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Performance of a Single-Stack DWV System Utilizing Low-Angle Stack-Branch Confluence and Bottom Shunt Venting

Robert S. Wyly and Grover C. Sherlin

Among the more important criteria for hydraulic and pneumatic performance of sanitary drain-waste-vent systems are (1) maintenance of water seals in fixture traps, (2) limitation of pneumatic pressures, (3) limitation of hydrostatic and hydrodynamic pressures, and (4) limitation of cross-flow between horizontal branches or trap arms.

Recent tests of a single-stack drainage system proposed for a high-rise apartment project in Fairfax County, Virginia have produced the following findings with respect to these performance criteria:

(1) test loads (total discharge rates) ranging up to magnitudes greater than predicted loads yielded reasonable average trap-seal retention;

(2) the use of trap-seal retention as a measure of performance appears to be more meaningful than the traditional pneumatic-pressure measure;

(3) fitting geometry and branch arrangement can be more critical in single-stack systems than in conventional vented systems; and

(4) present procedures for selecting test loads, for making tests, and for reporting and interpreting measured value, need improvement and standardization.

Key words: Criteria for plumbing; hydraulic test loads; performance of plumbing; single stack plumbing.

1. Introduction

Recent programs in the development of guide criteria for the evaluation of building systems have evolved a consideration of the building sub-system (**built elements**) in terms of several recognized qualities or **attributes** of a complete building system. Such considerations may be graphically presented in the form of a matrix, such as shown in figure 1 which was developed in PROJECT BREAKTHROUGH [1].[1] Among the attributes shown are several that are important in the evaluation of the plumbing system as well as of the interface between the plumbing system and other building subsystems. To achieve the attributes for plumbing in a real building, adequate performance requirements must be stated and then incorporated into the design and installation. One of the performance requirements of great importance in relation to plumbing is hydraulic adequacy or hydraulic performance, which is related primarily to the general attribute of health and safety. Other attributes such as structural adequacy, durability, acoustic acceptability, and fire resistance must also be provided for plumbing. Although each of these attributes could be discussed here, the scope of this presentation will be limited to certain aspects of the hydraulic performance of sanitary drain-waste-vent (DWV) systems.

In the design of conventional plumbing in the United States, good engineering practice and legal code requirements have established that in multistory

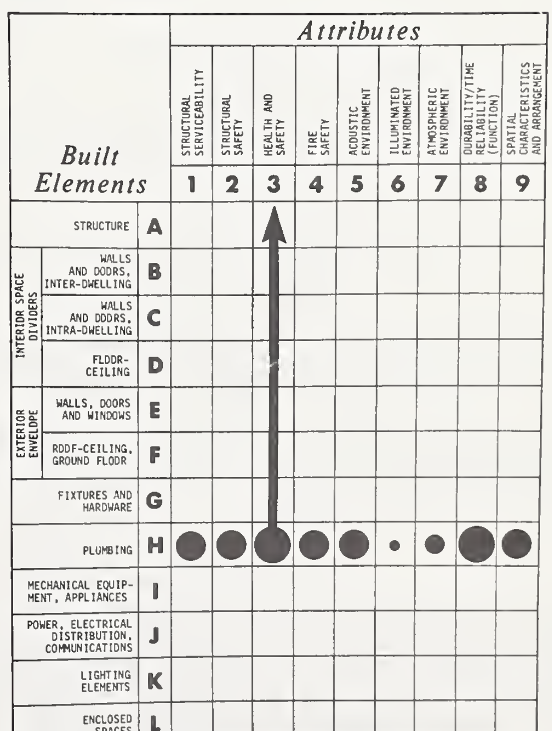

FIGURE 1. *Matrix of performance requirements for buildings.* The relative diameters of the intercept symbols suggest relative significance of the intercepts. The arrow indicates that this presentation is concerned with intercept H-3.

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

buildings sanitary drainage systems must be ventilated to the atmosphere through a separate system of piping connecting to the drainage system at appropriate points. The purpose of the ventilation system is to minimize the pneumatic pressure excursions in the drainage system caused by the intermittent discharge of plumbing fixtures and appliances. Without adequate ventilation excessive pressure excursions would cause the water seals of the fixture and appliance traps to be blown or siphoned out and this action could be accompanied by the ejection of unsanitary, toxic, or malodorous waste water or sewer gases into the building. In European practice the ventilation provided through the upward continuation of the drainage stack (the stack vent) to the outside air is referred to as primary ventilation and the ventilation provided through all other vent piping (vent stack, branch vent, individual vents, relief vent, etc.) is referred to as secondary ventilation.

Since before World War II, several types of sanitary DWV systems have been developed in Europe that virtually eliminated, or greatly reduced the complexity of the traditional secondary ventilation system.

In Europe, normal plumbing loads in many buildings, particularly multistory housing, have been served by 4-in drainage stacks utilizing only primary ventilation to the atmosphere. Two such systems are of Swiss and British design. Recent literature describes these and gives some test results in their design and use [2–9].

Considerable savings in material and labor costs have been reported to be possible through the use of a single-stack drainage system in place of a conventional system. In the United States installation of the single-stack system has been limited to a few localities where a waiver or variance was granted by the local plumbing authority.

The development of the experimental work reported herein came about as the result of a request from Fairfax County, Virginia to make technical recommendations concerning the suitability of such a system in a particular installation.

Throughout the remainder of this report the particular commercially available single-stack system used for this study is referred to as "System X."

Although, there have been some technical reports on System X systems installed in the United States, the configuration of the system proposed for installation in Fairfax County differed from those heretofore employed and the magnitude of the maximum connected fixture load [2] was greater than heretofore placed on this type of system in America. Faced with these considerations, the National Bureau of Standards recommended that tests be made to determine whether or not the proposed system could perform with hydraulic adequacy. The hydraulic adequacy could be established provided the system met the functional requirements of a conventional DWV system, namely:

(1) Maintenance of a barrier against the flow of sewer gas or foul air into the building.
(2) The provision of drainage capacity adequate to carry away normal loads without the overflowing or ejection of waste water within the premises or the backing up of waste in idle drains or fixtures.

Such requirements can be stated more specifically as the following criteria that identify measurable characteristics and thereby permit numerical comparisons:

(1) Maintenance of water seals in fixture traps,
(2) Limitation of pneumatic pressures,
(3) Limitation of hydrostatic and hydrodynamic pressures, and
(4) Limitation of cross-flow between horizontal branches or trap arms.

A test program was developed looking toward the evaluation of the system against the essential criteria. The project was funded jointly by the Copper Development Association and the National Bureau of Standards. The tests were carried out in the laboratories of the Lehrwerkstatten der Stadt Bern, Switzerland. This organization is a well known technical vocational training school for the building trades, that has both the facilities and the experienced personnel to conduct expeditious tests on sanitary drainage systems. Arrangements for appropriate American materials for the tests, and authorization for the Swiss laboratory to conduct the tests were made by technical staff of the Copper Development Association. Staff of the Building Research Division of the National Bureau of Standards recommended the test procedures, monitored the tests conducted in Bern, and processed the data compiled by the Swiss test team.

In a test program such as this, the National Bureau of Standards would normally utilize its own facilities or monitor tests at another laboratory in this country. However, in this case the Swiss laboratory was determined to be the only available laboratory having both the special apparatus and the ability to produce the required types of measurements in the short time available within the schedule of this particular program.

2. Program Plan and Technical Objectives

The program plan adopted was to (1) review available literature on the performance testing of and experience with System X to obtain indications of the probable performance of the system loaded as expected in the proposed application; (2) prescribe test procedures to obtain needed additional performance data; (3) monitor actual testing in Switzerland and interview research experts, plumbing engineers, and others concerning the state of the art and their experience with the use of System X; and (4) make recommendations to Fairfax County.

The technical objectives and the approach employed with respect to each are summarized as follows:

[2] The proposal was made that a 4-inch diameter System X stack would service back-to-back bathrooms serving separate dwelling units on each floor of a 26-story building.

Self-siphonage of fixture traps.

Discussions were held with Swiss investigators concerning this subject, and both American and European literature were identified that provide criteria to guard against self-siphonage. It was not considered necessary to conduct further tests with reference to self-siphonage.

Induced siphonage and back-pressure effects imposed on idle traps by the discharge of other fixtures on the system.

Previous test data of American and European origin were reviewed, and new tests were made on variations of System X simulating the designs proposed for the project in Fairfax County. Also, criteria were identified relating to the control of induced siphonage that might be caused by interaction between fixtures in any single branch-interval.

Cross-flow of waste water from active drains into idle horizontal drains at the junctions of two or more drains.

This aspect of cross-flow was investigated by discussing the matter with Swiss engineers and technologists, by reviewing previous test data and current Swiss plumbing codes, and by making observations in a new series of tests with transparent windows in the critical reaches of the drains.

Effects of additives such as detergents, paper diapers, and sanitary napkins on system performance.

Previous test data involving additives were reviewed, and new tests were made that included the three indicated additives. In the new tests, results were compared for drainage flows with and without additives.

Service experience.

Several Swiss building projects were identified in which large service loads have been placed on these systems, and discussions were held to gain information about the general quality of performance reported.

3. Apparatus and Test Procedures

3.1. Tests on 10-Story Stack

As described above, the facilities employed in the tests were provided by the Lehrwerkstatten der Stadt Bern, Switzerland.[3]

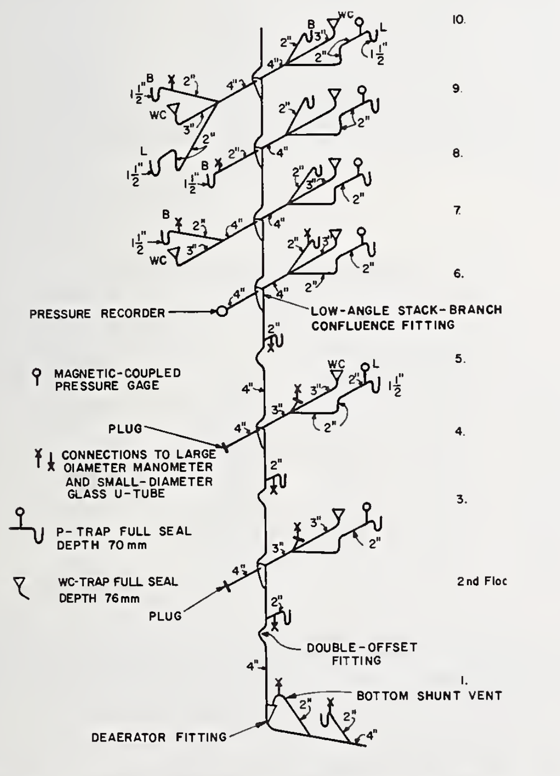

FIGURE 2. *Ten-story laboratory system used in testing for trap-seal retention and pressure excursion caused by interactions between fixtures at different elevations on stack.*

[3] Referred to as "LdSB" in following discussion.

Figure 2 is a schematic of the system utilized in making the multistory stack load tests.

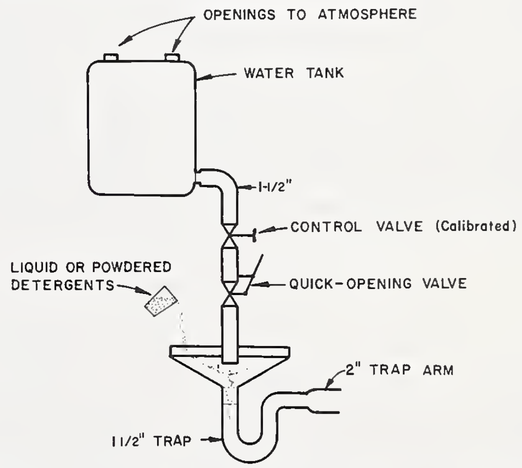

FIGURE 3. *Method for simulating discharge of bathtub or lavatory, and for introducing detergents.*

Figure 3 indicates the use of a plastic tank with preset valve in its drain to simulate the discharge from a lavatory or a bathtub. Also shown is the means employed to introduce detergents into the discharge.

