‘PULL THE CHAIN, FILL THE DRAIN’

CP 367 - THE EFFECT OF REDUCED WATER USAGE ON SEWER SOLID MOVEMENT IN SMALL PIPES

Report No.: P7904

defra
Department for Environment Food and Rural Affairs

NHBC Foundation
Housing research in partnership with BRE Trust

Severn Trent Water

PLASTIC PIPES GROUP
British Plastics Federation
Plastic Pipes and Fittings Group

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Collaborative Project CP: 367

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EXECUTIVE SUMMARY

The Code for Sustainable Homes (CSH) and proposed amendments to Building Regulations promote the need for reduced water consumption in domestic properties. However, there are concerns that this reduced water use could inadvertently lead to problems with the effective transport of sewer solids in the drains and small sewers close to property.

Solids movement in small diameter drains/sewers have been investigated through a number of previous projects, together with factors contributing to blockages. Whilst water savings are likely to be achieved primarily through the use of low flush WCs, this previous research has shown that it is the WC flush that keeps the solids moving in the small pipes with intermittent flows leading from houses.

There was therefore a need to fully understand the consequences of the proposed water saving measures on the transport of solids in drains/small sewers. This project has investigated the impact of reduced water usage through a series of practical tests using the WRc low flow drainage test facility.

A test programme was developed to examine the solids carrying capacity of WC flush volumes (2, 3, 4.5 and 6 litres) in a range of pipe configurations and conditions. A reference test was developed against which all other tests were compared. This test is based on current design standards for pipe gradients (100 mm diameter pipes with a gradient of 1:80), pipe types, pipe configurations and appliance locations.

A variety of different pipe configurations and physical factors were replicated on the WRc small pipe test facility. The sewer solid movement performance was investigated under each of these conditions and the performance was compared to the reference tests. From these investigations it was possible to assess if such changes would be acceptable or not with regard to the movement of sewer solids.

The testing programme was to a certain extent iterative. Whilst the main aims had been agreed before the investigations commenced, the test schedule was sufficiently flexible to enable specific aspects to be examined in more detail, as and when the need arose.

The following factors were investigated:

- The effect of different flush volumes (2.0, 3.0, 4.5 and 6 litres).
- The addition of various quantities of toilet paper with the solid, (4, 6, 8 and 12 sheets).
- A variety of different pipe characteristics / conditions, including:
  - pipe material,
  - joint distance,
  - the presence of defects,
  - gradient of the drain/sewer pipes,
  - discharges from upstairs and downstairs installations,
  - normal and small diameter soil stacks,
  - alternative sewer connection configurations, and
  - inclusion of interceptor traps.

- The movement of so called ‘flushable’ products.
- The solid carrying ability of bath and shower discharges, and
- Discharge characteristics of proprietary low flush WCs

Additionally, a number of tests were undertaken to examine the effect of multiple solid discharges and different sequences of high/low flush volumes from dual flush WCs.

An ‘acceptable’ result was generally taken as one where sewer solids travel at least 10 metres before reaching a point where it was able to move no further. This length was chosen as being the distance, in a typical domestic drainage configuration, from one WC discharge to the next downstream connection with a WC discharge. This arrangement is the minimum necessary to enable solids to continue to be moved until they reach a point where sufficient discharges are connected to the sewer, thereby enabling the solids to be carried away by the continuous flow.

Where the test results are unacceptable, i.e. solid movement of less than 10 metres, further tests were undertaken with the same configuration but with steeper gradients of 1:60 and 1:50. This was to enable the sewer solid movement combinations of different flush volume and physical pipe characteristics to be examined.

It should be noted that, unless stated otherwise, all tests were undertaken in a pipe accurately laid and in good condition.

The results can be used to inform further debate regarding the design of new drainage systems where significantly reduced levels of potable water consumption are anticipated. Similarly the information can be used to help formulate advice regarding acceptable levels of WC flush reduction when retrofitting in existing property.

WC flush volumes in common use are typically either 4.5 or 6 litres. Previously far larger volumes were used – some Victorian/Edwardian WCs used flushes of 9 or 13 litres. Dual flush WCs are now commonplace, these offer a choice of flush volume to the user, delivering either a normal flush volume (6 litres) or a reduced one (WC cisterns are available with either 3 or 4.5 litres as low flush volume). There is pressure to reduce flush volumes even further, subject to this being practical.

The principal findings of the study are:

- 2 litre and 3 litre flush volumes are insufficient to carry the solid at least 10 metres, i.e. nominally to beyond the next connection incorporating a WC.
- The addition of paper with the solid increases the effect of the WC flush wave. However, this is a temporary benefit, due to the rapid disintegration of the paper in the drain.
- The so called ‘flushable’ products do not present a risk of blockage when the pipe walls are smooth. However, the presence of small defects significantly increases the risk of snagging and therefore blockages. With 2 litre flushes up to 70 % of products snag, with 3 litres flushes and higher, the proportion reduces to between 10 and 20%.
- Proprietary low flush WC design focuses on WC bowl clearance. It does not give improved flow patterns in the downstream drain and as such does not enable sewer solids to travel further.

- The flush wave entering the drain from an upstairs WC differs from that from a downstairs WC:

  - 4.5 and 6 litre discharges from ‘upstairs’ give better sewer solid transport characteristics, when compared to ‘downstairs’ discharges.

  - 2 and 3 litre discharges from ‘upstairs’ give worse sewer solid transport characteristics, when compared to ‘downstairs’ discharges.

- Better design and construction of pipework between the WC and the external drainline may improve sewer solid movement. However, this benefit is only marginal and only observed at the lower flush volumes.

- The frequency of joints in the drain/small sewer does not have a significant effect on sewer solid movement, provided that the joints are small, well made and in generally good condition.

  However, joint defects can significantly reduce the distance travelled by a sewer solid. These defects include offset and pulled joints and rough internal surfaces.

- Pipe material has little or no effect on the distance travelled by sewer solids, provided that the pipe’s internal physical characteristics are free of defects.

- The condition of the existing drains/sewers must be established before retrofitting water saving appliances in properties connected to existing drains. This retrofitting includes both low flush WCs and the replacement of baths with showers.

  Retrofitting of low flow appliances should not be considered in systems with an interceptor trap. Similarly, care should be taken when retrofitting in properties that connect to drainage systems in potentially poor condition.

- Whilst WC flushes are the main vehicle for sewer solid movement, other discharges that generate a flow rate of 0.3 l/s or greater can be important. These enable the solid, once re-entrained, to be transported due to the constant flow. Typically these conditions are provided by an emptying bath. Considering the trend for more showering than bathing, as well as smaller baths (lower volume of water used), the WC flush (albeit reduced) still remains the most frequent and reliable event for sewer solid movement.

- The flows from water saving shower heads are unlikely to move the solid any further along the drain. Standard high flow shower heads have sufficient force and depth of water to momentarily move the solid but transport distance is minimal.

- Increasing the gradient of drains/sewers does not significantly improve the movement of sewer solids. Thus, an increase in gradient will not generally compensate for the reduced force of 2 or 3 litre flushes.

- Sewer solid movement may be impaired if a succession of solids are discharged. This is because the energy in the flush wave is used in moving the solid closest to the discharge. There is less force available to move solids further down the pipe.

- Where dual flush WCs are used the majority of solid movement comes from the larger flush.

The investigations have shown that the concerns regarding reduced WC flush volume and sewer solid movement were justified. A significant reduction in WC flush volumes, for example to a 4½ and 3 litre dual flush combination, is likely to be unacceptable if no other measures are taken to counter the effect of the reduced flush.

The research has shown that there are a number of alterations that could improve sewer solid flow in drains/small sewers. Some of these may include altering the design/construction of drainage systems, such as providing steeper gradients or pipes with less and better made/smoother joints. However, these changes may not always be practical, for example steeper gradients would require deeper sewers. Similarly, whilst drains with no defects should be the goal, it would be unwise to assume that this can always be achieved in the short/medium term.

Other changes, such as altering the ratio of high/low flushes in a dual flush WC could help to achieve improved sewer solid movement. Reducing the volume of the lower flush would not be detrimental as they generate little benefit to sewer solid movement, although any reduction would have to ensure that adequate bowl clearance could still be achieved. A corresponding increase in the higher flush volume on the other hand, would be beneficial to sewer solid movement. This increased higher flush volume could be achieved by using some of the 'savings' from the reduced lower flushes, which typically account for 75 % of all flushes. However, one of the current drawbacks with dual flush WCs is that people often don't understand or know which button to press. This needs to be addressed by better public education

There also exists the possibility of installing other devices to 'flush' the system. This is an adaptation of the flushing methods used by Victorian engineers to keep the main sewers clean. These new devices typically look at collecting grey water discharges, temporarily storing them and discharging when an adequate volume has been collected.

Clearly any changes in drainage design and the approach to water conservation needs to be considered in detail by all the stakeholders. It will be necessary to ensure that the proposed changes are practical and robust. However, it is clear that:

i) There is a government wish for potable water savings to be achieved within a relatively short time frame; and

ii) Simply reducing WC flush volumes is inappropriate without considering other measures to offset potential consequences of reducing flows in the drainage system.

The results of this research will help to inform debate in this area.

1. INTRODUCTION

It is widely accepted that there is a need to reduce water consumption in domestic properties, for example as detailed in the Code for Sustainable Homes (CSH) and proposed amendments to Building Regulations. There are various ways that this could be achieved but one of the greatest savings that could be made is through the use of low flush WCs.

However, other research has shown that it is the WC flushes that are the main means of moving sewer solids in small pipes with intermittent foul flows close to houses. Without these WC flushes there is an increased risk that sewer solids movement would be impaired and this could lead to an increased likelihood of blockages and property flooding/environmental pollution incidents.

Therefore, it is essential that the effect of reduced volume WC flushes and the increased likelihood of blockages is better understood. Clearly the need for water conservation is beyond question but any consequences of such a policy need to be examined. Such an exercise will help to ensure that measures are put in place so that water conservation measures do not result in an increased likelihood of blockages and sewer flooding.

WRc Portfolio project CP367 is a practical investigation to better understand the link between reduced water usage, in particular low flush WCs, and sewer solid movement in pipes close to houses. Testing has been undertaken on a purpose built, above ground facility using a variety of different WC flush volumes and different drainage configurations. This has enabled the limitations of reduced water usage in drainage systems built to current specifications to be far better understood. It has also enabled appropriate limits to reduced WCs flush volumes, when used in combination with existing drainage systems, to be suggested. At the same time a range of changes to both WCs flush patterns and the physical configuration of small drainage systems has been examined with a view to understanding which alterations may be beneficial.

This report gives details of the experimental work that was undertaken by WRc on the small pipe test facility. This shows that reduced volume WC flushes have the potential to significantly increase the likelihood of sewer blockages and flooding. Nevertheless, the report also shows that there are a range of 'opportunities' that have the potential to minimise the negative impacts of reduced water usage on solids movement in small drainage systems.

2. BACKGROUND

2.1 General

There is already a perception that there has been a gradual rise in the number of blockages in small sewers and drains that are close to and serve domestic property in recent years. Today over half of all sewage flooding of property incidents are the result of causes other than hydraulic overload due to heavy rain. Typically well over 90% of these ‘other causes’ are sewer blockages. Approximately 4 to 5% of all blockages result in internal flooding of property.

Currently in England and Wales many of these problems are not the responsibility of sewerage undertakers. However, the likely transfer of these assets to sewerage undertakers in the coming years will result in an even greater proportion of the problems becoming the sewerage undertakers’ responsibility.

Guidance, as detailed in the Code for Sustainable Homes (CSH) and the planned amendments to Part G of the Building Regulations, will result in less wastewater being passed to sewer. Representing up to 33.5% of water consumption in households (particularly in older properties), reducing WC flush volume offers the greatest opportunity for reducing water demand. New drainage systems will need to function with significantly less ‘flushing action’ than traditional systems have been able to rely on.

This project directly addresses a need to fully understand the impact of meeting the reduction in potable water consumption. The implications of introducing reduced WC flush volumes, water saving shower heads etc, are investigated to better understand the potential effects on solid movement.

2.2 Previous research

Previous investigations by WRc into potable water usage have shown that one of the greatest water savings can be made through the use of low flush WCs. However, other WRc research has also shown that it is WC flushes that are the main vehicle for moving sewer solids in the small pipes with intermittent flows leading from houses. Littlewood and Butler (2003) concluded that the WC would typically produce the greater flush wave with a 6 litre flush at a flow rate up to 2 l/s, compared to a washing machine discharging 180 litres at 0.7 l/s and a bath up to 80 litres at 1.1 l/s. Therefore, the appliance most influencing the movement of solid into the drain/small sewer is likely to be the WC. Other appliances also play a role in the solid movement but to a lesser extent.

Research has also been undertaken at the WRc test facility to investigate sewer solid settlement in small sewers and the subsequent influence on the formation of blockages. These investigations included different pipe materials (plastic and clayware), different pipe sizes (100 mm and 150 mm diameter pipes), offset, pulled and rough joints and backfill gradients from 1:100 to 1:500, compared to a standard positive gradient of 1:100. The report for this research, ‘*Understanding blockages in small diameter pipes, WRc report P6956, June 2006’* included the following conclusions/ recommendations:

- The choice of pipe material (clay, plastic) is not critical when considering solid movement/stranding in small diameter pipes with intermittent flows.

- Poor joints and other failures do not necessarily cause solids to strand. However, pipes with multiple defects and joints in poor condition may lead to reduced transport ability.

- Pipe diameter has a greater effect than material.

- The risk of solid stranding is significantly increased with smaller flush volumes i.e. 3 litres as opposed to 6 litres. The risk of blockages depends on a combination of parameters: gradient, pipe condition, pipe diameter and flush volume.

Another study was carried out at WRc to investigate the solid movement characteristics in small diameter clay pipes, (former section 24 sewers), but also to examine the effectiveness of no dig relining to reduce blockages.

The following recommendations were made:

- A significant difference was observed between 6 litre and 3 litre flushes, with a notable reduction in the distance travelled by solids using the 3 litre flush.

- Tests that included the use of toilet paper show initial transport of the solid is enhanced by the addition of paper. This benefit is only maintained for the flushes during which the paper remains intact (i.e. before it disintegrates).

- The lining of pipes, either those in good structural condition or those with defects, significantly improves the sewer solid transport characteristics.

- The condition of drains and sewers with intermittent flow should be considered prior to the installation of 'low flush' WC's.

Sewer abuse, (the disposal of fats, plastics, waste food and sanitary products to sewer), has also been investigated. These studies have emphasised the susceptibility to blockages of drains/sewers with relatively small and intermittent flows. Whilst sewer condition and peoples 'disposal' habits significantly influence the settlement of sewer solids/formation of blockages, these investigations all emphasised the importance of WC flushes.

A theoretical exercise has also been undertaken by WRc to assess the likely impact of reduced water usage on sewer solid movement in small pipes. This research used data from previous potable water and sewer solid movement projects. It suggested that a significant reduction in water usage, if not accompanied by other mitigating measures, could result in a significant rise in sewer blockages and associated property flooding/pollution incidents.

This project builds on the knowledge gained during these previous studies to extend the understanding of the effect of very low flows, as generated by 2 and 3 litre flush volumes, on the transport of sewer solids. The project also considers drainage design standards that may need to be modified to ensure that such problems are minimised.

2.3 Objectives of the current project

The objectives of this project have been to

i) Build on the understanding developed in previous projects; and

ii) Extend this understanding of how the flush wave generated by reduced flush volume WC's, various other water saving appliances and pipe configurations affect the distance travelled by the solid.

The results would then be examined to identify the limitations of using reduced WC flush volumes etc with current designs. Where necessary, further tests would be carried out to identify possible approaches to reduce the likelihood of blockages, odours etc.

2.4 Approach

As the project brief is '*a practical investigation to better understand the link between reduced water usage and potential increasing problems with solid movement in small pipes'*, a series of practical tests were devised. It was also necessary to design and construct the facilities on which to conduct these tests.

2.4.1 Reference test

A practical and repeatable reference test against which all other tests can be compared was developed. This was based on current standard pipe gradients, pipe types, pipe configurations and appliance locations. Using typical drainage configurations and features, repeat tests were conducted to establish representative test results for a range of WC flush volumes.

As the major concern is that low flows will be insufficient to transport the solid to a position where deposition is unlikely, a target distance for solids transport against which test results can be measured was also identified.

Previous investigations had identified that sewer solids need to be able to travel at least 10 metres before becoming stranded and able to move no further. This length was chosen as being the distance, in a typical domestic drainage configuration, to where flow from another WC discharge would be connected to the drain/sewer. The addition of another WC flush would give renewed 'energy' to enable sewer solids to continue to be moved along the pipe. Eventually, sufficient flow would join the sewer to enable solids to be carried downstream in a continuous flow with a reduced likelihood of stranding and causing a blockage.

2.4.2 Test programme

A test program and test methodology was developed; this was to enable the most significant factors that influence sewer solid movement (and deposition) to be investigated. Subsequently these influences could be quantified, in particular the effect of changing specific parameters.

A number of parameters that were thought to influence the transport of solids in drains were identified from previous research. It was also recognised that additional tests may subsequently be required to further investigate the relationship between reduced water usage and certain physical characteristics of the drainage system. Scope for this iterative process was allowed for in the testing programme.

The effects of the following parameters and influences on solids transport distance were examined:

- Flush volumes of 2.0, 3.0, 4.5 and 6 litres,
- The addition of toilet paper with the solid,
- The addition of various quantities of paper with the solid, (4, 6, 8 and 12 sheets),
- Sequencing of sewer solid discharges and non solid discharges from WCs,
- Flushable products,
- Upstairs and downstairs WC flush waves,
- Bath and shower discharges,
- Discharges from proprietary low flush WCs,
- Change of gradient of the drain (1:80, 1:60 and 1:50)
- Alternative sewer connection configurations,
- Small diameter soil stack,
- Defects in the drain, and
- Interceptor traps.

2.5 Test Facility

Tests were carried out using the WRc drain/small sewer test facility. This facility is designed to be able to install up to three 20 metre lengths of drain/small sewers of different diameters, pipe materials and pipe lengths, at gradients ranging from 1:80 to 1:40. Various appliances/features may be installed at any point along the pipe lengths. The detailed set up of the test facility for this project is described in Sections 3 3and 4 of this report.

It should be noted that, unless stated otherwise, all test were undertaken in a pipe accurately laid to line and level and in good condition.

2.6 Report structure

This document is a scientific/technical report detailing the low flow test research that was undertaken. The results are for use as background information by technical staff employed by regulators, manufacturers, system designers and system operators.

This document is structured as follows:

- Section 1 Introduction
- Section 2 Background
- Section 3 Development of testing programme
- Section 4 Methodology and test rig
- Section 5 Effect of WC flush volume at a 1:80 gradient
- Section 6 Effect of drainage layout within the property
- Section 7 Effect of pipe characteristics / condition
- Section 8 Effect of retrofitting to existing drainage systems
- Section 9 WC flush patterns and non WC discharge transport characteristics
- Section 10 Effect of change of gradient
- Section 11 Discussion
- Section 12 Conclusions
- Section 13 Recommendations

3. TESTING PROGRAMME

3.1 Overview

This section outlines the test programme that was developed. It describes the reference test and tests to examine the influence of different parameters thought likely to effect the solid movement. Some of the tests were developed in response to the results of prior tests in order to explain unexpected behaviour. Sections 4 to 10 report the results from these tests in detail.

3.2 Overall testing programme

A programme of tests was developed to examine the solids carrying capacity of low WC flush volumes, 2, 3, 4.5 and 6 litres, in a range of specific conditions. A reference test based on current design standards for pipe gradients, pipe types, pipe configurations and appliance locations was developed, against which all other tests can be compared.

Factors that may influence the movement of solids in small diameter pipes have been investigated. These tests investigated the change of parameters that may be applied within the property (i.e. the way in which the water discharge patterns can be modified by the users) or within the drainage system.

The following list summarises the parameters investigated:

- Wastewater use patterns
    - Flush volumes of 2.0, 3.0, 4.5 and 6 litres,
    - The addition of various quantities of paper with the solid, (4, 6, 8 and 12 sheets),
    - Discharges from a bath, shower and proprietary low flush WC,
    - Flushable products, and

  Additionally a number of tests were undertaken to examine the effect of multiple solid discharges and different sequences of high/low flush volumes from dual flush WCs.

- Pipe characteristics / conditions
    - gradient of the drain/sewer pipes,
    - upstairs and downstairs appliance installations
    - small diameter soil stack,
    - alternative sewer connection configurations,
    - material,
    - joints distance,
    - defects, and

- o interceptor traps.

3.3 Reference test

The standard design for a small drain/sewer close to properties is specified in the Approved Document H (2002 edition) of The Building Regulations 2000 for Drainage and Waste Disposal.

- This document states that "*a drain carrying effluent from a WC or trade effluent should have an internal diameter of at least 100 mm*" and
- It also recommends a gradient at 1:80 for a peak flow not less than 1 l/s connected to a WC and a 100 mm diameter pipe.

The reference test was therefore based on the following criteria:

- 103 mm internal diameter PE pipes.
- 5 metre pipe lengths.
- A pipe gradient of 1:80.
- A downstairs WC installation.
- Standard dual flush WC with valve flush mechanism.
- A standard pipe configuration of bends and branches etc. to connect the WC to the drain, and
- Westminster solid to represent sewer solids. (See Section 4.3 of this report for further details)

A detailed description of the installation and equipment is given in Section 4.2.

Tests were carried out with 2, 3, 4.5 and 6 litre flush volumes to establish transport distances for each of the flush volumes.

A second set of reference tests were carried out with the same configuration but with the addition of 4 sheets of paper flushed with the Westminster solid.

3.4 Tests to determine the effect of changing a parameter

The effect of changing a range of different parameters in a pipe at the standard gradient of 1:80 was investigated, one at a time, and the results were compared with the reference tests.

These tests helped to gain an understanding of how altering either the discharge characteristics or physical pipe parameters could affect sewer solid movement. This in turn enabled a far better understanding of the changes that have the potential to improve the solids carrying capacity and by how much, and equally importantly, what changes had a detrimental effect on solid transport distance.

The effect of defects and features in the drain/sewer were also investigated.

The following sub sections outline the main aspects of the tests that were carried out with the various groups of parameters/variables.

3.4.1 Addition of different quantity of paper – 4, 8 or 12 sheets of paper and flushable products

The reference tests were carried out using the Westminster solid alone and with 4 sheets of paper.

Tests using the Westminster solid with 8 and 12 sheets of paper were subsequently undertaken, as were tests using flushable products alone. These are summarised below.

An increase in the number of sheets of paper could increase the surface area exposed to the horizontal flush wave and therefore increase the force to push the solid further down the drain/small sewer pipes. Conversely, more paper could also increase the friction of the material against the pipe that the energy of the wave has to overcome.

It was noted that the effect of additional paper was dependent of whether water was retained behind the solid/paper between flushes. For example:

- With no water retained behind the solid/paper. The distance travelled using 2 litre flushes and with 8 or 12 sheets of paper was similar to that recorded during the reference tests with 4 sheets. This suggests that the quantity of paper is insignificant.

  Similar results were observed during the 3 litre flush tests.

- With water left behind the solid and paper. The tests carried out with 2 and 3 litre flushes showed that the distance travelled increased by between 28 % and 48 %. This suggests that other small discharges entering the drain to keep the reservoir of water topped up, for example from hand washing/rinsing, could be beneficial in helping the solid move further following a WC flush.

  Thus the retention of water behind the solid is far more significant than the number of sheets of paper used.

- Baby wipes and panty liners were used to examine the effect of reduced volume flush on the travel of flushable products.

  When the pipe walls are smooth, baby wipes pass through the drain without problems. There is a tendency for baby wipes to snag if there are any defects in the pipe. Under these conditions with 2 litre flushes snagging occurred in typically 35% of all tests. With higher flush volumes the snagging risk is significantly reduced.

  The results show that so called ‘flushable’ products do not create a risk of blockage when the pipe walls are smooth. Low flows are sufficient to carry the products of low mass. However, small defects can snag a flushable product. Other debris and solids discharged into the pipe can accumulate on/around the snagged object, forming a blockage.

3.4.2 Drainage layouts within the property

The reference test standard arrangement is with a ‘downstairs’ WC as described in Section 4.2. Tests using an ‘upstairs’ WC, small diameter soil stack and alternative drain connection arrangements were undertaken. The main findings are summarised below.

- Tests were undertaken using a WC raised by 2.5 metres above the level of the ‘downstairs’ WC simulating a WC located on the first floor. This was to investigate the effect on the solid movement of a discharge via a soil stack arrangement, compared to the downstairs WC connection. The results showed a significant detrimental effect with 2 litre flush volumes but improved transport capability with 4.5 and 6 litres flush volumes.

  With a 2 litre flush volume the majority of the wave energy is lost in the vortex of the water in the stack. This observation led to the instigation of tests with an 82 mm diameter stack to identify if this approach would overcome the energy losses. Whilst the smaller diameter stack has a positive effect on the distance of the Westminster solid travel with 2 litre flushes, the distance reached remains less than the distance travelled with the use of the downstairs WC.

- A typical pipe configuration from the WC to the sewer pipe was used for the majority of the tests. However observations showed significant loss of energy in the ‘Y’ branch.

  A long radius bend was subsequently installed and tests were carried out and compared to the reference tests. A significant benefit was observed with a 2 litre flush volume. However, the long radius bend has little or no benefit when 3 litre flushes were used. This suggests that the long radius bend has a greater influence where the flush waves are small; the loss of energy will be proportionally more in a lower flush.

3.4.3 Effect of different drainage system characteristics/conditions

A series of tests were undertaken to assess the effect of different characteristics on solid transport. The parameters investigated included:

- Different pipe materials; and
- The number of joints.

The tests confirmed previous findings - there is no significant difference in the distance travelled by the solid in either plastic or modern clay pipes with well made sleeve joints. This is largely due to the small, well aligned joints common to both pipe systems.

Similarly, the number/frequency of joints does not have a significant effect, provided that the joints are small and well made.

Other tests were undertaken to compare solid movement in pipes with poor and well made joints. This showed that the poorer the condition of the joints the shorter the distance travelled by the solid. In these conditions the number of joints is also significant.

A comparison of the results for tests carried out in both new and old clay pipes showed that, whilst the poor condition of the joints in old clay pipes is a major influence, the internal surface finish can also influence solid movement. This is especially so in the low flows generated by 2 litre flushes, the finish had little effect with flows generated by 3 litre flushes or greater.

3.4.4 Effect of retrofitting low flow appliances to existing systems

Many older pipe systems will be in less than perfect condition - the older clay pipes with larger/poor joints (as discussed above) will be typical of many systems. Thus, the retrofitting of property with water saving devices could be particularly problematic in such situations.

Previously research has shown that relining pipes can significantly improve sewer solid movement characteristics. This is because surface imperfections are covered and the disruption to flow at joints is significantly reduced.

Tests with an interceptor trap were undertaken as part of the current research. The results show that interceptors impede the free passage of sewer solids. Also, whilst so called 'flushable' products pass through the interceptor at higher flush volumes (6 litres), the ability of products to pass through the interceptor at lower flush volumes is significantly reduced.

3.4.5 Sequenced WC discharges and non WC flow patterns

A number of tests were carried out to replicate a range of discharge patterns from domestic properties. These tests included:

- The use of dual flush WCs, to represent a sequence of solid and non solid discharges.
- Discharges of baths and showers.

Dual flush WC tests were carried out with a sequence of solid / paper / solid / paper to replicate a typical flush pattern that includes a solid every 4 flushes. Other testing included a sequence of low and high flush volumes with a Westminster solid alone, as well as a sequence of solids and paper.

The tests showed that:

- Where dual flush WCs are used, the majority of solid movement comes from the larger flush. This becomes more so the further away from the flush source, until a point is reached where the lower flush no longer moves solids.
- Sewer solid movement may be impaired if a succession of solids are discharged. This is because the energy in the flush wave is used in moving the solid closest to the discharge and there is less force available to move solids further down the pipe. Also, the distance travelled by the combined solids (when bunched up together) is less than that travelled by a single solid.

Whilst discharges from baths and showers are less frequent and of lower peak flow rate than discharges from a WC, their effect on solid movement must not be ignored.

The bath and shower head tests showed that:

- The threshold flow rate for solid re-entrainment is between 0.25 l/s and 0.3 l/s; and

- The threshold for continuous solid transport is a minimum of 0.3 l/s.

Most discharges from baths attain this minimum flow requirement at some stage of the emptying process. The discharge from shower heads are less effective at transporting solids - water saving shower heads do not attain the minimum flow requirement of 0.25 l/s and standard high flow shower heads can re-entrain the solid but transport distance is minimal.

