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NATIONAL BUREAU OF STANDARDS REPORT

9848

SUPPLEMENTAL REPORT ON

REVIEW OF INFORMATION ON PERFORMANCE OF TWO TYPES OF SINGLE--STACK, SANITARY DWV SYSTEMS FOR BUILDINGS

Sponsored by
The Technical Studies Program
Federal Housing Administration
Department of Housing and Urban Development

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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NBS PROJECT — 42103-4214431

May 28, 1968

NBS REPORT — 9848

SUPPLEMENTAL REPORT ON

REVIEW OF INFORMATION ON PERFORMANCE OF TWO TYPES OF SINGLE-STACK, SANITARY DWV SYSTEMS FOR BUILDINGS

by
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Contents

Supplemental Report on

Review of Information on Performance of Two Types of

Single-Stack, Sanitary DWV Systems for Buildings

Abstract

This report presents detailed experimental data on two European single-stack drainage systems. The data are discussed and an attempt made to estimate the practical carrying capacities in terms of American plumbing fixtures. Recommendations are presented as to possible utilization of single-stack drainage in America and as to needed research, based on review of the European data by NBS personnel and by two private consultants.

1. Introduction

An earlier presentation [1], based on a preliminary review of European literature and test data, described two European single-stack sanitary drainage systems and presented a discussion as to potential applications of these systems in American plumbing practice. The primary appeal of these simplified drainage systems is in their cost-savings potential through elimination of the customary system of secondary ventilation piping, with particular reference to multistory housing.

Subsequently, the report [1] and the original European information on which it was based was submitted to review by two prominent independent American consultants knowledgable in the plumbing field. This report summarizes the findings of the consultants, presents some of the details of the European research data, and gives final recommendations of the National Bureau of Standards regarding possible utilization of single-stack drainage in America for housing.

2. Summary of British Data and Recommendations--British Single-Stack System.

In 1954 Wise and Croft [2] reported on the use of single stack drainage in multi-story flats in Britain. A type of multi-story stack venting as used in five- and six- story blocks in London County Council Flats was described. Figure 1 shows the typical plan and elevation of the systems. Two large-radius BS 416 135° bends were used at the foot of the stack. Traps with 3-in. seals were used on the waste branches. Manual flushing tests were carried out on several of these systems before the buildings were occupied, and some retesting was carried out 16 months after occupation. The authors stated that the latter tests

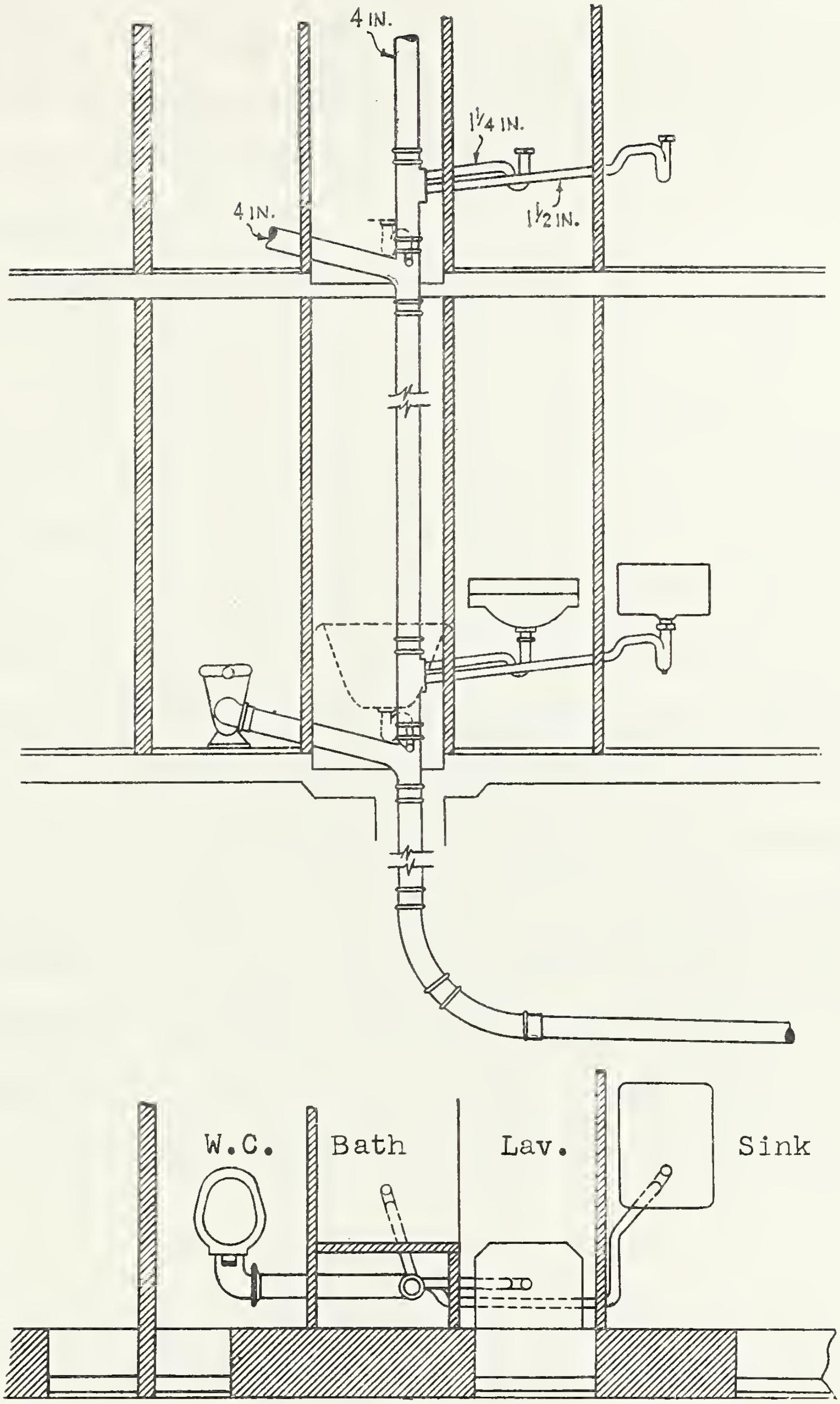


Figure 1. Early type of British single-stack design, installed in 4-, 5-, and 6-story LCC flats

showed "no significant difference in behaviour". Self-siphonage did not exceed 0.25 in. Induced siphonage was measured at the ground floor resulting from six repeated discharges of the first-floor W.C. (newspaper loading) plus the first-floor washbasin and kitchen sink. The seal losses in ground-floor fixture traps did not exceed 0.3 in. after this test. Five repeated discharges of the fifth-floor W.C., utilizing newspaper loadings, yielded seal losses in the traps of lower-floor fixtures not exceeding 0.25 in. The most severe test made was a simultaneous discharge of fourth and third floor W.C.'s using newspaper loadings and repeating the operation five times. The seal losses in the W.C. traps were 1.15, 1.05, and 0.5 in. for the second, first, and ground floors, respectively. They stated that the maximum back pressure observed at the ground-floor level corresponded to that indicated by a rise of water in the W.C. of 1/4 in. Tenants occupying all the ground- and first- floor flats with single-stack systems were interviewed 18 mo. to 2 yr. after occupation. No instances of air bubbling up through trap seals were reported, and any rise of water in the W.C.'s that might have occurred went unnoticed. On the other hand, there had been complaints of back pressure in adjacent two-pipe systems (vented systems utilizing separate soil and waste stacks) in the same block of flats, the authors noted.

Tests were made under controlled conditions in a 4-in., 6-story, cast-iron stack, joined to a 4-in. building drain 13 ft. long at a gradient of 1/60 and discharging freely into a tank. The junction fitting was a 6-in. radius, "Long" BS65 bend. Both continuous-flow tests and fixture-discharge tests were made. Tables 1 and 2 give results of repeated discharges of the fifth-floor W.C. using newspaper pieces of two different sizes. Traps were not refilled between the successive loadings. Continuous-flow tests showed the pneumatic performance for fitting "A" (W.C. branch fitting with 14° slope and 2-in. radius swept inlet)[1/] to be superior to fittings with straight "T" inlets or with BS cycloidal-curve inlets. That is, vacuum generated in the stack below the point of water entry was least for fitting "A".

Cost comparisons of several types of DWV arrangements were prepared for five-story systems. These are shown in Table 3. The cost savings with the simplest form of single-stack system as compared with a fully vented one-pipe system are estimated at more than 40% in this tabulation. It seems probable this comparison is only for piping materials costs, not including fixtures or labor.

[1/] See Figure 3.

Table 1 . Induced-siphonage tests, newspaper loads 1/ discharged from top (5th) floor, 2-in. radius swept W.C. branch fitting.

Test No.	Seal losses (in.) on floor number							Remarks.
	4	3		2	1		G	
	Trap	Trap	W.C.	Trap	Trap	W.C.	W.C.	
1	—	0·12	—	—	—	—	—	
2	—	0·15	—	—	—	—	—	
3	—	0·19	—	—	—	—	—	
4	—	0·20	—	—	—	—	—	
5	—	0·21	—	—	—	—	—	Paper did not flush.
6	0·21	0·24	0·40	0·36	0·30	0·25	0·20	
7	—	0·24	—	—	—	—	—	Paper did not flush.
8	—	0·24	—	—	—	—	—	Paper did not flush.
9	—	0·25	—	—	—	—	—	
10	—	0·25	—	—	—	—	—	
11	—	0·28	—	—	—	—	—	
12	—	0·28	—	—	—	—	—	
13	0·28	0·31	0·55	0·40	0·40	0·35	0·30	
14	—	0·31	—	—	—	—	—	
15	—	0·31	—	—	—	—	—	
16	—	0·33	—	—	—	—	—	
17	—	0·33	—	—	—	—	—	Paper did not flush.
18	—	0·33	—	—	—	—	—	
19	—	0·35	0·55	—	—	—	—	
20	—	0·35	—	—	—	—	—	
21	—	0·35	—	—	—	—	—	Paper did not flush.
22	—	0·35	—	—	—	—	—	
23	—	0·36	—	—	—	—	—	
24	—	0·36	—	—	—	—	—	Paper did not flush.
25	—	0·36	—	—	—	—	—	
26	0·30	0·36	0·60	0·50	0·55	0·50	0·35	At this stage there had been 20 flushes with paper.
45	0·30	0·38	0·60	0·51	0·55	0·50	0·40	Completion of 30 flushes with paper.

General Remarks—The disturbance in the traps and pans was slight. No air passed back through seals into the building.

Notes—Traps—1¼ in. bore, 3 in. seal P-type.

W.C.'s—B.S.1213 (1945) P-trap washdown pans with 2 in. seal except on floor 1 where there was a siphonic pan with 2·75 in. seal S-trap.

Each flush contained 6 pieces of newspaper unless otherwise stated.

1/ 2-gal (Imperial) high-level, washdown W.C. with 6-in. x 4-1/2-in. newspaper pieces.

Table 2 . Induced-siphonage tests, newspaper loads 1/ discharged from top (5th) floor, 2-in. radius swept W.C. branch fitting.

Test No.	Seal losses (in.) on floor number							Remarks.
	4	3		2	1		G	
	Trap	Trap	W.C.	Trap	Trap	W.C.	W.C.	
1	—	0·03	—	—	—	—	—	Paper did not flush.
2	—	0·63	—	—	—	—	—	Paper passed smoothly into the tank.
3	—	0·63	—	—	—	—	—	Paper did not flush.
4	—	0·91	—	—	—	—	—	Comment as test 2.
5	—	0·91	—	—	—	—	—	Paper did not flush.
6	—	0·91	—	—	—	—	—	Paper did not flush.
7	—	0·91	—	—	—	—	—	As test 2.
8	—	0·91	—	—	—	—	—	Paper did not flush.
9	—	0·91	—	—	—	—	—	As test 2.
10	0·72	0·91	0·48	1·42	1·00	0·85	0·20	As test 2.
11	—	0·91	—	—	—	—	—	The paper arrived in the drain about a second before the water. It stopped 8 ft. beyond the bend and was then washed into the tank by the following water.
12	—	0·91	—	—	—	—	—	The paper stuck as a wad in the bottom quarter of the drain about 5 ft. from the bend.
13	—	0·91	—	—	—	—	—	Stuck paper washed into the tank with the new paper. There was a ¼ in. rise of the ground floor W.C. seal.
14	—	0·91	—	—	—	—	—	Paper did not flush.
15	—	0·91	—	—	—	—	—	As test 2.
16	0·72	0·91	1·00	1·42	1·00	0·85	0 40	As test 2.
17	—	0·92	—	—	—	—	—	The paper stuck in the drain 12 ft. from the bend and was then washed into the tank by the water.
18	—	0·92	—	—	—	—	—	Paper did not flush.
19	—	0·98	—	—	—	—	—	As test 2.
20	—	0·98	—	—	—	—	—	As test 17.
21	—	0·98	—	—	—	—	—	As test 17. Air was drawn from the room into the stack through the third floor W.C.
22	0·72	0·98	1·15	1·42	1·00	0·90	0·45	As test 11. There was a ½ in. rise of the ground floor W.C. seal.
23	—	0·98	—	—	—	—	—	Paper did not flush.
24	—	0·98	—	—	—	—	—	As test 2.
25	—	0·98	—	—	—	—	—	Paper did not flush.
26	—	0·98	—	—	—	—	—	As test 2.
27	—	0·98	—	—	—	—	—	As test 2.
28	—	0·98	—	—	—	—	—	Paper did not flush.
29	—	—	—	—	—	—	—	As test 2.
30	—	—	—	—	—	—	—	Paper did not flush.
31	0·75	0·98	1·28	1·42	1·00	0·95	0·45	As test 2. Completion of 20 flushes with paper.

General Remarks—The disturbance in the traps and pans was slight. No air passed back through seals into the building.

Notes—Traps—1¼ in. bore, 3 in. seal P-type.
W.C.'s—B.S.1213 (1945) P-trap washdown pans with 2 in. seal except on floor 1 where there was a siphonic pan with 2·75 in. seal S-trap.
Each flush contained 6 pieces of newspaper unless otherwise stated.

1/ 2-gal (Imperial) high-level washdown W.C. with 8-in. x 6-in. newspaper pieces.

Table 3 . Costs and materials for various systems for 5-story flats.

System	Cost £	Weight (lb.) Iron	Brass	Copper	Lead
Two-pipe, fully vented	206	1,454	83	87	83
Two-pipe: w.c.'s vented, waste appliances not vented, but 3-inch seal traps used	152	1,372	59	34	108
One-pipe, fully vented	171	882	94	87	69
One-pipe, w.c.'s vented	122	849	60	45	55
Single-stack—					
(*a*) no venting, as Fig. 4 (*a*) ..	98	640	60	45	46
(*b*) with relief vent, Fig. 4 (*b*) ..	111	804	60	45	59
(*c*) no venting, as Fig. 4 (*a*), but ground floor appliances separately to manhole	98	596	57	45	44

Note: The "one-pipe, fully-vented" system corresponds approximately to American systems with individual venting and a separate vent stack. The system identified as "Single-stack-no venting" is the type of system referred to as "British single-stack" in the present report.

Table 4 . Rate and duration of discharge of fixtures (appliances).

Appliance	Discharge (gal. per min.)	Duration of Discharge (Sec.)
Washdown W.C. (2-gallon) ..	30	5
(3-gallon) ..	30	7
Basin—1½-inch trap	8	10
Bath —1½-inch trap	14	75
Sink —1½-inch trap	12	25

From this work, single-stack systems were recommended for up to five-story flats, provided offsets were avoided in the wet part of the stack. It was recommended that 2 gal. W.C.'s be used in preference to the 3-gal. size, the gallon here referred to being the British Imperial gallon. This would correspond to approx. 2.4 American gallons. Also recommended was the use of a single long-radius bend or two long quarter bends at the foot of the stack, and the lowest branch connection was recommended to be at least 3 ft above the invert of the building drain.

Regarding the problem of reasonable test loadings, the authors made the following statements: "Before induced siphonage and back pressure can be studied it is necessary to decide what tests should be applied to reproduce practical conditions. It is the custom in such work to discharge all or most of the appliances simultaneously but this is believed to be unnecessary and, in fact, it may not give the worst result. A more reasonable approach is by way of calculation of the probability of simultaneous discharge, taking into account duration of flow from each of the appliances[1/] and their frequency of use during peak periods of demand. These two factors give a guide on the number of appliances to be discharged together to cover all normal demands in service. It is, of course, important to know the effect of an occasional loading greater than that allowed for by such a test, and this can be covered in the

[1/] The term "appliance" corresponds to "fixture" in American terminology.

laboratory by discharging bigger combinations of appliances and, if necessary, by continuous flow tests. The latter is, in any case, a valuable method as it gives detailed information not obtainable with flushes lasting only a few seconds. Water is discharged continuously into the stack at a rate about equal to the maximum obtained with individual appliances."

The authors went on to state that data of reliable type on the rate and duration of discharge and frequency of use are therefore a basic requirement. They recognized that the value of once in 5 min. for public use of W.C.'s that had been recommended by Hunter in America [3] might be excessive as regards blocks of flats and residences in general. Thus they had set out to collect further data on the frequency of use, feeling this was necessary as the first step toward deciding on reasonable test loadings. Table 4 summarizes the more important hydraulic characteristics of the then-current British appliances.