Figure 4 depicts some of the instrumentation utilized for measuring the effects induced in idle traps by the discharge of other fixtures on the system. The glass tube connected to the bottom of the trap permitted observation of the depth of residual trap seal after application of the load, and the sensitive magnetic-coupled gage provided an estimate of the peak pneumatic pressure excursion in the trap arm during the period of the load application. Additional details are given in the appendix.

TABLE 1. *A guide for selecting test loads for multistory plumbing systems* [1]

Size of system [2,3] (Number of connected fixtures)										Number of concurrently operating fixtures to comprise test load [1]
$\frac{t}{T}=0.01$	$\frac{t}{T}=0.02$	$\frac{t}{T}=0.03$	$\frac{t}{T}=0.04$	$\frac{t}{T}=0.05$	$\frac{t}{T}=0.06$	$\frac{t}{T}=0.07$	$\frac{t}{T}=0.08$	$\frac{t}{T}=0.09$	$\frac{t}{T}=0.10$	
$\frac{1}{\tau}$, Probability of overload=0.01 [2]										
1 –15	1 –7	1 –5	1 –4	1 –3	1 –2	1 –2	1 –2	1 –2	1	1
16 –44	8 –22	6 –15	5 –11	4 –9	3 –7	3 –6	3 –5	3 –5	2 –4	2
45 –82	23 –41	16 –27	12 –21	10–16	8 –14	7 –12	6 –10	6 –9	5 –8	3
83 –128	42 –64	28 –43	22 –32	17–26	15–21	13–18	11–16	10–14	9 –13	4
129–178	65 –89	44 –60	33 –45	27–36	22–30	19–26	17–22	15–20	14–18	5
179–233	90 –116	61 –78	46 –58	37–47	31–39	27–33	23–29	21–26	19–23	6
234–291	117–145	79 –97	59 –73	48–58	40–48	34–42	30–36	27–32	24–29	7
292–351	146–175	98 –117	74 –88	59–70	49–58	43–50	37–44	33–39	30–35	8
352–413	176–206	118–138	89 –103	71–83	59–69	51–59	45–52	40–46	36–41	9
414–477	207–239	139–159	104–119	84–95	70–80	60–68	53–60	47–53	42–48	10
$\frac{1}{\tau}$, Probability of overload=0.001 [2]										
1 –5	1 –2	1 –2	1	1	1	1	1	1	1	1
6 –18	3 –9	3 –6	2 –5	2 –4	2 –3	2 –3	2	2	2	2
19 –42	10 –21	7 –14	6 –10	5 –8	4 –7	4 –6	3 –5	3 –5	3 –4	3
43 –73	22 –36	15 –24	11 –18	9 –15	8 –12	7 –10	6 –9	6 –8	5 –7	4
74 –115	37 –58	25 –38	19 –29	16–23	13–19	11–16	10–14	9 –13	8 –12	5
116–152	59 –76	39 –51	30 –38	24–30	20–25	17–22	15–19	14–17	13–15	6
153–193	77 –96	52 –64	39 –48	31–39	26–32	23–28	20–24	18–21	16–19	7
194–242	97 –121	65 –81	49 –60	40–48	33–40	29–35	25–30	22–27	20–24	8
243–291	122–146	82 –97	61 –73	49–58	41–48	36–42	31–36	28–32	25–29	9
292–350	147–175	98 –117	74 –88	59–70	49–58	43–50	37–44	33–39	30–35	10
351–400	176–200	118–133	89 –100	71–80	59–67	51–57	45–50	40–44	36–40	11
401–460	201–230	134–153	101–115	81–92	68–77	58–66	51–58	45–51	41–46	12
$\frac{1}{\tau}$, Probability of overload=0.0001 [2]										
1	1	1	1	1	1	1	1	1	1	1
2 –9	2 –4	2 –3	2	2	2	2	2	2	2	2
10 –23	5 –12	4 –8	3 –6	3 –5	3 –4	3	3	3	3	3
24 –44	13 –22	9 –15	7 –11	6 –9	5 –7	4 –6	4 –6	4 –5	4	4
45 –71	23 –36	16 –24	12 –18	10–14	8 –12	7 –10	7 –9	6 –8	5 –7	5
72 –103	37 –52	25 –34	19 –26	15–21	13–17	11–15	10–13	9 –11	8 –10	6
104–139	53 –69	35 –46	27 –35	22–28	18–23	16–20	14–17	12–15	11–14	7
140–178	70 –89	47 –59	36 –44	29–36	24–30	21–25	18–22	16–20	15–18	8
179–220	90 –110	60 –73	45 –55	37–44	31–37	26–31	23–27	21–24	19–22	9
221–264	111–132	74 –88	56 –66	45–53	38–44	32–38	28–33	25–29	23–26	10
265–311	133–156	89 –104	67 –78	54–62	45–52	39–44	34–39	30–35	27–31	11
312–360	157–180	105–120	79 –90	63–72	53–60	45–51	40–45	36–40	32–36	12
361–411	181–205	121–137	91 –103	73–87	61–68	52–59	46–51	41–46	37–41	13
412–463	206–231	138–154	104–116	88–93	69–77	60–66	52–58	47–51	42–46	14

[1] CAUTION: Tbis table gives no guidance on the selection of particular sequences to be employed in testing with a combination of a selected number of fixtures, nor on which particular fixtures should comprise the test combination. ln testing, it has been customary to seek the "worst case" by trial and error. Research is needed to establish representative values of t and T and to establish typical time distributions of peak use, for different types of fixtures, under service conditions.

[2] Computed from the Poisson probability function. The probability of occurrence of concurrent operations in excess of the number selected for a test load is computed as not greater than the indicated values for service systems not larger than indicated by the stated load range. This probability is termed $\frac{1}{\tau}$ in NBS BMS 65, Methods of Estimating Loads in Plumbing Systems.

[3] The ratio t/T is the individual probability of finding a particular fixture on a service system in operation if observed at random during a typical peak-load period, and is equal to the ratio of time duration of a single operation, t, to the average time between successive operations, T, for that fixture, in the terminology of NBS. BMS 65.

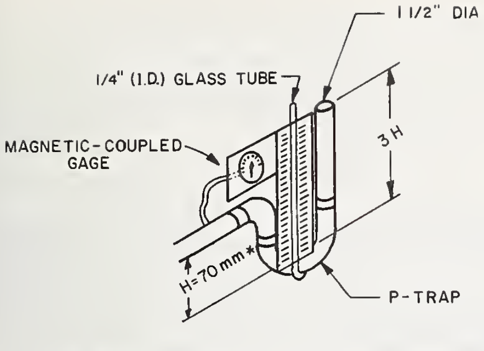

FIGURE 4. *Method for measuring trap-seal retention and peak pressure excursions in trap arm of P-trap.*

3.2 Selection of Test Loads [4]

One of the more difficult aspects of a hydraulic performance evaluation of a plumbing system is the selection of representative test loads.

In choosing test loads for multistory systems, table 1 may be utilized as a guide. This table is based on the Poisson approximation to the binominal probability theorem. It was developed at the National Bureau of Standards, using concepts similar to those that have for some time been utilized by British investigators [10, 11]. Presently, a similar but less comprehensive table appears in the British Code for Plumbing Practice [12]. Table 1 is not unreasonable as a guide for the testing of effects between branch intervals. Table 1A is a guide for selecting test loads to evaluate interactions between fixtures in the same branch interval, derived from Table 1 for a probability of overload, $1/\tau$ [5] $=0.01$ and for a probability of usage $t/T=0.10$. This was used in deciding upon test loads for Plans A and B, described in section 3.3. (See also appendix 7.3)

TABLE 1A. *A guide* [1] *for selecting test loads for single-branch-interval portions of plumbing systems*

Number of fixtures served by piping component being tested	Number of concurrently operating fixtures to comprise test loads
1	1
2	2 [2]
3	2
4	2
5	3
6	3
7	3
8	3
9	4

[1] CAUTION: This table gives no guidance on the selection of particular sequences to be employed in testing with a combination of a selected number of fixtures, nor on which particular fixtures should comprise the test combination. In testing, it has been customary to seek the "worst case" by trial and error.

[2] Also discharge each fixture individually.

[4] Additional discussion is to be found in section 7.2 of the appendix.

[5] In the expression $1/\tau$, τ is the Greek letter "tau".

Table 2, derived from table 1, shows test loads [6] computed for a selected drainage system having 50 bathrooms, each containing a lavatory, a water closet and bathtub. The objective in table 2 was to compute a realistic test load that provided a safety factor to compensate for uncertainties. The principal variables considered in the computation are (a) the probability of the individual fixture types being in operation during "rush hour" periods (as denoted by the ratio t/T; (b) the level of overload risk to be utilized for design $(1/\tau)$; (c) the types of fixtures to be assumed in peak use at the same period of the day; and (d) the vertical distribution to be utilized in introducing the separate fixture discharges comprising the test load.

One possible vertical distribution of each load is shown for a back-to-back bathroom plan (two fixtures of each type on each floor). The separate fixture discharges involved in the test load are more closely grouped in the 10-story test facility than are fixture discharges that would be expected to occur naturally in a 25-story stack. A review of various European data and a discussion with European investigators have indicated that, in laboratory tests, close-together, near-the-top grouping results in generally greater trap-seal reductions and pneumatic pressure excursions than would be obtained with a wider vertical distribution. For this reason, in a service situation, the probability of occurrence of effects similar in magnitude to those produced by the loads shown in table 2 should actually be much less than the value of $1/\tau$ shown.

The fixture-use frequencies (t/T) assumed in computing loads No. 1, 2, and 3 in table 2 are the British values obtained from surveys in flats [13] rounded to the next higher nominal values. The load distribution described in table 2 is a conservative one in which the different elements of the hydraulic load were to be introduced as close to the top of the system as possible with the apparatus that was to be provided at the LdSB. The method used for choosing the numbers of fixtures of each type to be discharged in a mixed system emphasized providing for the full effect of the heaviest loaders [7] as determined separately from table 1, before accounting for simultaneous operation of other lighter-loading fixtures assumed to be in peak use at the same period of the day. The British data indicated that bathtubs do not ordinarily contribute significantly to the morning peak load, hence need not be involved in simulating the morning load. Originally, British investigators believed that the evening peak load for bathrooms should comprise the discharge of water closets and bathtubs, and this assumption has been made in table 2 in computing the types 2 and 4 loads. However, recent British findings have been interpreted to indicate that the bathtub use is scattered over the

[6] At the time the test procedures were developed, the proposed connected load was understood to be 25 pairs of back-to-back bathrooms serving separate dwelling units; hence the computed test loads were for a 50 bathroom system rather than a 52-bathroom system. This is not considered a significant difference.

[7] The term is used here to refer to those fixtures producing the greatest rates of discharge. For the purpose of this presentation the characteristic discharge rate of a fixture is utilized as the measure of the "heaviness" of loading.

