or submerged end as the imposed conditions demanded. The return bend in the house sewer, composed of two 4-inch short sweep one-fourth bends, was set at an angle of 45°. The total developed length of house drain and house sewer was 38 feet. The fittings taking the fixture discharge were double “sanitary tees” of which one side was plugged flush with the inner wall of the fitting when employed as a single house installation, with the exception of the two deep seal glass traps shown. These were also plugged in the trap during tests in which the pressure changes were great enough to break the trap seals. The valves in the vent lines were of the cock-valve type, giving cross-sectional openings equal in area to the pipes in which they were installed. The valves in the branch horizontals of the house drain were gate valves.

The traps of the individually trapped fixtures were $1\frac{1}{2}$-inch lead P traps with nominal 2-inch seals except the lavatory, which was a $1\frac{1}{4}$-inch cast brass trap with a nominal 2.5-inch seal. The traps were fitted with glass windows and scales (fig. 77) to enable the reading of the seal depth at any time.

Air-pressure measurements were made at various points in the 3-inch stack and in the vent lines during the tests. These pressure measurements have but little value in judging the defects or advantages of a particular system, hence have been discussed elsewhere in connection with the pneumatics of plumbing systems.

The data are to be considered typical of the type of tests made and representative of maximum effects under the assumed “critical tests” and “critical conditions” imposed. Practically every group of tests, as well as individual tests, was repeated at least once. Other tests giving discharges near the assumed “critical test” rate were made in most cases. Many slight modifications were made in the different installations, of which only those showing appreciable changes in results of tests are recorded in detail.

1.3 Supplementary Information



Herbert N. Eaton

REFERENCE No. ____
DATE ____

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS
WASHINGTON 25, D. C.

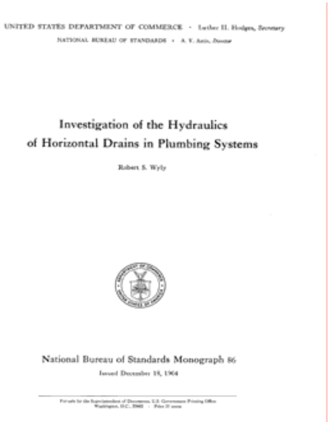
National Bureau of Standards Report

Memorandum for
Proposed A.S.A. Plumbing Code

July 29, 1946

The prolonged illness and death of Dr. Hunter left barren details/descriptions applied in preparing the report for fixture units based upon binomial probability of simultaneous events. A July 29, 1946 draft report (following WWII) by John French (7) undertaken to investigate Dr. Hunters’ files provided indications of source materials but was not published. Selected information for sources and basis of formulation of fixture units as developed and published were sought as set in a directive “... examining Dr. Hunter’s files” dated. Selected materials for information/suppositions from records/assumptions attempted to establish the origins/resources and applications in Dr. Hunter's developments. The primary focus of the task was ".. to reconcile requirements of "A.S.A Plumbing Code and Plumbing Manual BMS 66". That apparently was not resolved although conclusion stated was not to support the ASA version based upon differences between the methods form that study. {Note - **ASA – American Standards Association** refers to a Standards Committee (AESC) - AESC became the **American Standards Association (ASA)** in 1928. **ASA** was reorganized (1966); in 1969 became United States of America Standards Institute (USASI) and now ANSI.

R. Wyly (8) comments related Fixture Units background developments and sources that noted aspects of Dr. Hunter investigations. Comments provided limited indications of tests that Hunter had previously conducted and selected testing results. The research efforts enlarged the database from testing and gave newer design data for larger and complex plumbing drainage system configurations not previously evaluated and data tables presented in the report. Extension of fixture units sizing for capacities of drainage systems was proposed for needs future efforts for applications to larger drainage systems.

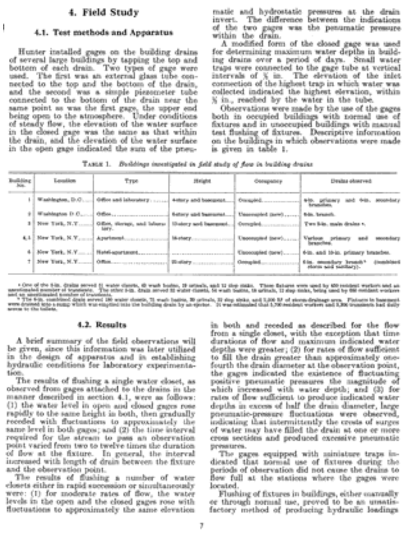


UNITED STATES DEPARTMENT OF COMMERCE • Luther H. Hodges, Secretary
NATIONAL BUREAU OF STANDARDS • A. V. Astin, Director

Investigation of the Hydraulics
of Horizontal Drains in Plumbing Systems

Robert S. Wyly

National Bureau of Standards Monograph 86
Issued December 18, 1964



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 pneumatic 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*

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.

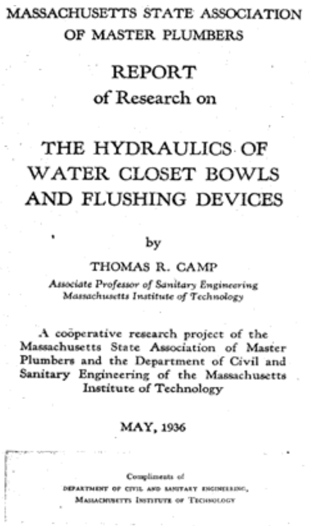
The gages equipped with miniature traps indicated that normal use of fixtures during the periods of observation did not cause the drains to flow full at the stations where the gages were located.

Flushing of fixtures in buildings, either manually or through normal use, proved to be an unsatisfactory method of producing hydraulic loadings

7

1.4 Other Research

Researchers at other U.S. and worldwide plumbing testing facilities were underway (illustrated) but it is unknown to what extent collaborative undertakings were undertaken. U.S. specialists shared inputs and were involved in the evolution of the "Hoover Codes". Referrals to the studies of such investigations appear in the Hoover code outcomes. Later efforts by Dr. Hunter from continuing research



MASSACHUSETTS STATE ASSOCIATION
OF MASTER PLUMBERS

REPORT
of Research on

THE HYDRAULICS OF
WATER CLOSET BOWLS
AND FLUSHING DEVICES

by

THOMAS R. CAMP
Associate Professor of Sanitary Engineering
Massachusetts Institute of Technology

A coöperative research project of the Massachusetts State Association of Master Plumbers and the Department of Civil and Sanitary Engineering of the Massachusetts Institute of Technology

MAY, 1936

Compliments of
DEPARTMENT OF CIVIL AND SANITARY ENGINEERING,
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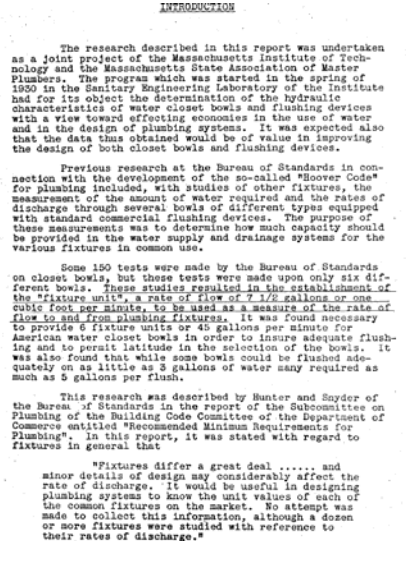


INTRODUCTION

The research described in this report was undertaken as a joint project of the Massachusetts Institute of Technology and the Massachusetts State Association of Master Plumbers. The program which was started in the spring of 1930 in the Sanitary Engineering Laboratory of the Institute had for its object the determination of the hydraulic characteristics of water closet bowls and flushing devices with a view toward effecting economies in the use of water and in the design of plumbing systems. It was expected also that the data thus obtained would be of value in improving the design of both closet bowls and flushing devices.

Previous research at the Bureau of Standards in connection with the development of the so-called "Hoover Code" for plumbing included, with studies of other fixtures, the measurement of the amount of water required and the rates of discharge through several bowls of different types equipped with standard commercial flushing devices. The purpose of these measurements was to determine how much capacity should be provided in the water supply and drainage systems for the various fixtures in common use.

Some 150 tests were made by the Bureau of Standards on closet bowls, but these tests were made upon only six different bowls. These studies resulted in the establishment of the "fixture unit", a rate of flow of 7 1/2 gallons or one cubic foot per minute, to be used as a measure of the rate of flow to and from plumbing fixtures. It was found necessary to provide 6 fixture units or 45 gallons per minute for American water closet bowls in order to insure adequate flushing and to permit latitude in the selection of the bowls. It was also found that while some bowls could be flushed adequately on as little as 3 gallons of water many required as much as 5 gallons per flush.

This research was described by Hunter and Snyder of the Bureau of Standards in the report of the Subcommittee on Plumbing of the Building Code Committee of the Department of Commerce entitled "Recommended Minimum Requirements for Plumbing". In this report, it was stated with regard to fixtures in general that

> "Fixtures differ a great deal ...... and minor details of design may considerably affect the rate of discharge. It would be useful in designing plumbing systems to know the unit values of each of the common fixtures on the market. No attempt was made to collect this information, although a dozen or more fixtures were studied with reference to their rates of discharge."

apparently led to advances for **FIXTURE UNITS concepts** developments with probability basis from continuity of research activities on an independent path.

Elsewhere, plumbing systems applications for varied design methods continued. An example from a 1962 report from Great Britain, twenty years following Hunter's report, maintained pipe-sizing methods from earlier basis of flow designations that applied to pipe sizing design as recommended practice.

INSTITUTE OF PLUMBING

Pipe Sizing to Hot and Cold Water Installations

(Enlarged Edition)

THE INSTITUTE OF PLUMBING

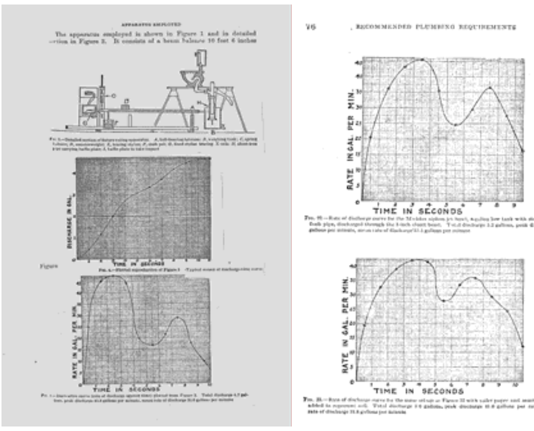
With the Secretary's Compliments

PREFACE TO 1962 EDITION

PREFACE TO ENLARGED EDITION

2. Publications Noted

Background - Information preceding the 1940 Hunter report directed for pipe sizing designs for plumbing systems based upon "Hoover Code(s)" (4, 5, 6). Sample illustrations shown indicate source basis applied to establishment of plumbing requirements for designers' purposes. Methods for plumbing system design for system services capacities buildings resulted from collaborative efforts. Implementation to regulatory purposes established systems' requirements in locales for regulatory acceptances (where codes applied). Hoover Code terminology applied "Fixture Unit" terminology but not as Hunter later established as integral with probability concept usage.



APPARATUS EMPLOYED

The apparatus employed is shown in Figure 1 and in detailed section in Figure 2. It consists of a beam balance 10 feet 6 inches

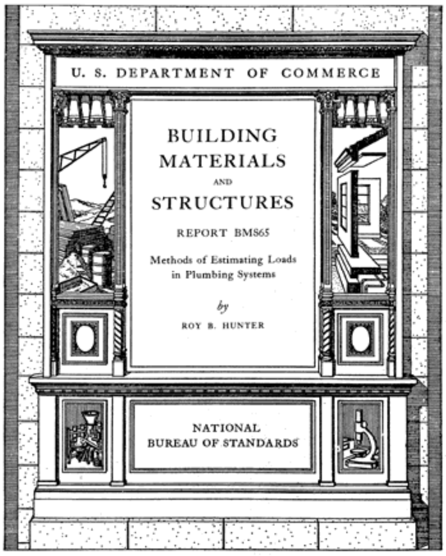
76 RECOMMENDED PLUMBING REQUIREMENTS

The water closets served as a basis for fixture of supply and drainage parameters that required detailed data input from test data for fixture discharge profiles (quite varied). Sample illustration indicates use of a tracing technique for recording time varying water closets' discharges into a collection chamber that provided measurement records noted in the figure. A test configuration balance (also shown) had provision for elimination of water discharge loading impacts. Data for collected volumes as function of discharge time indicated many profiles with multi-peaked outflow profiles (formatted as flow rate vs. time).

Over time Hunter Fixture Units modifications occurred but with few detailed study reports or detailed analyses/evaluations as codes/manuals adopted newer requirements. Recent investigators applied probability Monte Carlo event computer methods to random loadings, some for multistory buildings (reported at CIB W62 Symposia). Such concerns need address. Extensive data sources reported by researchers to CIB W62 on usages applicable to design requirements have been on diverse user-required capacities and consumption in restaurants, exercise facilities, hot tubs/bath-houses and tall buildings. Simultaneity usage patterns concerns from very recent water conservation actions (significantly less duration times) may result in limitations for simultaneous event history with reductions of ‘overlapping’ simultaneous events/functions.