Surveys were made of frequency of fixture use in the homes of Building Research Station staff, and in flats in London County Council housing. Examples of W.C. usage determined in two flats are shown in Table 5. Table 6 shows the frequencies of use and probabilities of concurrent operation that were calculated from data of this type. About 108 families in the BRS houses and in the flats on the LCC estates were involved in this survey. The occupants were asked to record the number

Table 5 . Typical results from survey of distribution of use of water closets in flats.

A.M.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.	Mon.	Tues.	Wed.	Thur.	Fri.	Sat.
5.30–6.30	0	0	0	0	0	0	0	1	1	2	1	0
6.30–7.30	1	1	1	1	1	1	1	3	0	1	2	0
7.30–8.30	1	1	2	2	2	1	4	2	4	3	2	4
8.30–9.30	1	1	0	0	0	0	2	1	1	0	1	2
9.30–10.30	1	0	1	1	2	1	1	1	1	1	2	3
	Family of 2 adults (wife not out at work)						Family of 2 adults and 2 children (wife not out at work)					

Table 6 . Probability of concurrent discharge of fixtures during morning peak.

Appliance	Duration of discharge t (sec.)	Interval between discharges T (sec.)	$p = \frac{t}{T}$	(1 – p)	The probability of finding r appliances discharging out of a total of 10		
					r = 0	r = 1	r = 2
W.C. 2 gal.	5	1140	0·0044	0·9956	0·956 (0·956)	0·0425 (0·0421)	0·000841 (0·000926)
W.C. 3 gal.	7	1140	0·0061	0·9939	0·940 0·940)	0·0576 (0·0573)	0·00159 (0·00175)
Basin	10	1500	0·0067	0·9933	0·934 (0·935)	0·0630 (0·0628)	0·00191 (0·002105)
Sink	25	1500	0·0167	0·9833	0·845 (0·846)	0·143 (0·141)	0·0110 (0·0118)

Table 7 . Probabilities of concurrent operation of numbers of fixtures in excess of various assumed numbers in a system of 10 sinks 1/, according to the Poisson approximation.

r = 0 – – – – 10, probability = 1·0000 – – – –
r = 1 – – – – 10, ,, = 0·1534 – – – –
r = 2 – – – – 10, ,, = 0·0124 – – – –
r = 3 – – – – 10, ,, = 0·00068 – – – –
r = 4 – – – – 10, ,, = 0·00002 – – – –
r = 5 – – – – 10, etc. ,, = 0·00000 – – – –

1/ Individual probability, p = 0.0167, from Table , for sink.

of times their W.C., basin, sink and bath were used between 5:30a.m. and 10:30 a.m., by 30-min. intervals, each working day for a week. This was assumed to be the peak period for flats because it was considered that the whole family uses the appliances during the hours immediately after rising. The authors stated that there is only scattered use for the rest of the day, even if baths are taken by the whole family on one particular evening; children normally bathe much earlier than adults and sinks and basins will not be in regular use in each flat during the same period. As a check, interested members of the Public Health Dept. and of the London County Council took part in the study in their homes. The authors stated that the statistical agreement between the surveys from the different groups of people corresponded very closely, and they provided some discussion of this matter. A significant observation was that "worst hour" use for sinks was later in the day than the "worst hour" for W.C.'s.

It was considered that the most congested usage in the home occurs in the morning. Although baths may be taken in the evening, this use was said to be scattered, and children bathe earlier than adults. It was also suggested that sinks and wash basins would probably not be in regular use during the period when baths are being taken. The surveys showed only a small incidence of bath usage during the morning hours. Though this has not been shown in Table 5, in households where morning baths were customary, they tended to occur later than the W.C. use.

From the above, the probability of finding some number of fixtures, in excess of a stated minimum, in concurrent operation in a system of 10 identical fixtures was calculated, as shown in Table 7. In order to arrive at reasonable test loads, calculations were made as shown in Tables 8 & 9.

The authors show that, even at use frequencies up to twice those found in surveys for "normal flat installations", the same test loads as given in Table 8 are sufficient to meet the criteria adopted. Also, a further safety factor is inherent in Tables 8 & 9 as used for test purposes. While the calculations are for the different types of fixtures separately, the tests loads comprise simultaneous discharge of the indicated numbers of each, a condition that would be extremely unlikely.

Griffiths wrote in 1959[4] "After the last war local authorities with large building programs, including multi-story flats in preparation, became interested in the possibility of simplifying the drainage pipework of dwellings. Consequently, in 1949, an investigation of the design of drainage systems was started at this Station. There was evidence that, in certain circumstances the vent piping normally provided to protect trap seals was unnecessary. A one-pipe system, with the vent piping omitted, was installed by St. Marylebone Borough Council in 1934 and was still working satisfactorily in 1948; thus the reduction of vent pipe work by appropriate design seemed a possible means of reducing cost of drainage systems."

Table 8 . Numbers of fixtures to be discharged together to allow for morning peak.

Number installed n.	W.C.		Basin p 0·0067	Sink p = 0·0167
	2 gal., p = 0·0044	3 gal., p = 0·0061		
1– 8	1	1	1	1
9–20	1	1	1	2

Table 9 . Numbers of fixtures to be discharged together to allow for possible bath night peak.

Number installed n.	W.C. p = 0·0044 or 0·0061	Bath p = 0·042
1– 4	1	1
5–11	1	2
12–20	1	3

Early investigations had shown three causes of system malfunctions--self siphonage, induced siphonage, and back pressure. Insofar as the question of single-stack drainage is concerned, induced siphonage and back pressure are the significant matters in design, as self-siphonage protection requires no measures beyond those required in conventional systems with secondary ventilation. Falling water draws air down the stack by frictional drag, causing negative pressure in the upper part of the stack and positive pressure near the foot. Tests showed that the magnitude of these pressures depended on stack height and velocity. Velocity in a given stack depends primarily on the rate at which water is discharged.

Practical trials were made in several buildings with 4-in. single-stack systems five stories high designed according to the 1954 recommendations of Wise and Croft. The pneumatic and hydraulic performance of these were reported satisfactory. Thus, by 1959 single-stack systems of this type without secondary ventilation had become widely used, "resulting in a saving of from a third to a half the cost of traditional systems", according to Griffiths.

For buildings of over five-story height, Griffiths recommended partial venting of 4-in. stacks, or the use of larger stacks without secondary ventilation. However, he pointed out that satisfactory performance of 5-in. single-stack systems up to 15 stories high had been

reported in Hamburg[5], and that tests by BRS on 6-in. single-stack systems in flats up to 10 stories high had shown a "high safety factor against excessive seal losses by siphonage".

Regarding detergent foam at lower floors of blocks of flats, Griffiths stated that this was not normally a problem with correctly designed single-stack systems, because ground-floor fixtures were usually connected separately to the building drain as a precaution against foaming near the foot of the stack.

The background and status of single-stack sanitary drainage in Britain was summarized in 1966 by Wise and Payne[6]. Quoting from these authors, "Satisfactory results have been obtained with 4-in. stacks used up to 10 stories, 5-in. up to 15 stories, and 6-in. up to 25 stories, without individual trap venting". The single-stack system was said to have been incorporated in the British Standards Institution Publication CP304, "Soil and Waste Pipes above Ground", issued in 1953 and now in process of revision to include appropriate extension of load limits for single-stack drainage systems. Subsequent inquiry directed to the British Standards Institution has indicated the revised CP304 will probably be issued in 1968.

Discharges with newspaper cause greater pressure fluctuations than water alone, a finding that was taken into account in establishing the original limits for the single-stack system in flats in 1954. The Code of Practice Committee in revising CP304 considered the available

evidence and decided to omit from the proposed revision of CP304 the test with newspaper as being unnecessarily severe. This permits some extension of the limits originally specified for single-stack drainage. The authors[6] gave the following recommendations as to the limits of British single-stack drainage, based on the latest information:

Low-Rise Housing

4-in. stacks may be up to 5-stories in height, with up to 10 bathrooms (5 pairs, back-to-back). 3 1/2-in. stacks are satisfactory for 1- and 2- story houses, and for single-family town houses of three stories.

High-Rise Housing

Studies between 1954 and 1963 permitted raising the limit for 5-in. stacks to 10 stories with up to 20 bathrooms (10 pairs), or 12 stories with one bathroom on each floor. These studies had also confirmed satisfactory experience with 6-in. stacks in buildings up to 16 stories high with one or two groups of fixtures on each floor, and there were indications that 6-in. stacks without secondary ventilation might be used satisfactorily in higher buildings. After 1963 further studies yielded results supporting an extension of the 1963 limits. Experimental data were obtained through the collaboration of local authorities who gave permission for the installation of several experimental systems designed to suit research requirements. Data were obtained from representative

installations of 4-, 5-, and 6-in. stacks in different heights of buildings. British Standard cast iron pipe and fittings were used throughout. The measurements obtained were said to have shown satisfactory performance of the single-stack systems up to the following limits:

<u>4-in. stacks</u>

10 floors with one group of fixtures on each floor--washdown W.C., bath, basin, and sink;

<u>5-in. stacks</u>

12 floors with two bathrooms but no sinks on each floor; or 15 floors with one group of fixtures on each floor;

<u>6-in. stacks</u>

25 floors with two bathrooms on each floor.

The experimentation in tall buildings consisted primarily of seal loss observations with manual loadings. The loads used in the test included discharges calculated to cover the morning peak condition and also some discharges with two baths emptying simultaneously, a load that was considered unlikely to occur or be exceeded in practice. The water closets were discharged without newspaper for reasons previously discussed by these authors. Preliminary experimentation had shown that the water closets were subjected to the greatest seal losses for a given loading because of the particular characteristics of the water

closet trap which tends to lose more seal for a given, static suction than an ordinary p-trap. For each test the recorded seal loss was the maximum found in at least 3 successive discharge tests.

The seal losses produced by different discharges in a 4-in. stack in an 11-story block of maisonettes are given in Table 10. A maisonette is a two-floor living unit, with the kitchen on one floor and the bathroom on the other. The stacks served two maisonettes at each level, (two wash-down W.C.'s, two basins, and two baths on the second, fourth, sixth, eighth, and tenth floors, and two sinks on the first, third, fifth, seventh, and ninth floors). Fixtures on the ground-floor were connected directly to the building drain.

Table 11 gives examples of results obtained for a 4-in. stack serving a 10-story block of flats with one group of fixtures (wash-down W.C., bath, sink, and basin) on each floor. The loss of 1.2 in. is slightly greater than the recommended limit of 1.0 in. but this load is greater than the calculated probable maximum. To supplement these findings, recordings of pressure within the stack during use of the building by people were also obtained. These measurements were said to have shown the actual pressures to be well within the range of ±1 1/2 in. of water gauge that the authors recommended.

Table 10. Results of manual trap-seal loss tests on a 4-in. stack without secondary ventilation in an 11-story block of maisonettes.

Discharge	Maximum
8th floor w.c., basin, 7th floor 2 sinks ...	0.4
10th floor w.c., 8th floor w.c.	0.7
10th floor 2 basins, 8th floor 2 basins ...	0.2
6th floor w.c., bath, 4th floor bath ...	1.0
4th floor bath, 2nd floor bath	0.6

Table 11. Results of manual trap-seal loss tests on a 4-in. stack without secondary ventilation in a 10-story block of flats.

Discharge	Maximum seal loss (in.)
9th floor w.c., basin	0.3
6th floor w.c., basin	0.3
9th floor w.c., basin and 8th floor w.c., basin	1.2

Table 12. Results of manual trap-seal loss tests on a 5-in. stack without secondary ventilation in a building 15-storys high.

Discharge	Maximum seal loss (in.)
14th floor, w.c., basin, sink, 13th floor, sink	1.1
14th floor, w.c. basin, sink, 11th floor, sink	0.8
14th floor, w.c., bath, 10th floor, bath ...	1.0

NOTE.—w.c.'s with 3 gallon flush.

Results of tests on a 5-in. stack serving one group of fixtures per floor on each of fifteen stories are given in Table 12. In Table 13 are shown results for another 5-in. stack which were obtained in a 12-story block of flats, with the stack serving two bathrooms but no sinks on each floor.

Discharge tests were carried out on a 6-in. single-stack system in a 20-story block of flats, the stack serving two wash-down W.C.'s two basins, and two baths on each floor, except the ground floor. The results are given in Table 14. Data were also obtained from a 25-story block of flats with six-in. stacks serving two groups of fixtures on each floor, each group consisting of a wash-down W.C., bath, and basin. These data are shown in Table 15.

Regarding self-siphonage of individual fixtures, it was concluded that this is not important with baths and sinks because any loss of seal caused by suction at the end of a discharge is normally replaced by the water that trickles from the fixture for a time. The authors noted that with water closets the branch does not run full and hence they recognized no need for a limit to its length as far as self-siphonage is concerned. They recognized that self-siphonage is important in connection with wash basins, and recommended certain measures for reducing the self-siphonage of traps used with this type of fixture.

Table 13. Results of manual trap-seal loss tests on a 5-in. stack without secondary ventilation in a 12-story block of flats.

Discharge	*Maximum seal loss (in.)*
2 w.c.'s on 11th floor	0.3
2 w.c.'s and 2 basins on 11th floor ...	0.4
w.c. and bath on 11th floor and bath on 10th floor	0.5
w.c. and bath on 11th floor and w.c. and bath on 10th floor	0.6

Table 14. Results of manual trap-seal loss tests on a 6-in. stack without secondary ventilation in a 20-story block of flats.

Discharge	*Maximum seal loss (in.)*
19th floor, w.c., 2 basins	0.4
19th floor, w.c., basin, 18th floor, w.c., basin	0.4
19th floor, w.c., bath, 18th floor, w.c., bath	0.5
19th floor, 2 w.c.'s, 2 baths	0.6
14th floor, 2 w.c.'s, 2 baths	0.6
9th floor, 2 w.c.'s, 2 baths	0.6

Table 15. Results of manual trap-seal loss tests on a 6-in. stack without secondary ventilation in a 25-story block of flats.

Discharge	*Maximum seal loss (in.)*
24th floor, 2 w.c.'s	0.4
24th floor, 2 w.c.'s, and 2 l.b.	0.7
24th floor, w.c. and 23rd floor, w.c. ...	0.3
24th floor, 2 w.c.'s and 23rd floor w.c. ...	0.3
24th floor, 2 w.c.'s and bath, 23rd floor w.c.	0.5

Table 16. Summary of loadings and heights of stacks found satisfactory without secondary ventilation.

4 *in. stack.*—10 floors with one group of appliances—washdown w.c., bath, basin and sink—on each floor;

5 *in. stack.*—12 floors with two bathrooms but no sinks on each floor; and 15 floors with one group on each floor;

6 *in. stack.*—25 floors with two bathrooms on each floor.

Precautions recommended were of three classes: (1) limitation of length and slope of branch, (2) enlarging and shaping the waste-pipe elements so that full-bore flow does not occur and (3) the use of special re-sealing traps.

Regarding the calculation of loads to be used for test purposes, "morning" and "evening" peaks were recommended in the 1954 paper[2], the calculated evening peak load being greater than the morning peak for large blocks of flats. Subsequently, experience and field measurements were obtained that showed little evidence of a significant, well-defined "evening peak", but clearly confirmed the "morning peak", and showed that the morning peaks were actually greater than the evening loads. Hence, it was recommended that the requirement for testing against the calculated evening peak be omitted, as well as the newspaper test. The requirement that the system perform with calculated morning peak load was retained.

Based on considerations reported by Wise in 1957[7] and on later experience, recommendations were made for design to limit pneumatic pressure fluctuations to 1.5 in. of water gauge, which they considered would yield up to about 1 in. of seal loss from a W.C. and somewhat less from the traps normally used with waste fixtures. Table 16 gives a brief summary of load limits for single-stack systems as recommended by Wise and Payne in 1966[6].

The authors stated that experience now exists supporting the use of single-stack sanitary drainage systems for carrying a certain amount of rain water load from the roofs of buildings, and a guide for calculating the hydraulic load contributed by rain water was given. It was recommended that the rain water roof drain be trapped before connecting to the sanitary drainage stack.

It was recognized that trouble has occasionally been experienced with suction due to wind removing water from traps. The authors stated that such action is not avoided by normal trap venting, but may be reduced if necessary by using a protective cowl at the top of the stack. They noted that research on wind pressures around buildings had shown the greatest suctions occur near the corners of roofs and edges of parapets; hence the installation of stacks in such positions on tops of buildings should be avoided.

In 1957 Wise had published a book entitled Drainage Pipe Work in Dwellings[7]. This book summarized in some detail the state of knowledge regarding single-stack drainage, among other things. A considerable amount of detailed experimental measurement data was shown and certain conclusions and recommendations were developed from this information. These recommendations, as they relate to single-stack drainage, are essentially identical to those appearing in Griffith's 1959 paper[4].

Writing in the April, 1967 issue of Air Conditioning Heating and Ventilation [8], Wise said, "The single-stack system, originally recommended in 1954 for buildings up to 5 stories high, is based on close grouping of fixtures around a single vertical stack, with branches connected to the stack by fittings that are covered by British Standards, a method that avoids the need for expensive vent piping". He stated that the cost of this type of system is about half that of conventional fully-vented systems.