The abovementioned tests which were undertaken in pipes in good condition showed that bath and shower discharges could help to move solids, although this was borderline in many cases. Accordingly, further tests were undertaken to assess the effect of small defects on such discharges. These test showed that shower discharges are unable to transport solids past minor defects in the pipe.

3.4.6 Effect of the change of gradient

A common theme behind many of the abovementioned test results is the inability of sewer solids to travel far enough in reduced WC flush conditions. With this in mind tests were subsequently undertaken to examine if steeper gradients would be beneficial to sewer solid movement.

Tests were undertaken at alternative gradients of 1:60 and 1:50, using both ‘upstairs’ and ‘downstairs’ WC locations, and compared with the reference test results. This showed that:

- The benefit of steeper gradient is not straight forward. Increasing the gradient of drains/sewers does not significantly improve the movement of sewer solids.

- There is a relationship between the increased gradient, higher velocities and shallower flow. An increased velocity gives greater horizontal force to move the solid. However, the shallow flow reduces a solid’s buoyancy and this counters the effect of the increased horizontal force.

Tests showed that:

- With a 2 litre flush, increasing the gradient from 1:80 to 1:60 is not sufficient to carry the solids from either a ‘downstairs’ or ‘upstairs’ WC an adequate distance, i.e. a nominal 10 metres to the next connection carrying a WC discharge.

- With a 3 litre flush and an increase of gradient from 1:80 to 1:50 the solid from a ‘downstairs’ WC flush is able to travel 70% further. However, there was only a limited improvement in the distance travelled by the Westminster solid from a comparable ‘upstairs’ WC flush.

Thus significantly increasing the gradient (to 1:50) would not enable sufficient solid movement from a 2 litre WC flush. Solid movement resulting from a 3 litre flush would be borderline.

3.5 <u>Test details</u>

Full details of the tests carried out using different parameters and the results of those tests are presented in the following sections:

- Section 5 Effect of WC flush volume at a 1:80 gradient
- Section 6 Effect of drainage layouts within the property
- Section 7 Effect of pipe characteristics / condition
- Section 8 Effect of retrofitting to existing systems
- Section 9 WC flush patterns and non WC discharge transport characteristics
- Section 10 Effect of change of gradient

4. METHODOLOGY AND TEST RIG

4.1 Overview

The methodology described in the following sections was used to measure, observe and analyse the movement of solids with small flows resulting from the reduced usage of water in retrofitted and new drainage systems. The tests carried out as described in Section 3 at the WRc test facility were to:

1. Investigate the influence of reduced volume WC flushes on sewer solid transport, and

2. Investigate the effect that different physical arrangements would have in mitigating the negative effects on sewer solid transport resulting from reduced water usage.

4.2 Test facility

The test facility comprises of three above ground channels. Two of these channels can have pipe work up to 20 metres in length placed upon them. The third channel can accommodate pipes up to a total of 10 metres in length (see Photograph 4.2). Side connections of up to 5 metres can also be accommodated (see Figure 4.1). The pipes can be of any material and up to 225 mm diameter. The gradient of the facility can be set from 1:80 to 1:40. Various appliances/features may be installed at any point along the pipe lengths.

The tests have been undertaken using different pipe types, as follows:

- 103 mm diameter plastic pipes, in 5 m lengths, assembled using standard push-fit connectors.

- 103 mm diameter plastic pipes, in 1.67 m lengths, assembled using standard push-fit connectors.

- 100 mm diameter clayware pipes, in 0.65 m (2') lengths, assembled using standard spigot and socket joints (i.e. older pipe systems).

- 100 mm diameter clayware pipes, in 1.65 m lengths, assembled using standard push-fit connectors (i.e. modern clay pipe systems).

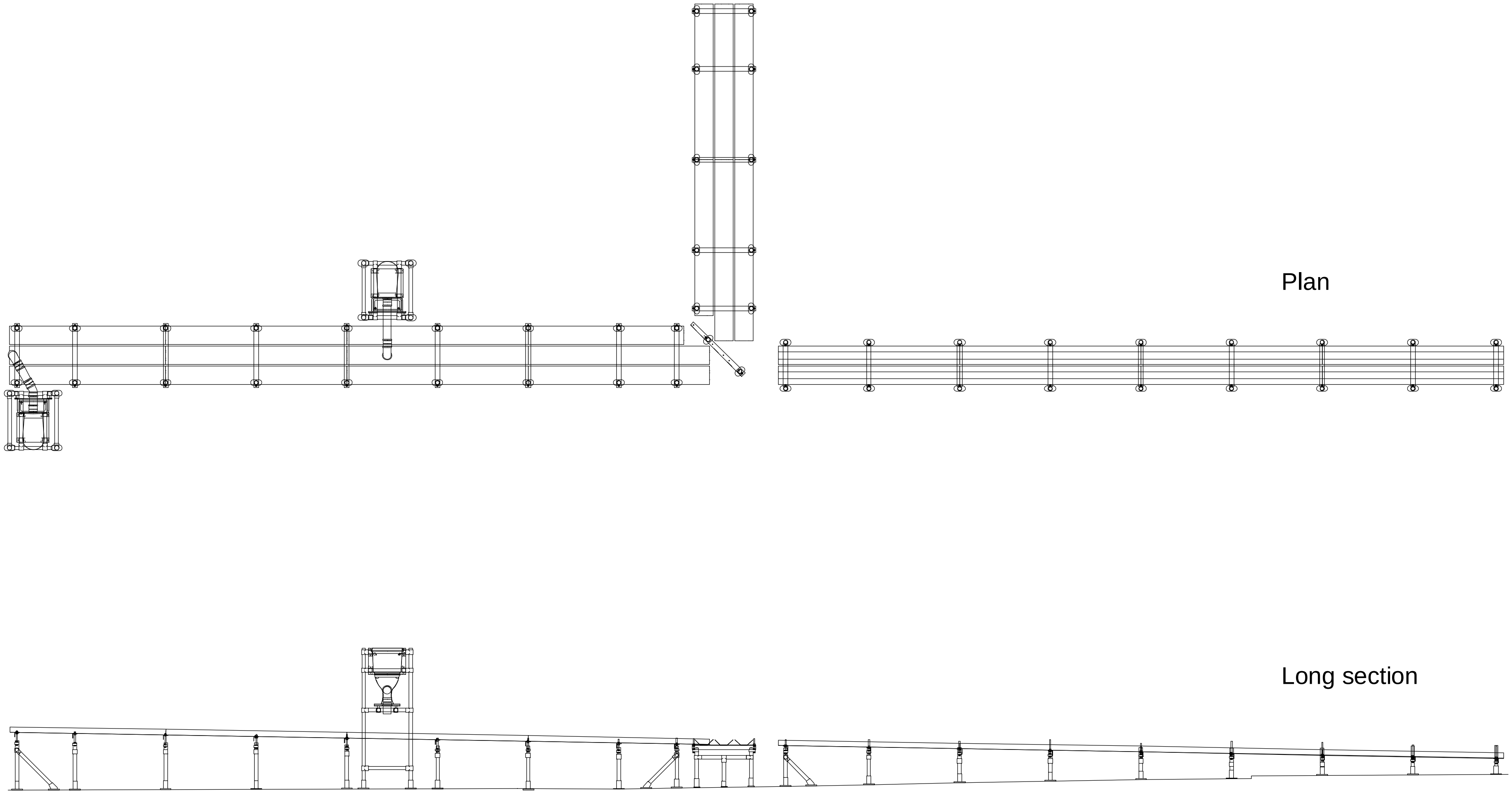


Figure 4.1 Layout of test facility

Photograph 4.1 Test rig – Layout

Photograph 4.2 Test rig – Pipes arrangement

4.2.1 Drainline arrangements

A typical downstairs WC outlet pipe arrangement is shown in Photograph 4.3. This incorporates a short radius bend from the bowl outlet in the vertical plane, a short length of pipe to a long radius rest bend. This is connected to a 500mm length of plain pipe to a 45^{o} elbow into a 45^{o} Y branch connected to the drain run.

Photograph 4.3 Test facility – Typical inlet connection to the drainage system

The configuration used for the downstairs WC was replicated for tests conducted via a soil stack as shown in Photographs 4.3 and 4.4. This was used for all tests conducted using the upstairs arrangements for the examination of WC, bath and shower heads flows.

Photograph 4.4 Test facility - Soil stack connection to the drainage system

Photograph 4.5 Upstairs WC and bath soil stack arrangement

4.2.2 Appliances connected

Two Ceramic Dual flush 3/6 litre WCs have been used for the majority of the testing. Although the WC is designed to be a dual 3 and 6 litre flush, the volumes were adjusted to either 2, 3, 4.5 or 6 litres as dictated by the testing programme.

In addition, a low flush WC has been used to investigate if the flush wave from a proprietary low flush WC is different to that generated by a conventional dual flush WC. The unit used is an IFO Cera ES4 designed to deliver 2.7 and 4 litre flushes.

A 280 litre water tank with a standard six hole bath waste pipe was used to simulate discharges from an upstairs bath. This was connected to the soil stack via 1.5 metres of 50 mm diameter soil pipe.

Shower discharge tests were conducted using three styles of shower head. These were:

1. Water saving shower head with air induction, delivering 0.1 l/s,
2. Water saving shower head, delivering 0.16 l/s, and
3. Standard non water saving shower head, delivering 0.25 l/s.

4.3 Westminster Solid

The solid used for most of the testing is an artificial faecal stool, known as Westminster Solid. This solid has been developed by Imperial College and WRc as a representative faecal stool based on the National Bureau of Standards (NBS) faecal stool. The Westminster Solid is used because it gives repeatable results for solid testing. The solid is characterised by its dimension and its specific gravity of 0.97. A picture of the solid can be seen in Photograph 4.6.

Photograph 4.6 The Westminster solid

4.4 Testing procedure

A standard procedure was adopted for the tests using the Westminster solid, as detailed below. For non standard tests, the methodology is described in the corresponding Sections.

1. Calibrate the WC flush to give the required volume for the relevant tests (2, 3, 4.5 or 6 litres).
2. Flush the line of any debris before detailed testing commences.
3. Place the Westminster solid (or flushable products) into the toilet bowl.
4. Flush the WC with the required volume (2, 3, 4.5 or 6 litres).
5. Record the distance travelled by the solid.
6. Allow the water to drain down behind the solid (where paper is used behind the solid, observe the flow downstream the solid until it becomes insignificant or nil).
7. Repeat flush with the test volume for a maximum of 15 flushes.
8. Record the distance travelled by the solid (or flushable product) after each flush until the solid becomes 'stranded'. 'Stranded' is defined as the solid not moving for three

successive flushes. Alternatively, if the solid continues to move in only small increments, 'stranded' is the distance after 15 successive flushes.

9. Repeat the test to give a total of at least 10 tests if the results are consistent. Otherwise, repeat the test up to 15 or 20 times according to the variability of the test.

5. EFFECT OF WC FLUSH VOLUME AT 1:80

5.1 Introduction

This section describes the tests that were undertaken to establish the sewer solid movement characteristics for WC flushes of 2 litres, 3 litres, 4.5 litres and 6 litres using a nominal 100 mm diameter pipe at a gradient of 1:80, i.e. the Building Regulations recommendations for drainage systems close to property.

5.2 Testing schedule

The arrangements investigated included:

- A reference test (with the Westminster solid alone),
- The effect of the addition of 4 sheets of toilet paper with the Westminster solid,
- The effect of different quantities of toilet paper (4, 8 or 12 sheets of paper),
- The distance travelled by flushable products alone (baby wipe and panty liner).

5.3 Different WC flush volumes at 1:80 – Reference test

5.3.1 Test programme

- The test rig was set up with:
  - 20 metres of pipe laid at a gradient of 1:80.
  - 103 mm diameter plastic pipes, with joints every 5 metres.
  - A downstairs WC.
  - A typical inlet connection to the drainage system.
- The solid flushed was the Westminster solid alone.
- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.
- The test was repeated with 2 litre, 3 litre, 4.5 litre and 6 litre flush volumes.

5.3.2 Results

The volume of water (WC flush) has a significant influence on the distance travelled by the solid. Figure 5.1 shows the average distance travelled by the Westminster solid without paper in the 103 mm plastic pipe (joints at 5 m) for the WC flush volumes tested.

Observations of the solid movement for the individual tests show that the further the solid is from the WC, the less the distance travelled by each flush.

The results indicate that 2 litre flushes typically carry the solid up to 3 metres, 3 litre flushes up to 7 metres, 4.5 litre flushes up to 12 metres and 6 litre flushes over 17 metres.

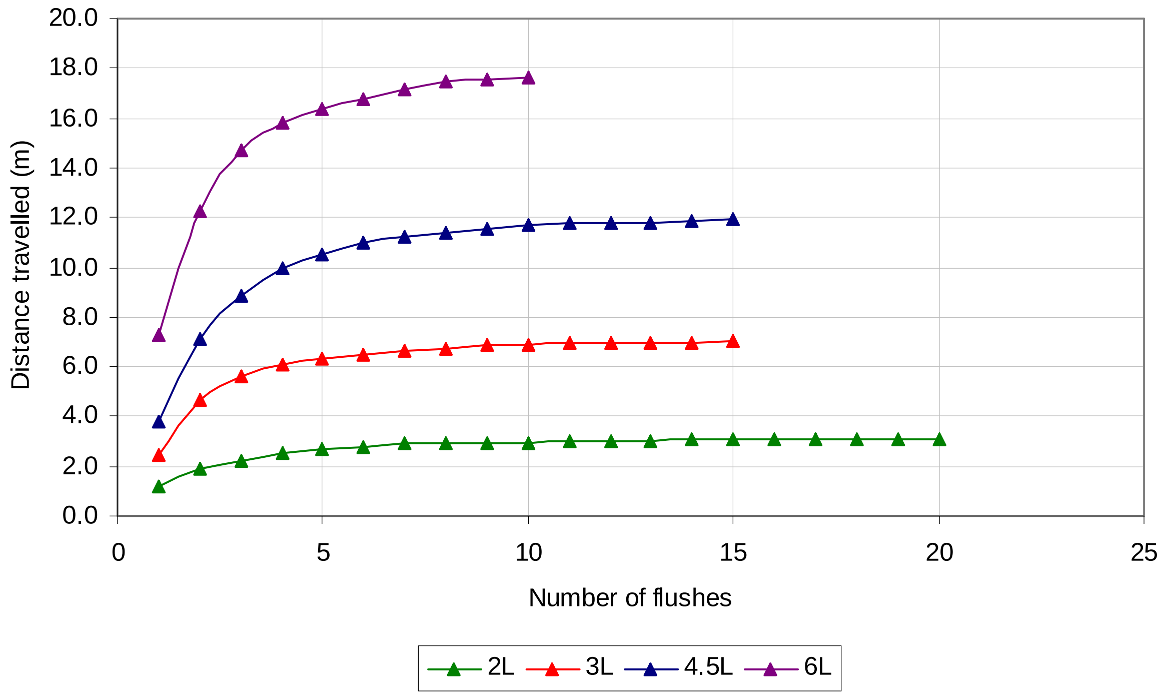


Figure 5.1 Influence of the volume of water (WC flush) (Gradient 1:80)

5.3.3 Summary

- The solid alone, using 2 or 3 litres of water, does not travel far enough to reach the next house connection, assuming an average connection distance is every 10 metres.
- 4.5 and 6 litre flushes are sufficient to carry the solid beyond 10 metres.

5.4 Addition of 4 sheets of paper

5.4.1 Test programme

Previous research highlighted the positive effect of paper behind the solid. The presence of paper might therefore offset the negative effect of low flushes on the solid movement.

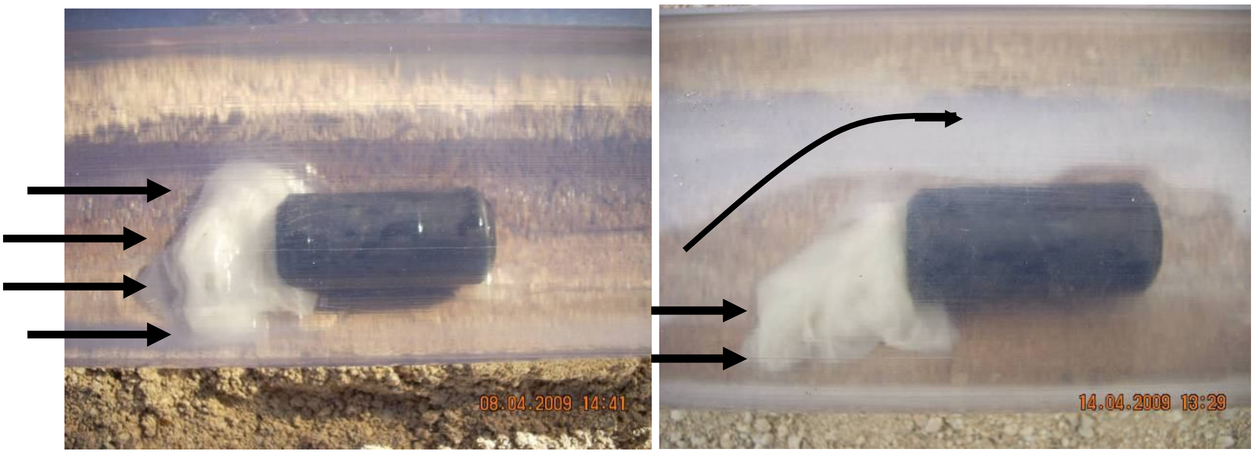
- The test rig was set up with:
    - 20 metres of pipe, laid at a gradient of 1:80.
    - 103 mm diameter plastic pipes, with joints every 5 metres.
    - A downstairs WC.
    - A typical inlet connection to the drainage system.
- The solid flushed was the Westminster solid and 4 sheets of paper.
- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.
- The test was carried out with 2 litre, 3 litre, 4.5 litre and 6 litre flush volumes.

5.4.2 Observations

The addition of paper with the Westminster solid into the WC bowl has an influence on the distance travelled by the solid. However, the effect that the paper has varies depending whether the paper settles out behind or adjacent to the solid after the first flush. Furthermore, this position of the paper will remain similar in successive flushes – the flush moves the paper/solid together.

There are two extremes; these are illustrated in Photograph 5.1, as follows:

- When paper forms a complete dam behind the solid, this results in increased water pressure moving the solid further, typically by 70% compared to the distance travelled without paper.
- When paper gathers to one side of the solid and/or partially moves alongside the solid, the solid may move no further or a little further (0.5 to 1 m) than it would in tests without the paper.



Photograph 5.1 **Positions of paper behind the solid – Complete dam (on the left) and gathered on one side (on the right)**

This variability in results is illustrated in Figure 5.2. This shows the results of 20 tests with 3 litre WC flushes. It shows two different distance-flush characteristics. The tests giving a lower flush distance are typical of those where the solid stated to move around the solid. The tests showing the higher travel distances are indicative of those where the paper formed an effective dam behind the solid.

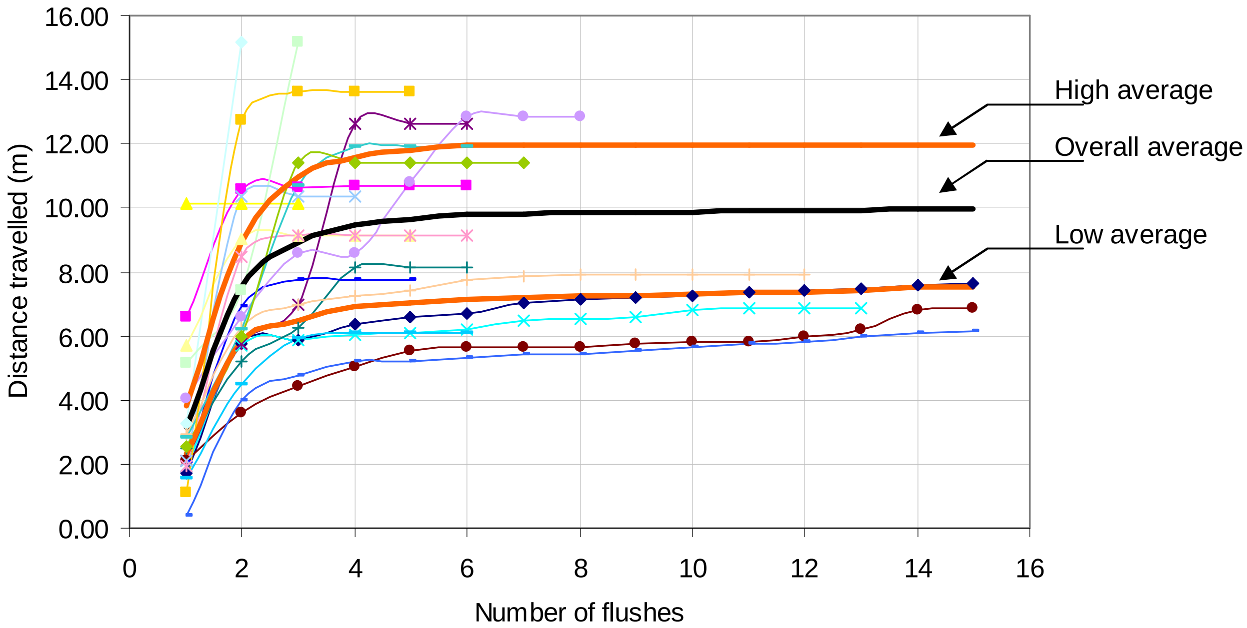


Figure 5.2 **Variability of test results with Westminster solid with 4 sheets of paper (3 l in 5 m joint plastic pipe – 1:80)**

5.4.3 Comparison with reference test

Despite the variations in the results, general conclusions can be drawn. As shown in Figure 5.3, with a volume of water of 3 litres, the distance travelled by the Westminster solid plus paper increases from 7 metres, for the reference test, to 10 metres, i.e. an increase of 40% in the distance travelled.

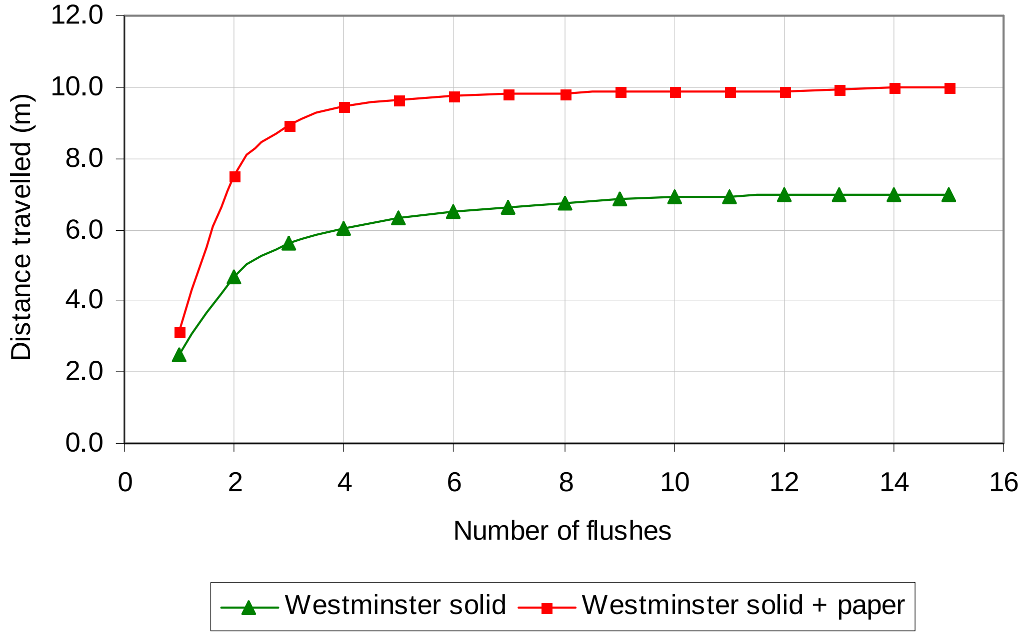


Figure 5.3 Westminster solid + 4 sheets of paper versus Solid alone - 3 litres (Gradient 1:80)

The inclusion of toilet paper results in the solid travelling further for all flush volumes considered. Table 5.1 presents the results obtained in tests using 5 metre long plastic pipes. The low and high averages show that a wide range of results was obtained, i.e. in a similar pattern to that illustrated in Figure 5.2. The presence of paper increases the distance travelled by:

- between 30% to 90 %, with 2 litre flush volumes;
- between 7% to 70 %, with 3 litre flush volumes; and
- 20 % or more, with 4.5 litre flushes.

As with the tests with the Westminster solid alone, the further the solid/paper is from the WC discharge point, the less the distance travelled by the solid/paper in each single flush.

Table 5.1 Distance travelled by the Westminster solid alone and with 4 sheets of paper (Gradient 1:80)

Volume of water used (WC flush)	Distance travelled by the Westminster Solid	Distance travelled by the Westminster solid + paper
2 litres	3.0 m	Low average: 4.0 m High average: 5.6 m
3 litres	7.0 m	Low average: 7.5 m High average: 12.0 m
4.5 litres	11.9 m	14.5 m
6 litres	17.7 m	Over 20 m

5.4.4 Results

The presence of paper increased the average solid carry distance. This was most significant for the lower flush volumes but was still evident at the 6 litre flush.

However, the distance travelled was not greater in all tests. This is because the tests were influenced by the position of the paper behind the solid on solid re-entrainment. These values reported in Figure 5.4 represent the overall average distance travelled by the solid.

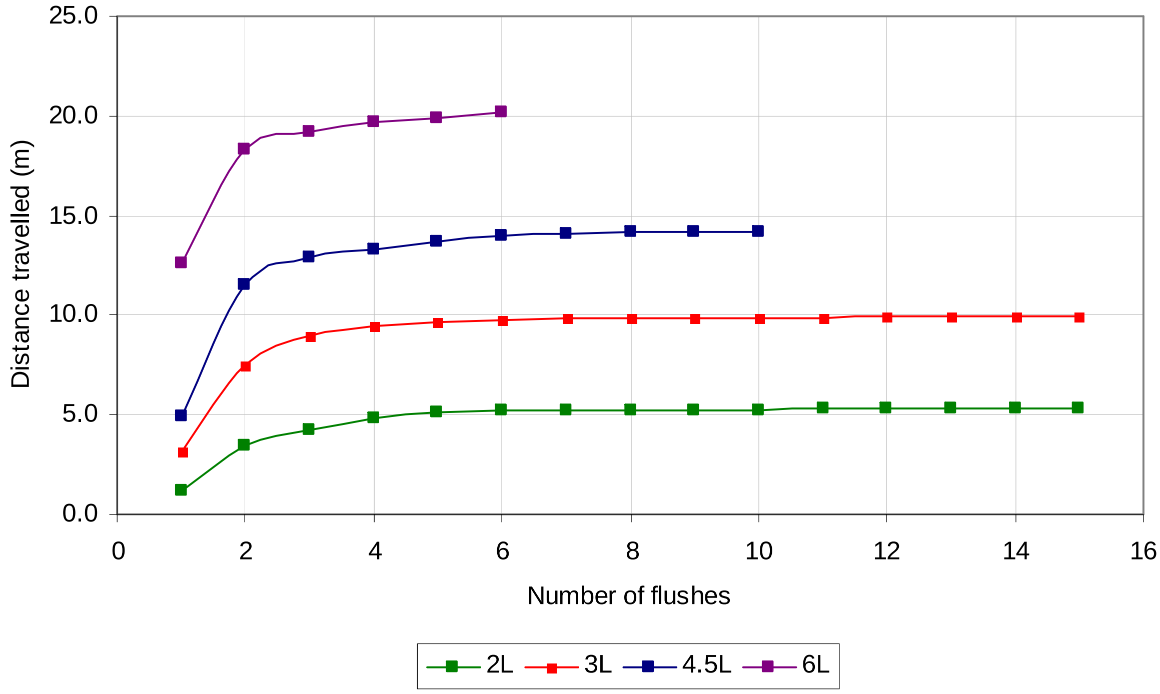


Figure 5.4 Influence of the volume of water with the addition of 4 sheets of toilet paper (Gradient 1:80)

5.4.5 Summary

- The results from the 2 litre tests suggest that the solid carrying capability is still inadequate to avoid blockages (i.e. significantly less than 10 metres).
- The 3 litre tests are borderline, i.e. 10 metres may be just sufficient distance in smaller properties before a connection from another WC joins the flow. In larger properties, particularly those with long lateral drains, 10 metres is unlikely to be sufficient distance.
- The 4.5 litre tests are encouraging with a solid carry distance approaching 15 m.
- The results obtained with 6 litre flushes confirm the suitability of existing drain/small sewer design standards when using conventional WC flush rates.