3. Target Documents

Subsequently the model codes adopted Dr. Hunter procedures that also appears in handbooks for domestic and worldwide usages (often locally altered tabulations). Current U.S. codes include similar tabulations but now modified and altered for water conservation needs, and appear in reference handbooks by plumbing and water utility sources. Frequent referral and terminology identification to “Hunter” persists in current times. Tabulated ‘fixture units’ for water supply and drainage design for fixture loads remain a primary dimensionless system for established code applications requirements for pipe sizing in buildings[1].


U. S. DEPARTMENT OF COMMERCE

BUILDING
MATERIALS
AND
STRUCTURES

REPORT BMS65

Methods of Estimating Loads
in Plumbing Systems

by
ROY B. HUNTER

NATIONAL
BUREAU OF STANDARDS

From the report**:** The Foreword by Lyman J. Briggs, Director of NBS, states: “… ***additive reports in the Building Materials and Structures series will be written”. “This report deals with one of the factors which must be considered in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number and kind of plumbing fixtures”……“This report deals … in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number of fixtures and kind of plumbing fixtures… ‘….. “…estimating loads …, it will be understood that such numerical values, when not the actual results of Bureau tests or experiments, represent the author’s judgment in regard to the most suitable factor to use in the application of the method, and that these are not to be regarded as standard values, unless after approved as such by a representative and authoritative body.”***

The author’s Abstract stated: ***“.. that a method of estimating the demand and sewage loads for which the provision should be made in designing plumbing systems in order that the service may be satisfactory. … The relative load producing values of different kinds of commonly used plumbing fixtures are analyzed, and a table is developed giving relative load weights in terms of a load factor called the ‘fixture unit. An estimate curve developed by the means of the probability function is given, and its use in conjunction with the table of fixture units is illustrated.”***

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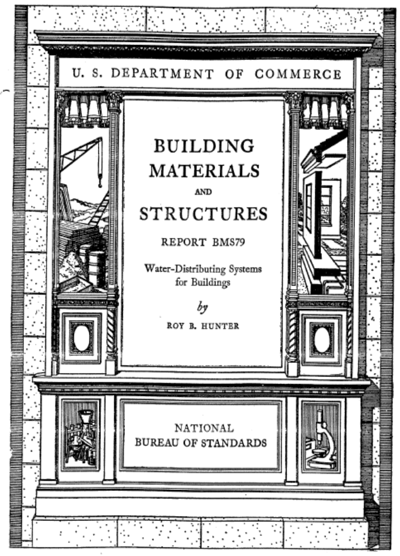
[1] Decades later “DRAINET” developed by Prof. Swaffield provides computer numerical solutions for transient partially filled drainpipe attenuated drain flow dynamics (9) with solid(s) waste transport.

Section II - effort extent in "Purpose" provides:"…organized from the mass of information obtained by the author over a number of years, beginning with the investigation in 1921 of plumbing of small dwellings, and including……. current research (1937-40) on plumbing for low cost housing, together with the results of intervening experiments related to plumbing requirements, and to interpret the results of these investigations in a form suitable for direct and piratical application. …"

3.1 Associated Reports

Dr. Hunter provided application based utilizations based on Fixture Units descriptive usages. Few reports show publication date sequences that vary, possibly due to Institute required review procedures (3, 10). Example of the Plumbing Manual applications specific to water distribution systems provides fixture water supply application for sizing demonstrates that noted differences from existing methods (at the time) for new Fixture Units utilization of Hunter method.


U. S. DEPARTMENT OF COMMERCE

BUILDING
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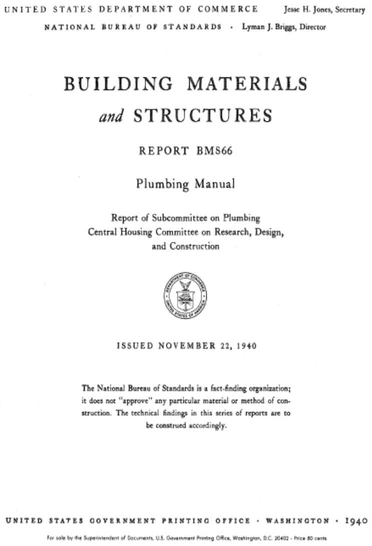
REPORT BMS79

Water-Distributing Systems
for Buildings

by
ROY B. HUNTER

NATIONAL
BUREAU OF STANDARDS


UNITED STATES DEPARTMENT OF COMMERCE Jesse H. Jones, Secretary
NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS
and STRUCTURES

REPORT BMS66

Plumbing Manual

Report of Subcommittee on Plumbing
Central Housing Committee on Research, Design,
and Construction

ISSUED NOVEMBER 22, 1940

The National Bureau of Standards is a fact-finding organization; it does not "approve" any particular material or method of construction. The technical findings in this series of reports are to be construed accordingly.

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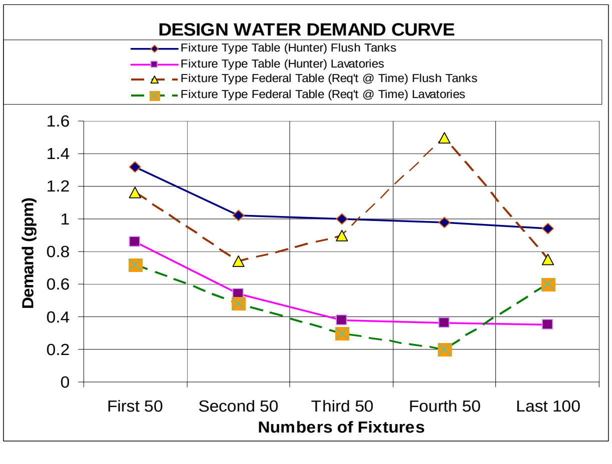
For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402 - Price 80 cents

The figure compares demand estimates in *gpm* usage from the so-called probability function in manual of 1923 with new mode. There, demand cited in gallons per minute directly for several fixtures shows indicated estimated irregularities cited as erroneous since ".. the estimates for given increments in numbers of fixtures should gradually approach a constant minimum as the total number increases.". The discussion suggested "… tendency to oversize supply pipes does not lie in any inherent fault in the probability function, but in the method …. but a table which does not provide for the probability, or rather the improbability, of overlapping between or among two or more groups of different kinds" (3).



Tabulated ‘fixture units’ for water supply and drainage design remained a primary system established in code requirements (modified over time) as changes developed for altered required fixture capacities.

4. Requirements - Loadings - References

Many design and code examples appeared for required sizing practices in the tabulated listings of Hoover codes. From the ’32 version tabulated required drains and stacks loadings of drainage elements from fixture units (definition of that time) examples are shown. Later Hunter developments from probable loading developed listings based upon probability of simultaneous event conditions differed substantially.

the flow in the building drain from 100 such groups will be continuous over that time and will fluctuate around that average.

In order to provide in a measure for the differences in capacity in terms of the number of fixtures (or fixture units), the requirements for sizes of plumbing drains are stated in five steps, two applying to stacks and three applying to building drains, as follows: (a) A simple table (table 805, pt. II) giving the permissible limits in fixture units for different sizes of soil and waste stacks when detailed plans of piping and distribution of fixtures are not submitted for approval; (b) a table (table 805(*b*)–III, pt. III) of limits for soil and waste stacks when detailed plans showing the complete proposed piping lay-out and the complete distribution of fixtures are submitted for approval of the authority having jurisdiction over plumbing; (c) a simple table (table 807, pt. II) giving the limits in fixture units for building drains and building sewers of different sizes when detailed plans are not submitted for approval; (d) a table of limits (table 807(*c*)–III, pt. III) for secondary branches, main building drains, and building sewers under nonpressure-drainage conditions when detailed plans showing the slopes, lengths, and diameters of the pipes of the proposed installation and showing the distribution of fixture units for each drain and branch are submitted to the authority having jurisdiction over plumbing for approval; and (e) a table (table 807(*d*)–III, pt. III) giving limits for primary branches, secondary branches, main building drains, and building sewers under pressure drainage when detailed plans showing slopes, lengths, diameters, and elevations of the lowest horizontal branch on each stack of the proposed installation are submitted to the authority having jurisdiction over plumbing for approval.

Par. 803. Fixture-Unit Ratings.—In general, fixtures are rated in fixture units on the basis of the average volume discharged, the average rate of discharge, and the average frequency of use. Fixtures not given a rating in table 803, part II, when installed in sufficient numbers to justify their consideration relative to the total load to be provided for, may be given the rating of some comparable fixture given in the table. For example, a bedpan washer may be assigned the same rating as a water closet in public use. Similarly, other fixtures may be assigned the same rating as some fixture given in table 803, which has the same size of trap and fixture drain and uses water in comparable volumes and frequencies; or fixtures may be assigned ratings proportional to the cross-sections of fixture drains. It should be noted that ratings are given in integers in the scale of 1 to 10, and that no greater accuracy is required in assigning ratings for unusual or unlisted fixtures.

Par. 805. Sizes of Soil and Waste Pipes.—(*a*) Table 805, part II, is particularly applicable for buildings of one or two stories (one or two branch intervals) in which nothing is to be gained by considering the distribution of fixtures further than as controlled by the limits set on the number of fixture units on one horizontal branch. The table may be applied safely, but not economically, to buildings of any height.

Table 805(*b*)–III.—*Permissible limits in fixture units on soil and waste stacks*

Diameter	Limits in fixture units		
	In any branch interval for—		Maximum on 1 stack
	One branch interval only *N*	Two or more branch intervals *N*/2*n*+*N*/4	
Inches	*Number*	*Number*	*Number*
1¼	1	1	2
1½	3	2	8
2	6	6	24
3	32	16/n+8	60
4	240	120/n+60	600
5	540	270/n+135	1,500
6	960	480/n+240	2,800
8	1,800	900/n+450	5,400
10	2,700	1,350/n+675	8,000
12	4,200	2,100/n+1,050	14,000

(*b*) The provisions of section 805(*b*), part II, and table 805(*b*)–III, part III, are intended to permit an economical use of pipe in regard to sizes when the building is of sufficient height to render it safe to install a greater number of fixtures on a stack of given diameter than is permitted under table 805, part II; and they are especially applicable to buildings of three stories (three branch intervals) or more in height and to systems with relatively small horizontal branches. It is essential in applying section 805(*b*), part II, that the number of fixture units in any one branch interval shall be

[47]

Fixture Unit applications of the method in plumbing systems design were necessary for implementations with explanatory introductions and details/explanations to water supply and drainage systems. Differences cited needs for achieving descriptive documentation for design and use in regulatory applications with requirements and rules illustrated for applications to demonstrating compliance. Even in the “Plumbing Manual” (3) there appears “…still a marked lack of agreement among recommended plumbing requirements” and also the purpose indicated that “.. intended to serve as a guide in their own work and as recommended procedure where local codes do not govern.”

UNITED STATES DEPARTMENT OF COMMERCE   Jesse H. Jones, Secretary
NATIONAL BUREAU OF STANDARDS · Lyman J. Briggs, Director

BUILDING MATERIALS
and STRUCTURES

REPORT BMS66

Plumbing Manual

Report of Subcommittee on Plumbing
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ARTICLE IX.—SOIL, WASTE, AND VENT PIPES

Sec. 90. Material.—All main or branch soil, waste, and vent pipes within the building shall be of cast iron, galvanized steel or wrought iron, lead, brass, or copper, except that no galvanized steel or wrought iron pipe shall be used for underground soil or waste pipes.

Sec. 91. Fixture Unit.—The following table, based on the rate of discharge from a lavatory as the unit, shall be employed to determine fixture equivalents:

	Fixture units
One lavatory or washbasin	1
One kitchen sink	1½
One bathtub	2
One laundry tray	3
One combination fixture	3
One urinal	3
One shower bath	3
One floor drain	3
One slop sink	4
One water-closet	6
One bathroom group consisting of 1 water-closet, 1 lavatory, and 1 bathtub and overhead shower; or of 1 water-closet, 1 lavatory, and 1 shower compartment	8

One hundred and eighty square feet of roof or drained area in horizontal projection shall count as one fixture unit.

Sec. 92. Soil and Waste Stacks.—Every building in which plumbing fixtures are installed shall have a soil or waste stack, or stacks, extending full size through the roof. Soil and waste stacks shall be as direct as possible and free from sharp bends and turns. The required size of a soil or waste stack shall be determined from the distribution and total of all fixture units connected to the stack in accordance with the following table, except that no water-closets shall discharge into a stack less than 3 inches in diameter:

Maximum fixture units on one stack

32

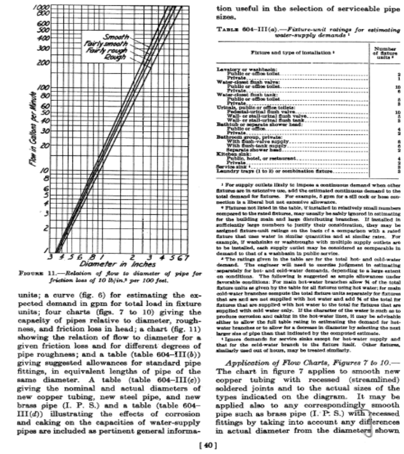


Figure 11.—*Relation of flow to diameter of pipe for friction loss of 10 lb/in.² per 100 feet.*

units; a curve (fig. 6) for estimating the expected demand in gpm for total load in fixture units; four charts (figs. 7 to 10) giving the capacity of pipes relative to diameter, roughness, and friction loss in head; a chart (fig. 11) showing the relation of flow to diameter for a given friction loss and for different degrees of pipe roughness; and a table (table 604–III(*b*)) giving suggested allowances for standard pipe fittings, in equivalent lengths of pipe of the same diameter. A table (table 604–III(*c*)) giving the nominal and actual diameters of new copper tubing, new steel pipe, and new brass pipe (I. P. S.) and a table (table 604–III(*d*)) illustrating the effects of corrosion and caking on the capacities of water-supply pipes are included as pertinent general information useful in the selection of serviceable pipe sizes.