TABLE 2. *Hydraulic test loads computed*[1] *for 50-bathroom DWV system*[3] *(to be distributed near top of 10-story test system)*

Load no. and type[2]	Vertical distribution of load on test system for various levels of overload risk, $1/\tau$		
	(A) $1/\tau=0.01$	(B) $1/\tau=0.001$	(C) $1/\tau=0.0001$
1	3 WC's+1 LAV	4 WC's+1 LAV	5 WC's+1 LAV
(Morning peak, WC's+LAV's,[4] worst case) t/T for WC=0.01 t/T for LAV=.01	Floor No. 10 2 WC's=54 gpm for 9 s 1 LAV=10 gpm for 7.5 s Floor No. 9 1 WC=27 gpm for 9 s TOTAL=91 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 1 LAV=10 gpm for 7.5 s Floor No. 9 2 WC's=54 gpm for 9 s TOTAL=118 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 1 LAV=10 gpm for 7.5 s Floor No. 9 2 WC's=54 gpm for 9 s Floor No. 8 1 WC=27 gpm for 9 s TOTAL=145 gpm
2	3 WC's+5 BT's	4 WC's+6 BT's	5 WC's+6 BT's
(Evening peak, WC's+BT's worst case) t/T for WC=0.01 t/T for BT=.05	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 1 WC=27 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 1 BT=12 gpm for 1.7 min TOTAL=141 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 2 BT's=24 gpm for 1.7 min TOTAL=180 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 1 WC=27 gpm for 9 s 2 BT's=24 gpm for 1.7 min TOTAL=207 gpm
3	3 WC's+7 BT's+1 LAV	4 WC's+9 BT's+1 LAV	5 WC's+10 BT's+1 LAV
(Composite peak, WC's, LAV's, BT's—worst case) t/T for WC=0.01 t/T for LAV=.01 t/T for BT=.05	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min 1 LAV=10 gpm for 7.5 s Floor No. 9 1 WC=27 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 2 BT's=24 gpm for 1.7 min Floor No. 7 1 BT=12 gpm for 1.7 min TOTAL=175 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min 1 LAV=10 gpm for 7.5 s Floor No. 9 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 2 BT's=24 gpm for 1.7 min Floor No. 7 2 BT's=24 gpm for 1.7 min Floor No. 6 1 BT=12 gpm for 1.7 min TOTAL=226 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min 1 LAV=10 gpm for 7.5 s Floor No. 9 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 1 WC=27 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 7 2 BT's=24 gpm for 1.7 min Floor No. 6 2 BT's=24 gpm for 1.7 min TOTAL=265 gpm
4	5 WC's+3 BT's	6 WC's+4 BT's	8 WC's+3 BT's
(Evening peak, WC's+BT's, worst case) t/T for WC=0.03 t/T for BT=.03	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 2 WC's=54 gpm for 9 s 1 BT=12 gpm for 1.7 min Floor No. 8 1 WC=27 gpm for 9 s TOTAL=171 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 8 2 WC's=54 gpm for 9 s TOTAL=210 gpm	Floor No. 10 2 WC's=54 gpm for 9 s 2 BT's=24 gpm for 1.7 min Floor No. 9 2 WC's=54 gpm for 9 s 1 BT=12 gpm for 1.7 min Floor No. 8 2 WC's=54 gpm for 9 s Floor No. 7 2 WC's=54 gpm for 9 s TOTAL=252 gpm

[1] Computed as described in section 3.2. The discharge rates assumed for fixtures are generally similar to those recommended in the National Plumbing Code Handbook, by Vincent T. Manas, (McGraw-Hill, 1953). The term "t" is the average duration of a single discharge, and "T" is the average time between successive uses of the fixture during the period of maximum usage.

[2] Various other loads can be computed, depending on the values of t/T and on concurrence of peak usage periods for the different types of fixtures.

[3] Back-to-back arrangement assumed in choosing spatial distribution of fixtures discharged together.

[4] Abbreviations are WC for water closet, LAV for lavatory, and BT for bathtub.

evening hours, and that the "evening peak" for bathrooms may be expected to produce loads of lower magnitude than the morning peak.

The essential steps followed in computing the loads in table 2 were:

Loads No. 1 and No. 4

Two types of fixtures with the same value of t/T are involved. load No. 1 will be processed first.

Step 1: Consider the heaviest loaders separately; i.e., WC's,[8] which in this design are 50 in number. By the use of table 1, find in the column for $t/T=0.01$, the location of the numbers that would bracket the number 50. From this location move in the same row across the table to the column that gives the "Number of concurrent operating fixtures to comprise test load."

Step 2: Consider the total number of fixtures of concern in this example (50 WC's and 50 LAVS = 100). Find in the column for $t/T=0.01$ the location of the numbers that bracket the number 100. Then in the same row move across the table to the column "Number of concurrently operating fixtures to comprise test load."

Step 3: Obtain the number of non-WC fixtures to be discharged by subtracting the number of WC's obtained in step 1 from the total number of all fixtures to be discharged that was obtained in step 2.

The use of table 1 is very similar for load 4 as for load 1. For step 1 the value of 50 WC's will be located in the column where $t/T=0.03$. Likewise in step 2 the value of 100 for WC's plus BT's will be located in the same column.

Load No. 3

Three types of fixtures with two or more different values of t/T are involved. In this type of load, it is assumed that the peak-load conditions for all fixture types involved occur at the same time of day.

Step 1: Same as step 1 for loads no. 1 and no. 4.

Step 2: Based on the average value of t/T for all non-WC fixtures considered as a composite group, obtain from table 1 the total number of fixtures to be discharged from this group.

Step 3: Consider the second-heaviest loaders separately; i.e., bathtubs. For this group, find the number to be discharged, based on its assumed value of t/T.

Step 4: Obtain the number of fixtures of the third-heaviest loading type, if any, to be discharged, by subtracting the number obtained in step 3 from the number obtained in step 2.

Load No. 2

Two types of fixtures with different values of t/T are involved.

Step 1: Same as step 1 for loads no. 1 and no. 4.

Step 2: Based on the average value of t/T for both fixture types, find the total number of fixtures to be discharged.

Step 3: Same as step 3 for loads no. 1 and no. 4.

It has been customary to design with a risk of overload, $1/\tau$, of 0.01. Table 1 provides the means for selecting loads with values of $1/\tau$ of 0.01, 0.001, and 0.0001. Table 2 gives computed loads at all three levels.

Because conventional vented 4-in systems are not designed to carry a simultaneous discharge exceeding 144 gpm based on $1/\tau = 0.01$, it may not be reasonable to employ test discharges exceeding this value in evaluating innovative systems.

Large safety factors probably are associated with the loads shown in tables 2 and 3 for the following two reasons: first, the assumption that the peak load from mixed fixtures will always include the computed peak load from the water closet group is quite unlikely; and second, the arbitrary grouping of fixture discharges near the top of the stack would not be representative of the normal service loading pattern which would tend to be distributed over the height of the stack. The close-together distribution tends to produce more severe hydraulic and pneumatic effects than practically all other distributions that might be expected to occur with natural loading.

Because the stack as actually constructed and as illustrated in figure 2 did not provide for introduction of all the hydraulic load elements at exactly the same elevations called for in table 2, some modifications in vertical distribution were required. Referring to table 3 for the loads actually used in the multistory tests, it will be seen that additional loads were tried, that included the discharge of six bathtubs, the intentional modifications in vertical distribution of loads 1A and 1B, and the addition of solids or detergents to some of the loads for comparison with clean water. Also, one new load was applied for the purpose of studying the effect of a time delay in discharging the load at the lower floor of a two-floor concurrent hydraulic load.

3.3. Tests on Single-Interval Systems

Figures 5 and 6 show two arrangements of branch piping tested for possible hydraulic and pneumatic interactions between different fixtures on a given floor. These arrangements are designated "Plan A" and "Plan B." These were considered the arrangements most likely to be used in the project in Fairfax County.

[8] To facilitate tabular presentation of data abbreviations for fixtures have been used as follows: WC's = Water Closets, LAVS = Lavatories and BT's = Bathtubs.

TABLE 3. *Hydraulic test loads applied to 10-story system shown in figure 2*

Test No.	Type of load	Flow rate	Additives	Vertical distribution of fixtures discharged				Equivalent fixture-unit load [13]
				Floor 10	Floor 9	Floor 8	Floor 7	
		gpm						
1A [1]	Simultaneous	91	None	2 WC 1 LAV	—	1 WC	—	200
1A * [2]	Simultaneous	91	None	1 WC 1 LAV	1 WC	1 WC	—	200
1B [1]	Simultaneous	118	None	2 WC 1 LAV	—	2 WC	—	350
$1B_{1.5\ dcw}$	Time-delay [14]	118	None	2 WC 1 LAV	—	2 WC	—	350
$1B_{3.0\ dcw}$	Time-delay [14]	118	None	2 WC 1 LAV	—	2 WC	—	350
$1B_{4.5\ dcw}$	Time-delay [14]	118	None	2 WC 1 LAV	—	2 WC	—	350
$1B_{1.5\ d\ D}$	Time-delay [14]	118	Paper diaper [4]	2 WC(1W/D) [16] 1 LAV	—	2 WC	—	350
$1B_{3.0\ d\ D}$	Time-delay [14]	118	Paper diaper [4]	2 WC(1W/D) 1 LAV	—	2 WC	—	350
$1B_{4.5\ d\ D}$	Time-delay [14]	118	Paper diaper [4]	2 WC(1W/D) 1 LAV	—	2 WC	—	350
1B * [3]	Simultaneous	118	None	1 WC 1 LAV	1 WC	1 WC	1 WC	350
$1B\ *_{D}$	Simultaneous	118	Paper diaper [4]	1 WC(W/D) 1 LAV	1 WC(W/D)	1 WC	1 WC(W/D)	350
$1B\ *_{N}$	Simultaneous	118	Sanitary Napkin [5,6]	1 WC(W/SN+TP) 1 LAV	1 WC(W/SN+TP)	1 WC	1 WC(W/SN+TP)	350
1C	Simultaneous	145 [7]	None	2 WC 1 LAV	1 WC	1 WC	1 WC	515
$2A_{DET}$	Simultaneous	141	Detergent [8,9]	1 WC 2 BT(1W/DET)	1 WC 2 BT	1 BT(W/DET)	1 WC	487
2B	Simultaneous	180 [10]	None	2 WC 2 BT	1 WC 2 BT	1 WC 2 BT	—	770
5	Simultaneous	72 [15]	None	2 BT	1 BT	2 BT	1 BT	
5_{DET}	Simultaneous	72 [15]	Detergent [11]	2 BT(1W/DET)	1 BT(W/DET)	2 BT	1 BT (W/DET)	
6	Simultaneous	99 [12]	None	2 BT	1 WC 1 BT	2 BT	1 BT	245

[1] Identical to computed loads in table 2, except computed 9th floor load introduced at 8th floor instead.
[2] Load 1A * is a slightly more uniform vertical distribution than 1A.
[3] Load 1B * is a slightly more uniform vertical distribution than 1B.
[4] One paper diaper, large-size, flushed in each WC indicated, without removing plastic membrane.
[5] One sanitary napkin, large size (SN), flushed together with toilet tissue described in [6].
[6] Three loosely-wadded balls of 4 double-thickness squares of toilet tissue, (TP) in each WC indicated.
[7] Load is a slightly more uniform distribution than computed in table 2.
[8] Type 2 detergent, 3.1 ml in 200 ml water solution introduced through bathtub drain in 12 s.
[9] Load is a slightly more uniform vertical distribution than computed from table 1.
[10] Identical distribution to that computed in table 2.
[11] Type 1 laundry detergent powder, 74 cc in water solution introduced through bathtub drain in 1 min.
[12] Identical load to No. 5, except that discharge of 1 WC on 9th floor has been added.
[13] Equivalent fixture-unit values read from Hunter's curve for systems employing flush-valve WC's (see NBS, BMS 65, BMS 79), except as indicated in note 15 below.
[14] Time delay of 1.5, 3.0, or 4.5 sec after discharge of 10th floor load; then 8th floor load discharged. cw=clean water, D=paper diaper, N=sanitary napkin and d=delay in seconds.
[15] Since this load did not involve WC's, no equivalent fixture-unit load is given. However, if a value t/T=0.04 and $1/\tau$=0.01 are assumed, a test load of 6 fixtures is obtained from table 2 for a system comprising 46-58 fixtures of a type likely to be subject to maximum usage at a particular time of the day. Final plans called for a maximum of 52 bathtubs on each stack in the project in Fairfax County.
[16] Abbreviations in parentheses such as 2WC (1W/D) means two WC's were discharged (one with diaper). Similarly other abbreviations used are SN for sanitary napkin, TP for toilet paper and DET for detergent.