In this paper, Wise commented on carriage of solid materials. Discharges with newspaper, for example, had caused greater pressure variation than water alone, a finding that was taken into account in determining the original limits for the single-stack system in apartments. However, the British Code of Practice Committee, in revising CP304[9], had recently reviewed test methods for drainage systems and decided that tests with newspaper were unnecessarily severe. This has resulted in some extension of the limits originally specified for single-stack drainage. Wise discussed the problem of selection of actual combinations of discharges likely to occur in practice, and referred to several British papers in which probability theory had been applied to plumbing systems. He referred to ongoing research conducted under the auspices of the Building Research Station in which the patterns of water use in a 17-story apartment house in London were being measured and the data

being studied. He indicated that in due course the findings would be applied to the existing data on performance of single-stack systems with predetermined, manual test loads. He also confirmed previous statements that it is reasonable to limit pneumatic pressure variations in the drainage system to about ±1 1/2 in. water gauge, referenced to atmospheric pressure. He considered from his data that such a tolerance would limit the maximum seal loss to about 1 in. from the water closet trap and somewhat less from normal waste traps.

In the 1967 paper[8] as well as in other papers from Britain on this subject, certain specific sketches and recommendations were offered of a practical nature regarding pipe arrangements and fittings that would yield acceptable performance. The 1967 paper reaffirmed the recommendations on loading limits for single-stack sanitary drainage systems as previously given in the 1966 paper[6].

In March, 1967 the BRS issued digest No. 80 on soil- and waste-pipe systems for housing[10]. This bulletin summarizes the principal recommendations as developed in 1966 by Wise and Payne[6] and presented particularly a graph for determination of minimum slopes and maximum lengths of unvented fixture drains, a table summarizing the minimum pipe sizes required for various loading conditions as affected by type of multi-story house and its height, and a diagram giving the main features and precautions to be considered in the design of single-stack systems to

achieve satisfactory performance. Finally, a table was given which summarized the principal items to be considered in the design of various horizontal-drain elements of the system and the fittings with which they are to be connected to other parts of the system. Also some simple recommendations were given to guard against the dangers of back pressure and detergent foam at the lower elevations in a drainage system. It was recommended that the turn at the foot of the stack be comprised of long-radius fittings complying with designated British Standards. Two 45° bends in series were recommended in preference to one 90° bend because of the greater effective radius thereby obtained for the turn at the foot of the stack. Further recommendations to reduce detergent effects near the bottom of the stack included suggestions to connect ground-floor fixtures directly to the building drain, or to use a bend at the base of the stack one size larger than the stack itself.

Digest 80 again reaffirmed the importance of the sweep in the water-closet branch connection fittings. It was stated that the shape of the water-closet branch connection to the stack is important because it influences the amount of induced siphonage acting upon branches to other fixtures lower in stack. It was stated that if straight-inlet water closet branches were used, more venting or larger diameter stacks than those recommended may be necessary. Finally recommendations were made as to limitations on the positioning of bath-waste connections to the stack in relation to the elevation of the water closet branch

connection. To avoid the back flow of water closet discharges into bath waste pipes, it was recommended that the bath waste pipes be connected either above the intersection of the center lines of the water closet branch and the stack, or at an elevation more than 8 in. below that point in the stack.

Recent inquiry of British sources has resulted in clarification of some of the above recommendations. The following are offered:

1. Ground-floor appliances connected directly to the building drain need not be vented, according to British experience.
2. British experience with connecting appliances to the stack as close as 3 ft. from the building drain has proven satisfactory in buildings of 5 stories and less. Presumably, practice in taller buildings is to avoid connections to the stack in the lowest branch interval in favor of direct connection to the building drain.
3. While British practice frequently provides a "man hole" in the building drain for access purposes, British experts do not consider that this provides useful ventilation in the vicinity of the foot of the stack; hence pneumatic performance of the system should not be substantially affected by elimination of the man hole.

4. In British practice, the recommended rules for connection of fixtures in the lowest branch interval have avoided detergent foam difficulties.

5. From dimensional considerations, it seems possible to mix British Standard cast-iron soil pipe fittings and American cast iron soil pipe. In initial trials or laboratory tests in America it might be instructive to use some British junction fittings in order to check their potentially superior pneumatic performance due to geometry of the branch inlets.

Figures 2 and 3, and Tables 17 and 18, based on information provided by the Building Research Station[10], summarize the principal current recommendations of BRS relating to design and installation of single stack drainage in Britain. Earlier recommendations and several representative piping diagrams for single stack drainage systems were given in a 1962 publication of the Ministry of Housing and Local Government[11]. Figure 4 shows one of these plans, for a single stack system in a 20 story apartment building.

3. Summary of Swiss Data and Recommendations--Sovent Single-Stack System

A number of detailed laboratory reports were reviewed, describing tests of the Sovent system of single-stack drainage in laboratory and field installations[1/], conducted under the direction of Dr. Fritz Sommer of the Trade School in Bern, Switzerland.[12,13] The laboratory tests of

[1/]For information from this source, contact Dr. Fritz Sommer, Vorsteher, der Spengler - und Sanitarinstallateurabteilung Lehrwerkstatten der Stadt Bern, Lorrainestrasse 3, Bern, Switzerland.

Table 17. Design of single branches and fittings[1]

Component	Action to be guarded against	Design recommendations
Lavatory basin waste	Self-siphonage	3 in. seal P-traps to be used. The maximum slope of a $1\frac{1}{4}$ in. waste pipe to be determined from Fig.2 according to the length of the waste pipe. Any bends to be not less than 3 in. radius to centre-line. Waste pipes longer than the recommended maximum length of 5 ft 6 in. should be vented, or a larger diameter waste pipe or approved resealing trap should be used.
Bath and sink wastes $1\frac{1}{2}$ in. trap and $1\frac{1}{2}$ in. waste pipe	Self-siphonage	3 in. seal traps to be used. Self-siphonage not important. Length and slope of waste branch not critical, but long waste pipes may be troubled by sedimentation and access for cleaning should be provided.
	Backing up of discharge from W.C. branch into bath branch	Position of entry of bath waste into stack to be as in Fig. 3. The bath waste pipe may be connected to the stack so that its centre-line meets the centre-line of the stack at or above the point where the centre-line of the W.C. branch meets the centre-line of the stack, or at least 8 in. below it.
Soil branch connection to stack	Induced siphonage lower in the stack when W.C. is discharged	W.C. connections should be swept in the direction of flow. Fittings should have a minimum sweep of at least 2 in. radius[2]. W.C. branches up to 20 ft long have been used successfully.
Bend at foot of stack (Fig. 3)	Back pressure at lowest branch. Build-up of detergent foam	Bend to be of large radius (Fig. 4 of B.S. 65: 1952, or equivalent) or two 135° bends to be used. Vertical distance between lowest branch connection and invert of drain to be at least 2 ft 6 in. (1ft 6 in. for 3-storey houses with 4 in. stack.)
Offsets in stack	Back pressure above offset	There should be no offsets in stacks below the topmost appliances unless venting is provided to relieve any back pressure. Offsets above the topmost appliances are of no significance.

1/From BRS Digest 80 [9].

2/If straight-inlet W.C. branches are used, more venting or a larger-diameter stack may be necessary.

Table 18. Maximum Loads[1/] for British Single-Stack Sanitary Drainage Systems for Multi-Story Housing (Apartments or Flats)

Stack diameter	Allowable Number of Branch Intervals	
	With one fixture group[2/] on each floor	With two fixture groups[2/] on each floor
in.		
4	up to 10	up to 5
5	up to 15	up to 12
6	up to 25	up to 25

[1/] Derived from 1967 recommendations of the Building Research Station, applicable to British conditions [9].

[2/] One "fixture group" comprises one each lavoratory, water closet, bathtub, and kitchen sink. Where dwellings contain more fixtures, it may be necessary to provide more venting or reduce the allowable load.

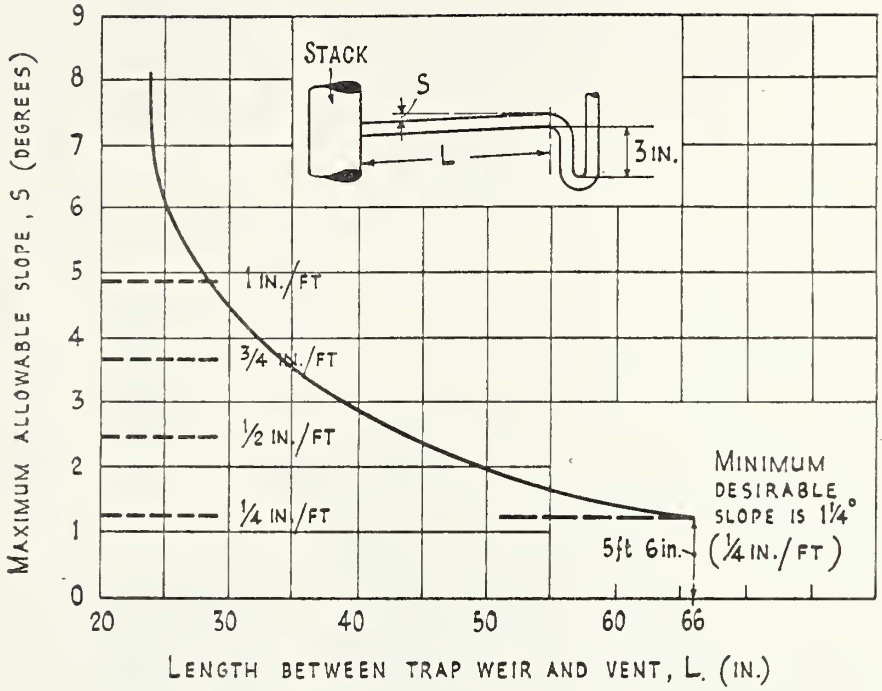
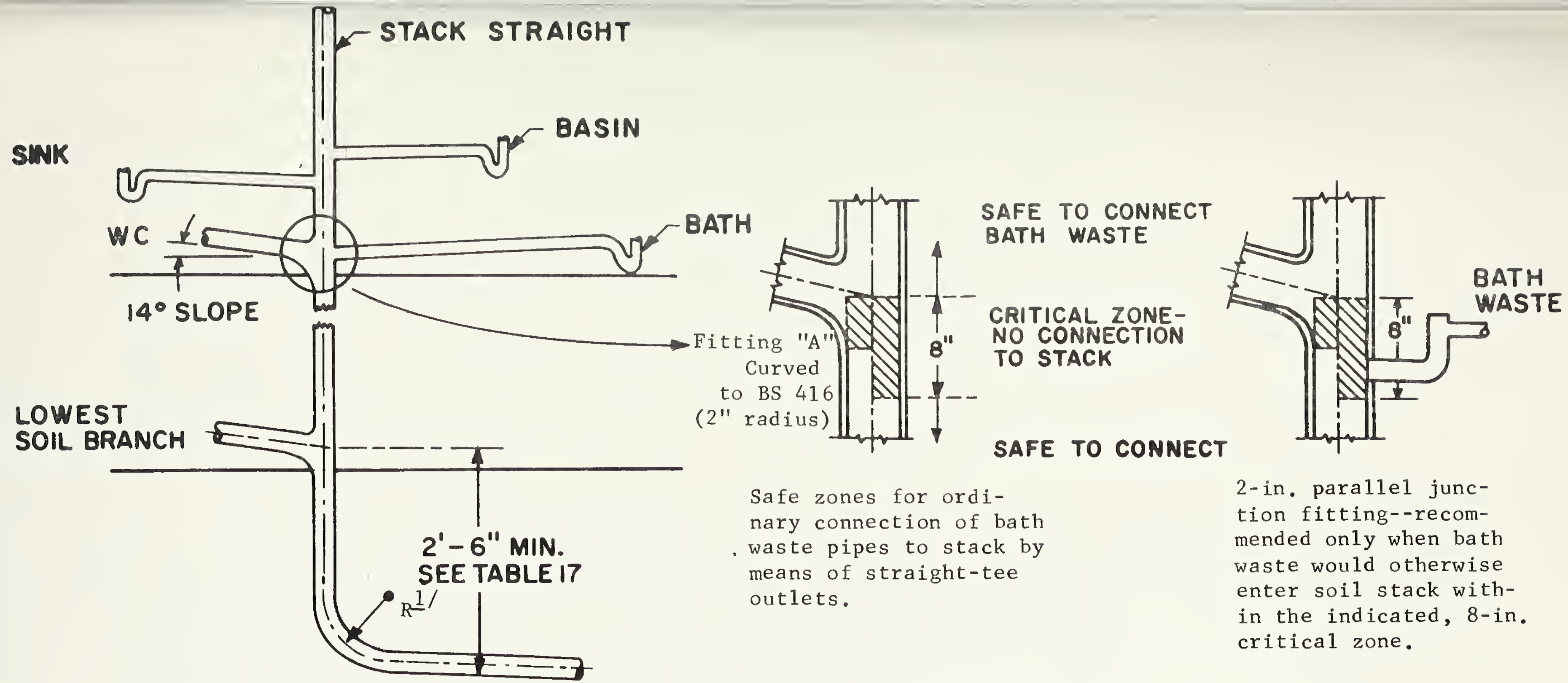


Figure 2 Maximum lengths and slopes of unvented 1 1/4-in. lavatory drain using tee inlet to stack and 3-in. deep-seal P trap--recommendations by the British Building Research Station, 1967.



1/Use single large-radius 1/4 bend, or preferably two large-radius 1/8 bends in series

Figure 3. Main features of British single-stack, sanitary drainage system design--recommendations of the Building Research Station and the Ministry of Housing and Local Government.