Table 604–III(*a*).—*Fixture-unit ratings for estimating water-supply demands* [1]

Fixture and type of installation [2]	Number of fixture units [3]
Lavatory or washbasin:	
Public or office toilet	2
Private	1
Water-closet flush valve:	
Public or office toilet	10
Private	6
Water-closet flush tank:	
Public or office toilet	5
Private	3
Urinals, public or office toilets:	
Pedestal-urinal flush valve	10
Wall- or stall-urinal flush valve	5
Wall- or stall-urinal flush tank	3
Bathtub or separate shower head:	
Public or office	4
Private	2
Bathroom group, private:	
With flush-valve supply	8
With flush-tank supply	6
Separate shower head	2
Kitchen sink:	
Public, hotel, or restaurant	4
Private	2
Service sink [4]	3
Laundry trays (1 to 3) or combination fixture	3

[1] For supply outlets likely to impose a continuous demand when other fixtures are in extensive use, add the estimated continuous demand to the total demand for fixtures. For example, 5 gpm for a sill cock or hose connection is a liberal but not excessive allowance.

[2] Fixtures not listed in the table, if installed in relatively small numbers compared to the rated fixtures, may usually be safely ignored in estimating for the building main and large distributing branches. If installed in sufficiently large numbers to justify their consideration, they may be assigned fixture-unit ratings on the basis of a comparison with a rated fixture that uses water in similar quantities and at similar rates. For example, if washsinks or washtroughs with multiple supply outlets are to be installed, each supply outlet may be considered as comparable in demand to that of a washbasin in public service.

[3] The ratings given in the table are for the total hot- and cold-water demand. The engineer will need to exercise judgment in estimating separately for hot- and cold-water demands, depending to a large extent on conditions. The following is suggested as ample allowances under favorable conditions: For main hot-water branches allow ¾ of the total fixture units as given by the table for all fixtures using hot water; for main cold-water branches compute the total fixture units separately for fixtures that are and are not supplied with hot water and add ¾ of the total for fixtures that are supplied with hot water to the total for fixtures that are supplied with cold water only. If the character of the water is such as to produce corrosion and caking in the hot-water lines, it may be advisable either to allow the full table rating in estimating the demand for hot-water branches or to allow for a decrease in diameter by selecting the next larger size of pipe than that indicated by the computed estimate.

[4] Ignore demands for service sinks except for hot-water supply and that for the cold-water branch to the fixture itself. Other fixtures, similarly used out of hours, may be treated similarly.

Application of Flow Charts, Figures 7 to 10.—The chart in figure 7 applies to smooth new copper tubing with recessed (streamlined) soldered joints and to the actual sizes of the types indicated on the diagram. It may be applied also to any correspondingly smooth pipe such as brass pipe (I. P. S.) with recessed fittings by taking into account any differences in actual diameter from the diameters shown

[40]

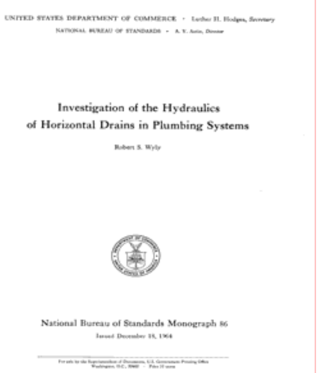
Par. 802. Minimum Sizes of Soil and Waste Pipes.—In a simple table of sizes applying generally to buildings of various sizes and plans, it is impossible to give the minimum sizes of soil and waste pipes actually required in particular buildings. In a building-drainage system the load or volume rate of flow in its different parts is not the sum of the rates of flow from the fixtures in which the load originated. As the sewage load passes through a building-drainage system there is a continuous increase in the time of flow over the time of flow into the system, with a corresponding decrease in the volume rate of flow past any given point in the system. For this reason, as the size of building-drainage systems increases (a greater number of fixtures and longer drains), there is a tendency toward continuous uniform flow as the distance from the fixtures increases. In a very large building the flow in the main building drain becomes continuous during the periods of heavy use of fixtures and fluctuates around the average rate of flow from all fixtures during such periods.

For example, assume that in 100 bathroom groups a water closet discharges 4 gallons once every 5 minutes, a bathtub 8 gallons every 15 minutes, and a lavatory 1.5 gallons every 3 minutes. The average flow from 1 bathroom group will be $\frac{4}{5}+\frac{8}{15}+\frac{1.5}{3}=1.8$ gpm. The average flow from 100 bathroom groups during the whole time all fixtures are being used at those average rates will be 100×1.8 or 180 gpm and

the flow in the building drain from 100 such groups will be continuous over that time and will fluctuate around that average.

In order to provide in a measure for the differences in capacity in terms of the number of fixtures (or fixture units), the requirements for sizes of plumbing drains are stated in five steps, two applying to stacks and three applying to building drains, as follows: (a) A simple table (table 805, pt. II) giving the permissible limits in fixture units for different sizes of soil and waste stacks when detailed plans of piping and distribution of fixtures are not submitted for approval; (b) a table (table 805(*b*)–III, pt. III) of limits for soil and waste stacks when detailed plans showing the complete proposed piping lay-out and the complete distribution of fixtures are submitted for approval of the authority having jurisdiction over plumbing; (c) a simple table (table 807, pt. II) giving the limits in fixture units for building drains and building sewers of different sizes when detailed plans are not submitted for approval; (d) a table of limits (table 807(*c*)–III, pt. III) for secondary branches, main building drains, and building sewers under nonpressure-drainage conditions when detailed plans showing the slopes, lengths, and diameters of the pipes of the proposed installation and showing the distribution of fixture units for each drain and branch are submitted to the authority having jurisdiction over plumbing for approval; and (e) a table (table 807(*d*)–III, pt. III) giving limits for primary branches, secondary branches, main building drains, and building sewers under pressure drainage when detailed plans showing slopes, lengths, diameters, and elevations of the lowest horizontal branch on each stack of the proposed installation are submitted to the authority having jurisdiction over plumbing for approval.

Par. 803. Fixture-Unit Ratings.—In general, fixtures are rated in fixture units on the basis of the average volume discharged, the average rate of discharge, and the average frequency of use. Fixtures not given a rating



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

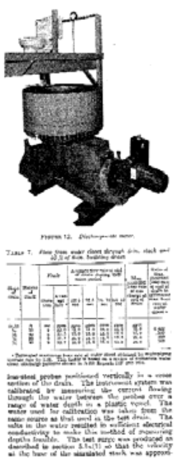
Robert S. Wyly

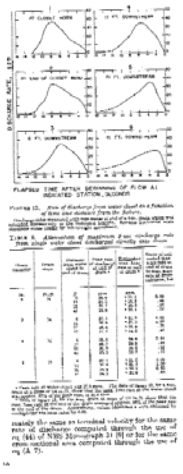
National Bureau of Standards Monograph 86
Issued December 18, 1964

The undertaking by J. French (7) was an attempt to seek greater knowledge of the basis for Hunter's published reports.

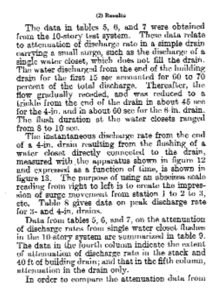
4.1 Perspectives

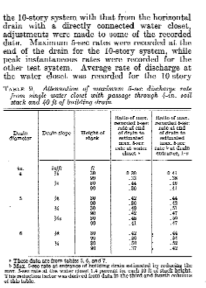
Indicated research aspects noted on Dr. Hunter investigations by R. Wyly (..) in related materials on Fixture Units developments are to the point of the topic. Comments in the report provided test series limitations or indications from certain historic parts of past testing methods. Report applications to water demand pipe system sizing from tabulated fixture units were described and special concerns indicated in table footnotes. For drainage systems utilization of Fixture Units ratings concerning implications from the earlier reports and results from additional test series introduced later interpretations for drain loadings as derived from detailed testing series and results/conclusions.

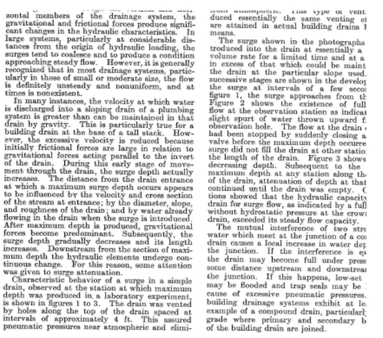


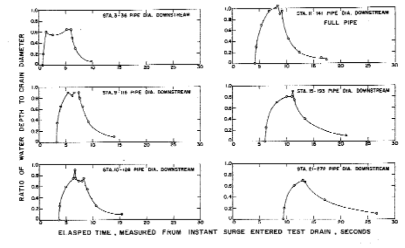


From earlier Hunter test efforts rather unique experimental developments were noted and indicated test experimental illustrations. Water closet discharge profiles and drain connected indicated attenuation of flows were determined.









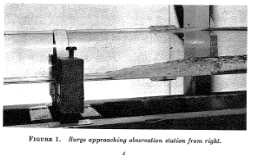


FIGURE 1. Surge approaching observation station from right.

That prior research demonstrated surge attenuation from water closets interacting with other pipe flows. The attenuation of surge waves combined with other essentially steady fixture outflows (washbasins, showers, and baths) had become an aspect of needed data applied to developments in tabulated correlations developed for fixture units. Newly measured distributions of attenuated water closet surges also were developed but shown as

normalized water depth to drain diameter but substantiated earlier measured data forms. Extensions for tabulated loadings results to design applications for allowed loadings in determining allowable total drainage discharges (not in Fixture Units) for design purposes was not made. The methods extended scope of tables to buildings greater than three stories or more in height and for systems with relatively small horizontal branches. The Wyly study showed tabulated results that indicated the extent of capacity increases in drains when surges occurred. As stated: "capacities for hydraulics in steady gravity driven flows are constant" and "of limited value in solution of problems of surge flow". Further, for surge flows "hydraulic elements vary both with distance and time at any cross-section". The tabulated test indications ranged over values from two to five times the capacity for steady flow conditions. Expanded series of tests for branch drain discharges into main drain (few varied conditions) with unsteady flow from branch loadings were undertaken. Compilations into broad tabular data listings for applications to branch installation designs resulted.

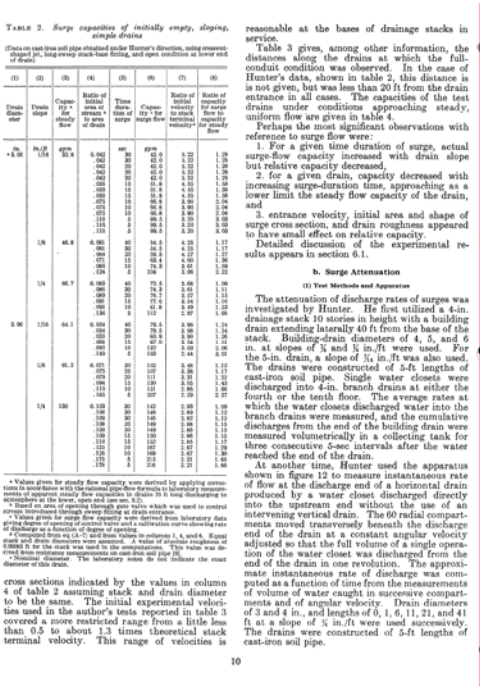


TABLE 2. *Surge capacities of initially empty, sloping, simple drains*

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 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

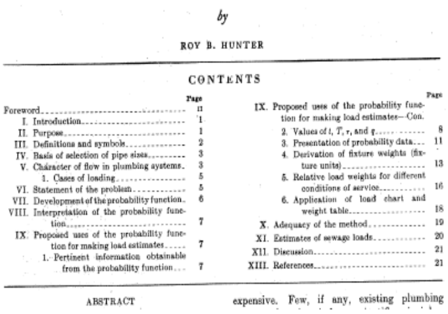
The attenuation of discharge rates of surges was investigated by Hunter. He first utilized a 4-in. drainage stack 10 stories in height with a building drain extending laterally 40 ft from the base of the stack. Building-drain diameters of 4, 5, and 6 in. at slopes of ⅛ and ¼ in./ft were used. For the 5-in. drain, a slope of 1/16 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.

10

5. Hunter BMS 65 (1)

The report Foreword by the Director L.J. Briggs, states "This report deals with one of the factors which must be considered in the selection of adequate yet economical sizes of pipes for plumbing systems – namely, the load to be expected from a given number and kind of plumbing fixtures. Also, "..it will be followed by other reports in the Building and Materials and Structures series dealing with other aspects of plumbing problems".



