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Dependence of Model Waste Solid Transport Characteristics in Drainage Systems on Solid Geometry, Mass and Pipe System Parameters

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EPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, ***Secretary***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Director***

ABSTRACT

Test results are presented for the transport characteristics of an extensive range of geometrically similar model solids in a 100 mm diameter UPVC drain pipe. Model solids were based on commercially available sanitary towels (napkins) discharged into the pipe system via a series of U.K. standard water closet types.

Following a data fit analysis, relationships are presented linking solid transport characteristics to solid, pipe and water closet (w.c.) parameters.

These relationships, linked to observation of installed hospital drainage systems in the U.K., will allow laboratory test methods to be utilized in predicting the effect of design changes on system performance.

PREFACE

This report is one of a group documenting National Bureau of Standards (NBS) research and analysis efforts in developing water conservation test methods, analysis, economics, and strategies for implementation and acceptance. This work is sponsored by the Department of Housing and Urban Development/Office of Policy Development and Research, Division of Energy Building Technology and Standards, under HUD Interagency Agreement H48-78.

The report was prepared by Dr. J. A. Swaffield, guest research worker at NBS-Stevens Institute of Technology from Brunel University, U.K.

The test results included in this report were compiled from published work from the Drainage Research Group, Department of Building Technology, Brunel University, U.K.

The test programs were funded by the U.K. Department of Health, the U.K. Association of Sanitary Protection Manufacturers and Brunel University.

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NOTATION

C_1	Extrapolated solid velocity at pipe entry
C_2	Solid deceleration with respect to distance
D	Pipe diameter
F	Total flush volume available
F_B	Volume discharged behind solid
G	Pipe slope
g	Accleration due to gravity
K_1	Non dimensional solid velocity term at pipe entry
K_2	Non dimensional solid deceleration with respect to L/D
K	Constant in calibration equation
L	Pipe length traversed from entry
ℓ	Solid length
m_s	Solid mass (saturated)
q	Index in calibration equation
t	Solid thickness
V^*	Non dimensional solid velocity term
v	Solid velocity at point L
w	Solid width
x	Characteristic lengths
y	Characteristic lengths
ρ_w	Water density
UPVC	Unplasticized polyvinyl chloride (pipe material)

1. INTRODUCTION

Little use has been made in the past of laboratory based studies to model the waste solid transport characteristics of building drainage systems. This has been due to a lack of understanding of the transport mechanisms involved and the difficulty of producing a suitable model solid for laboratory usage. The test solids utilized for water closet (w.c.) evaluation and type acceptance tests cannot be used to model system transport. The solids commonly used, for example, the European 50 x 20 mm diameter ball test, the British single 43 mm diameter ball test and the Dutch sponge tests, have been designed to reproduce w.c. discharge criteria and would not be representative of system transport. Early transport tests by the Japanese utilizing PVC sponge solids were subject to problems arising from the specific gravity variations of the models that appeared to be dependent on the solid soaking time prior to usage.

A number of criteria need to be satisfied if a laboratory test solid is to be successful in modeling system transport mechanisms:

1. The solid must be cheap and available in bulk to repeatable dimensions and mass. Reusable solids are discounted on the grounds that water soaking time may become an important factor, as may deterioration of the model surface, although impermeable solids with sealed voids could be reused.

2. A sufficient range of geometrically similar solids meeting criterion 1 above should be available if the full range of system loading is to be represented in the laboratory.

3. The solid must be acceptable in the laboratory environment.

4. The transport characteristics of each solid must be documented in terms of its geometry and mass, or be capable of being interpolated from tests on similar solids.

5. The transport characteristics of installed systems should have been monitored to present a range of typical waste transport characteristics. The range of system loading would then be modeled by choosing the appropriate model solids from the documented transport characteristics mentioned in criterion 4 above.

If these points can be met then laboratory tests may be utilized to assess the effect of design changes on the performance of the system. Such modifications as reduced water usage or reductions in pipe slope or diameter could be evaluated. Similarly, the effect of introducing new w.c. designs having lower water usage could be evaluated.

This brief report summarizes a series of laboratory investigations designed to determine the dependence of solid transport on pipe geometry, water usage and solid dimensions and mass.

2. BACKGROUND TO THE LABORATORY TEST PROGRAM

During an extensive laboratory test program undertaken at Brunel University, U.K., as a component of a hospital drainage system study for the U.K. Department of Health, it was apparent that the transport characteristics of a maternity pad solid in a 100 mm diameter UPVC, glass or cast iron waste pipe could be expressed in the form

$$V = C_1 - C_2 \, 1 \sqrt{L/G} \tag{1}$$

where

V = solid velocity at distance L from pipe entry

G = pipe gradient

C_1 = extrapolated solid velocity at L=0 from equation (1), the units of this constant being m/s.

C_2 = solid deceleration coefficient with respect to distance L, the units of this constant being $m^{1/2}/s$.

These results are represented in figure 1 and are more fully explained in [1,2], together with an analysis of the flow mechanisms observed.

The model solid employed was a commercially available maternity pad, or heavy duty sanitary napkin, dimensions 270 mm x 60 mm x 20 mm, water saturated weight 250 gms, currently supplied to U.K. hospitals, an acceptable, cheap model solid for the very large number of tests carried out.

Observation of fecal and other waste materials in hospital installed drainage systems also displayed this solid transport characteristic equation, the values of C_1 and C_2 varying with the solid type [3]. This reproduction in practice of the observed laboratory results indicated the possibility of representing typical system loading by a suitable choice of model solids of a type similar to the maternity pad. It was decided to undertake an analysis of the factors determining the values of C_1 and C_2, this survey to include both pipe size, w.c. flush volume and solid geometry and mass parameters.

The maternity pad solid was also employed for a series of tests designed to illustrate the effect of pipe diameter and w.c. flush volume, the test results confirming the relationships illustrated in figure 1, but displaying a more rapid deceleration as flush volume decreased [4].

The extension of this program to geometry and mass effects was made possible by a request from the U.K. Association of Sanitary Protection Manufacturers for assistance in developing a flushability criterion for w.c. disposal of sanitary towels (napkins), diapers and tampons. Appendix 1 reproduces a recent paper [5] describing this test program.

At the culmination of the test programs, a total of some 30 solid geometry/mass combinations had been tested with corresponding data for 100 mm and 75 mm pipe diameters and w.c. flush volumes ranging from the U.K. standard of 9.1 liters down to 4 liters. This body of data was considered sufficient to test the dimensional analysis based on the solid/system parameters presented below.

3. ANALYSIS OF THE VARIABLES GOVERNING SOLID TRANSPORT

As shown by figure 1 and equation (1) the velocity profile against distance travelled along a waste pipe may be expressed as:

$$V = C_1 - C_2 \sqrt{L/G}$$

Non dimensionally this may be expressed as

$$\frac{V}{\sqrt{gx}} = \frac{C_1}{\sqrt{gx}} - C_2 \sqrt{y/gx}\,\sqrt{L/yG} \qquad (2)$$

where

g = acceleration due to gravity

x,y = suitable characteristic lengths

Equation (2) may be written as

$$V^* = K_1 - K_2 \sqrt{L/yG} \qquad (3)$$

where

V^* = is a non dimensional group having the same form as Froude Number.

The terms K_1, K_2 may be expressed as functions of the solid and pipe system as follows:

$$K_1, K_2 = f_1 (\ell, t, w, \rho_s, D, F, F_B, \rho_w) \qquad (4)$$

where

ℓ = solid length

w = solid width

t = solid thickness

ρ_s = solid density

D = pipe diameter

F = total flush volume

F_B = flush discharge behind the solid

ρ_w = water density

Excluded from (4) is the pipe roughness effect as the bulk of the data available refers to UPVC pipe systems.

Thus, the nine variables involved yield six dimensionless groups:

$$K_1, K_2 = f_2 \left(\frac{\ell}{D}, \frac{w}{D}, \frac{t}{D}, \frac{F}{F_B}, \frac{\rho_s \ell wt}{\rho_w F_B} \right) \qquad (5)$$

The solid width w may be used as the length characteristic x in equation (2) while the pipe diameter D would be appropriate as the y length term.

Approved test methodology would require the study of the dependence of K_1, K_2 on each group in turn, requiring the other four to be held constant. Unfortunately, this was not possible as the model geometry terms were dictated by human anatomy and fashion. Similarly, the mass terms were dictated by physiology. Within these limits the various contributing manufacturers produce a range of towels as shown by table 1.

A general equation of the form

$$K_1, K_2 = \left(\frac{\ell}{D}\right)^i \left(\frac{w}{D}\right)^j \left(\frac{wt}{D^2}\right)^k \left(\frac{F}{F_B}\right)^m \left(\frac{\rho_s \ell wt}{\rho_w F_B}\right)^n \qquad (6)$$

was postulated and data fit tested by means of a computer program run on the NBS Center for Building Technology's Perkin Elmer 732 Computer. The results of the data fit trials are discussed below.

4. EXPERIMENTAL AND MEASUREMENT TECHNIQUES

Appendix 1 describes the test installation employed for the flushability criteria development work at Brunel University. The rig consisted of 14 m length of 100 mm diameter transparent UPVC waste pipe set at a gradient of 1/80. Solid velocity was recorded over six 300 mm lengths at 2 m intervals along the test pipe by means of photoelectric cells and electronic timers.

The water volume vs. time profile at discharge from the 14 m pipe length was recorded via a linear displacement transducer driven by a surface float in the collection tank. Sensitivity was sufficient to record solid entry into the collection tank, yielding the relative volumes of water discharged ahead and behind the solid.

This basic system was also employed in the variation of flush volume and pipe diameter tests as well as being based on the original test system used for the maternity pad investigation represented by figure 1.

Solid dimensions were recorded dry by means of vernier caliper gauge, the average of 20 measurements being taken.

Similarly, dry weight values were based on the average of 20 measurements from a random sample chosen from at least 100 solids. This avoided batch inconsistencies in manufacture.

Saturated weight values were recorded based on an initial study for each product to determine time to achieve full saturation. In most cases saturated weight became a constant at about 30 seconds soaking time.