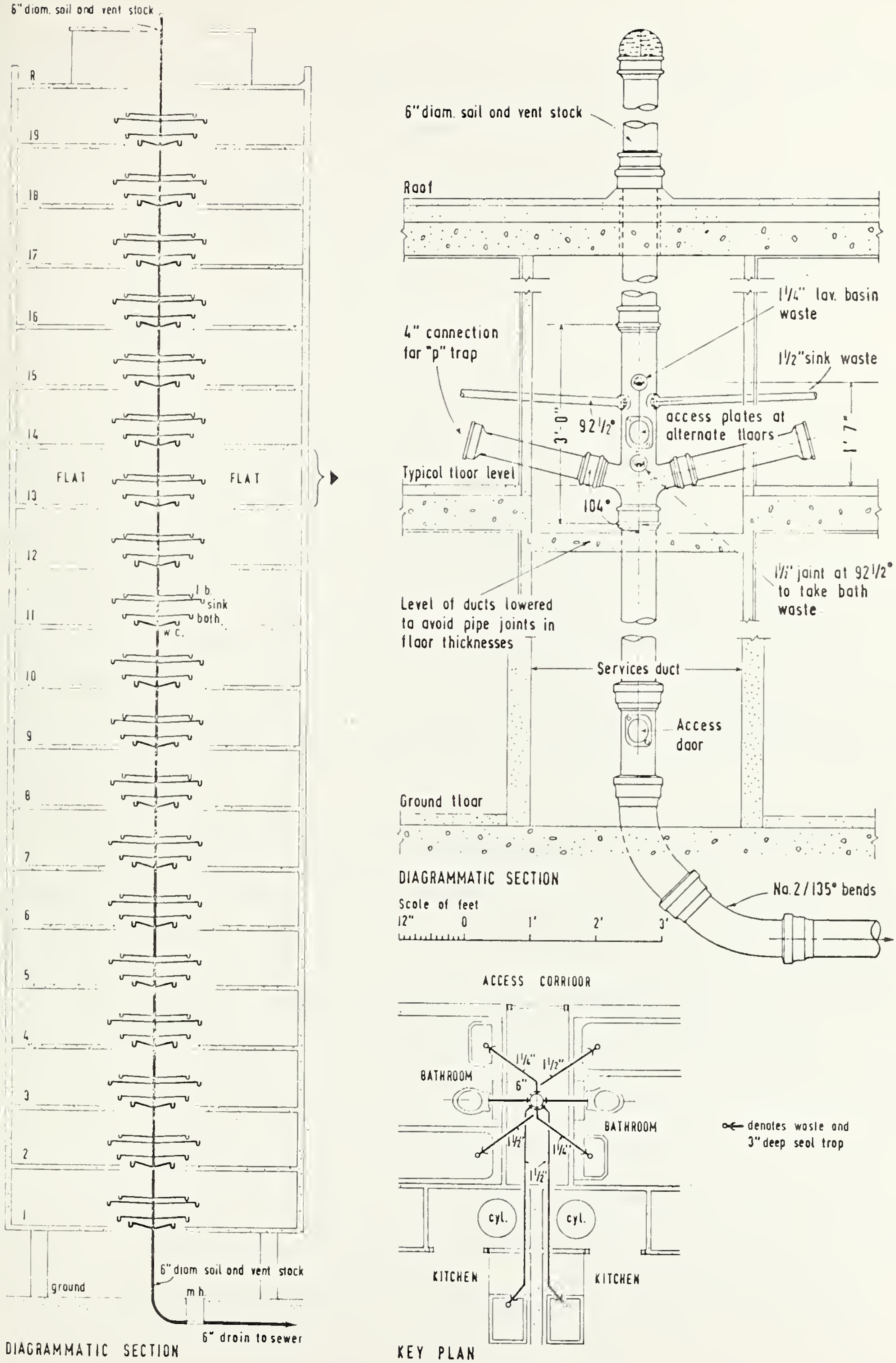


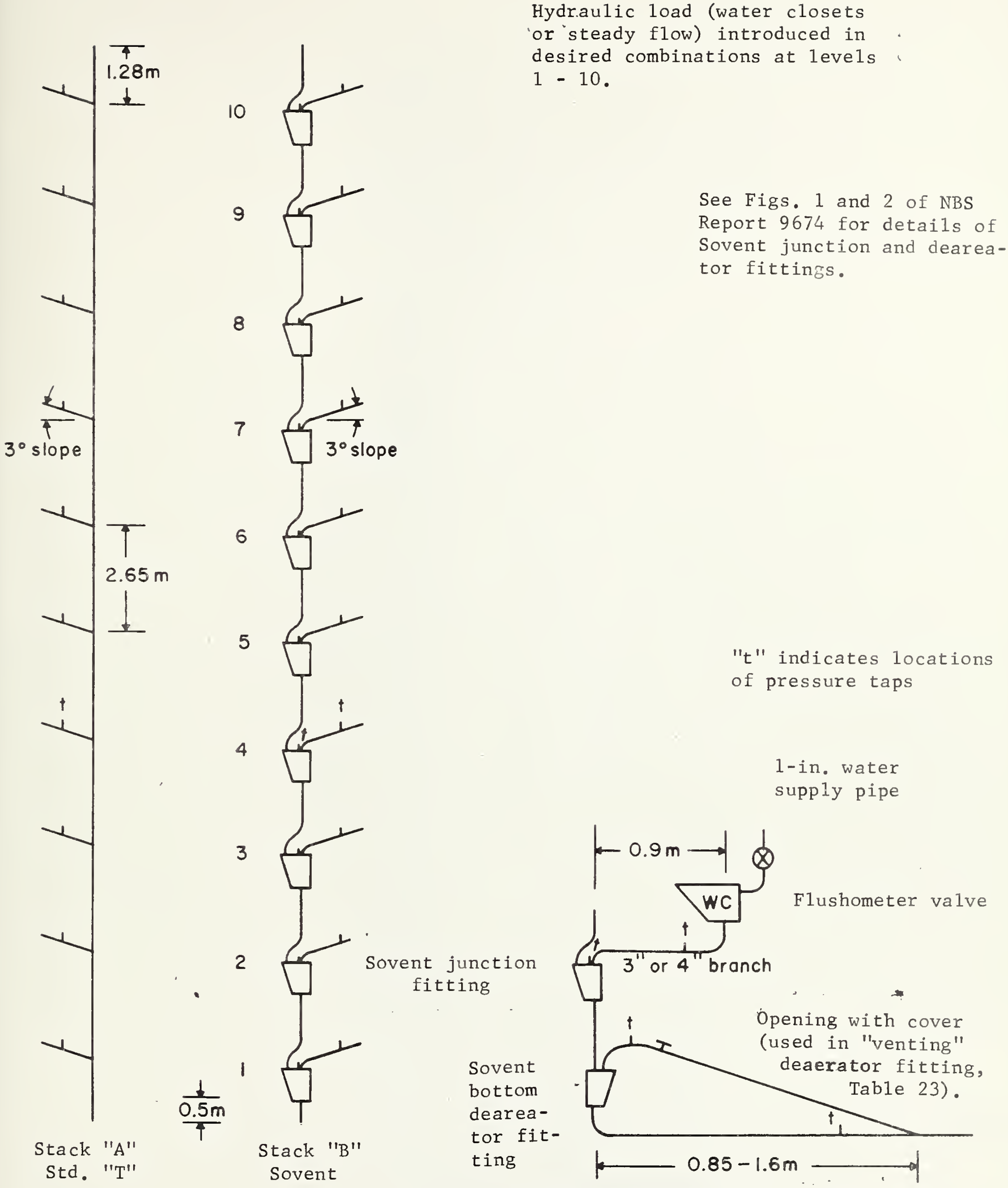
Figure 4 A plan for single stack drainage in 20-story apartment building--recommendations by the British Ministry of Housing and Local Government, 1962. Illustrates back-to-back grouping, 6-in. stack.

performance of the Sovent system involved flushing of water closets on 10-story systems, and the measurement of the amplitude of fluctuations in the air pressure in the horizontal branches or in the junction fittings. In some tests, the volume of air drawn down the stack and its maximum rate of inflow were measured. In other tests, continuous records of the branch pressures were obtained from which mean speeds of water falling in the stack were inferred. Both steady flow and fixture-discharge loadings were employed, and some experimentation with additives such as toilet paper, paper diapers, and detergents was carried out. Figure 5 shows some of the test arrangements utilized.

In field tests, several buildings were instrumented for pneumatic pressure measurements, and manual flushing tests carried out before the buildings were occupied. In a few instances, the measurements were carried out in occupied buildings over a period of months, utilizing natural loadings.

Table 19 compares pneumatic performance of a 4-in. Sovent stack and an identical stack utilizing standard T fittings, as determined on the 10-story test system with clean water loadings. Table 20 gives data from a similar pair of stacks comparing the effects produced by loads involving the discharge of clean water with and without diaper paper.

Subscripts used with the fixture-load designations in Tables 19-26 ($WC_{7,8}$ for example) indicate the numbers of the floors on which the designated fixtures were located. The subscripts used with the velocity values in columns 8 and 9 of Table 19 indicate the floor numbers at the ends of the vertical reach over which the velocities were determined.



Stacks open at bottom, 4-in. branches, tank-type WC's for data in Tables 19 - 20.

Test arrangement used in Sovent stack for data in Tables 23 - 26.

Figure 5. Examples of test apparatus utilized in laboratory studies of Sovent system.

Table 19. Summary of Tests Comparing Performance of Sovent System with Similar System Using Standard

Tee Branch Fittings--Clean Water Loads, European Washdown--Type W.C.'s, 4-in. Branches

Test Load			Equivalent Service Load				Water Velocity				Air Demand[8]					Maximum Pressure Excursions[8]							
Type	No. of Intervals Loaded	Rate	From Table 29		From Fig. 9[2]	From Table 29 and A40.8[3]	Inferred from Data[4]		Computed from Theory[5]	Free-fall Value[6]	Volume Measured		Rate: Maximum Value Measured		Rate: Computed by Theory [5]	Negative				Positive			
			p = 0.01[1]	p = 0.03			Stk. A[9]	Stk. B[9]			Stk. A[9]	Stk. B[9]	Stk. A[9]	Stk. B[9]		Stack A[9]		Stack B[9]		Stack A[9]		Stack B[9]	
		lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	m/s	m/s	m/s	m/s	l	l	l/m	l/m	l/m	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor
Steady Flow	1	100/26.4			10				2.54				2100	1140	1650	24	4	2	2			2	5
	1	200/52.8			55				3.05				3200	1320	1880	55[7]	8	8	8			4	5,6,7
	1	300/79.3			145				3.87				3200	1400	2300	138	7	18	3,4			6	9
WC_{10}	1	120/31.7	15	5	17	60	$5,7_{9-3}$	2.5-3.0	2.73	14.2	350	230	1970	980	1760	11	8	1	10	4	8	3	8
$WC_{8,10}$	2	240/63.4	44	15	85	176	9.2_{6-2}	3.5_{5-2}	3.60	16.1	480	300	2620	1390	2190	30	5	5	8	3	7	4	7
$WC_{6,8,10}$	3	360/95.1	83	29	220	332	8.8_{5-2}	3.6_{5-2}	4.24	15.3	500	400	3030	1720	2460	47	5	14	3			4	5
$WC_{7,7}$	2	240/63.4	44	15	85	176	5.1_{5-2}	3.0_{5-2}	3.60	13.5	---	300		1380	2190	34	5	10	7			4	6

[1] A value of p = 0.0061 was determined for 3-gal., tank-type, washdown W.C.'s in an English survey of frequency of use in housing

[2] These values based on assumption of use frequencies greater than observed in English surveys.

[3] Computed by multiplying equivalent No. W.C.'s determined from Table 29 for p = 0.01, by the fixture-unit-value of 4 given for a tank-supplied W.C. in A40.8-1955.

[4] Based on inspection of strip-chart recordings of pneumatic pressures in horizontal branches, assuming onset of vacuum occurs at same instant that water in the stack begins to pass the branch.

[5] Based on method derived from NBS Monograph 31.

[6] Computed for free-fall speed in a vacuum, based on vertical distance between mid-point of hydraulic load and mid-point of reach over which measurements were taken.

[7] Pneumatic pressures differing from atmospheric by more than 25 mm w.g. are underlined.

[8] To obtain gpm, multiply l/m by 0.264. To obtain ft/s, multiply m/s by 3.28. To obtain in., multiply mm by 0.0394.

[9] Stack "A" was a 10-story, 4-in. stack utilizing "standard T" fittings. Stack "B" was identical, except that Sovent fittings were utilized.

Table 20 Effect of Paper Diapers on Pneumatic Pressures in Two Experimental Stacks,

European Washdown - Type W.C.'s, 4-in. Branches

Test Load			Equivalent Service Load			
Fixtures	No. Intervals Loaded	Rate	From Table 29		From Fig. 9[2]	From Table 29 and A40.8[3]
			p = 0.01[1]	p = 0.03		
		lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units
WC_{10}	1	120/31.7	15	5	17	60
$WC_{8,10}$	2	240/63.4	44	15	85	176

	Maximum Pressure Excursions[8]															
Fixtures	Stack A[5]								Stack B[6]							
	Clean Water				Clean Water + Diaper Ppr[4]				Clean Water				Clean Water + Diaper Ppr.[4]			
	Negative		Positive		Negative		Positive		Negative		Positive		Negative		Positive	
	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor	Value mm	Floor
WC_{10}	11	8	4	8	38[7]	8			1	10	3	8	5	6	5	6,7,8
$WC_{8,10}$	30	5	3	7	62	7			5	8	4	7	10	6	4	5,6

[1]A value of p = 0.0061 was determined for 3-gal. tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

[2]These values based on assumption of use frequencies greater than observed in English surveys.

[3]Computed by multiplying equivalent No. W.C.'s determined from Table 29 for p = 0.01, by the fixture-unit-value of 4 given for a tank-supplied W.C. in A40.8-1955.

[4]One piece commercial diaper paper, 50 cm x 11 cm, folded lightly two times, placed in each WC bowl comprising test load.

[5]10-story, 4-in. stack, with "standard tee" fittings.

[6]10-story, 4-in. stack with Sovent fittings.

[7]Values in excess of 25 mm (1 in.) are underlined.

[8]To obtain in., multiply mm by 0.0394.

Figures 6a and 6b show pressure measurements for steady-flow loads of stated magnitudes in 80 mm (3.15 in.) and 70 mm (2.75 in.) stacks of standard T and Sovent design. This kind of measurement has also been made in 100 mm (nominal 4 in.) stacks, for a wide range of water discharge rates. Naturally, greater carrying capacities were determined for the 100 mm stacks as shown in Figure 7.

Tables 21 and 22 summarize results of manual flushing tests in unoccupied apartment buildings equipped with 4-in. Sovent stacks. Tables 23, 24, and 25 give data on performance of a 4-in. Sovent stack erected in the 10-story test tower, utilizing 3-in. toilet branches, restricted secondary ventilation, and American-type flushometer W.C.'s. Table 26 gives data under approximately the same conditions as Tables 23 and 24, but with 4-in. branches and no secondary ventilation.

Interpretations, by the Swiss, of the tests on and experience with the Sovent system seem to have resulted in some general recommendations by Swiss designers, among which are the following:

1. Stacks should be run straight, without offsets or bends from the highest floor down at least to the lowest level on which fixtures are installed.
2. At the level of the foot of the stack, or at the level where an offset must be installed, a deaerator fitting and associated relief vent is recommended to relieve excess pressure and to reduce the tendency to hydraulic jump in the building drain.

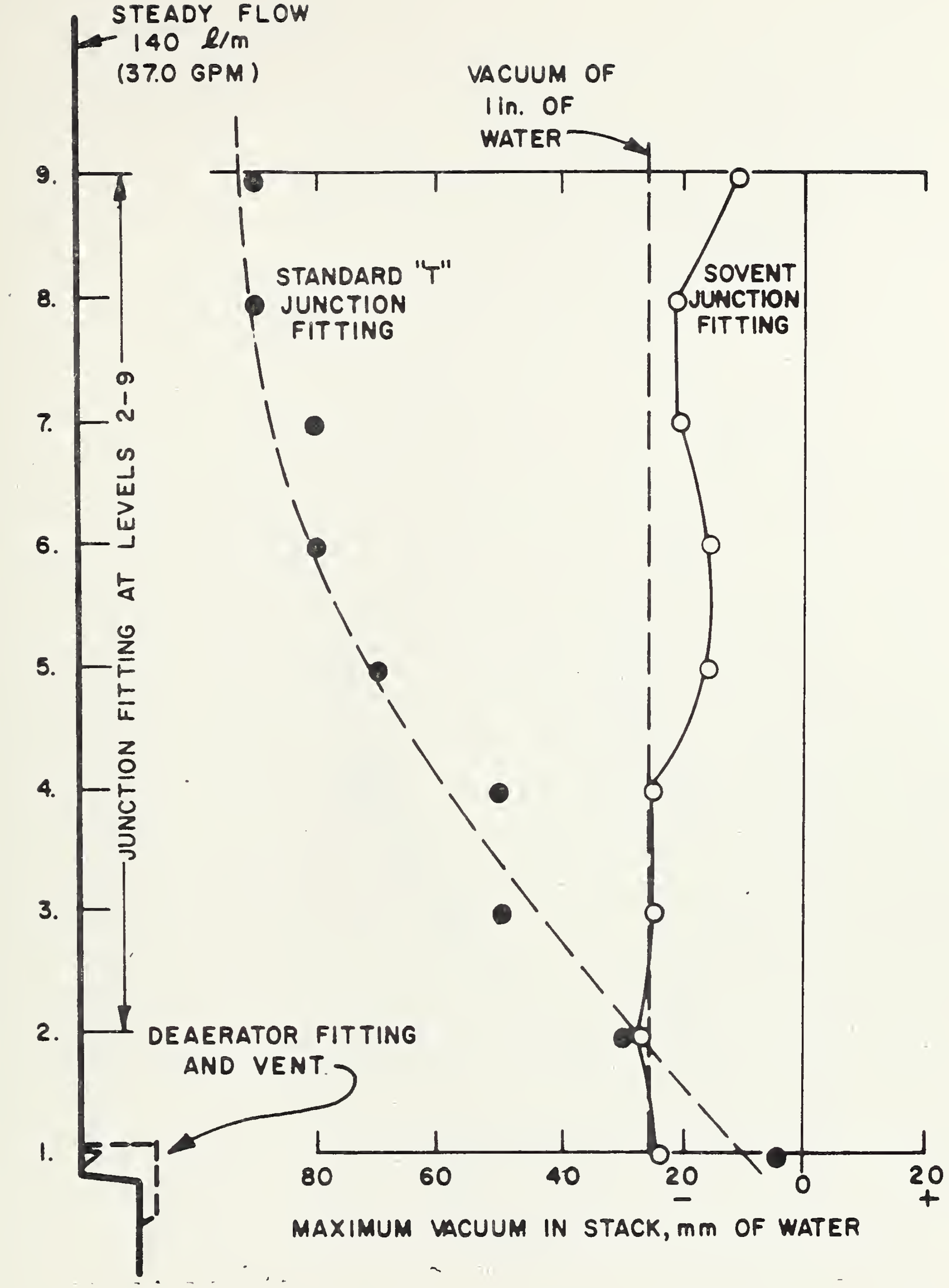


Figure 6a Vacuum in horizontal branches of 70 mm (2.75 in.) PVC plastic drainage stack, with 37.0 gpm continuous-flow water load.

● Stack with "standard T" junction fittings

○ Stack with Sovent junction fittings.