Methods of Estimating Loads in Plumbing Systems

by

ROY B. HUNTER

CONTENTS

ABSTRACT

expensive. Few, if any, existing plumbing

From the authors' Introduction "Simplification and standardization must comply with accepted health regulations and minimum requirements for plumbing, which in turn should be based on scientific principles, The report deals with one of the factors, on which minimum requirements should be based, the maximum load to be provided for in plumbing systems. Other reports are planned dealing with water supply and water distribution systems in buildings, principles of building drainage, and principles of venting." And in the "Purpose' there appears " this series of papers is to collect in organized manner information obtained by the author over a number of years (from 1921 to research of 1937-1940) on plumbing, together with results from research (1937 - 1940) on plumbing with intervening experiments and interpreting results in a form suitable for direct and practical application. It is hoped that this series of papers will supply logical answers to questions pertaining to pipe sizes and design of plumbing construction".

Selected report materials indicate Fixture Units developments for the adopted technique and methodical procedure adopted. Developed materials apparently resulted from the depths of efforts from prior studies, acquisition of vast amounts of test data, analytical determinations and organized compilations of comprehensive sets of data from many prior years of research.

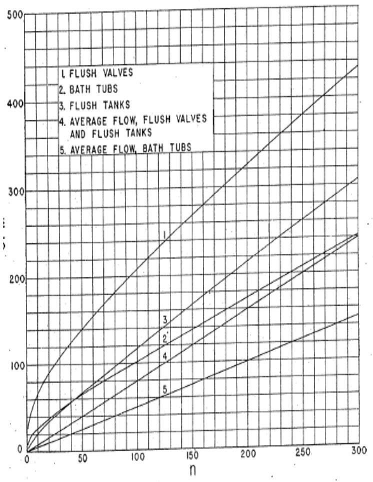


Figure 3.—*Probable flow in relation to n.*

Curves 1, 2, and 3, in figure 3, show the relation of demand loads to number of fixtures, based on estimated time factors representing congested conditions of service—that is, the maximum practical rate at which fixtures can be used continuously in actual service. Assuming the correctness of the factors employed in evaluating the probability functions, the curves may be used for estimating the demand loads for any particular number of fixtures of one given kind. However, the design load for all kinds of fixtures installed in one system should not be the sum of the design loads computed separately for each kind of fixture, even though the individual curves may be correct. Simultaneous operation of different kinds of fixtures is a chance occurrence which would have to be evaluated by another probability function.

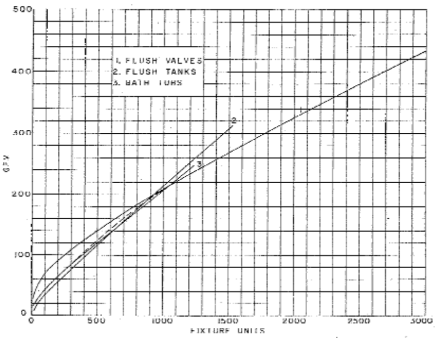


Figure 4.—*Relation of demand to fixture units.*

fixture units, referred separately to the flush-valve curve for an estimate, the demand estimate would be about 15 percent lower than the corresponding estimate made directly from the flush-tank curve. The corresponding error in the estimate for 300 bathtubs made in the same manner would be about 3½ percent. These errors are immaterial, for the only result, in case the design load was exceeded in service by that amount, would be an increase in the time required to refill the fixtures by 15 percent and 3½ percent, respectively, or, in case the same time is occupied in refilling, a reduction by these percentages in the volume of water used. Below the point of intersection, referring flush tanks and bathtubs separately to the flush-valve curve would result in overestimating the demand by amounts varying from very small percentages for 880 to 1,040 fixture units to about 94 and 23 percent, respectively, for 100 fixture units. However, the error in an estimate made from curve 1 for the total demand load for flush valves for water closets and for bathtubs will be less than the error indicated by an estimate made separately for the bathtubs from the same curve in all cases in which the flush valves predominate, on the basis of total fixture units of the two kinds of fixtures. In cases where flush tanks for water closets are used exclusively or predominantly in the system, a closer estimate could be made on the basis of total weights, by using curve 2 and the total fixture units for all kinds of fixtures involved. Obviously the error made by using curve 2 for both flush tanks and bathtubs for any number of either up to 300 would be small. Also, the demand load relative to the number of fixture units may be approximately repre-

Selection of minimum pipe size requires accurate flow capacities for conditions to be used for load and to know accurately the load the pipe will be called upon to carry. Pipe flow formulae (usual means of estimating pipe capacities of pipes) expressions are based upon dynamic equilibrium

It is necessary to define the expression, "operating simultaneously," in order to completely define a particular event of "r fixtures operating simultaneously." In the following development of the theory, this event will be considered as occurring when r, and only r, fixtures are found flowing at the instant of observation; and hence the r fixtures found flowing will include all those, and only those, which began their operation during the t-second interval immediately preceding the instant of observation.

VII. DEVELOPMENT OF THE PROBABILITY FUNCTION

By the generally accepted concept of probability, the probability that a particular fixture out of a number, n, will be found operating at any arbitrarily chosen instant of observation is t/T, where t has been defined as the duration of each operation and T as the time between operations of each fixture. In the same manner, the probability that the particular fixture will not be in operation at the instant of observation is $1-t/T$ or $(T-t)/T$.

A law of combinations that applies to the composite event of which the probability is sought in this problem may be stated as follows: The number of ways in which two or more independent events can occur together is the product of the ways each can occur separately. A similar law of probability may be stated as follows: The probability of two or more independent events occurring together, in this case at the same instant, is the product of the probabilities of their separate occurrence.

By the law of combinations, the probability that none of the remaining $n-1$ fixtures will be operating at the instant of observation is

$$\sum_{r=0}^{r=n} p_r^n = \sum_{r=0}^{r=n} C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = 1 \ldots \quad (3)$$

Equation 3 is equivalent to the binomial expansion of $\left(\frac{t}{T}+\frac{T-t}{T}\right)^n=1$ and is the conventional expression for certainty, since either no fixtures, $r=0$, or some number of fixtures from $r=1$ to $r=n$ must be operating at the instant of observation.[3]

VIII. INTERPRETATION OF THE PROBABILITY FUNCTION

As previously stated, the probability function, p_r^n, eq 2, gives the probability that exactly r fixtures out of a total of n will be found operating at an arbitrary instant of observation, provided that all n fixtures are in continuous use at the assumed rate. The probability, p_r^n, may also be interpreted as the percentage or fraction of the time in the long run that r flows will occur in the manner defined, since the fraction

$$\frac{\text{time of } r \text{ fixtures operating}}{\text{total time}}$$

is also the probability of the occurrence. Hence for any given values of n and r, if the probability function as developed is multiplied by a time τ in seconds such that

$$\tau p_r^n = \tau C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = 1 \text{ second}, \ldots \quad (4)$$

or

$$C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = \frac{1}{\tau}$$

the equation signifies that r fixtures will be in simultaneous operation for an aggregate of 1 second out of every τ seconds that all n fixtures are in use at the assumed rate. Likewise, the condition that a chosen design factor, $r=m$, will not be exceeded more than a given fraction of the time $1/\tau$, is expressed by

$$\sum_{r=m+1}^{r=n} p_r^n = 1/\tau \ldots \quad (5)$$

Equations 4 and 5 are based on the assumption that all n fixtures will be in continuous use over the entire time τ at the average rate of once in T seconds. The time τ may be reduced to days or years on the basis of the daily period of peak use, by assuming or determining this period and computing on the basis of a day of that length.

IX. PROPOSED USES OF THE PROBABILITY FUNCTION FOR MAKING LOAD ESTIMATES

1. Pertinent Information Obtainable From the Probability Function

It may be helpful in judging the reasonableness of the proposed application of the probability function to summarize the information obtainable from the probability function before proceeding with the selection of the time-factors applicable to practical cases.

The following pertinent information can be obtained from the equations developed:

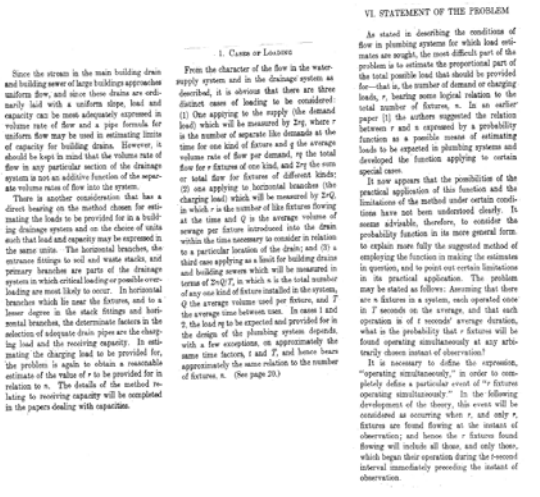
(a) The probability that a given number of fixtures, m, out of a total of n, will be operating at an arbitrary instant of observation, determined by eq 2.

(b) The fraction of the time that m and only m fixtures will be operating at the same instant, a second interpretation of eq 2.

(c) The fraction of the total time that any number of fixtures greater than the design number, m, will be operating at the same instant, determined by eq 5.

(d) The ratio of any two successive terms in the series of eq 2; for example, the ratio of the fraction of the time $r+1$ to the fraction of the time r fixtures will be operating at the same instant, determined by

$$C_{r+1}^n \left(\frac{t}{T}\right)^{r+1} \left(\frac{T-t}{T}\right)^{n-r-1} \div C_r^n \left(\frac{t}{T}\right)^r \left(\frac{T-t}{T}\right)^{n-r} = \frac{n-r}{r+1} \times \frac{t}{T-t} \quad (6)$$



Since the stream in the main building drain and building sewer of large buildings approaches uniform flow, and since these drains are ordinarily laid with a uniform slope, load and capacity can be most adequately expressed in volume rate of flow and a pipe formula for uniform flow may be used in estimating limits of capacity for building drains. However, it should be kept in mind that the volume rate of flow in any particular section of the drainage system is not an additive function of the separate volume rates of flow into the system.

There is another consideration that has a direct bearing on the method chosen for estimating the loads to be provided for in a building drainage system and on the choice of units such that load and capacity may be expressed in the same units. The horizontal branches, the entrance fittings to soil and waste stacks, and primary branches are parts of the drainage system in which critical loading or possible overloading are most likely to occur. In horizontal branches which lie near the fixtures, and to a lesser degree in the stack fittings and horizontal branches, the determinate factors in the selection of adequate drain pipes are the charging load and the receiving capacity. In estimating the charging load to be provided for, the problem is again to obtain a reasonable estimate of the value of r to be provided for in relation to n. The details of the method relating to receiving capacity will be completed in the papers dealing with capacities.

1. Cases of Loading

From the character of the flow in the water-supply system and in the drainage system as described, it is obvious that there are three distinct cases of loading to be considered: (1) One applying to the supply (the demand load) which will be measured by Σrq, where r is the number of separate like demands at the time for one kind of fixture and q the average volume rate of flow per demand, rq the total flow for r fixtures of one kind, and Σrq the sum or total flow for fixtures of different kinds; (2) one applying to horizontal branches (the charging load) which will be measured by ΣrQ, in which r is the number of like fixtures flowing at the time and Q is the average volume of sewage per fixture introduced into the drain within the time necessary to consider in relation to a particular location of the drain; and (3) a third case applying as a limit for building drains and building sewers which will be measured in terms of $\Sigma nQ/T$, in which n is the total number of any one kind of fixture installed in the system, Q the average volume used per fixture, and T the average time between uses. In cases 1 and 2, the load rq to be expected and provided for in the design of the plumbing system depends, with a few exceptions, on approximately the same time factors, t and T, and hence bears approximately the same relation to the number of fixtures, n. (See page 20.)

VI. STATEMENT OF THE PROBLEM

As stated in describing the conditions of flow in plumbing systems for which load estimates are sought, the most difficult part of the problem is to estimate the proportional part of the total possible load that should be provided for—that is, the number of demand or charging loads, r, bearing some logical relation to the total number of fixtures, n. In an earlier paper [1] the authors suggested the relation between r and n expressed by a probability function as a possible means of estimating loads to be expected in plumbing systems and developed the function applying to certain special cases.

It now appears that the possibilities of the practical application of this function and the limitations of the method under certain conditions have not been understood clearly. It seems advisable, therefore, to consider the probability function in its more general form, to explain more fully the suggested method of employing the function in making the estimates in question, and to point out certain limitations in its practical application. The problem may be stated as follows: Assuming that there are n fixtures in a system, each operated once in T seconds on the average, and that each operation is of t seconds' average duration, what is the probability that r fixtures will be found operating simultaneously at any arbitrarily chosen instant of observation?

