NBSIR 73-161

Field Test of Hydraulic Performance of a Single-Stack Drainage System at the Operation BREAKTHROUGH Prototype Site in King County, Washington

Robert S. Wyly and Daniel E. Rorrer

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Institute for Applied Technology
National Bureau of Standards
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U. S. DEPARTMENT OF COMMERCE, Frederick B. Dent, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

FOREWORD

This report describes the results of a field demonstration of hydraulic performance of an innovative design of drain-waste-vent (DWV) plumbing system installed in several housing units at the Operation BREAKTHROUGH Prototype Site in King County, Washington. The work was sponsored by the Department of Housing and Urban Development in response to a request by the Factory Built Housing Section, Department of Labor and Industries, State of Washington, and conducted by the Building Environment Division, National Bureau of Standards.

Because the state of the art in testing for hydraulic performance of innovative plumbing systems is in an early developmental stage, it was necessary to select a methodology for testing. One of the purposes of this report is to describe this methodology in some detail, since there are no standard methods which are applicable.

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FIELD TEST OF HYDRAULIC PERFORMANCE OF A SINGLE-STACK DRAINAGE SYSTEM AT THE OPERATION BREAKTHROUGH PROTOTYPE SITE IN KING COUNTY, WASHINGTON

R. S. Wyly and D. E. Rorrer

ABSTRACT

A procedure for measuring the hydraulic performance of DWV systems in the field is described, and the results obtained with this procedure in a field demonstration of the hydralic performance of a single-stack drain-waste-vent (DWV) system are presented.

Among the most important criteria for hydraulic performance of drain-waste-vent systems are the following:

(1) Trap-seal retention in idle fixtures.

(2) Ability of the system to resist the ejection of suds, sewage, or foul gases due to hydrostatic or pneumatic pressures in the DWV system.

(3) Absence of cross flow between fixtures.

(4) Absence of self-siphonage in the individual fixture traps.

Considering the needs for minimization of maintenance in service and for the continuation of venting during cold weather, the following additional criteria can be identified:

(5) Ability to maintain adequate hydraulic performance over a long period of service without excessive maintenance of branch piping.

(6) Adequacy of performance under climatic conditions conducive to frost closure of vent terminals.

The procedures for selection and application of hydraulic loads, based on state-of-the-art guidelines, are described as applied to the soil and waste stacks evaluated for conformance to criteria (1) through (4) above.

The results show adequate performance in relation to criteria (1) through (4), with a single example of nonconformance on criterion (3), subject to the limiting condition that some uncertainty exists as to the degree of leak resistance of the DWV systems made available for the tests.

Recommendations are offered concerning further work that could provide information to confirm estimated conformance to criteria (5) and (6).

1. Introduction

1.1. Background

The single-stack sanitary drain-waste-vent (DWV) system as designed for several housing units at the King County prototype site in the Operation BREAKTHROUGH (OBT) program was derived from British designs and was evaluated in the design stage on the basis of a 1971 in-house working paper prepared by the National Bureau of Standards (NBS) concerning the application of simplified DWV designs derived from British single-stack drainage to housing systems produced in Operation BREAKTHROUGH. The working paper was prepared in part from a careful review and analysis of British and European data and in part from professional judgment (see Appendix A for definition of single-stack drainage).

Because of the prevailing opinion that American plumbing fixtures and use patterns produce heavier loads than those typically occurring in British and European service, and because some of the important details of the system as installed are not suitably documented, the Factory-Built Housing Section, Department of Labor and Industries, State of Washington (FBH), requested that The Department of Housing and Urban Development (HUD) supply additional evaluation of the single-stack sanitary drainage system. Since the Uniform Plumbing Code (the model code used in the State of Washington) is generally interpreted to require secondary ventilation of DWV systems (and as such precludes the use of single-stack systems), officials of FBH also requested HUD to furnish corroborating evidence of satisfactory hydraulic performance.

The concerns expressed by FBH in relation to the hydraulic performance of the single-stack design relate primarily to trap-seal retention, blowback of suds or gases, long-term serviceability of branch piping, and resistance to frost closure of vent terminals (see Appendix A.1 for definitions of these terms).

1.2. Scope of Work

The scope of work originally approved by HUD in response to the needs of FBH was described as follows:

a. Conduct field demonstration of hydraulic performance with simulated hydraulic loads, following test procedures mutually acceptable to Washington State, NBS, and HUD, patterned after procedures that have been used in similar situations and that are described in NBS BSS41 and elsewhere [1, 2, 3].[1]

b. Conduct laboratory tests at NBS concerning significant hydraulic parameters not subject to suitable evaluation under prevailing field conditions; e.g., effects of variations in fitting geometry and branch configuration, performance with stacks of greater height, or other parameters identified and agreed upon through NBS-FBH-HUD discussions.[2]

c. Survey service experience after occupancy of the units in cooperation with officials of FBH and HUD; and with owners, occupants,

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

[2] The scope of these laboratory tests has been subsequently reduced considerably; this is discussed in some detail in section 4.4.

and maintenance personnel. Identify causes of hydraulic performance problems which may develop in the first few months of occupancy, with particular reference as to whether problems are due to improper design or installation, or to the particular functional properties of the DWV systems.

d. Based on parts (a), (b), and (c), report on the adequacy of the design and on the adequacy of possible modified designs that may be authorized for study under part (b). Utilizing the results of this study and incorporating recommendations on quality assurance procedures for single-stack systems, prepare an updated edition of the criteria guidelines that were used in the OBT program.[3]

The present report covers test procedures and results under item (a) above. Discussion and recommendations are also given concerning completion of the work under items (b), (c), and (d) above.

It should be understood that the results of the tests reported here and the conclusions drawn from these results are known to be applicable only to the system tested. This situation arises in part from the fact that working drawings were not available for determination of installation detail, and from the fact that many variations of so-called single-stack design can be developed, not all of which could be expected to perform identically to the design tested.

1.3. Acknowledgments

The site tests described in this report were funded by the Department of Housing and Urban Development. Preparatory arrangements

[3]The scope of this task has been reduced as discussed in section 4.2.3.

were made by the Seattle office of HUD and by the Prototype Site Developer. Briefings were presented to FBH and the King County Building Department. Assistance in conducting the tests was provided by FBH and IAPMO.[4] Without the cooperation and assistance of these groups, the performance demonstration could not have been carried out effectively. The Building Environment Division wishes to express special appreciation to a number of individuals from the above organizations who contributed notably to the success of the endeavor. The parts played by these individuals are acknowledged in Appendix C.

2. SUMMARY OF TEST PROCEDURE AND INSTRUMENTATION

2.1. Test Approach

Test loads to be applied to the systems were determined on the basis of a review of relevant publications from both domestic and foreign sources. This review resulted in the development of a test plan which was primarily patterned after existing English single-stack standards, and which utilized hydraulic loadings approximating the design flow rates currently used in American plumbing practice. The procedure used for these tests is described in some detail in Appendix A. The selection of the particular DWV stacks to be tested was made by reviewing the plans of the single-stack DWV system which was installed at the King County OBT site and, through professional judgment, estimating which particular stack was least likely to perform satisfactorily. Schematic representations of the particular DWV stacks selected for the tests are shown in Appendix A, figures A1 through A5.

[4] International Association of Plumbing and Mechanical Officials.

These figures are, for the most part, copies of schematic piping diagrams provided by the Housing System Producer [4].

Among the most important criteria for consideration in the evaluation of the hydraulic performance of any DWV system under load are the following:

a. Trap-seal[5] retention in idle fixtures.

b. Ability of the system to resist the ejection of suds, sewage, or foul gases due to hydrostatic or pneumatic pressures in the DWV system.

c. Absence of cross flow[5] between fixtures.

d. Absence of self-siphonage[5] in the individual fixture traps.

2.2 Site Conditions and Preparation

Before beginning stack testing under load, all fixtures were calibrated for drainage flow rate and all stacks selected for test were inspected for leakage while discharging various fixtures.[6] Adjustable fixtures (such as bathtubs and water closets) were set for optimum performance[7] and the automatic dishwashers were disconnected from the food-waste-disposal units.[8]

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[5]See Appendix A for definitions. It is to be understood that the exclusion of the normal and beneficial siphonic action of a water closet is not intended by criterion (d).

[6]Visual inspection only. No pressure tests were made by NBS, since HUD's records indicated such tests had been successfully completed.

[7]According to manufacturer's recommendations. See Appendix B1.

[8]This was permissible and necessary since the dishwashers were not involved in creating the hydraulic loads in these tests and because the dishwasher drain connection was required to be closed in order to permit measurement of the kitchen sink trap-seal retention, by the particular method used.

In the cases where leakage was detected in the chosen DWV stack, an identical system that was not leaking was selected as determined by visual means during the discharge of various fixtures. This was done to reduce the possibility that observed hydraulic performance might be artificially enhanced due to air relief through unintended openings in the DWV piping.

Instrumentation for the detection of water-surface elevation in the traps was placed at the required points throughout the test stack and initial readings were recorded prior to each test run. In addition, photographs were taken at each test point of major interest or importance.

2.3 Instrumentation

Trap seal depth measurements were made using instrumentation described as follows:

a. Rulers were placed vertically in the water closet traps, from which visual observations were made of the existing water depth at appropriate times.

b. Battery-powered probes were placed in bathtubs, lavatories, laundry sinks, floor drains, and clothes washer standpipes. These probes were connected to a transistor detection circuit which provided the means for the determination of water level changes in 0.1 in increments by a visual light indicator. All probe angular and placement errors, as well as indicator light reading errors, were such that worst-case stack performance would be indicated. This particular technique was developed by NBS specifically for use in the tests of the systems at the King County OBT Prototype Site.

c. A pneumatic pressure/vacuum gauge and two-mode manifold assembly were used to determine water level before and after each test run requiring detection of trap-seal depth changes in kitchen sink traps. This was done by measuring the pressure necessary to push air through the trap seal from the fixture side of the trap and/or by measuring the vacuum necessary to draw air through the trap seal from the drain side of the trap. For accurate results in the vacuum mode, this technique assumes that the inside diameter of both the trap and fixture tailpiece are equal and constant. In the tests reported herein, essentially identical values of full trap-seal depth were determined in the pressure and vacuum modes. This confirmed the reliability of the vacuum mode used with the traps involved in these tests. This method of trap-seal depth measurement was also used in the self-siphonage tests on lavatories. Since this technique requires a certain amount of operator skill, all measurements so taken were repeated for consistency.

d. Cross-flow measurements were made by placing a dye solution in the traps of selected active fixtures, and, after application of test loads, visually observing for color in samples of water drawn from appropriate idle fixture traps.

3. Determinations concerning blow back (positive pressures resulting in ejection of suds, sewage, or gases out of the system) were based on visual and auditory observations of the idle traps considered most subject to such effects. In these tests, the determinations were made in the traps within the lowest branch interval, generally those connected to the soil or waste stack nearest its base.