The effect of varying degrees of presoaking administered to each product is described in appendix 1. For the purposes of this study, this effect is included in the variation in flush water volume discharged behind the solid.

5. PRESENTATION OF RESULTS

Table 1 summarizes the test measurements described above for all the products tested for the Association of Sanitary Protection Manufacturers as well as the Department of Health maternity pad tests and the Brunel University funded reduced water volume and pipe size study.

The derived relationships linking the transport characteristics, K_1 and K_2 are presented in figures 2 and 3. It will be noted that the groups:

$$\frac{w}{D}, \frac{t}{D}$$

have been rewritten as:

$$\frac{wt}{\pi D^2/4} \quad \text{and} \quad \frac{w\ell t}{D^3}$$

for the purpose of presenting these relationships. Although this is not strictly necessary, it was felt that this term led to a practical blockage factor that could have a physical interpretation.

It will be seen from table 1 that all products tested are referred to by a code AB. In this code A refers to the manufacturer and B is a number allocated to each product tested. Code 34 indicates the maternity pad solid.

6. DISCUSSION OF RESULTS

A general format for a possible relationship based on the analysis presented may be represented by

$$K_1, K_2 = \left(\frac{\ell}{D}\right)^i \left(\frac{w}{D}\right)^j \left(\frac{wt}{D^2}\right)^k \left(\frac{F}{F_B}\right)^m \left(\frac{m_s}{\rho_w F_B}\right)^n$$

where $m_s = \rho_s \ell t w$ - the solid mass.

Due to an inability to deal with each group in isolation it was decided to investigate the dependence of the measured transport characteristics on pipe blockage factor, as defined above, and w.c. performance, as defined by the ratio of water discharged behind the solid to the total volume available, F_B/F.

Referring to the w.c. efficiency, as defined by F_B/F it was found that the ratio was dependent on the total flush volume available as might be expected from an analysis of the forces acting to discharge the solid initially at rest in the pan from the w.c. bowl.

Equation 6 was therefore restructured as:

$$K_{1,2} \cdot \left(\frac{D}{\ell}\right)^i \cdot \left(\frac{D}{w}\right)^j \cdot \left(\frac{D}{t}\right)^k \cdot \left(\frac{\rho_w F_B}{m_s}\right)^n = \left(\frac{wt}{\frac{\pi D^2}{4}} \quad \frac{F}{F_B}\right)^p \qquad (7)$$

and a series of computer trial fits were investigated to determine a suitable form for the relationship.

Inspection of equation 7 would suggest that the relationship tends to infinity as the x or y ordinate tends to zero, as shown by figures 2 and 3.

A number of characteristic points may be identified:

1. Table 1 indicates that the available spread of terms D/ℓ and D/w is much less than that of the term D/t. This is a result of product design criteria as described previously.

2. As the blockage factor decreases and tends to zero so the values of the K_1 or K_2 multiplier terms increase resulting in the y ordinate tending to infinity.

3. As pipe diameter decreased the value of the $\frac{wt}{\pi D^2/4} \cdot \frac{F}{F_B}$ term increases, a group of points representing 75 mm pipe diameter results in figures 2 and 3 illustrate this.

4. At values of x ordinate below 0.1 the $K_{1,2}$ multiplied y ordinate term increases rapidly and hence is more susceptible to measurement errors. As shown by table 1 the products represented by these results, Codes 41, 61, and 75 had thin profiles, 2 to 7 mm, so that measurement errors have the potential for multiplication. Similarly, the true blockage within the pipe could be underestimated due to the solid taking up the local water surface profile slope, hence increasing its projected area in the flow direction.

5. Model solid dimensions were recorded dry for practical reasons. The true thickness of the solid could vary in the saturated state in the pipe. This would only be a serious source of measurement error for the thinner solids.

6. Saturated weights were recorded following some 30-40 records soaking in all cases. It was felt that these figures could be used with confidence in the data fit trials described.

As shown in figures 2 and 3, the transport characteristics of the chosen model solids may be represented by equations of the form

$$K_1 \text{ or } K_2 = K \frac{\ell}{D} \frac{w}{D} \frac{t}{D} \left(\frac{m_s}{\rho_w F_B} \right)^2 \frac{wt}{\frac{\pi D^2}{4}} \cdot \left(\frac{F}{F_B} \right)^q \qquad (9)$$

where

K is a positive constant
q is a negative index
and i = j = k = 1; n = 2.

It should be noted that the flush volume behind the solid included in these relationships was recorded at discharge from the 14 m pipe at a gradient of 1/80. Strictly, this figure should be appropriate to the solid discharge from the w.c. to be truly independent of pipe slope. However, as these relationships are to be used as calibration coefficients to model known system loading, this is acceptable.

The results presented are limited to UPVC waste pipe at this stage. Although tests with cast iron pipe were included in [1], these results applied only to the maternity pad solid. Tests comparing glass, UPVC and cast iron 100 mm diameter pipe transport indicated that surface roughness alone was not sufficient to explain transport variations as the smooth bore glass yielded transport results between UPVC and cast iron.

Figure 4 represents the waste solid deposit positions as predicted by writing V=0 in equation 3, i.e.,

$$\sqrt{L/DG} = K_1/K_2 = K_3$$

and from figures 2 and 3

$$K_1 = 0.8 \frac{\ell wt}{D^3} \left(\frac{m_s}{\rho F_B} \right)^2 \left(\frac{wt}{\pi D^2/4} \quad \frac{F}{F_B} \right)^{-2.77}$$

$$K_2 = 1.04 \frac{\ell wt}{D^3} \left(\frac{m_s}{\rho F_B} \right)^2 \left(\frac{wt}{\pi D^2/4} \quad \frac{F}{F_B} \right)^{-2.3}$$

hence

$$K_3 = 0.77 \left(\frac{wt}{\pi D^2/4} \quad \frac{F}{F_B} \right)^{-0.47}$$

In practice the solid deposition may occur from any velocity below about 0.2 m/s due to its retardation by any pipe discontinuity, such as a coupling or joint. At velocities in this range the solid motion is entirely due to the water head differential across the solid and any retardation of the solid allows the driving water to leak past the solid, thus, destroying the driving hydrostatic force.

7. CONCLUSIONS

The test results presented for a wide range of geometrically similar solids allow their transport characteristics to be expressed in terms of solid geometry and mass and drainage system parameters including pipe diameter and w.c. flush volume.

These relationships confirm the dependence of solid transport on the $\sqrt{L/G}$ term during the deceleration phase. Experimental work has identified this phase as being predominant in the internal building branch drain situation.

The ability to predict model solid performance from these relationships in combination with the observation currently being undertaken in installed drainage systems will allow laboratory based test programs to both model system loading and predict the effect of design changes on system performance.

8. REFERENCES

1. Swaffield, J. A. and Wakelin, R. H. M., Observation and Analysis of the Parameters Affecting the Transport of Waste Solids in Internal Drainage Systems, Journal Institution Public Health Engineers, U.K., November 1976.

2. Swaffield, J. A. and Wakelin, R. H. M., A Study of the Transport of Solids in Internal Drainage Systems, CIBW62 Seminar, Oslo, May 1977.

3. Bokor, S. D. and Swaffield, J. A., Application of Laboratory Test Techniques to Building Drainage Design, IPHE Seminar, Brunel University, U.K., June 1980.

4. Marriot, B. S. T. and Swaffield, J. A., Effect of Reduced Volume w.c. Flush on Internal Drainage Performance, CIBW62 Seminar, Brussels, October 1978.

5. Howarth, G., Wakelin, R. H. M., and Swaffield, J. A., Development of a Flushability Criterion for Sanitary Products, CIBW62 Meeting, Brunel University, June 1980.