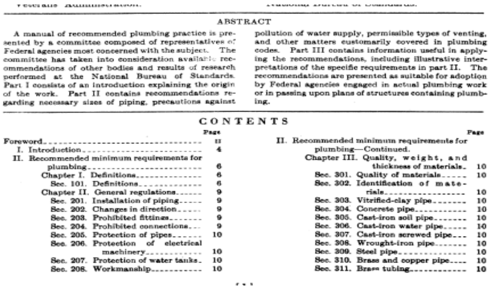
It is necessary to define the expression, "operating simultaneously," in order to completely define a particular event of "r fixtures operating simultaneously." In the following development of the theory, this event will be considered as occurring when r, and only r, fixtures are found flowing at the instant of observation; and hence the r fixtures found flowing will include all those, and only those, which began their operation during the t-second interval immediately preceding the instant of observation.

and applies only to the irregular and intermittent flows that occurs in plumbing systems during that time (usually very short) and in that section of the pipe in which the variable factors involved (velocity or volume rate of flow, pressure, or hydraulic gradient, and hydraulic radius) are constant[2] and applies only to the particular conditions – namely, condition of uniform continuous flow in the pipe. Hence, conventional pipe formulae applies to irregular and intermittent flows that occur in plumbing systems only during that time (usually very short) and in sections which the variables involved (velocity or volume rate of flow, pressure, or hydraulic gradient, and hydraulic radius) are constant. ***That descriptive explanation was an attempted explanation for conditions of "steady state approximations" utilization.***

6. Manual Report BMS 66 (4)

Applications of Fixture Units for practical implementation procedures were provided in the Manual (3). Anticipated benefits from newly developed procedures and applications were indicated to be:

- Especially for large buildings;
- Better sewage transport
- More satisfactory operation
- More economical construction.

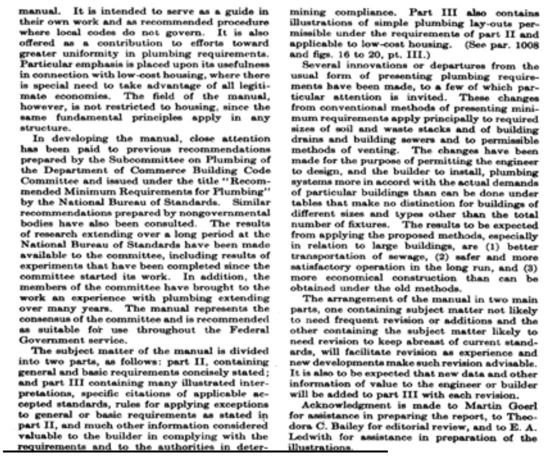


ABSTRACT

A manual of recommended plumbing practice is presented by a committee composed of representatives of Federal agencies most concerned with the subject. The committee has taken into consideration available recommendations of other bodies and results of research performed at the National Bureau of Standards. Part I consists of an introduction explaining the origin of the work. Part II contains recommendations regarding necessary sizes of piping, precautions against pollution of water supply, permissible types of venting, and other matters customarily covered in plumbing codes. Part III contains information useful in applying the recommendations, including illustrative interpretations of the specific requirements in part II. The recommendations are presented as suitable for adoption by Federal agencies engaged in actual plumbing work or in passing upon plans of structures containing plumbing.

CONTENTS

The report background had past committee actions with input or reviews for the new document. It is divided into two parts -
(1) General and basic requirements; Subject matter not likely to need frequent revision, and
(2) Matter likely to need revision to keep abreast of current standards when revision is advisable.



manual. It is intended to serve as a guide in their own work and as recommended procedure where local codes do not govern. It is also offered as a contribution to efforts toward greater uniformity in plumbing requirements. Particular emphasis is placed upon its usefulness in connection with low-cost housing, where there is special need to take advantage of all legitimate economies. The field of the manual, however, is not restricted to housing, since the same fundamental principles apply in any structure.

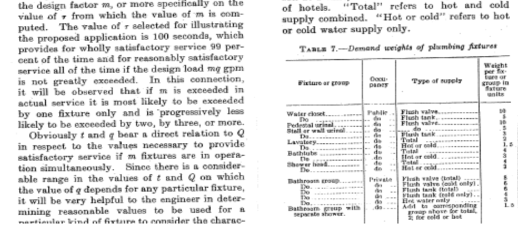
In developing the manual, close attention has been paid to previous recommendations prepared by the Subcommittee on Plumbing of the Department of Commerce Building Code Committee and issued under the title "Recommended Minimum Requirements for Plumbing" by the National Bureau of Standards. Similar recommendations prepared by nongovernmental bodies have also been consulted. The results of research extending over a long period at the National Bureau of Standards have been made available to the committee, including results of experiments that have been completed since the committee started its work. In addition, the members of the committee have brought to the work an experience with plumbing extending over many years. The manual represents the consensus of the committee and is recommended as suitable for use throughout the Federal Government service.

The subject matter of the manual is divided into two parts, as follows: part II, containing general and basic requirements concisely stated; and part III containing many illustrated interpretations, specific citations of applicable accepted standards, rules for applying exceptions to general or basic requirements as stated in part II, and much other information considered valuable to the builder in complying with the requirements and to the authorities in determining compliance. Part III also contains illustrations of simple plumbing lay-outs permissible under the requirements of part II and applicable to low-cost housing. (See par. 1008 and figs. 16 to 20, pt. III.)

Several innovations or departures from the usual form of presenting plumbing requirements have been made, to a few of which particular attention is invited. These changes from conventional methods of presenting minimum requirements apply principally to required sizes of soil and waste stacks and of building drains and building sewers and to permissible methods of venting. The changes have been made for the purpose of permitting the engineer to design, and the builder to install, plumbing systems more in accord with the actual demands of particular buildings than can be done under tables that make no distinction for buildings of different sizes and types other than the total number of fixtures. The results to be expected from applying the proposed methods, especially in relation to large buildings, are (1) better transportation of sewage, (2) safer and more satisfactory operation in the long run, and (3) more economical construction than can be obtained under the old methods.

The arrangement of the manual in two main parts, one containing subject matter not likely to need frequent revision or additions and the other containing the subject matter likely to need revision to keep abreast of current standards, will facilitate revision as experience and new developments make such revision advisable. It is also to be expected that new data and other information of value to the engineer or builder will be added to part III with each revision.

Acknowledgment is made to Martin Goerl for assistance in preparing the report, to Theodora C. Bailey for editorial review, and to E. A. Ledwith for assistance in preparation of the illustrations.



2. VALUES OF t, T, τ, AND q

In applying the probability function for estimating the design load mq, it is necessary to select values of t, T, and τ from which to compute the value of m and to select a value of q, the factors excepting τ pertaining to a particular kind of fixture and service. The actual values selected in any case are largely a matter of engineering judgment. In this connection, it is to be understood that in the following development and illustrative examples, the values selected represent the author's judgment in regard to the appropriate values for producing satisfactory service and are based on the author's interpretation of the information available.

For the purposes of this discussion *satisfactory service* is defined in a relative sense as that in which interruption in service because of controllable factors, such as the sizes and arrangement of pipes, is infrequent and is of sufficiently short duration to cause no inconvenience in the use of fixtures or any unsanitary condition in the plumbing system. Attainment of satisfactory service will depend on the selection of the design factor m, or more specifically on the value of τ from which the value of m is computed. The value of τ selected for illustrating the proposed application is 100 seconds, which provides for wholly satisfactory service 99 percent of the time and for reasonably satisfactory service all of the time if the design load mq gpm is not greatly exceeded. In this connection, it will be observed that if m is exceeded in actual service it is most likely to be exceeded by one fixture only and is progressively less likely to be exceeded by two, by three, or more.

Obviously t and q bear a direct relation to Q in respect to the values necessary to provide satisfactory service if m fixtures are in operation simultaneously. Since there is a considerable range in the values of t and Q on which the value of q depends for any particular fixture, it will be very helpful to the engineer in determining reasonable values to be used for a particular kind of fixture to consider the charac-

It is a characteristic of water closets that they will operate more or less effectively under any average rate of supply from about 15 gpm up to rates of about 30 gpm or more delivered in any time ranging from about 6 seconds up. For each type and design of water-closet bowl there is an intermediate smaller range of average rate of supply within which there is no detectable difference in the effectiveness of the flush in emptying the bowl of its contents. There is likewise a range in time of flow within

Table 7 gives the fixture weights suggested in accordance with the use to which the fixtures are subjected and the manner in which they are installed. The term "public" refers to fixtures which are individually open for use at all times when the building is open, as in public toilets or general toilets in office buildings. "Private" refers to fixtures installed in groups in such a manner that the entire group may be and generally is confined to the use of one person at a time, as in residences or private baths of hotels. "Total" refers to hot and cold supply combined. "Hot or cold" refers to hot or cold water supply only.

TABLE 7.—*Demand weights of plumbing fixtures*

Fixture or group	Occupancy	Type of supply	Weight per fixture or group in fixture units
Water closet	Public	Flush valve	10
Do	do	Flush tank	5
Pedestal urinal	do	Flush valve	10
Stall or wall urinal	do	do	5
Do	do	Flush tank	3
Lavatory	do	Total	2
Do	do	Hot or cold	1.5
Bathtubs	do	Total	4
Do	do	Hot or cold	3
Shower head	do	Total	4
Do	do	Hot or cold	3
Bathroom group	Private	Flush valve (total)	8
Do	do	Flush valve (cold only)	6
Do	do	Flush tank (total)	6
Do	do	Flush tank (cold only)	4
Do	do	Hot water only	3
Bathroom group with separate shower	do	Add to corresponding group above for total, 2; for cold or hot	1.5

Detailed sample to both water supply and drainage applications illustrate use of Fixture Units. No distinctions or differentiation for utilizations of Fixture Units separately or for needs of adjustments from initial developments. The BMS 65, where the origins and

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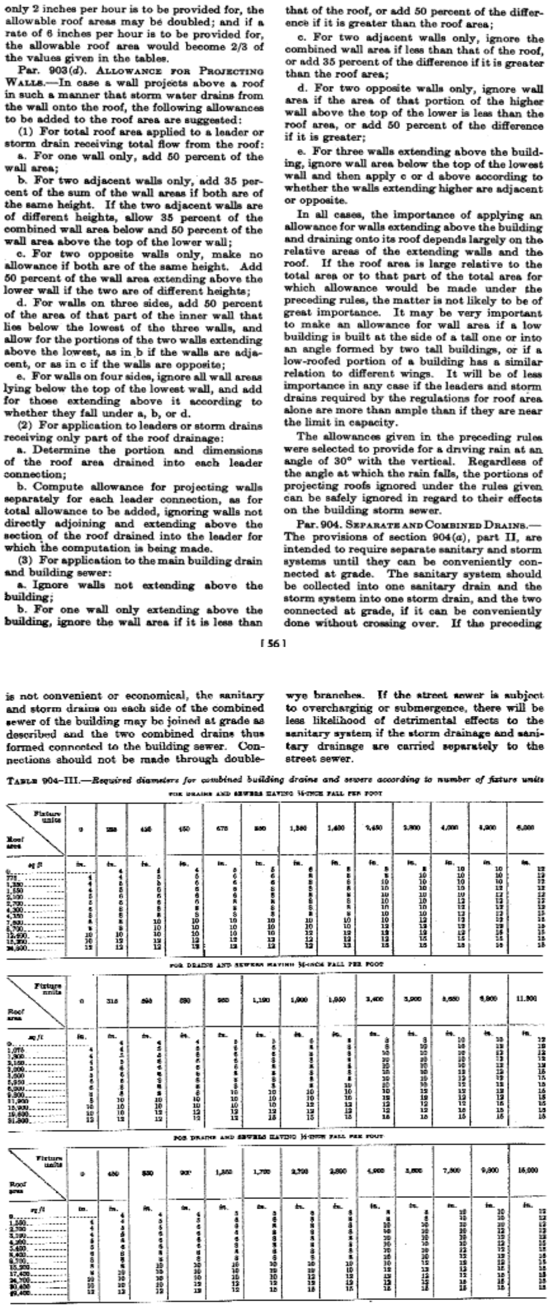
[2] Early recognition for dynamics' essential details were not readily established at that time of his research

source indications were provided, the supply/discharge seemingly appear commingled for further applications. ***That issue of whether there exists a need to distinguish or utilize the aspects together or separately remains open and the subject requires further considerations. Are there any limitations or assumed utilizations to both aspects of piped plumbing applications? Scrutiny of those developed bases/descriptions for developed and recommended Fixture Units from probability of simultaneous events requires further study since of implied generalities to both water supply and drainage does not appear or specifically addressed in published discussion of the earlier developments as applied directly in BMS 66.***

Report applications provide illustrative examples with discussion of usages to applications for many aspects of plumbed systems in small and large buildings and extension to roof drainage applications/combinations with drains and storm systems. However, the examples do not discuss the aspects of load simultaneity of the system but imply such states. Sample from the report indicates the breadth.



only 2 inches per hour is to be provided for, the allowable roof areas may be doubled; and if a rate of 6 inches per hour is to be provided for, the allowable roof area would become 2/3 of the values given in the tables.

Par. 903(*d*). ALLOWANCE FOR PROJECTING WALLS.—In case a wall projects above a roof in such a manner that storm water drains from the wall onto the roof, the following allowances to be added to the roof area are suggested:

(1) For total roof area applied to a leader or storm drain receiving total flow from the roof:

a. For one wall only, add 50 percent of the wall area;

b. For two adjacent walls only, add 35 percent of the sum of the wall areas if both are of the same height. If the two adjacent walls are of different heights, allow 35 percent of the combined wall area below and 50 percent of the wall area above the top of the lower wall;

c. For two opposite walls only, make no allowance if both are of the same height. Add 50 percent of the wall area extending above the lower wall if the two are of different heights;

d. For walls on three sides, add 50 percent of the area of that part of the inner wall that lies below the lowest of the three walls, and allow for the portions of the two walls extending above the lowest, as in b if the walls are adjacent, or as in c if the walls are opposite;

e. For walls on four sides, ignore all wall areas lying below the top of the lowest wall, and add for those extending above it according to whether they fall under a, b, or d.