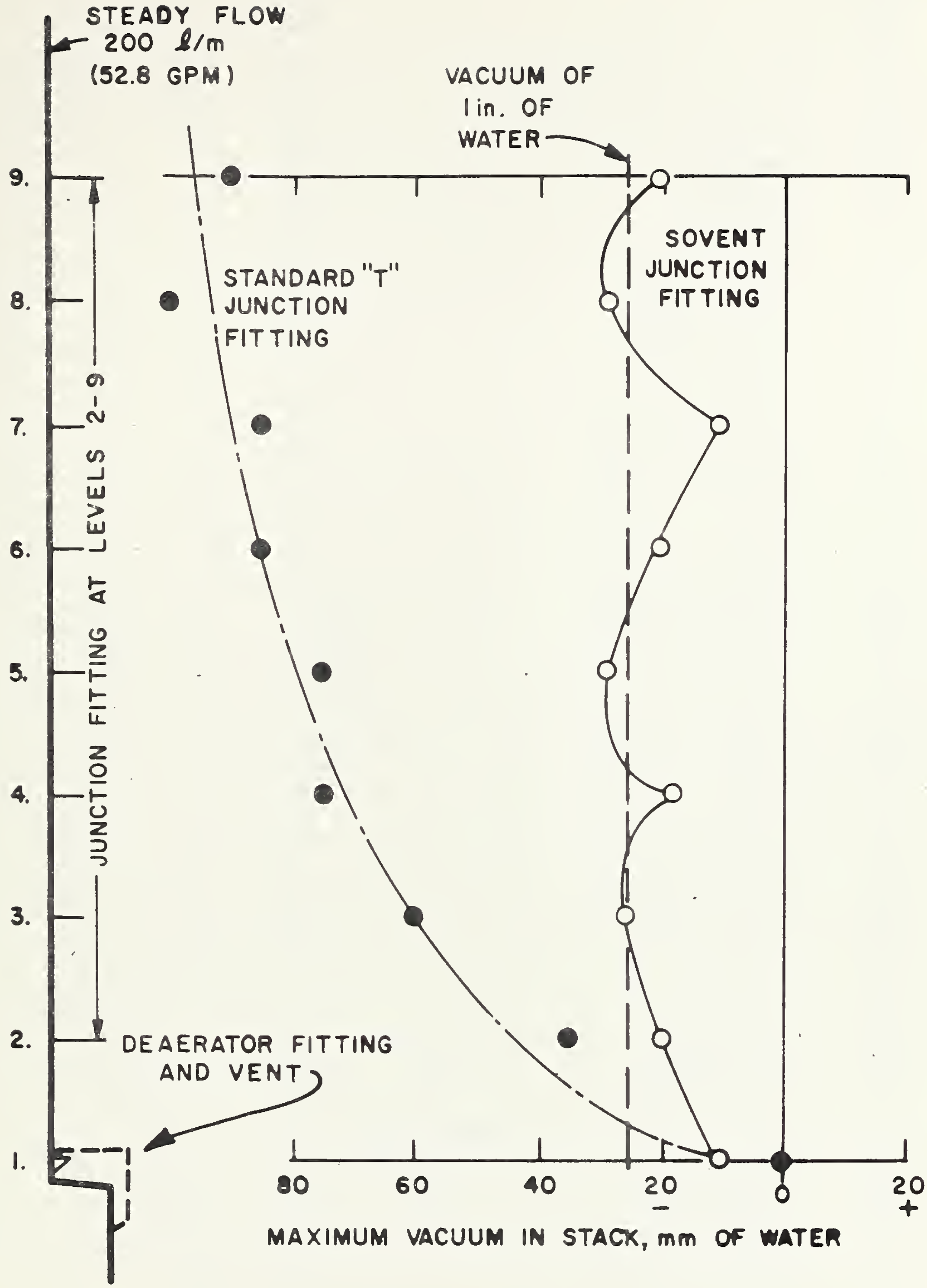
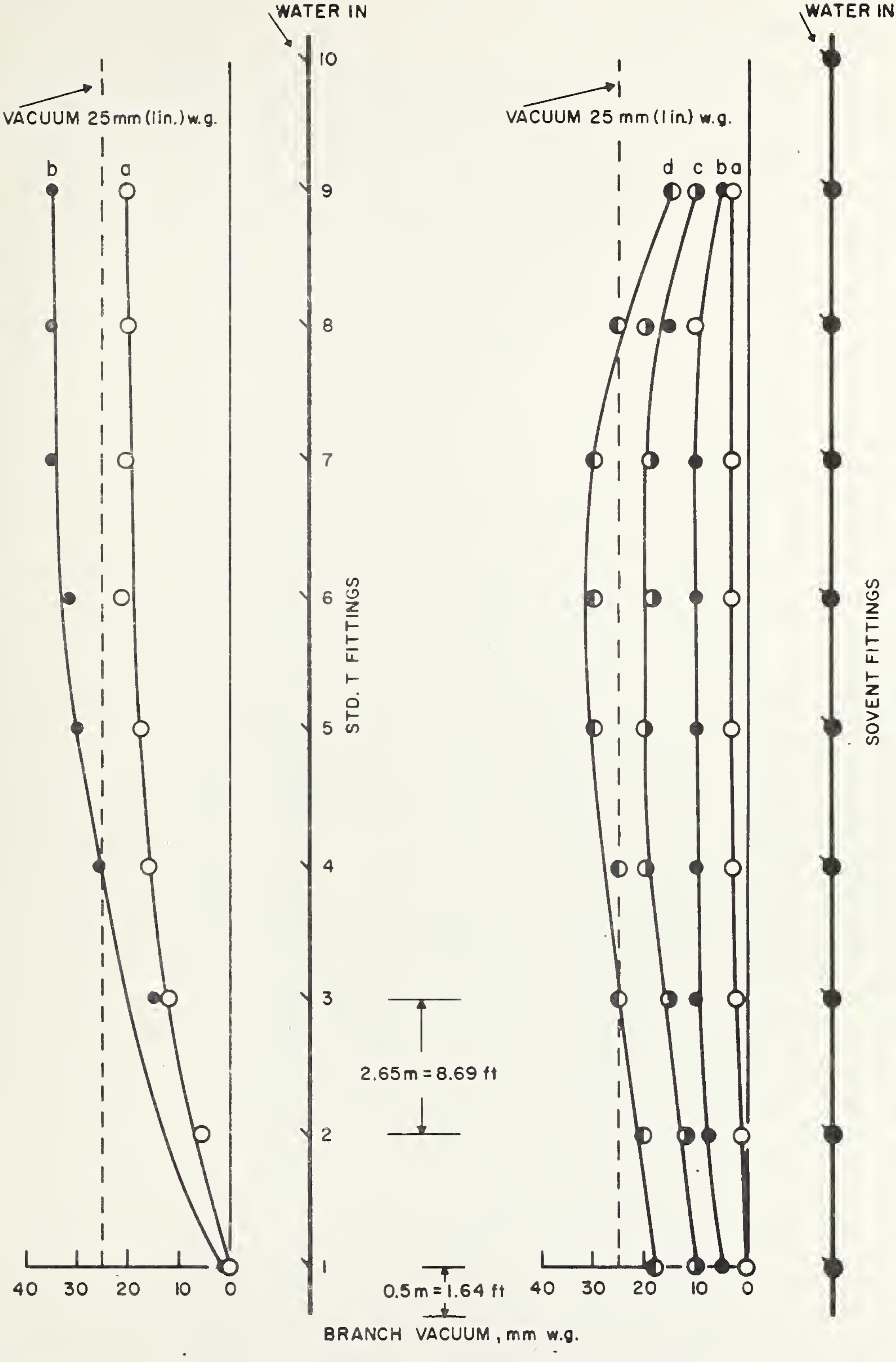


Figure 6b Vacuum in horizontal branches of 80 mm (3.15 in.) PVC plastic drainage stack, with 52.8 gpm continuous-flow water load.

● Stack with "standard T" junction fittings.

○ Stack with Sovent junction fittings.



igure 7. Vacuum in horizontal branches of 100 mm (3.94 in.) drainage stacks, with various rates of continuous-flow water load--Swiss data.

a. 100 lpm = 26.4 gpm
b. 200 lpm = 52.8 gpm
c. 300 lpm = 79.3 gpm
d. 400 lpm = 106 gpm

Table 21 Pneumatic Pressures in Sovent Systems in 13- and 14- Story Apartment Buildings at 101 and 111 Bolligenstrasse, Bern, Switzerland--Manual Flushing Tests, Close-Meter Loads, 4-in. Branches

Street Number	Test Load: Fixtures l[6]	Test Load: Fixtures r[6]	No. of Intervals Loaded l	No. of Intervals Loaded r	Rate[1] l	Rate[1] r	Equivalent Service Load: From Table 29, p = 0.01[2] l	p = 0.01[2] r	p = 0.03 l	p = 0.03 r	From Fig. 9[3] l	From Fig. 9[3] r	From Table 29 and A40.8[4] l	From Table 29 and A40.8[4] r	Maximum Pressure Excursions[5]: Negative l Value	Negative l Floor	Negative r Value	Negative r Floor	Positive l Value	Positive l Floor	Positive r Value	Positive r Floor
					lpm/gpm	lpm/gpm	No. W.C.'s	No. W.C.'s	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	Fixt. Units	Fixt. Units	mm		mm		mm		mm	
101	WC_{8+14}	WC_{7+14}	2	2	240/63.4	240/63.4	44	44	15	15	85	85	176	176	15	14	19	14	8	12	9	8
	WC_{3+8+14}	WC_{3+7+13}	3	3	360/95.1	360/95.1	83	83	29	29	220	220	332	332	14	14	13	4	3	5,9,10,11,12,15	18	3
	$WC_{3+7+11+14}$	$WC_{1+4+7+13}$	4	4	480/127	480/127	129	129	46	44	400	400	314	514	18	8	19	13	7	12	8	8
	$WC_{1+3+8+11+14}$	$WC_{1+4+7+13}$	3	4	660/159	480/127	--	129	--	44	830	400	---	516	18	14	19	13	6	12	9	8
	T_{1+7+13} WC_{3+11}	T_{2} WC_{7+13}	3	3	-------	-------	--	---	--	--	---	---	---	---	9	5,9	17	13	3	5	11	8
	T_{7+13} WC_{3+11}	S_{1+7+13} WC_{4}	4	4	-------	-------	--	---	--	--	---	---	---	---	11	5	9	4,12	6	8	9	1
111	WC_{8+13}	WC_{8+13}	2	2	240/63.4	240/63.4	44	44	15	15	83	83	176	176	16	10	15	10	9	3,6,7,9	9	6,7,9
	WC_{3+8+13}	WC_{3+8+13}	3	3	360/95.1	360/95.1	83	83	29	29	220	220	332	332	17	3,13	18	3,13	11	1	12	1
	$WC_{4+7+10+13}$	$WC_{4+7+10+13}$	4	4	480/127	480/127	129	129	46	46	400	400	316	516	20	4	21	4,10	10	3	10	5
	$WC_{3+5+7+9+11+13}$	$WC_{3+5+7+9+11+13}$	6	6	720/190	720/190	--	---	--	--	850	850	---	---	$\underline{26}$[7]	3	25	3,4	17	1	20	1
	T_{4+9+14} WC_{7+12}	T_{4+9+14} WC_{7+12}	3	3	-------	-------	--	---	--	--	---	---	---	---	20	4	20	4	17	5	16	3
	$T_{3+7+11+14}$ WC_{5+9+13}	$T_{3+7+11+14}$ WC_{5+9+13}	7	7	-------	-------	--	---	--	--	---	---	---	---	22	9	22	9	20	2,3	20	2,3

1/ Assumed values (120 l/min per W.C.) as indicated for "Geberit" fixtures in report on tests at 46 Waldmannstrasse, Bern.

2/ A value of p = 0.0061 was determined for 3-gal., tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

3/ These values based on assumption of use frequencies greater than observed in English surveys.

4/ Computed by multiplying equivalent No. W.C.'s determined from Table 29 for p = 0.01, by the fixture-unit value of 4 given for a tank-supplied W.C. in A40.8--1953.

5/ To obtain in., multiply mm by 0.0394.

6/ These buildings had pairs of stacks, termed left (l) and right (r). The "l" stacks served 13 pairs (26) of bathrooms installed back-to-back. The "r" stacks served 13 floors with back-to-back bathrooms and kitchen sinks.

7/ Pneumatic pressures differing from atmospheric by more than 25 mm (1 in.) e.g. are underlined.

Test Load					Equivalent Service Load				Maximum Pressure Excursions			
Fixtures	No. Intervals Loaded	No. Fixtures Discharged	Additives	Rate	From Table 29		From Fig. 9[3]	From Table 29 and A40.8[4]	Negative		Positive	
					p = 0.01[2]	p = 0.03			Value	Floor	Value	Floor
				lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	mm		mm	
WC_{20L}	1	1	None	140/37.0	15	5	23	60	6	20	6	16
WC_{20L}	1	1	Paper Diaper	140/37.0	15	5	23	60	16	17	24	17
$WC_{20L+20R}$	1	2	None	280/74.0	44	15	125	176	20[5]	18	13	20,18,17
$WC_{20L+17R}$	2	2	None	280/74.0	44	15	125	176	9	20,17	7	11
$WC_{20L+17R}$	2	2	Paper Diaper	280/74.0	44	15	125	176	24	17	15	18
$WC_{20L+17R+14L}$	3	3	None	420/111	83	29	300	332	25	11	10	13
$WC_{20L+17R+14L+11R}$	4	4	None	560/148	129	46	540	516	22	11	12	12
$WC_{20L+14R+8L}$	3	3	None	420/111	83	29	300	332	12	20	9	12
$WC_{20L+14R+8L}$	3	3	Paper Diaper	420/111	83	29	300	332	14	14	10	16,15
$WC_{20L+20R+14L+8R}$	3	4	None	560/148	129	46	540	516	<u>28</u>[5,6]	12	23	12
$WC_{20L+20R+14L+8R}$	3	4	Paper Diaper	560/148	129	46	540	516	22[5]	11	17	18,13
$WC_{20L+20R+14R+8L+3R}$	4	5	None	700/185	---	--	820	---	<u>26</u>[5,6]	18	20	20
$WC_{20L+20R+14R+8L}$	4	5	Paper Diaper	700/185	---	--	820	---	21[5]	17,15	<u>30</u>[5,6]	1
$WC_{20L+20R+14L+14R+8L+8R}$	3	6	None	840/222	---	--	1,100	---	<u>43</u>[5,6]	14	22	20,12

[1] To obtain in., multiply mm by 0.0394.

[2] A value of p = 0.0061 was determined for 3-gal, tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

[3] These values based on assumption of use frequencies greater than observed in English surveys.

[4] Computed by multiplying equivalent No. W.C.'s determined from Table 29 for p = 0.01, by the fixture-unit value of 4 given for a tank-supplied W.C. in A40.8--1955.

[5] Larger values, differing from atmospheric by more than 25 mm (1 in.) W.G., were obtained at the 20th floor, for all loads involving the simultaneous discharge of both the back-to-back W.C.'s on the 20th floor. It was determined that this was the result of poor design of this particular branch system. These values are omitted in the tabulation given here, since the condition could have been avoided by better design of the branch system.

[6] Pneumatic pressure differing from atmospheric by more than 25 mm (1 in.) W.G. are underlined.

Table 23 Performance of Experimental Sovent System with Various Loads,

American Flush-Valve Type W.C.'s, 3-in. Branches, <u>Junction Fittings and Deaerator Fitting Vented</u> 8/

Test Load				Equivalent Service Load				Maximum Pressure Excursions			
Fixtures	No. Intervals Loaded	Additives	Rate	From Table 29		From Fig. 9 6/	From Table 29 and assumption of 4 f.u./WC 7/	Negative		Positive	
				p = 0.01 1/	p = 0.03			Value	Floor	Value	Floor
			lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	mm 5/		mm 5/	
WC_{8+9}	2	Detergent	204/54	44	15	60	176			20	1,2
WC_{3+6+9}	3	Detergent	306/81	83	29	160	332	20	4	15	1,2
								18	4		
$WC_{6+7+8+9}$	4	None	408/108	129	46	300	516	<u>28</u> 4/	3		
								<u>30</u>	3		
		Toilet ppr 2/						<u>30</u>	3		
								15	7,8		
								<u>29</u>	3		
								<u>48</u>	3		
		Detergent						<u>60</u>	3		
$WC_{3+5+7+9}$	4	None	408/108	129	46	300	516	<u>26</u>	3		
$WC_{5+6+7+8+9}$	5	None	510/135	---	--	470	---	<u>52</u>	3		
								<u>40</u>	3		
		Toilet ppr,						<u>48</u>	3		
		Diaper ppr 3/						<u>30</u>	3		
		& Toilet ppr.						22	4,5		
$WC_{4+5+6+7+8+9}$	6	None	612/162	---	--	660	---	<u>68</u>	3		
								<u>68</u>	3		

1/ A value of p = 0.0061 was determined for 3-gal., tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

2/ 10 separate pieces standard toilet paper, single thickness.

3/ One piece commercial diaper paper 50 cm x 11 cm, folded lightly two times, placed in each WC bowl comprising test load.

4/ Pneumatic pressures differing from atmospheric by more than 25 mm (1 in.) w.g. are underlined.

5/ To obtain in., multiply by 0.0394.

6/ These values based on assumption of use frequencies greater than observed in English surveys.

7/ For p = 0.01; A40.8 gives 4 f.u./WC for tank toilets ordinarily used in housing in America.

8/ See Figure 5 for method of "venting" deaerator fitting. Junction fittings vented by 15 mm (5/8") i.d. tubing connected into fitting top.