5.5 Addition of a different quantity of paper – 4, 8 or 12 sheets of paper

5.5.1 Test programme

The previous tests were carried out using 4 sheets of paper. An increase in the number of sheets of paper could increase the surface area exposed to the flush wave and therefore increase the force to push the solid further down the drain/small sewer pipes. Conversely, more paper could also increase the friction of the material against the pipe that the energy of the wave has to overcome.

The following tests were undertaken to examine these influences.

- The test rig was set up with:
    - 20 metres of pipe, laid at a gradient of 1:80.
    - 103 mm diameter plastic pipes, with joints every 5 metres.
    - A downstairs WC.
    - A typical inlet connection to the drainage system.
- The solid flushed was the Westminster solid and either 4 sheets, 8 sheets or 12 sheets of paper.
- The test was repeated 5 times for each case.
- The testing procedure was as described in Section 4.4.
- The test was carried out with 2 litre and 3 litre flush volumes.

It soon became apparent that water tended to hold behind the solid (as a small reservoir) and drain down would take some time. Furthermore, depending on whether drain down was allowed or not, this could have an effect on the distance travelled by the Westminster solid and paper when the next flush wave arrives. To investigate this effect, two different tests were carried out, each with the different quantities of paper, as follows:

- Simulating complete drain down by extracting the water behind the solid (to accelerate the process of drainage). Thus simulating a sequence of flushes when the water has time to drain down from behind the solid before subsequent WC flushes.
- Not allowing drain down. The use of other water devices in combination with the WCs such as hand basins, sinks or other devices that regularly discharge water into the drain in small quantities could reduce the likelihood of drain-down from behind the solid. These discharges are insufficient to move the solid. They do however keep the pipe wet and create a reservoir of water behind the solid.

5.5.2 Results

2 litre flush volume

The results using different quantities of paper and leaving no water behind the solid before the following flush are presented in Figure 5.5. Compared to the results of the flush tests carried out with the Westminster solid alone, the addition of between 4 and 12 sheets of paper allows the solid to travel between 30 to 50 % further.

Tests carried out when leaving water behind the solid give a greater variability. This is because the quantity of water held behind the solid will depend upon the orientation of the paper behind the solid and this will vary in every test as previously discussed in Section 5.4.

The results obtained when the 2 litre flushes not allowing drain down are presented in Figure 5.6. The presence of water behind the solid with paper allows the solid/paper to travel about 60 % further compared to the travel of the Westminster solid alone. The pattern is similar for tests carried out with 4, 8 or 12 sheets of paper.

The final distance at which stranding occurs is also similar regardless the number of paper sheets. This would suggest that the quantity of paper is insignificant when using 2 litre flushes.

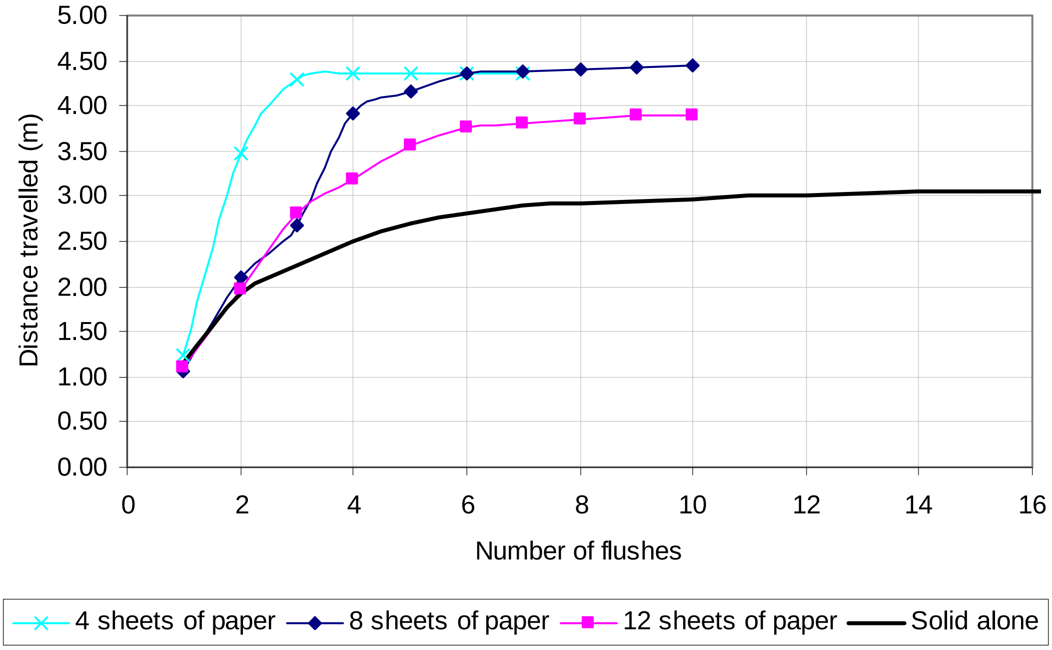


Figure 5.5 Different quantities of paper – No water reservoir behind solid, 2 litres (Gradient 1:80)

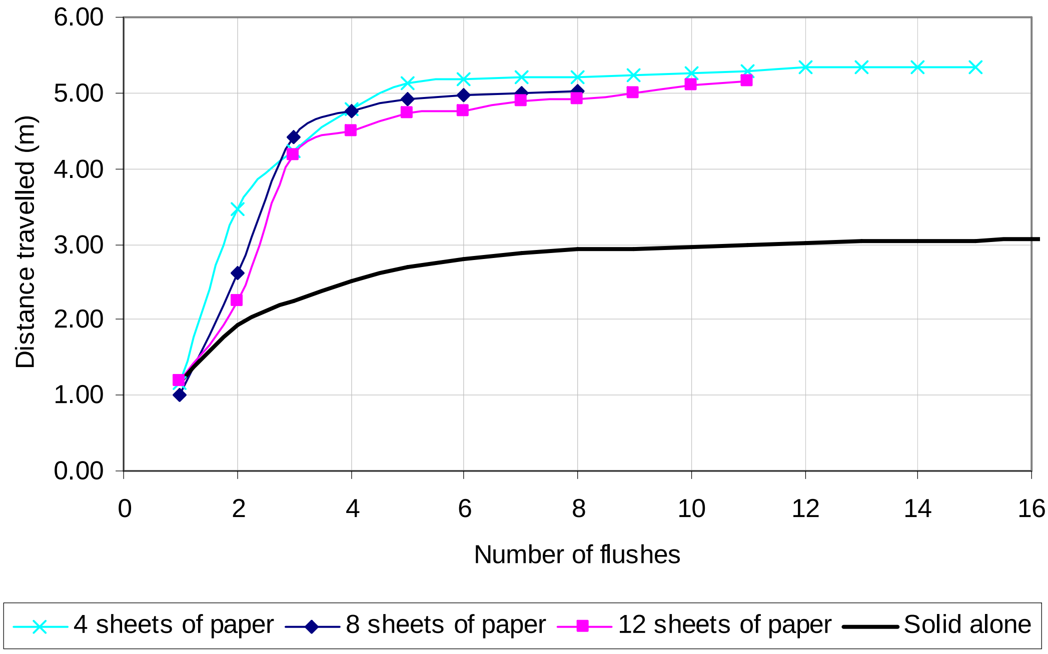


Figure 5.6 Different quantities of paper – With water behind solid, 2 litres (Gradient 1:80)

3 litres

The results of tests using different quantities of paper when leaving no water behind the solid before the following flush are presented in Figure 5.7. When no water is present behind the solid and paper, the distance travelled is marginally less than the distance travelled by the Westminster solid alone.

The results are very similar regardless of the number of sheets of paper – the final distances travelled are all within half a metre of each other. The quantity of paper therefore has little effect on the capacity to carry the solid further along the pipe.

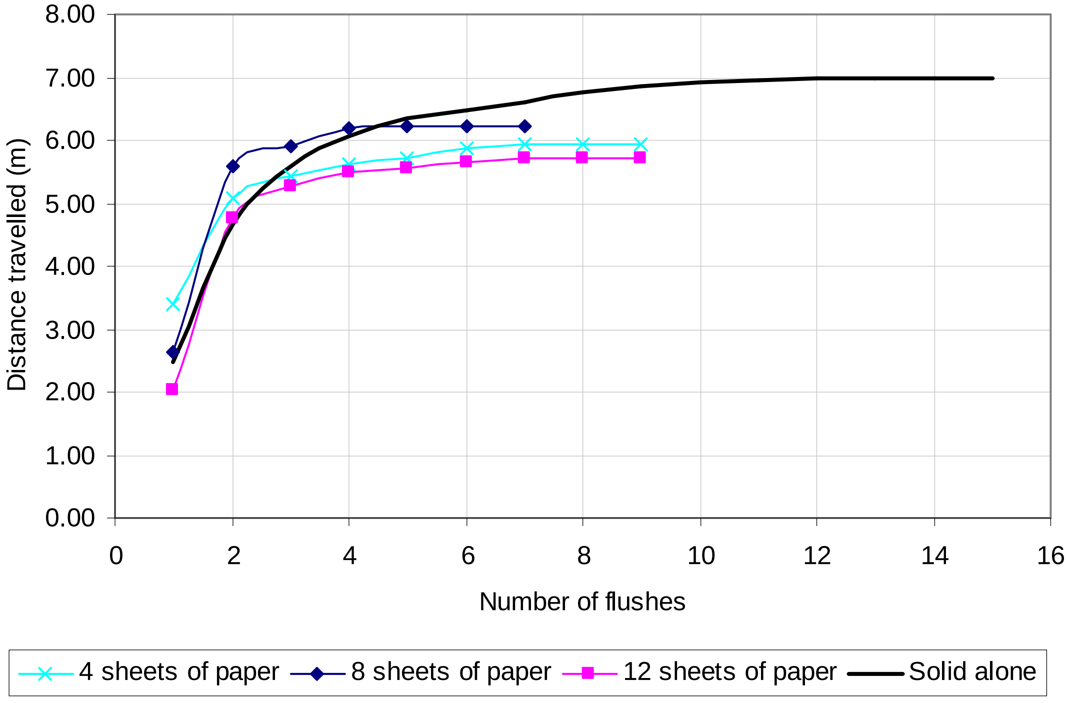


Figure 5.7 Different quantities of paper – No water reservoir behind solid, 3 litres (Gradient 1:80)

The results of the tests carried out with 3 litre flushes when leaving water behind the solid and paper are presented in Figure 5.8. As observed with the 2 litre tests, the presence of paper and water behind the solid is beneficial for its travel along the pipe. The distance reached increases by between 28 % and 48 %, compared to the results for the Westminster solid alone.

A comparison of the results with different quantities of paper (Figure 5.8) shows that the results are somewhat variable. The distance travelled with 12 sheets of paper is marginally greater than the distance travelled when using just 4 sheets. However, somewhat illogically the distances travelled when using 8 sheets is less than the distance travelled when using either 4 or 12 sheets. The reason for this is not clear – it may in part be explained by the high variability in results when considering the influence of paper, as previously described in Section 5.4.2/Photograph 5.1. Nevertheless, it is clear that:

- The inclusion of paper does significantly increase the solid travel distance.
- The quantity of paper (from 4 to 12 sheets of paper) does not appear to have significant influence on the increase in travel distance.

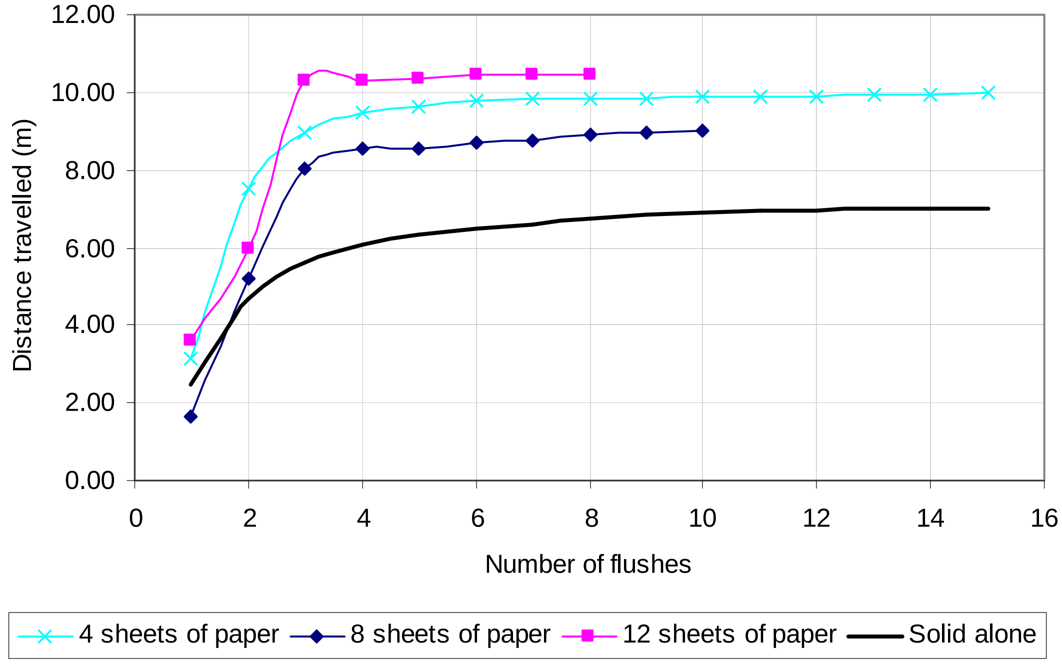


Figure 5.8 Different quantities of paper – With water reservoir behind solid, 3 litres (Gradient 1:80)

5.5.3 Summary

- The addition of toilet paper in combination with a solid increases the travel distance. In some circumstances this can be up to 50% further than the solid alone.
- The quantity of paper does not appear to have a significant influence on the distance travelled by the solid/paper combination, provided that a critical mass has been reached.
- The solid/paper combination will move further if there is a reservoir of water behind the solid immediately prior to a WC flush being made.
- This water reservoir can be ‘topped up’ by discharges from other appliances such as sinks. Whilst these smaller flows are insufficient alone to move the solid, when used in combination with the WC flush, could help to keep the pipe wet and hence maximise the solid travel distance with the next WC flush.

- The quantity of paper (4 sheets, 8 sheets or 12 sheets of paper) does not appear to influence the distance travelled by the solid in the drain/small sewer, especially when there is no water behind the solid at the time of the WC flush.
- The addition of toilet paper in combination with a solid can increase the travel distance.

5.6 Flushable products

5.6.1 Test programme

Sewer abuse is a problem and a cause of many blockages. Previous WRc research on has shown that flushable products are likely to get caught at joints or small defects on the internal wall of the pipe. Their presence could stop the solid travelling further down the pipe and, with together an accumulation of solids, paper and flushable products, cause a blockage. The effect of reduced water usage could exacerbate the problem.

The following tests were set up to examine the effect of reduced flush volume on the travel of these products.

- The test rig was set up with:
  - 20 metres of pipe, laid at a gradient of 1:80.
  - 103 mm diameter plastic pipes, with joints every 5 metres.
  - A downstairs WC.
  - A typical inlet connection to the drainage system.
- The solid flushed was either a baby wipe or a panty liner.
- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre, 3 litre and 4.5 litre flush volumes.
- Additional tests were carried out with the same flushable products using a clay pipe (as flushable products are likely to snag on small defects.) as follows:
  - 9 metres of pipe, laid at a gradient of 1:80.
  - 100 mm diameter clay pipes, with joints every 1.65 metre.

5.6.2 Results

The tests showed that:

- Panty liners easily pass through both pipelines. Typically, it takes between 1 and 3 flushes for the product to pass through the line, this is irrespective of the flush volume.
- Baby wipes will pass through the drain line providing they don't snag. With 3 and 4.5 litre flush volumes, the baby wipe pass through after 1 to 3 flushes while 7 or 8 flushes are needed with 2 litre flush volume for the wipe to travel the same distance.

5.6.3 Summary

- Flushable products do not create a risk of blockage when the pipe walls are smooth. Low flows are sufficient to carry the products of low mass. Nevertheless, the presence of small defects can result in some products becoming snagged. This is most prevalent in the very low WC flushes (2 litres) but still presents a 10 to 20% risk when using 3 and 4.5 litre flushes. The snagging can trigger the accumulation of other sewer debris, possibly leading to a blockage.

5.7 Summary of the effect of WC flush volume at 1:80

- 5a – The solid alone using 2 or 3 litres of water does not travel far enough to reach the next house connection, assuming an average connection distance is every 10 metres.

- 5b - 4.5 and 6 litre flushes are sufficient to carry the solid beyond 10 metres.

- 5c – When 4 sheets of paper are added to the first 2 litre WC flush with the Westminster solid, the solid carrying capability is still inadequate to avoid blockages (i.e. significantly less than 10 metres).

- 5d – The 3 litre tests are borderline when paper is present behind the solid, i.e. 10 metres may be just sufficient distance in smaller properties before a connection from another WC joins the flow. In larger properties, particularly those with long lateral drains, 10 metres is unlikely to be sufficient distance.

- 5e – The 4.5 litre tests with the addition of paper are encouraging with a solid carry distance approaching 15 m.

- 5f – The results obtained with 6 litre flushes confirm the suitability of existing drain/small sewer design standards when using conventional WC flush rates.

- 5g – The quantity of paper (4 sheets, 8 sheets or 12 sheets of paper) added behind the Westminster solid at the first flush does not appear to influence the distance travelled by the solid in the drain/small sewer, especially when there is no water behind the solid at the time of the WC flush.

- 5h – The addition of toilet paper behind the Westminster solid at the first flush in combination with a solid can increase the travel distance.

- 5i – Flushable products do not create a risk of blockage when the pipe walls are smooth. Low flows are sufficient to carry the products of low mass. Nevertheless, the presence of small defects can result in some products becoming snagged. This is most prevalent in the very low WC flushes (2 litres) but still presents a 10 to 20% risk when using 3 and 4.5 litre flushes. The snagging can trigger the accumulation of other sewer debris, possibly leading to a blockage.

6. EFFECT OF DRAINAGE LAYOUT WITHIN THE PROPERTY

6.1 Introduction

This section describes the tests that were undertaken to understand the effect of different 'arrangements' within the property on solid movement.

Initially two different 'arrangements' were tested:

i) A proprietary low flush WC – to assess if the flush wave characteristics in the drainline were any different to those of a normal WC with a downrated flush volume.

ii) A WC located at a higher level, to represent an 'upstairs' flush.

The results of these tests were compared with the 'downstairs' WC reference tests.

During the testing programme it became apparent that sewer solid travel in lower flushes (i.e. 2 and 3 litres) was impaired by both:

a) the energy losses in typical pipe layouts between the WC and the outside drainline; and

b) the separation of solids from the water in 100mmm diameter soil stacks

Additional tests were therefore carried out to investigate if pipe layouts with less joints/bends would be beneficial. Similarly, tests were carried out with a reduced diameter soil stack.

6.2 Testing schedule

The arrangements investigated included:

- A proprietary low flush WC
- A WC located at an 'upstairs' level.
- A more energy efficient pipe arrangement between the WC and drainline, i.e. the long radius bend,
- A reduced diameter soil stack (100 mm versus 82 mm) with an 'upstairs' WC.

The flush and solid movement properties of these various tests were compared with the appropriate reference tests.

6.2.1 Proprietary low flush WC

6.2.2 Test programme

A proprietary low flush WC was tested to assess if the flush wave characteristics in the drainline were any different to those of a normal WC with a downrated flush volume.

An IFO Cera ES4, was tested as an example of a proprietary low flush WC. (design flush volumes of 2.7 litres and 4 litres).

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows

- Firstly using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above cases.
- The rest of the testing procedure was as described in Section 4.4.

6.2.3 Results

The results when using the proprietary low flush WC were compared with the reference tests, as shown in Figure 6.1 and Figure 6.2 (Westminster solid alone and with paper respectively).

The tests demonstrate that the type of WC makes no significant difference to the distance travelled by the solid.

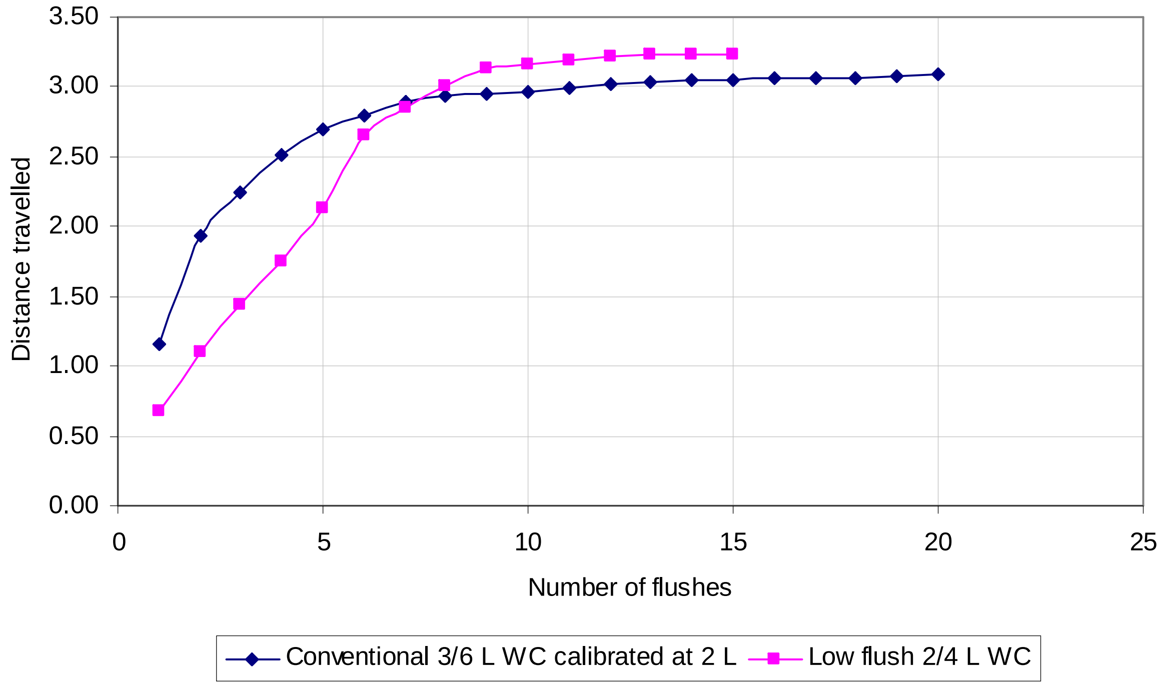


Figure 6.1 Conventional versus low flush WC – 2 litres, Westminster solid

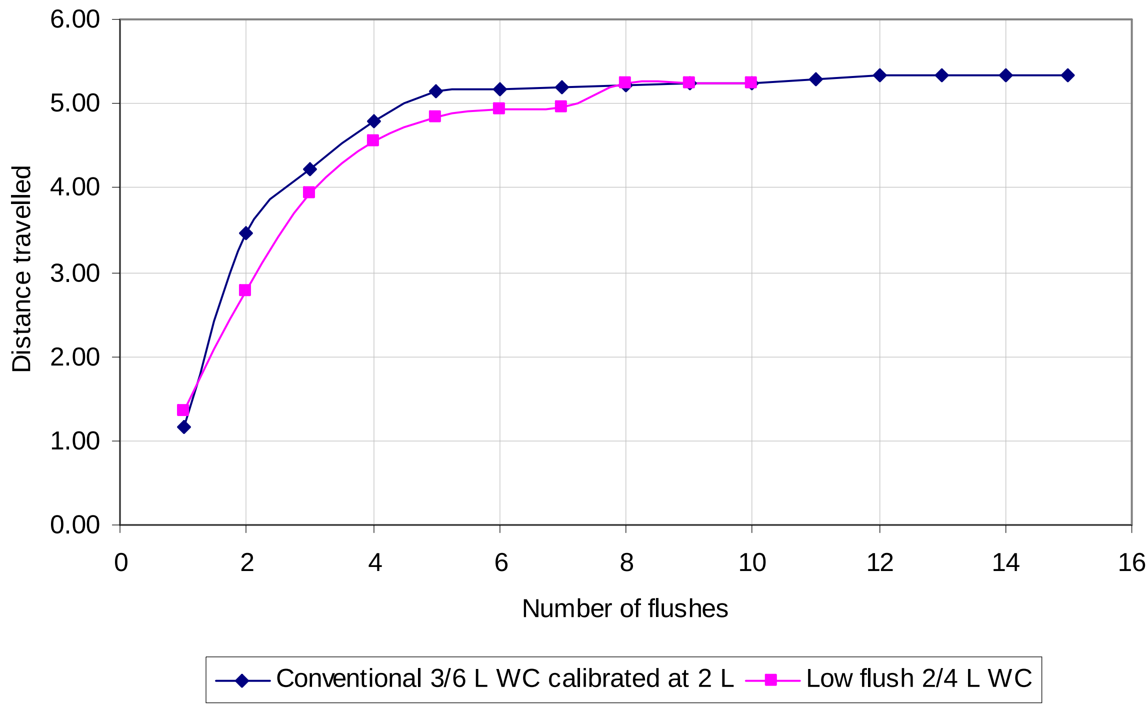


Figure 6.2 Conventional versus low flush WC – 2 litres, Westminster solid + 4 sheets of paper

6.2.4 Summary

- There is no significant difference in the distance travelled by the solid when using the proprietary low flush WC as opposed to a conventional WC (calibrated down to 2 litres).
- The low flush WC design focuses on bowl clearance properties. There appears to be little difference in the flush wave entering the drainline to that from a conventional WC.

6.3 ‘Upstairs’ WC

6.3.1 Test programme

The effect of reduced water usage on sewer solid flow when using a ‘downstairs’ WC has been reported in Sections 5.3 and 5.4. The following section considers the effect when using an ‘upstairs’ WC’s, and compares the two sets of results.

It was expected that the momentum gained by water falling down the soil stack would result in a greater flush wave compared to that generated by a downstairs WC.

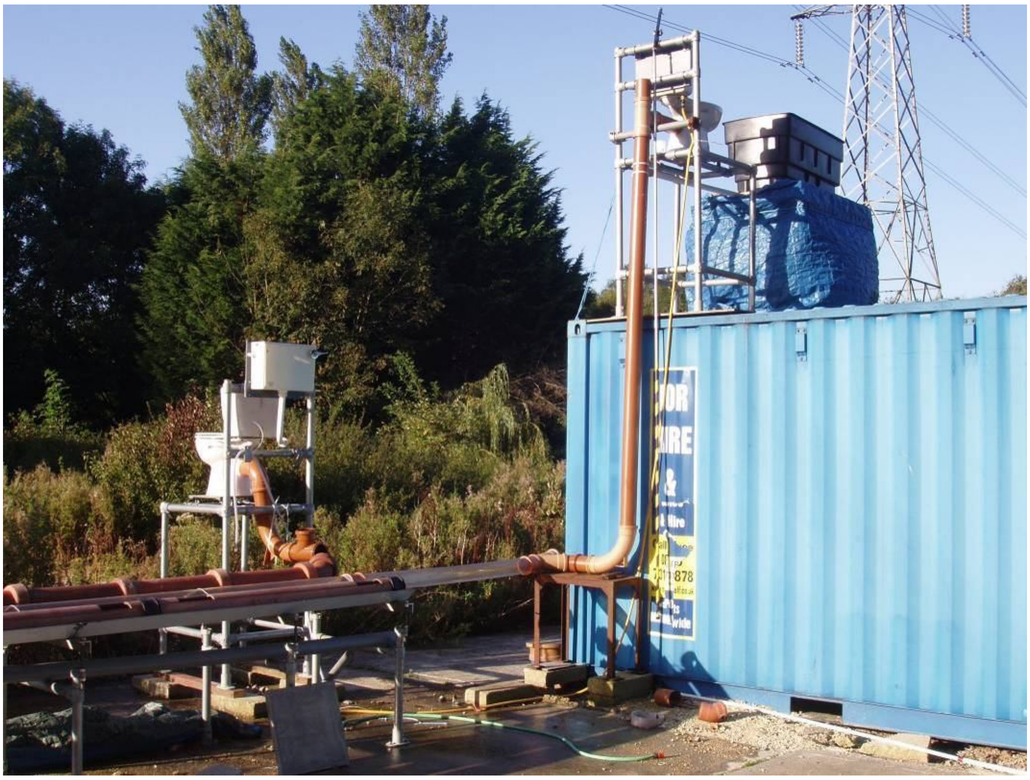
The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- An upstairs WC was placed at a height of 2.5 metres above the downstairs WC (see Photograph 6.1 and 6.2).
- A 100 mm diameter soil stack.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- Firstly using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above cases.
- The rest of the testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre, 3 litre, 4.5 litre and 6 litre flush volumes.

Photograph 6.1 Upstairs WC arrangement



Photograph 6.2 Upstairs WC soil stack arrangement

6.3.2 Results

A comparison of the ‘downstairs’ and ‘upstairs’ WC test results show a range of different solid movement behaviour, depending on the volume of water flushed.