Tables 4 and 5 describe the tests performed on the two single-interval systems. Table 6 describes four variations in piping arrangement tried in the tests with the Plan B system.

4. Results

4.1. Tests on 10-Story Stack

Table 7 shows for each floor the relative trap-seal retention in the 1½ in lavatory P-trap, for various applied loads. Table 7A shows similar data for WC trap-seal retention employing a number of time-sequence variations of a given combination of fixtures. In none of these measurements was the average retention less than 56 percent of the maximum trap-seal depth, which was 70 mm (about 2¾ in) for the P-trap and about 76mm (3 in) for the WC trap. Thus there was in excess of 1½ in of average residual trap seal, even with the heaviest loads employed in obtaining the data shown.

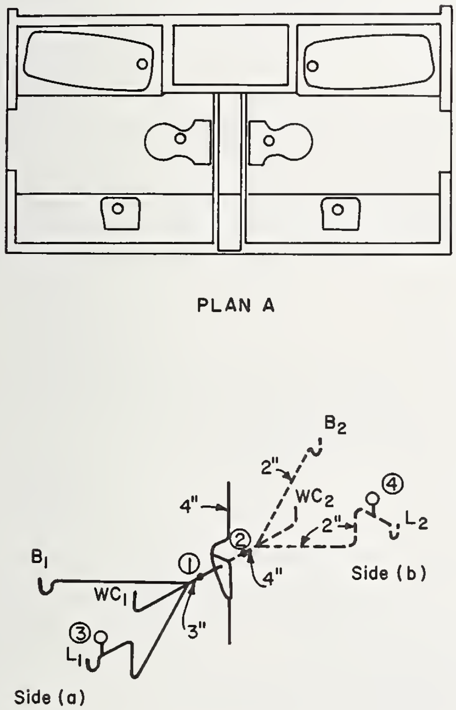

Figure 5. *Single-branch-interval element, Plan "A", used in testing for trap-seal retention and pressure excursion caused by interactions between fixtures within the same branch interval.*

1, 2 Transparent windows in top of drain for observation of maximum depth of water in branch.

3, 4 Magnetic-coupled pressure gages for observation of peak pressure excursions in trap arms.

Side (a) System actually tested (3-in combination soil-and-waste branch).

Side (b) System not tested (4-in combination soil-and-waste branch).

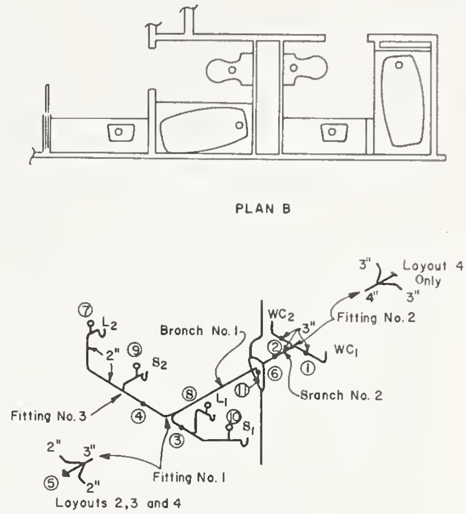

Figure 6. *Single branch-interval element, Plan "B", used in testing for trap-seal retention and pressure excursions caused by interactions between fixtures within the same branch interval.*

1, 2, 3, 4, 6 Stations for observing maximum depth of water and/or pneumatic pressure in branches.
3, 4 These stations were equipped with transparent windows in top of branches.
5 This station was equipped with transparent window at heel of fitting, for observation of flow in 3-in waste branch.
7, 8, 9, 10 Magnetic-coupled pressure gages for observation of peak pressure excursions in trap arms.
11 Transparent window in side of aerator fitting to permit observation of flow inside fitting.

Table 4. *Description of tests made on single-interval test system, plan A*[1]

Test load number	Number of runs	Loading conditions [2]	
		Fixtures operated	Material discharged [3]
1	4	WC	CW
2	3	WC	CW+Paper diaper
2C [4]	2	WC	CW+Paper diaper
3	4	WC+B	CW
3_D [5]	4	WC+B	CW in both, + Paper diaper in WC
3_{D+DET}	4	WC+B	CW+Paper diaper in WC, 0.0043 concentration Type 3 detergent in bathwater

[1] See figure 5 and table 1A.
[2] Multiple-fixture loads involved simultaneous discharge of indicated fixtures: WC=water closet and B=bathtub.
[3] CW=clean water. Paper diaper test load involved flushing one diaper, including plastic membrane.
[4] This load similar to no. 2; but was more severe because diaper was wetted, wadded into round-ball shape, and carefully placed in WC bowl in this shape just before flushing. Idle P-trap simulating lavatory trap was not refilled after the first run, thus providing a 2-run cumulative series.
[5] Subscript abbreviations are D for diaper and DET for detergent.

Table 5. *Description of tests made on single-interval test system, plan B* [1]

Test load	No. runs	Fixtures operated	Loading conditions Time sequence	Material discharged [3]	Piping Arrangement
1	2	L_1	Single-fixture load	CW	Layout 1
2	1	L_2	"	CW	"
3	4	B_1	"	CW	"
	4	B_1	"	CW	" 3
3^4_{DET}	1 [2]	B_1	"	0.00043 concentration type 3 detergent in bathwater	" 3
4	2	B_2	"	CW	" 1
	2	B_2	"	CW	" 3
4_{DET}	2	B_2	"	0.00043 concentration type 3 detergent in bathwater	" 3
5	4	WC_1	"	CW	" 3
5_D	4	WC_1	"	CW+Paper diaper	" 3
	2	WC_1	"	CW+Paper diaper	" 4
6	4	WC_2	"	CW	" 3
7	3	B_1+B_2	Simultaneous	CW	" 1
	3	"	"	CW	" 2
	4	"	"	CW	" 3
8	2	L_1+B_1	L_1 ended discharge before B_1	CW	" 1
9	1	L_1+B_1	B_1 ended discharge before L_1	CW	" 1
10	1	L_2+B_2	L_2 ended discharge before B_2	CW	" 1
11	2	L_1+B_2	Discharges ended same time	CW	" 3
11_{DET}	3	L_1+B_2	Discharges began same time	0.00043 concentration type 3 detergent in bathwater	" 3
12	4	WC_1+WC_2	Simultaneous	CW	" 3
	3	"	"	CW	" 4
12_D	3	"	"	CW, paper diaper in WC_1	" 3
	4	"	"	CW, paper diaper in WC_1	" 4

[1] See figure 6 and tables 1A and 6. Here L=lavatory, B=bathtub and WC=water closet.
[2] Followed by 3 additional runs without refilling trap, yielding a 4-run cumulative seal-reduction series.
[3] CW=Clean water. Paper diaper, test load involved flushing diaper, including plastic membrane.
[4] Subscript abbreviation are D for diaper and DET for detergent.

Table 6. *Description of four variations in piping arrangement for single-interval test system, plan B.* [1]

Layout [1] no.	Fitting size and type [2]						Branch diameter	
	No. 1		No. 2		No. 3			
	Size	Type	Size	Type	Size	Type	No. 1	No. 2
	in		in		in		in	in
1	2×2×2	ST	3×3×3	ST	2×2×2	ST	2	3
2	3×3×2×2	LT	3×3×3	ST	2×2×2	ST	3	3
3	3×3×2×2	LT	3×3×3	ST	2×2×2	LT	3	3
4	3×3×2×2	LT	4×4×3×3	LT	2×2×2	LT	3	4

[1] See figure 6 and table 5.
[2] Short-turn (ST), short-radius pattern; or long-turn (LT), long-radius pattern.

TABLE 7. *Relative trap-seal retention in 10-story stack tests resulting from loads of table 3.*

Average [4] relative P-trap seal retention, $\left(1-\frac{\Delta H}{H}\right)$ [5]										
Test										Floor
1A	1A *	1B	1B *	$1B\,*_D$ [7]	$1B\,*_N$	1C	5	5_{DET}	6	
0.97	0.98	0.98	0.97	0.93 [3]	0.98	0.97	0.99 [1]	0.99 [3]	1.00 [2]	10
.98	.98	.99	.98	0.97 [3]	.97	.99	.96 [1]	-- [6]	.97 [2]	9
.92	.94	.90 [1]	.93	.89	.93	.93	96 [1]	.96 [3]	.96 [2]	8
.91	.91	.90	.87	.81	.88	.85	.86 [1]	.87 [3]	.87 [2]	7
--	--	--	--	--	--	--	--	--	--	6
.74	.71	.65	.68	.61	.64	.59	.71 [1]	.60 [3]	.60 [2]	5
--	--	--	--	--	--	--	--	--	--	4
.70	.81	--	.62	69	.72 [3]	.56 [3]	67 [1]	.68 [3]	.65 [2]	3
--	--	--	--	--	--	--	--	--	--	2
--	--	--	--	--	--	--	--	--	--	1

[1] Single run only.
[2] Average of two runs.
[3] Average of three runs.
[4] Average of four identical runs, except where otherwise indicated.
[5] $\frac{\Delta H}{H}$ is the relative trap-seal reduction, where "ΔH" is the average reduction and "H" is the full trap-seal depth.
[6] Dash-marks indicate either no data were taken, or that the data taken were irrelevant to the particular tabulation. Trap-seal measurements were not obtained at floors 1, 2, 4, and 6.
[7] Subscripts are abbreviations of D for diaper, N for sanitary napkin, and DET for detergent.

TABLE 7A. *Relative trap-seal retention in 10-story stack tests resulting from different time sequence variations of load 1B* [1]

Relative WC trap-seal retention [2], $\left(1-\frac{\Delta H}{H}\right)$ [3]							Floor
Test load [5]							
$1B_{scw}$	$1B_{1.5dcw}$	$1B_{1.5dD}$	$1B_{3.0dcw}$	$1B_{3.0dD}$	$1B_{4.5dcw}$	$1B_{4.5dD}$	
----- [6]	1.00	0.99	0.99	1.00	1.00	0.98	9
0.98 [4]	0.97	0.98	.98	0.99	0.98	.99	7
-----	.87	.85	.88	.83	.90	.85	5
-----	.90	.91	.93	.89	.91	.90	3

[1] Loads described in table 3 (clean water and paper diapers).
[2] Average of 3 identical runs, except where otherwise indicated.
[3] $\frac{\Delta H}{H}$ is the relative trap-seal reduction where "ΔH" is average reduction and "H" is full trap-seal depth.
[4] Average of 4 identical runs.
[5] Symbols: cw=clean water; *D*=diaper; s=simultaneous; d=time delay. (Example: $1B_{3.0dD}$ represents Load 1B with a 3.0 sec time delay, with a paper diaper included in the discharge from the 10th floor (see table 3)).
[6] Dash-marks indicate either no data were taken, or that the data taken were irrelevant to the particular tabulation. Trap-seal measurements were not obtained at floors 1, 2, 4, and 6.