3. RESULTS

3.1. General

Out of ten DWV stacks which were examined, four of these were found to be leaking. These leaks were evidenced by water emanating from ceilings, electrical fixtures, and other parts of the structure below the level at which fixtures were discharged. It was not possible to determine, in the context of this investigation, the actual number of leaking DWV stacks on the site. Since the points of leakage were hidden within the structure, no attempts were made to determine the exact locations or causes. Substitute stacks that did not exhibit leaks from discharging fixtures were used in the tests for DWV system performance. No pressure tests for leak detection were planned, nor were any made as part of the work described herein. Table B3 Appendix B summarizes the data of primary interest as determined by the on-site tests.

3.2 Hydraulic Performance

3.2.1. Trap Seal Retention

All traps which were examined in tests for induced-siphonage maintained a satisfactory residual seal depth. The maximum reduction in trap seal observed after four runs was 0.3 in of water with an average reduction of between 0.1 in and 0.2 in. These figures represent a trap-seal retention of at least 2.5 in.

Under normal loading conditions, trap-seal retention of more than 50% of the full trap-seal depth effectively satisfies the intent of all major model codes. This means that reductions of as much as 1 3/8 in are allowable in traps with full seal depths of 2 3/4 in.[9]

[9] In the system tested, full seal depths ranged from 2 1/8 in for a laundry tub to 3 1/2 in for the water closets.

Trap-seal retention of 50% or more in all traps on a DWV system after repeated loading without refill of idle traps was set forth as an acceptable performance limit in the Guide Criteria for Operation BREAKTHROUGH (see Criterion H.3.8.1). Acceptance of a 1-in trap-seal retention in a trap with a 2-in seal depth has been indicated by research experts [5, 6]. More recently, the Building Codes Bureau of the State of New York has accepted a trap-seal retention of 50% in traps with at least a 2-in seal depth determined in accordance with OBT Criterion H.3.8.1 as satisfying the intent of the New York State Building Construction Code Applicable to Plumbing for the purposes of testing a single-stack DWV system [7].

During one run on stack No. 1 a slight sucking sound was heard momentarily in the floor drain; however, net seal reduction in the drain was only 0.2 in. This could possibly indicate a reverse slope on the floor drain branch. Because seal retention was adequate, and because no blow back or suds ejection occurred, the momentary sucking action (air flow <u>into</u> the floor drain) is not considered significant.

3.2.2. Blow Back

No evidence of blow back was observed during any of the demonstration of performance runs. The maximum momentary positive pressure recorded at any trap was 0.6 in of water with most pressures averaging between 0.2 in and 0.4 in. These pressure fluctuations were well within a satisfactory range for the traps involved.

3.2.3 Self-Siphonage

In all but one of the tests designed to examine the performance of the traps most subject to self-siphonage, no self-siphonage greater than

0.13 in of water was detected. The one instance in which self-siphonage did occur was on a kitchen sink with the food waste disposal unit operating and with a full sink of detergent-charged water. In this case, the maximum trap-seal reduction was 1.5 in from a 2.75 in original full trap seal, which is excessive according to the criterion suggested in section 3.2.1. However, a person using the food waste disposal unit would not normally operate it with a full sink of sudsy water, and would normally wash the sink bowl with clean water (and thereby replenish the trap seal) after draining the kitchen sink. Thus, this is not considered a significant deficiency as determined by the test made. This result may be attributable to the use of an S-trap configuration (see S1 on figure A4). No trap-seal reduction was detected for this trap with clean water loads nor with detergent loads with the food-waste disposal unit not running.

3.2.4 Cross Flow

No cross flow was detected between back-to-back water closets nor between back-to-back bathtubs or kitchen sinks which were checked. Cross flow was detected between one pair of back-to-back lavatories which were located in two different dwelling units.

It was not known, at the time the tests were made, what significance, if any, should be placed on the occurrence of cross flow between these particular lavatories. The cross flow may have resulted from improper installation, e.g., a reverse slope in the horizontal branch drain or the use of an inappropriate fitting in the common branch serving the back-to-back lavatories. Such a branch assembly would perform the same with respect to cross flow regardless of whether a part of a conventional vented system or a single-stack system.

4. DISCUSSION AND RECOMMENDATIONS

4.1. Significance of Findings in Context of OBT Guide Criteria

The tests described herein indicated conformance to the functional requirements of the OBT Guide Criteria, within the limitations of the test program and with certain exceptions, as described below. It should be understood that the absence of detailed documentation on as-built installation detail limits the value of the findings in relation to extrapolation to systems other than those tested. Also, the fact that leaks were found in some of the DWV systems by discharging the fixtures in pretests before selecting stacks to be tested raises a question as to whether there may have been leaks in the systems that were tested. If undetected leaks existed in the DWV systems on which the hydraulic tests were made, test results could have indicated somewhat better performance than had there been no leaks. The program described herein did not provide for pressure testing for leak detection. Those items found to be in non-conformance, by the tests employed, are:

a. Leakage

The DWV system should not leak (Criterion H.3.2.1). The tests which were conducted indicated non-conformance of some of the DWV assemblies under this Criterion. It is considered highly probably that had these same assemblies been tested on-site after completion of erection by the methods referenced in the Guide Criteria, similar leaks would have been detected. It is recommended that the detected leaks be corrected and the causes for same be determined.

b. Cross flow

The OBT Guide Criteria state that excessive cross flow between fixtures in the DWV system is not permitted (Criterion H.8.4.4.c.).

While unrelated to the single stack design, final housing unit inspection should verify that cross flow due to improper installation does not exist.

4.2. General

4.2.1 Potential Effects Due to Possible Fouling of Horizontal Drains

The results of the functional tests and the cross-flow and self-siphonage tests did not reveal any significant problems. However, these performance demonstrations were conducted on fixtures which were installed in new and unused DWV systems. After a period of service, the horizontal branch drains of DWV systems tend to accumulate grease and/or other foreign matter, and this restriction can retard the discharge from a fixture if the accumulation is sufficiently far advanced to cause the development of a hydrostatic head above the crown of the fixture drain. With traditional designs, the use of a separate fixture drain for each fixture isolates any effects of such excess hydrostatic head to the fixture served by that drain. However, with a back-to-back fixture arrangement employing a common horizontal branch drain, as utilized in the design described herein, the development of restrictions at critical locations could contribute to excessive cross flow and siphonage of either or both of the traps served by the common branch, particularly where the connection to the drainage stack is lower than the dip of the trap. Thus, maintenance needs with this common-branch arrangement might be greater than with conventional designs. The survey described in section 4.2.4 could aid in the resolution of this question.

4.2.2. Possible Frost-Closure Effects

Severe frost closure may result in a temporary deterioration in functional performance of single-stack as well as conventional systems. Thus, the preventative measures generally specified for conventional designs in frost-closure-prone areas may also be sufficient for single-stack designs. The survey recommended in section 4.2.4. would establish whether frost closure is a problem for the single-stack system installed at the OBT Prototype Site in King County, Washington.

4.2.3. Recommended Laboratory Tests

The site tests indicated satisfactory functional performance of the single-stack design approach used in the King County system; hence, extensive laboratory testing of functional performance is no longer considered necessary.

However, some laboratory tests will be conducted concerning the cross-flow potential of the subject back-to-back lavatory design. These tests will assess the performance of the special twin-ell fitting used in the back-to-back lavatory arrangement, and of the drain slope used.

4.2.4. Recommended Survey of In-use Experience

It is recommended that a survey be conducted to obtain data on in-use experience with these designs. The data would include maintenance experience, user response to functional characteristics, frost closure, and other applicable items. This survey would consist of sampled data collected over a period of not less than three years, and it would include comparable housing systems with conventional DWV designs. Also selected field tests would be conducted to assess the effects of accumulated fouling matter in horizontal common fixture branches and in S-trap-like fixture drains.

4.2.5. Criteria for Design and Evaluation of Single-Stack Systems

Originally this study was to include a detailed review of existing criteria for single-stack drainage (see item (d) of section 1.2). However, this task was deleted with HUD and FBH concurrence for two reasons. First, HUD made available to FBH a copy of the most recent NBS guidelines for the evaluation of single-stack designs in the OBT Program. These recommendations were derived from a review of the state-of-the-art. Second, the current program sponsored by HUD (being conducted by American Standard, Inc. at Stevens Institute of Technology) on testing of single-stack designs is expected to produce improved criteria and design data.

APPENDIX A. TEST PROCEDURE FOR DEMONSTRATION OF HYDRAULIC PERFORMANCE

A.1. Terminology

In general, the terminology used herein is consistent with that commonly used in plumbing codes and in the plumbing trade. However, for the sake of clarity, the following terms are specially defined for this work.

Active fixture - A fixture that is discharged for the purpose of creating or contributing to a hydraulic test load.

Blow-back - Ejection of liquids, suds, air, or other gases through the trap seal to the room-side of a trap as a result of excessive pneumatic, hydrostatic, or hydrodynamic pressures on the drain-side of the trap.

Cross-flow - Movement of waste water from the trap of an operating (active) fixture to the trap of a non-operating (idle) fixture.[10]

DWV system - The drain-waste-vent system, including all the sanitary drainage and venting piping inside the building or relevant living unit(s), and including the building drain or relevant part thereof.

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[10] In other test programs it might be appropriate to broaden the definition to cover movement from active to idle trap arm, active to idle branch drain, etc.

Idle fixture - A fixture that is not discharged during the imposition of a hydraulic test load by active fixtures.

Induced siphonage - Reduction in trap seals of non-operating (idle) fixtures caused by the discharge of one or more operating (active) fixtures.

Run - A complete hydraulic event, beginning with the discharge of selected fixtures and ending when the water so discharged has passed through the DWV system.

Self-siphonage - Reduction in trap seal of a fixture (after completion of fixture discharge) caused solely by the discharge of that fixture.

Single-stack drainage - A simplified type of DWV system in which conventional individual, common and branch vents, as well as the conventional vent stack, are omitted. In essence, both drainage and venting are accomplished by one stack in contrast to the conventional design which employs both a drainage and a vent stack, together with individual, common, and/or branch vents.

Trap seal - The depth of water in a trap, measured vertically from the top dip of the trap bore upward to the free surface of the water.

Trap-seal reduction - A decrease from full trap-seal depth.

Trap-seal retention - The amount of trap seal retained. (The difference between the full depth and the reduction.)

A.2. Selection of Stacks for Demonstration

Table A1 identifies the demonstration stacks and indicates the basis for their selection.

Figures A1 through A5 show the stacks referred to in table A1. Certain calculations are shown on the schematics including connected fixture-unit loads and estimated peak discharge rates.

Table A2 lists the various observations by test number and fixture discharged. Table A3 categorizes the tests by load composition and type of observation.

A.3. Selection of Test Loads

The literature describes at least two general approaches that have been used in selecting test loads for DWV testing [1, 2, 3]. The British approach for the testing of systems used in dwellings is to consider the test loading to be comprised of water closets, lavatories, and/or kitchen sinks as/if applicable[11]. The British recommendations ignore the effect of bathtubs that are connected to the same stack as water closets, lavatories, and kitchen sinks. In the case of a stack serving bathtubs only, the number to be discharged simultaneously should be taken to be the same as for sinks, according to CP 304 [3].

In the selection of the test loads for the two- and three-branch interval stacks, the British procedure of considering each type of fixture (to be involved in the load) separately was utilized. In addition, test loads were selected that involved bathtubs. This produced loads generally in excess of those predicted from the Hunter curve for drainage design [8, 9].