Observations showed that the solid generally falls down the stack before the water. The solid then comes to rest in the drain before the water arrives. As the flow reaches the solid there may be a small forward movement of the solid, depending on the volume of water under test.

The above results had not been anticipated and it was uncertain if the behaviour patterns were typical of a true sewer solid. There were suspicions that the hardness of the solid may have given unrepresentative results. Therefore a number of basic tests were conducted using bananas as the solid. It was noted that there was no significant difference in the way the two solids behaved, either in the stack or in the drain at the base of the stack. All further tests were therefore undertaken using the Westminster solid.

Westminster solid alone

With a 2 litre flush the solid does not move a significantly different distance as shown in Figure 6.3. The differences with an ‘upstairs’ WC discharge are:

- Virtually all the movement is achieved in the first flush. The initial distance travelled from the stack along the drain is critical in determining the final position reached by the solid.

- The final distance reached is less than the distance travelled with the ‘downstairs’ WC flush. This suggests that less energy is contained in the 2 litre flush wave from an upstairs WC, when compared to a downstairs WC.

When using 3 litre flushes the difference in solid travel distance is more significant. The distance travelled by an ‘upstairs’ discharge is typically only $^{2}/_{3}$ of that from the downstairs WC (see Figure 6.4). Nevertheless, unlike the 2 litre flush, the successive flushes continue to move the solid forward in the pipe, although the distance moved is not that great.

The solid travels further from the upstairs WC when using 4.5 litre flushes. The distance travelled in the first flush is about 1 metre further and movement is seen in subsequent flushes. Eventually the solid from an ‘upstairs’ WC will travel about 10% further (see Figure 6.5).

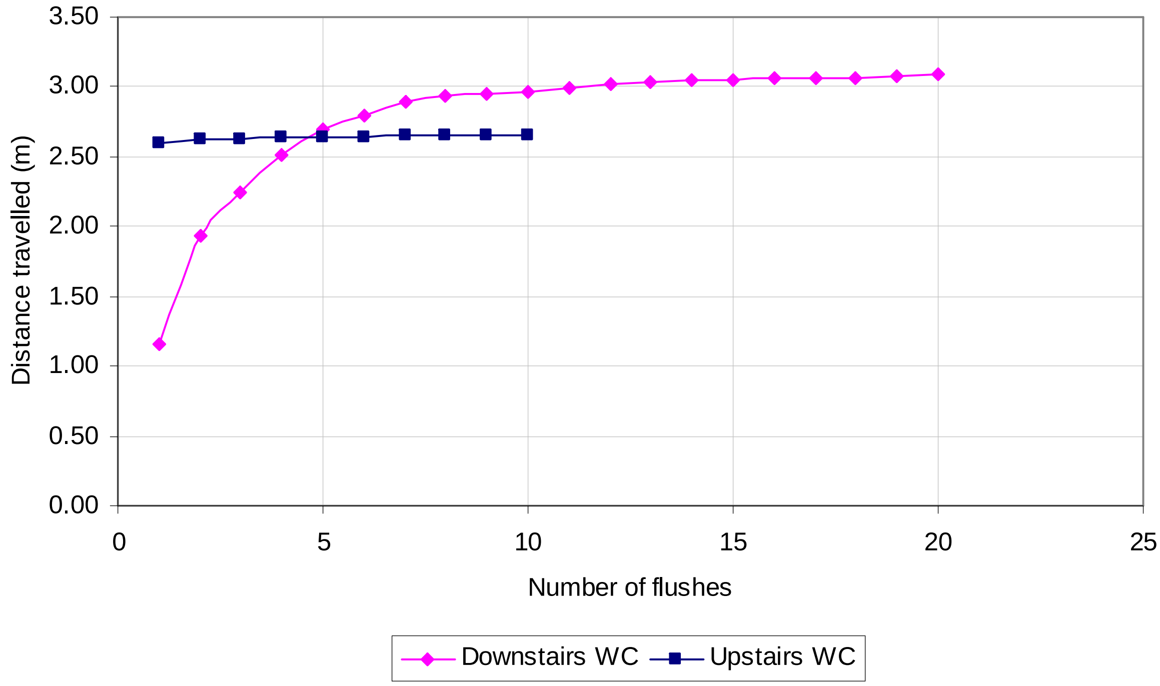


Figure 6.3 Downstairs versus Upstairs WC – 2 litres, Westminster solid

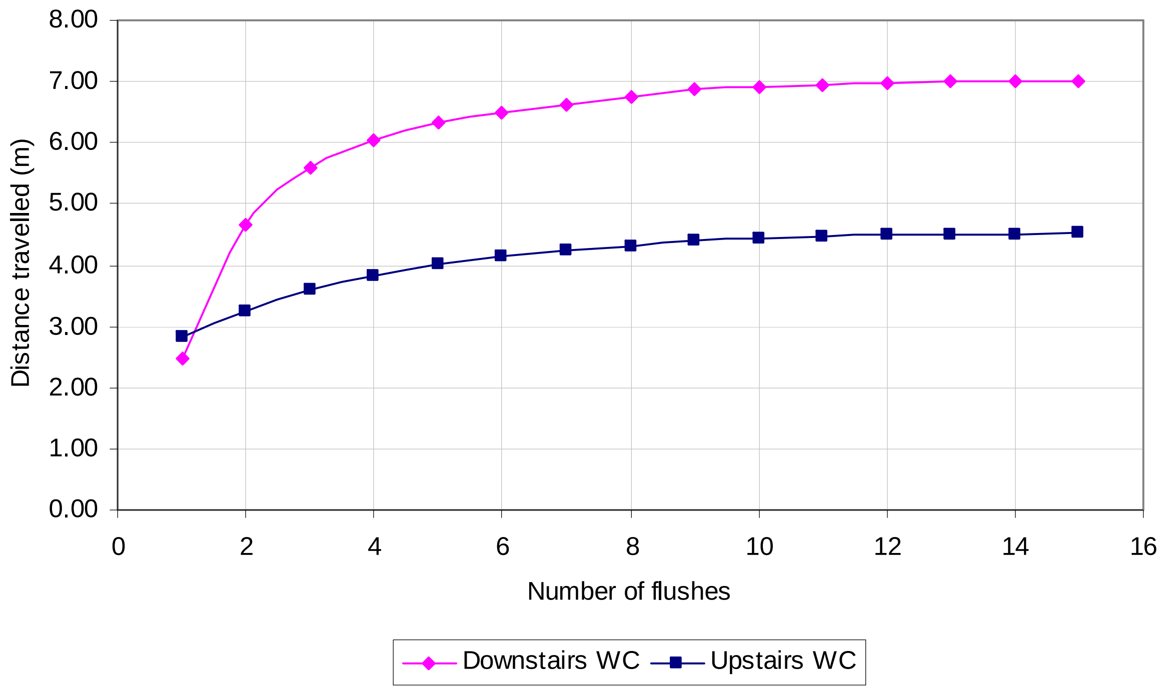


Figure 6.4 Downstairs versus Upstairs WC – 3 litres, Westminster solid

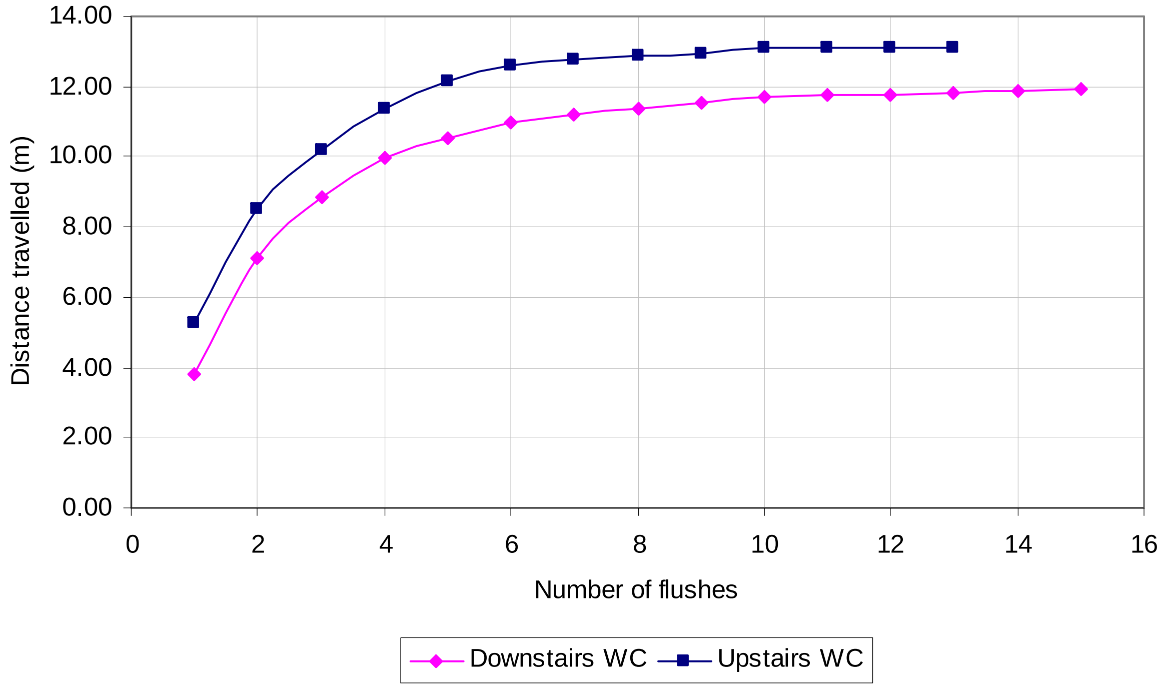


Figure 6.5 Downstairs versus Upstairs WC – 4.5 litres, Westminster solid

Westminster solid + 4 sheets of paper

Similar observations can be made from the tests using the Westminster solid plus paper. A summary of the results obtained for the different flush volumes investigated are presented in Figure 6.6.

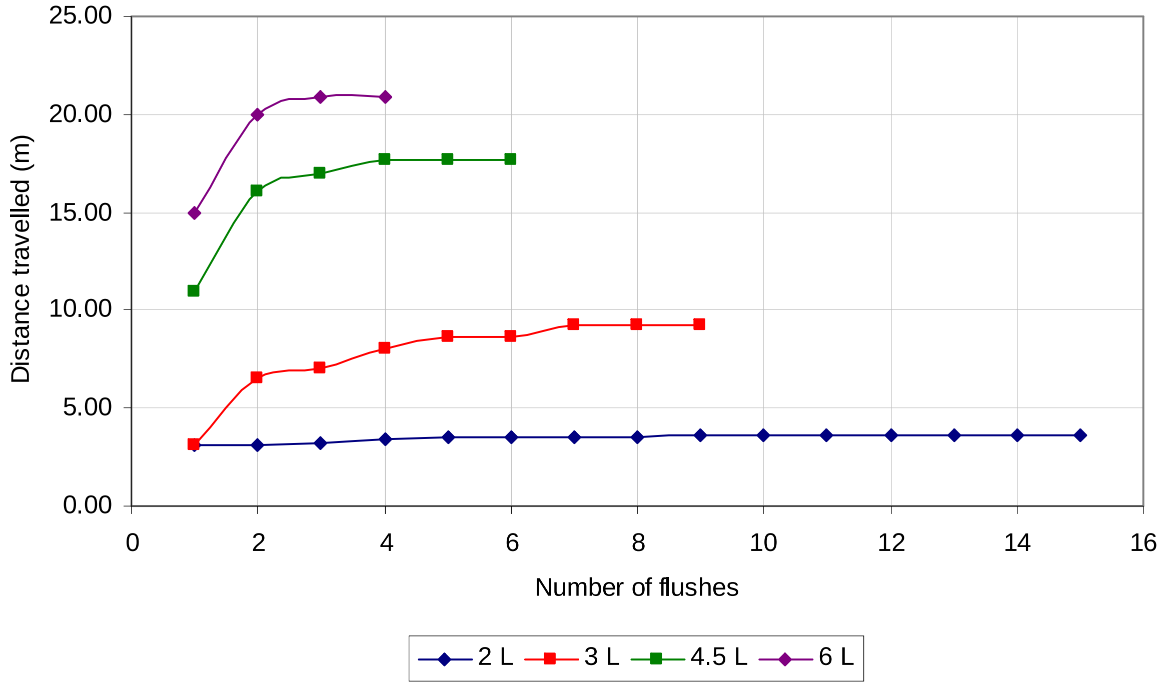


Figure 6.6 Upstairs WC results – Westminster solid + 4 sheets of paper

6.3.3 Summary

There is an energy loss caused by the vortex of the water in the stack. This is most significant in the smaller flush volumes. For the 2 litre flush this absorbs virtually all the energy, with the 3 litre flush the proportion of energy lost is less. In both cases the solid travels less distance from an 'upstairs' discharge. Conversely, with 4.5 and 6 litre discharges the force is greater from an 'upstairs' flush - the solid travels further.

The tests with the Westminster solid alone show that the solid travel distance is still insufficient (i.e. < 10 metres) with the lowest flush volumes (2 and 3 litres). Also, there is a risk of solids accumulating at the base of the stack. Solid movement with the higher flushes (4.5 and 6 litres) is adequate (i.e. ≥ 10 metres), being greater than that from a 'downstairs' WC.

Similar observations are made from the tests with the Westminster solid and 4 sheets of paper: the distance travelled is insufficient with 2 or 3 litre flushes, while higher flush volumes remain adequate.

- The distance travelled by a solid using 2 or 3 litre 'upstairs' flushes is less than that from a comparable flush from a 'downstairs' WC. The distance travelled by a solid with 2 or 3 litre flushes is therefore insufficient regardless of WC location.
- With higher flush volumes (4.5 and 6 litres) discharges from an 'upstairs' WC are able to carry the solid further than from a 'downstairs' WC. The distances travelled by solids are adequate.

6.4 Stack diameter for the upstairs WC – 82 mm versus 100 mm stack

6.4.1 Test programme

The tests carried out with the upstairs WCs, as presented in Section 6.3, show that the 2 or 3 litre flush waves from the upstairs WC (via a 100mm diameter soil stack) do not increase the solid transport distance over that from a 'downstairs' discharge. This was not as expected.

With this in mind visual observations were made of the flow during the testing. This showed that with the upstairs WC the water is spirals around the soil stack wall in a vortex until it reaches the bottom of the stack. This results in:

- proportionally high energy losses, and
- attenuates the flush wave.

It was considered that a reduction of the stack diameter may reduce the vortex effect and therefore increase the flush waves solids carry distance.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- An upstairs WC, placed at a height of 2.5 metres above the downstairs WC at WRc test rig (see Photograph 6.1 and 6.2).
- Either an 82 mm diameter or a 100 mm diameter soil stack, as appropriate.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- Firstly using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above cases.
- The rest of the testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre and 3 litre flush volumes.

6.4.2 Results

2 litres results

Previous observations using a typical arrangement with a 100 mm diameter stack have shown that it is the first few flushes (if not the first flush only) of an upstairs WC that determine the distance reached by the solid. Figure 6.7 and Figure 6.8 compare the results of the 100 mm and 82 mm stack tests. The results obtained with the smaller diameter stack show that:

- The distance travelled by the initial flush is significantly less.
- The solid continues to move with successive flushes.
- The solid eventually travels a similar distance regardless of the soil stack diameter.

The solid distance travelled with the 82 mm stack arrangement (both Westminster solid alone and with paper) remains less than the distance travelled by the solid when discharged from the 'downstairs' WC.

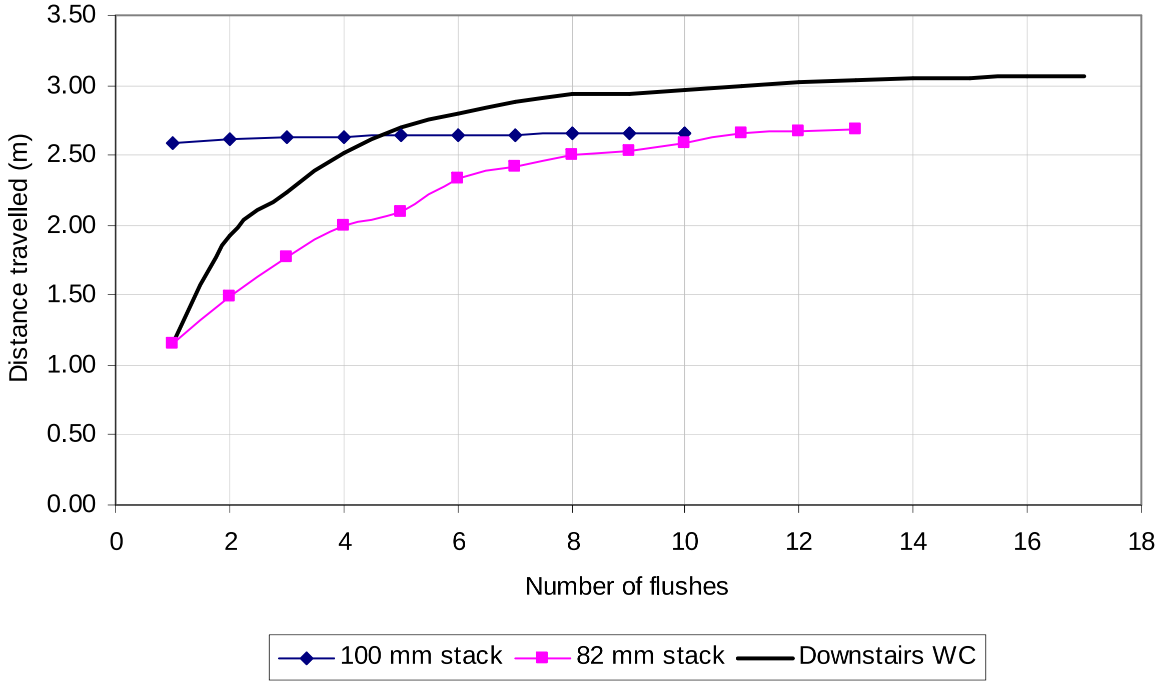


Figure 6.7 100 mm versus 82 mm stack, 2 litres with Westminster solid (Gradient 1:80)

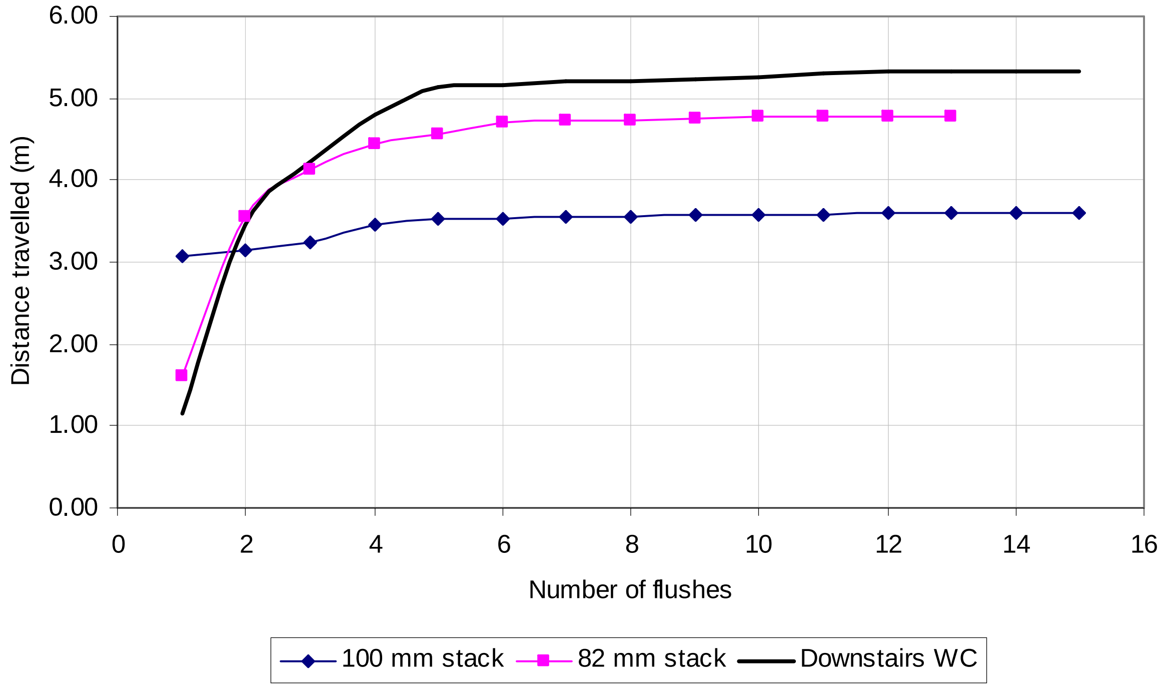


Figure 6.8 **100 mm versus 82 mm stack, 2 litres with Westminster solid and 4 sheets of paper (Gradient 1:80)**

3 litre results

When using the smaller diameter stack the distance reached by the Westminster solid with 3 litre flushes is increased by almost 45% (see Figure 6.9).

Nevertheless, there is little difference in the distance travelled by the solid from discharges using either the 100mm or 82 mm diameter stack arrangement, when 4 sheets of paper are added (see Figure 6.10).

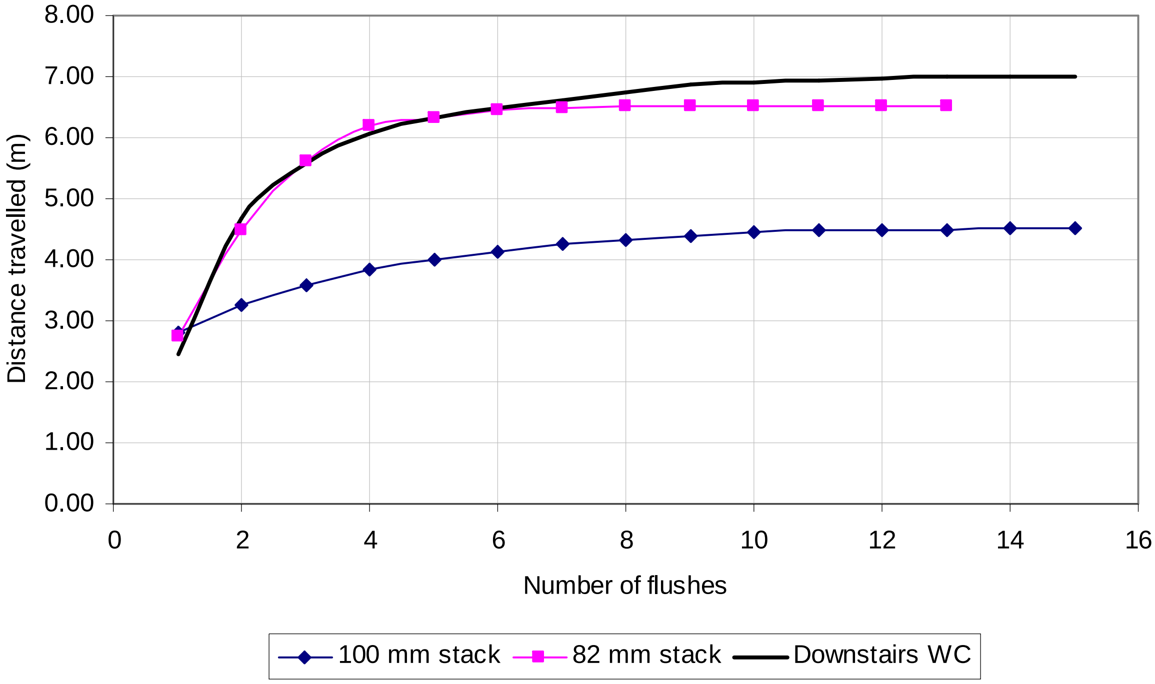


Figure 6.9 **100 mm versus 82 mm stack, 3 litres with Westminster solid (Gradient 1:80)**

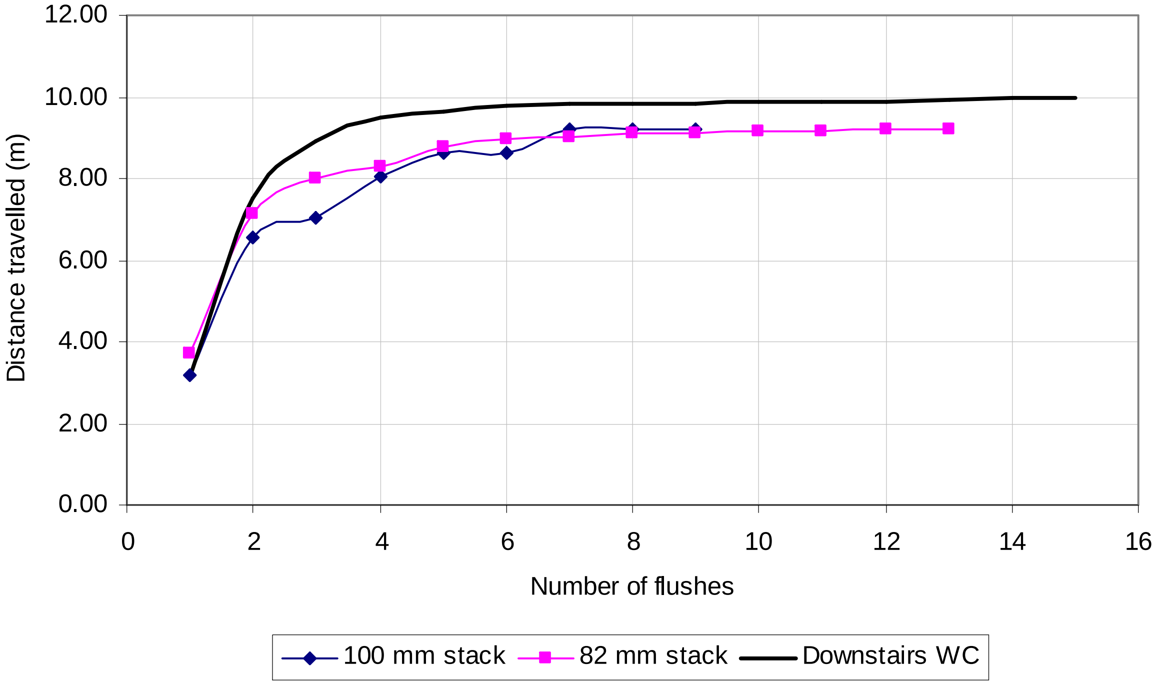


Figure 6.10 **100 mm versus 82 mm stack, 3 litres with Westminster solid and 4 sheets of paper (Gradient 1:80)**

6.4.3 Summary

- The smaller diameter stack increases the distance travelled by the Westminster solid in certain flow/solid combinations. This is particularly so with:

  - 3 litre flushes; and

  - 2 litre flushes that include toilet paper.

- Curiously, the smaller diameter stack does not increase the distance travelled by the Westminster solid in the following combinations:

  - 2 litre flush only; and

  - 3 litre flush with toilet paper.

- Unfortunately, neither the 2 nor 3 litre flushes, when using a smaller stack diameter, are sufficient to carry the solid an adequate distance (i.e. 10 metres or greater).

6.5 Long radius bend between the WC and drain/sewer

6.5.1 Test programme

A typical pipe configuration connecting the WC to the drainline is as described in Section 4.2. This was used for the majority of the tests.

Visual observations show that there are significant energy losses as the flow passes through the 'typical' arrangement and enters the 'Y' branch. This disturbance results in the flow entering the drainline as a snaking, non parallel flow and this is maintained for approximately 1 metre downstream. In addition flow reverses into the upstream connection. Photograph 6.3 shows the snaking flow.

This disturbance to the flow contributes to the loss of energy available to transport the solid. Therefore, a long radius bend was considered a possible arrangement that would limit this turbulence.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.

- 103 mm diameter plastic pipes, with joints every 5 metres.

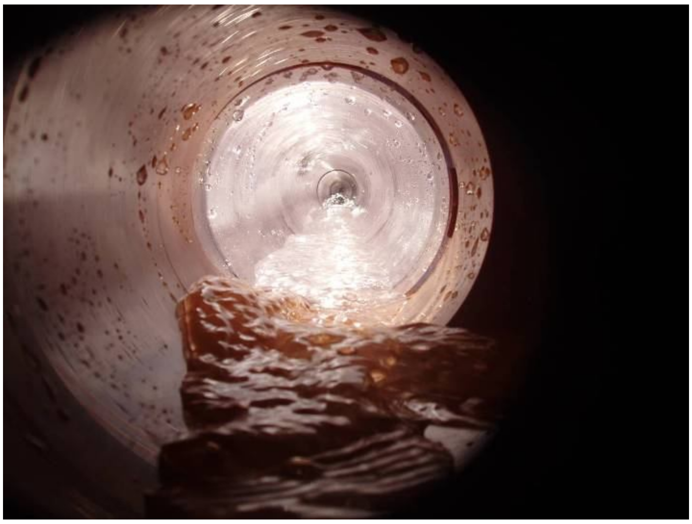
- A downstairs WC.