Table 24 Performance of Experimental Sovent System with Various Loads,

American Flush-Valve Type WC's, 3-in. Branches, Junction Fittings Vented[8]

Test Load				Equivalent Service Load				Maximum Pressure Excursions			
ures	No. Intervals Loaded	Additives	Rate	From Table 29		From Fig. 9[6]	From Table 29 and assumption of 4 f.u./WC[7]	Negative		Positive	
				p = 0.01[1]	p = 0.03			Value	Floor	Value	Floor
			lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	mm[5]		mm[5]	
	1	None	102/27.0	15	5	10	60	9 8 8	9 9 9		
		Diaper ppr[3]						10 7	9 3,9		
		Toilet ppr[2]						8 7	5,9 6,9		
		Detergent								9 9	2 2
	2	None	204/54.0	44	15	60	176	15 12 12	9 9 9		
		Toilet ppr						13 11 12	5 5,8 6		
		Diaper ppr + Toilet ppr						13 11 11	5 9 2,4,5	11	5
	2	None	204/54.0	44	15	60	176	15 15 18	7 7,6 7		
		Toilet ppr						12 12 12	4,3 7 7		
		Diaper ppr + Toilet ppr						18 15 12	3 3 3,7	15	1,2,3
9	3	None	306/81.0	83	29	160	332	20 20	9 9		
		Toilet ppr						15 20 21	4,5,7 6 3		
		Detergent								38[4]	1
		Diaper ppr + Toilet ppr						20 15	3 3		
9	3	None	306/81.0	83	29	160	332	15 15	6,9 9		
8+9	4	Diaper ppr + Toilet ppr	408/108	129	46	300	516	35 25 30	3 3 3	25	3
7+8+9	5	Toilet ppr	510/135	---	--	470	---	45 30	1 2	30	1
		Diaper ppr + Toilet ppr						30 31	3 5	40 31	3 1
6+7+8+9	6	None	612/162	---	--	660	---	57	3	48	1

lue of p = 0.0061 was determined for 3-gal, tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

eparate pieces standard toilet paper, single thickness.

piece commercial diaper paper 50 cm x 11 cm, folded lightly two times, placed in each W.C. bowl comprising test load.

sures differing from atmospheric by more than 25 mm (1 in.) w.g. are underlined.

btain in., multiply by 0.0394.

e values based on assumption of use frequencies greater than observed in English surveys.

uted by multiplying equivalent No. W.C.'s determined from Table 29 for p = 0.01, by the fixture-unit value of 4 given for a tank-supplied W.C. in A40.8-1955.

tion fittings vented by 15 mm (5/8") i.d. tubing connected into fitting top.

Table 25 Air Demand at Roof Terminal of Experimental Sovent System with Various Loads, American Flush-Valve Type W.C.'s, 3-in. Branches

Test Load				Equivalent Service Load				Air Demand	
Fixtures	No. Intervals Loaded	Additives	Rate	From Table 29		From Fig. 9[5]	From Table 29 and assumption of 4 f.u./WC[6]	Measured Rate	Rate Computed by Theory[2]
				p = 0.01[1]	p = 0.03				
			lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	lpm/gpm	lpm/gpm
WC_9	1	None Toilet ppr[3] Diaper[4]	102/27.0	15	5	10	60	920/243 970/256 1120/296	1660/439
WC_{8+9}	2	None Toilet ppr Diaper+Toilet ppr	204/54.0	44	15	60	176	1040/275 1320/349 970/256	2090/552
WC_{7+7}	1	None Toilet ppr Diaper+Toilet ppr	204/54.0	44	15	60	176	1320/349 1320/349 1250/330	2090/552
WC_{7+8+9}	3	None Toilet ppr Diaper+Toilet ppr	306/81.0	83	29	160	332	1330/351 1390/367 1120/296	2350/621
$WC_{6+7+8+9}$	4	None Toilet ppr Diaper+Toilet ppr	408/108	129	46	300	516	1330/351 1390/367 1280/338	2560/676
$WC_{5+6+7+8+9}$	5	None Toilet ppr Diaper+Toilet ppr	510/135	---	--	470	---	1330/351 1390/367 1390/367	2690/711

1/ A value of p = 0.0061 was determined for 3-gal., tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

2/ Based on method derived from NBS Monograph 31.

3/ Ten separate pieces standard toilet paper, single thickness.

4/ One paper diaper placed in each WC bowl comprising test load.

5/ These values based on assumption of use frequencies greater than observed in English surveys.

6/ For p = 0.01; A40.8 gives 4 f.u./WC for tank toilets ordinarily used in housing in America.

Table 26 Performance of Experimental Sovent System with Various Loads, American Flush-Valve Type W.C.'s, 4-in. Branches, Junction Fittings Not Vented

Test Load				Equivalent Service Load				Maximum Pressure Excursions	
xtures	No. Intervals Loaded	Additives	Rate	From Table 29		From Fig. 9[6]	From Table 29 and assumption of 4 f.u./WC[7]	Negative[4]	
				p = 0.01[1]	p = 0.03			Value	Floor
			lpm/gpm	No. W.C.'s	No. W.C.'s	Fixt. Units	Fixt. Units	mm/in.	
	1	None	102/27	15	5	10	60	4/0.16	9
								9/0.35	9
								8/0.32	9
		Paper Diaper[2]						10/0.39	3,2
								10/0.39	3,2
								5/0.20	2
	1	None	102/27	15	5	10	60	20/0.79	5
								18/0.71	5
		Paper Diaper						28[5]/1.10	5
		Toilet Paper[3]						20/0.79	5
-9	2	None	204/54	44	15	60	176	15/0.59	8
								15/0.59	3
								13/0.51	2
		Paper Diaper and Toilet Paper						18/0.71	3
								13/0.51	3,2
								12/0.47	3,2
+9	2	Paper Diaper	204/54	44	15	60	176	18/0.71	3
								12/0.47	3,2
		Paper Diaper and Toilet Paper						22/0.87	3
+8+9	3	None	306/81	83	29	160	332	10/0.39	7,6,5,3
								22/0.87	3,2
								20/0.79	3
		Paper Diaper and Toilet Paper						28/1.10	3
								23/0.91	2
								30/1.18	3
+7+8+9	4	None	408/108	129	46	300	516	38/1.50	3
								30/1.18	3
								30/1.18	3
		Paper Diaper and Toilet Paper						35/1.38	3
								28/1.10	3
								34/1.34	2
+6+7+8+9	5	None	510/135	---	--	470	---	30/1.18	2
								32/1.26	3
								40.1.58	2

value of p = 0.0061 was determined for 3-gal., tank-type, washdown W.C.'s in an English survey of frequency of use in housing.

ne paper diaper placed in each W.C. bowl comprising test load.

'en separate pieces standard toilet paper, single thickness.

'here positive pressures existed, they were not greater than the negative pressures, and usually were much smaller.

'neumatic pressures differing from atmospheric by more than 25 mm (1 in.) W.G. are underlined.

'hese values based on assumption of use frequencies greater than observed in English surveys.

'or p = 0.01; A40.8 gives 4 f.u./WC for tank toilets ordinarily used in housing in America.

3. A 4-in. Sovent stack is apparently considered by leading designers adequate to serve up to 30 or more apartment units, by careful design.
4. Critical sections of unvented horizontal and vertical waste piping serving individual small fixtures or small groups of such fixtures are increased in diameter at least one pipe size above what would be necessary if individual venting were employed, so as to minimize self siphonage or induced siphonage resulting from the discharge of one or more fixtures on a given branch interval.
5. In some instances, a building drain as much as two pipe sizes larger than the stack is recommended. Generally, a one pipe-size increase is recommended.
6. A building drain slope of at least 2% (about 1/4 in./ft.) is recommended.
7. It is best not to install plumbing fixtures at the level of the foot of the stack, because of possible detergent foam effects. Evidently, direct connection of fixtures to the building drain is recommended at this level.
8. Without venting, toilet branches are customarily limited to 4 in. diameter, although this limitation is being studied critically in current programs. Investigators believe 3-in. branches may be acceptable under certain conditions.

Review of available test data provides the basis for the following comments:

1. Test loadings on Sovent stacks involving the simultaneous discharge of up to 6 European-type water closets have generally produced maximum pressure excursions falling within the range ±1.5 in. W.G., and up to 4 W.C.'s discharged together have generally resulted in maximum excursions within the range ±1.0 in. W.G., according to the data summarized in Tables 19 through 22.

2. The European data on the Sovent system from laboratory tests and from actual buildings seem to indicate that the imposition of a load comprising a given number of close-together fixtures discharged simultaneously in a test tower not over 10 stories high may yield greater pressure effects than the same load naturally imposed in a similar system in a real building of greater height, due to the tendency for the natural loading to be more widely distributed vertically.

3. Laboratory tests on a 10-story test tower using American-type water closets (flushometer-supplied) have shown pressures in the range of about ±1.0 in. with 3 W.C.'s discharged together under various conditions, both with 3 in. vented branches (limited secondary ventilation) and with 4-in. non-vented branches.

4. Table 25 shows air demand rates of the order of 1.5 to 2.0 times as great as theoretical values computed by the NBS method. It should be realized, however, that in American venting practice the pipe sizes and lengths are calculated for 2/3 of the theoretical values, which puts them close to the values measured in the Sovent tests. Table 19 shows that the measured values of water velocities in the Sovent stack were only slightly less than the values computed from American theory. No explanation can be conceived for experimental findings that the velocities for the stack utilizing "standard tee" junction fittings are much greater than computed from theory. Possibly the detached water masses in the central core of the stack, or the inner filaments of the water stream, may have been moving at greater speed than the mean speed of the stream. If so, which seems likely, it may be that these small masses or inner filaments triggered the response of the instruments attached to the branches, thus indicating, not the mean speed of the flow, but rather the maximum speed in the velocity profile.

Figure 8 shows one Sovent design employed in the construction of a large group of high-rise apartment buildings located in the Geneva area, ranging up to 30 stories in height. In this drawing, the traps have been omitted. Trap seal depths of at least 70 mm (2 3/4 in.) for lavatories, sinks, bathtubs and bidets, and of at least 50 mm (2 in.) for water closets were recommended in 1966 by the Swiss Sewage Systems Association[14]. The traps used in the Le Lignon installations appeared to have seal depths

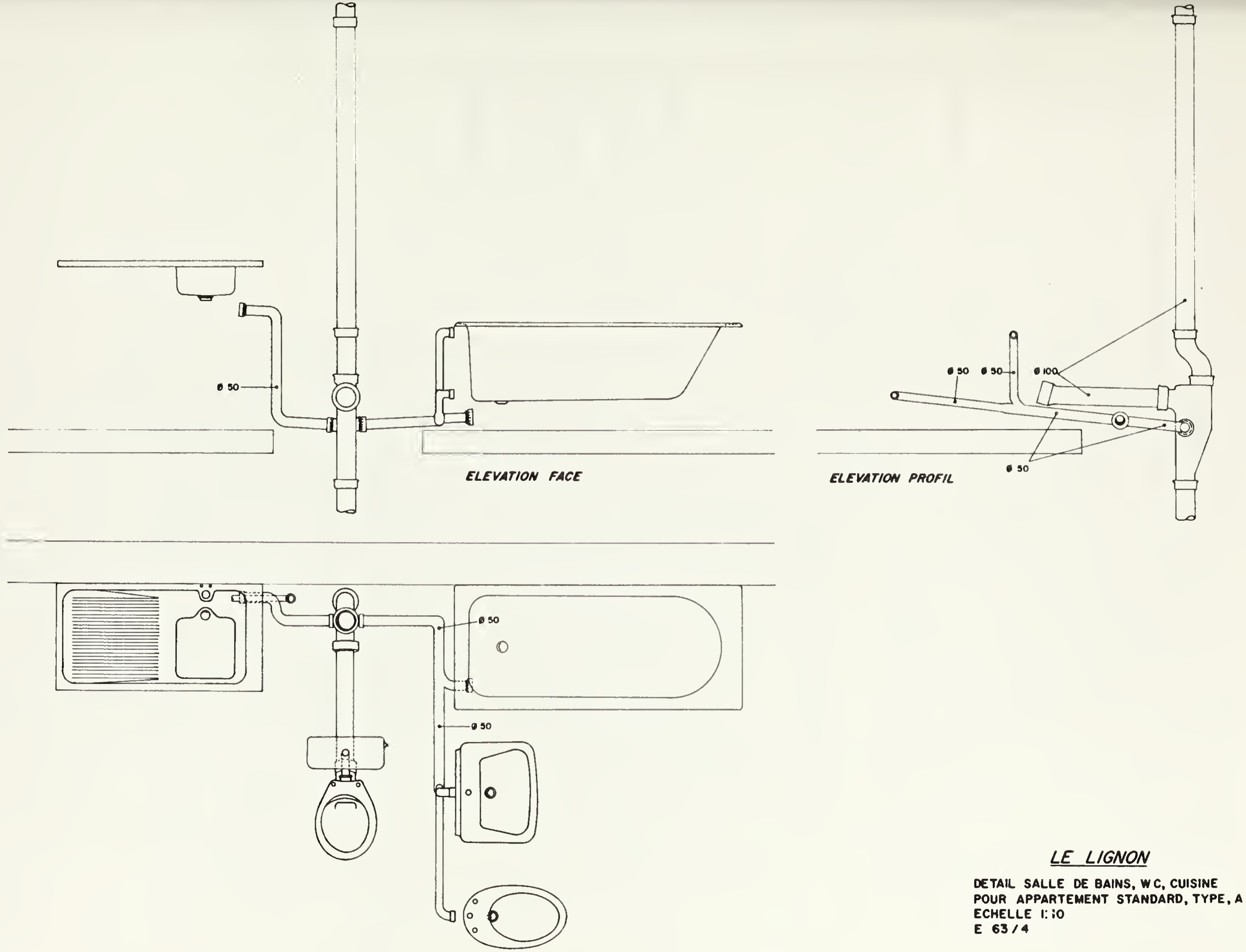


FIG. 8 SOVENT DRAIN-WASTE-VENT SYSTEM USED IN HIGH-RISE APARTMENTS IN LE LIGNON, GENEVA

not much in excess of the stated minimum values. Bottle traps are customarily utilized for lavatories and kitchen sinks, and P-traps for bathtubs. The water closets and bidets in this design were of the rear-outlet type, with integral traps. Secondary ventilation was entirely eliminated from this design. The customary deaerator fitting and relief vent was utilized near the foot of the stack, not shown here. For the purposes of the present report, the water distribution piping and the rainwater stack have been omitted from the drawing.

4. Estimation of Service Load Corresponding to an Arbitrary Test Load

Perhaps the most difficult problem in interpreting test data on plumbing hydraulics lies in the estimation of the service load, expressed in number of connected fixtures, or "fixture unit" load, that will yield approximately the same hydraulic and pneumatic effects from natural use as observed in tests utilizing arbitrarily selected loads. The difficulty arises principally from three causes:

1. Inadequate knowledge of the probable degree of concurrence of multiple hydraulic discharges in a plumbing system in a building occupied by people in pursuit of their normal activities.
2. Lack of specific information on the effect of spatial distribution of the individual elements of a given multi-fixture, concurrent hydraulic load, insofar as it affects hydraulic and pneumatic phenomena.

3. Uncertainty as to whether a series of chosen test loads has involved combinations and time sequences of fixture discharges suitably representative of the range likely to occur in service in a similar system.

It has been customary, in the more scientific approaches to this problem, to rely on an application of the theory of probability. In testing, various combinations and sequences of fixtures are discharged, and residual trap seals or maximum excursions of pneumatic pressures at critical points are measured. Then, the smallest number of fixtures, or the smallest combined rate of discharge that produce a condition bordering on unacceptable performance in the test situation is taken as the limiting load, and an effort made to infer the number of service-connected fixtures, or "fixture unit" load, that might be expected to produce the corresponding performance through natural use in a similar service installation with a sufficient frequency to warrant consideration in design.

Because of the various uncertainties in this procedure, there is a natural tendency to "play it safe" by seeking the worst possible combinations and sequences of fixture discharge in testing, and by assuming a rather high probability of concurrent use in the service situation. Field measurements in Britain and Switzerland, reported in the literature surveyed, seemed to support this proposition, in that the trap seal losses and pneumatic pressures measured in field tests with natural loads were generally less than might have been anticipated from initial laboratory tests.

Realizing a need for some mathematical tool in relating the European data to American practice, Table 27 could be considered as a conservative guide for estimating the number of connected fixtures in a real system that might be expected to yield the same hydraulic load as a given hydraulic load induced in a test system. The mathematical basis of this table corresponds to that presented in NBS BMS 65[3], and utilized in A40.8-1955[15].

For some time it has been suggested that the values of use frequency, p[1/], assumed in American practice are too large, leading to the prediction of combined discharges greater than actually occur frequently enough to require consideration in design. In fact, surveys in British housing[2] have shown surprisingly low values of p. However, since comparable surveys to establish p under American conditions for housing have not been made, a range of values of p is offered for the present purpose. In A40.8 the DWV loading tables are based on p = 0.03 for flush-valve water closets in public use, and on a fixture-unit rating scale which recognizes a lesser loading effect by "private-use" fixtures than by "public-use" fixtures, and a lesser loading effect by small fixtures than by water closets.

[1/] The term p is the same as $\frac{t}{T}$ in the terminology of BMS 65.