Trap seals were excessively depleted in two tests, to the extent that one or more seals were lost on the lower floors. These tests were $2A_{DET}$ (a 141 gpm total load with detergent, equivalent to about 487 fixture units [9]), and 2B (a 180 gpm total load with clean water, equal to about 770 fu [9]), as shown in table 3. There was no suitable basis for predicting whether the system would or should successfully withstand these unusually large loads, so tests were made to explore the matter. In evaluating the results of tests $2A_{DET}$ and 2B, the following considerations are relevant:

1. With loads of these magnitudes, many plumbing codes require 5-in soil stacks with conventional venting.
2. The design hydraulic capacity of vented 4-in drainage stacks is approximately 144 gpm [14,15].
3. A rational plan for experimentation should include a number of loads of different magnitudes ranging up to levels that result in failure. Tests $2A_{DET}$ and 2B provided this feature.
4. The purpose of introducing detergent into the soil stack in these tests was to obtain some data on the general phenomena of detergent action in DWV systems. Actually, only bathroom fixtures were planned for the stacks in the project under consideration. As indicated in (6) below, existing criteria do not provide for estimating relative capacities of conventional versus single-stack systems with detergent loads.
5. Because conventional systems have not generally been tested in the manner described herein, it does not seem purposeful to speculate on the relative performance of conventional versus System X at load levels approaching and exceeding the generally accepted design loads for conventional systems.
6. The generally accepted criteria for sizing conventional soil and waste stacks recommended by Hunter [16,17,18] and by Dawson and Kalinske [19, 20] and further described by Wyly and Eaton [15] were developed before synthetic detergents were in general use. For this reason, estimates of relative maximum carrying capacities of single-stack and conventional vented systems with detergents seem to be largely conjectural in the absence of suitable research on this matter.

Table 8 shows the ratio between trap-seal reductions in the WC trap and the lavatory P-trap as determined at two or three different floors for each of several different loads. These data show that trap-seal reduction for the WC trap averaged only 40 percent as much as for the P-trap.

A number of tests were made to explore the effects of sanitary napkins, paper diapers, and detergents on trap-seal retention (tables 8A and 8B). Such additives evidently caused scatter in the data. More testing would have provided an improved statistical basis for conclusions on these matters. In the tests made, the relative trap-seal retention with diapers was not reduced by more than 0.07 below the corresponding values obtained with clean water. Similarly, the corresponding maximum reduction for sanitary napkins and detergents were 0.04 and 0.11, respectively.

[9] Fixture-unit values were obtained from "Hunter's Curve" for drainage systems, following the method outlined in certain NBS publications [15, 16, 17]. The term fixture-unit, abbreviated herein as fu, is a measure of the probable discharge into the drainage system by various types of plumbing fixtures. The fixture-unit value for a particular fixture depends on its volume rate of drainage discharge, on the time duration of a single drainage operation, and on the average time between successive operations during peak-use periods

TABLE 8. *Ratio of average seal reduction in WC trap to that in P trap with various loads*

Load [1]	Floor	No. runs for each trap WC/P	Ratio $\Delta H_{wc}/\Delta H_p$ [2]
1A *	7	--- [3]	---
	5	4/4	0.28
	3	2/3	.50
1B *	7	---	---
	5	4/4	.32
	3	4/4	.39
$1B *_D$ [4]	7	---	---
	5	4/4	.35
	3	4/4	.37
$1B *_N$	7	---	---
	5	4/4	.24
	3	3/4	.39
1C	7	---	---
	5	4/4	.29
	3	3/3	.42
5	7	1/1	.20
	5	1/1	.50
	3	1/1	.43
5_{DET}	7	3/3	.45
	5	3/3	.66
	3	3/3	.63
6	7	2/2	.28
	5	2/2	.54
	3	2/2	.43
			Avg. 0.40

[1] See table 3 for description of loads.
[2] Based on average values from indicated numbers of identical runs. "ΔH" is trap-seal reduction produced by the indicated load. Identical units used for ΔHwc and ΔHp in computing the ratio.
[3] Dash-marks indicate either no data were taken, or that the data taken were irrelevant to the particular tabulation. Trap-seal measurements were not obtained at floors 1, 2, 4, and 6.
[4] Subscripts are abbreviations of D for diaper, N for sanitary napkin, and DET for detergent.

Observations were also made for the effects of sanitary napkins, paper diapers, and detergents on pneumatic pressure excursions in the soil and waste branches. The data for sanitary napkins and paper diapers are rather erratic; their true effects on pressures are not altogether clear, partly because of an insufficient number of replicate measurements. The detergent data show considerable increase in momentary pneumatic pressure excursions in the majority of the tests.

The data in tables 7 and 7A show an average trap-seal retention of more than 1½ in for every test condition. With the heavier loads, considerable scatter in the data was observed from run to run, especially with detergents and paper diapers.

Table 8A. *Effects on trap-seal retention*[1] *caused by additives to simultaneous hydraulic loads*

Additive	Floor	Relative trap-seal retention $\left(1-\frac{\Delta H}{H}\right)$[4]		
		Clean water[2]	Additive[2]	Change[3]
Paper diaper (loads 1B * and 1B $*_D$)[2]	7	0.87	0.81	−0.06
	5	.68	.61	− .07
	3	.62	.69	+ .07
Sanitary napkin (loads 1B * and 1B $*_N$)[2]	7	.87	.88	+ .01
	5	.68	.64	− .04
	3	.62	.72	+ .10
Detergent (loads 5 and 5_{DET})[2]	7	.86	.87	+ .01
	5	.71	.60	− .11
	3	.67	.68	+ .01

[1] Data from table 7.
[2] Loads described in table 3.
[3] A positive change (+) indicates greater relative retention with the additive, and a negative change (−) indicates less retention with the additive.
[4] "ΔH" is trap-seal reduction; "H" is the full trap-seal depth.

Table 8B. *Effects on trap-seal retention*[1] *caused by paper diapers with time- sequence variations* of load 1B[2]

Floor	Time delay (sec)	Relative trap-seal retention $\left(1-\frac{\Delta H}{H}\right)$[4]		
		Clean water	Diaper	Change[3]
7	1.5	0.97	0.98	+0.01
	3.0	.87	.85	− .02
	4.5	.90	91	+ .01
5	1.5	.98	.99	+ .01
	3.0	.88	.83	− .05
	4.5	.93	.89	− .04
3	1 5	.98	.99	+ .01
	3.0	.90	.85	− .05
	4.5	.91	.90	− .01

[1] Data from table 7A.
[2] Loads described in table 3.
[3] A positive change (+) indicates greater relative retentionwith the diaper load; a negative change (−) indicates less relative retention with the diaper load.
[4] "ΔH" is trap-seal reduction; "H" is the full trap-seal depth.

4.1.1. Relation between Trap-Seal Reduction and Pneumatic Pressure

The data in tables 9A and 9B have been presented in a form that reveals the consistency of the relationship between trap-seal reductions and the pneumatic pressure excursions causing such reductions. Although the data do not possess strong statistical attributes, it is apparent that the trap-seal reductions were in most instances less than the corresponding maximum negative pressure excursions, particularly for the WC traps. The data suggest that in cases involving relatively large pulsating pressure changes, the rocking of the water in the trap seals might have been the cause of greater trap-seal reductions than would be expected from the assumption of steady-state pressure differentials.

As discussed in the appendix in paragraph 7.1, the pressure measurements made in the 10-story tower and reported herein were made using the battery of basement manometers. Apparently the correlation between dynamic pressures measured by four different methods was poor; so for the purposes of analysis it was decided to utilize the measurements taken on the basement manometer battery, in keeping with the usual practice at the LdSB.

Generally, the ratio between pressure excursion and trap-seal reduction was more consistent for the WC trap than the smaller P-trap, and trap-seal reduction in relation to pressure excursion was relatively less for the WC trap than the P-trap. Probably this was because of the greater mass of water in the water-closet trap, a condition which tends to give greater stability and resistance to adverse effects from transient phenomena such as rapidly fluctuating pneumatic pressures. Averaging values in table 9A (for those loads not involving the discharge of bathtubs) shows that trap-seal reduction in the P-traps was about 78 percent of the pressure excursion for both positive and negative pressures. Average trap-seal reduction for the water-closet was about 29 percent of the average of the peak negative pressure values and 35 percent of the corresponding average of positive pressure values. These compare with a similarly derived ratio of about 67 percent reported by Lilly-

Table 9A. *Ratio of average*[1] *trap-seal reduction to average*[1] *pneumatic-pressure excursion for loads not involving bathtubs.*

Load	Floor	Ratio $\frac{\Delta H}{\Delta P}$ [2] P-trap		WC trap	
		−	+	−	+
1A	8	0.57_3	0.49_3	---	---
	7	$.47_3$	$.47_3$	---	---
	5	1.01_3	$.79_3$	---	---
	3	0.85_3	1.42_3	---	---
1A *	8	0.40	0.45	---	---
	7	.74	.47	---	---
	5	1.32	1.97	0.37	0.55
	3	0.74	0.87	$.37_3$	$.43_2$
1B	8	---[3]	---	---	---
	7	0.48	0.32	---	---
	5	.53	.99	---	---
	3	---	---	---	---
$1B_{1.5d\,cw}$ [4]	8	---	---	---	---
	7	---	---	0.24_3	0.08_3
	5	---	---	$.30_3$	$.43_3$
	3	---	---	$.31_3$	$.54_3$
$1B_{1.5dD}$ [4]	8	---	---	---	---
	7	---	---	0.10_3	0.05_3
	5	---	---	$.34_3$	$.19_3$
	3	---	---	$.21_3$	$.29_3$
$1B_{3.0d\,cw}$	8	---	---	---	---
	7	---	---	0.14_3	0.12_3
	5	---	---	$.43_3$	$.47_3$
	3	---	---	$.27_3$	$.33_3$
$1B_{3.0dD}$	8	---	---	---	---
	7	---	---	0.03_3	0.04_3
	5	---	---	$.66_3$	$.39_3$
	3	---	---	$.48_3$	$.25_3$
$1B_{4.5d\,cw}$	8	---	---	---	---
	7	---	---	0.14_3	0.07_3
	5	---	---	$.31_3$	$.44_3$
	3	---	---	$.30_3$	$.29_3$
$1B_{4.5dD}$	8	---	---	---	---
	7	---	---	0.13_3	0.04_3
	5	---	---	$.35_3$	1.17_3
	3	---		$.30_3$	0.30_3
1B *	8	0.50	0.67	---	---
	7	.88	.46	---	---
	5	1.25	1.57	0.40	0.50
	3	0.82	0.74	.32	.29
$1B\,*_N$	8	0.48	0.95	---	---
	7	.88	.54	---	---
	5	.96	1.85	0.23	0.44
	3	.79	0.67	$.31_3$	$.26_3$
$1B\,*_D$	8	0.78	0.89	---	---
	7	1.33	.36	---	---
	5	0.94	.23	0.33	0.79
	3	.66	.12	.25	.27
1C	8	0.42	0.21	---	---
	7	.51	.22	---	---
	5	1.05	1.21	---	---
	3	0.89	0.92	---	---
Av., all values		−0.78	+0.79	−0.29	0.35

[1] Average of 4 identical runs, except where otherwise indicated. Subscripts on listed values indicate number of runs when less than four.

[2] ΔP is pressure excursion in trap arm or horizontal branch produced by indicated load (see table 3), and ΔH is the reduction in trap-seal depth, both expressed in identical units of water column.

[3] Dash-marks indicate no data were taken, or that the data taken were irrelevant to the particular tabulation. Trap-seal measurements were not obtained at floors 1, 2, 4, and 6.

[4] Subscripts are abbreviations of cw for clear water, d for delay in seconds, D for diaper, and N for sanitary napkin.