- Either a typical inlet or a long radius bend connection to the drainage system (both arrangements are shown in Photograph 6.2.).

The testing was undertaken as follows:

- Firstly using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above cases.
- The rest of the testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre and 3 litre flush volumes.

Photograph 6.2 Test rig – Typical arrangement (left) and long radius bend arrangement (right)



Photograph 6.3 Movement of the water in the typical inlet arrangement

6.5.2 Results

A significant benefit is observed when using the long radius bend with a 2 litre flush volume. The Westminster solid when flushed alone reaches a distance of 5 m, compared to the 3 m reached with the typical arrangement (see Figure 6.11). When paper is included, the solid carrying distance again increases, but only by a metre.

However, the improved hydraulic conditions of the long radius bend have little or no effect on the solid carrying capability when 3 litre flushes are used, as illustrated in Figure 6.12.

This suggests that the long radius bend has a greater influence where the flush waves are small. The loss of energy in a lower flush will be more significant than the same loss when there is a greater flush wave.

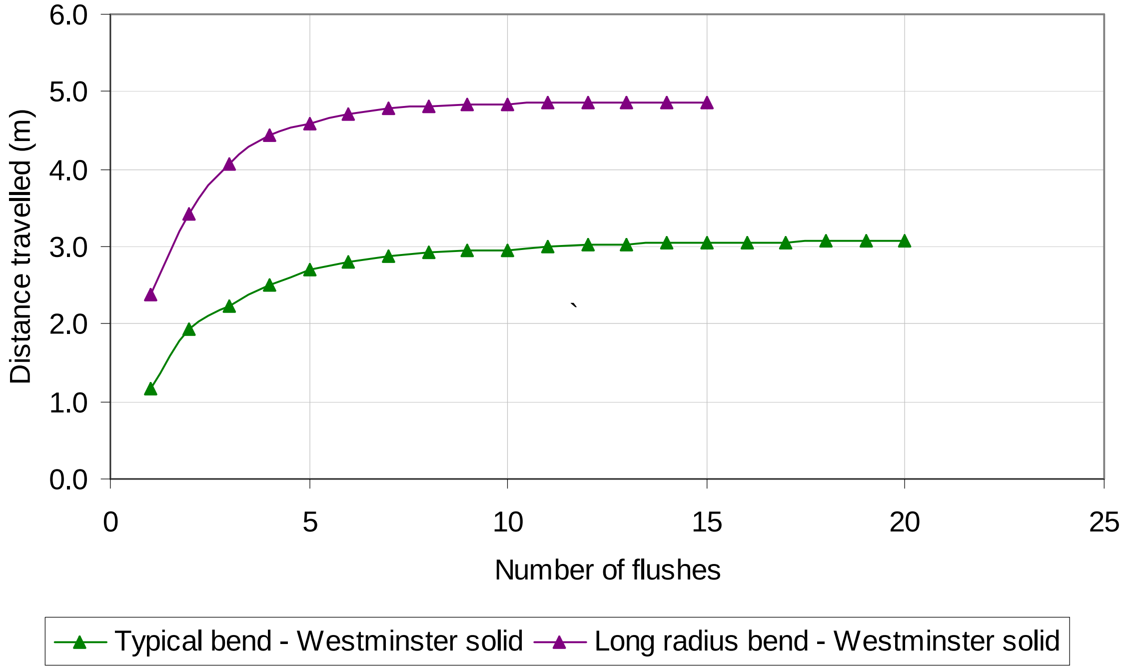


Figure 6.11 Typical inlet arrangement versus long radius bend – 2 litres, Westminster solid (Gradient 1:80)

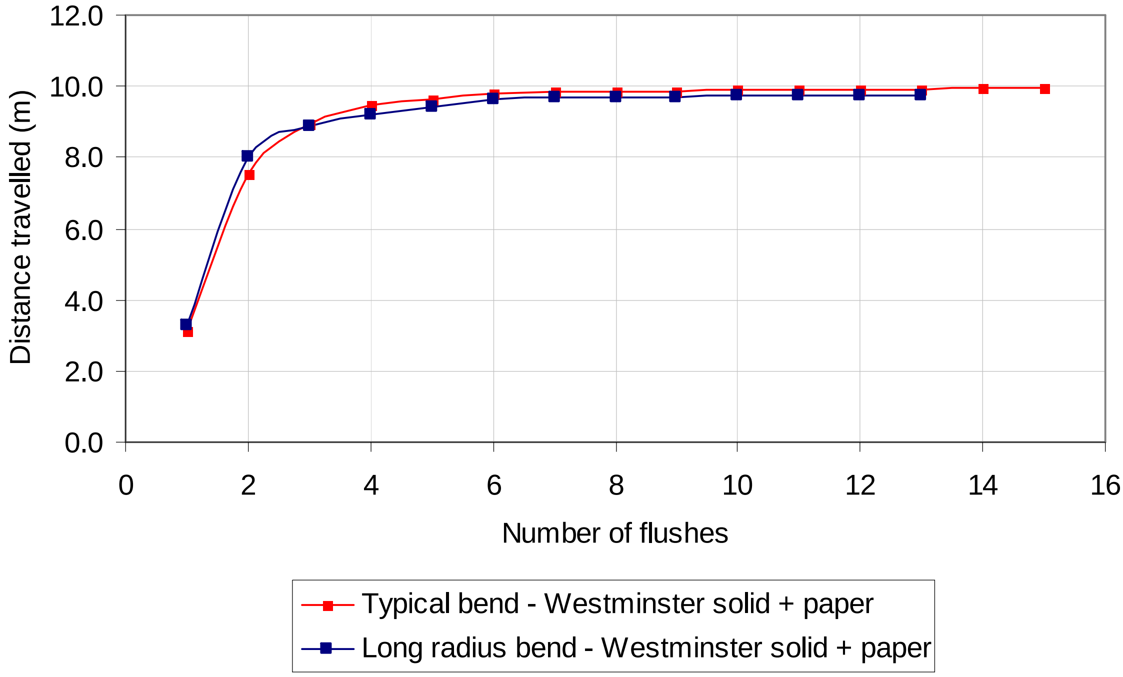


Figure 6.12 Typical inlet arrangement versus long radius bend – 3 litres, Westminster solid + 4 sheets of paper (Gradient 1:80)

6.5.3 Summary

- The use of a long radius bend reduces energy losses as the flow wave enters the drainline. This could increase the distance travelled by the solid at the lowest flush volume (2 litres) but little or no benefit is observed in the 3 litre flushes.

- The tests have shown that the long radius bend or similar energy saving arrangements could be advantageous where energy loss is critical.

6.6 <u>Summary of effect of different 'arrangements' in the property on solid movement</u>

- 6a - There is no significant difference in the distance travelled by the solid when using the proprietary low flush WC as opposed to a conventional WC (calibrated down to 2 litres).

- 6b - The low flush WC design focuses on bowl clearance properties. There appears to be little difference in the flush wave entering the drainline to that from a conventional WC .

- 6c - The distance travelled by a solid using 2 or 3 litre 'upstairs' flushes is less than that from a comparable flush from a 'downstairs' WC. The distance travelled by a solid with 2 or 3 litre flushes is therefore insufficient regardless of WC location.

- 6d - With higher flush volumes (4.5 and 6 litres) discharges from an 'upstairs' WC are able to carry the solid further than from a 'downstairs' WC. The distances travelled by solids are adequate.

- 6e - The smaller diameter stack increases the distance travelled by the Westminster solid in certain flow/solid combinations. This is particularly so with 3 litre flushes and 2 litre flushes that include toilet paper.

- 6f - Curiously, the smaller diameter stack does not increase the distance travelled by the Westminster solid in the following combinations: 2 litre flush only and 3 litre flush with toilet paper.

- 6g - Unfortunately, neither the 2 nor 3 litre flushes, when using a smaller stack diameter, are sufficient to carry the solid an adequate distance (i.e. 10 metres or greater).

- 6h - The use of a long radius bend reduces energy losses as the flow wave enters the drainline. This could increase the distance travelled by the solid at the lowest flush volume (2 litres) but little or no benefit is observed in the 3 litre flushes

- 6i - The tests have shown that the long radius bend or similar energy saving arrangements could be advantageous where energy loss is critical.

7. EFFECT OF PIPE CHARACTERISTICS / CONDITION

7.1 Introduction

This section describes the tests that were undertaken to understand the effect of different pipe characteristics/conditions on sewer solid movement. These include:

- Pipe length/number of joints;
- Pipe diameter;
- Pipe materials; and
- Pipe defects.

The influence of pipe diameter has been studied in previous research. In general smaller diameters improve hydraulic conditions in low flow situations and this in turn increases the distance travelled by solids. However, there is a practical limitation as to how small a foul discharge pipe can be. The UK regulations require a minimum of 100 mm diameter, though smaller sizes are used in parts of mainland Europe. Also, the introduction of a smaller size in the UK could be problematic; it would require building material stockists to dual stock products for two diameters. Such a dual approach would also run the risk of the ‘wrong’ pipe being used.

This section therefore focuses on the effect of the number of joints, different pipe materials and the presence of a defect in the pipe.

7.2 Testing schedule

The arrangements investigated included:

- The effect of the frequency of joints in the pipe line (every 5 m versus every 1.67 m)
- The effect of pipe materials (plastic versus clay)
- The combined effect of number and condition of joints, and pipe material, and
- The effect of a defect in the pipe line.

The flush and solid movement properties of these various tests were compared with the appropriate reference tests.

7.3 Effect of the number of joints – 1.67 m long pipes versus 5 m long pipes

7.3.1 Test programme

Joints, if poor and frequent can significantly affect the energy lost by the flush wave and, therefore, decrease the distance travelled by the solid. The frequency of joints is investigated in this section. The combined effect of joint numbers and condition is investigated in Section 7.5.

To investigate the effect of the number of joints, different lengths of plastic pipes, 1.67 m and 5 m, both with sleeve joints were used.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres or every 1.67 metres, as appropriate.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- Firstly, using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above cases.
- The rest of the test procedure was as described in Section 4.4.
- The tests were repeated with 2 litre and 3 litre flush volumes.

7.3.2 Results

The frequency of the joints, i.e. the length of each pipe, has no notable influence on the distance travelled by the sewer solid when plastic pipes and joints are joints in good condition are used.

The differences in travel distance are small and are due to experimental variation, as illustrated in Figure 7.1 and Figure 7.2.

7.3.3 Summary

- Altering the frequency of joints in a drain/small sewer has no effect on sewer solid movement, provided that the joints are small and well made.

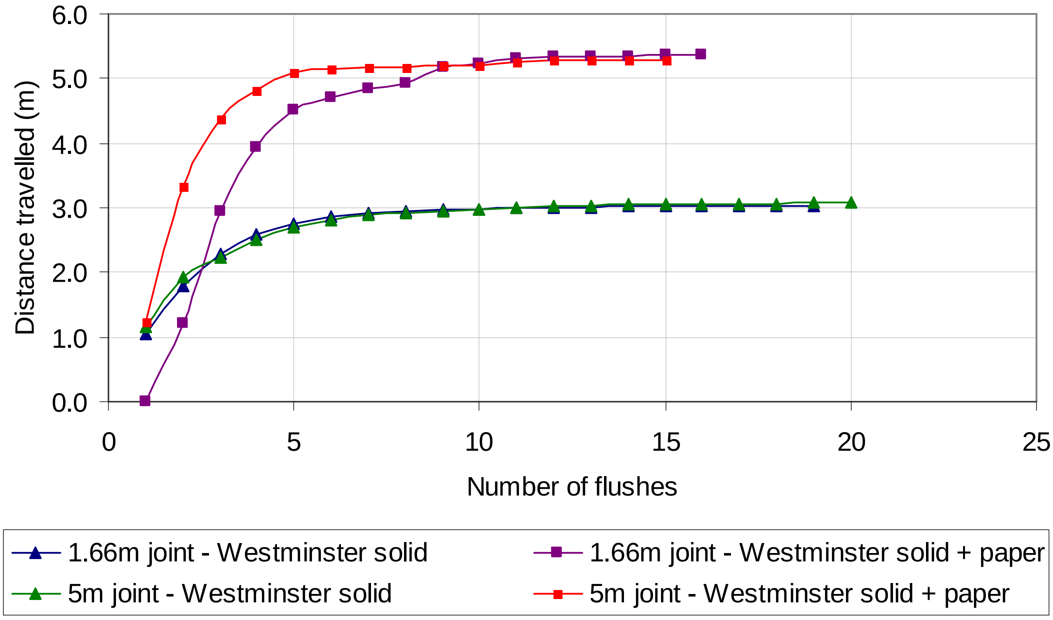


Figure 7.1 1.66 m pipes versus 5 m pipes – 2 litres (Gradient 1:80)

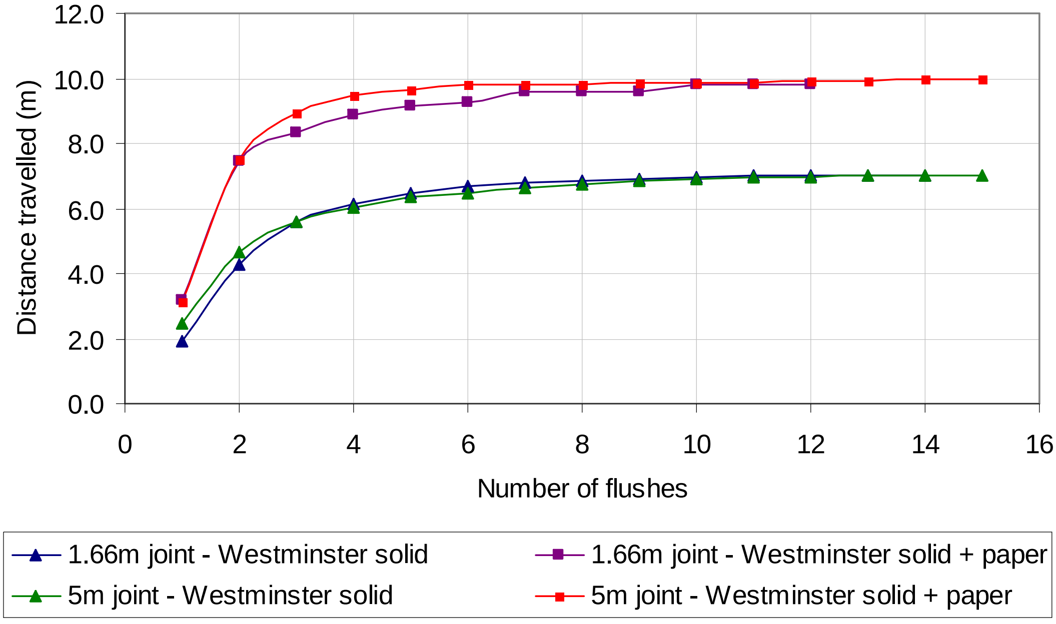


Figure 7.2 1.66 m pipes versus 5 m pipes – 3 litres (Gradient 1:80)

7.4 Effect of pipe materials

7.4.1 Test programme

Previous research has suggested that pipe material is not a significant influence on sewer solid movement, provided that the pipes have comparable physical properties (joint size / condition and internal pipe condition). Plastic and modern clay pipes with push fit sleeve joints had been used in the testing.

Further tests were undertaken during this study to better understand the effect of material used. A range of different pipes have been tested including:

- plastic pipe;
- ‘modern’ clay pipe (sleeve joints);
- ‘old’ clay pipe (spigot and socket joints); and
- ‘old’ clay pipe with an epoxy lining.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- Either:
  - 103 mm diameter plastic pipes, with sleeve joints every 1.67 metres.
  - 100 mm diameter ‘modern’ clay pipes, with sleeve joints every 1.67 metres.
  - 100 mm diameter clay pipes, with spigot and socket joints every 0.6 metre.
  - 100 mm diameter relined clay pipes, with joints every 0.6 metre.
- A ‘downstairs’ WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- Firstly, using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for each of the above permutations
- The testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre and 3 litre flush volumes.

7.4.2 Results

Comparison of 1.65 m long clay pipes and 1.67 m long plastic pipes

The results of the tests carried out with modern 100 mm diameter sleeve jointed clay pipes and 103 mm diameter plastic pipes are illustrated in Figure 7.3. These show that there is no significant difference in the distance travelled by the solid in the pipes made of different materials.

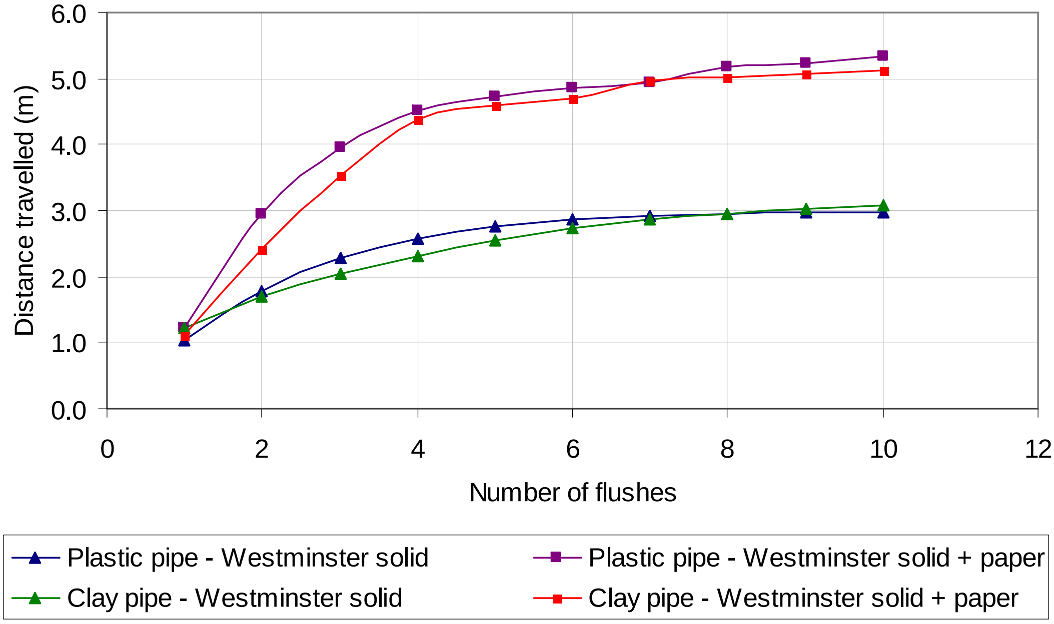


Figure 7.3 1.67 m plastic pipes versus 1.65 m clay pipes – 2 litres (Gradient 1:80)

Comparison of old clay pipes and relined clay pipes

Tests have also been carried out on short length clay pipe (spigot and socket joints at 0.65 m). A length of relined pipes was also tested and both sets of results are illustrated in Figure 7.4.

The diameter of the relined pipe will be marginally less than the unlined pipe. Whilst smaller diameter pipes will favour better hydraulic conditions, in this case the difference in pipe diameter will be minimal and not have a major effect upon the hydraulic/sewer solid flow conditions. The vast majority of improvement in the flow conditions will be due to the smoother pipe walls and not the slightly reduced pipe diameter.

The epoxy lining to the pipe allows the solid to travel further than in the unlined pipe, by 10% to 20% with 3 litre flushes. The lining has two major effects on the hydraulic flow characteristics, as follows:

- The pipe wall surface is smoother, therefore reducing frictional losses caused by rough surfaces/small irregularities.

- The lining bridges the joints between pipes. This both reduces the turbulence at the joint and covers the rough edges of the joints on which the solids became stranded in the unlined pipe.

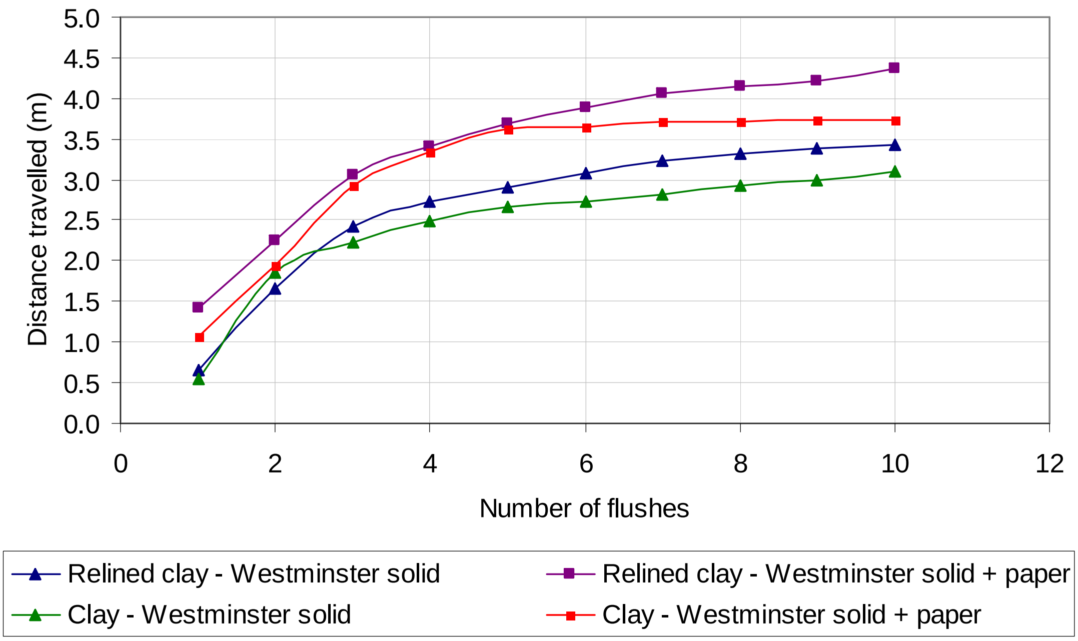


Figure 7.4 0.66 m clay pipes versus 0.66 m relined clay pipes - 3 litres (Gradient 1:80)

Further comparisons, for example between the sewer solid movement characteristics of ‘modern’ clay and ‘old’ clay pipes are made in Section 7.5.

7.4.3 Summary

- There is no significant difference in the distance travelled by the solid in plastic and ‘modern’ clay pipes with sleeve joints in good condition. This is largely due to the small, well aligned joints found in both plastic and modern clay pipes.

- The lining of ‘old’ clay pipes improves the performance by covering the large joints and covering irregularities in the pipe surface.

7.5 The combined effect of number and condition of joints, and pipe material

7.5.1 Test programme

The various combinations of joint frequency, joint size and pipe material have shown that both joint condition and internal pipe condition have an influence of sewer solid movement. Poor/large joints and rough surfaces inside the pipe both have a detrimental effect on solid movement.

The 0.65 m long 'old' clay pipes used represent 'worst case' conditions. This is both from the number of joints and the condition of joints perspectives. The 'old' clay pipe wall also has a different finish with more irregularities that could catch items such as 'rags'. Significant energy losses could therefore be expected.

Further tests were undertaken to better understand the effect of the combination of these parameters by comparing:

- Pipes with good and poor joints, through a comparison of 'modern' and 'old' clay pipes; and
- All four pipe types used in the tests (plastic, 'modern' clay, 'old' clay, relined 'old clay).

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- Either:
  - 103 mm diameter plastic pipes, with joints every 1.67 metres.
  - 100 mm diameter 'modern' clay pipes, with joints every 1.65 metres.
  - 100 mm diameter 'old' clay pipes, with joints every 0.6 metre.
  - 100 mm diameter relined clay pipes, with joints every 0.6 metre.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- Firstly, using the Westminster solid and then the Westminster solid with 4 sheets of paper.
- The test was repeated 10 times for various of the above permutations
- The testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre and 3 litre flush volumes.

7.5.2 Results

Comparison of ‘old’ and ‘modern’ clay pipes

The results of tests comparing the sewer solid movement characteristics are illustrated in Figure 7.5 and Figure 7.6. for tests with 2 litre and 3 litre flushes respectively.

As previously mentioned the number of joints, condition of joints and internal roughness of the pipe will influence the extent of energy loss in the flush wave and hence the sewer solid distances travelled.

Tests results with 2 litre flushes show that the distance travelled by the Westminster solid alone is similar in both ‘old’ and ‘modern’ clay pipes. This is somewhat contradictory to some of the other test results where any loss of energy in a small flush will result in reduced solid movement. A possible explanation to this may be that there was so little energy in the flush at this distance that any turbulence and disturbance at the joint has a minimal impact.

The sewer solid flow behaviour with paper is more predictable:

a) The solid travels further than without paper in both pipe configurations: and

b) The solid movement in the ‘modern’ pipe is superior to that in the ’old’ pipe (the distance travelled by the solid in the modern clay pipes is 24% higher)

The results for tests with 3 litre flushes show, somewhat predictably, that:

- The sewer solid flow characteristics in ‘modern’ clay pipes are superior to those in the ‘old’ clay pipes. The sewer solid typically travels 50 % further.
- The addition of paper increases the distance travelled by the sewer solid in both the ‘old’ and ‘new’ clay pipes. Typically this is by 15 - 20% further.

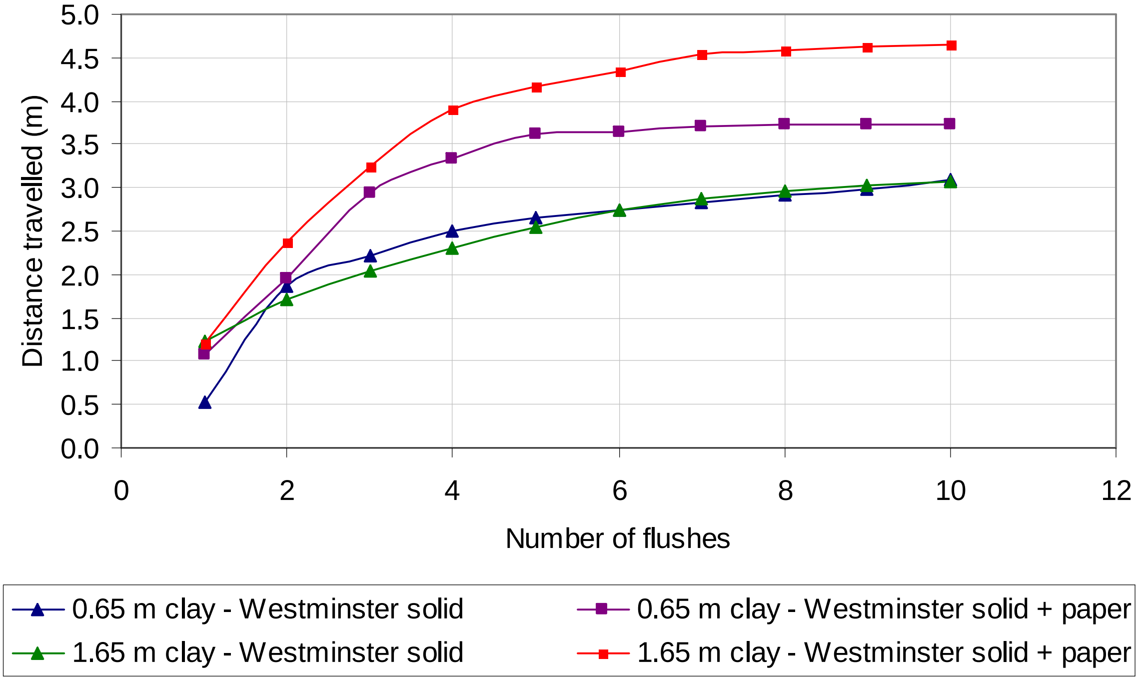


Figure 7.5 **0.65 m old clay pipes versus 1.65 m modern clay pipes – 2 litres (Gradient 1:80)**

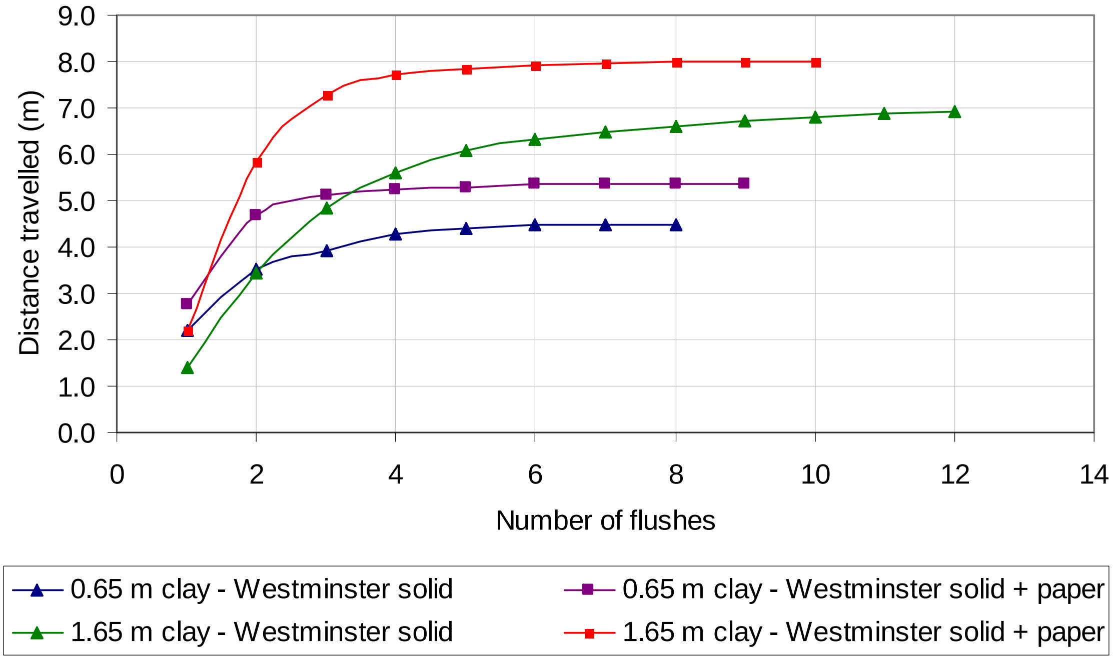


Figure 7.6 **0.65 m old clay pipes versus 1.65 m modern clay pipes – 3 litres (Gradient 1:80)**

Comparison of all materials

The sewer solid flow characteristics for all four pipe types are illustrated in Figure 7.7 and Figure 7.8 for the 3 litre and 2 litre flush tests respectively. A comparison of these results shows that:

- 'Modern' clay and plastic pipelines have very similar physical properties (smooth sleeved joints and smooth internal pipe walls). Not surprisingly the sewer solid flow characteristics are very similar for both pipe types.
- The unfavourable hydraulic conditions caused by the comparatively large spigot and socket joints in the 'old' clay pipes give notably reduced sewer solid flow distances. Figure 7.7 and Figure 7.8 highlight this effect. For 3 litre flushes with the Westminster solid alone the distance travelled in 'old' clay pipes is 40% less than in other pipes.
- The hydraulic conditions in 'old' clay pipes can be improved by relining. With 2 litre flushes, the distance reached by the Westminster solid and 4 sheets of paper in the lined 'old' clay pipes is close to the distance travelled in the 'modern' clay pipes (see Figure 7.8).