Table 2/

GUIDE FOR ESTIMATING NUMBER OF CONNECTED FIXTURES ON SERVICE SYSTEM THAT WOULD PROBABLY GIVE SAME HYDRAULIC LOAD AS A GIVEN NUMBER OF CONCURRENTLY OPERATING FIXTURES IN A TEST SYSTEM 1, 2/

Number of Concurrently Operating Fixtures Comprising Test Load	p 3/ = 0.02	p 3/ = 0.03	p 3/ = 0.05	p 3/ = 0.10
1	1	1	1	1
2	9	6	4	2
3	24	16	10	6
4	45	30	19	10
5	70	47	29	15
6	97	66	40	21
7	127	85	52	26
8	159	106	65	34
9	191	128	78	40
10	226	151	92	47

1/ Based on theory of probability as outlined in NBS BMS 65, and applied in the American Standard National Plumbing Code ASA A40.8-1955. An allowable probability level of 0.01 is taken for concurrent operation of exactly the indicated number of fixtures in column 1, and the cumulative probability of concurrent operation of greater numbers of fixtures is also limited to 0.01.

2/ The use of this table is mathematically valid only for systems comprising a single type of fixture, but may also be useful in relation to mixed systems where p is similar for the different types of fixtures.

3/ The term "p" is the individual probability of finding any particular fixture on a service system in operation if observed at random during a typical, peak loading period, and is equal to the ratio of time duration of a single discharge, t, to the average time between successive discharges, T, in the terminology of BMS 65 [3].

Table 27 could be utilized to estimate the number of connected fixtures in a field system yielding a hydraulic load comparable to that used in a particular laboratory test. The service fixture-unit load that would yield a peak discharge equal to that produced in the laboratory test may be estimated by the use of the curve shown in Figure 9, assuming applicability of the concepts presented in BMS 65. Computation of the DWV loading tables in A40.8-1955 and in the current proposed revision of A40.8 involved the use of this curve together with a knowledge of hydraulic and pneumatic carrying capacities of pipes.

5. Estimated Service Loads Corresponding to Maximum Loads Found Safe in Tests.

As indicated in Section 4, it may be informative to consider the significance of hydraulic test loads found safe in tests, in terms of corresponding service load that might be expected to yield similar hydraulic results through natural concurrent operation of the different fixtures on a field system. Table 27 may be utilized for systems with a single type of fixture to estimate the service load in terms of connected fixtures if values of $p = \frac{t}{T}$ are known. Figure 9 may be utilized to estimate service load in terms of American fixture units if the individual fixture discharge rates and values of p are in accordance with those used in BMS 65[3]. Further development of the method of Figure 9 is required before it can be satisfactorily applied where fixture discharge

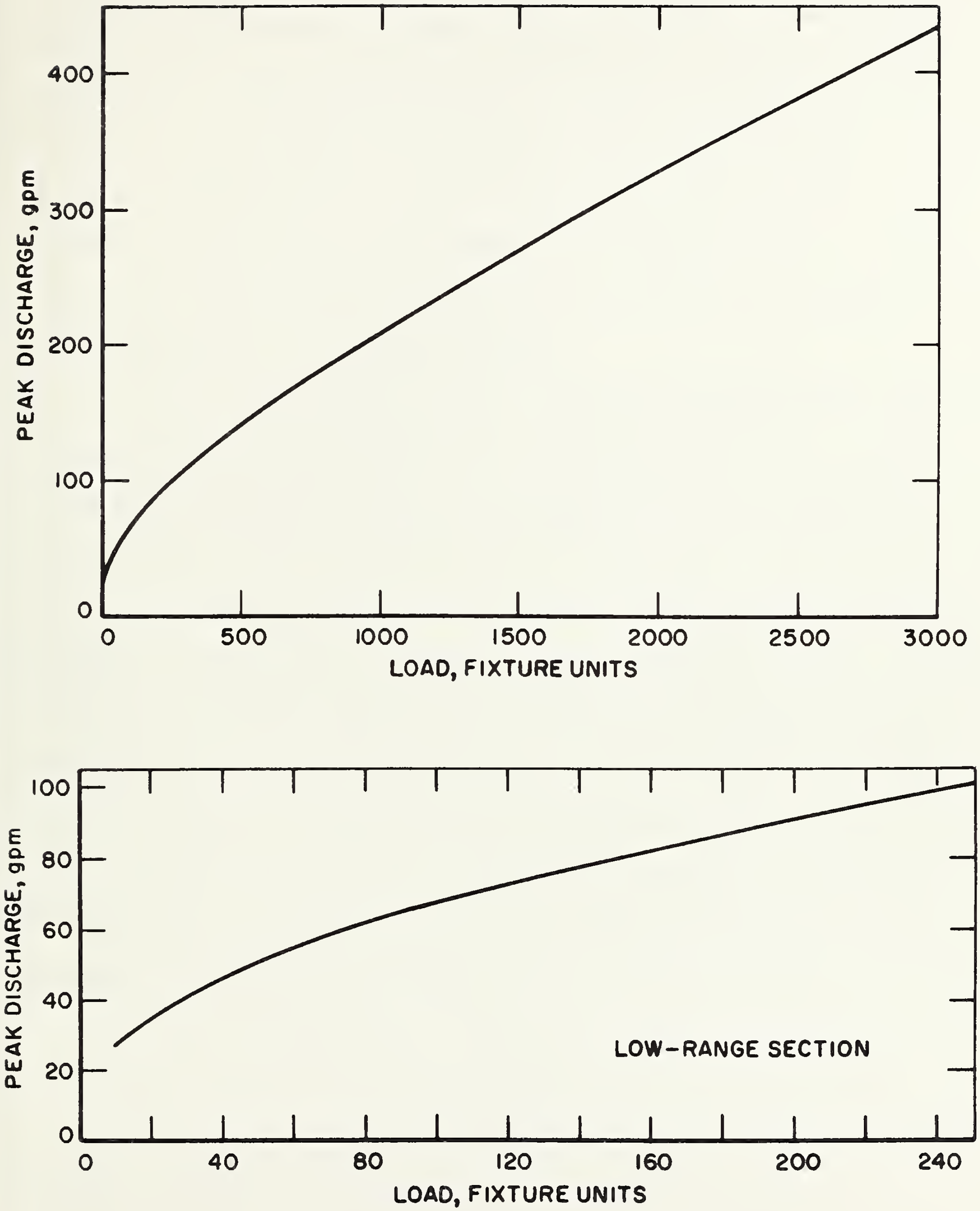


Figure 9. Hunter's curve for estimating peak discharge in sanitary drainage systems of buildings.

rates and values of p differ substantially from those utilized in BMS 65. If fixture discharge rates and/or values of p are less than those employed in BMS 65, use of Figure 9 may be expected to yield unduly low values of allowable service load. It seems to be generally assumed that in tests on high-rise systems principal reliance should be placed on the results from water-closet discharges. Whether this is an altogether valid assumption may depend on the characteristic values of p for the various fixtures, on the geometry of critical fittings, and on configuration of the drainage system.

In the case of small systems, there may be some reason to question the wisdom of blind reliance on the theory of probability; however, no generally-accepted alternative appears to have been developed.

In further consideration of the use of the binomial probability function in relation to testing, it seems reasonable to allow a service-connected load that is hydraulically equivalent to an arbitrary test load that yields satisfactory performance, and there seems to be no good reason to restrict the probability of occurrence of this satisfactory event to a value as small as 0.01. However, it is important to limit the probability of occurrence of concurrent discharges <u>greater</u> than the combinations known from testing to yield borderline performance. Since the concepts on which Table 27 are based restrict the probability of occurrence of both unsatisfactory <u>and</u> certain satisfactory loads, the use of Table 27 for relating test loads and corresponding service loads seems unnecessarily conservative.

Two needs might arise in this type of testing: (1) How many fixtures in natural use in a service installation may be assumed to yield hydraulic equivalency to a given number of the fixtures simultaneously or sequentially (concurrently) discharged together in a test? (2) In testing a given system by arbitrary discharging of fixtures, how many fixtures should be discharged to yield a reasonable test load? Tables 28, 29, and 30 have been prepared in response to these needs, and are based on a limitation on probability of occurrence of unsatisfactory loads only. These tables should be considered only as guides pending further study, but will prove useful in interpreting some of the European data presented in this report. Their use does not free the investigator from the need to try various time sequences and combinations of fixtures in testing, but does give him a number of fixtures to use in these trial tests. The tables may also be useful in indicating the numbers of fixtures that might be allowed in service to yield hydraulic equivalency to a given, satisfactory test load. As a safety factor for mixed system, it seems both prudent and convenient to discharge together the indicated number of each fixture type likely to be in substantial use during peak load periods, as obtained separately for each type from Table 30. In order to make the best use of these tables, it is necessary to have reliable information on the typical ratios of draining time to time between successive uses ($p = t/T$) for the various fixture types. Data of this kind are not presently available for modern American plumbing systems, unfortunately.

Table 28.[1/] Relationship Between Test Load and Allowable Number of Connected Fixtures on Service System with Natural Loading

Number of Concurrently Operating Fixtures Comprising Satisfactory Test Load	Corresponding Allowable Number of Connected Fixtures in Service System[2/]		
	$p = 0.01$[3/]	$p = 0.02$[3/]	$p = 0.03$[3/]
1	15	8	5
2	44	23	15
3	83	44	29
4	129	69	46
5		96	65

[1/] In the application of this table to mixed systems, a mathematically conservative approach is to consider each fixture type separately in estimating the allowable number of service-connected fixtures corresponding to an arbitrary test load.

[2/] Computed from the binomial probability theory. The probability of occurrence of concurrent discharges in excess of the satisfactory test load is not greater than 0.01 for service systems of the stated size or less.

[3/] The term "p" is the individual probability of finding any particular fixture on a service system in operation if observed at random during a typical, peak loading period, and is equal to the ratio of time duration of a single discharge, t, to the average time between successive discharges, T, in the terminology of BMS 65 [3].

Table 29.[1] Service Load Ranges That Might be Considered Safe on Basis of Satisfactory Test Performance with Arbitrarily Chosen, Concurrently Discharged Fixtures

Number of Concurrently Operating Fixtures Yielding Satisfactory Performance	Corresponding Service Load Range (No. of Connected Fixtures)			
	$p = 0.01$	$p = 0.02$	$p = 0.03$	$p = 0.05$
1	1 - 15	1 - 8	1 - 5	1 - 3
2	16 - 44	9 - 23	6 - 15	4 - 9
3	45 - 83	24 - 44	16 - 29	10 - 18
4	84 - 129	45 - 69	30 - 46	19 - 28
5		70 - 96	47 - 65	29 - 39

[1] Based on same considerations as Table 28.

Table 30[1] Numbers of Fixtures to be Discharged

Together in Testing Installed Systems[2]

No. to be discharged	No. Installed			
	p = 0.01	p = 0.02	p = 0.03	p = 0.05
1	1 - 15	1 - 8	1 - 5	1 - 3
2	16 - 44	9 - 23	6 - 15	4 - 9
3		24 - 44	16 - 29	10 - 18
4			30 - 46	19 - 28
5				29 - 39
6				40 - 51

[1] Derived from Table 29, meeting the criteria given in the footnote beneath Table 28.

[2] Discharge together (concurrently or simultaneously) the indicated number of each fixture type (value of p) likely to be in substantial use during peak load periods. For example, if three types of fixtures (p = 0.01, p = 0.02, and p = 0.03) are to be considered as significant in contributing to a peak condition, and there are 10 of each fixture type installed, then a conservative test load would involve the concurrent discharge of one fixture having a value of p = 0.01, and of two fixtures of each of the two types with p = 0.02 and p = 0.03.

It should be realized that the use of Tables 29 and 30 will yield somewhat greater allowable service loads, or permit the use of smaller test loads, than would be the case if the traditional double probability criterion is applied, as indicated in connection with Table 27. It is believed that further research on the matter would confirm the more liberal approach reflected in Tables 29 and 30.

5.1 Discussion of British Tests in Relation to Corresponding Service Loads

Tables 1 and 2 give results of tests on a 5-story, 4-in. stack, utilizing manual flushes of single water closets with newspaper loads (6 pieces of newspaper, 6 in. x 4 1/2 in.--Table 1; 8 in. x 6 in.--Table 2). Trap seal losses were well below 1 in. with the smaller pieces, and below 1 1/2 in. with the larger pieces. If it be assumed these tests indicate satisfactory performance with one W.C., and that the probability of an individual W.C. use is 0.03, Table 28 indicates that the corresponding maximum allowable connected service load would be five water closets. By use of Figure 9, using a discharge rate of 30 gpm (British measure) = 36 gpm (American measure), an allowable fixture-unit load of 21 is obtained.

In the British application of the data, however, the field surveys of usage showed the probability of individual W.C. use to be less than 0.01 (see Table 6). Based on p = 0.01, Table 28 yields a corresponding service load of 15 water closets. This agrees well with value of 20 fixtures for p = 0.0061 as shown in Table 8. The corresponding fixture-unit load for p = 0.01 cannot be obtained from Figure 9 in its present form, but would be much greater than the 21 fixture units corresponding to p = 0.03 (60 fixture units if 15 water closets are allowable and a value of 4 f.u./W.C. is assumed for a tank-supplied fixture, as in the American Standard National Plumbing Code).

As discussed elsewhere in this report, the BSI Code of Practice Committee 304 has decided to omit consideration of newspaper tests in the determination of allowable loads as being unnecessarily restrictive. The data of Tables 10 - 15, involving no newspaper, will be considered next.

For simplification of the analysis of the data of Tables 10 - 15, the numbers of connected fixtures have been calculated that correspond to satisfactory test loads of 1, 2, 3, 4, and 5 fixtures, for values of p = 0.01, 0.02, and 0.03. These calculations are given in Table 28.

Table 31 summarizes the data in tables 10 - 15 and shows estimated service loads corresponding to the test loads. Test discharges conservatively estimated to be equivalent to fixture-unit loads of up to approximately 100 produced trap seal losses of 1 in. or less for 4- and 5-in. stacks, and estimated equivalent loads of up to about 200 fixture units produced trap seal losses of well under 1 in. for 6-in. stacks. While these loads are much less than allowable in American practice, where secondary ventilation is generally employed, the corresponding allowable number of bathroom--kitchen units at 8 fixture-units (see Table 11.4.2 of A40.8--1955) would be 12 and 25. These values agree well with the limits recommended by the British (see Sec. 2 of this report). Table 32 gives estimated American fixture-unit loads considered conservatively equivalent to the loads allowed by the British. From this it appears the allowable loads on British single-stack systems may be as great as required for the fixtures and appliances actually installed in many multistory apartment buildings of moderate heights in this country. If so, the fact that much greater loads can safely be placed on American vented stacks of the same diameters becomes, to some degree, academic. However, secondary ventilation probably provides a reserve capacity, or "safety" factor to guard against effects of gradual fouling; future addition of fixtures, appliances, etc.; and other contingencies. These types of contingencies should also be recognized in the design of single stack systems.

Table 31. Estimated Service Loads Corresponding to Test Loads--English Data

Data Source	Test Load		Corresponding Service Load			Maximum Trap-Seal Loss
			From Table 29	From Fig. 9 4/	From A40.8 4,5/	
	Load 1/	gpm 2/	No. Fixtures 3/	Fixt. Units	Fixt. Units	in.
Table 10 4-in. stack, 11-stories, maisonettes	1 WC	36	15		60	
	1 L	9.6	15		15	
	2 S	28.8	23		46	
		74.4 6/		126	121	0.4
	2 WC	72	44	116	176	0.7
	4 L	38.4	129	26	129	0.2
	1 WC	36	15		60	
	2 B	33.6	9		27	
		69.6		107	87	1.0
	2 B	33.6	9	18	27	0.6
Table 11 4-in stack, 10 stories, flats	1 WC	36	15		60	
	1 L	9.6	15		15	
		45.6		49	75	0.3
	2 WC	72	44		176	
	2 L	19.2	44		44	
		91.2 7/		203	220	1.2
Table 12 5-in. stack, 15 stories	1 WC	36	15		60	
	1 L	9.6	15		15	
	2 S	28.8	23		46	
		74.4 6/		126	121	1.1
	1 WC	36	15		60	
	2 B	33.6	9		27	
		69.6		107	87	1.0
Table 13 5-in. stack, 12 stories, flats	2 WC	72	44	116	176	0.3
	2 WC	72	44		176	
	2 L	19.2	44		44	
		91.2 7/		203	220	0.4
	1 WC	36	15		60	
	2 B	33.6	9		27	
		69.6		107	87	0.5
	2 WC	72	44		176	
	2 B	33.6	9		27	
		105.6 7/		280	203	0.6
Table 14 6-in. stack, 20 stories, flats	1 WC	36	15		60	
	2 L	19.2	44		44	
		55.2		61	104	0.4
	2 WC	72	44		176	
	2 L	19.2	44		44	
		91.2 7/		203	220	0.4
	2 WC	72	44		176	
	2 B	33.6	9		27	
		105.6 7/		280	203	0.6
Table 15 6-in. stack, 25 stories, flats	2 WC	72	44	116	176	0.4
	2 WC	72	44		176	
	2 L	19.2	44		44	
		91.2		203	220	0.7
	3 WC	108	83	290	332	0.3
	3 WC	108	83		332	
	1 B	16.8	3		9	
		124.8		380	341	0.5

1/Water Closet--WC
Lavatory--L
Kitchen Sink--S
Bathtub--B

2/Discharge rates from Table 4, converted to American gpm.