(2) For application to leaders or storm drains receiving only part of the roof drainage:

a. Determine the portion and dimensions of the roof area drained into each leader connection;

b. Compute allowance for projecting walls separately for each leader connection, as for total allowance to be added, ignoring walls not directly adjoining and extending above the section of the roof drained into the leader for which the computation is being made.

(3) For application to the main building drain and building sewer:

a. Ignore walls not extending above the building;

b. For one wall only extending above the building, ignore the wall area if it is less than that of the roof, or add 50 percent of the difference if it is greater than the roof area;

c. For two adjacent walls only, ignore the combined wall area if less than that of the roof, or add 35 percent of the difference if it is greater than the roof area;

d. For two opposite walls only, ignore wall area if the area of that portion of the higher wall above the top of the lower is less than the roof area, or add 50 percent of the difference if it is greater;

e. For three walls extending above the building, ignore wall area below the top of the lowest wall and then apply c or d above according to whether the walls extending higher are adjacent or opposite.

In all cases, the importance of applying an allowance for walls extending above the building and draining onto its roof depends largely on the relative areas of the extending walls and the roof. If the roof area is large relative to the total area or to that part of the total area for which allowance would be made under the preceding rules, the matter is not likely to be of great importance. It may be very important to make an allowance for wall area if a low building is built at the side of a tall one or into an angle formed by two tall buildings, or if a low-roofed portion of a building has a similar relation to different wings. It will be of less importance in any case if the leaders and storm drains required by the regulations for roof area alone are more than ample than if they are near the limit in capacity.

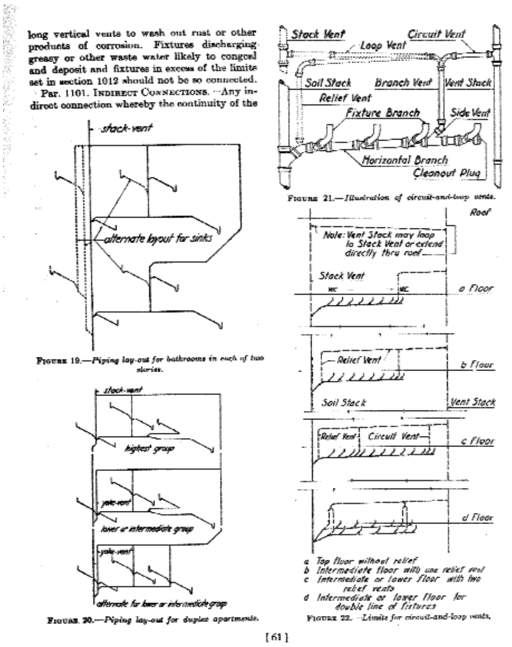
The allowances given in the preceding rules were selected to provide for a driving rain at an angle of 30° with the vertical. Regardless of the angle at which the rain falls, the portions of projecting roofs ignored under the rules given can be safely ignored in regard to their effects on the building storm sewer.

Par. 904. SEPARATE AND COMBINED DRAINS.—The provisions of section 904(*a*), part II, are intended to require separate sanitary and storm systems until they can be conveniently connected at grade. The sanitary system should be collected into one sanitary drain and the storm system into one storm drain, and the two connected at grade, if it can be conveniently done without crossing over. If the preceding

[56]

is not convenient or economical, the sanitary and storm drains on each side of the combined sewer of the building may be joined at grade as described and the two combined drains thus formed connected to the building sewer. Connections should not be made through double-wye branches. If the street sewer is subject to overcharging or submergence, there will be less likelihood of detrimental effects to the sanitary system if the storm drainage and sanitary drainage are carried separately to the street sewer.

TABLE 904-III.—*Required diameters for combined building drains and sewers according to number of fixture units*



long vertical vents to wash out rust or other products of corrosion. Fixtures discharging greasy or other waste water likely to congeal and deposit and fixtures in excess of the limits set in section 1012 should not be so connected.

Par. 1101. INDIRECT CONNECTIONS.—Any indirect connection whereby the continuity of the

FIGURE 19.—*Piping lay-out for bathrooms in each of two stories.*

FIGURE 20.—*Piping lay-out for duplex apartments.*

FIGURE 21.—*Illustration of circuit-and-loop vents.*

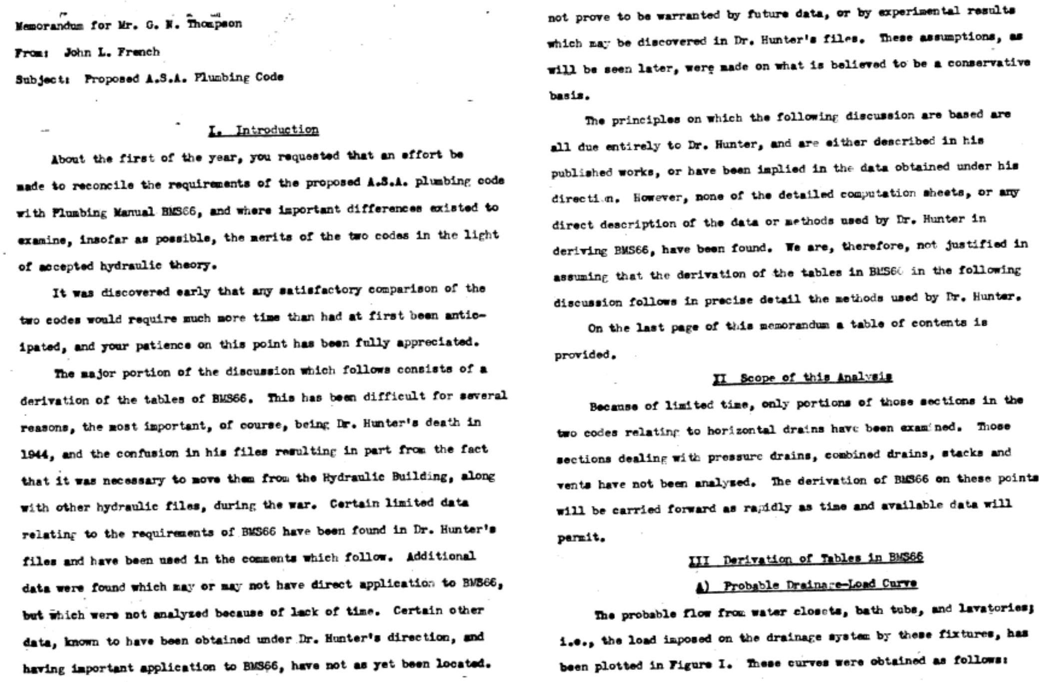
FIGURE 22.—*Limits for circuit-and-loop vents.*

[61]

7. J. FRENCH 1946 Report (7)

The task of researching Dr. Hunter's files following WW II was an attempt to establish aspects from research and developments in setting the new method of Fixture units into applications that had indicated differences from the then accepted standard. The draft report was not published; several aspects from a copy are indicated from materials assembled for the report.

A few examples are reproduced from that study to illustrate selected report findings. That source indicated the limited extent of information found (or determined) from the files and records and limited resource materials found. The study specific "Conclusions" (shown in the reproduction) indicates "recommending that the Bureau (NBS) should not concur in publication of the proposed (at the time) code". Several additional findings reported that newer considerations by Hunter after the initial reports (BMS 65 & 66) publication seemed likely. Other selected indications are provided in the copied materials.



Memorandum for Mr. G. N. Thompson

From: John L. French

Subject: Proposed A.S.A. Plumbing Code

I. Introduction

About the first of the year, you requested that an effort be made to reconcile the requirements of the proposed A.S.A. plumbing code with Plumbing Manual BMS66, and where important differences existed to examine, insofar as possible, the merits of the two codes in the light of accepted hydraulic theory.

It was discovered early that any satisfactory comparison of the two codes would require much more time than had at first been anticipated, and your patience on this point has been fully appreciated.

The major portion of the discussion which follows consists of a derivation of the tables of BMS66. This has been difficult for several reasons, the most important, of course, being Dr. Hunter's death in 1944, and the confusion in his files resulting in part from the fact that it was necessary to move them from the Hydraulic Building, along with other hydraulic files, during the war. Certain limited data relating to the requirements of BMS66 have been found in Dr. Hunter's files and have been used in the comments which follow. Additional data were found which may or may not have direct application to BMS66, but which were not analyzed because of lack of time. Certain other data, known to have been obtained under Dr. Hunter's direction, and having important application to BMS66, have not as yet been located.

not prove to be warranted by future data, or by experimental results which may be discovered in Dr. Hunter's files. These assumptions, as will be seen later, were made on what is believed to be a conservative basis.

The principles on which the following discussion are based are all due entirely to Dr. Hunter, and are either described in his published works, or have been implied in the data obtained under his direction. However, none of the detailed computation sheets, or any direct description of the data or methods used by Dr. Hunter in deriving BMS66, have been found. We are, therefore, not justified in assuming that the derivation of the tables in BMS66 in the following discussion follows in precise detail the methods used by Dr. Hunter.

On the last page of this memorandum a table of contents is provided.

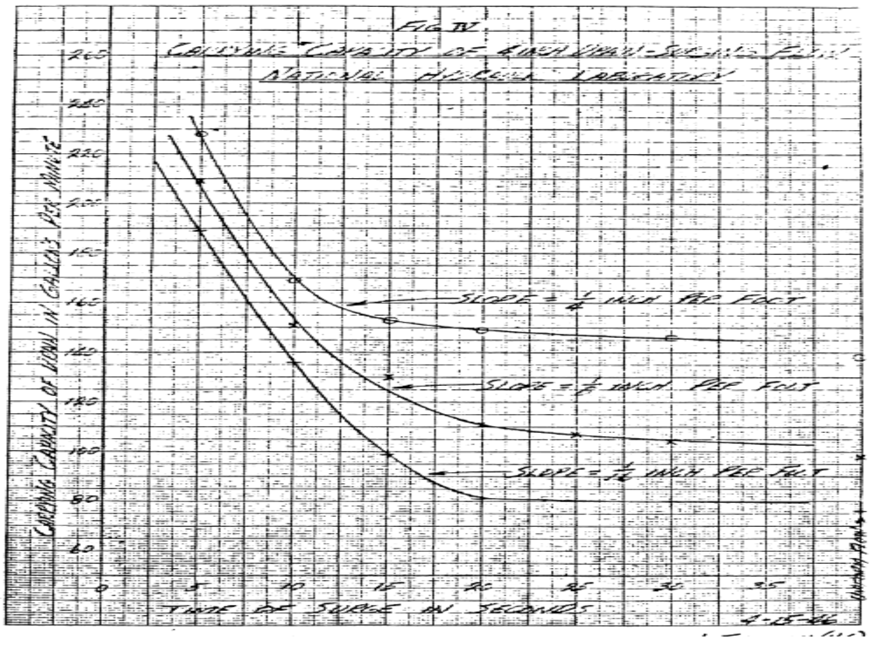
II Scope of this Analysis

Because of limited time, only portions of those sections in the two codes relating to horizontal drains have been examined. Those sections dealing with pressure drains, combined drains, stacks and vents have not been analyzed. The derivation of BMS66 on these points will be carried forward as rapidly as time and available data will permit.