SOLID TYPE.	LENGTH MM.	WIDTH MM.	THICKNESS MM.	DRY WT. GMS.	SATURATED WT. GMS.	PRESOAK GMS.	PIPE DIA. MM.	WC TYPE	FLUSH VOLUME LITRES	VOLUME BEHIND SOLID LITRES	C1. M/S.	C2. $M^{1/2}/S.$
11	164.0	58.0	8.5	7.7	102.0	8.0	100.0	1	9.1	7.6	1.132	0.0113
12	185.0	65.0	12.0	6.6	120.0	20.0	100.0	1	9.1	4.7	1.079	0.0213
13	215.0	65.0	13.0	10.2	150.0	20.0	100.0	1	9.1	4.9	1.312	0.0296
14	195.0	64.5	13.0	13.4	140.0	20.0	100.0	1	9.1	6.8	1.107	0.0130
15	228.0	69.5	12.0	14.3	140.0	0.	100.0	1	9.1	7.7	1.218	0.0227
16	240.0	63.5	10.0	18.1	210.0	0.	100.0	1	9.1	5.6	1.094	0.0228
21	196.0	65.0	10.0	8.6	140.0	0.	100.0	1	9.1	7.5	1.227	0.0183
21	196.0	65.0	10.0	8.6	140.0	8.0	100.0	1	9.1	6.4	1.196	0.0208
22	190.0	70.0	14.0	10.6	195.0	0.	100.0	1	9.1	7.4	1.165	0.0190
22	190.0	70.0	14.0	10.6	195.0	8.0	100.0	1	9.1	6.0	1.296	0.0280
22	190.0	70.0	14.0	10.6	195.0	0.	100.0	1	7.2	4.7	1.460	0.0300
22	190.0	70.0	14.0	10.6	195.0	0.	100.0	1	5.7	0.9	1.850	0.0640
23	225.0	65.0	17.0	12.5	210.0	0.	100.0	1	9.1	6.8	1.362	0.0271
23	225.0	65.0	17.0	12.5	210.0	8.0	100.0	1	9.1	5.6	1.325	0.0301
23	225.0	65.0	17.0	12.5	210.0	20.0	100.0	1	9.1	5.4	1.213	0.0232
31	226.0	70.0	16.0	18.0	210.0	0.	100.0	1	9.1	6.3	1.050	0.0220
32	218.0	63.0	16.0	17.5	220.0	0.	100.0	1	9.1	5.6	1.170	0.0300
34	270.0	60.0	20.0	16.5	250.0	0.	100.0	2	9.1	6.3	1.510	0.0390
34	270.0	60.0	20.0	16.5	250.0	0.	100.0	1	9.1	5.9	1.507	0.0388
34	270.0	60.0	20.0	16.5	250.0	0.	100.0	1	7.5	3.7	1.742	0.0550
34	270.0	60.0	20.0	16.5	250.0	0.	100.0	3	9.1	6.7	1.564	0.0390
34	270.0	60.0	20.0	16.5	250.0	0.	100.0	3	7.5	4.7	1.747	0.0528
34	270.0	60.0	20.0	16.5	250.0	0.	75.0	3	9.1	7.3	1.525	0.0040
34	270.0	60.0	20.0	16.5	250.0	0.	75.0	3	7.5	5.6	1.783	0.0497
34	270.0	60.0	20.0	16.5	250.0	0.	75.0	3	6.0	4.0	1.965	0.0606
41	155.0	45.0	7.0	8.9	65.0	0.	100.0	1	9.1	8.6	1.400	0.0182
41	155.0	45.0	7.0	8.9	65.0	0.	100.0	1	7.2	6.5	1.320	0.0207
41	155.0	45.0	7.0	8.9	65.0	0.	100.0	1	5.7	3.7	1.410	0.0307
41	155.0	45.0	7.0	8.9	65.0	0.	100.0	1	4.0	0.6	1.540	0.0380
61	133.0	51.0	3.2	2.3	29.0	0.	100.0	1	9.1	7.9	1.050	0.0109
62	184.0	61.0	6.1	6.1	65.0	20.0	100.0	1	9.1	6.8	1.080	0.0110
71	216.0	67.0	16.0	17.4	215.0	0.	100.0	1	9.1	6.2	1.338	0.0310
72	220.0	70.0	14.0	13.4	155.0	0.	100.0	1	9.1	7.8	1.340	0.0250
72	220.0	70.0	14.0	11.4	155.0	20.0	100.0	1	9.1	6.9	1.093	0.0194
72	220.0	70.0	14.0	11.4	155.0	20.0	100.0	1	9.1	7.5	1.000	0.0126
73	170.0	52.0	12.0	9.0	102.0	0.	100.0	1	9.1	5.7	1.067	0.0117
73	170.0	52.0	12.0	9.0	102.0	8.0	100.0	1	9.1	6.2	1.074	0.0091
74	220.0	62.0	14.0	15.0	158.0	20.0	100.0	1	9.1	6.1	1.120	0.0125
75	137.0	50.0	2.5	2.0	26.0	2.0	100.0	1	9.1	7.0	1.138	0.0133

W.C. TYPE CODE : 1 TWYFORDS P-TRAP, BS.1213.
2 U.K. DEPT. OF HEALTH STANDARD P-TRAP W.C.
3 TWYFORDS 90° OUTLET W.C., BS.5503.

TABLE 1. SUMMARY OF MODEL SOLID AND SYSTEM PARAMETERS TOGETHER WITH TRANSPORT CHARACTERISTIC TEST RESULTS.

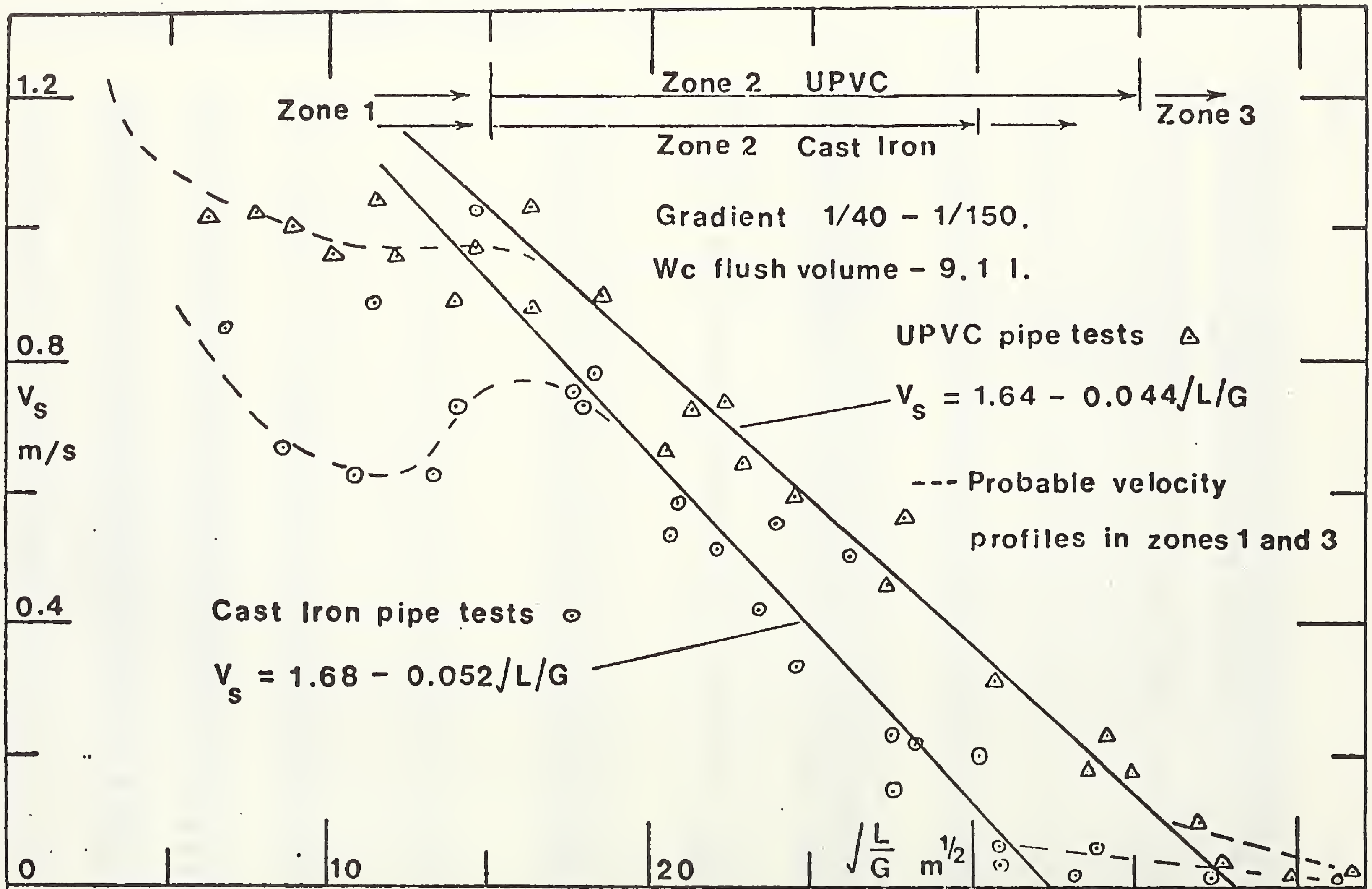

Figure 1. Comparison of maternity pad transport in UPVC or Cast Iron 100 mm diameter pipe.

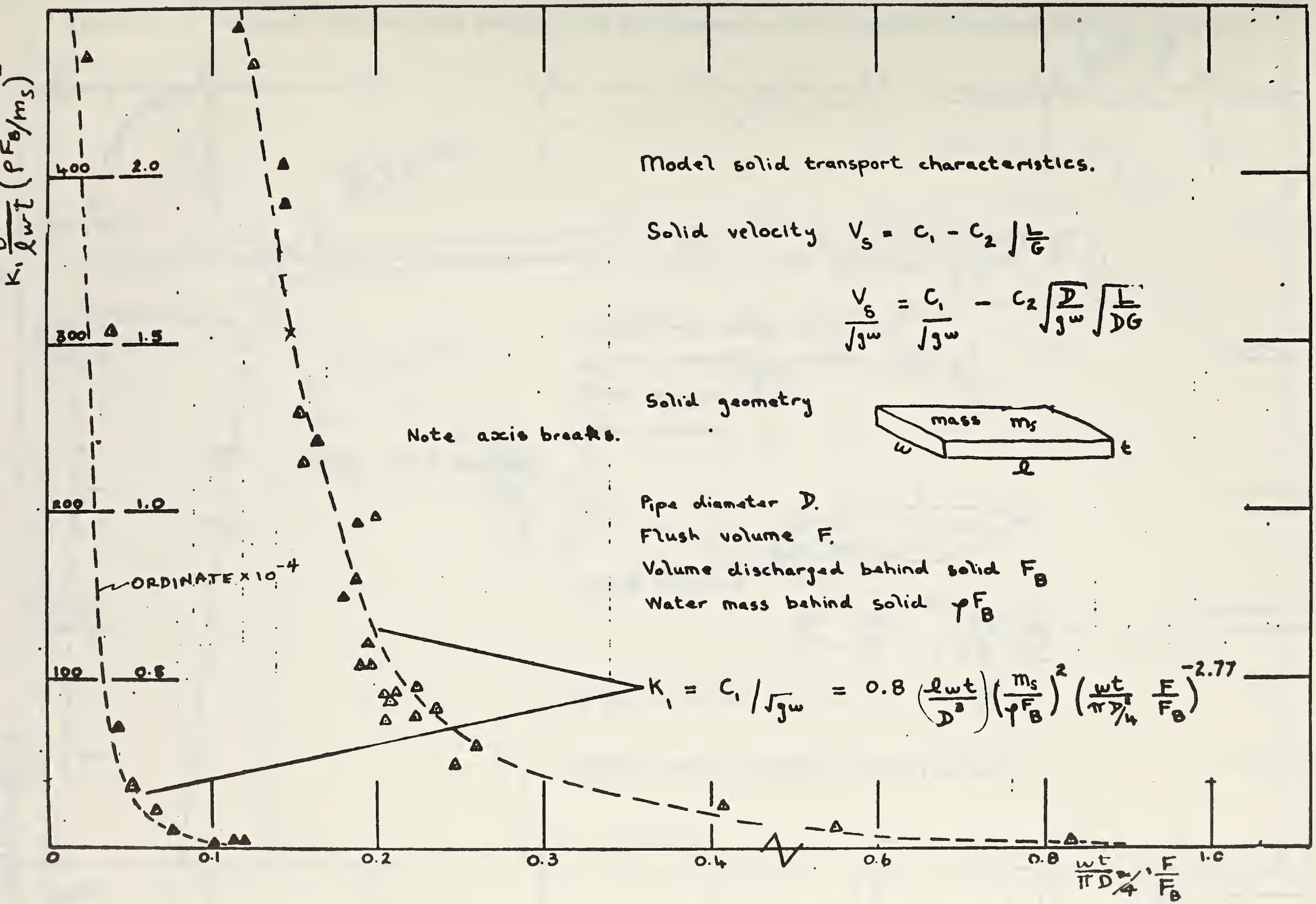

Figure 2. Relationship between extrapolated solid velocity at pipe entry and pipe and solid parameters.