TABLE 9B. *Ratio of average*[1] *trap-seal reduction to average*[1] *pneumatic-pressure excursion for loads involving bathtubs.*

Load	Floor	Ratio $\frac{\Delta H}{\Delta P}$ [2]			
		P-Trap		WC Trap	
		—	+	—	+
5	8	---[3]	---	---	---
	7	1.43_1	0.50_1	0.29_1	0.10_1
	5	1.33_1	2.00_1	$.67_1$	1.00_1
	3	2.30_1	2.30_1	1.00_1	1.00_1
5_{DET}	8	---	---	---	---
	7	$.97_3$	0.83_3	0.43_3	0.37_3
	5	1.29_3	2.80_3	$.85_3$	1.83_3
	3	1.00_3	1.08_3	$.63_3$	0.68_3
6	8	0.40_2	0.24_2	---	---
	7	1.20_2	3.60_2	0.33_2	1.00_2
	5	1.40_2	2.24_2	$.75_2$	1.20_2
	3	1.09_2	1.40_2	$.47_2$	$.60_2$
Av., all values		-1.24	$+1.70$	-0.60	$+0.86$

[1] Subscripts on listed values indicate number of runs.
[2] ΔP is pressure excursion in trap arm or horizontal branch produced by indicated load (see table 3) and ΔH is the reduction in trap-seal depth, both expressed in identical units of water column.
[3] Dash-marks indicate either no data were taken, or that the data taken were irrelevant to the particular tabulation. Trap-seal measurements were not obtained at floors 1, 2, 4, and 6.

white and Wise [21] for British washdown water closets, the traps of which hold less water than do those of the American WC's used in these tests.

The data for tests involving bathtubs (see table 9B) yielded noticeably different ratios. For three tests (5, 5_{DET}, and 6) average trap-seal reduction in the P-trap was 1.24 times the average value of peak negative excursions and 1.70 times that for the corresponding average of positive pressure values. Average trap-seal reduction in the WC trap was 0.60 times the average value of the peak negative pressure excursions and 0.86 times the corresponding average of positive pressure values.

These results suggest that water closet traps of the type used in the tests resist trap-seal reduction more successfully than small-bore P-traps. The results also suggest that if trap-seal retention is taken as the criterion of hydraulic performance, hydraulic loads that are of short duration or of transient nature (such as the composite discharges from WC's and LAV's) tend to produce less trap-seal reduction in idle traps for a given magnitude of pressure excursion than do long-duration, near-steady-rate composite loads such as bathtub discharges.

4.1.2. Effects of Load Distribution by Elevation and Time Sequence

Tests with multi-fixture simultaneous loads in which two or more of the vertical distributions of load elements were tried, showed that in most cases pneumatic pressure excursions were reduced when the vertical spacing between the elements was increased. This agrees with indications from European studies [21, 22, 23].

Table 9C shows results of tests to determine pressure excursions using Load 1B with three different degrees of time delay between the discharge of the 10th floor WC and the 8th floor WC (see table 3). No pattern of relationship is evident from the limited number of measurements made.

In most of the comparisons in table 9C the delayed-sequence diaper loads yielded greater pressure excursions than did the comparable delayed-sequence clean-water loads.

4.1.3. Unvented Offsets

Concerning the use of unvented offsets in the stack, some writers have suggested that an advantage of System X design stems from the falling water being slowed down by the double-offset-like geometry[10] of this System's aerator[11] fitting.

A double-offset fitting with suitable radius of curvature probably can simulate such slowing effect on the water velocity by a normal System X aerator fitting, and such fittings used in place of idle aerator fittings would provide a cost reduction in those branch intervals where no soil branches need be provided for.

Double offsets were not planned for the project in Fairfax County, but because they might be relevant in other installations, the test stack was provided

[10] See figure 2 for illustration. In essence, the flow in the stack is first deflected laterally and then returned to the original line of flow by means of a single fitting or an assemblage of two or more fittings in series.
[11] The aerator fitting is sometimes called a mixer fitting.

TABLE 9C. *Effect on average of peak pneumatic pressure excursions resulting from variation of time sequence for load 1B*[1] *in 10-story stack tests*

Floor	Ratio $\frac{P}{P_s}$ [2,3] Test load[4]													
	$1B_{scw}$ [5]		$1B_{1.5dcw}$		$1B_{1.5dD}$		$1B_{3.0dcw}$		$1B_{3.0dD}$		$1B_{4.5dcw}$		$1B_{4.5dD}$	
	−	+	−	+	−	+	−	+	−	+	−	+	−	+
9	1.00	1.00	1.41	0.73	1.41	2.00	1.41	1.20	1.29	0.87	1.29	1.06	1.41	2.46
7	1.00	1.00	0.53	1.10	0.60	1.09	0.67	.50	1.80	.82	0.67	0.91	0.60	1.22
6	1.00	1.00	55	1.03	.70	1.58	.60	.84	.90	.98	.95	.53	2.70	1.33
5	1.00	1.00	.72	0.92	.72	2.40	.46	.76	.44	1.33	.54	.68	0.72	0.40
4	1.00	1.00	.77	.65	1.12	1.59	.84	1.51	.81	1.29	.71	1.21	1.11	1.70
3	1.00	1.00	.65	.40	.94	0.66	.59	.46	.50	.94	.73	0.57	0.77	0.74
2	1.00	1.00	1.00	.94	.76	1.28	.72	.82	.68	1.09	.68	1.24	.72	1.26

[1] Loads described in table 3.
[2] Average of 3 identical runs, except where otherwise noted.
[3] P is average of peak pressure excursions in branch produced by two-floor load with a time delay between upper and lower element; P_s is average of peak pressure excursion for the case of a simultaneous discharge, i.e., delay=0, employing clean water.
[4] Symbol "cw" stands for clean water; "D" stands for diaper. For example, designation $1B_{3.0dD}$ represents load 1B with a 3.0 sec time delay, with a paper diaper included in the discharge from the 10th floor (see table 3). Symbol "s" stands for simultaneous, and "d" stands for time delay.
[5] For the purpose of this table, the data for Load $1B_{scw}$ have been shown with a value of 1.00. Therefore, the data for time delay loads show effects relative to the simultaneous loads.

with offsets at floors 2, 4, and 6, as indicated in figure 2.

Owing to the urgency imposed by a tight schedule for the test program and to delays in arrival of the prescribed American fittings to be used for the double offsets, European fittings were substituted. Later comparison of the standards for the respective fittings revealed that the European radius was less than the American one (approximately 75 mm versus 95 mm). It is generally understood that the radius and shape of any fitting that serves to deflect the water falling down the stack of a single-stack system must be carefully selected to avoid the generation of adverse pressure differentials. Too small a radius may cause plug-action at the offset, accompanied by excessive pneumatic pressure excursions. Some European designers of single-stack systems have recommended omission of all unvented bends in the stack above the bottom of the lowest branch interval.

The measurements obtained on the stack in the test tower showed somewhat greater pressure excursions and trap-seal reductions at and below the double-offset fittings than might have been expected from a consideration of similar previous European data obtained without offsets.

The European investigators feel that performance of the test system in the lower part of the stack would have been better had the longer radius American offset fittings been used as planned. Additional tests could provide the data needed to fully evaluate this characteristic, but the program described herein did not permit further tests. It is not considered essential that such tests be made in evaluating the proposed designs.

4.2. Tests on Single-Interval Systems

4.2.1. Plan-A System

Table 10 shows relative trap-seal retention for several loads applied to the Plan-A system. Average relative retention for multiple single runs was not less than 0.91, minimum single-run retention was 0.86, and the one (2-run) cumulative seal retention test made showed a relative retention of 0.86.

Table 11 shows that maximum water depths in the 3-in horizontal soil and waste branch were never as great as the branch diameter. The full-pipe condition was approached only with the unlikely load, designated 3_{D+DET}, created by a special ball-shape preforming of the diaper before flushing. The less-than-full pipe condition and the straight-inlet geometry of the 3-in combination soil-and-waste branch connection to the aerator (mixer) fitting evidently account for the fact that pneumatic pressures in the idle 2-in horizontal drains connected to the 3-in branch were not significantly different from the pressures within the body of the aerator fitting. Evidently, in the design tested the straight-inlet geometry of the 2-in waste branch fitting made possible the venting of the idle waste fixture traps by permitting air to move over the top of the water flowing in the 3-in combination soil- and waste-branch.

Table 10. *Relative trap-seal retention in lavatory trap in tests on single-interval system, plan A* [1]

Test load number	Relative trap-seal retention, $\left(1-\frac{\Delta H}{H}\right)$ [2]	
	Average	Minimum
1	1.00_4	1.00_4
2	0.99_3	0.96_3
2C	$.86_2$	$.86_2$ [3]
3	1.00_4	1.00_4
3_D [4]	0.98_4	0.96_4
3_{D+DET}	$.91_4$	$.86_4$

[1] See figure 5 and table 4.
[2] "ΔH" is trap-seal reduction. and "H" is the full trap-seal depth. Subscripts on values indicate the numbers of successive test runs made.
[3] Identical values obtained in each run of 2-run cumulative series.
[4] Subscripts are abbreviations of D for diaper and DET for detergent.

4.2.2. Plan-B System

As shown in table 12, test load 7 with layout 1 produced a few trap-seal reductions greater than ordinarily considered acceptable. Improvement was evident with layout 2, which involved enlarging the common horizontal waste branch from 2-in to 3-in diameter (branch no. 1, fig. 6) and replacement of the double elbow with a double long-turn T-Y fitting (fitting no. 1, figure 6). With layout 3, no reductions of any significance occurred. Layout 3 differed from layout 2 in the replacement of a short-turn bath-waste fitting with a long-turn fitting (fitting no. 3, fig. 6).

Table 13 shows that with layout 3 trap seals were reduced only slightly below full-seal level with various loads. The data do not show any serious decrease in trap-seal retention due to bubble-bath (type 3 detergent) additive.

Table 11. *Estimated maximum water depths in 3-in soil branch of single-interval system, plan A* [1]

Test load number	Estimated maximum value for ratio of water depth to branch diameter, H/D	
	Average	Maximum
1	0.6_4 [3]	0.6_1 [3]
2	$.8_3$	$.8_3$
2C	$.9_2$	$.9_2$
3 [2]	$.8_4$	$.9_4$
3_D [4]	$.9_4$	$.9_4$
3_{D+DET}	$.9_4$	1.0_4

[1] See figure 5 and table 4. Depths estimated visually by observation through transparent plastic window in top of soil branch (point 1, figure 5).
[2] Based on 4 runs with decreasing head (run-to-run) in vessel simulating bathtub; i.e., head decreased because water was let out for a short period of time in each run and not refilled between runs. Max value of $H/D=0.9$ for 1st run and min value$=0.8$ 4th run.
[3] Subscripts indicate the number of replicate runs.
[4] Subscripts are abbreviations of D for diaper and DET for detergent.

Observations through a transparent window (point 5, figure 6), when one or both WC's were flushed, showed some cross-flow into the common horizontal waste branch. This effect was greater with the flushing of paper diaper loads than with clean-water loads. Visual observation suggested that a downward extension of the baffle in the System X mixer fitting by an estimated one inch should prevent the cross flow. Experimentation with a modified baffle could not be carried out in the time available for the tests. It is understood that the final design of the fittings would incorporate a lowered baffle.

4.3. Site Visits, Interviews, and Literature Review

From site visits, interviews with authorities, and review of literature, a number of significant findings were developed.

At Le Lignon housing development in Geneva, 4-in System X stacks have been installed, each serving as many as 30 bathrooms and 30 kitchen sinks. These systems had been used in Le Lignon for more than 5 years at the time of the site visit.