III Derivation of Tables in BMS66

A) Probable Drainage-Load Curve

The probable flow from water closets, bath tubs, and lavatories; i.e., the load imposed on the drainage system by these fixtures, has been plotted in Figure I. These curves were obtained as follows:



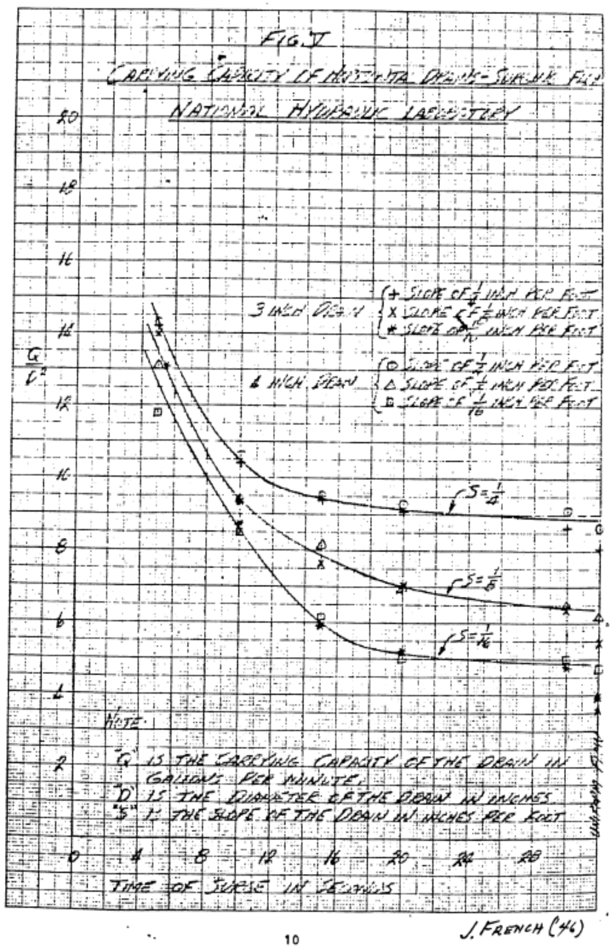


FIG. V
CARRYING CAPACITY OF HORIZONTAL DRAIN-SURGE FLOW
NATIONAL HYDRAULIC LABORATORY
$\frac{Q}{D^2}$
20
18
16
14
12
10
8
6
4
2
0
4
8
12
16
20
24
28
TIME OF SURGE IN SECONDS
3 INCH DRAIN
+ SLOPE OF 1/4 INCH PER FOOT
X SLOPE OF 1/8 INCH PER FOOT
* SLOPE OF 1/16 INCH PER FOOT
6 INCH DRAIN
⊙ SLOPE OF 1/4 INCH PER FOOT
△ SLOPE OF 1/8 INCH PER FOOT
□ SLOPE OF 1/16 INCH PER FOOT
S = 1/4
S = 1/8
S = 1/16
NOTE:
"Q" IS THE CARRYING CAPACITY OF THE DRAIN IN GALLONS PER MINUTE.
"D" IS THE DIAMETER OF THE DRAIN IN INCHES.
"S" IS THE SLOPE OF THE DRAIN IN INCHES PER FOOT
UNIFORM FLOW
10
J. FRENCH (46)

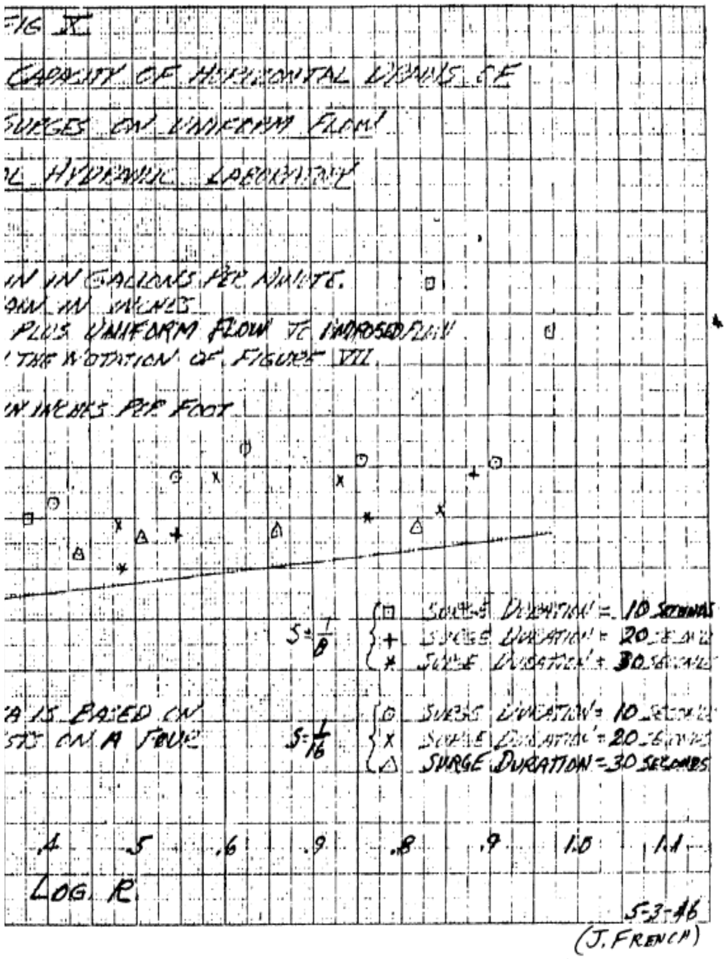


FIG VI
CAPACITY OF HORIZONTAL DRAINS OF
SURGES ON UNIFORM FLOW
L HYDRAULIC LABORATORY
N IN GALLONS PER MINUTE.
AIN IN INCHES
PLUS UNIFORM FLOW TO IMPOSED FLOW
THE NOTATION OF FIGURE VII
N INCHES PER FOOT
S = 1/8
□ SURGE DURATION = 10 SECONDS
+ SURGE DURATION = 20 SECONDS
* SURGE DURATION = 30 SECONDS
S = 1/16
⊙ SURGE DURATION = 10 SECONDS
X SURGE DURATION = 20 SECONDS
△ SURGE DURATION = 30 SECONDS
A IS BASED ON
STS ON A FOUR
.4
.5
.6
.9
.8
.9
1.0
1.1
LOG. R.
5-3-46
(J. FRENCH)

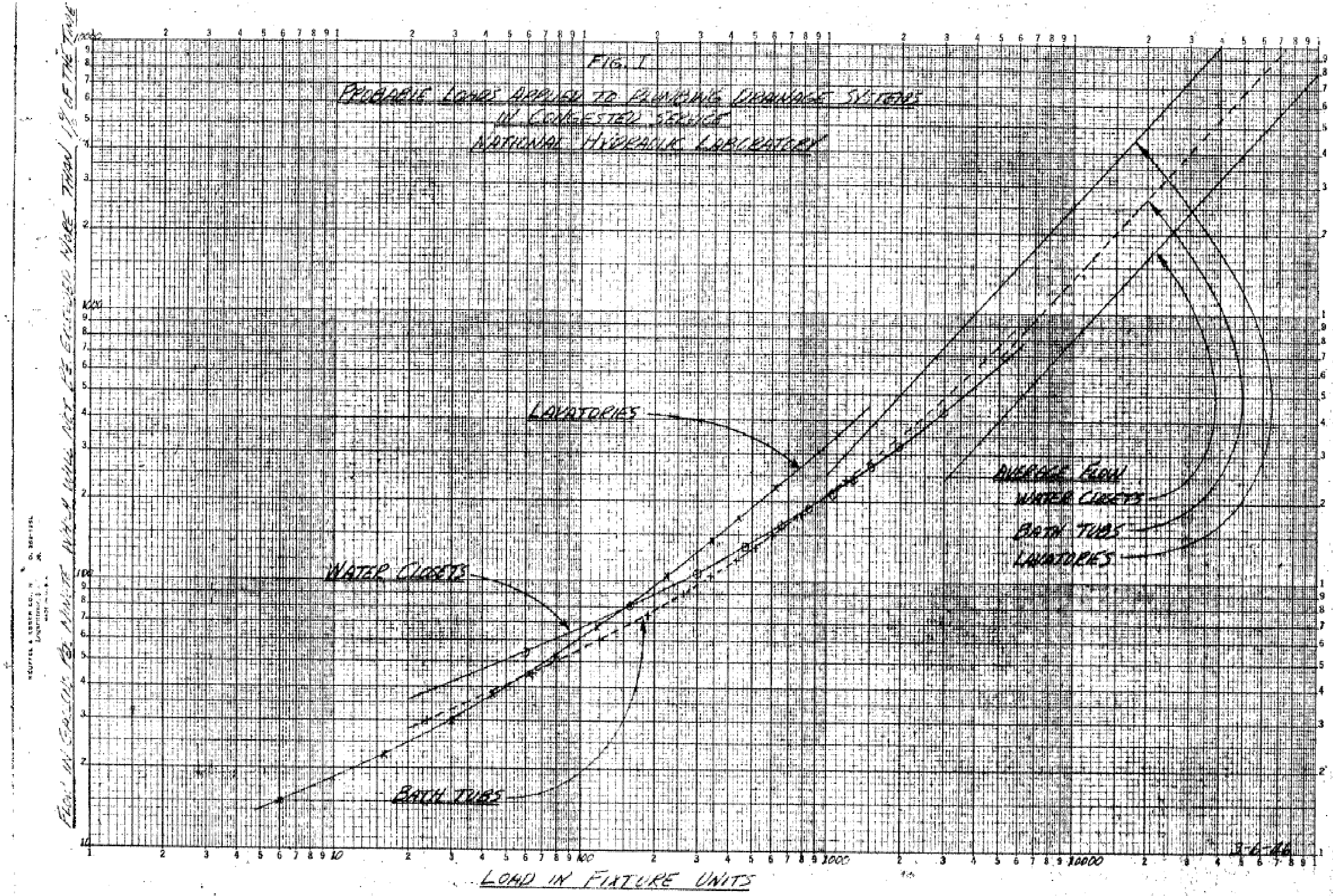


FIG. I

PROBABLE LOADS APPLIED TO PLUMBING DRAINAGE SYSTEMS IN CONGESTED SERVICE

NATIONAL HYDRAULIC LABORATORY

Probable Proposed Revision of BMS66

Permissible Loadings Found in Dr. Hunter's Files

Appendix I.

Sec. 807. Sloping Drains and Sewers (Sanitary Only).

(a) Horizontal Branches – The maximum number of fixture units installed on a horizontal branch of a given diameter shall not exceed the values given in Column (2) of Table X.

(b) Primary Branches – The maximum number of fixture units drained into a primary branch of given diameter and slope shall not exceed the values given in Columns (3) to (6) of Table X, except as provided for in paragraph of this section for pressure drainage conditions.

(c) Secondary Branches and Main Building Drain; (Sanitary System only). If the Building Drain has one primary branch only, or not more than one primary branch of 3-inch diameter or larger, the main building drain shall be of the diameter required by Table X for primary branches, except as provided by paragraph c of this section for pressure drainage conditions. If the building drain has two or more primary branches of 3-inch diameter or greater, the number of fixture units drained into the main building drain and its secondary branches may be increased by 10 percent, of the number permitted for a primary branch of the same diameter and slope, for each primary branch upstream from the secondary branch or main in question within the limits given in Table Y, provided:

(1) that the building drain and its secondary branches are laid at a uniform slope;

(2) that all connections are made by means of single-Y fittings; and

(3) that no primary branch which extends less than 15 feet in length at grade before connecting to the main or a secondary branch shall be counted in applying this rule. The provisions of paragraph (c) shall not apply except when construction plans showing the sizes,

(d) Pressure Drainage Conditions. In case no horizontal branch or other trapped drain connects to the sanitary drainage system within 3 feet above the grade line of the building drain (sewage ejectors excepted), the permissible number of fixture units as given by Table Y for primary branches and computed under paragraph c for secondary branch and main building drain may be increased by the factor (1 + 1/2 H/h) within the limits given in Table Y, where h is the total fall in feet in the building drain including its longest branch and H is the elevation in feet of the lowest horizontal branch above the horizontal plane through the end of the main building drain. The provisions of this paragraph shall not apply except when construction plans as required for the application of paragraph c showing in addition the elevation of the lowest horizontal branches on all stacks in the system and details relating to any other proposed connections such as a sewage ejector, are submitted to and approved by the authority having jurisdiction.

(e) Building sewer. The building sewer, if laid at the same slope as the main building drain or at a greater slope, shall be of the same diameter as the main building drain.

If for any reason it is necessary to decrease the slope of the building sewer below that of the building drain, the diameter of the building sewer shall be such that its capacity for non-pressure drainage (paragraph c), as given by Table X (columns (6) to (9)) for Main building drains for the slope to be installed, is equal to or greater than the number of fixture units to be carried; and the diameter of the building sewer for pressure drainage (paragraph d) shall be such that building drains for the slope to be installed, is equal to or greater than the number of fixture units to be carried; and the diameter of the

Table X (807)

Capacities of Horizontal Branches and

Primary Branches of Building Drains

Diameter of pipe inches	Maximum permissible number of fixture units				
	Horizontal[(1)] branch	Primary branch			
		1/16 in. fall per foot	1/8 in. fall per foot	1/4 in. fall per foot	1/2 in. fall per foot
(1)	(2)	(3)	(4)	(5)	(6)
1-1/4	1	–	–	2	2
1-1/2	3	–	–	5	7
2	6	–	–	21	26
3	32	–	36	42	50
3	20	–	24	27	36
4	160	–	180	216	250
5	360	–	390	480	575
6	620	–	700	840	1000
8	1400	1400	1600	1920	2300
10	2500	2500	2900	3500	4200
12	3900	3900	4650	5600	6700
15	7000	7000	8300	10000	12000