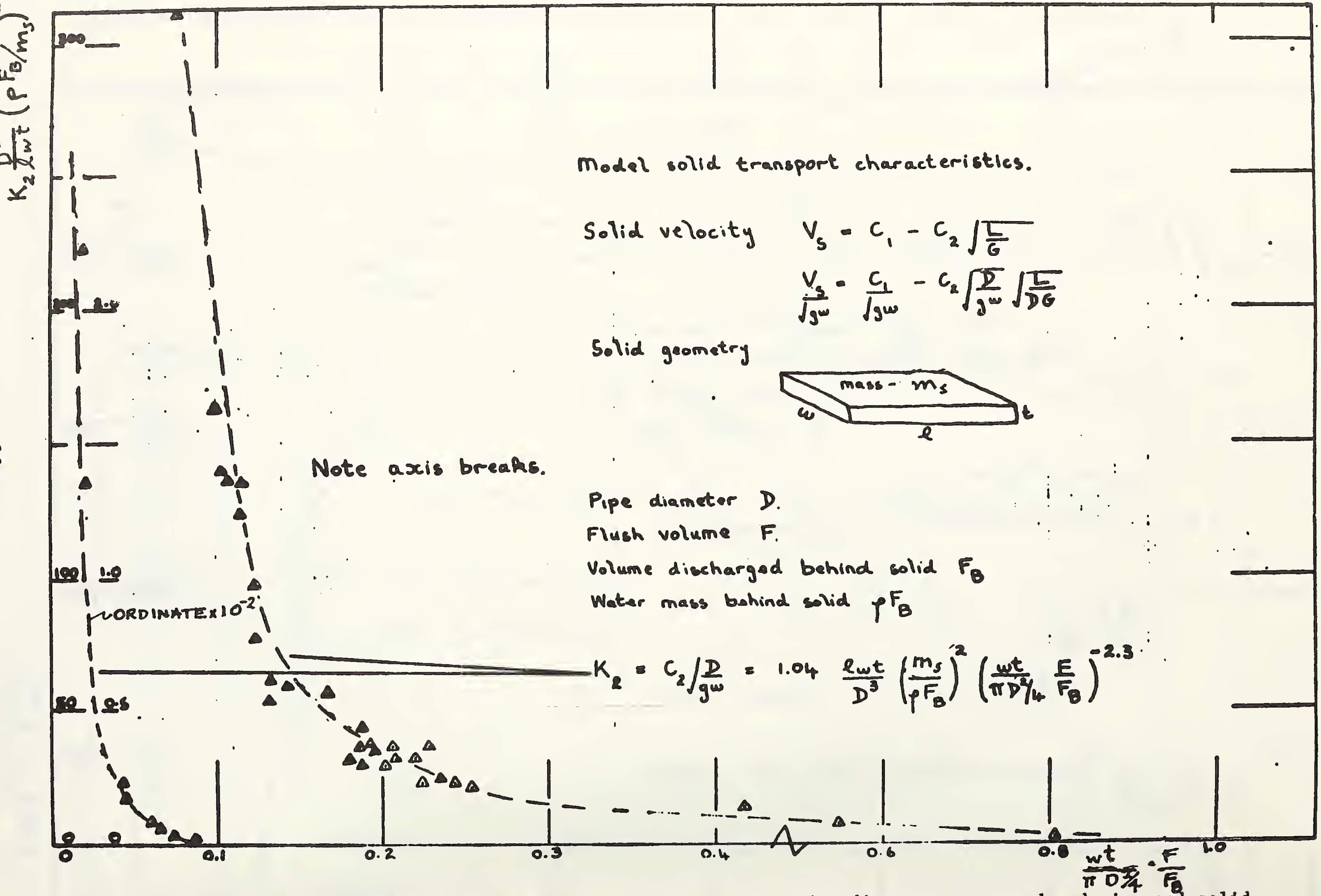

Figure 3. Relationship between solid deceleration with respect to pipe distance traversed and pipe and solid parameters.

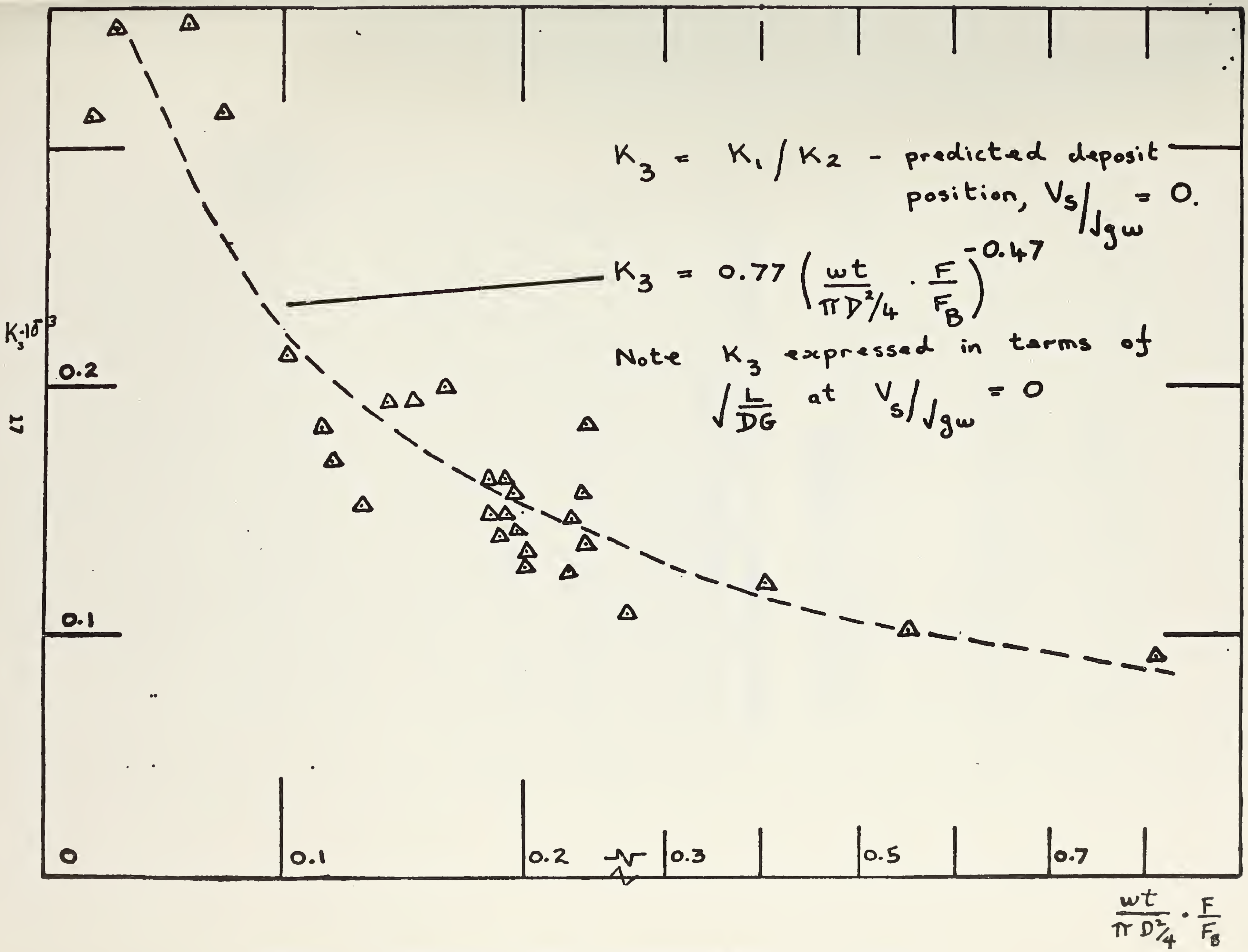

Figure 4. Predicted solid deposition position based on zero velocity.

APPENDIX 1

Flushability Criteria for U.K. Sanitary Products

Reprint of Reference 5

DRAINAGE AND WATER SUPPLY FOR BUILDINGS

A TWO DAY SEMINAR ON CURRENT RESEARCH
AND FUTURE NEEDS AND OBJECTIVES

BRUNEL UNIVERSITY, UXBRIDGE, ENGLAND
JUNE 3 AND 4 1980

DEVELOPMENT OF A FLUSHABILITY CRITERION FOR SANITARY PRODUCTS

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DEVELOPMENT OF A FLUSHABILITY CRITERION FOR SANITARY PRODUCTS

by

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SUMMARY

The development of a set of flushability criteria for sanitary protection products is described. The need for a criterion is stated and the initial test work undertaken to establish the required pass levels is fully described.

The results show that the form of earlier empirical relations developed at Brunel to link waste solid velocity to pipe length and gradient apply to a wide range of solid size and shape parameters.

Finally the agreed test specification is presented together with a view of future development work in this area. The results collected over the test period are to be analysed further to identify any correlation between transport characteristics and size and shape parameters.

INTRODUCTION

The Association of Sanitary Protection Manufacturers (ASPM) is a body formed to represent the views of, and set agreed standards amongst, all members of the industry. One of these standards to be examined was the term "flushable" which is printed on nearly all the packages of sanitary protection products.

