Solid Transport in near horizontal drainlines

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Solid Transport: mechanism and modelling

- Background
- Modelling flows/attenuating waves
- Choice of Solid simulator
- Extra large solids/ partial blockages
- Movement thresholds
- Modelling example
- Conclusions
Background

- Engineering modelling of solid transport inside buildings since the 1970s
- Informed Government policy
- Enabled reduction in water volume used by appliances
- And now allows for the continued monitoring and assessment of these water volume reductions.
Water consuming appliances

UK domestic water usage data, Griggs and Shouler (1994).
How is water used?

UK – Breakdown of water consuming appliances (2007)
Flush Volume Reduction
Laboratory investigations

- Attenuating flows
- Adjoining flows
- Junction effects
- Hydraulic Jump
- Non-woven products (wipes) transport
- Single solid transport
- Multiple solid transport
- Large solids/ partial blockages
Method of Characteristics Modelling

Mathematical basis – Solution of the St. Venant Equations of continuity and momentum

\[ A \frac{\partial V}{\partial x} + V T \frac{\partial h}{\partial x} + T \frac{\partial h}{\partial t} = 0 \]

\[ g \frac{\partial h}{\partial x} + g(S - S_c) + V \frac{\partial V}{\partial x} + \frac{\partial V}{\partial t} = 0 \]

Provided that:

\[ \frac{\partial V}{\partial t} \pm \frac{g}{c} \frac{\partial h}{\partial t} + g(S - S_c) = 0 \]

\[ \frac{\partial x}{\partial t} = V \pm c \]
Laboratory test rig
Solid Position Measuring System

System secured with Velcro straps for ease of set-up and adjustment.

- L 500mm
- $V_{s1}$
- Infra red emitter in solid
- Infra red detector with digital Schmidt output
- Counter
- To Data Acquisition PC
Laboratory set-up
Solids used in laboratory
Solid in a steady flow
Multiple Solids in a steady flow
Solids used for modelling large accumulations or partial blockages
Large Accumulated Solids
Partial blockage : leak past
Mathematical modelling: Attenuation dependencies
Mathematical modelling: Velocity decrement Zones

Definition of the three zone model of solid transport in attenuating flows.

Zone 1 - deformable solids compressed on discharge to branch. Initial deceleration on contact with drain surfaces followed by acceleration as discharge flow increases.

Zone 2 - deformable solids extend in deeper flow, solid velocity linked to surrounding water velocity by a decrement factor.

Zone 3 - deformable solids compressed, solid velocity dependent upon dammed water volume behind solid and leakage rate past the solid.
Mathematical modelling: Solid characteristics in a flow
Mathematical modelling: Mach model

Solid Velocity against normal depth wavespeed
Mach model for interacting solids
Model outputs: Depth profile due to presence of solid

Pipe diameter = 100mm  Pipe So= 0.01  Solid dia=36mm  Solid Sg=1.05Qw= 1l/s

Modification of flow depth as solid moves along pipe
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Modification of flow depth as solid moves along pipe
Model Outputs: Depth profile for interacting solids

- Pipe diameter = 100mm
- Pipe So = 0.01
- Solid dia = 25mm
- Solid Sg = 1.05
Model Outputs: Depth profile for interacting solids

Pipe diameter = 100mm
Pipe So = 0.01
Solid dia = 25mm
Solid Sg = 1.05

Inflow Profile

Water depth (mm)

Time

Distance (m)

Solid 1
Solid 2

0 10 14
10 16 21 26
2.5
0.8

0 1 6 11 16 21 26
50 40 30 20 10
Model Outputs: Depth profile for interacting solids

Pipe diameter = 100mm  Pipe So= 0.01
Solid dia=25mm  Solid Sg=1.05

Surge wave arrives and envelopes solid 2

Inflow Profile

Water depth (mm)

Distance (m)
Model Outputs: Depth profile for interacting solids

![Diagram showing depth profile of interacting solids](image-url)

- **Pipe diameter**: 100mm
- **Pipe So**: 0.01
- **Solid diameter**: 25mm
- **Solid Sg**: 1.05

**Inflow Profile**

- **Surge wave overtakes solids**

**X-axis**: Distance (m)

**Y-axis**: Water depth (mm)

**Time**: Solid 1, Solid 2

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**Note**: The diagram illustrates the depth profile for interacting solids within a pipe, showing the movement and interaction of solids with a surge wave.
Critical Distances
Conceptual model for large accumulated solids in long pipe runs (no adjoining flows)
Solid movement threshold

\[ H_n = \left( (2.643 \times 10^{-7} \times B^{0.78} - 9.064 \times 10^{-8}) \times D^{3.784} + 8.384 \right) \times S + 4.72 \]

Where
- \( H_n \) = normal water depth
- \( B \) = % blockage
- \( D \) = Pipe Diameter
- \( S \) = Specific gravity
Validation of model for large accumulated solids

![Graph showing predicted depth vs. actual depth with an R² value of 0.9782.](image)
Example: 41 m test rig

41 m (135 ft) test rig in 3 m (10ft) lengths with swept bends
Maximum transport distance for 6litre/4.5 litre flush in pipes of different diameter set to different slopes
Test Results Solid transport in 75 mm (3 in) pipe

- 40 litres (1.0 USG)
- 35 litres (0.9 USG)
- 30 litres (0.8 USG)
- 25 litres (0.7 USG)
- 20 litres (0.5 USG)
- 15 litres (0.4 USG)
- 10 litres (0.3 USG)
- 5 litres (0.1 USG)
- 0 litres (0.0 USG)

Distance (metres)

Time (seconds)
Test Results Solid transport in 100 mm (4 in) pipe

- 6 litre (1.6 USG slope = 1/50)
- 3 litre (0.8 USG slope = 1/50)
- 4.8 litre (1.28 USG slope = 1/50)
- 6 litres (1.6 USG) slope 1/100
- 4.8 litre (1.28 USG slope 1/100)
- 3 litres (0.8 USG slope = 1/100)
Average number of flushes to clear 41m

- 3 litre (0.8 USG) flush
- 4.8 litre (1.28 USG) flush
- 6 litre (1.6 USG) flush

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<th>Diameter (mm)</th>
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Conclusions

- Modelling solid transport is as important now as it’s ever been.
- Water conserving strategies must take solid transport into account, however a pragmatic approach is required.
- WC characteristics are important close to the point of discharge – less so, further down stream.
Conclusions continued

• Critical transport distances (distance to adjoining flows) are very important and cannot be ignored.

• There is a maximum distance solids can travel given a fixed set of system parameters – design codes should recognise this.

• Innovative methods are required to ensure systems are kept clear in a system without adjoining flows.
Thank you for listening