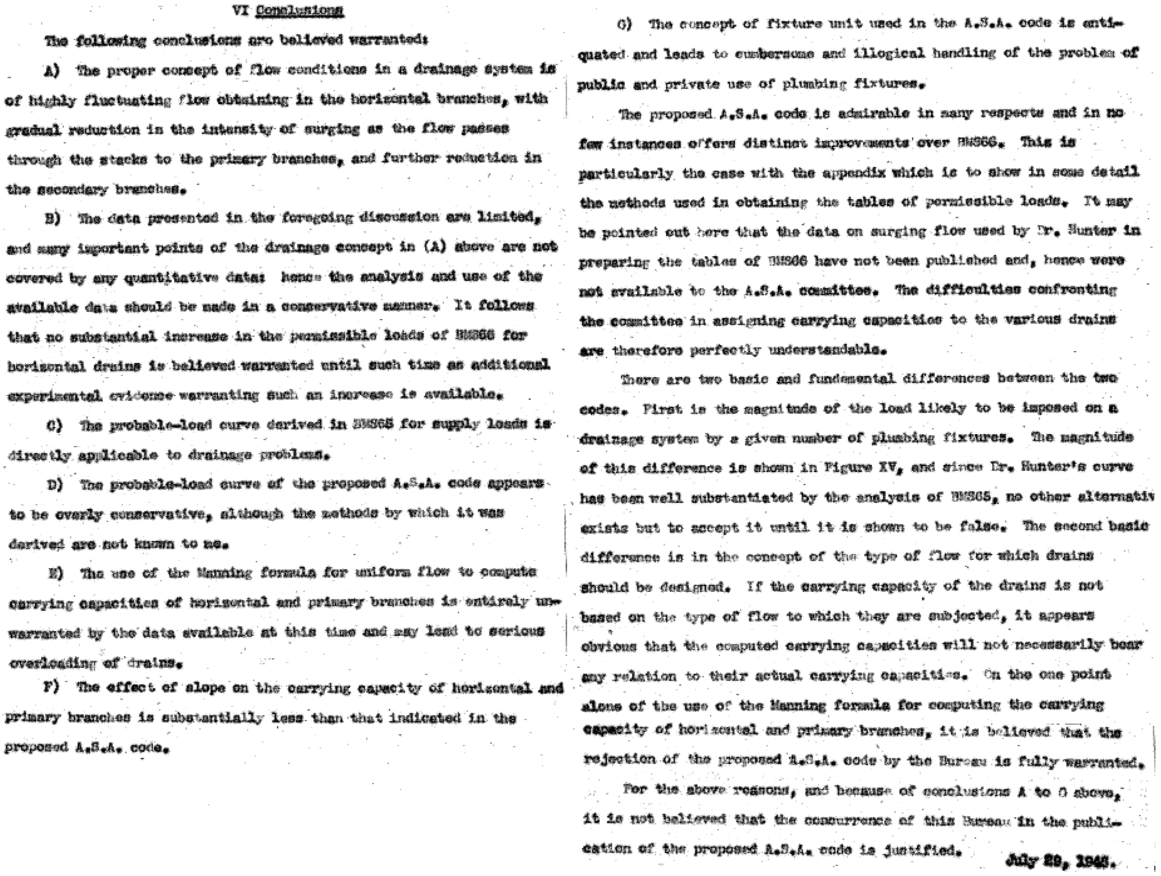
(1) Slope of horizontal branches may be equal to or greater than the minimum slope for given diameters.

Table Y (807c)

Limits in Capacities of Building Drains for Non-Pressure

Drainage Conditions (Sanitary only).

Diameter of pipe inches	Primary branch				Secondary branch or main			
	1/16" fall per foot	1/8" fall per foot	1/4" fall per foot	1/2" fall per foot	1/16" fall per foot	1/8" fall per foot	1/4" fall per foot	1/2" fall per foot
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
2	–	–	21	26	–	–	–	–
3	–	36	42	50	–	85	125	170
4	–	180	216	250	–	440	625	880
5	–	390	480	575	–	820	1160	1640
6	–	700	840	1000	–	1410	2000	2820
8	1400	1600	1920	2300	1950	2750	3900	5500
10	2500	2900	3500	4200	4375	6200	8750	12400
12	3900	4600	5600	6700	7500	10600	15000	21200
15	7000	8300	10000	12000	11900	16800	23800	33700



VI Conclusions

The following conclusions are believed warranted:

A) The proper concept of flow conditions in a drainage system is of highly fluctuating flow obtaining in the horizontal branches, with gradual reduction in the intensity of surging as the flow passes through the stacks to the primary branches, and further reduction in the secondary branches.

B) The data presented in the foregoing discussion are limited, and many important points of the drainage concept in (A) above are not covered by any quantitative data: hence the analysis and use of the available data should be made in a conservative manner. It follows that no substantial increase in the permissible loads of BMS66 for horizontal drains is believed warranted until such time as additional experimental evidence warranting such an increase is available.

C) The probable-load curve derived in BMS65 for supply loads is directly applicable to drainage problems.

D) The probable-load curve of the proposed A.S.A. code appears to be overly conservative, although the methods by which it was derived are not known to me.

E) The use of the Manning formula for uniform flow to compute carrying capacities of horizontal and primary branches is entirely unwarranted by the data available at this time and may lead to serious overloading of drains.

F) The effect of slope on the carrying capacity of horizontal and primary branches is substantially less than that indicated in the proposed A.S.A. code.

G) The concept of fixture unit used in the A.S.A. code is antiquated and leads to cumbersome and illogical handling of the problem of public and private use of plumbing fixtures.

The proposed A.S.A. code is admirable in many respects and in no few instances offers distinct improvements over BMS66. This is particularly the case with the appendix which is to show in some detail the methods used in obtaining the tables of permissible loads. It may be pointed out here that the data on surging flow used by Dr. Hunter in preparing the tables of BMS66 have not been published and, hence were not available to the A.S.A. committee. The difficulties confronting the committee in assigning carrying capacities to the various drains are therefore perfectly understandable.

There are two basic and fundamental differences between the two codes. First is the magnitude of the load likely to be imposed on a drainage system by a given number of plumbing fixtures. The magnitude of this difference is shown in Figure XV, and since Dr. Hunter's curve has been well substantiated by the analysis of BMS65, no other alternativ exists but to accept it until it is shown to be false. The second basic difference is in the concept of the type of flow for which drains should be designed. If the carrying capacity of the drains is not based on the type of flow to which they are subjected, it appears obvious that the computed carrying capacities will not necessarily bear any relation to their actual carrying capacities. On the one point alone of the use of the Manning formula for computing the carrying capacity of horizontal and primary branches, it is believed that the rejection of the proposed A.S.A. code by the Bureau is fully warranted.

For the above reasons, and because of conclusions A to G above, it is not believed that the concurrence of this Bureau in the publication of the proposed A.S.A. code is justified.

July 29, 1948.

8. Conclusions & Recommendations

The review provides an historical perspective for insights on methods developed that introduced "Hunter Fixture Units" into practices for plumbing systems and continues as a means for plumbing engineers/designers and as applied in adopted local authorities' applications for plumbing code requirements.

Considerations for further study involving probability analyses have broadly expanded by computer numerical methods applications of Monte Carlo and other techniques applicable to random event(s) theory and interpretations. Extensive field usage data from CIB W62 colleagues' presentations to W62 provide resources that offer opportunities to generalize and further evaluate statistical loadings/simultaneity aspects. Those efforts could contribute greatly to current thrusts for water conservation.

Function times for water closets have decreased to about four seconds for water closet discharges for new reductions of water consumption - down to about four or five liters, or 1.28 gallons, that vastly alters probable simultaneous event overlaps. With that factor for probable simultaneity a decrease of probable t/T value occurs (about 250 %) and then simultaneity for concurrent events in usages may not correlate with the fixture unit value of six as adopted in the Hunter curves/report.

Direct computational designs based upon numerical methods of solution for the governing dynamic equations for flow in partially filled pipes (also full bore flow techniques) also provides means for plumbing system designs (as advanced by Prof. Swaffield and Heriot-Watt team with several others). This alternate method avoids tabulated listings and provides great flexibility with competency for individual design basis of many building applications and usage(s) for specifics applied to conventional and individualistic design applications. Detailed study comparisons would be a useful evaluation for decisions on applications from conventional tabulated values to more exact method for plumbing systems designs.

9. Presentation of Author

Dr. Lawrence Galowin is a consultant, formerly a National Institute of Standards and Technology (NIST) leader in plumbing research; now retired but serves as Guest Researcher. Consultant in: desalination developments by wave energy pumping for RO methods & potable water relief by Slow Sand Filtering. He also serves on ASME national plumbing standards committees, and continues performance parameters research.

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11. Appendix

I. From Section III Definitions and Symbols (1): Clarity of special defined elements**:** A number of terms employed in the plumbing industry, and a few that are now introduced for the first time, are defined in the sense to be used in this (and later papers) of this series. Included are following listed elements and others in the report:

plumbing system
building main
water distributing system
sanitary system
plumbing fixture
drain
fixture drain
waste pipe
soil pipe
stack
horizontal branch
building drain
building sewer
primary branch; secondary branch
vent or vent pipe
vent stack or main vent
Demand load; Sewage load
Charging load
Receiving capacity
Terminal velocity

Design factor m is the particular value of r out of n fixtures that will be found in operation a selected fraction of the time under the assumed conditions of use.

Fixture unit, or load fact, is a numerical factor which measures on some arbitrary scale the load producing effect of a single plumbing fixture of a given kind. The use of the fixture unit makes it possible to reduce the load-producing characteristics to a common basis.

Specific symbols follow:

n = the total number of fixtures or supply openings of a given kind in the system.

r = the number of fixtures out of a total of n which at any given instant of observation are found operating to impose a demand load on the supply system, or a sewage load on the drainage system.

m = the design factor (definition above)

q = the average volume rate of flow, in gallons per minute, to or from a plumbing fixture during actual operation. Q = the total volume of water in gallons that flows or is discharged by a fixture at each use.

t = average duration of flow in seconds for a given kind of fixture for one use

T = average time in seconds between successive operations of any given fixture of a particular kind

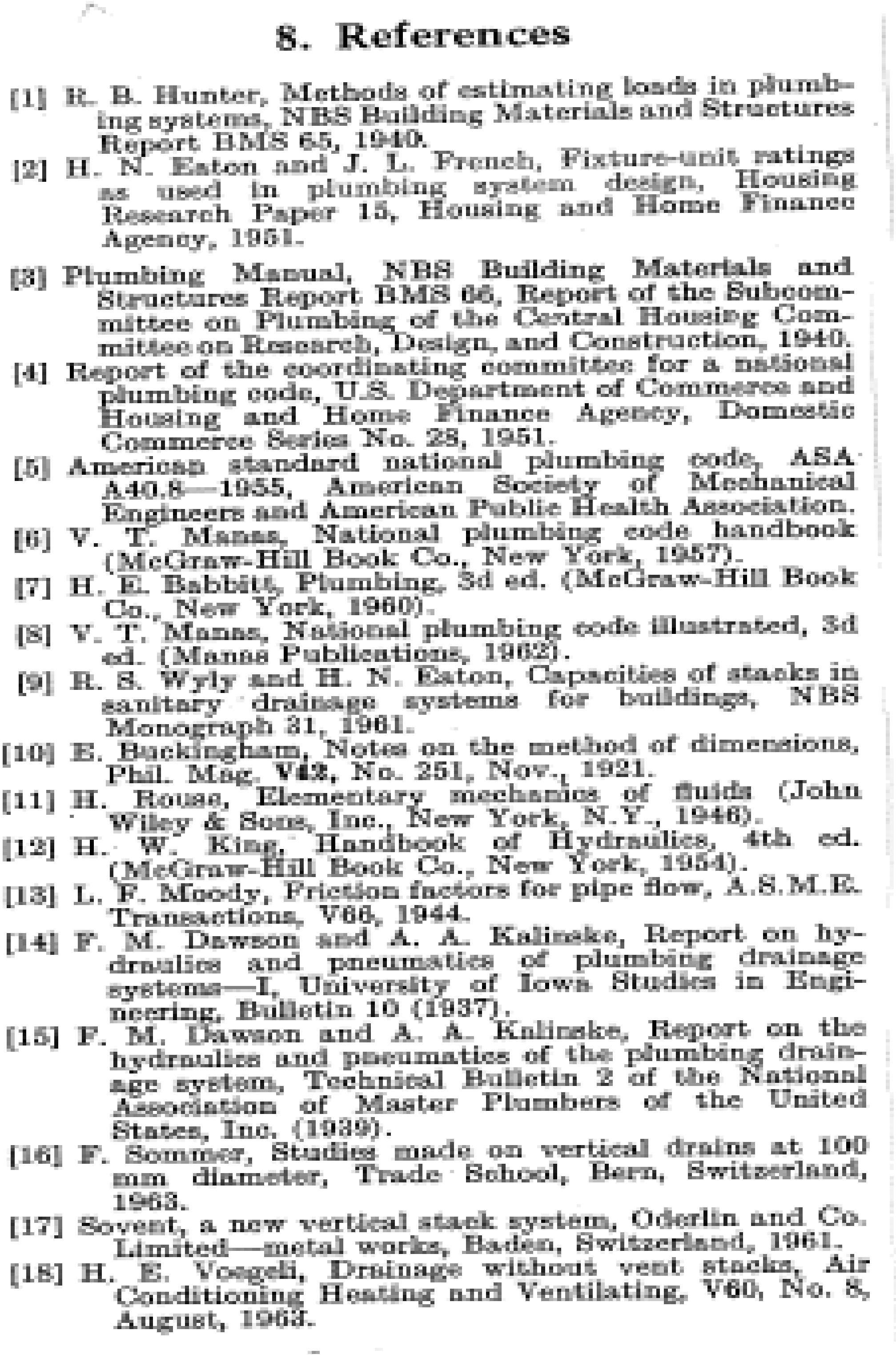
τ = time interval in seconds such that the event in question (for example, exactly r fixtures will be found operating will occur for an aggregate off 1 second

C_r^n = number of combinations of n things taken r at a time

p_r^n = probability of exactly r fixtures out of a total of n fixtures being found in operation at an arbitrary instant of observation

$\sum_{r=m}^{r=n} p_r^n$ = the probability that some number of fixtures between $r=m$ *and* $r=n$, inclusive, will be found operating at an arbitrary instant of observation

II. From (8) the Reference List provides some insights into topics that were of interest in a selected number of plumbing research efforts following WW II.



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