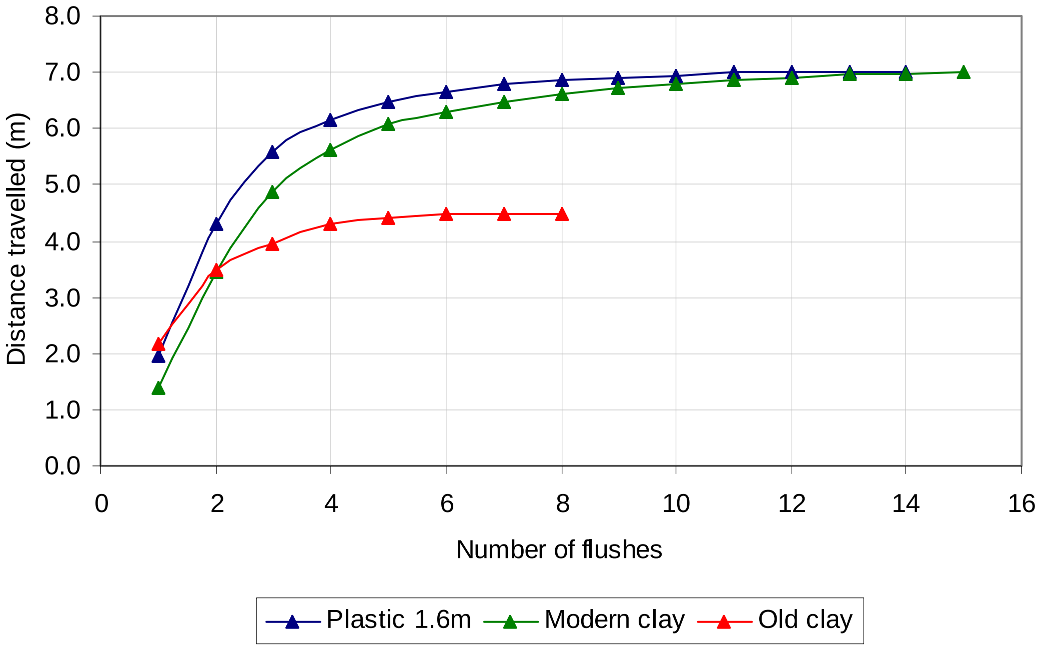


Figure 7.7 Plastic, old clay and modern clay pipes – Westminster solid alone, 3 litres (Gradient 1:80)

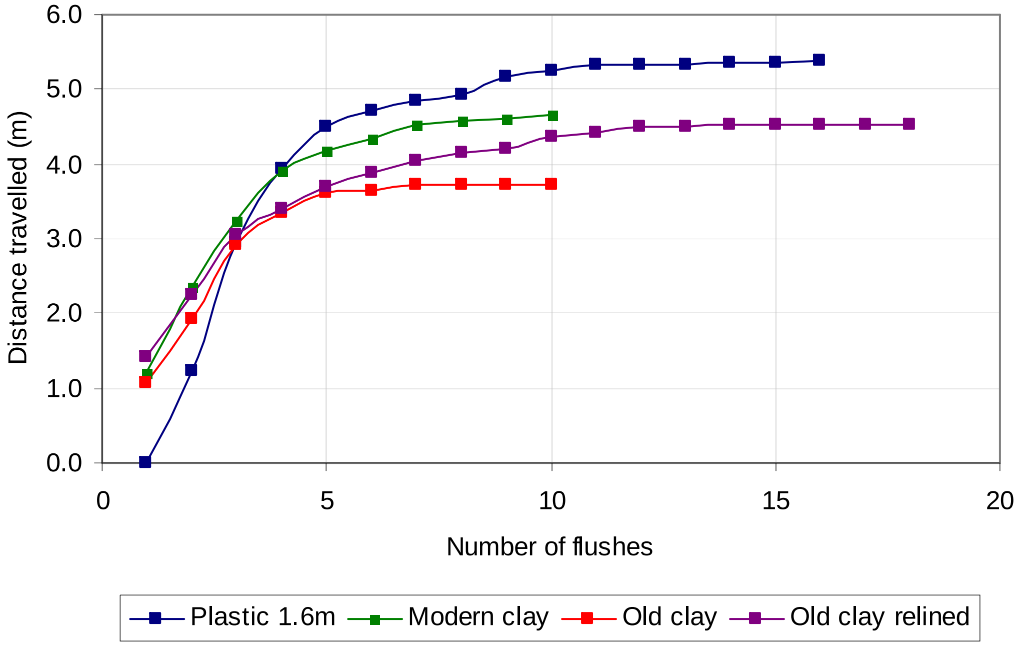


Figure 7.8 Plastic, old clay, old relined clay and modern clay pipes – 2 litres, Westminster solid + 4 sheets of paper (Gradient 1:80)

7.5.3 Summary

- Pipe material itself has very little influence on sewer solid flow characteristics. This is seen in a comparison of the plastic and ‘modern’ clay pipes where there is little difference in the sewer solid distances travelled. Both pipe systems have relatively smooth well made sleeve joints and smooth internal pipe walls.

- The greatest influences on sewer solid flow are:

  - The joint condition; and

  - The roughness of the internal pipe wall.

- The ‘old’ clay pipes have joints which are larger / in poorer condition and more frequent. It is these factors that contribute to the relatively poor sewer solid movement characteristics, not the type of pipe material.

7.6 Effect of Pipe Defects

7.6.1 Test programme

Pipe defects can have major effect on the ability of a drain/small sewer to carry sewer solids. The tests outlined in sections 7.3 to 7.5 have shown that pipe condition is important, in particular the number of/poor condition of joints and the roughness of a pipe's internal walls. In this section the effect of more serious joint defects are considered.

Previous research carried out by WRc found that joint defects have a greater influence on sewer solid carrying ability the further away the defect is from the source of the WC flush. This is because a defect takes energy out of the flush wave and this process is most significant when the flush wave is already significantly dissipated. This previous research also indicated that a fairly modest defect, for example a relatively small offset joint(s), would have a significant effect when located at a distance equal to two thirds of the distance that the solid would travel in a pipe of reasonable condition, i.e. as demonstrated in the reference tests.

Accordingly a series of further tests were carried out to confirm and better understand this phenomenon, as described below.

Tests using a 'downstairs' WC are described below. Tests using an 'upstairs' WC discharge are described in Section 7.7.

A ring of plastic of 2 mm thickness was inserted to the inside of the pipe. This was to simulate an offset joint or other defect where there would be a gap or difference in the level of the pipe surface, for example a crack or fracture.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 1.6 metre.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- A Westminster solid alone was flushed.
- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.
- The tests were repeated with 2 litre, 3 litre and 4.5 litre flush volumes.
- The defect was placed in the pipe at distances specified in Table 7.1.

Table 7.1 Distance of the defect from the WC

Volume of water	Distance reached without defect	Distance of the ring from the WC
2 litres	3.0 m	2.1 m
3 litres	7.0 m	4.7 m
4.5 litres	11.9 m	7.9 m

7.6.2 Results

2 litre tests, downstairs WC

In 6 of the 10 tests undertaken the solid stopped at the defect and was unable to overcome the obstacle.

In the four other tests, the solid came to rest just upstream (40 to 100mm) of the defect. The solid was subsequently re-entrained from immediately upstream of the defect and was therefore riding on the crest of the flush wave and at sufficient height to clear the defect. The final distance travelled was then similar to the distance reached without the presence of the defect, between 3.0 and 3.3 metres.

The likelihood of the solid being able to pass over the defect was therefore related to the distance from the defect that the solid stopped at in the flush immediately before reaching the defect. In 60% of tests the solid stopped too far back from the defect for it to still pass over the defect in the next flush wave. In these tests the defect was sufficient to stop the solid moving in any subsequent flushes.

3 litre tests

The solid stopped at the defect in all 10 tests carried out.

4.5 litre tests

The solid stopped at the defect in 8 of the 10 tests undertaken.

In the two remaining tests the solid was able to pass over the defect. The solid eventually reached 10.0 and 11.5 m, close to the distance reached without defect in the pipe.

The above tests show that a relatively small offset joint could have a significant detrimental effect on sewer solid movement. A larger defect, for example a 5 or 10 mm displacement would have an even greater effect.

7.6.3 Summary

- The presence of a defect or offset joint stops the solid in most cases.

7.7 Effect of pipe defects – Upstairs WC

7.7.1 Test programme

The test programme described in section 7.6 was repeated but for an 'upstairs' WC discharge.

An upstairs WC was placed at a height of 2.5 metres above the downstairs WC, as previously described in Section 6 and illustrated in Photograph 6.1 and 6.2),

The tests were repeated with 2 litre, 3 litre and 4.5 litre flush volumes.

7.7.2 Results

The tests carried out with 2 litre flushes showed that the solid is not stopped at the defect. In fact, the solid passed over the defect with the first flush in most cases.

In the tests using a 3 litre flush and with the defect at the corresponding distance from the WC, the solid passed the defect in 40 % of the tests

With the 4.5 litre flush volume and with the defect at the corresponding distance from the WC, the solid stopped at the defect on all occasions.

7.7.3 Summary

- A defect in the pipe has similar effect on sewer solid movement with both the downstairs and upstairs WC discharges. The solid is stopped by the defect in most tests.

7.8 Summary of the effect of drain characteristics/conditions on solid movement

- 7a - The frequency of joints in the drain/small sewer does not have an effect on sewer solid transport difference, provided that the joints are small and well made.

- 7b - Pipe material itself has very little influence on sewer solid flow characteristics. This is seen in a comparison of the plastic and 'modern' clay pipes where there is little difference in the sewer solid distances travelled. Both pipe systems have relatively smooth well made sleeve joints and smooth internal pipe walls.

- 7c - The 'old' clay pipes have joints which are larger / in poorer condition and more frequent. It is these factors that contribute to the relatively poor sewer solid movement characteristics, not the type of pipe material.

- 7d - The lining of ‘old’ clay pipes improves the performance by covering the large joints and covering irregularities in the pipe surface

- 7e - With both downstairs and upstairs WC discharges, the presence of a defect or offset joint stops the solid in most cases.

8. EFFECT OF RETROFITTING TO EXISTING DRAINAGE SYSTEMS

8.1 Introduction

Sections 5, 6 and 7 of this report have investigated the effect of altering various physical parameters on the movement of sewer solids through drains and small sewers. The information gained can be used to both inform those responsible for future drainage design and assess the impact of retrofitting in existing catchments

This section focuses on the tests that were undertaken to understand the consequences of retrofitting low flow appliances to existing systems. A significant proportion of older systems, unlike new build drainage, will not be free of defects, for example there will be offset and pulled joints, joints with rough edges and lengths with a poor gradient. It is important therefore that the effect of these ‘defects’ are fully understood and taken into account.

The effect of pipe materials and joints common in older sewer systems are described in Section 7.

An additional feature installed in many pre-1939 systems are interceptor traps. These were originally installed as a method of preventing odours entering a property. This function has been superseded by modern pluming practices that incorporate an odour trap at each appliance connected to the sewer. Although currently rarely installed, there are a large number of interceptors, both in known and unknown locations. Many already suffer blockages and there are concerns that retrofitting low flow appliances will increase their propensity to blockages.

8.2 Testing schedule

The effect of joint defects was investigated as described in Section 7.

An interceptor trap was subsequently installed in the ‘old’ clay pipe test line. The remainder of this section describes the tests that were carried out on the interceptor trap.

8.3 Effect of an interceptor

8.3.1 Test programme

A typical interceptor trap is shown in Photograph 8.1. This shows that interceptor consists of a permanently submerged sump which all flows, including solids, have to pass through.

Because of the shape of such a device, there is a risk that the solid could remain in the trap or settle at the bottom of the interceptor. The reduced water usage is likely to increase the risk of blockages due to the inability of the low flows to carry the solid through the interceptor. This is leading to renewed concerns about the presence of interceptors in the network.

Photograph 8.1 Interceptor

The interceptor was installed 8 metres from the downstairs WC connection in the test pipe which was constructed of short length (24") salt glazed clay pipes laid at a gradient of 1:80. This distance (WC to the interceptor) is considered typical of many arrangements and represents an interceptor at the property boundary.

The previous tests described in section 7.4, in particular in Figures 7.3 and 7.4, showed that 2 or 3 litres flushes are inadequate to effect solid movement in 'old' clay pipe systems up to 8 metres, i.e. to the interceptor. Therefore there was no practical value in testing interceptor traps with these lower flushes. Flush volumes of 4.5 and 6 litres were used in the following tests.

Various solids were introduced in the pipeline including

- the Westminster solid (S.G. of 0.95),
- a high specific gravity version of the Westminster solid (S.G. of 1.05),
- baby wipes, and
- panty liners.

Tests were carried out with a single solid or flushable product placed at the entry into the interceptor. The test was limited to 5 flushes for each solid/product. .

8.3.2 Results

Tests with both Westminster solids (standard solid and the high S.G. solid) showed that both the 4.5 litre and 6 litre flush waves are insufficient to carry the solid through the interceptor into the downstream pipe.

With a 6 litre flush the Westminster solid is washed into the interceptor sump, however, it returns to the entrance of the interceptor when the flow rate decreases. There is insufficient momentum in the flow to pass the solid beyond the u-bend. This indicates that such solids may be carried beyond the interceptor with the increased momentum from a higher flush volume. Predictably, the same solid would not even wash into the sump with 4.5 litre flushes.

The higher density solid was washed into the sump but would not be re-entrained with either the 4.5 or 6 litre flushes.

Flushable products are more easily transported through the interceptor. The baby wipe was able to pass through the interceptor in 50% of the 6 litre tests and panty liners in 60% of the 6 litre tests. The proportion of products passing through the interceptor dropped to 30% for baby wipes and 20% for panty liners using 4.5 litre flushes.

The behaviour of the flushable products in the interceptor is dependent on their shape. While the panty liner can be carried through the interceptor in a single flush, the baby wipe needs to be pushed to the bottom of the interceptor in one flush before being transported to the other side by the subsequent flush.

8.3.3 Summary

- 8a - The interceptor impedes the free passage of solids along the drain/small sewer.
- 8b - Flushable products may go through the interceptor using the higher flush volumes (6 litres) but the decrease of the flush volume below 6 litres significantly affects the ability to pass the interceptor, which could contribute to blockages problems.
- 8c - Sewer solids are very unlikely to pass through an interceptor at reduced flush volumes.

9. WC FLUSH PATTERNS AND NON WC DISCHARGE TRANSPORT CHARACTERISTICS

9.1 Introduction

In the previous sections the effects of altering physical parameters have been investigated.

This section describes the tests that were undertaken to understand the effect of combinations of further solid or paper discharges from the WC, as well as the effect of other water using appliances such as the shower and the bath.

Previous research undertaken by WRc suggests that:

- Each person flushes the WC on average 7 times a day
- Only 25% of flushes involve a solid plus paper.
- Of the remaining flushes half carry a small quantity of paper and half are water only.

9.2 Testing schedule

The water use patterns investigated included:

- A succession of solids and paper discharges, using a single flush volume,
- A sequence of solids and paper discharges, with a sequence of large and small flushes from dual flush cisterns,
- The effect of the discharge from bath emptying, and
- The effect of the discharge from a shower.

9.3 Sequence of solids and paper

9.3.1 Test programme

The reference tests described in Section 5 were undertaken using a single solid. In the following tests a second solid was introduced into the flush sequence whilst the first solid was still in the drainline.

Prior to the testing it was uncertain if the addition of a second solid would:

- Reduce the transport distance, due to the increased total weight of the material being transported: or
- Promote a greater distance travelled, due to the force from the second solid providing momentum.

A sequence of solid/paper discharges was investigated, taking into account that on average, 1 in 4 flushes will carry a solid as well as paper.

The influence of successive flushes has been investigated by the following sequence:

- Flush 1 with Westminster solid n^{o}1
- Flush 2: no solid
- Flush 3 with 4 sheets of paper
- Flush 4: no solid
- Flush 5 with Westminster solid n^{o}2
- Flush 6: no solid
- Flush 7 with 4 sheets of paper
- Flush 8 to 15: no solid

The test facility was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing methodology was as follows:

- The solid flushed was either the Westminster solid or 4 sheets of paper, as appropriate.
- The test was repeated 5 times.
- The testing procedure was as described in Section 4.4.
- The tests were carried out using 2 litre and 3 litre flush volumes.

9.3.2 Results

The distance travelled by the two solids in the drainline using 2 litre and 3 litre flushes are presented in Figure 9.1 and Figure 9.2 respectively. The blue line represents the travel of the first solid for which paper has been added at flush number 3. The pink line represents the travel of the second solid; paper has been added at flush number 7.

2 litre tests

Using a 2 litre flush volume, the first solid follows the pattern observed previously for the standard Westminster solid test (see Figure 9.1). The addition of paper at flush 3 does not appear to have an effect on the rate of progress as the solid continues to progress along the solid only flush profile. The second solid is introduced into the drain with flush 5 and the travel of the second solid is not affected by the presence of the first solid until the two solids come together at c.3.5 m.

This second solid follows the pattern of a standard Westminster test until paper is added. This increases the rate of progress to that of the solid plus paper tests (solid + 4 sheets of paper).

When the second solid reaches the first one, the new group of 2 solids with the associated paper travels by a short distance (about half a metre) along the pipe before being deposited.

At this distance there is insufficient energy in the 2 litre flush to overcome the combined friction of the grouped solids to re-entrain the material.

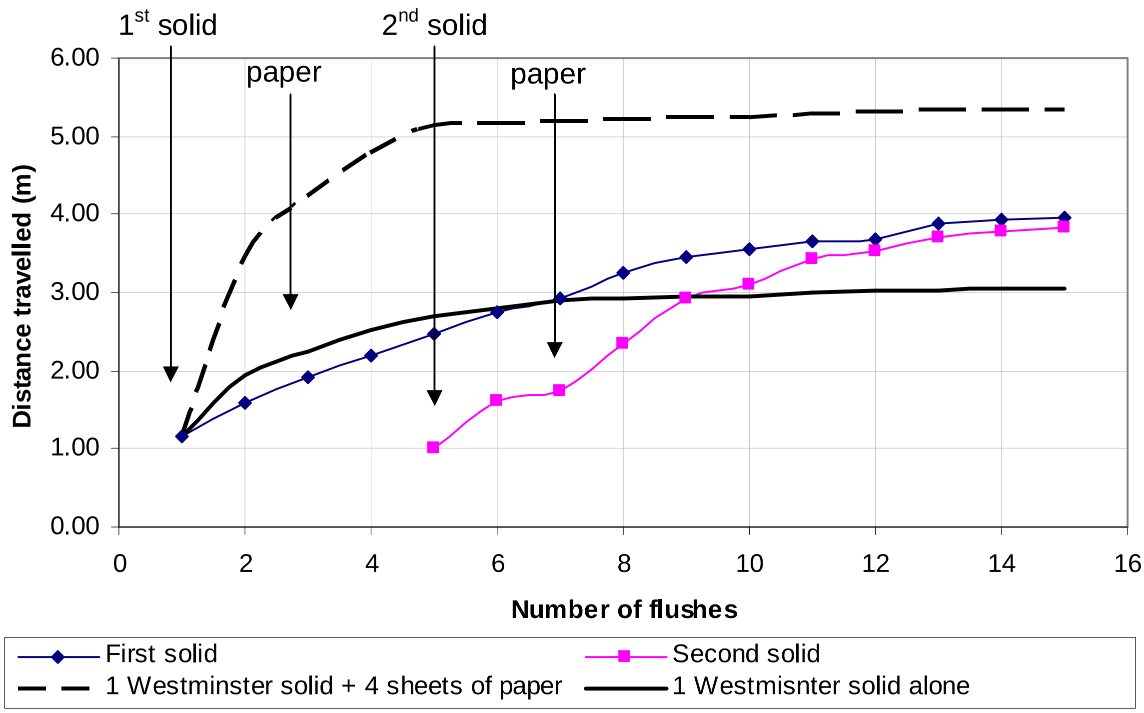


Figure 9.1 Sequence of solids and paper with 2 litres (Gradient 1:80)

Figure 9.1 also shows that the final distance travelled by the grouped solids is less than the distance travelled in the reference test with paper but greater than the distance travelled in the reference test with the Westminster solid alone.

The distance travelled by the group is limited by the second solid absorbing the energy of the flush wave. The wave reaching the first solid is attenuated with there being insufficient buoyancy to re-entrain the leading (first) solid.

3 litre tests

3 litre flush tests were conducted using the same sequence of flushes, solids and paper.

Using 3 litre flushes, the first solid follows the trend of solid movement observed in the reference tests with and without paper. The same movement pattern can be observed for the first few flushes of the second solid in Figure 9.2.

As soon as the second solid is flushed down the WC, the first (leading) solid stops moving as the energy is absorbed by the following solid.

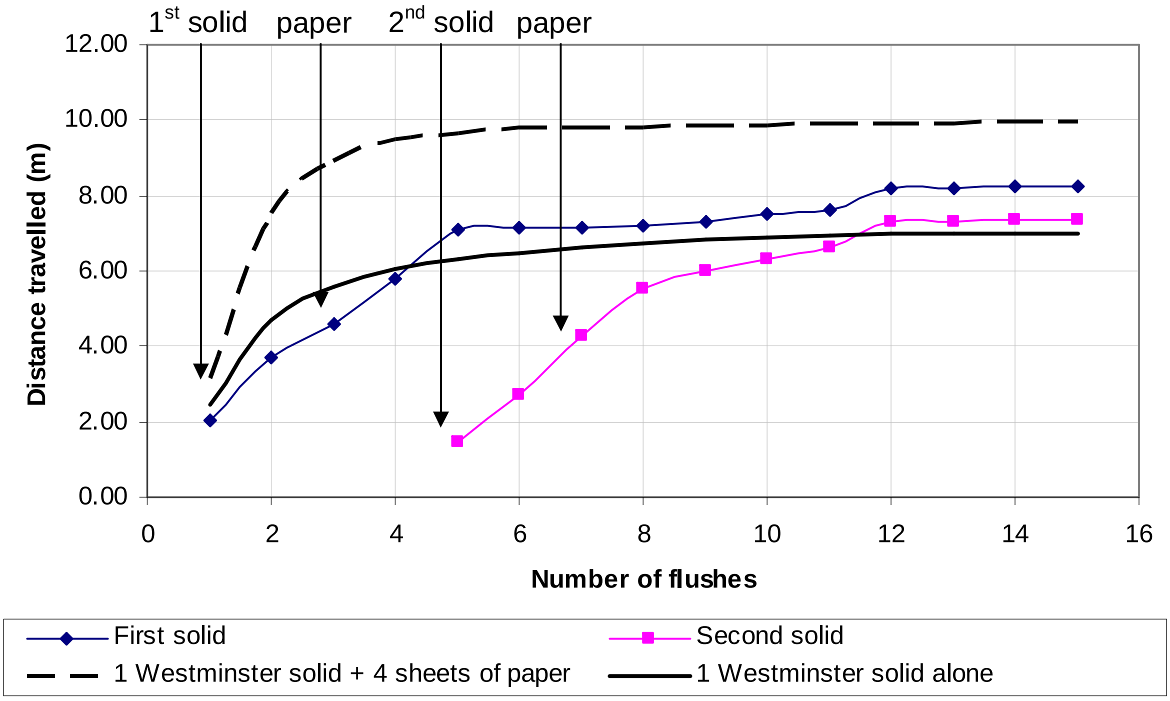


Figure 9.2 Sequence of solids and paper with 3 litres (Gradient 1:80)

As the second solid travels to and almost reaches the leading solid, both solids move in series with a constant distance between the two. The movement of the second solid pushes the water trapped behind the paper that is forming a dam behind solid 1, resulting in an increase in depth and buoyancy to the leading solid. A backward wave is created when the water hits solid 1, maintaining a distance between the two solids that is only incrementally reduced as water escapes around the leading solid (see Figure 9.3).

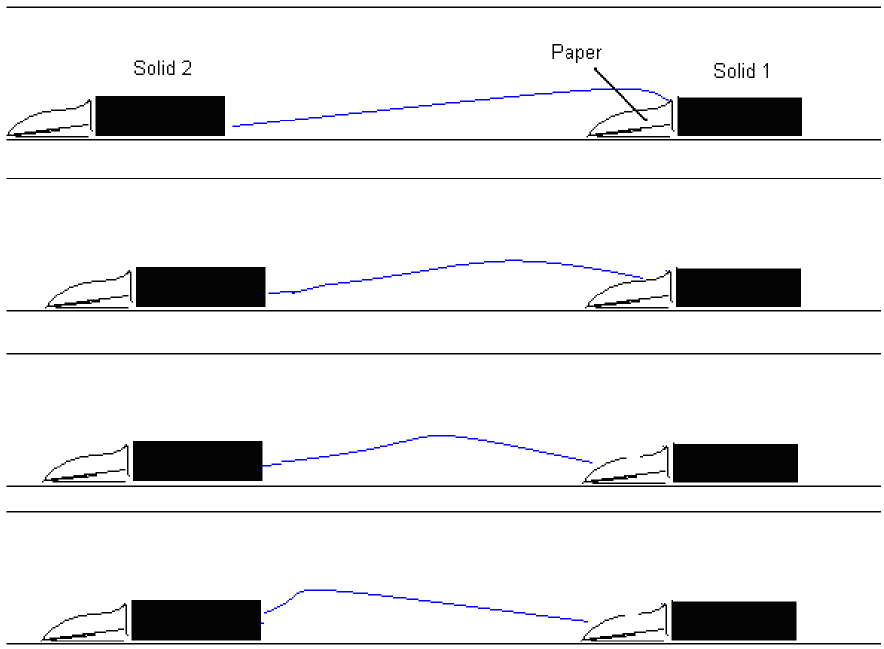


Figure 9.3 Backward wave phenomenon

9.3.3 Summary

- The addition of a second solid slows the progress of the first solid and paper, by absorbing the energy of the wave.
- The distance travelled by the sequence of solids and paper is between the distance travelled by the Westminster solid alone and the solid with paper.
- An exchange of waves is observed between the two solids as soon as they are close to each other. This initially maintains a gap between the solids.
- When both solids are grouped together in the pipe, the energy required to re-entrain the combined group is higher and therefore more water is needed to move the solid along compared to a single solid at the same distance from the WC.

9.4 Dual flush and typical flush pattern

9.4.1 Test programme

As explained in section 9.3.1 typical WC use involves the flushing of solids with paper for 1 in 4 flushes.