These sanitary protection products can vary widely in size, construction and weight, as follows:-

(a)	Tampons -		2 to 5 grammes and 5 cms long	
(b)	Towels (Napkins) -	Mini	4 to 8 grammes	15 cms long
		Towels	6 to 20 grammes	20 cms long
(c)	Panty Shields -		2 to 4 grammes	15 cms long

The towel raw materials are basically "cellulose" - fillings of tissue, fluffing pulp with a non-woven cover. There is sometimes a plastic film inside the towel as a fluid barrier. Plastic can also be used as a release tape to cover the pressure sensitive adhesive on the back of the towel. The non-woven cover can be very specialised - either completely non-absorbent polyesters or a "flushable" cover which disperses after some time in water. Rayon or a rayon/cotton mixture is the usual fibre for tampons.

The actual number of products used per day is estimated as follows:-

PRODUCT		NO. OF PADS MILLIONS/DAY
TAMPONS		2.49
TOWELS	Mini	0.62
	Looped	1.06
	Self Adhesive	2.28

Our own surveys have shown that approximately 80% of the ladies dispose of these products by flushing down the toilet i.e. five million products per day. There are various flushability instructions given on the packs.

"Simply flush it away - all in one piece"

"Just remove the cover and flush away separately"

"Completely flushable (no need to pull apart), just flush the whole towel away"

"Remove outer covering, empty contents and flush away. Then flush cover separately"

"Do not flush"

These instructions support the general public's view that "flushable" means it will disappear down the toilet. However the ASPM wanted to be more specific in its definition of "flushable".

Flushability Definition

The Technical Committe of the ASPM considered that the definition was really in two parts - the product should flush from the pan but also cause no problems in the subsequent drainage system. Various Research Establishments were contacted, with the following general conclusions:

(a) Drain blockages were in fact due in the main to a drain fault i.e. poor joints or faulty pipework.

(b) Although the BSI minimum flush volume is 9 litres, in the majority of WC systems the volume is 12 litres. However there are moves to reduce this minimum standard and in addition dual flush and controlled flush systems could be introduced.

(c) If the towels managed to get into the main sewage pipe trunking system no problems should occur.

(d) The amount of plastic in the products is unlikely to cause a problem at the sewage farm.

Therefore it seemed reasonable to concentrate on a method of measuring the failure of the product to leave the WC and also the "state" of the product after travelling some distance in the pipework. ASPM member companies had already simple WC systems plus a collection device for evaluating flushability. Unfortunately these were non-standard methods with no scientific measurements.

However it was possible using the test rig developed by the Drainage Research Group at Brunel University to define both a test method and specification. In summary they have:

(a) A test rig available consisting of a WC pan, connected to a short vertical section and then 14 metres of horizontal pipe. The velocity of the solid can be measured at various points along the pipe length and the volume of water ahead of the solid measured.

(b) Developed a theory of solid transport which will allow them to predict the drainage performance of a solid at any gradient of pipe and various types of pipe.

Flushability Specification

A 100 samples should be tested on the BRUNEL rig and the following criteria must be satisfied.

(a) WC failures: A maximum of six WC failures plus pipe stoppages below 10 metres are allowed i.e. 3 WC failures + 3 stoppages below 10 metres.

(b) If a WC failure occurs then the product must flush greater than 10 metres along the pipework on the second flush.

Flushability Rig and Method

TEST EQUIPMENT

A. The test pipe consisted of 7 x 2 m lengths of 100 mm bore UPVC discharge pipe connected at its upstream end to a vented discharge Twyfords P-trap WC via a Terrain UPVC 104° junction and $92\frac{1}{2}^{\circ}$ UPVC bend. The centre line of the UPVC pipe was 300mm below simulated floor level at this connection.

The pipe is supported over its whole length by means of two 7 m long lightweight aluminium ladders. Initial level setting by use of a surveyor's level ensured later gradient adjustments to an accuracy of 0.5 mm. A gradient of 1/80 was used for all the reported tests. The performance of the test pipe was monitored by recording the velocity of the waste solids at six points along the pipe length. Table 1 indicated the positions chosen. The discharge was collected at the downstream end of the test pipe by a tank equipped with a depth recording linear displacement transducer linked to a pen recorder. From the volume vs time output of this system the quantity of water entering the collection tank ahead of the solid could be accurately measured.

Table 1 SUMMARY OF VELOCITY MEASURING POSITIONS

Test Code

B.

Velocity Position	1	2	3	4	5	6
Distance from WC (m)	3.05	5.08	7.11	9.15	11.18	13.21
Separation photocells		-0.3m				

C.	Velocity Position	1	2	3	4	5	6
	Distance from WC (m)	3.05	5.08	7.11	9.15	11.18	13.21

Velocity measuring length -1.0m

SAMPLE PREPARATION

D. (a) If an adhesive backed towel is tested, the release strip must be taken off and towel placed on a clean, fresh section of "pantie" cloth. (The cloth to be defined and sample at Brunel). A 2 kilogramme weight (3cm wide x 20cm long) is placed on towel for 90 seconds. The towel to be then peeled longitudinally from the cloth. If however on dropping the towel into the pan it sticks to the side of pan due to the adhesive then these results should be ignored.

E. (b) The product should be pre-soaked with water

Tampons - no pre-soak
Panty shields - 2cc
Mini towel - 6cc
Towel - 20cc

The water should be applied over the middle third of the product and to avoid excess running off the surface it should take 1 minute to apply the fluid.

F. (c) The product must be torn, if necessary, as defined on the package.

SAMPLE PLACEMENT

G. (a) The product should be held vertically and the bottom of the pad (not loops) should be level with the rim of the toilet and in the centre of the basin.

H. (b) The product is dropped into the pan and 20 seconds later the toilet is flushed.

MEASUREMENT

I (a) WC FAILURE: If the product fails to leave the toilet, this is noted plus the number of flushes required to remove the product.

J. (b) VELOCITY: The velocity is recorded at various points along the pipework system as defined in the test equipment. It may be necessary to change the method of measuring the velocity if the solid disperses.

K. (c) STOPPAGE DISTANCE: If the product stops in the pipework the distance from the WC is recorded.

L. (d) % VOLUME OF FLUID AHEAD: This is recorded as it should confirm a satisfactory flush. It is measured by a signal from the depth recorder in the collection tank at the end of the pipework.

NUMBER OF TESTS:

A minimum of a 100 tests should be completed.

FLUSHABILITY REPORT

DRAINAGE RESEARCH GROUP,
DEPARTMENT OF BUILDING TECHNOLOGY,
BRUNEL UNIVERSITY,
UXBRIDGE, MIDDLESEX. (Tel: Uxbridge 37188 ext. 344 & 359)

The attached test specification details the test rig and methods used to determine the acceptance of the towel for disposal by WC flushing. The operative paragraphs of the specification are listed where appropriate:-

Towel type Dr. White's Panty Pads Super Plus

Test equipment A

Velocity measurement positions C

Sample preparation D,E,F

Sample placement G,H

Measurements I,J,K,L

Number of WC flushes 100

WC flush failures -

WC 2nd flush failures

Theoretical zero velocity pipelength based on $V = C_1 - C_2 \sqrt{L/G}$ $\sqrt{L/G} = 62.44$
$L = 48.7\text{m}$ at 1/80

Stoppage distances recorded Mean = - Max = - Min = - STD = -

Number of stoppages in pipe 0

Volume discharged ahead of solid Mean = 1.96 Max = 3.94 Min = 0.98 STD = 0.59 1
21.6% 43.2% 10.8% 6.43%

Comments on test performance No problems encountered during WC tests.

This product passes the test specification

FLUSHABILITY ASSUMPTIONS

In carrying out this investigation to determine a flushability method various assumptions have been made and certain facts found:-

(1) WC Pan: A BSI P-trap WC was used as the majority of U.K. houses would have this type of toilet. At this stage siphonic systems have not been investigated.

(2) Flush Volume: The current British Standard stipulates a minimum flushing volume of 9 litres, and this was used in the test method. However it is more likely that the volume is 11/12 litres in the home. There are available reduced volume flush systems and controlled flush systems, none of these have been investigated.

(3) Cover Flushing: In the past it has been recommended on those towels which have the cover torn that the cover is flushed separately. It was found better to flush cover and contents together.

(4) Air Entrapment: One of the major factors in poor performance was air entrapment in the product which forced the product to float.

(5) Product Placement: It was decided to specify the position from which the product is dropped so as to try to eliminate any product falling onto the sides of the pan, and prevent any bridging effect on long products.

(6) Pre-soak: It was found that the product performance in general deteriorated if water was added to the product before flushing. Various levels of pre-soaking have been defined.

Tampons	-	0
Panty shield	-	2cc
Mini	-	6cc
Towels	-	20cc

(7) Product Shape: At this stage it was felt better to ignore the fact the product could be shaped after use. This was due to the difficulty of reproducing a standard shape, and some evidence that it did not affect the performance.

(8) Sample size: A 100 samples were tested as typical of 6 months usage and it was felt that a 1 in 15 first failure would be acceptable. Care should be taken not to refer the specification as "6% of towels can fail to leave the WC".

(9) Stoppage Distance 10 metres: There are no British Standards for pipework distances, but it was considered by Brunel that the majority of systems would be less than 10 metres even taking into consideration the twists and turns that sometimes occur.

In conclusion we do have an industry agreed specification and test method of flushability of sanitary protection products, and hopefully the number of complaints we have from our customers due to flushability problems will reduce from the present one complaint in 100 million products used!

Background to the flushability test work at Brunel

The Drainage Research Group at Brunel have been involved in a fundamental study of the mechanisms of solid transport in above ground drainage systems for a number of years. The initial research, funded by the U.K. Department of Health and Social Security, had led to the establishment for the first time in 1976 of an empirical relationship linking solid velocity to both pipe length travelled and to pipe gradient. Initially (1) this was limited in its application to tests involving maternity pad model solids w.c. flushed under laboratory conditions into a 14 m length of drainage pipework set at gradients from 1/40 to 1/200. Pipe material was initially transparent UPVC although glass and cast iron pipes were also tested. In 1977 further funding from DHSS allowed this programme to continue and to include, in its current stage, the monitoring of installed systems as a means of demonstrating the application of the empirical relationship mentioned above to the wide range of waste transported along a typical drainage system.