3/Based on p = 0.01 for WC and L, p = 0.02 for S, and p = 0.05 for B (see Tables 6, 8, and 9 for values of p determined in English survey of frequency of fixture use.).

4/These values are based on the assumption of frequencies of use and fixture discharge characteristics similar to those assumed in American practice. Since use frequencies determined in English installations are considerably lower than the values utilized in developing Figure 9, and since the hydraulic properties of American and English fixtures may differ somewhat, the fixture-unit values obtained from Figure 9 (and A40.8) corresponding to the English loads may not be suitably applicable to English conditions.

5/ Computed from values in the fourth column by assuming fixture-unit values for individual fixtures as given in the American Standard National Plumbing Code ASA A40.8-1955:

WC (tank supplied) = 4 f.u.
L (1 1/4 in. outlet) = 1 f.u.
S = 2 f.u.
B = 3 f.u.

6/This is the test load recommended by Wise as representative of a "morning peak" (see Table 8).

7/The total discharge rates for these test loads are greater than for the test loads recommended by Wise as representative of a "morning peak" (see Table 8).

Table 32. Fixture-Unit Loads Estimated as Equivalent to Loads Allowed on British Single Stack Systems

Stack Diameter	Allowable British Load	Estimated Equivalent American Load[1/]
in.		Fixture Units
4	5 stories, each with 2 WC, 2 L, 2 B, 2S.	80
	10 stories, each with 1 WC, 1 L, 1 B, 1S.	80
5	12 stories, each with 2 WC, 2 L, 2 B, 2 S	192
	15 stories, each with 1 WC, 1 L, 1 B, 1 S.	120
6	25 stories, each with 2 WC, 2 L, 2B, 2 S	400

[1/] Each bathroom group assigned a fixture-unit total of 6, and each kitchen sink a value of 2, as recommended in ASA A40.8-1955.

5.2 Discussion of Sovent Tests in Relation to Corresponding Service Loads

Tables 19 - 26 give results of manual tests on 4-in. Sovent systems, both in buildings and in a laboratory test apparatus. From the use of Figure 9 and Table 29, estimated values of equivalent service load have been obtained, and are shown in the tables. The method is similar to that used in Sec. 5.1 in analyzing the British data. The test data show that the pneumatic pressure excursions were within ±1.5 in. (38 mm) for all test loads of 3 W.C. or less, as well as for greater loads in a number of tests, particularly in tests in tall buildings. Studies at the Building Research Station in England led to recent BRS statements that maximum trap-seal losses of 1 in. may be assumed roughly equivalent to maximum pressure excursions of ±1.5 in. Thus, adoption of a criterion of ±1.5 in. pressure excursion in the analysis of the Sovent data should be comparable to a criterion of 1.0 in. trap seal loss in the analysis of the British data. The equivalent service load corresponding to a test load of 3 W.C. may be estimated in the range of 116 to 332 American-style fixture units, depending on the assumptions made. Table 33 shows the computations.

Table 33. Estimated Service Loads Corresponding to Test Loads--Swiss Data

Test Load		Corresponding Service Load				
		From Table 29		From Fig. 9[2]	From Table 29 and assumption of 4 f.u./W.C.	
Load	Discharge Rate	$p = 0.01$[1]	$p = 0.03$		$p = 0.01$[1]	$p = 0.03$
	gpm	No. W.C.'s	No. W.C.'s[2]	Fixt. Units	Fixt. Units	Fixt. Units[2]
1 WC	37.0	15	5	23	60	20
2 WC	74.0	44	15	125	176	60
3 WC	111.0	83	29	310	332	116
4 WC	148.0	129	46	530	516	184
1 WC	31.7	15	5	17	60	20
2 WC	63.4	44	15	85	176	60
3 WC	95.1	83	29	220	332	116
4 WC	126.8	129	46	400	516	184
1 WC	27.0	15	5	10	60	20
2 WC	54.0	44	15	60	176	60
3 WC	81.0	83	29	160	332	116
4 WC	108.0	129	46	300	516	184

1/ English surveys in housing developments showed a characteristic value of $p = 0.0061$.

2/ These values based on assumption of use frequencies greater than observed in English surveys.

Another approach in reference to load analysis for the Sovent system is to consider the installations being used in the Lignon development, Geneva. A typical system is shown in Figure 8.[1/] Swiss engineers have reported satisfactory service with 30 bathroom-kitchen units of this design connected to a 4-in. Sovent stack. For comparison purposes, it will be conservatively assumed that this combination can be rated at 8 fixture units per dwelling unit, as recommended in ASA A40.8-1955 for one bathroom group in addition to a kitchen sink without food-waste-disposal unit. Since the Swiss installation illustrated has one additional fixture--a bidet--the combination might well be rated as more than 8 fixture units. However, since information is generally inadequate to determine accurate fixture-unit ratings for individual fixtures and small groups of fixtures, a value of 8 will be assumed for the plumbing group shown in Figure 8, yielding an estimated 240 fixture units on the stack. This is almost exactly in the middle of the range 116 - 332 fixture units inferred as allowable from the data analysis discussed above. From this, it is seen that 4-in. Sovent Systems are in use carrying greater loads and serving taller buildings than are the 4-in. British single-stack Systems (see Table 32), apparently with success.

[1/] Derived from a drawing furnished through the courtesy of Mr. H. Niederer, A. Schneider S.A., Geneva.

6. Consultants' Review

Two prominent independent consultants experienced in the field of plumbing (designated A and B) were employed to make a limited review of NBS Report 9674, and of European data which have been made available to the National Bureau of Standards for this study.

Both felt that the conclusions and recommendations in NBS Report 9674 are fair and justified on the basis of the information reviewed. Consultant "A" felt, however, that a discussion citing the considerable amount of research forming the basis of the American requirements on secondary ventilation would have been helpful. It is recognized that this suggestion has merit in connection with a comprehensive presentation of various methods of sanitary drainage. Several investigations of the fluid dynamics of plumbing have been conducted--at the National Bureau of Standards, University of Iowa, University of Illinois, City of Detroit Plumbing Laboratory, and elsewhere--aimed at establishing the limits of loading for vented systems, and at checking the performance of selected types of sanitary drainage with simplified venting. However, it is believed that in no instance, except in the case of one-story stack venting, was there any serious intention to develop practical information regarding the load limits that might be tolerated for systems without any secondary ventilation. The same consultant noted that the single-stack systems described in NBS Report 9674 utilized stacks of at least 4-in. in

diameter, and pointed out that American 3-in. soil stacks with appropriate secondary ventilation may be used under the provisions of many codes in apartment buildings up to 6 stories in height where one apartment is served on each floor. This should be considered in making cost comparisons for systems of this height.

Consultant "B" found that the British system is based on a considerable amount of research work recorded in the professional literature, and felt that sound explanations of the pertinent hydraulic phenomena had been presented. He considered that a need exists for more complete data in support of some of the explanations offered for phenomena observed in the Sovent studies[12,13,16], but confirmed the statements in the European reports indicating less tendency to "plugging" of a soil stack at a branch junction when a Sovent junction fitting is used, and considered it "encouraging" that the data showed less pressure reduction in the stack when Sovent fittings were used than when "standard T" fittings were used.

Both consultants recommended more testing under American conditions, beginning with laboratory studies, before recommending either method of single-stack drainage for American use, and that final judgment be based on evaluation of data from field trials in this country.

Additional recommendations and comments provided in the consultants' reports are summarized as follows:

1. Comparative field tests with different drainage-system designs should be conducted in the same building (4 stories or more in height), utilizing identical loadings, occupancy, and fixtures. Provisions for instrumentation should be made in construction, and manual tests should precede tests to monitor performance with natural loadings.
2. The most significant indicator of performance in this work is trap-seal retention. In order to dispense with the need for measuring trap-seal loss (or residual trap seal), it will be necessary to establish a reliable relationship between pressure excursions and trap-seal loss.
3. In considering cost-savings potential, it is important to compare American minimum-vented systems (such as minimum types acceptable under USASI A40.8-1955) with the candidate systems.
4. It was thought that the Sovent design would prove more economical for tall buildings, while the British design may be the least costly of the two for buildings up to about 10 stories high.

5. Research findings should be reported in journals commonly read by plumbing officials, design engineers, contractors, and manufacturers. A coordinated educational program would be helpful in the event of favorable results.

6. It was estimated that perhaps 5 years of testing and field trials with favorable results would be required to establish widespread acceptance of single-stack drainage by the trade and by plumbing officials, judging from past experience with other modified DWV systems.

7. Several valid recommendations were provided on testing details and as to hydraulic phenomena that may need evaluation under American conditions. These details will not be repeated here, but a list of them has been prepared and can be furnished when needed. The substance of these recommendations is summarized in the Appendix.

7. Conclusions

Based on the available information, the following broad conclusions are offered:

1. The potential for cost savings in the use of single-stack sanitary drainage appears to be sufficiently great to warrant a careful evaluation under American conditions. Under European conditions savings of 30 to 50% have been attributed to the use of single-stack drainage. Cost comparisons in America should be in relation to the systems considered minimum in widely recognized model codes such as USASI A40.8.
2. The allowable sanitary load for a single-stack system at a given diameter is much less than for an American vented system of the same diameter--estimated at roughly one fourth to one half as great. It is important, however, to recognize that in many buildings, such as multi-story apartment houses of moderate heights, the plumbing load to be provided for may be within the range of capacity indicated by the European data for properly designed 4-in. single stack systems. Allowable maximum loads and story heights for 4-in. Sovent systems appear to be greater than for 4-in. British systems. For the higher buildings and greater loads, the British have recommended 5- and 6-in. single-stack systems.

3. Performance data and capacity limits for at least two varieties of single stack systems should be determined under American conditions, the British and the Sovent designs being the two most obvious candidates. Among the more important criteria of performance to be considered in needed laboratory and field tests would be trap-seal retention, gas transmission through traps, noise, and potential for fouling and corrosion. Both manually imposed and natural loadings should be used in field tests.

4. Various details of instrumentation and testing have been suggested in NBS Report 9674, in the present report, and in the reports of the Consultants. These recommendations are summarized in the Appendix.

5. A coordinated program of laboratory and field testing, together with dissemination of information describing findings, should yield some significant results within one year. A considerably longer additional period would probably be required to enable the widespread, orderly, acceptance of single-stack drainage, assuming that useful limits of satisfactory performance can be established by concurrent laboratory and field tests as has apparently been accomplished under European conditions.

6. It is essential to prepare a design manual giving detailed drawings for several acceptable systems, and providing discussion and guidance in the matter of general principles and critical criteria. It is recommended that for the initial effort the manual be limited to multi-story housing applications, and that the allowable loadings be expressed in numbers of bathrooms, bathroom-kitchen combinations, or other standard fixture groups.

Acknowledgment is made to the Technical Studies Program, Federal Housing Administration, Department of Housing and Urban Development for its support of the work reported, and to the many individuals, too numerous to list individually, who made indirect but significant contributions to the success of the investigation.

Special appreciation and thanks are extended to the following individuals for their cooperation in making valuable primary information available relating to the study, for assistance in the development of the program, and for providing for building site visits and laboratory demonstrations:

Federal Housing Administration:

Mr. Nat L. Eure

Mr. Thomas W. Rowell

Private Consulting Engineers:

Mr. Herbert N. Eaton (Hagerstown, Maryland)

Mr. L. Glen Shields (Detroit, Michigan)

Dr. O. H. C. Messner (Zurich, Switzerland)

Mr. Hans Niederer (Geneva, Switzerland)

Mr. Henry Voegeli (Cheshire, Connecticut)

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Mr. Thomas Pfau (Oderlin Company, Baden, Switzerland)

Others:

Mr. James T. Finch (Plumbing official, suburban London)

Mr. J. H. Hutchison (Plumbing contractor, London)

Mr. Alex Gibson (Plumbing Department Manager, Geo. Wimpey Builders, Edinburgh, Scotland)

Mr. F. G. Till (Manager, Technical Design Dept., Allied Ironfounders, Ltd., London)

Mr. J. C. Clancey (Chief Inspector, Medical Dept., Greater London Council)

Mr. Hans Kaiser (Chief, Plumbing Drainage and Sewerage Dept., Winterthur, Switzerland)

Mr. Wolfgang Grassmeier (Chief Engineer, Plumbing Drainage and Sewerage Department, Munich, Germany)

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    a. Gleichzeitigkeitsversuche, Holligenstrasse 111, Bern, June, 1962.

    b. Untersuchungen an Fall-leitungen der NW 100 mm, 1963/1, April, 1963.

    c. Untersuchungen an Fall-leitungen der NW 100 mm, 1963/2, July, 1963.

    d. Sovent--Abwassersystem, ablaufversuche im 20 Stockwerke-Hochhaus, Waldmanstrasse 45, Bern, September, 1963.

    e. Untersuchungen an Fall-Leitungen in Ø 80 & 70 mm (Standart & Sovent), May, 1967.

13. Reports made available by the Oderlin Company, Baden, Switzerland. Among these were the following:

a. Sovent--a New Vertical Stack System (undated).

b. Test reports dated January 21, 1966; September 30, 1966; November 4, 1966; December 15, 1966; and July 13, 1967.

c. Sovent System, Application in Domestic and Industrial Buildings (as of December 31, 1966).

14. Basic Principles of Sewage Systems, Swiss Sewage System Association, Zurich, 1966.

15. American Standard National Plumbing Code, USASI A40.8-1955, American Society of Mechanical Engineers and American Public Health Association, 1955.

16. H. E. Voegeli, Drainage without Vent Stacks, Air Conditioning, Heating and Ventilating, Vol. 60, No. 8, August, 1963.

9. Appendix

As indicated in Secs. 6 and 7, several suggestions relating to details of test programs, test procedures, and test apparatus have been made. The more significant of these are summarized here.

1. Investigate relative hydraulic performance of horizontal branches without secondary ventilation as based on (a) fixture drains individually extended and nominally horizontally positioned to connect the fixture traps to the stack (as utilized in the British system), and (b) fixture drains of two or more fixtures joined by the use of one or more vertical sections, to form a common, nominally horizontal branch leading to the stack (as utilized in the Sovent system).
2. Tests should include observations for pneumatic pressures and residual trap seal depths in relation to (a) idle traps, and (b) traps involved in hydraulic loads.
3. Investigate the proposition that performance and carrying capacity may be improved through (a) relatively slight modification of the geometry of conventional junction fittings, and (b) the use of fixtures having low rates of discharge.
4. Study relative pneumatic performance of a Sovent system equipped with its usual deaerator system and short radius bend at the foot of the stack, in comparison with performance of the same system in which the deaerator system and stack-foot fitting are replaced with a long-sweep fitting.

5. Conduct selected tests to study system performance when subjected to loads involving representative solids, paper, or detergents.

6. In some tests compare performance of Sovent single-stack, British single-stack, and American vented systems with identical loadings.

7. Provisions for instrumentation, such as pressure taps and electrical power outlets, should be made during construction. Taps should be provided at the crown of selected horizontal branches, fixture drains, or fittings.

8. Where feasible, transducers should be provided to sense not only differential air pressure, but also water levels in traps. Additionally, some means of measuring the acoustical performance of the system should be provided. Some electro-mechanical means would be needed for ease in discharging predetermined combinations and sequences of fixtures. It is recognized that not all these refinements will be practicable in field tests.

9. In initial work, at least, the use of simple pressure switches, level sensors, a time-pulse circuit, and dial counters might be employed to yield a useful record of the cumulative amount

of time that the pneumatic pressure and trap-seal depth is outside specified limits. The signals might also be recorded on a suitable electrical recorder in order to establish a time distribution pattern, if desired.

10. In further comparisons of performance data, it may be instructive to compare the concurrent discharge rates used in test stacks with what is allowable in service stacks of the same diameter as inferred from the fixture-unit loads given in plumbing codes.

11. In order to provide sufficient data to fully explain some of the phenomena reported in European studies of single-stack systems, more laboratory work is suggested in measurement of the pressures upstream and downstream of the fittings used at or near the foot of the stack. Additionally, more data on air demand and water velocities in the stacks would be helpful, as well as quantitative data on the degree of mixing of air and water that takes place. The use of the "salt-slug" technique has been recommended for investigating water velocities in stacks. Such work should involve comparisons with performance of an American system with identical loads.

In further test work, it was suggested that more attention be given to the effect of the vertical distribution of the elements of a multi-fixture, concurrent hydraulic load; that further attention be given to the selection of reasonable test loads, particularly in small systems; and that the hydraulic-jump phenomenon be re-evaluated as to its significance in causing pneumatic pressure disturbances in the vicinity of the foot of stacks with hydrualic loads in the range that might be allowed for single stack systems.

12. Certain experimentation with Sovent stacks in Switzerland has indicated that under most conditions a sequenced, multi-fixture load tends to produce less severe pneumatic disturbances than the same fixtures discharged simultaneously. This finding should be confirmed with more extensive testing, and if confirmed as might be expected, should be considered in interpreting test results.

13. Additional attention needs to be directed to the determination of limits of performance of Sovent systems with 3-in. soil branches. Evidently most of the European experience and test data are with 4-in. branches. The 3-in. soil branch is commonly used in American practice. It is understood that industry research in this country, now in progress, may provide needed data on this point.

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