To simulate this pattern, a dual flush WC was used. The sequence was a high flush (between 4 and 4.5 litres) followed by three low flushes (between 2.5 and 3 litres). Two sets of tests were carried out, as follows:

- First set - with only one Westminster solid to observe the direct effect of the dual flush.
- Second set - studied the effect of the addition of paper and the introduction of a second solid in the drain/small sewer. The characteristics of the flush pattern are described in Table 9.1.

Table 9.1 Dual flush tests with 2 solids and paper – Sequence of flushes

Flush number	Flush volume	Products flushed
1	High	Westminster solid + 4 sheets of paper
2	Low	-
3	Low	4 sheets of paper
4	Low	-
5	High	Westminster solid + 4 sheets of paper
6	Low	-
7	Low	4 sheets of paper
8	Low	-
9	High	4 sheets of paper
10	Low	-
11	Low	4 sheets of paper
12	Low	-

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of 1:80.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- The solid flushed was either the Westminster solid or 4 sheets of paper, in the sequence as indicated in Table 9.1
- The test was repeated 5 times.
- The testing procedure was as described in Section 4.4.

9.4.2 Results

Test results obtained with the Westminster solid alone are presented in Figure 9.4. This shows that:

- The first high flush carries the solid to 3.5 m, which is similar to the reference test with 4.5 litres.
- The following three flushes, which are low flushes of 2.5 to 3 litres, each only moves the solid by a short distance.
- The fifth flush, of 4.5 litres, transports the solid to almost 7 m, a distance reflecting the reference tests of 4.5 litre flushes.
- The following low flushes fail to re-entrain the solid.
- Further movement of the solid only occurs with the higher flush volume.

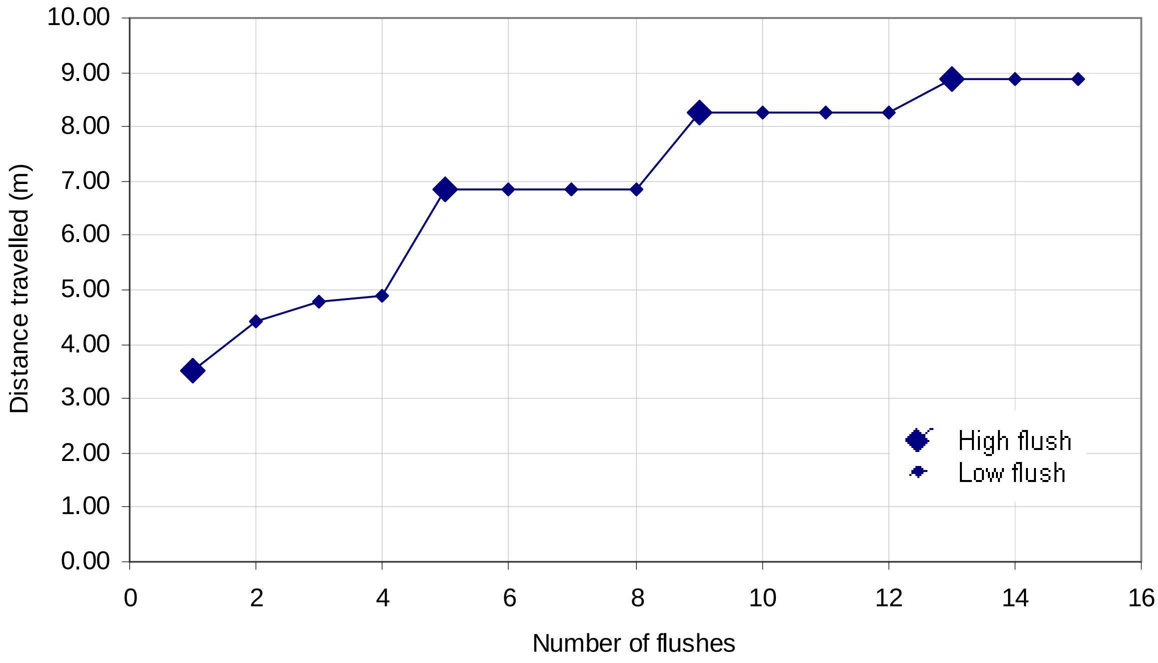


Figure 9.4 Dual flush results with one Westminster solid (Gradient 1:80)

Figure 9.5 presents the results of tests with 2 solids in conjunction with a dual flush sequence.

- With the first flush the single Westminster solid and 4 sheets of paper are deposited at c.6.0 m, slightly further than would be expected with the solid alone.
- The following low flush, liquid without paper, generates some movement. This is thought to be due to the previously flushed paper forming a dam behind the solid and providing a obstacle for the flush wave to push forward.

- The next low flush with paper does not move the solid but carries the paper to the back of the solid.

- The third low flush re-entrains the solid due to the increased surface area of paper forming a dam behind the solid.

- A second solid and additional paper is introduced with the fifth flush. The distance reached by the second solid is similar to that travelled by the first solid at the first flush. The following two low flushes also have the same effect of that found with the first solid.

- Following the introduction of the second solid the movement of the first solid is then highly dependent on the travel of the following solid and they travel in tandem before forming a group. As previously described in Section 9.3.2 and Figure 9.3 the solids then travel close together in series. The movement of the second solid is helped by the water 'stored' between the two solids as this increases the buoyancy effect and forward movement.

- Further low flushes do not transport the solids. The distance from the WC is too far removed from the WC and the low flushes are attenuated. The mass of the 2 solids and numerous sheets of paper present an obstacle that low flushes cannot re-entrain.

- The next high flush again moves the solid, to the end of the test rig.

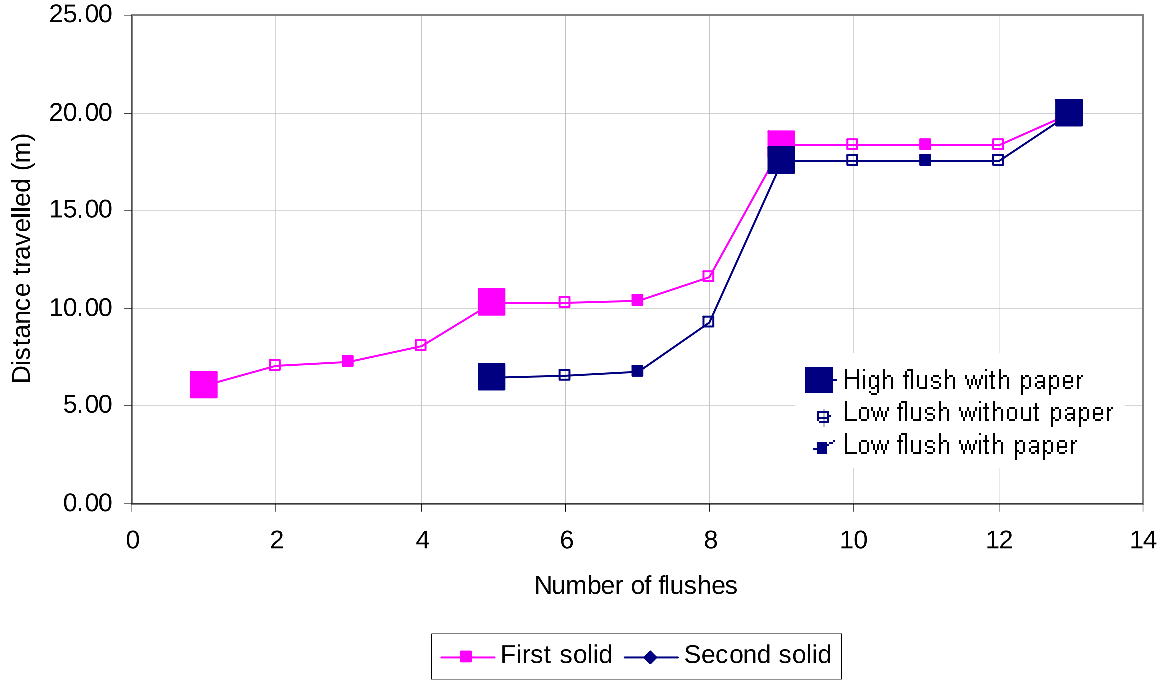


Figure 9.5 Dual flush results with 2 solids and paper (Gradient 1:80)

9.4.3 Summary

- Solid movement is mainly due to the high volume flushes. Low flushes do help the solid to travel along the pipe, but not by a significant distance.

- The distance travelled by the solid(s) reflects the movement generated by higher flushes only.

- Low flush volumes do not significantly contribute to the movement of solids.

- Consideration should be given to modifying the volumes of dual flush WC's so that the high flush volume is higher and the low flush volumes are lower. This would maintain the overall water savings but provide larger flush waves to re-entrain and transport the solid further along the drain.

  There is no barrier to this suggestion as the WC performance specification in the Water Supply (Water Fittings) Regulations 1999 allows for dual-flush WC suites with a maximum full flush of six litres and a maximum reduced flush volume of two thirds of the full flush volume. A dialogue with manufacturers is therefore necessary to first persuade them of the merit of modifying the flush volumes and secondly to ensure that the low flush is still sufficient to achieve bowl clearance.

9.5 Non WC discharges

Previous research by Littlewood and Butler (2003) concluded that flows from a bath or shower were insufficient to have any significant beneficial effect on the transport of solids in the sewer. This finding has been the reason that most studies into the movement of solids in small diameter pipes have primarily examined the behaviour of the flush wave discharged by the WC.

To confirm this premise a number of practical tests have been undertaken to establish flow rates from baths and showers and the ability of the wave to re-entrain and transport the solid. There is a tendency for bathing to decline and be replaced by showering. It is therefore important that the influence of a bath flush is understood, particularly in the context of reduced WC flush volumes.

9.6 Bath discharge tests.

9.6.1 Test programme

A large volume of water is discharged by a bath, the volume ranges from 65 litres to 100 litres depending on the size of the bath with an average of 85 litres (Market Transformation Programme, 2008a). However, the discharge is limited by the rate at which the water can pass through the plug hole, trap and the small diameter (50mm) waste pipe.

A bath was installed at the same height as the upstairs WC with a 1.5m length of 50mm soil pipe fitted to the soil stack with a strap boss. The plug hole was a standard 6 hole fitting and the trap provided a 20 mm water seal. This arrangement is illustrated in Figure 9.6.

Visual observations of the flow from the 50mm soil pipe to the stack showed the soil pipe was running at approximately half bore. This suggests that the main flow restriction is the waste orifice (plug hole). The flow from the bath was measured at the base of the stack with a range of hydraulic heads (depth of water in the bath) and a range of flow obstructions (blocking the waste orifices) to simulate fouling of the plug hole with hair, scum etc.

Figure 9.6 Drainage arrangement for the bath discharge tests

9.6.2 Results

Figure 9.7 shows the flow rates discharged from the bath with various heads and flow restrictions. It shows a maximum flow of 0.73 l/s with a 30m mm head and no obstructions at the plug hole. As the depth of water in the bath reduces the discharge reduces correspondingly, to 0.4 l/s with a 60mm head.

Blocking successively larger proportions of the plug hole reduced the discharge rates. As before, the discharges also reduced as the head of water in the bath reduced.

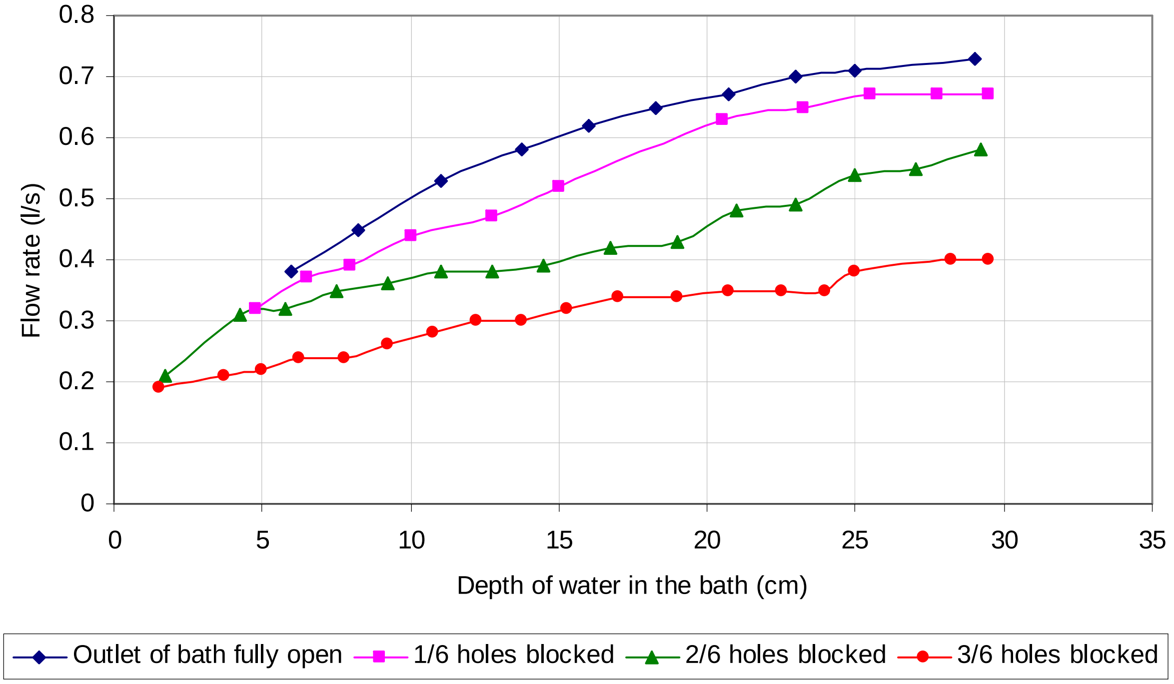


Figure 9.7 Flow rate of water discharged from the bath (Gradient 1:80)

Tests were also carried out at the rig to evaluate the distance travelled by the solid in the drains/small sewers by the bath discharge wave. The Westminster solid was placed at 1.7 metre from the base of the stack in the drain. The bath water was then released to examine the capacity of the wave to re-entrain and transport the solid.

It was noted that the solid was re-entrained after c.15 seconds of flow and once re-entrained the solid continued to be transported due to the constant flow rate of the emptying bath by all flows above 0.3 l/s. The solid is carried beyond 20 metres by the bath flow in 2 minutes 20 seconds.

9.7 Shower discharge tests

9.7.1 Test programme

The increasing popularity of showers and the development of reduced water usage shower heads highlight the need to better understanding of the effect of shower discharges in drains and small sewers.

The three shower heads used in the tests as are described in Table 9.2. Sewer solid movement tests were carried out using the following combinations:

- A Westminster solid alone,
- A solid and 4 sheets of paper, and
- A solid and 4 soaked sheets of paper.

The solid was placed at 1.7 m from the base of the stack, i.e. the distance at which a solid would travel no further with a 2 litre upstairs flush, as determined in earlier tests. Discharges were then made into the drain line. These were at the appropriate flow rate and were carried out for the average showering duration of 5.2 minutes (Market transformation programme, 2008b).

Table 9.2 Description of shower heads

Reference	Brief description	Flow rate (l/s)
A	Water saving shower head with air induction	0.1
B	Water saving shower head	0.16
C	Typical shower head	0.25

9.7.2 Results

The results giving details of the solid movement in relation to the shower flow are presented in Table 9.3. Tests showed that no movement of the solid occurs with either of the water saving shower heads. However, the higher flow rate head (0.25 l/s) can re-entrain the solid but movement is intermittent with the solid travelling under 10 metres for the 5.2 minute duration of the shower discharge.

Table 9.3 Results for tests with shower heads

Shower head reference	**A**	**B**	**C**
Flow rate	0.1 l/s	0.16 l/s	0.25 l/s
Movement of solid without paper behind	No movement of the solid	No movement of the solid	Up to 10 m after 5.2 min
Movement of solid with fresh paper	Between 5 and 10 m after 3 to 5 min	Above 20 m in less than 2 min	Above 20 m in less than 1.5 min
Movement of solid with soaked paper	No movement of the solid	Movement of the solid depends on the paper position (between 0 and 9 metres)	Above 20 m in less than 1.5 min

The addition of paper (added at the bottom of the stack) helps the solid to be transported along the pipes with all three shower flush rates. The solid travels 20 metres with flow rates B and C. With flow rate A, the solid is transported further but the distance travelled remains less than 10 metres during the 5.2 minute shower discharge.

When the paper is pre-soaked before being placed behind the solid, the distance travelled is generally reduced compared to the tests carried out with ‘fresh’ paper (i.e. dry paper before the flow from the shower hits the paper). The solid movement is dependant on the paper position behind the solid as well as the flow rate as with WC flushes.

9.7.3 The effect of defects on bath/shower discharges

A simulated 3 mm high defect was installed in the drainline 5 metres from the base of the stack. Tests were carried out to establish if the Westminster solid was able to pass over a defect when the bath is emptying. The solid passed over the defect with flows from 0.6 down to 0.3 litres per second.

With the defect placed at 10 metres from the soil stack, the solid was able to pass over the defect with flows ranging from 0.6 down to 0.4 litres per second. Under 0.4 litres per second, the Westminster solid stranded at the defect.

These results suggest that bath discharges may be sufficient to transport solids over small pipe defects.

Extrapolating these results to shower flows suggests that, with the flow discharged by a shower being between 0.1 and 0.3 litres per second, the discharge will not be sufficient to transport a solid over a defect.

9.7.4 Summary

- The threshold flow rate for solid re-entrainment is between 0.25 l/s and 0.3 l/s.
- The threshold for solid transport is a minimum of 0.3 l/s.
- Most discharges from baths attain this minimum flow requirement at some stage of the bath emptying process
- Standard high flow shower heads can re-entrain the solid but transport is minimal.
- Water saving shower heads do not attain this minimum flow requirement.
- Bath discharges may be sufficient to re-entrain solids and allow them to pass over minor pipe defects.
- Shower discharges are unable to re-entrain and transport solids in pipes with minor defects

9.8 Summary of the effect of sequences and non-WC flow pattern

When two solids are discharged in succession:

- 9a - The addition of a second solid slows the progress of the first solid and paper, by absorbing the energy of the wave.
- 9b - The distance travelled by the sequence of solids and paper is between the distance travelled by the Westminster solid alone and the solid with paper.
- 9c - When both solids are grouped together in the pipe, the energy required to re-entrain the combined group is higher and therefore more water is needed to move the solid along compared to a single solid at the same distance from the WC.

When successive discharges of different flush volumes are used:

- 9d - Solid movement is mainly due to the high volume flushes. Low flushes do help the solid to travel along the pipe, but not by a significant distance.
- 9e - The distance travelled by the solid(s) reflects the movement generated by higher flushes only.
- 9f - Low flush volumes do not significantly contribute to the movement of solids.
- 9g - Consideration should be given to modifying the volumes of dual flush WC's so that the high flush volume is higher and the low flush volumes are lower. This would maintain the overall water savings but provide larger flush waves to re-entrain and transport the solid further along the drain.

When considering bath and shower discharges:

- 9h - The threshold for solid re-entrainment is between 0.25l/s and 0.3l/s.
- 9i - The threshold for solid transport is a minimum of 0.3l/s.
- 9j - Most discharges from baths attain this minimum flow requirement at some stage of the bath emptying process.
- 9k - Standard high flow shower heads can re-entrain the solid but transport is minimal.
- 9l - Water saving shower heads do not attain this minimum flow requirement.
- 9m - Shower discharges are unable to re-entrain and transport solids in pipes with minor defects.

10. EFFECT OF CHANGE OF GRADIENT

10.1 Introduction

This section describes the tests undertaken to understand the effect of different drainline gradients (1:80, 1:60 and 1:50) on solid movement at low flows.

The Current Building Regulations 2000 (Part H), as amended in 2002, specify a minimum gradient of 1 in 80 for a 100 mm diameter drain carrying a WC discharge. Work undertaken during this project, as reported in the earlier sections, suggests that there are likely to be problems if reduced WC flushes are used with current drainage configurations.

Accordingly a number of tests were undertaken by increasing the gradient, first to I in 60 and then to 1 in 50. This section presents results of those investigations.

10.2 Testing schedule

The arrangements investigated included:

- A comparison of the solid movement in pipelines laid at different gradients (1:80, 1:60 and 1:50) with a 'downstairs' WC, and
- A comparison of the solid movement in pipelines laid at different gradients (1:80 and 1:60) with an 'upstairs' WC.

10.3 Effect of steeper gradient – Downstairs WC

10.3.1 Test programme

The test rig was modified to replicate systems with steeper gradients.

It was anticipated that the steeper gradient would both increase the distance travelled by solids and the velocity of the solid in the drain/small sewer.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of either 1:80, 1:60 or 1:50.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- A downstairs WC.
- A typical inlet connection to the drainage system.

The testing was undertaken as follows:

- The solid flushed was either the Westminster solid or 4 sheets of paper.
- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.

- The tests were carried out using 2 litre and 3 litre flush volumes.

10.3.2 Comparison with reference test

The shape of the flush travel pattern is similar whichever gradient is used, it is the distance travelled by the solid that differs (see Figure 10.1). Similar observations were be made with 3 litre flush volumes.

In general:

- The first flush gives the greatest solid travel distance;
- The next four flushes give progressively lower solid travel distances; and
- The remaining flushes move the solid very little distance, if at all.

The benefit of steeper gradient is not straight forward. Increasing the gradient from 1:80 to 1:60 resulted in an increase in the transport distance of approximately 20% (0.5 metre). However, tests at 1:50 showed a far greater benefit, for example the distance travelled by the solid by increased by more than 70% when using 2 litre flushes.

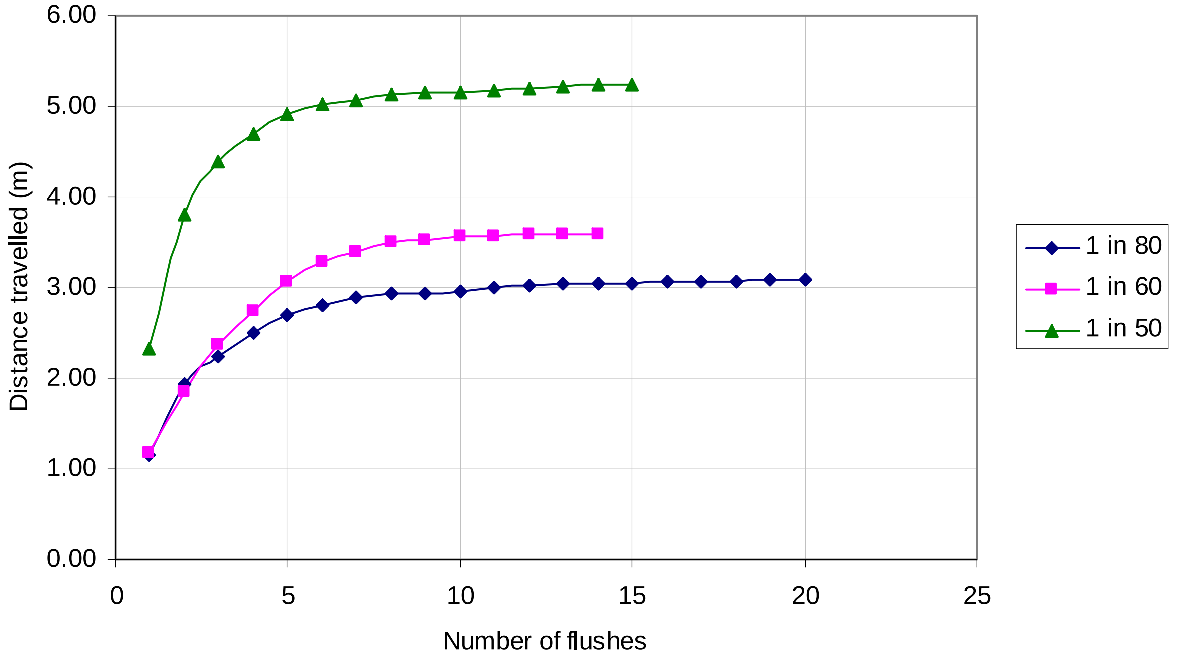


Figure 10.1 Comparison of 2 litre results for different gradients – Westminster solid

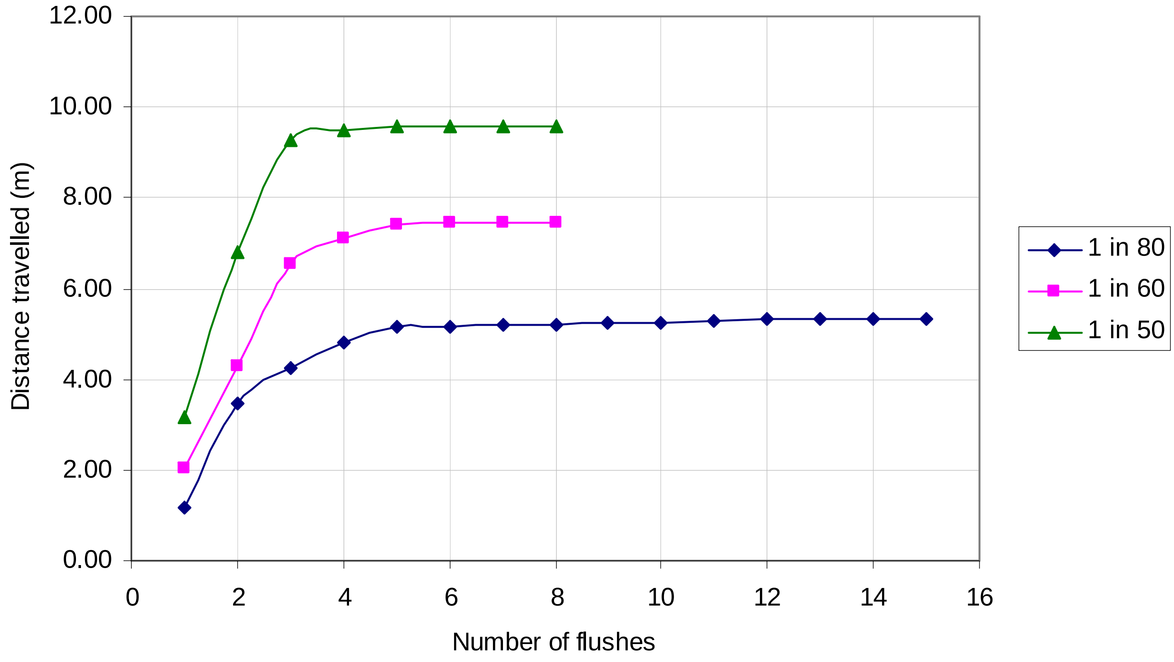


Figure 10.2 Comparison of 2 litre results for different gradients – Westminster solid + 4 sheets of paper

10.3.3 Results

The final distances travelled by the solid with the three gradients investigated are reported in Table 5.1.

The comparison of the results for 1:80 and 1:60 tests shows that:

- When flushing the Westminster solid alone there is little increase in the solid travel distance when using the steeper gradient.
- When flushing with a combination of solid and paper there can be a significant increase in the travel distance subject to the volume of water trapped behind the solid/paper.
- Similar improvements are seen with both 2 litre and 3 litre flush volumes.

The increased gradient from 1:80 to 1:50 shows that:

- There is a 70% increase in the distance travelled.
- This increase is for both 2 litre and 3 litre flushes.

Table 10.1 Distance travelled for different gradients – Downstairs WC

Gradient	1:80	1:60	1:50
2 litres			
Westminster solid	3.0 m	3.6 m	5.2 m
Westminster solid + 4 sheets of paper	4.0 to 5.6 m	5.9 to 9.0 m	9.6 m
3 litres			
Westminster solid	7.0 m	7.6 m	12.4 m
Westminster solid + 4 sheets of paper	7.5 to 12 m	9.2 to 14.5 m	Over 20 m

10.3.4 Summary

- Increasing the gradient from 1:80 to 1:60 is not sufficient to carry the solids an adequate distance, i.e. nominally to the next house connection (10 metres).
- The increase of the gradient to 1:50 allows the solid to travel 70% further compared to a gradient of 1:80. However, the distance travelled is still inadequate, i.e. less than 10 metres.
- Increasing the gradient alone is insufficient to enable the sewer solid travel distance to be acceptable with either 2 or 3 litre flushes.

10.4 <u>Effect of steeper gradient – Upstairs WC</u>

10.4.1 Test programme

The results previously presented in Section 6.2.1 show that a 2 litre 'upstairs' WC discharge is not sufficient carry the solid an acceptable distance (i.e. 10 metres or greater) when the pipe is laid at a gradient of 1:80.

Further tests have been carried out to understand the effect of increasing the gradient to 1:60 with an upstairs WC discharge.

The test rig was set up with:

- 20 metres of pipe, laid at a gradient of either 1:80 or 1:60.
- 103 mm diameter plastic pipes, with joints every 5 metres.
- A downstairs WC.