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[11] CP 304 does not specifically state what loading allowance is to be made for clothes washers connected to a combination soil-waste system component.

The fixture-unit loads and "Hunter" flow rates appearing on figures A1 through A5 and in table A6 were obtained from the application of the National Standard Plumbing Code [10] and BMS 79 [9], respectively.

Table A4, derived from a table presented in BSS 41 [1] was used to select test loads for single-branch interval portions of the systems. Table A5, also derived from BSS 41, was used to select composite loads for the two- and three-branch-interval stacks. In the application of table A5, the following approach was used:

(1) British-determined values of use frequency, t/T (see table A5), rounded to the next highest hundredth, were utilized: i.e., t/T = 0.01 for water closets and lavatories; t/T = 0.05 for bathtubs; t/T = 0.02 for kitchen sinks. British data were used because corresponding American data for residential occupancy were not available.

(2) A test load comprising water closets and bathtubs was determined, considering each type separately and discharging the resultant separately computed loads simultaneously. This is a conservative application, as discussed in BSS 41.[1].

(3) Another test load was determined in a manner similar to that in (2) but comprising, in addition, lavatories or kitchen sinks. (Lavatories for stack No. 1 and sinks for stack No. 4.)

(4) In the case of stack No. 1, a load comprising the simultaneous discharge of two back-to-back water closets and a bathtub within the same branch interval was applied. The estimated discharge from this load was nearly the same as in (3), but involved a different combination of fixtures.

(5) The test loads (in gpm) assumed (estimated) in the preparation of the test plan for the multi-story systems were based on the results reported in earlier investigations of fixture flow rates [8, 11,12]. It would have been appropriate to have used the flow-rate values determined from on-site calibrations, as in table B1, but this was not done because the test plan had to be completed before the site tests were conducted. The estimated test load flow rates all exceeded the values obtained from the "Hunter curve" [8, 9, 11, 13] by substantial amounts in most cases. It is significant that the actual test load flow rates closely approximated the Hunter values, some loads being a little less and some a little greater than the Hunter rate.

Table A6 compares the estimated test load discharge rates for the multi-story systems with the values obtained from the "Hunter" curve. The actual rates can be computed by reference to tables A2 and B1.

Table A7 provides further detail on the procedure used in selecting the test loads for use in the determination of adequacy of trap-seal retention and of absence of blow-back at idle fixtures in the tests designed to detect induced effects at different floor levels. It should be remembered that in this work, where table A5 was utilized, it was applied separately to each fixture type assumed to be involved in the peak period of use, as recommended in CP304.[3].

As shown in BSS 41 this approach results in heavier loads than if the different types involved are first grouped before computing test loads. Calculations using the estimated fixture discharge rates, the British values of t/T, and the British non-grouping technique showed that the test loads utilized, computed in this manner, were actually greater than if computed using the grouping approach and the greater values of t/T often assumed by American plumbing engineers for some of the fixtures, as described in BSS 41.

A.4. General Approach in Tests[12]

A.4.1. Self-Siphonage Demonstration

a. Fill fixture indicated in table A2. (Lavatory to overflow level, kitchen sink to 5 3/4 in (7.5 gal).

b. Discharge fixture

(1) For lavatory, discharge by operating the pop-up waste mechanism.

(2) For kitchen sink, discharge by

(a) Lifting basket strainer

(b) Operating the food-waste disposal unit with the basket strainer removed.

(3) Observe trap-seal reduction in active trap. Replenish trap before each run and repeat to give results in duplicate.

A.4.2 Demonstration of Induced Effects on Idle Traps

a. Fill fixtures that are to be involved in creating the hydraulic load (see table A2).

Lavatory to overflow level

Sink to 5 3/4 in (7.5 gal)

[12] Table A3 is a summary of some of the most significant parameters as related to the various hydraulic loads listed in table A2.

Bathtub to 6 1/2 in above outlet orifice (25 gal)

Water closet to manufacturers mark in tank

b. Discharge fixtures simultaneously that are to be involved in creating the hydraulic load.

(1) For lavatory, discharge by operating the pop-up waste mechanism.

(2) For kitchen sink, discharge by

(a) Lifting basket strainer

(b) Operating the food-waste disposal unit with the basket strainer removed.

(3) Bathtub - discharge by operating the pop-up waste mechanism.

(4) Water closet - trip handle on tank.

c. Observe trap-seal reduction, blow back, and/or cross flow as applicable.

Replenish all idle traps before demonstration. Apply selected hydraulic load for four successive runs without trap-seal replenishment. Observe for blow-back near bottom of stack during each application of load. Observe for cross-flow and/or trap-seal reduction at appropriate idle traps after a series of four successive runs.

A.5 Details of Test Procedures

A.5.1 Communications

Utilize 2-way radio communications when appropriate, such as in circumstances where test personnel are distributed on two or more floors.

Designated chief will signal load application and call for and record each measurement after application of load. Before the start of each series of hydraulic loads, each crew member will be instructed by the chief as to what measurements or other activities he will be responsible for. This will serve to assure that confusion is kept to a minimum and that all data is appropriately recorded.

A.5.2 Additions to Clean-Water Loads

(1) Detergent (in kitchen sink)--A concentration of granulated detergent shall be prepared and used as recommended by the manufacturer with the sink loads requiring detergent. Place the detergent required for a single run in the sink bowl involved. Run tempered water (approx 100°F) at wide-open rate from faucet to agitate the detergent. Scoop off excess suds in container provided for the purpose so that the water level in the sink can be determined to be 5 3/4 in (7 1/2 gal). Each detergent run (the first and third runs in a series of four flushes) shall be followed by a similar run using clean water with no detergent.

(2) Bubble-bath additive (in bathtub)--A concentration of bubble-bath flake additive shall be prepared and used as recommended by the manufacturer with the bathtub loads requiring such additive. Measure the additive required for a single run and place in the bathtub involved in the load. Run tempered water (approx 100°F) at wide-open rate from faucet to agitate the additive. Scoop off excess suds in container provided for the purpose so that the water level in the bathtub can be determined to be at 6 1/2 in (25 gal). Each bubble-bath run (the first and third runs in a series of four flushes) shall be followed by a similar run using clean water.

(3) Paper diaper (in the water closet)--One large-size paper diaper shall be flushed with loads requiring paper diaper. The paper diaper shall be placed in the appropriate WC bowl as instructed on the package by the manufacturer except that the cloth membrane shall not be removed (the plastic membrane shall be removed). Each paper diaper run (the first and third runs in a series of four flushes) shall be followed by a similar run using clean water with no paper diaper.

A.5.3 Detection of Cross Flow

Where it is desired to detect cross flow (see table A2), add a small quantity of suitable dye, before each run, to the active trap opposite the idle trap being observed. After end of the run or series of runs, and after trap-seal retention is measured, withdraw a sample of the water from the idle trap and observe for evidence of dye crossover.

A.5.4 Detection of Blow Back

Where it is desired to detect blow back, e.g., basement and/or first-floor idle fixtures (see table A2), station an observer at the critical location. Observer shall observe visually the most critical idle trap seal under suitable illumination, and shall listen for evidence of blow back in other nearby critical idle traps during application of hydraulic load.

A.5.5 Detection of Trap-Seal Surface Elevation

Where it is desired to detect trap-seal reduction/retention, or to determine initial depths of trap seal, utilize electrical water-level-change detector. Where the electrical approach is not feasible, utilize the pneumatic water-level-change detector, e.g., kitchen sink with food-waste disposal unit.

(1) Procedure, pneumatic approach[13, 14]--fill trap with water. Close off overflow openings and other supplemental openings on room-side of trap seal.

(a) Place suction cup of instrument over drain outlet, and set valves for vacuum mode. Operate squeeze-bulb pump slowly while observing gage. Record stabilized high-value from gage. Slowly remove vacuum.

(b) Then set valves for pressure mode and repeat. Remove suction cup from drain outlet. After prescribed hydraulic loading is completed, repeat procedures (a) and (b) and again record stabilized high-values from gage for both vacuum and pressure modes. Generally, the trap-seal reduction may be calculated as $(a_1 - a_2)/2$, or in the event $(a_1 - a_2) > H$, then trap-seal reduction may be approximated by $b_1 - b_2$. This procedure in the vacuum mode yields accurate results if the inside diameter of the trap and tailpiece are equal and constant.

(c) From (a) and (b), the initial values may be used to compute the full trap-seal depth, the general relationship being $H \approx \frac{a_1}{2} \approx b_1$, assuming the trap is symetrical and that the trap and lower tailpiece have a uniform internal diameter.

---

[13] H is the full trap-seal depth.

[14] a_1 is the initial gage reading in vacuum mode, inches of water

a_2 is the final gage reading in vacuum mode, inches of water

b_1 is the initial gage reading in pressure mode, inches of water

b_2 is the final gage reading in pressure mode, inches of water

(2) Procedure, electrical approach--Fill trap with water. Place electrical probe vertically in tube extending upward from room-side of the trap seal, until with a slowly-moving upward motion of the probe, a selected numbered lamp on the indicator panel begins to fade, but is not "out". Secure probe at that position so that vertical movement is impossible, recheck and record the highest lamp number that is "on". After completion of hydraulic loading on the idle trap thus prepared, the increase in the number of unlighted lamps multiplied by 0.1 in shall be taken as the trap-seal reduction.

(3) Procedure, scale approach--For a water closet, fill the idle trap with water. Secure a vertically positioned ruler (scale calibrated in inches and fractions of an inch) in the water closet bowl. Observe and record initial scale reading (h_1). After prescribed hydraulic loading is completed, again observe and record scale reading corresponding to elevation of the water surface at that time (h_2). Trap-seal reduction may be calculated as (h_1 - h_2).

A.5.6 Calibration of Fixtures for Volume, Discharge Rate, and Duration of Discharge

(1) Lavatory--Measure volume of water necessary to fill to overflow level, then discharge by operating the pop-up waste mechanism. Measure the time duration of discharge. Repeat to obtain duplicate measurements. Compute volume in gallons, duration of discharge in seconds, and average discharge rate in gpm.

(2) Kitchen sink--Fill to a depth of 5 3/4 in (7.5 gal) then discharge by lifting basket strainer out of sink. Measure the time duration of discharge. Repeat to obtain duplicate measurements. Calibrate both

with and without the food-waste disposal unit operating during the discharge. Compute volume in gallons, duration of discharge in seconds, and average discharge rate in gpm.

(3) Bathtub--Fill to a depth of 6 1/2 in above drain orifice ($\approx$25 gal), then discharge by operating the pop-up waste mechanism. Measure the time duration of discharge. Repeat to obtain duplicate measurements. Compute volume in gallons, duration of discharge in seconds, and average discharge rate in gpm.

(4) Water closet (tank type)--Adjust high-water level to correspond to manufacturer's mark. Trip flush handle and measure time until flush valve closes at bottom of tank. Then determine volume of water required to refill tank to high-water level. Also measure or compute volume of water delivered to the bowl through trap-refill tube and to tank through hush tube during the time that water is being discharged from the tank, and add this volume to the larger volume represented between the high and low water levels in the tank, to obtain "total volume of flush."