In the National Plumbing Code [14] a bathroom "group" with bathtub, tank-type WC, and lavatory is rated at 6 fu, a bidet is rated at 4 fu, and a kitchen sink without food-waste grinder is rated 2 fu. Computations using such ratings would yield a connected load of 360 fu on the Le Lignon stacks which is equivalent to 60 bathrooms of the variety being considered for installation in the project in Fairfax County, Virginia, assuming that the important hydraulic properties of such fixtures and the patterns of fixture use are similar in their net effects in Switzerland and Fairfax County, Virginia.[12]

A YMCA-type, 20-story building with 3 WC's per floor was said to have functioned satisfactorily with a 4-in System X. It is assumed that in addition there were 2 lavatories and 2 showers on each floor, the total fixture unit load would be 360 fu, based on the fixture-unit ratings of the National Plumbing Code. Again, this would approximate the load produced by 60 American-type bathrooms, assuming like hydraulic fixture properties and like use patterns.

Many Swiss System X installations are said to involve 40 bathrooms (20 stories of back-to-back bathrooms) on a 4-in stack. Such a design for the Tscharnergut apartments in Bern [13] was reported as receiving in addition to the bathroom load, the discharge from 40 kitchen sinks without food-waste grinders. This loading yields a total of 320 fixture units, estimated equivalent to 53 standard American bathrooms without kitchen load figured as above. It was learned that in many installations storm water from the roof is also drained into the sanitary stacks. Swiss engineers thought it unlikely that peak rainwater loads and design peak sanitary loads would occur simultaneously.

A System X installation was visited in Montreaux that served 27 stories of back-to-back bathrooms with an estimated fixture-unit group rating of 11 per

[12] Equivalency of Swiss and American loading effects is by no means certain, in the absence of detailed research on load patterns under American conditions.
[13] Installations of System X in this project date from 1961.

TABLE 12. *Effect on relative trap-seal retention of changing piping arrangement for single-interval system, Plan B [1], test load 7 [1]*

Layout number	Number of runs	Relative trap-seal retention, $\left(1-\frac{\Delta H}{H}\right)$ [2]											
		WC1		WC2		L1		L2		B1		B2	
		Av.	Min	Av.	Min	Av.	Min	Av.	Min	Av.	Min.	Av.	Min.
1	3	1.00	1.00	1.00	1.00	0.81	0.71	0.96	0.94	0.75	0.57	0.45	−0.10
2	3	1.00	1.00	1.00	1.00	.93	.91	.96	.96	.93	.86	.72	0.17
3	2	1.00	1.00	1.00	1.00	1.00 [3]	1.00 [5]	.99 [3]	.99 [4]	1.00	1.00	1.00	1.00

[1] See figure 6 and tables 5 and 6.
[2] "ΔH" is trap-seal reduction and "H" is the full trap-seal depth. Also abbreviations are WC for water closet, L for Lavatory and B for bathtub.
[3] Corresponding value of 0.96 obtained next day with different operators (2 runs).
[4] Corresponding value of 0.93 obtained next day with different operators (2 runs).
[5] Corresponding value of 0.93 obtained next day with different operators (2 runs).

TABLE 13. *Relative trap-seal retention in tests on single-interval system, layout 3 plan B [1]*

Test load no.	No. runs	Relative trap-seal retention, $\left(1-\frac{\Delta H}{H}\right)$ [2]											
		WC1		WC2		L1		L2		B1		B2	
		Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.
3	4	--- [3]	---	---	---	0.96	0.86	1.00	1.00	---	---	1.00	1.00
3_{DET} [6]	1		---	---	---	.90 [4]	.90	0.99 [5]	0.99 [5]	---	---	0.99 [5]	0.99
4	2	---	---	---	---	1.00	1.00	.94	.93	1.00	1.00	---	---
4_{DET} [6]	2	---	---	---	---	1.00	1.00	.94	.93	1.00	1.00	---	---
5	4	---	---	1.00	1.00	---	---	---	---	---	---	---	---
5_D	2	---	---	0.99	0.99	---	---	---	---	---	---	---	---
6	4	1.00	1.00	---	---	---	---	---	---	---	---	---	---
7	2	---	---	---	---	0.96	0.93	0.93	0.93	---	---	---	---
11	3	---	---	---	---	---	---	.94	.93	0.93	0.93	---	---
11_{DET}	3	---	---	---	---	---	---	.84	.79	.93	.93	---	---

[1] See figure 6 and table 5.
[2] "ΔH" is trap-seal reduction, and "H" is the full trap-seal depth.
[3] Dash marks indicate in general that no measurement of trap seal was made.
[4] Cumulative relative retention in 4-run series=0.86.
[5] Cumulative relative retention in 4-run series=0.97.
[6] Subscripts are abbreviations of D for diaper and DET for detergent.

bathroom [14], or a total of 594 fixture units, figured as described above. This installation utilized 5-in stacks. Under most American codes, 5-in stacks would also have been required for such a fixture-unit load and would have required conventional venting.

With respect to the elements of the Swiss design that guard against self-siphonage of active fixtures, and against the induced siphonage of idle fixtures (as might result from discharge of other fixtures connected to the same horizontal branch as the idle fixtures), the principal basis for the design rules appears to be the research of Dr. Schellenberg, one of the leading Swiss authorities in plumbing engineering. This research was conducted at the laboratories of the City of Zurich, as well as at the LdSB. The rules were published in 1966 [24]. The main approach recommended for avoiding siphonage of traps in a given branch interval (as caused by the discharge of one or more fixtures within that interval) was to size the various elements of the branch-piping system so that full-pipe flow would not occur at any section where such "plug formation" might result in adverse pressure differentials. In accomplishing this, fittings used to change direction should be selected that would not cause substantial interference with the normal flow pattern nor unduly restrict the air space above the water in a horizontal drain. In this way, it is possible to maintain effectively an air space above the water in the horizontal branches, and to provide "wet venting" capability in the short vertical waste pipes that in the System X design are connected to the downstream outlet of off-the-floor fixture traps. Thus, the design seeks to control self-siphonage and to

[14] Two lavatories, 1 bidet, 1 WC (tank type), and 1 bathtub.

equalize pneumatic pressures between the atmosphere, the trap arms, and the mixer (aerator) fitting by admitting sufficient air relief through incompletely filled drainage piping.

Discussions with a local plumbing authority in Winterthur, several mechanical engineers in Zurich and Geneva, a plumbing contractor in Winterthur, and research and code experts in Zurich and Bern in 1967 and 1969 revealed no problems with fouling or corrosion that they considered attributable to the omission of secondary ventilation. Further comment on this will be found in the appendix.

5. Summary

The information reviewed and the new test data obtained in this study provide a basis for the following conclusions:

a. The study showed that, within the scope of the investigation as carried out, it is reasonable to expect satisfactory hydraulic and pneumatic performance of the proposed single-stack installations in Fairfax County, as determined by the ability of the system tested to maintain more than 1½ in of water seals in the traps, with test loads as estimated by an application of probability theory greater than those expected in the proposed application. It is important that generally accepted quality of design, installation, and inspection be maintained, for both conventional and single-stack systems, to assure satisfactory operation.

b. A number of these systems installed in Swiss apartment buildings have been identified that serve loads believed equal to or greater than those expected for the proposed project in Fairfax County.

c. Tests in tall Swiss apartment buildings with manually-produced hydraulic discharges greater than the peak discharge rates predicted from Hunter's curve [15] for the systems proposed for the project in Fairfax County have yielded measurements indicating satisfactory pneumatic conditions.[16] Long-term monitoring of the pressures in the same systems with natural loadings after occupancy of the buildings showed smaller pneumatic pressure excursions than exhibited in the manual tests.

d. Laboratory measurements with various loads on a 10-story test system closely simulating the design proposed for the project in Fairfax County showed that average trap seal retention was not less than about 56 percent of maximum seal depth, and that no waste water or air was forced back through the traps. This was true even with simulated bathroom loads giving discharge rates greater than predicted from 50 standard American bathrooms according to Hunter's peak-discharge curve.

e. Protection against self-siphonage of active fixture traps and against induced siphonage of idle traps (by the discharge of fixtures in the same branch interval as the idle traps) appears possible by following design rules patterned after the 1966 recommendations of the SSIV [24][17]. The substance of these recommendations should be incorporated in the System X design.

f. A 90-degree horizontal-to-horizontal change in drain direction should be accomplished gradually, such as through the use of a long-turn T-Y fitting in preference to a short-turn fitting, or through the use of a 90° long-radius elbow or two 45° long-radius elbows in series.

g. The data suggest that where two horizontal waste lines from opposite directions, one or both of which serve two or more fixture units, are joined to a common horizontal branch **at the same axial point,** the common branch should be 2½ or 3-in diameter.

h. The tests with paper diapers showed that with some hydraulic loads the diapers caused an increase in pneumatic pressure excursions and trap-seal reductions. The effect of detergents was less well-defined, but the indications are that this too may increase pneumatic pressure excursions and trap-seal reductions in some instances. The tests with sanitary napkins did not appear to show a significant effect from their use. Average trap-seal retention was (1) at least 56 percent of the original trap-seal depths for a range of clean-water loads up through 145 gpm (or 515 fixture units from Hunter's curve)[18], and (2) at least 61 percent for paper diaper loads up through 118 gpm (350 fixture units)[19].

i. The data showed that the WC traps were much less subject to seal reduction than were the P-traps, and suggested that greater loads can be allowed for a given trap-seal reduction than for a pneumatic-pressure excursion of the same magnitude. Therefore, in the further refinement of evaluative techniques for sanitary DWV systems the primary criterion should be trap-seal retention rather than pneumatic pressure excursion.

j. The vertical distribution of the elements of a compound hydraulic load [20] affects pressure excursion and trap-seal retention. The worst case appears to be the introduction of the load elements as close together as possible, near the top of the stack, and this tends to be the practice in testing because of the limited height of the available laboratory test apparatuses. However, in natural loading the individual elements of a compound load probably will tend to be distributed along the length of the stack rather than in a close-together-grouping near the top. Since the test loads were introduced close to the top of the stack, the corresponding allowable natural. fixture-unit loads inferred by the method described herein should be on the safe side. This should tend to compensate for any adverse influence from unequal hydraulic load patterns in Swiss and American usage.

k. Although the guides given herein for selecting

[15] NBS BMS 65, Methods of Estimating Loads in Plumbing Systems.

[16] Pressures within approximately ± 1-in water column, referenced to atmospheric pressure

[17] It is understood that in Europe these rules are customarily applied by qualified design engineers familiar with the System X system, and that the same principles are to be applied in designing Americn installations. SSIV is Schweizerischer Spenglermeister-und-Installateur-Verbandes, Auf der Mauer 11, 8023 Zurich, Switzerland.

[18] For comparison, the presently proposed maximum fixture-unit load per stack in the Fairfax County project is 312, which should produce a peak discharge of approximately 112 gpm according to Hunter's curve.

[19] The effects produced by this load were apparently intensified to some degree because of the diapers.

[20] A compound hydraulic load is comprised of two or more individual elements of discharge, introduced with some degree of concurrence.

test loads are useful, they do not assure that the field performance will agree exactly with the test performance. European data show that pneumatic pressure excursions, monitored instrumentally with natural service loads, have been smaller than investigators had predicted from tests [21,23,25]. In order to obtain closer agreement between test results and field performance, and to bring about desirable refinements in American evaluative technique, it will be necessary to make comprehensive measurements in actual buildings with natural loads to better define load patterns by time, magnitude, frequency, and vertical distribution. Further comment on this will be found in the appendix.

Considerable research and development work has been carried out to introduce System X into the United States, by plumbing engineers and its proponents in connection with design of systems to suit American buildings. However, much remains to be done in developing realistic guide criteria for the design and evaluation of a wide range of systems that might employ some version of the single-stack principle, and yet might differ from the System X in significant ways. It is important to identify and define the controlling parameters and to investigate the performance characteristics over a range of representative conditions. This would permit the establishment of suitable test procedures and technical criteria for determining the design and acceptability of any type of single-stack drainage system, irrespective of manufacturer, architect, or plumbing designer.