The initial relationship linking solid velocity, and hence the probability of deposition, to pipe length and gradient was found to have a form -

$$V = C_1 - C_2 \sqrt{\frac{L}{G}} \qquad - (1)$$

where L is the distance travelled along the pipe set at a gradient G, over the main length section of w.c. fed branch drain pipe runs. This basic equation was found to apply in the same format to pipes of various materials, e.g. glass, UPVC or cast iron, or to pipes of various cross sectional dimensions and shapes, e.g. 100 mm and 75 mm diameter and elliptical. Similarly the relationship for various flush volumes with the standard maternity pad solids was found to have a form -

$$V = \frac{C_4 - F}{C_5} - \frac{C_6 - F}{C_7} \sqrt{\frac{L}{G}} \qquad - (2)$$

where C_{4-7} are empirical constants.

Thus when the group was approached by ASPM to aid in the development of a set of flushability criteria for sanitary products that would include solid transport as well as w.c. discharge targets it was clear that the test work envisaged would fit conveniently into the research programme. The Association of Sanitary Protection

Manufacturers are to be thanked both for entering fully into this co-operation with Brunel and for allowing the test results to be published in an anonymous form.

Development of the test rig

As the proposed work fitted so closely into the group's programme it was possible to modify one of the existing test pipe runs to form the basis of a flushability test rig. A P-trap w.c. was chosen as the standard input device based on enquiries on market penetration of various w.c. types. The pipe chosen was 14 m of 100 mm diameter transparent UPVC to facilitate the use of standard photo-electric cell and light source instrumentation developed at Brunel to record solid passage along the pipe and hence velocity. Choice of pipe length and gradient were more difficult. After much discussion a gradient of 1/80 and a successful transport length of 10 m was chosen as reasonable to represent both the more convoluted pipe networks to be found in domestic installation and also the possible worst case formed by an isolated branch w.c., possible in a large building toilet area or a downstairs second w.c. in the domestic sector.

Test programme and results

The initial objective in 1978 was the confirmation of the application of a relationship of the form of equation 1 to the range of products to be tested, not only in the complete form compatible with the single maternity pad test but also in the torn state compatible with the manufacturer's instructions.

Figures 1 and 2 illustrate typical test results from this initial test series where dry untorn and torn towels were flushed from the w.c. In all cases the form of equation 1 is confirmed. Under the normal untorn towel test condition the photo-electric cell/light source pair separation was 0.3 m. However, due to the interaction between multiple solids transported along the pipe, the setting employed for the torn towel tests was increased to 1 m. Although this yields average rather than point velocities the $\sqrt{L/G}$ dependence holds, although the gradient of the data equation is much reduced, indicating an improved travel capability.

Figure 3 illustrates the mechanism of multiple solid transport in the drainage pipe, the successive accelerations, both positive and negative, being referred to as the "push me - pull you" effect. At this stage it is perhaps useful to introduce two other measurement terms, namely the flush volume ahead of the solid and the theoretical zero solid velocity value of $\sqrt{L/G}$.

Throughout the tests, and the earlier DHSS work, values of the quantity of water collected at the drain discharge ahead of the solid were recorded by a simple float driven level sensing device in the collection tank. It had been observed that the transport characteristics of a solid depend largely on its position in the flush and this is borne out by the ASPM results. Solids that fail the test specification on w.c. failure rate may be shown to have a wide spread of volume ahead results; indeed a w.c. failure may be regarded as a limiting value to these results. In the test rig described values of volume ahead above 30% of the 9 litre flush volume generally lead to problems in satisfying the test specification.

The theoretical zero velocity point from equation 1 is of course given by -

$$C_3 = \left(\sqrt{\frac{L}{G}}\right)_{V=0} = C_1/C_2 \qquad (3)$$

In practice deposition may occur from any velocity below about 0.2 m/s. At these low solid velocities the continuing transport is entirely dependent on the retention of a water volume behind the solid. Any irregularity in the pipe can then retard the solid sufficiently to allow excessive water leakage past and deposition will then occur.

At this stage in the testing programme it was decided to investigate the effect of pre-soaking the towel prior to placing in the w.c. bowl. Available literature would suggest (2) that the volume range of menstrual fluid, consisting of blood, mucin and epithelial cells, should be 8 - 20 g. It was decided to employ pre-soak water volumes in this range. Figure 4 and Table 2 illustrate the results of these tests. It is apparent that the addition of pre-soak water to the pad resulted in a deterioration in both the w.c. discharge and solid transport properties of the five pads investigated initially. This result at first seemed to be contradictory to the expected mechanism. However, a series of films taken of the pad sinking action in the w.c. bowl prior to flushing led to an acceptable explanation of these results. With an initially dry towel dropped into the bowl the saturation of the towel material occurs by capillary action so that the level of the water in the saturated towel is always above the bowl water level. This results in a force which draws the towel down into the bowl water.

If the central area of the towel is pre-soaked then two effects are noticeable, firstly the saturated towel tends to cling to the ceramic side of the bowl, and this prevents its immersion in the bowl water, and secondly the presence of a saturated strip across the towel seems to prevent the capillary action and bowl water does not move up inside the towel past this area.

Both these effects lead to a later discharge from the w.c. and hence to deterioration of the transport performance in the drainage system. Any tendency to retain air within the towel cover is naturally exacerbated by this failure to totally sink, again leading to late w.c. discharge.

The final simulation considered was a controlled degradation of the adhesive now used on many towels due to the lessening popularity of looped towels. Although this was not a major problem in terms of the number of towel types affected it is obviously necessary to simulate the loss of adhesive if for no other reason than to be able to state that any failures to pass the test specification were not due to uncharacteristic towel adhesion to the w.c. bowl or to the pipe invert.

After much discussion, and some tests involving preheating of towels to degrade the adhesive, a test procedure involving compressing the towel onto representative commercially available female underwear material was developed.

In parallel to the work reported, similar tests were undertaken on tampons and disposable diaper materials. Figure 5 illustrates these investigations and again confirms the $\sqrt{L/G}$ group predominance. One effect that was noticeable with all torn products but more pronounced with diapers was the random discharge from the w.c. In some cases the material was discharged as a continuous, well spread out stream of pulp with no deposition problems. However in some cases the w.c. action resulted in the diaper pulp being discharged in a concentrated mass with rapid deceleration and deposition in the waste pipe.

CONCLUSIONS

The tests reported involving sanitary towel products have contributed to the development of the flushability specification presented earlier in this paper. This specification has now been approved by ASPM as the basis for future product testing.

In developing the specification, the decisions taken were based on the widest possible application of the test findings, hence the choice of a relatively cheap and common domestic w.c. type. It may be necessary to investigate further the effects of other w.c. types on the flushability of sanitary products, in particular siphonic w.c. designs may well be a topic for future investigation.

The test results will be analysed further to investigate whether there is a correlation between values of C_1, C_2, and C_3 and the geometry of the solids and their position in the w.c. flush, as represented by the volume ahead of solid data.

ACKNOWLEDGMENTS

The Association of Sanitary Protection Manufacturers are to be thanked for making available test results from a programme of work carried out by the Drainage Research Group at Brunel on a consultancy basis.

REFERENCES

1. Swaffield J.A. and Wakelin R.H.M. "Observation and analysis of the parameters affecting the transport of waste solids in internal drainage systems". Journal IPHE 1976.

2. Sears W.G. "Anatomy and Physiology for Nurses" Edward Arnold 1958.

Table 2 : COMPARISON OF THE W.C. PERFORMANCE AND TRANSPORT CHARACTERISTICS OF THE TOWELS TESTED WITH AND WITHOUT ADDITION OF PRESOAK WATER PRIOR TO PLACING IN THE W.C. (Note value of C_3 represents $\sqrt{L/G}$ at V=0, a theoretical stoppage position.

Material	A		B		C		D		E	
Condition	Dry	+8ml H_2O	Dry	+8ml H_2O	Dry	+8ml H_2O	Dry	+20ml H_2O	Dry	+20ml H_2O
No. wc failures/ No. tests	0/5	6/30	0/5	4/34	1/6	6/30	0/15	0/20	0/15	0/20
% flush ahead solid	18.75	33.96	25.5	38.4	18.0	29.4	8.2	21.9	14.3	21.9
No. stoppages	0	4	0	5	0	0	0	0	0	0
Mean stoppage position, m	-	10.3	-	9.8	-	-	-	-	-	-
V(L=3.0m)m/s	0.84	0.78	0.75	0.72	0.86	0.86	1.17	0.83	1.06	0.75
V(L=13.2m)m/s	0.58	0.37	0.51	0.34	0.64	0.52	0.61	0.47	0.60	0.45
C_3	62.4	46.3	51.0	44	67.0	57.6	55.3	54	54	56.47
Towel characteristics	l = 190 mm		225 mm		196 mm		226 mm		220 mm	
	w = 70 mm		65 mm		65 mm		70 mm		70 mm	
	t = 14 mm		17 mm		10 mm		16 mm		14 mm	
Saturated wt.	195 g		210 g		140 g		210 g		155 g	

Note that the presoaked towels have worse transport characteristics under each of the measurement criteria of w.c. failures, stoppage positions, volume ahead of solid and velocity at any point along the waste pipe.