Repeat to obtain duplicate measurements. Compute volume of flush in gallons, duration of discharge from the tank in seconds, and average discharge rate from the tank in gpm.

It is realized that the characteristics of the discharge from the water closet bowl into the drainage system differ somewhat from the corresponding characteristics of the discharge from the tank into the bowl, depending on the siphonic action and other aspects of the bowl. However, since on-site conditions preclude calibrations based on measurements of the discharge from the bowl, tank-discharge calibrations represent the only feasible alternative.

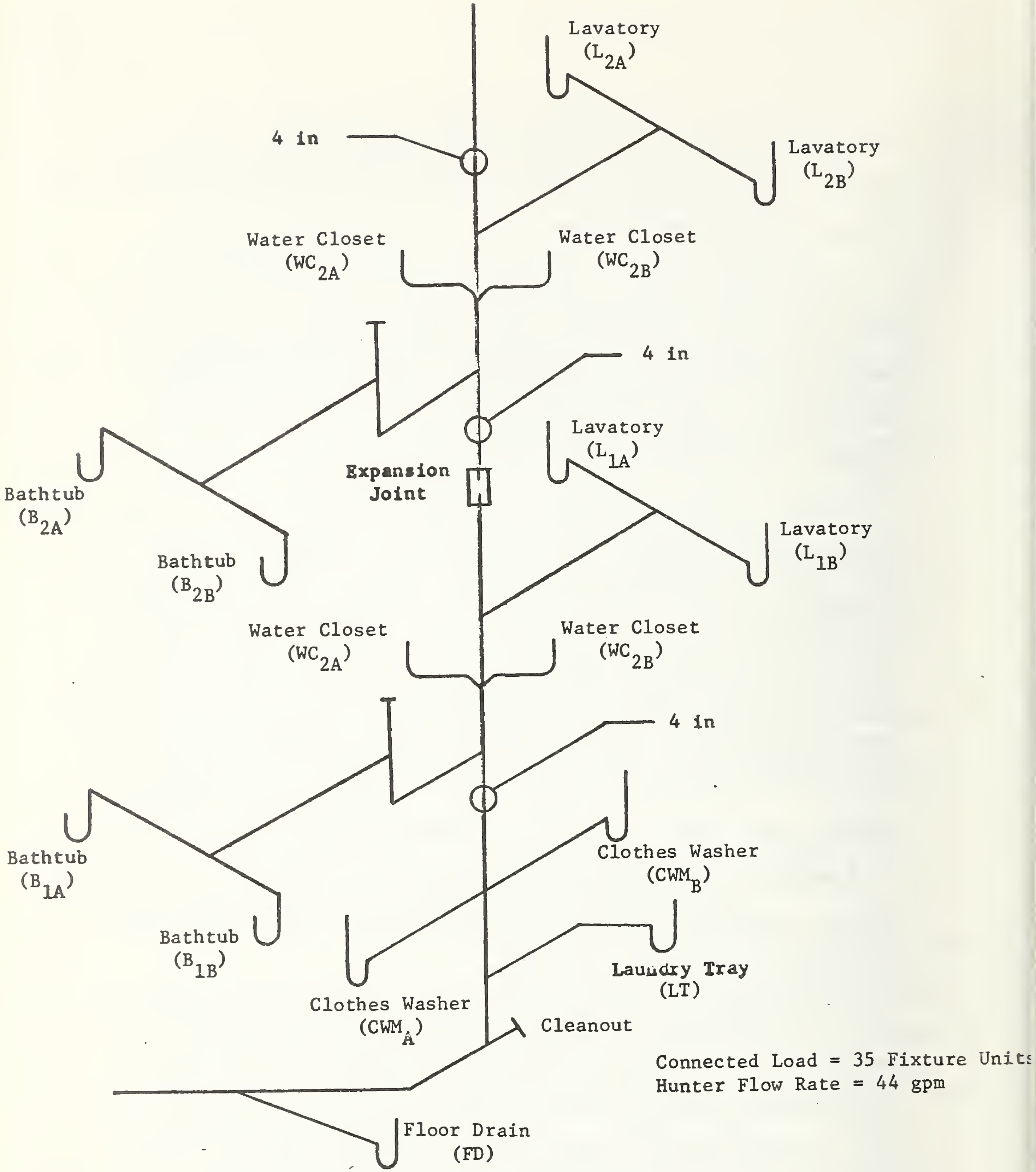


Figure A1

MFLR Back-To-Back Bathroom/Laundry Stack

12311 N.E. 147th Court, Apartments 1C, 1D, 2C, 2D

Operation BREAKTHROUGH Prototype Site, King County, Washington

(Stack No. 1)

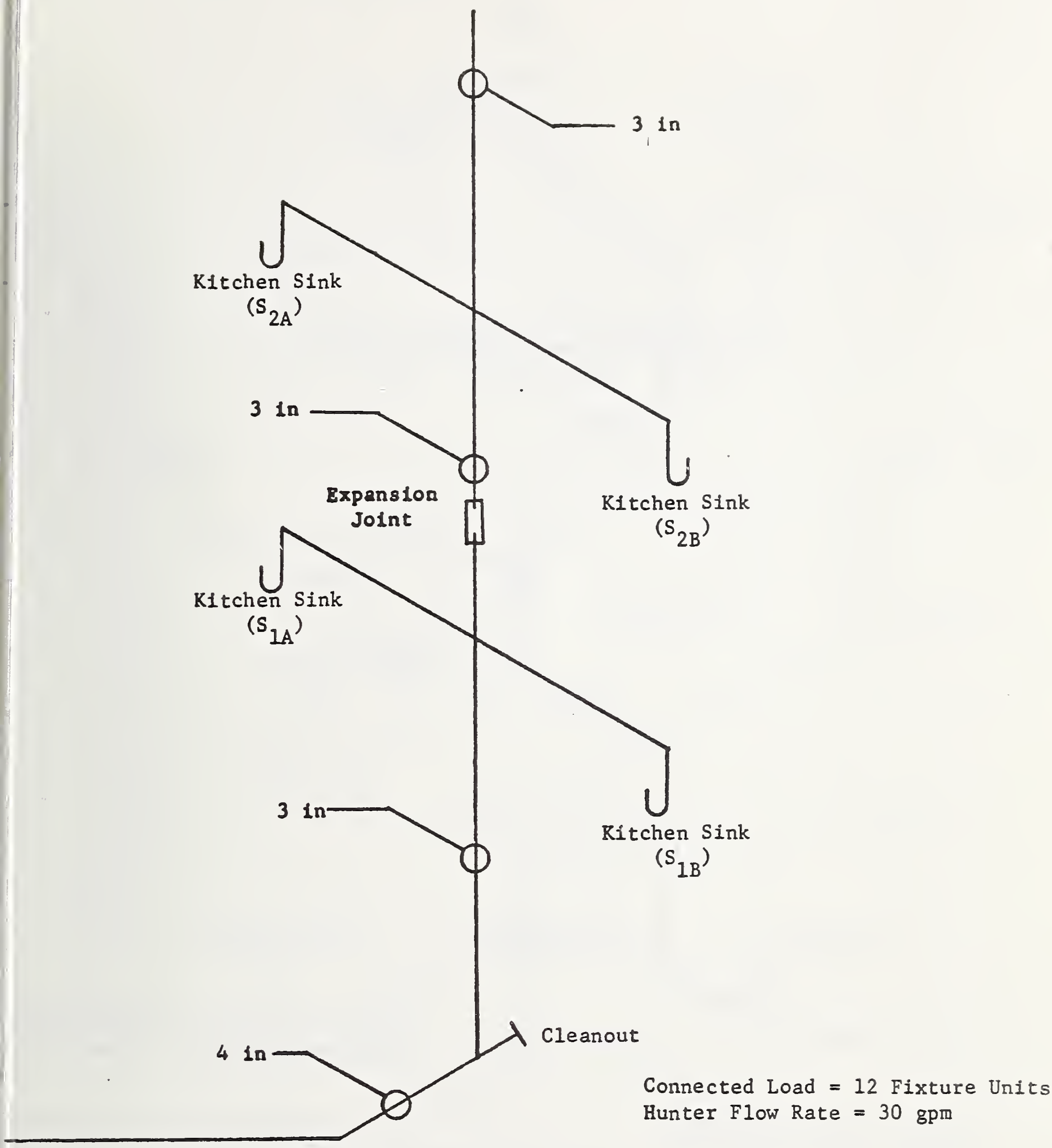


Figure A2

MFLR Back-To-Back Kitchen Stack
12311 N.E. 147th Court, Apartments 1C and 2C
Operation BREAKTHROUGH Prototype Site, King County, Washington

(Stack No. 2)