- A typical inlet connection to the drainage system.

The solid flushed was either the Westminster solid or solid with 4 sheets of paper.

- The test was repeated 10 times.
- The testing procedure was as described in Section 4.4.
- The tests were repeated with both 2 litre and 3 litre flush volumes.

10.4.2 Results

The test results are presented in Table 10.2. This shows that with a 2 litre flush volume:

- There is little increase in the solid travel distance with the Westminster solid alone when increasing the gradient from 1:80 to 1:60.
- When flushing with a combination of solid and 4 sheets of paper there can be a significant increase in the travel distance. The solid travelled almost 70% further at the steeper gradient (1:60, compared to 1:80), to reach 6 metres.

When using 3 litre flushes, the distance travelled is almost doubled for the tests with the solid alone and increased by 54% when 4 sheets of paper are added. However, the 3 litre flush wave is still borderline.

Table 10.2 Distance travelled for different gradients – Upstairs WC

Gradient	1:80	1:60
2 litres		
Westminster solid	2.7 m	3.0 m
Westminster solid + 4 sheets of paper	3.6 m	6.1 m
3 litres		
Westminster solid	4.5 m	8.8 m
Westminster solid + 4 sheets of paper	9.2 m	14.2 m

10.4.3 Summary

It was noted from visual observations of the upstairs flush that the profile of the wave was significantly different with the steeper gradients. At 1:60 the velocity of the flush wave is higher and the depth is correspondingly shallower than would be the case with a 1:80 gradient.

The higher velocity should, in theory, help the solid travel further. However, the shallower depth results in less buoyancy, and this counters much of the positive effect of the increased velocity. This may explain the limited benefit of the increased gradient on the solid alone with a 2 litre flush.

When paper is added the dam behind the solid reduces the velocity and increases the depth of water. The escaping water around the side of the solid provides an increased buoyancy to the solid and consequently an increased distance travelled.

- The steeper gradient of the pipeline allows limited improvement of the distance travelled by the Westminster solid for a 2 litre flush but significant improvement for a 3 litre flush.

- The increase in gradient in insufficient alone to increase the distance travelled with a 2 or 3 litre flush to carry the solid to the house connection (10 metres).

10.5 Summary of the effect of gradient

- 10a - Increasing the gradient from 1:80 to 1:60 is not sufficient to carry the solids an adequate distance, i.e. nominally to the next house connection (10 metres).
- 10b - The increase of the gradient to 1:50 allows the solid to travel 70% further compared to a gradient of 1:80. However, the distance travelled is still inadequate, i.e. less than 10 metres.
- 10c - Increasing the gradient alone is insufficient to enable the sewer solid travel distance to be acceptable with either 2 or 3 litre flushes.
- 10d - The steeper gradient of the pipeline allows limited improvement of the distance travelled by the Westminster solid for a 2 litre flush but significant improvement for a 3 litre flush from an upstairs WC.
- 10e - The increase in gradient in insufficient alone to increase the distance travelled with a 2 or 3 litre flush from an upstairs WC to carry the solid to the house connection (10 metres).

11. OBSERVATIONS DURING TESTING

11.1 Introduction

The opportunity was taken during the testing to observe the different sewer solid movement mechanisms that are found in pipes with small discharges. A number of influences were observed over a wide range of tests and these have helped to explain why sewer solid movement sometimes appears to be inconsistent.

An example of this 'inconsistency' is the difference of sewer solid movement from downstairs and upstairs WCs. It would seem logical for the solid to travel further with an upstairs flush due to the greater gravitational force and this is true with 6 and 4.5 litre flushes. However, for 2 and 3 litre flushes the converse appears to be true, there is better sewer solid movement from a downstairs flush.

The following sub-sections briefly explain the mechanisms commonly found in sewer solid flow.

11.2 Mechanisms of solid movement

Observations of the solid behaviour suggest there are two main forces required to remobilise a solid along a pipe with small and intermittent flows: buoyancy forces applied to lift the solid and horizontal forces applied to the back of the solid or paper to effect forward movement.

Buoyancy (lifting)

The buoyancy is dependant upon there being sufficient and deep enough water for the solid to float (most sewer solids are marginally buoyant). This is best achieved with larger flush volumes and/or slacker gradients.

Horizontal force (moving)

The horizontal force is the result of the flush wave. It will depend upon both the volume of the flush and velocity at the point where it comers into contact with the solid.

If the buoyancy force is high (deep water), the horizontal force required to move the solid can be correspondingly less than would be the case in a very shallow flow. In very shallow flow the majority of the movement will come from the horizontal forces pushing on the solid.

There are a number of reasons why the flow may be shallow, these include:

i) A very low flush, resulting in very little flow;

ii) The attenuation of the flush wave as it moves along the pipe. This is due to frictional losses distributing the wave over a longer time period ;

iii) A relatively steep gradient, resulting in faster/shallow flow;

iv) Flow conditions being modified as the flush passes the solid. (Typically this could be deeper subcritical flow temporarily becoming shallow supercritical flow as it passes around the solid).

Three phases of solid movement

The effect of the WC flush on the solid movement can be described in three phases and as a combination of the two mechanisms, as described below:

1. The solid is re-floated once the flush wave reaches it. This depends upon there being sufficient wave depth to refloat the solid, as described above.

   If there is insufficient buoyancy, the horizontal forces required to cause movement are correspondingly higher than would be the case if there is adequate buoyancy.

2. Once the solid is mobilised, the force applied by the water at the back of the solid must be sufficient to push and solid. The solid can move as long as the leakage of flow on each side of the solid maintains the buoyancy and does not result in the depth of water around the solid reducing to such an extent that the solid is no longer buoyant.

   The solid will cease to move once:

   - there is no appreciable horizontal force behind the solid, and/or
   - the solid is no longer buoyant.

3. There are two effects that will become more significant the further the flush/solid is away from the WC flush source. These are:

   i) The WC flush wave will attenuate. Typically the wave will become more spread out and shallower. This will reduce the buoyancy provided by the flush wave.

   ii) The kinetic energy held in the flush wave will reduce. This is because energy is taken to overcome surface frictional losses and other head losses at bends/joints. This will reduce the horizontal forces available to move the solid.

These observations have previously been observed in other similar research, for example:

a) Littlewood and Butler (2003) described three mechanisms of solid movement:

   i) The “sliding dam” mechanism is observed mainly when the solid is large compared to the flush wave, therefore water builds up behind the solid. (The “sliding dam” is essentially the horizontal force pushing the solid)

   ii) The velocity decrement mechanism is observed when the size of the solid is small compared to the volume flushed. (This mechanism is essentially the buoyant solid moving in the body of the flush wave).

   iii) A combination of the above 2 mechanisms.

b) Walski et al. (2009) studied the movement of partially submerged large solids with specific gravity greater than 1. The conclusions included “that increasing the flow would more easily provide favourable conditions to move the partially submerged solid. Increasing the slope would not ensure conditions to move the solid."

11.3 Length of wave

The flush wave becomes attenuated by the pipe configuration and pipe surface frictional losses. Once re-entrained the solid will continue to be carried providing there is sufficient depth and horizontal force. As the tail of the wave is attenuated the solid becomes stranded irrespective of how long the attenuated flow continues.

The wave length will vary depending on flush volumes and gradient. This has been measured for the four WC flush volumes tested and the results are presented in Figure 11.1. As could be expected, the greater the WC flush volume, the longer the wave. Nevertheless, while the volume of the WC flush is tripled between the 2 litre and 6 litre flush, the length of the wave is only increased by between 54% and 80%, depending on the gradient considered.

The volume of water per unit length of pipe can be calculated and the average volume of water contained in a metre of pipe is presented in Figure 11.2. This clearly demonstrate that the greater the WC flush volume, the greater the water volume per metre of pipe and therefore the greater the depth of water in the drain/small sewer. This directly increases the buoyancy and the movement of the solid. Also, and importantly, the volume of water in the pipe per metre / depth of flow increases with decreasing gradient, as illustrated by a comparison of the 1:50 and 1:80 gradient curves.

The movement of a deformable solid is further described by McDougall & Wakelin (2007) as a combination of "momentum transfer from the surrounding water flow, buoyancy due to flow depth and gravitational and frictional forces". Moreover, the solid stops when the "surrounding flow is insufficient to support transport…...at any velocity below 0.2 m/s".

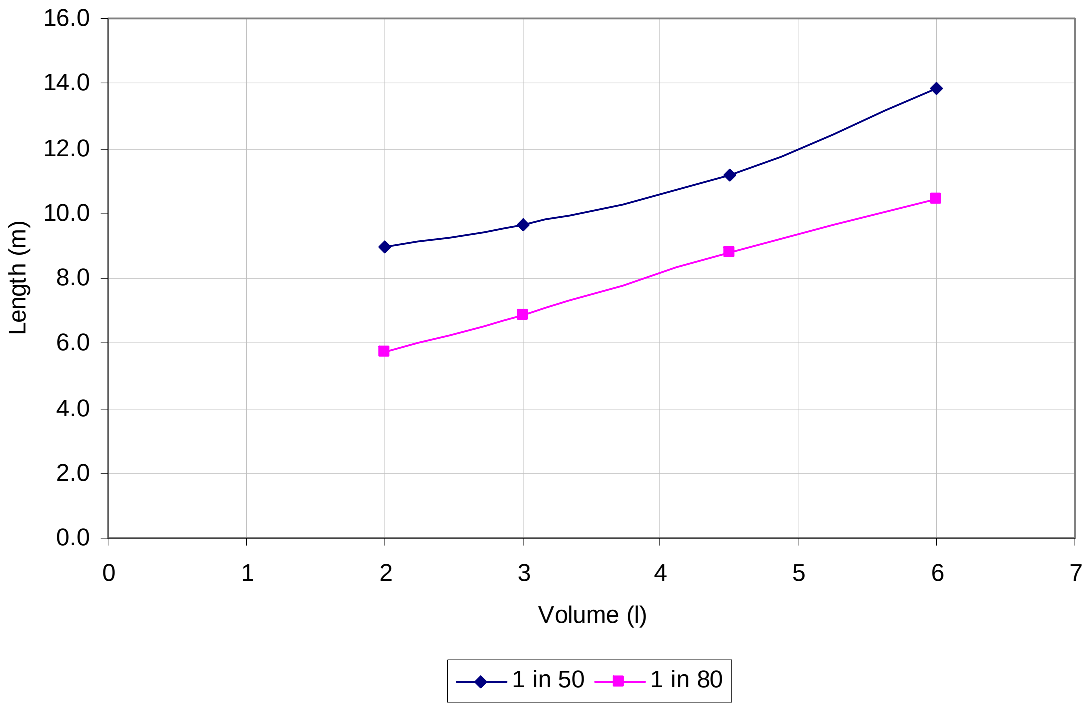


Figure 11.1 Length of the wave of water at the flush volumes investigated and different gradients.

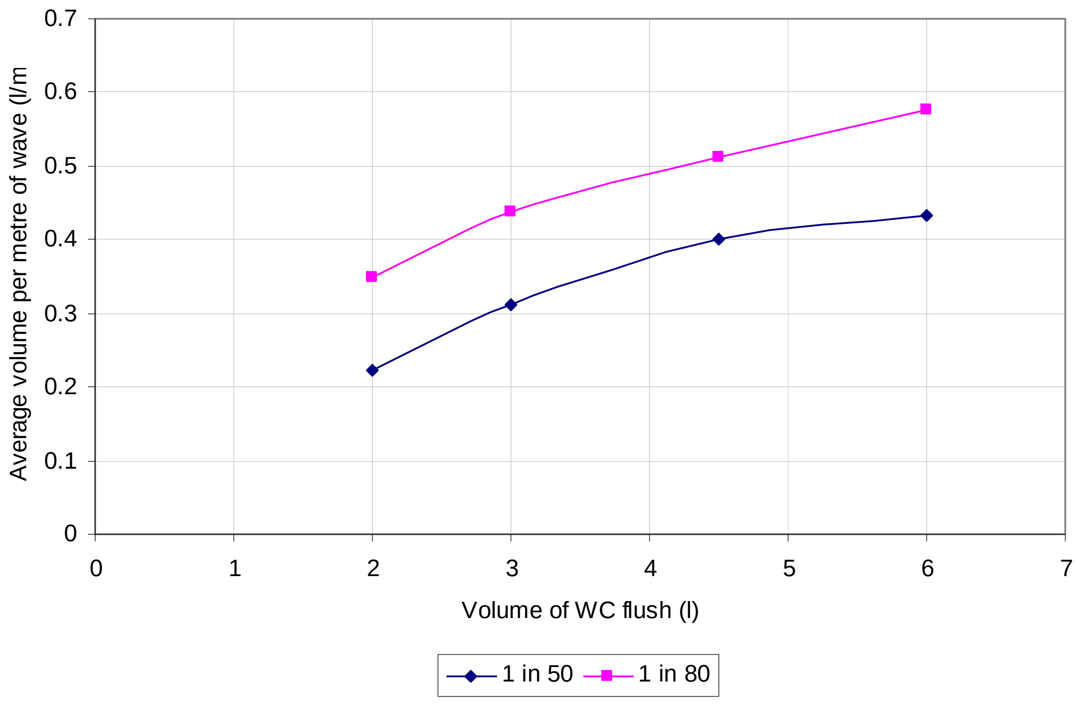


Figure 11.2 Average volume of water per metre of WC flush wave

11.4 Effect of paper

The effect of paper behind the solid significantly increases the distance travelled by the solid for all flush volumes and gradients. This is due to two main characteristics.

1. The increase of surface area presented to the horizontal flush wave. Most of the energy of the flush wave is transmitted via the paper dam to the solid whereas, with the solid alone, much of the energy is lost in the water that passes around the sides of the solid.

2. The increase in depth of water behind the paper. As the water passes around the paper dam, the depth reduces gradually from a relatively high depth/low velocity to a relatively low depth/higher velocity flow. The higher depths afforded by this gradually varying flow condition provide increased buoyancy to the solid immediately downstream of the paper dam, promoting movement.

The effect of the paper on the solid's movement will depend upon the orientation of the paper as it butts up against or around the solid. A uniform arrangement of the paper centrally positioned behind the solid provides the greatest benefit. However, with the paper in an offset position, water is allowed to pass along one side of the solid prematurely releasing the available energy. Photograph 11.1 shows the solid stranded because the flow is able to pass around the solid and not providing buoyancy to one side of the solid. This is despite flows being of a volume that would in different circumstances re-entrain the solid.

The position of the paper when its butts up against the solid can result in a significant variation in flow conditions around the solid. This in turn gives a much broader spread of sewer solid movement test results than was recorded for the tests for the Westminster solid alone.

It was also observed that pre-wetting the paper resulted in a rapid disintegration and the paper fragments were unable to form a dam at the rear of the solid. This would suggest that the beneficial effects recorded with the addition of paper may only be temporary and not continue for the duration the solid is in the drain.

Photograph 11.1 Paper offset with water escaping past one side of the solid

With the pipe installed at a gradient of 1:60 it was also observed that as the water escaped past the paper dam, the flow conditions changed from subcritical to supercritical. This resulted in a deep trough in the water surface alongside the solid, reducing the buoyancy to the solid as illustrated in Figure 11.3.

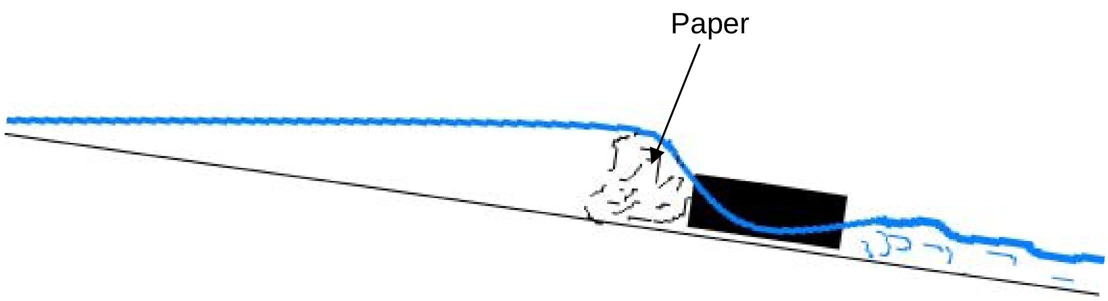


Figure 11.3   Effect of paper and steeper gradient

12. CONCLUSIONS

It should be noted that unless otherwise stated, all test results apply to pipes in good structural condition.

12.1 Effect of WC flush volume (Section 5)

- Initial results with the Westminster solid alone indicate that **2 litre and 3 litre flush volumes** discharged to a 100 mm pipe at a gradient of 1:80 are insufficient to carry the solid beyond 10 metres, i.e. nominally to beyond the next connection incorporating a WC. This reduced flush volume could result in a significantly higher risk of blockages.

  Conversely, **4.5 litre and 6 litre flush volumes** are sufficient to transport the solid beyond the nominal 10 metres, to beyond the next connection incorporating a WC.

- **The addition of paper with the solid** increases the travel distance of the solid for all flush volumes.

  However the 2 litre flush volume is still insufficient to transport the solid to beyond 10 metres. With the 3 litre flush the transport distance is borderline, i.e. the transport distance attains 10 metres during some of the tests and may be sufficient distance in some circumstances. The 4.5 litre tests are encouraging with a solid carry distance approaching 15 m. Results obtained with 6 litre flushes confirm the suitability of existing drain/small sewer design standards when using conventional WC flush rate.

- The **quantity of paper** (4 sheets, 8 sheets or 12 sheets of paper) does not appear to influence the distance travelled by the solid in the drain/small sewer.

- The benefit of paper behind the solid may only be temporary, due to the rapid disintegration of toilet paper in the drainline.

- The behaviour of **flushable products** does not vary significantly with the flush volume. These products do not present a risk of blockage when the pipe walls are smooth. Nevertheless, the presence of small defects significantly increases the risk of snagging and therefore blockages. With 2 litre flushes up to 70 % of products could snag, with 3 litre or higher flushes the proportion reduces to between 10 and 20%.

12.2 Effect of drainage layout within the property (Section 6)

- The use of a proprietary **low flush WC** does not alter the sewer solid carrying abilities once the flush has cleared the WC/u-bend and entered the drainline. This type of WC is essentially designed to enable better bowl clearance at low flushes. Similar distances are travelled by the solid with both the WC designed for low flush volumes and those designed for higher flush volumes, calibrated to 2 litres.

- The distance travelled by the solid using **upstairs WC** flushes is less than that generated by a flush from a downstairs WC when 2 litre and 3 litre flushes are used. However, the converse is true for 4.5 and 6 litre flushes. Thus, the additional energy brought about by the increased height of the upstairs WC is not beneficial with lower flushes.

- A **long radius bend** has certain advantages over a traditional pipe outlet arrangement from the house. Less energy is taken out of the flush wave at joints/changes of direction and, whilst this is of negligible significance for the higher flush volumes, the arrangement may be of benefit for low flush volumes, in particular 2 litres.

- One of the reasons why the upstairs WC discharge was detrimental to solid flow movement at lower flushes (2 and 3 litres) was the tendency for the water and solid to separate in the soil stack. The solid falls down the stack in advance of the water which spirals around the inner wall of the stack. A **smaller diameter soil stack was used** to examine if this separation effect was minimised. The 82 mm stack has a positive effect on the solid travel distance with 2 and 3 litre flushes. Unfortunately, the distance reached remained less than the distance travelled with the use of the downstairs WC and less than the nominal 10 metres required.

12.3 Effect of drain characteristics/condition on solid movement (Section 7)

- The **frequency of joints** in the drain/small sewer does not have a significant effect, providing the joints are small and well made.

- **Pipe material** has little or no influence on the distance travelled by solids provided the pipe's characteristics are the same, for example sleeve jointed plastic or modern clay pipes.

- **Defects** have the ability to adversely affect the distance travelled by a sewer solid. These defects include offset and pulled joints and rough internal surfaces of pipes. In general, the greater the defect the more detrimental this will be.

- **Old clay pipes** reduce the transport ability of low flows due to the rougher internal surface and frequency of poor joints.

12.4 Effect of retrofitting to existing drainage systems (Section 8)

- Previous comments on pipe characteristics also apply to the retrofitting of property discharging to existing drainage systems.

- An **interceptor** impedes the free passage of solids along the drain/small sewer. Flushable products pass through the interceptor using the higher flush volumes (6 litres) but the decrease of the flush volume below 6 litres significantly affects the ability to pass through the interceptor.

12.5 WC flush patterns and non WC discharge transport characteristics (Section 9)

- Solids are moved by a combination of the buoyancy and the horizontal force provided by the flush wave. The horizontal force will reduce with distance travelled and obstacles/defects encountered. The majority of the remaining horizontal force will be dissipated by the action of the wave hitting a solid – much of the force will be transferred from the wave to the solid. This means that, if there is a second solid further down the pipe, there will be little force left to move this second solid. Thus:

i) The addition of a **second solid** slows the progress of the first solid by absorbing the energy of the wave.

ii) When **two solids** are grouped together in the pipe, the energy required to re-entrain the combined group is higher. Therefore a greater flush wave is needed to move the solid, compared to a single solid at the same distance from the WC.

- Previous WRc research has shown that 75% of WC flushes do not involve solids and therefore could be at the lower flush volume of a dual flush cistern. However, this research has shown that the lower flush volumes (3 litres) have little beneficial effect on the transport of the solid. Therefore, in practice only one flush in four will move the sewer solids along the pipe.

  From a sewer solid movement perspective it may be beneficial to reduce the lower flushes (which do little to move the solids) and use this water saving to increase the volume of the higher flushes (which will increase the solid movement). (A reduced low flush volume would need to obtain adequate WC bowl clearance).

- The minimum flow rate at which the solid starts moving is between 0.25 l/s and 0.3 l/s. This is normally attained for a short period in 4.5 or 6 litre volume WC flushes but not in 2 or 3 litre volume WC flushes. Similar flow rates can also be obtained for a short period from a traditional bath discharge and, to a very limited extent, from a high flow shower head.

12.6 Effect of the change of gradient (Section 10)

- Increasing the **gradient** of the pipe from 1:80 to 1:60 (and 1:50) marginally improves the distance travelled by the Westminster solid. Nevertheless, the increase is still insufficient to transport a solid to beyond 10 metres with 2 and 3 litre WC flushes at 1:60 and is only borderline with 3 litres flushes at 1:50.

  Thus increasing gradient in isolation to any other alterations will not be sufficient to solve potential sewer solid movement problems.

12.7 Overall conclusions

1. 2 litre and 3 litre flush volumes are insufficient to carry the solid at least 10 metres, i.e. nominally to beyond the next connection incorporating a WC.

2. The addition of paper with the solid increases the effect of the WC flush wave. However, this is a temporary benefit, due to the rapid disintegration of the paper in the drain.

3. Flushable products do not present a risk of blockage when the pipe walls are smooth. However, the presence of small defects significantly increases the risk of snagging and therefore blockages. With 2 litre flushes up to 70 % of products could snag, with 3 litres flushes and higher the proportion reduces to between 10 and 20%.

4. WC's specifically designed for low flush volumes focus on WC bowl clearance. They do not give improved flow patterns in the downstream drain and as such do not enable sewer solids to travel further.

5. Upstairs WC discharges of 2 litres via a 100 mm dia. soil stack do not have the energy to re-entrain the solid deposited at the base of the stack.

6. The sewer solid flow characteristics from both 2 and 3 litre 'upstairs' discharges are worse than those from a comparable 'downstairs' discharge. Conversely, 4.5 and 6 litre discharges from 'upstairs' give better sewer solid transport characteristics to those from 'downstairs' discharges.

7. An improvement in solid transport due to the use of alternative property connection arrangements only provides marginal benefits for low flow discharges. These improvements include:

   - More energy efficient pipe arrangements between the WC discharge and entering the drainline.

   - Reduced diameter soil stacks – the minimise soil – water separation in the stack.

8. The frequency of joints in the drain/small sewer does not have a significant effect, providing the joints are small, well made and in generally good condition.

9. Joint defects can significantly reduce the distance travelled by a sewer solid. These defects include offset and pulled joints, as well as rough internal surfaces.

10. Pipe material has little or no effect on the distance travelled by sewer solids, provided that the pipe's internal physical characteristics are similar.

11. The condition of the pipe work must be established before retrofitting of water saving appliances to properties connected to existing drains. This includes both low flush WCs and the replacement of baths with showers.

12. Retrofitting of low flow appliances should not be considered in systems with an interceptor trap. Similarly, care should be taken when retrofitting in property that connects to drainage systems in potentially poor condition.

13. Whilst WC flushes are the main vehicle for sewer solid movement, other discharges that enable a flow rate of 0.3 l/s or greater can be important. These enable the solid, once re-entrained, to be transported due to the constant flow. Typically these conditions are provided by an emptying bath. Considering the trend for more showering than bathing, the WC flush (albeit reduced) still remains the most frequent and reliable event for sewer solid movement.

14. Water saving shower heads do not re-entrain the solid, standard high flow shower heads can re-entrain the solid but transport is minimal.

15. Discharge of a second solid to the drain reduces the energy available to re-entrain the first solid. In practice this means that a solid's movement will be severely impaired once a second solid is discharged. The overall distance travelled by the solids will be less than would have been the case if only a single solid had been discharged.

16. The increase of gradient does not have a significant effect on transport of the solid with 2 or 3 litre flushes. This is due to changes in the hydraulic characteristics of the wave, i.e. faster and shallower, thereby reducing the ability of the flush wave to give buoyancy to the solid.

13. RECOMMENDATIONS

13.1 Recommendations

- A minimum flush volume of 4.5 litres should be used as it is necessary to transport solids in drains and sewers to a minimum distance of beyond 10 metres.

- Pipe configuration guidance should be reviewed to reduce energy loss in the pipe work connections adjacent to the property.

- Where installation of water saving appliances is proposed for new residential developments the hydraulic design and supervision of the installation of the drains must be given a high priority. This is to ensure that the gradients are correct and there are no joint defects

- Detailed consideration must be given to the condition of existing drainage pipes when retrofitting property with water saving appliances that connect to the existing pipe systems.

- Increasing the pipe gradient to greater than 1:80, as a solution to the anticipated sewer solid transport problems associated with the installation of water saving appliances, may not be the answer. The results of this study indicate that increasing the gradient would not guarantee hydraulic conditions suitable for transporting solids a minimum of 10 metres.

  Other measures such as altering the low and high flushes in a dual flush WC may be more beneficial (see paragraph 13.2.1 below). This requires further investigation.

- It would be advantageous for discussions to take place between interested parties to agree a way forward with regard to future foul drainage layouts leading from and close to residential property. These discussions should, inter alia, consider:

  - The need for different designs brought about by the changing styles of housing, i.e. more terraced town housing and less detached / semi detached property.

  - The increasing trend towards the use of wet rooms at the front of property.

  - The effect of reduced water usage on sewer solid flows, i.e. the need for shorter lengths of drain that take very limited volumes of flow.

13.2 Way forward

13.2.1 New design and construction

- Consideration should be given to adjusting the volume ratio of dual flush cisterns so that the low flush is lower and the high flush is higher. This could be achieved, for example, by reducing the lower flush volumes by 0.33 litre and increasing the higher flush volume by 1 litre. It would be necessary to ensure that any such change would not impede the ability of the WC bowl to be cleaned by the lower flush.

- Further investigations to look at the feasibility of rearranging typical drainage layouts should be considered. Such alterations could help to counter the negative impact on sewer solid movement brought about by the reduced usage of water in devices such as a WC. An example could be a shorter pipe length and a more direct connection from the WC (limiting the number of bends for example) to the sewer. In doing so this would reduce the pipe friction and the energy losses in flows from the house to the sewer.

- Predictions of WC, shower, bath and other water device usage are available for the year 2020. These could be investigated to predict the scale of potential blockage problems.

- Consider the installation of devices specifically designed to offset deposition of solids in the drain due to low flows. These include a new generation of grey water flushing devices and alike.

13.2.2 Retrofitting water efficient devices in existing catchments

- The installation of water efficient devices in existing catchments might cause problems, especially since the drain / sewer has been designed for much higher flows.

  The retrofitting with water saving devices of property discharging to old clay pipe systems is likely result in an increased number of blockages. This is especially so for drains equipped with an interceptor. Problems such as blockages or the accumulation of solids and/or flushable products are likely to occur at the interceptor and/or joints in the old clay system.

- Further investigation may be beneficial to determine the relationship between the installation of water saving devices and blockage occurrence. This will depend upon physical characteristics of the sewer system, including the structural condition of the pipes and joints.

13.2.3 Getting the best out of water conservation measures, whilst at the same time ensuring that flow regimes enable adequate sewer solid movement

See recommendation in 13.2.1, first bullet point.

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