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7. Appendix

7.1. Supplemental Details relating to experimental Apparatus, Test Systems, and Test Procedures

The water closets used in the test program were a current model siphon-jet flush-valve type made by a prominent American manufacturer. Each WC was equipped with a 1-in flushometer valve regulated to discharge approximately 4 gal (15 liters) during a period of 8-10 s, giving an average rate of discharge of about 27 gpm (102 lpm [21]).

The vertical interval between successive floors of the test system shown in figure 2 was about 8′-8″ (2.65 m). The stack was 4-in diameter copper DWV tube.

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[21] "lpm" is the abbreviation for "liters per minute."

System X fittings were fabricated from copper sheet in the shops of the LdSB, following drawings provided by an American fittings manufacturer. Two side entries were provided on each of the low-angle stack-branch confluence fittings. At the base of the stack, the deaerator fitting was connected to the building drain by means of a 2-in vent, at a point downstream of the 90° elbow. The building drain was 4-in dia copper DWV tube.

The discharges of bathtubs and lavatories were simulated by the use of seven plastic tanks distributed on floors 10, 9, 8, and 7. Each tank was equipped with a 1½ in control valve for flow rate adjustment, and a 1½ in quick-closing valve for starting and stopping the flow by manual means. The tank-valve combinations were calibrated to give an average discharge rate of about 48 lpm (12 gpm was originally intended) over a period of 102 s to simulate the discharge of a bathtub, and about 40 lpm (10 gpm was originally intended) over a 7.5 s period to simulate the discharge of a lavatory.

Pressure measurements were provided for by instrumentation as follows:

1. Central battery of water manometers (estimated 25 mm, i.d.) in the basement below the test tower. These manometers were connected through runs of copper tube (estimated 15 mm, i.d.) and flexible rubber tube connectors to the horizontal branches on each of the ten floors, and to the building drain.
2. A close-connected U-tube manometer (6 mm., i.d.) with a flexible coupling was installed at each of the stations indicated in (1) above for comparison with the basement manometers.
3. Magnetic-coupled gages were installed with close connections to trap arms of certain P-traps on floors 10, 9, 8, 7, and 5.
4. A continuous-recording pressure monitor designed at the LdSB was connected to one of the idle branch outlets of the aerator fitting on the 7th floor.

In the discussions of pneumatic pressure measurements in the tests on the 10-story test tower (sections 4 and 5), the pressures referred to are those measured by the battery of basement manometers, unless otherwise indicated. This method was chosen because of the apparently poor correlation of responses from methods 1 through 4 above when measuring the same dynamic pressure patterns, and because most of the research conducted earlier at the LdSB had been carried out using the manometer battery.

Data obtained earlier at the LdSB have shown that under typical dynamic conditions in sanitary DWV systems, different pressure-measuring instruments yield different peak values, depending on the time constants of the instruments as well as the dynamics of the fluid motion within the instruments and gage lines. Thus it is difficult to correlate dynamic pressure with trap-seal retention.

It is desirable that test methods for the evaluation of sanitary DWV systems be based on pressure measurements rather than trap-seal retention so as to simplify the measurement task; however, because the pressure measurements are unreliable indicators of trap-seal retention, a substantial research need is indicated for correlation of dynamic pressure excursion with trap-seal retention.

Trap-seal retention of the P-traps was measured by piezometers connected through the cleanout openings. The water closet trap-seal retention was measured by graduated "dip-stick" scales.

Additives to the water that were used in several tests were paper diapers, sanitary napkins, and detergents. The diapers used were the large size of a popular brand, flushed through the WC's without removal of the plastic membrane. For the test loads using diapers, only a single diaper was used with each WC so identified.

The sanitary napkins used were the large size of a well-known American brand, flushed singly through WC's where indicated, together with four 3-pc sections of double-thickness toilet tissue of a popular American brand.

The detergent loads were introduced by pouring a water solution of about 200 ml into the bathtub traps (see figure 3) for specified periods while water was being discharged through them. The concentrations used in the detergent loads were reduced to about one-half of the manufacturers recommendations to simulate some depletion of detergent strength that usually occurs in a service condition before the fluid is discharged into the drain. The detergent loads were:

Type 1—74 cc of powdered detergent in water solution introduced with a 12-gpm bathtub discharge over a 1-min period—simulates use of automatic clotheswashing machine (test no 5_{DET} on 10-story stack).

Type 2—3.1 ml of liquid detergent in water solution introduced with a 12-gpm bathtub discharge over a 12-s period—simulates manual dishwashing in kitchen sink (test no. $2A_{DET}$ on 10-story stack)

Type 3—32.5 ml of flake bubble-bath additive in water solution introduced with a 12-gpm bathtub discharge over a 1.7-min period—simulates use of bubble-bath substance in bathtub (test no. 3_{D+DET} on single-interval system A; and tests no. 3_{DET}, 4_{DET} and 11_{DET} on single-interval system B)

7.2. Selection of Test Loads

Performance tests have been described for British single-stack drainage systems [6, 12, 23] that possibly could have been applied directly in choosing the loads employed for the tests reported herein. However, in order to take account of some of the hydraulic properties of American fixtures that may differ from those of their British counterparts, it is believed the method used in deriving tables 2 and 3 is to be preferred. The principal shortcomings of either approach are (1) lack of adequate American data establishing representative values of the average time between successive operations of the fixtures, (2) lack of statistics on concurrence of peak-use periods for different types of fixtures, and (3) lack of generally accepted rational method for selecting a vertical distribution of a multielement hydraulic test load.

A 50-bathroom connected load with 3 standard fixtures per bathroom would require a "morning peak" test load comprising 2WC + 2Lav, according to the current British guide [12]. For comparison, the use of table 1 yields a load of 3WC + 1Lav for $\frac{1}{\tau} = 0.01$ (load no. 1A). For a 40-bathroom load, the British guide calls for 2WC + 2Lav while the use of table 1 yields 2WC + 1Lav, computed in accordance with the procedure used for load 1A in table 2. The British guide is shown in table A-1. Thus it can be seen that the magnitude of the loads obtained from the use of the British CP 304 guide table may be roughly comparable to those obtained from the use of table 1, the difference being largely in the use factors and hydraulic properties assumed for the fixtures, and in the method of allowing for the unlikelihood of concurrence of peak loads in two or more groups of plumbing fixtures of different types.

TABLE A-1. *British guide*[1] *for selecting numbers of fixtures to be discharged in testing sanitary DWV systems for dwellings.*

Number of fixtures of each kind on stack	Number of fixtures to be discharged simultaneously		
	Two-gal. (9 liters)[2] water closet	Wash Basin	Kitchen Sink
1–9	1	1	1
10–24	1	1	2
25–35	1	2	3
36–50	2	2	3

[1] From CP 304–1968 [12]. In using this guide, the British practice is to compute separately the number of each type of fixture to be discharged, taking into account the time of day when peak usage for each fixture type may be expected.
[2] Approximately 2.4 American gallons.

Table 1 offers advantages in providing for choice of $\frac{1}{\tau}$ (level of overload risk) and for $\frac{t}{T}$ (ratio of duration of fixture operation to average time between successive uses). The table, together with the explanation of its use, also provides for the exercise of judgment in the application of data relating to concurrence of peak periods of use for different types of fixtures. For example, are kitchen sinks in peak use at the same time of day as water closets ? Are bathtubs in peak use at the same time as kitchen sinks, etc.?

Table 1A should prove useful in selecting reasonable test loads for the evaluation of hydraulic interactions in systems or portions of systems installed within a single branch interval. The assumption of a larger value of $\frac{t}{T}$ for table 1A than generally assumed in the use of table 1 for the testing for effects between branch intervals is not unreasonable, because this takes account of (1) the inherent likelihood that actual values of $\frac{t}{T}$ will frequently deviate substantially from average values, especially in small systems, and (2) the consequences of an overload of one fixture beyond the design load can be relatively more significant in a system comprising a small number of fixtures than in a large system.

Both tables 1 and 1A, as well as the procedures for their application, may need adjustment as new research data on the hydraulics of plumbing fixtures and appliances, and on use patterns in service become available. Standardization in this area is needed, both for laboratory and field applications. The scope of such standardization should include procedures for field tests utilizing steady flow or simulated short duration fixture flow that could be utilized on rough plumbing before the work is closed in and fixtures installed, as well as for tests with fixture loads that could be made later before occupancy.

7.3. Evaluation of Branch Design Finally Selected

The branch designs finally selected for installation in the project in Fairfax County should be compared with the designs tested to establish whether the principal values of the test results have been realized insofar as possible in the final design.

7.4. Optimum Hydraulic Properties of Fixtures

Trap-seal retention in idle traps apparently is greatest in traps with a large water seal. Therefore, 1½-in traps used with lavatories and 2-in traps with bathtubs and kitchen sinks should be preferable to the smaller sizes often used, from the standpoint of trap-seal retention. Similarly, trap-seal depths of at least 3-in should be preferable to 2-in.

Trap-seal retention is also improved when the fixtures have relatively low rates of discharge and discharge relatively small volumes of water. Water closets with volumes of less than 4 gal and peak momentary discharge rates less than 35 gpm should be specified if possible.

7.5. Fouling and Corrosion in DWV Systems

Fouling and corrosion are complex pnenomena in any DWV system, and are not adequately understood in conventional systems. No experimental or theoretical evaluation of these factors was attempted in the present study. A review of the literature on the system tested and interviews with several Swiss experts showed no cause for concern. However, since this question may deserve further study under American service conditions, it should be considered in any new research on single-stack systems. Follow-through studies of maintenance history in single-stack installations and comparable conventional installations could provide relevant information. Laboratory experimentation with various configurations, branch-pipe sizes, drain slopes, discharge rates, waste materials, and other factors could provide valuable data supplementing the field observations.

7.6. The Value of a Follow-through Research Program

It is widely recognized that new studies are urgently needed to update and expand the criteria that are used by designers and evaluators of plumbing systems. The needs are particularly acute in reference to the prediction of peak hydraulic loads and to the correlation of test results with field performance. This is essential if simulative testing of DWV systems in the laboratory is to be standardized. The potential for payoff from an adequate program of research is evident not only in relation to the evaluation of innovative systems, but also in relation to the problem of selecting reasonable safety factors for pipe sizing in conventional systems. Estimates of the national savings that could be realized through an adequate knowledge of peak loads on plumbing systems and a general application of such knowledge in the construction of conventional systems alone have ranged up to several hundred million dollars annually.

The results of this kind of research could be of great and lasting value in connection with the nation's continuing need for housing. In particular, the type of information that could be provided for the first time would be most beneficial in improving criteria and test procedures for industrialized housing systems. The technology of such research is now available; and the resulting information would be most beneficial in improving criteria and test procedures for industrialized housing systems as well as more conventional designs.

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Among the more important criteria for hydraulic and pneumatic performance of sanitary drain-waste-vent systems are (1) maintenance of water seals in fixture traps, (2) limitation of pneumatic pressures, (3) limitation of hydrostatic and hydrodynamic pressures, and (4) limitation of cross-flow between horizontal branches or trap arms.

Recent tests of a single-stack drainage system proposed for a high-rise apartment project in Fairfax County, Virginia have produced the following findings with respect to these performance criteria:

(1) test loads (total discharge rates) ranging up to magnitudes greater than predicted loads yielded reasonable average trap-seal retention;

(2) the use of trap-seal retention as a measure of performance appears to be more meaningful than the traditional pneumatic-pressure measure;

(3) fitting geometry and branch arrangement can be more critical in single-stack systems than in conventional vented systems, and

(4) present procedures for selecting test loads, for making tests, and for reporting and interpreting measured values need improvement and standardization.

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