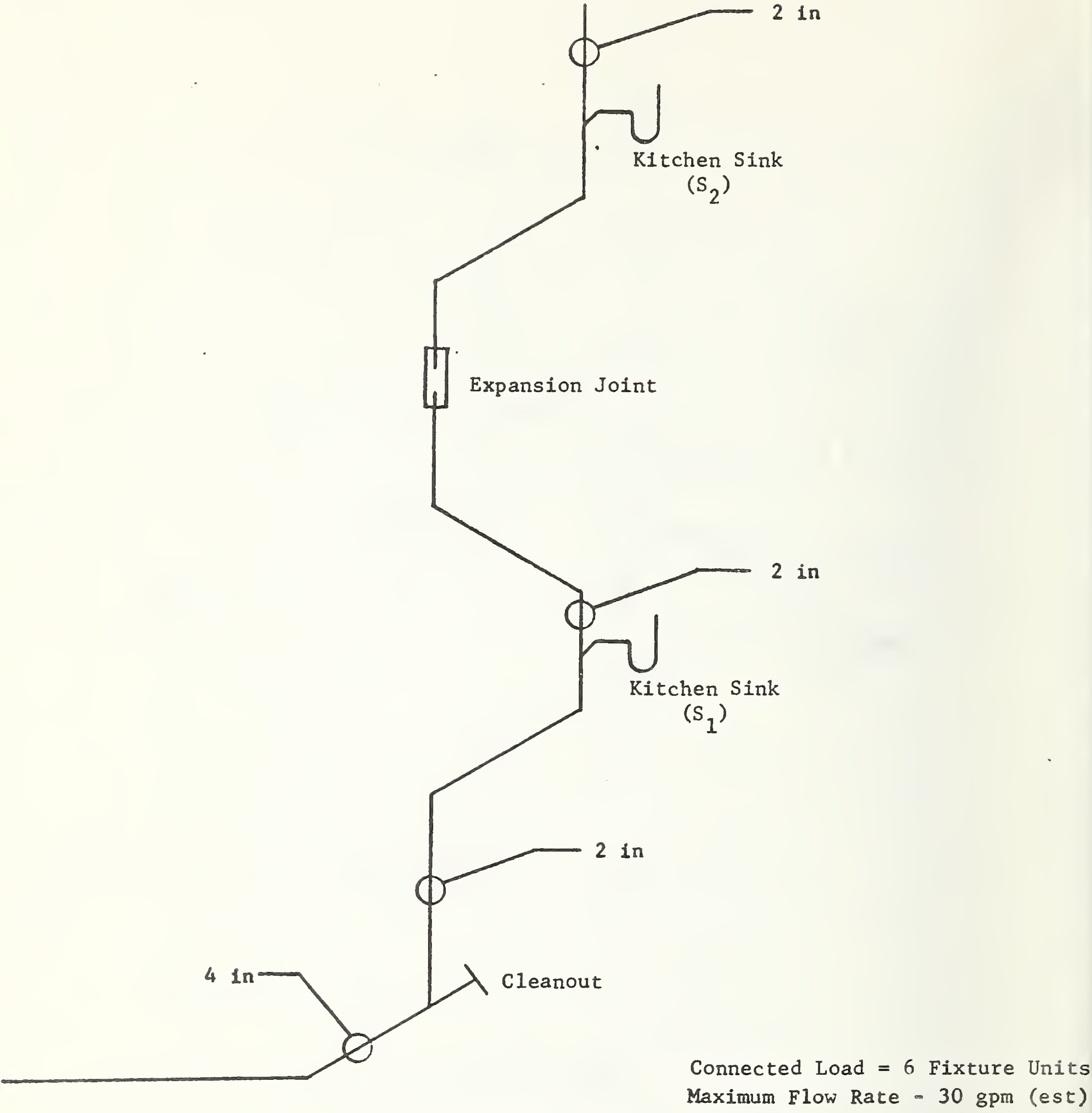
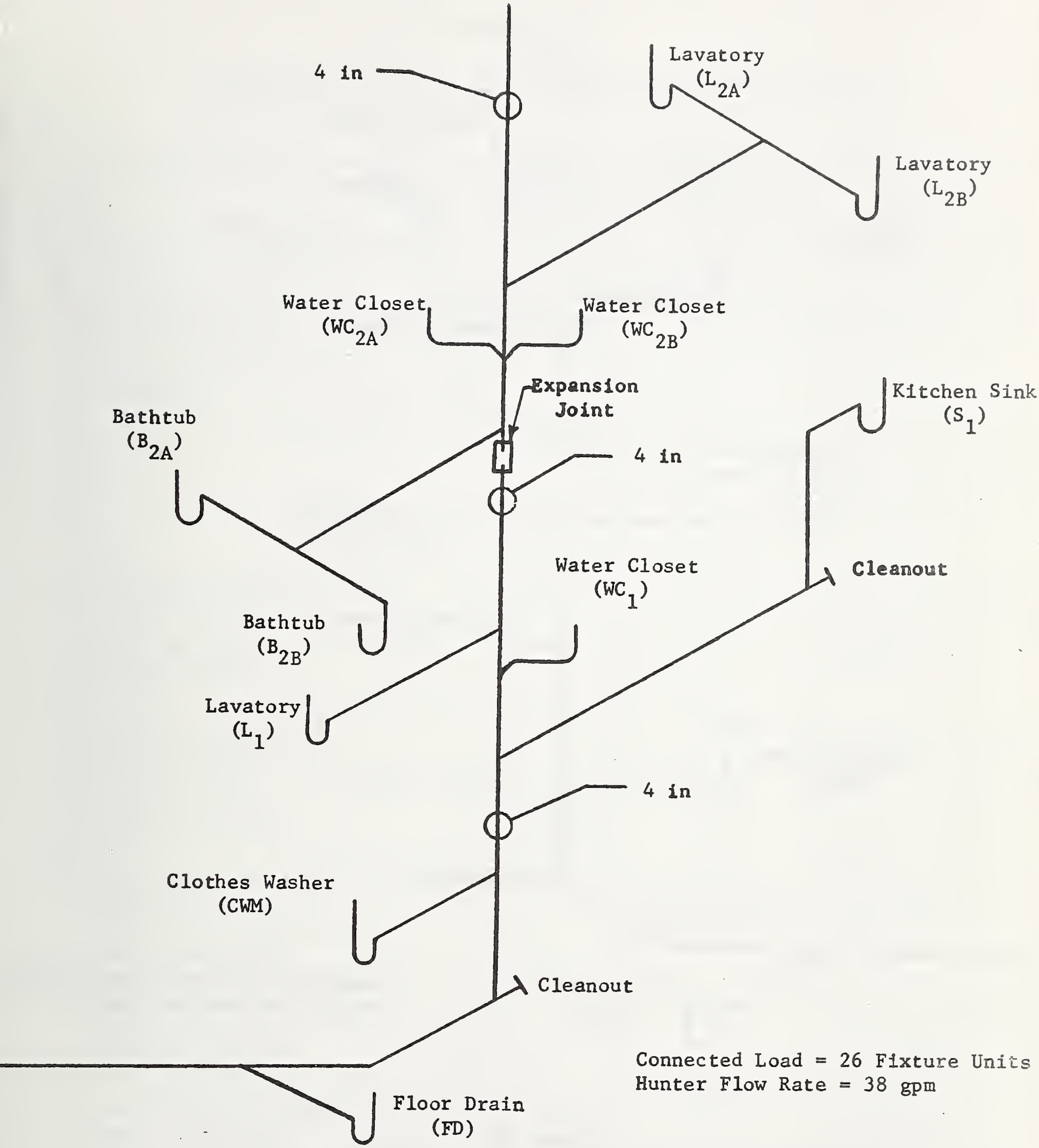


Figure A3

MFLR Single-Kitchen Stack
12311 N.E. 147th Court, Apartments 1A and 2A
Operation BREAKTHROUGH Prototype Site, King County, Washington

(Stack No. 3)

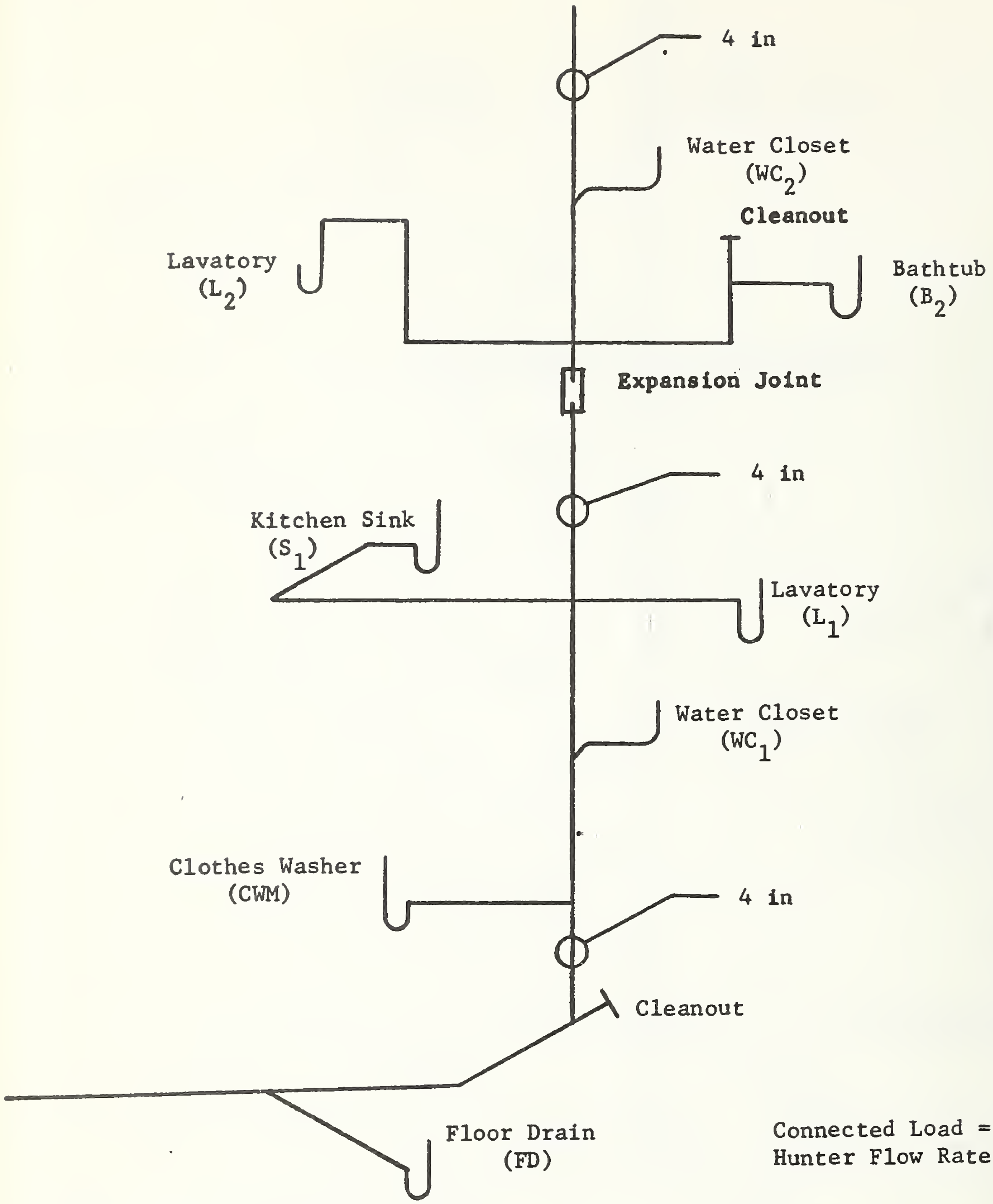


Connected Load = 26 Fixture Units
Hunter Flow Rate = 38 gpm

Figure A4

SFA Back-To-Back Bathrooms/Half Bath/Kitchen/Laundry Stack
12312 N.E. 147th Court (Lot 39)
Operation BREAKTHROUGH Prototype Site, King County, Washington

(Stack No. 4)



Connected Load = 20 Fixture Units
Hunter Flow Rate = 35 gpm

Figure A5

SFA Single Bath/Half Bath/Kitchen/Laundry Stack
12307 N.E. 147th Court (Lot 35)
Operation BREAKTHROUGH Prototype Site, King County, Washington

(Stack No. 5)

Table A1

Description of Stacks Observed, and Rationale for Selection
(Operation BREAKTHROUGH Prototype Site, King County, Washington)

Stack Description	Test Order	Levitt Unit No.	Housing Type	Rationale for Selection
Stack No. 1, 4 inch soil stack; back-to-back bathrooms on 1st and 2nd stories; laundry and floor drain in basement.	1	10 & 11	MFLR (Multi-Family Low Rise)	Heaviest loading due to back-to back arrangement. Trap-seal retention of lower floor fixtures should be verified. Possible cross flow in twin ells. Possible back pressure at bottom of stack.
Stack No. 2, 3 inch separate kitchen stack; back-to-back kitchens on 1st and 2nd stories.	4	10 & 11	MFLR	Greatest loading for sink stacks. Possible suds problem at bottom of stack.
Stack No. 3, 2 inch separate kitchen stack; single kitchen on 1st and 2nd stories.	2	10 & 11	MFLR	Possible back pressure & suds problem due to off-sets and small stack diameter.
Stack No. 4, 4 inch soil stack; back-to-back 2nd story bathrooms, half-bath & kitchen 1st story, clothes washer and floor drain in basement.	3	5	SFA (Single Family Attached)	Possible self-siphonage of sink trap due to unvented vertical section in drain. Possible suds problem or back pressure in basement.
Stack No. 5, 4 inch soil stack; full bath 2nd story kitchen & 1/2 bath 1st story, clothes washer in basement.	5	8	SFA	Possible self-siphonage of lavatory trap due to unvented vertical section in drain.