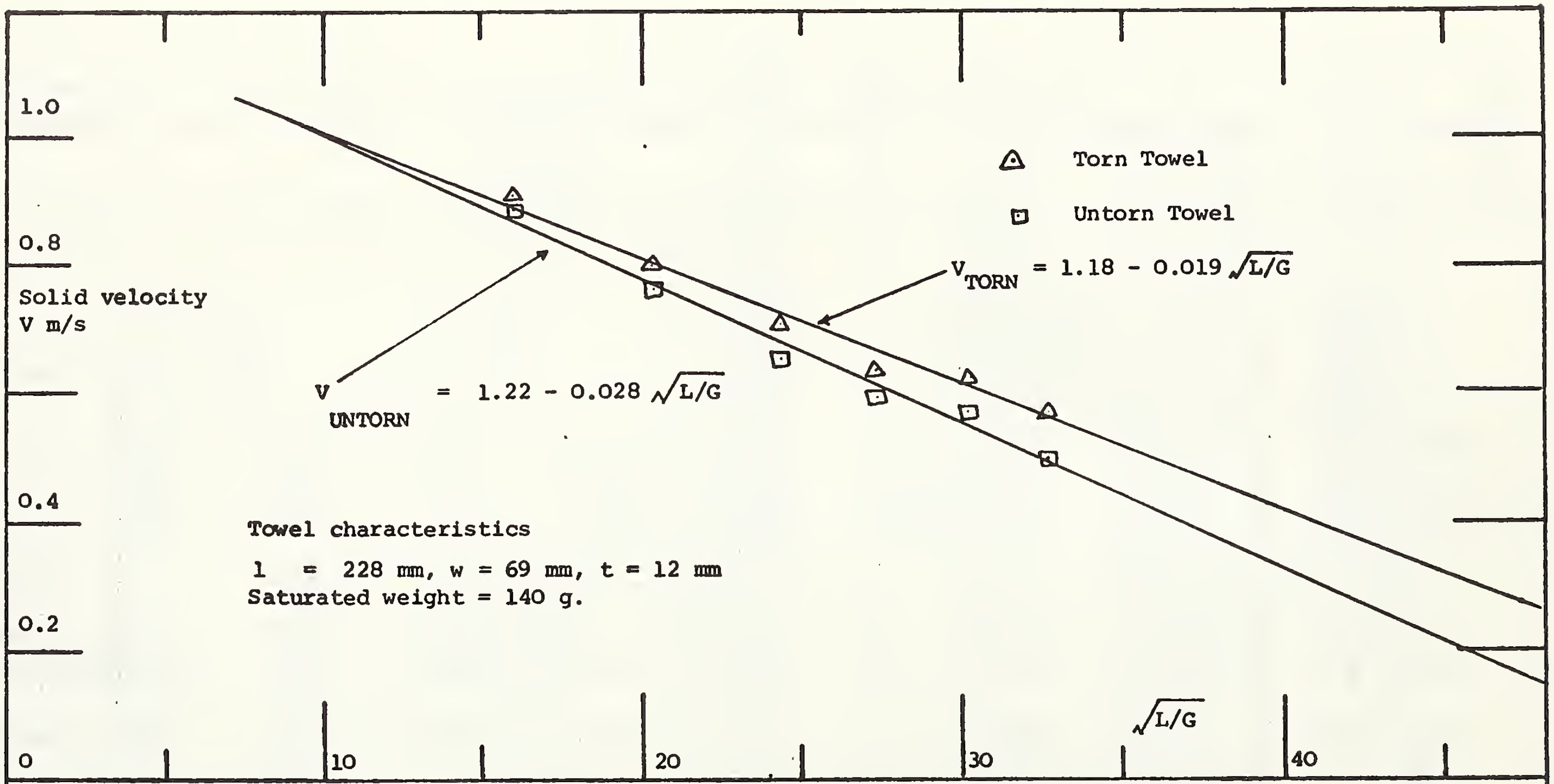

FIGURE 1. Initial test example illustrating velocity dependence on $\sqrt{L/G}$ group for both torn and untorn towels flushed into 14 m of 100 mm diameter UPVC piping via a 9 litre flush P-trap w.c. Note L denotes distance travelled along a pipe set at a gradient G.

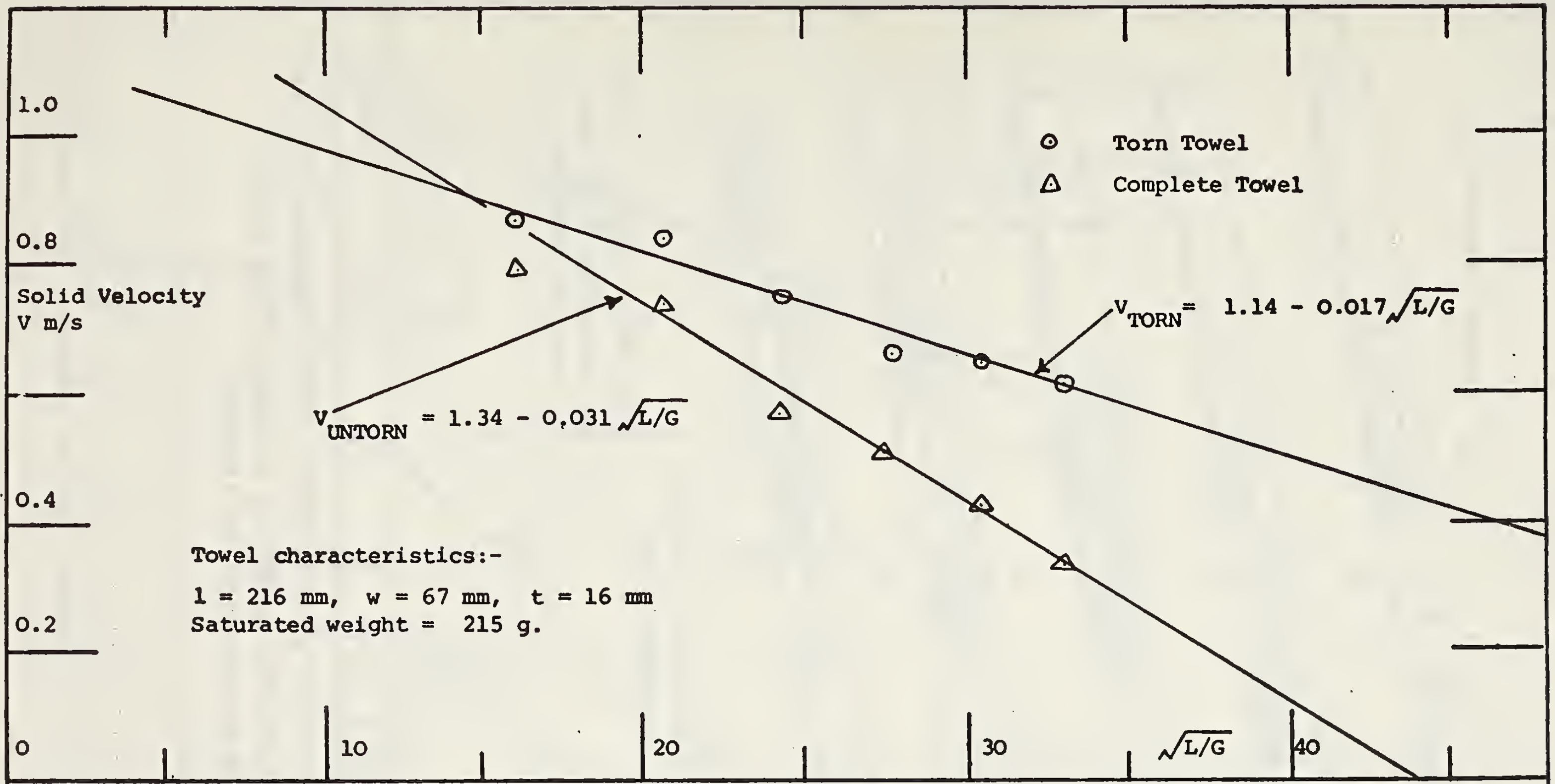

FIGURE 2. Initial test example illustrating velocity dependence on $\sqrt{L/G}$ for both complete and torn sanitary towel transported along 14 m of 100 mm diameter UPVC drainage piping.

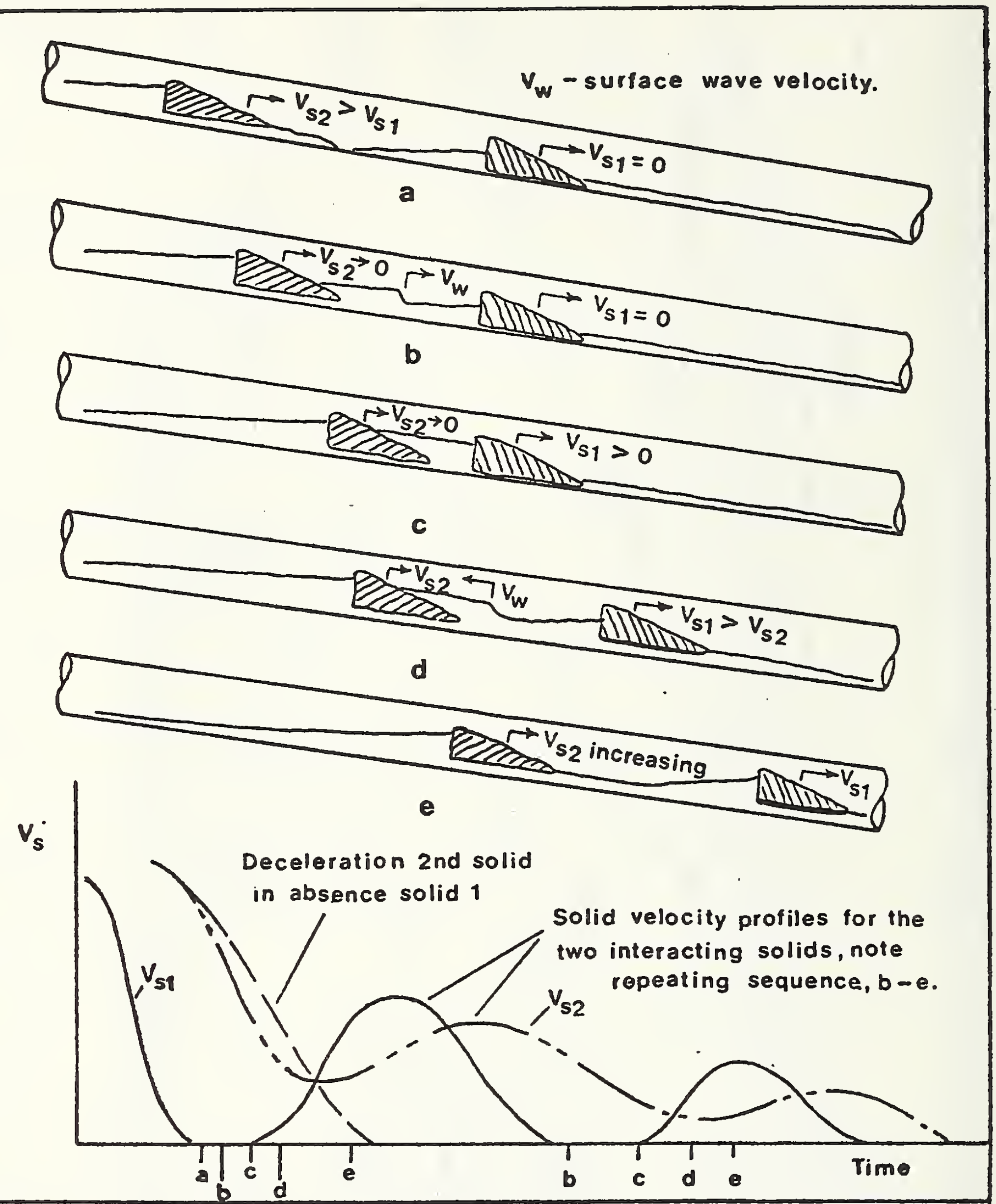

Figure 3 . Interaction of two solids, this sequence applies to separated solids in a single flush and to solids in consecutive flushes.