Table A2

Description of Hydraulic Loads and Observations for Performance Demonstration of Single-Stack Systems at the Operation BREAKTHROUGH Prototype Site, King County, Washington (TEST PLAN)

Test No.	Description		
	Fixture(s) to be Discharged	Estimated Discharge[15]	Observations (Remarks)
		gpm	
1.1.1	$L_{2A(CW)}$	10.0	Observe L_{2B} for cross flow, seal reduction
1.2.1	$B_{2A(CW)}$	13.5	Observe B_{2B} for cross flow, seal reduction
1.2.2	$B_{2A(BB)}$	13.5	Observe B_{2B} for cross flow, seal reduction
1.3.1	$WC_{2A(CW)}$	27.0	Observe WC_{2B} for cross flow, seal reduction
1.3.2	$WC_{2A(PD)}$	27.0	Observe WC_{2B} for cross flow, seal reduction
1.4.1	$L_{2A(CW)}$+ $WC_{2B(CW)}$	37.0	Observe B_{2A} & WC_{2A} for seal reduction
1.5.1	$B_{2A(CW)}$+ $WC_{2B(CW)}$	40.5	Observe B_{2B} & WC_{2A} for seal reduction
1.6.1	$WC_{2A(CW)}$+ $B_{2A(CW)}$+ $B_{2B(CW)}$	54.0	Observe idle fixtures[16] for seal loss and blow-back on first floor and in basement
1.6.2	Same as 1.6.1	54.0	Except flush PD in WC_{2A}
1.6.3	Same as 1.6.1	54.0	Except use BB in B_{2A}
1.7.1	$WC_{2A(CW)}$+ $L_{2A(CW)}$+ $B_{2A(CW)}$+ $B_{2B(CW)}$	64.0	Observe idle fixtures[16] for seal loss and blow-back on first floor and in basement
1.7.2	Same as 1.7.1	64.0	Except flush PD in WC_{2A} and use $B_{1A(CW)}$ instead of $B_{2B(CW)}$
1.7.3	Same as 1.7.1	64.0	Except use BB in B_{2A} and use $B_{1A(CW)}$ instead of $B_{2B(CW)}$

[15] Based on the assumption of the following mean discharge rates:

WC = 27.0 gpm B = 13.5 gpm
Lav = 10.0 gpm S = 15.0 gpm

[16] For the purposes of this demonstration, it will be sufficient to make measurements on only one trap of each pair of idle back-to-back fixtures that are plumbed symetrically.

Table A2 Continued

Test No.	Description		
	Fixture(s) to be Discharged	Estimated Discharge [15]	Observations (Remarks)
		gpm	
1.8.2	$WC_{2A(PD)}$+ $WC_{2B(CW)}$+ $B_{2A(CW)}$	67.5	Observe idle fixtures[16] for seal loss and blow-back on first fl and in basement
1.8.3	Same as 1.8.2	67.5	Except use BB in B_{2A}
3.1.1	$S_{2(CW)}$	15.0	Observe for seal loss and blow-back in S_1
3.1.2	Same as 3.1.1	15.0	Except use Det in S_2
3.1.3	Same as 3.1.2	15.0	Except operate fwdu during discharge of sink
4.1.1	$S_{1(CW)}$	15.0	Observe for self siphonage of S_1
4.1.2	Same as 4.1.1	15.0	Except add Det and operate fwdu
4.2.1	$WC_{2A(CW)}$+ $L_{2A(CW)}$+ $S_{1(CW)}$	52.0	Observe for seal loss and blow-back in idle fixtures on first fl and in basement
4.2.2	Same as 4.2.1	52.0	Except use PD in WC_{2A}
4.2.3	Same as 4.2.1	52.0	Except use Det in S_1 and operate fwdu
2.1.1	$S_{2A(CW)}$	15.0	Observe for seal loss and blow-back in S_{1A}
2.1.2	Same as 2.1.1	15.0	Except use Det in S_{2A} and operate fwdu
2.2.1	$S_{2A(CW)}$+ $S_{2B(CW)}$	30.0	Observe for seal loss and blow-back in first floor fixtures
2.2.2	Same as 2.2.1	30.0	Except use Det in S_{2A} and operate fwdu
5.1.1	$L_{2(CW)}$	10.0	Observe for self-siphonage of L_2

[15] Ibid

[16] Ibid

NOTES: Subscripts for fixtures discharged indicate floor no., right or left side (A or B) in back-to-back arrangements, and whether clean water (CW), detergent (DET), bubble bath (BB), or paper diaper (PD) is used.

Table A2 Continued

NOTES: Continued

The subscript fwdu stands for food-waste-disposal unit.

Fixture Symbols:

- WC - water closet
- B - bathtub
- L - lavatory (wash basin)
- S - sink (kitchen)
- CWM - clotheswashing machine
- DWM - dishwashing machine
- LT - laundry tray (tub)
- FD - floor drain

Test No. Code:

First number stands for the stack number (see table A1).
Second number identifies a particular combination of fixtures discharged.
Third number identifies variations in the load, e.g., clean water, detergent, paper diaper, fwdu running/not running, etc.

Table A3

Guide for Application of Procedures for Performance Demonstration of Single-Stack Systems at the Operation BREAKTHROUGH Prototype Site, King County, Washington (TEST PLAN)

Test No.	Load Composition	Phenomena to be Observed	Similar to Series No.
1.1.1, 1.2.1 1.3.1, 1.4.1 1.5.1	Clean, cold water	Cross flow and seal reduction in certain fixtures on 2nd floor	
1.2.2	Bubble-bath in warm[17] water in bathtub	"	1.2.1
1.3.2	Paper diaper in WC	"	1.3.1
1.6.1, 1.7.1 1.8.1	Clean, cold water	Seal reduction and blow back in idle fixtures on 1st floor in basement	
1.6.2	Paper diaper in WC	"	1.6.1
1.7.2	"	"	1.7.1
1.8.2	"	"	1.8.1
1.6.3	Bubble-bath in warm[17] water in bathtub	"	1.6.1
1.7.3	"	"	1.7.1
1.8.3	"	"	1.8.1
3.1.1	Clean, cold water	Seal reduction and blow back in first floor sink	
3.1.2 (w/o fwdu)	Detergent in sink with warm[17] water	"	3.1.1
3.1.3 (w/fwdu)	"	"	3.1.1
4.1.1 (w/o fwdu)	Clean, cold water	Self siphonage of first floor sink	
4.1.2 (w/fwdu)	Detergent in sink with warm[17] water	"	4.1.1
4.2.1	Clean, cold water	Seal reduction and blow back in idle fixtures on 1st floor and in basement	
4.2.2	Paper diaper in WC	"	4.2.1
4.2.3 (w/fwdu)	Detergent in sink with warm[17] water	"	4.2.1

[17] Estimated 100°F.

Table A3 Continued

Test No.	Load Composition	Phenomena to be Observed	Similar to Series No.
2.1.1	Clean, cold water	Seal reduction and blow back in 1st floor fixtures	
2.2.1	"	"	
2.1.2	Detergent in sink with warm[17] water	"	2.1.1
2.2.2	"	"	2.2.1
5.1.1	Clean, cold water	Self siphonage of second floor lavatory	

17 Ibid

Table A4

A Guide 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 Load [18]
1	1
2	2 [19]
3	2
4	2
5	3
6	3
7	3
8	3
9	4

[18] 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. Investigators generally employ simultaneous fixture discharges as a feasible compromise.

[19] Also discharge each fixture individually.

Table A5

A Guide for Selecting Test Loads for Multistory Plumbing Systems[20]

Size of System[21, 22] (Number of Connected Fixtures) — Frequency of Use Ratio; Duration of Discharge/Time between Uses										Number of Concurrently Operating Fixtures to Comprise Test Load[21]
$\frac{t}{T} = 0.01$	$\frac{t}{T} = 0.02$	$\frac{t}{T} = 0.03$	$\frac{t}{T} = 0.04$	$\frac{t}{T} = 0.05$	$\frac{t}{T} = 0.06$	$\frac{t}{T} = 0.07$	$\frac{t}{T} = 0.08$	$\frac{t}{T} = 0.09$	$\frac{t}{T} = 0.10$	
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

[20] 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. Investigators generally employ simultaneous fixture discharges as a feasible compromise.

[21] 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 0.01 for service systems not larger than indicated by the stated load range (number of connected fixtures). The fundamentals of this procedure are presented in certain NBS publications (1, 8, 11).

[22] 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.

Table A6

Comparison of Estimated Test Load Discharge Rates with the Corresponding "Hunter" Curve Values for Tests Involving Multistory Soil and Waste Stacks

Test Load No.	"Hunter" Load Values		Estimated Discharge Rate of Test Load [23]
	Fixture Units	gpm	gpm
1.6.1, 1.6.2, 1.6.3	35	44	54.0
1.7.1, 1.7.2, 1.7.3	35	44	64.0
1.8.2, 1.8.3	35	44	67.5
2.2.1, 2.2.2	12	30 approx	30.0
4.2.1, 4.2.2, 4.2.3	26	38	52.0
3.1.1, 3.1.2, 3.1.3	6	Not Applicable [25]	15.0

23 Values in this column are based on generally accepted fixture flow rates. Actual flow rates, which were determined later by site calibration, differed from these values (see table B1). Test-load discharge rates computed from the actual fixture discharge rates more closely agreed with the "Hunter" load values.

24 Hunter curve does not extend below 10 fixture units. Estimated "fair" test load - 1 sink, or approximately 15 gpm.

NOTE: The fixture-unit loads were computed from the rating scheme given in reference [10], and the corresponding "Hunter" flow rates were obtained from reference [9].

Table A7. Bases of Load Selection for Tests Involving Induced Effects at Different Floor Levels

Test Series	Fixture Types Comprising Load	FIXTURES			Guide for Choosing Numbers of Fixtures to be Discharged	Load Type Per BSS 41/CP 304 Terminology
		Number of Fixtures of Indicated Type to be Considered in Load Computation	Number to be Discharged Together	Frequency of Use,[25] t/T		
1.6	WC B	4 4	1 2	0.01 .05	Table A5	No. 2, Evening peak bathroom load
1.7	WC B L	4 4 4	1 2 1	.01 .05 .01	Table A5	No. 3, Composite peak bathroom load
1.8	WC B	2 (top floor) 2 (top floor)	2 1	- -	Special Choice: 2 back to back WC's flushing, plus one bathtub draining on same floor. Agrees with use of Table A4 for selection of 3 fixtures operating (of the 6 on top fl) arbitrarily chosen as the two WC's and one of the bathtubs.	—
2.1	S	2	1	0.02	Table A5	—
2.2	S	4	2	-	Special Choice: Worst case by engrg. judgment. Agrees with use of Table A4 considering 4 fixtures	—
3.1	S	2	1	.02	Special Choice: Worst case by engrg. judgment. Equivalent to use of Table A4, considering 2 fixtures	—
4.2	WC L S	3 3 1	1 1 1	.01 .01 .02	Table A5	No. 1 morning peak bathroom load, plus kitchen sink

[25] The values given are those determined from British sources. The term "t" is the duration of a single operation of a fixture, and "T" is the average time between successive operations in a period of peak use.

APPENDIX B. ON-SITE PREPARATIONS

B.1. Fixture Flow-Rate Calibrations

Tables B1 and B2 contain a summary of the results of fixture and trap calibration, determined essentially as briefly described in Appendix A and as described in more detail below. The measurements indicated were used to determine volume discharged, duration of discharge, and average discharge rate as called for in the test plan, section A.5.6.

a. Bathtubs

Quantities of water, as measured with a graduated container, were placed in the individual bathtubs and corresponding depth markings were placed on masking tape which was attached to the inside of the tub before the surface was wetted. The bathtub was then drained and the time necessary to empty all of the water into the building DWV system was determined by means of a stop watch.[26] Measurements of the time for filling and draining the bathtubs were made as many as four times in order to establish a meaningful average. In those cases where the first drain time was consistent with the time previously obtained on fixtures of the same type and model, replicate measurements were not made. Attempts were made to adjust the bathtub drain pop-up mechanisms such that a maximum flow rate could be obtained in the open position, and such that no leakage into the drain occurred in the closed position. In some few cases, elapsed time was recorded at intermediate depths while the bathtub was draining so that a volume discharged versus time profile could be

[26]The time required to drain the small quantity of trail flow was neglected as being irrelevant and misleading for the purposes of these tests.

established. In addition the time required to fill certain fixtures with maximum water valve (faucet) openings was recorded; this was done in order to establish a meaningful estimate as to the maximum flow rates obtainable at the fixtures (see criterion H3.10.1.a of the Guide Criteria).

b. Lavatories

The volume of water necessary to fill each of the three different types of lavatories utilized in the housing units was measured with a graduated container and the value recorded. Each lavatory was filled to the overflow level and the pop-up stopper was released causing drainage to occur. The time required to empty all of the water into the DWV system was recorded for each lavatory fixture in a manner similar to that described above for bathtubs. This measurement was repeated several times on certain fixtures in order to obtain an idea of the degree of repeatability.

c. Kitchen Sinks

The dishwasher discharge line was disconnected from the food waste disposal unit and a rubber stopper was installed in its place, on those kitchen sinks which were to be used as idle fixtures (this was necessary to the use of the pneumatic method for measuring trap-seal depth, because this method required closing off all overflow openings and other supplemental openings on the room-side of the trap seal. Measured quantities of water were then placed in the kitchen sinks and time measurements were made in a manner similar to that described for the bathtubs. These calibrations were conducted with the food waste disposal unit not operating, and then were repeated with the disposal unit operating. The detailed description of test procedures included in the original test plan is given in Appendix A.5.

d. Water Closets

The water closet calibrations were conducted approximately in accordance with the procedure outlined in section A.5.6(4). In order to make the required computations, the following on-site procedure was used, beginning with a typical fixture selected at random:

(1) The float mechanism was adjusted to yield a water level in the tank corresponding to the manufacturer's recommended water level with the supply stop valve fully open, in a normal flushing cycle.

(2) The elevation of the water surface was determined at the instant that the tank flush valve closed, and a corresponding reference mark made on the side of the tank.

(3) A reference mark was made on the inside of the tank at approximately the mid-range elevation of the water surface in the tank during the flush cycle.

(4) Next, the supply stop valve was fully closed, and the tank was emptied to the low-water level as determined in (2). Then, with the tank flush valve closed, the volumes of water required to be added to the tank, using a graduated container to bring the water level up to the mid-range mark (item 3) and to the manufacturer's recommended water level (item 1), were determined.

(5) The volume of water delivered by the trap-refill mechanism during the period of time when the tank flush valve was open in a normal flush, was determined with the supply stop valve fully open.

(6) The following measurements of time were made:

(a) Time to empty tank (ending with drop of tank flush valve), with supply valve fully closed.

(b) Time to empty tank (ending with drop of tank flush valve), with supply valve fully open.

(c) Time to fill tank to the mid-level mark referred to in item (3) above, with stop valve fully open.

The volume measurements described above were made on one water closet of each manufacturers make and model type. The other water closets involved in the tests were assumed to have the same volume/discharge characteristics as those of the same make and type which were actually calibrated as described above. The time for each of the other water closet tanks to empty (ending with the drop of the tank flush valve) was measured, with the supply stop valve fully open, as in (6)(b) above. It was assumed that the time for the tank to refill to mid-elevation, as in (6)(c) above was the same for all the water closets of the same make and type. It was also assumed that the volume of water delivered by the trap-refill mechanism, as in (5) above, was the same for all the water closets of the same make and type.

Based on these measurements and assumed values, the volumes, times, and average discharge rates for the several water closet tanks were computed, as listed in table B1. These rates include the small rates contributed by the trap-refill mechanism while the tank is in the process of emptying.

e. Full Trap-Seal Depths

Full trap-seal depths were measured using the pneumatic method where feasible and, when sufficient access was available, the results thus obtained were checked by a simple ruler measurement of the trap geometry. The full trap-seal depths are summarized in table B1.

B.2. Fixture-Leakage Abatement

All fixtures to be used in the demonstration program were inspected for leakage around their drain and overflow fitting connections and, where such leaks were discovered, they were eliminated.

B.3. Other On-Site Preparations

Prior to beginning the performance demonstration tests on any of the selected stacks, a positive visual identification of stack and fixtures was made. This identification was established in order to preclude the possibility of inadvertantly performing a series of test runs on a stack other than the one selected, or with the wrong fixtures discharging. The appropriate building, apartment, and lot numbers were recorded, and the stack was assigned a number which was marked on tape and placed with each fixture group served by the stack.

With each stack thus identified, a short series of fixture discharges into the DWV system was made, and a visual check for leaks was conducted. On occasions where leaks occurred in the DWV system, another geometrically similar stack was chosen.

Once stack selection and preliminary leak tests were completed, each fixture to be involved in the demonstration was assigned an identification number and this number was placed on the fixture by means of masking tape. This facilitated rapid positive identification of idle and active fixtures as called for in the test plan and improved verbal communication during the tests. Finally, all instrumentation to be used in the test demonstration involving the stack selected was installed in the appropriate locations and initial values were recorded. This instrumentation included electrical probes and rulers. In some cases the pneumatic water-level-change detector was used, and in such cases initial pneumatic readings were made and recorded. Check-out of the communications (walkie-talkie and loud voices) to be used was conducted and, when proven satisfactory, the performance demonstration tests involving the stack selected were begun.

Table B1

Hydraulic Properties of Fixtures
at the King County, Washington OBT Prototype Site
(As Determined from On-Site Calibrations)

Fixture/Stack	Unit No.[27]	Lot[28]	Volume gal	Time seconds	Flow Rate gpm
WC_{1A}/1(P)	10-11	Unknown	4.41	16.6	15.44
WC_{1B}/1(P)	10-11	Unknown	4.28	16.8	15.81
WC_{2A}/1(P)	10-11	Unknown	4.38	16.3	16.14
WC_{2B}/1(P)	10-11	Unknown	4.36	16.0	16.35
B_{1A}/1(P)	10-11	Unknown	25.0	142.0	10.56
B_{1B}/1(P)	10-11	Unknown	25.0	173.0	8.67
B_{2A}/1(P)	10-11	Unknown	25.0	169.0	8.88
B_{2B}/1(P)	10-11	Unknown	25.0	148.0	10.14
L_{1A}/1(P)	10-11	Unknown	2.1	15.2	8.26
L_{1B}/1(P)	10-11	Unknown	2.1	14.8	8.49
L_{2A}/1(P)	10-11	Unknown	2.1	13.2	9.52
L_{2B}/1(P)	10-11	Unknown	2.1	15.2	8.26
S_{1A}/2(P)	10-11	Unknown	7.5	32.9	13.68
S_{1B}/2(P)	10-11	Unknown	7.5	35.2	12.78
S_{2A}/(P)	10-11	Unknown	7.5	31.0	14.52
S_{2B}/2(P)	10-11	Unknown	7.5	32.6	13.80
S_{1A}/2(P)	10-11	Unknown	7.5	39.0	11.54[29]
S_{1B}/2(P)	10-11	Unknown	7.5	36.2	12.43[29]
S_{2A}/2(P)	10-11	Unknown	7.5	33.0	13.64[29]
S_{2B}/2(P)	10-11	Unknown	7.5	36.2	12.43[29]
S_1/3(P)	10-11	Unknown	7.5	36.2	12.43
S_2/3(P)	10-11	Unknown	7.5	30.2	14.88
S_1/3(P)	10-11	Unknown	7.5	39.0	11.54[29]
S_2/3(P)	10-11	Unknown	7.5	35.5	12.68[29]

[27] Unit Number refers to the drawing code number of the dwelling unit in which the fixture was located.

[28] Lot number refers to the HUD lot location within the OBT Prototype Site.

[29] With food-waste disposal unit running.

Table B1 Continued

Fixture/Stack	Unit No.[27]	Lot[28]	Volume gal	Time seconds	Flow Rate gpm
S_1/4(T)	5	39	7.5	30.2	14.90
S_1/4(T)	5	39	7.5	36.0	12.50[29]
S_1/5(R)	8	Unknown	7.5	33.2	13.55
S_1/5(R)	8	Unknown	7.5	38.0	11.84[29]
WC_1/4(T)	5	39	4.26	14.8	17.27
WC_{2A}/4(T)	5	39	4.28	15.0	17.11
WC_{2B}/4(T)	5	39	4.36	16.0	16.35
B_{2A}/4(T)	5	39	25.0	147.0	10.20
B_{2B}/4(T)	5	39	25.0	151.0	9.93
L_1/4(T)	5	39	1.94	14.8	7.85
L_{2A}/4(T)	5	39	2.0	15.0	8.00
L_{2B}/4(T)	5	39	2.1	14.8	8.49
S_1/4(T)	5	39	7.5	30.2	14.90[29]
S_1/4(T)	5	39	7.5	36.0	12.50
S_1/5(R)	8	Unknown	7.5	33.2	13.55
S_1/5(R)	8	Unknown	7.5	38.0	11.84[29]
WC_1/5(R)	8	Unknown	4.34	15.8	16.50
WC_2/5(R)	8	Unknown	4.29	15.2	16.95
B_2/5(R)	8	Unknown	25.0	150.0	10.00
L_1/5(R)	8	Unknown	1.94	14.2	8.19
L_2/5(R)	8	Unknown	2.09	16.2	7.75

[27] Ibid

[28] Ibid

[29] Ibid

Table B2

Full Trap-Seal Depths As Measured on Site
Operation BREAKTHROUGH Prototype Site, King County, Washington

Trap/Stack No.	Nominal Dia. In	Unit No.[27]	Lot[28]	By Ruler Inches of Water	By Pneu. Method[30] Inches of Water
B_{2A}/1	1-1/2	10-11	Unknown	--	3/P --
B_{2B}/1	1-1/2	10-11	Unknown	--	2-7/8/P --
FD/1	2	10-11	Unknown	--	No Results - FD Not Connected to Trap
FD/4	2	5	38	--	" " "
S_1/4	1-1/2	5	38	--	2-3/4/P; 2-3/4V
S_1/4s	1-1/2	5	39	--	3P; 3V
WC_{1A}/1	--	10-11	Unknown	3-1/2	
WC_{1B}/1	--	10-11	Unknown	3-1/2	
WC_{2A}/1	--	10-11	Unknown	3-1/2	
WC_{2B}/1	--	10-11	Unknown	3-1/2	
L_{1A}/1	1-1/4	10-11	Unknown	2-7/8	
L_{1B}/1	1-1/4	10-11	Unknown	2-7/8	2-3/4P
CWM_B/1	2	10-11	Unknown	2-3/4	
CWM_A/1	2	10-11	Unknown	2-3/4	
LT	1-1/2	10-11	Unknown	2-1/8	
S_{1B}/2	1-1/2	10-11	Unknown	3	3P; 3V
S_{2A}/2	1-1/2	10-11	Unknown	3	
S_1/3	1-1/2	10-11	Unknown	3[31]	2 3/4P; 2 3/4V
S_2/3	1-1/2	10-11	Unknown	3[31]	
S_{1A}/2	1-1/2	10-11	Unknown	--	3-3/8P; 3-3/8V

27 Ibid

28 Ibid

30 The symbol "P" means the measurement is based on the use of the instrument in the pressure mode, and the symbol "V" in the vacuum mode.