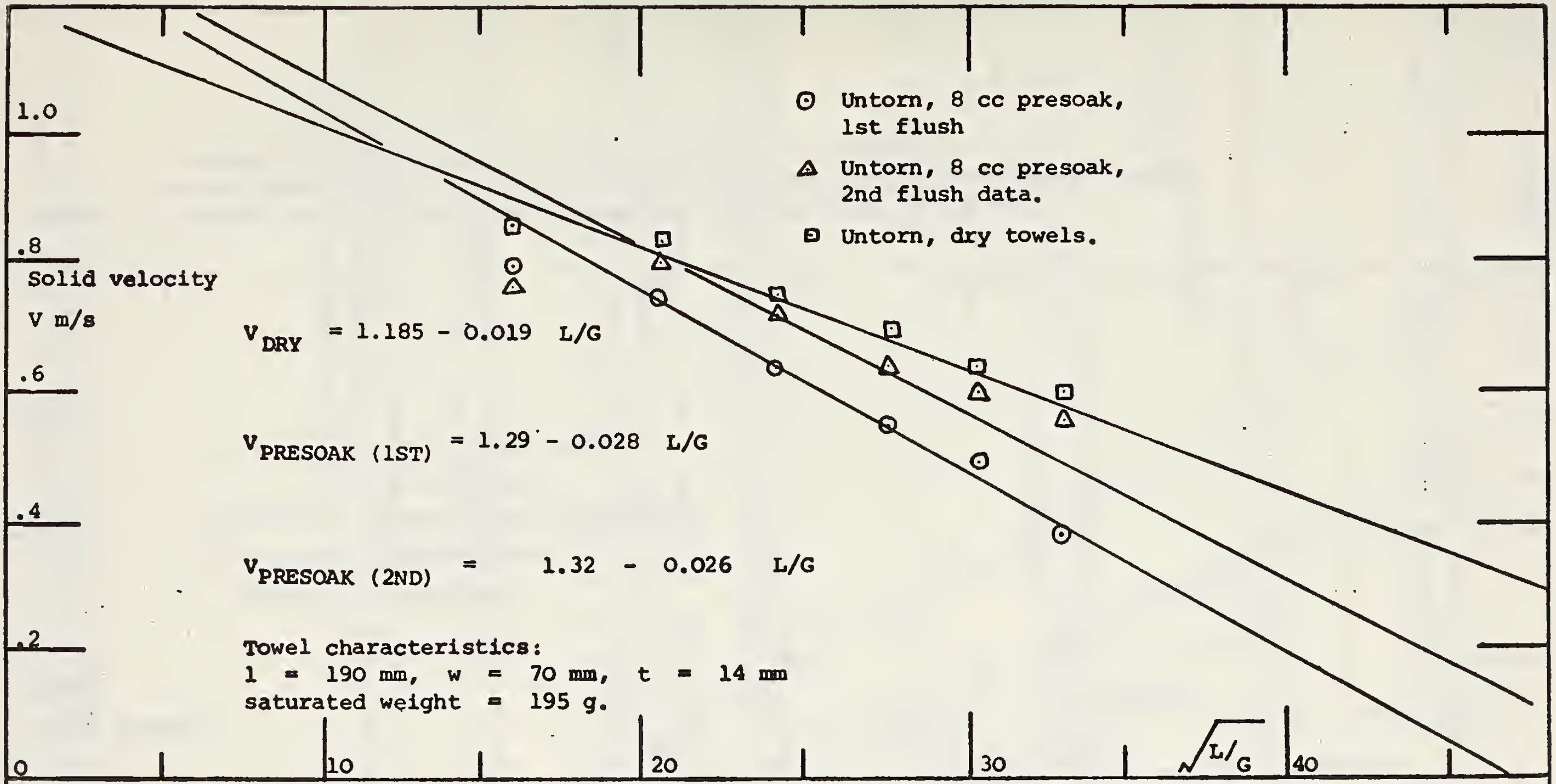

Figure 4. Effect of a 8 cc presoak on the transport characteristic of an untorn sanitary towel. Note improvement in travel characteristics on 2nd flush. This was due to the towel leaving the pan relatively earlier in the flush on the second attempt; in this case mean volume ahead on 1st flush was 34% and 30% on 2nd flush.

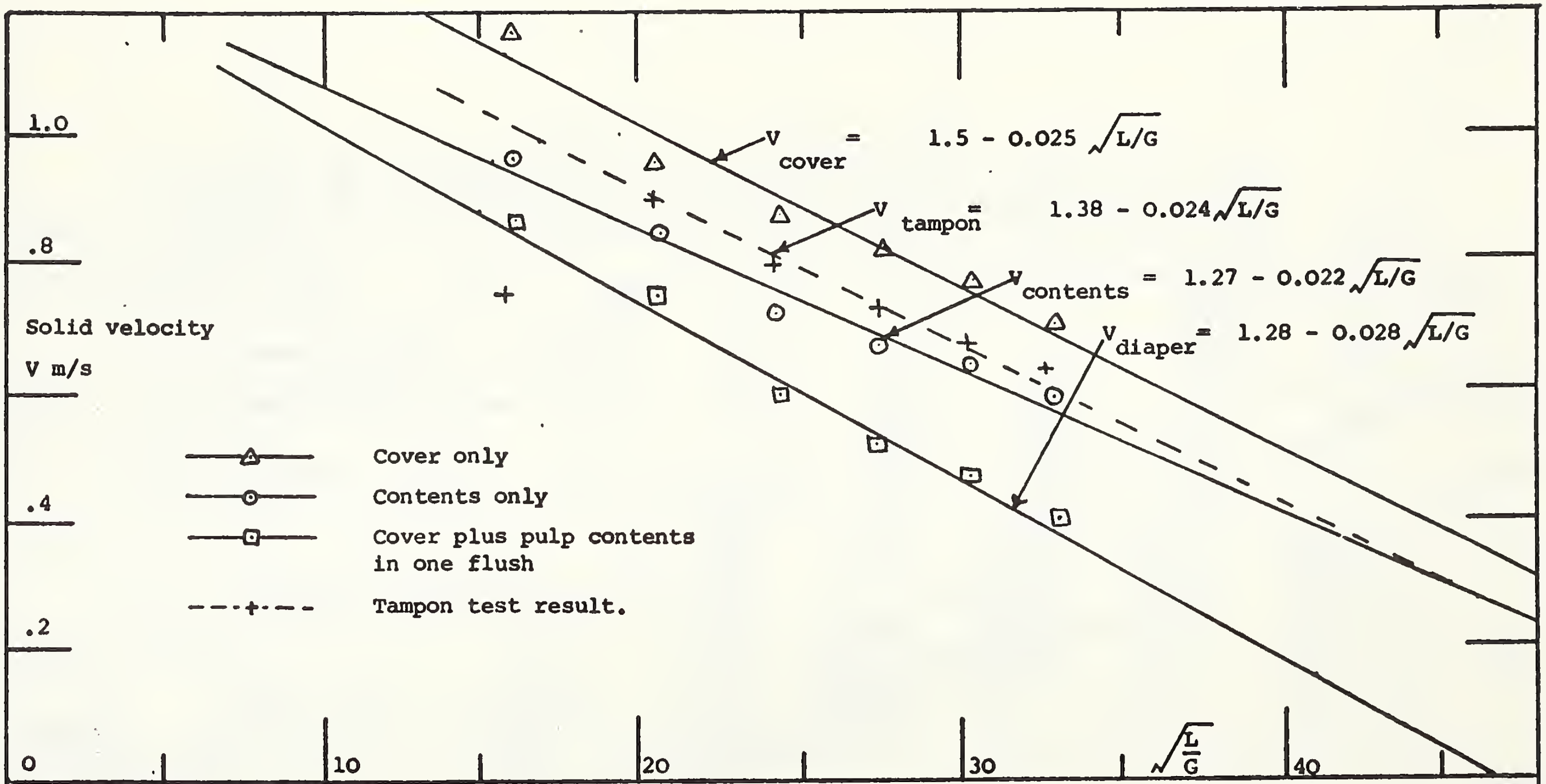

Figure 5. Velocity vs $\sqrt{L/G}$ profiles for tampons and a disposable diaper. Note diaper transport investigated for both cover and pulp contents flushed together and separately in two consecutive w.c. operations.

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5. AUTHOR(S)

John A. Swaffield

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

Test results are presented for the transport characteristics of an extensive range of geometrically similar model solids in a 100 mm diameter UPVC drain pipe. Model solids were based on commercially available sanitary towels (napkins) discharged into the pipe system via a series of U.K. standard watercloset (w.c.) types.

Following a data fit analysis, relationships are presented linking solid transport characteristics to solid, pipe and w.c. parameters.

These relationships, linked to observation of installed hospital drainage systems in the U.K., will allow laboratory test methods to be utilized in predicting the effect of design changes on system performance.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

building drainage; waste solid transportation; water conservation; W.C. efficiency

13. AVAILABILITY

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