31 This particular No. 3 stack (in Unit 10-11) was not tested. Ruler measurements were not repeated on substitute No. 3 stack, which was tested.

Table B3

Data Summary - Hydraulic Performance Demonstration of Single-Stack Plumbing System at the Operation BREAKTHROUGH Prototype Site, King County, Washington[32]

Test Number	Fixture Numbers	Maximum Trap Seal Loss In Inches of Water	Maximum Positive Pressure Surge In Inches of Water[33]	Additional Observations and Remarks[35]
1.1.1	L_{2B}	-0-	-	Crossflow was observed
1.2.1	B_{2B}	0.1	-	No crossflow observed
1.2.2	B_{2B}	-0-	-	No crossflow observed
1.3.1	WC_{2B}	-0-	-	No crossflow observed
1.3.2	WC_{2B}	-0-	-	No crossflow observed
	B_{2A}	0.1	-	No crossflow observed
1.4.1	B_{2A}/WC_{2A}	-0-	-	
1.5.1	WC_{2A}	-0-	-	
	B_{2B}	0.1	-	
1.6.1	B_{1A}	-0-	-	
	WC_{1A}	0.03	-	
	LT/FD	0.1	-	
	L_{1A}	0.2	-	
	CWM	0.3	-	
1.6.2	B_{1A}/LT	-0-	-	
	WC_{1A}	0.06	-	
	FD	0.1	-	
	L_{1A}/CWM	0.2	-	
1.6.3	B_{1A}/LT	-0-	-	
	WC_{1A}	0.06	-	
	L_{1A}	0.1	-	
	CWM/FD	0.2	-	

Table B3 Continued

Test Number	Fixture Numbers	Maximum Trap Seal Loss In Inches of Water	Maximum Positive Pressure Surge In Inches of Water [33]	Additional Observations and Remarks [34]
1.7.1	L_{1B}/LT	-0-	-	
	B_{1B}	-0-	0.3	
	WC_{1B}	0.06	-	
	FD	0.1	-	
	CWM	0.1	0.4	
1.7.2	L_{1B}/B_{1B}/FD	-0-	-	
	WC_{1B}	0.06	-	
	LT	0.2	0.4	
	CWM	0.3		
	B_{2A}	-	-	Water supply flow rate was 7.98 gpm
1.7.3	L_{1B}	-0-	-	
	WC_{1B}	0.03	-	
	B_{1B}	0.1	0.6	
	LT	0.2	-	
	CWM	0.3	0.4	
	FD	0.3	-	
1.8.2	L_{1B}/B_{1B}/FD	-0-	-	
	WC_{1B}	0.06	-	
	LT	0.2	-	
	CWM	0.3	-	
1.8.3	L_{1B}/B_{1B}	-0-	-	
	WC_{1B}	0.06	-	
	LT	0.1	-	
	FD	0.2	-	A slight sucking sound was heard during Run 4
	CWM	0.2	0.4	
2.1.1	S_{1A}	-0-	-	
2.1.2	S_{1A}	-0-	-	
2.2.1	S_{1A}	-0-	-	
	S_{1B}	0.13	-	

Table B3 Continued

Test Number	Fixture Numbers	Maximum Trap Seal Loss In Inches of Water	Maximum Positive Pressure Surge In Inches of Water[33]	Additional Observation and Remarks[34]
2.2.2	S_{1A}	-0-	-	
	S_{1B}	0.13	-	
3.1.1	S_1	0.19	-	
3.1.2	S_1	0.13	-	
3.1.3	S_1	0.06	-	
4.1.1	S_1	0.13	-	Due to self-siphonage
4.1.2	S_1	1.50	-	Due to self-siphonage
4.2.1	WC_1	0.06	-	
	L /CWM/FD	0.1	-	
4.2.2	L /CWM/FD	-0-	-	
	WC_1	0.13	-	
4.2.3	L_1	-0-	-	
	CWM	-0-	0.3	
	FD	-0-	0.2	
	WC_1	0.06	-	
5.1.1	L_2	-0-	-	Due to self-siphonage

[32] For test description, test numbering sequence, observations, and symbols, see Appendix A, table A1.

[33] Negative pressure measurements were not made, because in these tests the principal concern was with the usefulness of the instrumentation in indicating the existence of positive pressures in the lowest branch interval, by measuring the rise in water level on the fixture side of idle traps. Great accuracy was neither expected nor determined for these measurements.

[34] Blowback was not observed on any test.

APPENDIX C. ACKNOWLEDGMENT OF COOPERATION AND ASSISTANCE

The Building Environment Division (BED) wishes to express special appreciation to a number of individuals who contributed notably to the success of the Performance Demonstration.

Background briefing and definition of the problem was provided under the able direction of Mr. Austin K. Van Dusen, Director, FBH. Helpful further and more detailed assistance in these categories was furnished by Mr. Gail L. Ferry, Deputy Director, FBH; Mr. Jim Arvan, Director of Inspections, FBH, Mr. Kenneth E. Swanson, Plans Examiner, FBH; Mr. Norman Latter, Technical Director, IAPMO; and Messrs. Charles E. Kelly and Stan Gerrard representing IAPMO in the Seattle area. Messrs. Arvan, Latter, and Kelly also deserve special thanks for their long hours of careful work in providing technical assistance to BED staff in conducting the various tests according to a tight time schedule.

Helpful further briefing and background discussion were provided under the direction of Mr. Fred Aldridge, Director of Environmental Management, King County; and Mr. Fred King, Chief Plumbing Inspector, King County.

Special thanks are expressed to Mr. Randy Kirk, The Boeing Company, and Mr. John H. McGowan, The Boeing Company, who handled the many detailed arrangements at the site as required to facilitate the tests.

The able administrative support of Mr. William Werner, HUD, Washington, in recognizing the need for this demonstration is acknowledged. The excellent services provided by Mr. George Herrin, HUD-Seattle in

coordinating the meeting and transportation schedules of the BED personnel and in other important details contributed notably to the satisfactory conclusion of the work.

REFERENCES

[1] Wyly, Robert S. and Sherlin, Grover C., Performance of a Single-Stack DWV System Utilizing Low-Angle Stack-Branch Confluence and Bottom-Shunt Venting, National Bureau of Standards BSS 41 (April, 1972).

[2] Wise, A. F. E., Payne, R., and Griffiths, T. J., Sanitary Services for Modern Housing, Public Works and Municipal Services Congress (1966).

[3] Sanitary Pipework Above Ground, Code of Practice for, CP304-1968, British Standards Institution, London, England.

[4] Operation BREAKTHROUGH Plumbing Drawings for Units 5, 7, 8, 10, and 11; King County, Washington; Department of Housing and Urban Development File Numbers H.1239.09. (502, P-2/504, P-4/505, P-5/507, P-7), Schematic Piping Diagrams, 6/18/71.

[5] Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings, National Bureau of Standards BH2 (1924).

[6] French, John L., Stack Venting of Plumbing Fixtures, NBS Building Materials and Structures Report BMS 118 (1950).

[7] Maybeck, Edward M., Demonstration of Performance for a Sovent System Installed at Townsend Tower, Near East Side Renewal Project for New York State Urban Development Corp., Syracuse New York, Barnard and Maybeck, Consulting Engineers, Rochester, N.Y. (July 17, 1972).

[8] Hunter, R. B., Methods of Estimating Loads in Plumbing Systems, NBS Building Materials and Structures Report BMS 65 (1941).

[9] Hunter, R. B., Water Distributing Systems for Buildings, NBS Building Materials and Structures Report BMS 79 (1941).

/‾10_/ National Standard Plumbing Code, National Association of Plumbing-Heating-Cooling Contractors, Inc. (1971).

/‾11_/ Eaton, Herbert N. and French, John L., Fixture Units as used in Plumbing System Design, Housing and Home Finance Agency HRP 15, (March, 1951).

/‾12_/ Manas, Vincent T., National Plumbing Code Handbook, McGraw-Hill (1957).

/‾13_/ Nielsen, Louis S., Performance Test for Single-Stack System, Technical Forum, Plumbing-Heating-Cooling Business (April 1970).

FORM NBS-114A (1-71)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 73-161	2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE Field Test of Hydraulic Performance of a Single-Stack Drainage System at the Operation BREAKTHROUGH Prototype Site in King County, Washington			5. Publication Date 6. Performing Organization Code
7. AUTHOR(S) Robert S. Wyly and Daniel E. Rorrer			8. Performing Organization NBSIR 73-161
9. PERFORMING ORGANIZATION NAME AND ADDRESS NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			10. Project/Task/Work Unit No. 4628387 11. Contract/Grant No.
12. Sponsoring Organization Name and Address Department of Housing and Urban Development 451 Seventh Street, S.W. Washington, D. C. 20410			13. Type of Report & Period Covered Final report 1972 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)

A procedure for measuring the hydraulic performance of drain-waste-vent (DWV) systems in the field is described, and the results obtained with this procedure in a field demonstration of the hydraulic performance of a single-stack DWV system are presented.

Among the most important criteria for hydraulic performance of drain-waste-vent systems are the following:

(1) Trap-seal retention in idle fixtures.
(2) Ability of the system to resist the rejection of suds, sewage, or foul gases due to hydrostatic or pneumatic pressures in the DWV system.
(3) Absence of cross flow between fixtures.
(4) Absence of self-siphonage in the individual fixture traps.

Considering the needs for minimization of maintenance in service and for the continuation of venting during cold weather, the following additional criteria can be identified:

(5) Ability to maintain adequate hydraulic performance over a long period of service without excessive maintenance of branch piping.
(6) Adequacy of performance under climatic conditions conducive to frost closure of vent terminals.

- continued -

17. KEY WORDS (Alphabetical order, separated by semicolons) Crossflow; field testing, plumbing; performance criteria, plumbing; performance, functional; single-stack drainage; siphonage, induced; siphonage, self; test loads, hydraulic; trap-seal reduction detector; trap-seal retention

18. AVAILABILITY STATEMENT	19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
[x] UNLIMITED.	UNCLASSIFIED	
[ ] FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NTIS.	20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	22. Price