Investigation of the Flow Field inside a Drainage System: Gully – Pipe - Manhole

Md Nazmul Azim Beg¹,2, Rita F. Carvalho¹, Jorge Leandro¹, Pedro Lopes¹ and Lincoln Cartaxo¹

¹MARE - Marine and Environmental Research Centre
Department of Civil Engineering, University of Coimbra,
Coimbra, Portugal

²Early Stage Researcher, Marie Curie Actions ITN (QUICS)

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Introduction

One of the busiest city in Dhaka, due to 46mm of rainfall in one and a half hour; on afternoon of September 1, 2015. 
*Photo Credit: The Daily Star on September 2, 2015.*

Pluvial flooding at City centre of Coimbra on May 2006 

Chertsey, UK on February 11, 2014 
*Photo source: The Guardian on 11 February, 2014*
Introduction

• Flooding is one of the biggest threats for a busy urban city

• The urban drainage system is responsible for safe routing of flood water; hence an efficient drainage is mandatory

• Drainage system efficiency is dependent on the individual efficiency of each element

• Gully and Manhole are two common elements of an urban drainage system

• Flow analysis inside these structures can lead to a better understanding of the efficiency of a drainage system
Objective

• To validate CFD model with experimental measurement at the laboratory
• To analyse the different flow behaviour inside a gully-manhole drainage system
Methodology

Physical Model set up

The physical model facility is installed at the Department of Civil Engineering, University of Coimbra.

- 1m diameter manholes
- Connected by a Ø300 sewer pipe
- 0.5m wide and 1% slopped surface channel
- $0.6 \times 0.24 \times 0.32$ [m] ($L \times W \times D$) gully
Methodology

Numerical Model set up

- cfMesh
- Mesh size 2cm
- 1 cm at the boundaries
- 821,500 computational with 1.01 million nodes

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Field Data collection
Methodology

OpenFOAM simulation

- OpenFOAM v. 2.3.0
- *interFOAM* solver: considering isothermal, incompressible and immiscible two-phase flow (air and water for this case)
- Mass and Momentum conservation

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0
\]

\[
\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \mathbf{u}) = -\nabla p^* + \nabla \cdot \mathbf{\tau} + \mathbf{g} \cdot \nabla \rho + \mathbf{f}_\sigma
\]

- Uses Volume of Fluid (VOF) method (Hirt and Nichols 1981) to track the free surface or interface location
- RAS k-\(\varepsilon\) turbulent model was used
- PISO algorithm is used
Methodology

Tests performed

• Numerical model: combination of two different experimental studies:
  1. only the manhole with inlet and outlet pipe were used; a flow of 43.7 l/s was applied through the manhole inlet.
  2. flow through the drain and gully was observed; 19.8 l/s flow was measured at the upstream of the drain inlet

• Two different Numerical simulations are tested

<table>
<thead>
<tr>
<th></th>
<th>Drain inlet Q (l/s)</th>
<th>Manhole inlet Q (l/s)</th>
<th>Manhole surcharge level (m)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation 1</td>
<td>19.8</td>
<td>43.7</td>
<td>0.67</td>
<td>Experimental case scenario</td>
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<tr>
<td>Simulation 2</td>
<td>19.8</td>
<td>43.7</td>
<td>1.29</td>
<td>Additional scenario</td>
</tr>
</tbody>
</table>

• 40 seconds of run to reach steady state condition
• Each steady state simulation took 138hrs using 16 processors
Results

Comparison with experimental tests performed

• During the experimental study, velocity at the gully was observed at three plane using Nortec Vectrino acoustic velocimeter

• The first and the third plane are at 5 cm distance from the longitudinal walls of the gully

• The second plane is the central plane

• Each plane contained 121 velocity measurements
Results

Comparison with experimental tests performed
Results

Comparison with experimental tests performed

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<thead>
<tr>
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<tbody>
<tr>
<td></td>
<td>X=0.1m</td>
<td>X=0.2m</td>
<td>X=0.3m</td>
<td>X=0.4m</td>
<td>X=0.5m</td>
<td>Avg.</td>
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<tr>
<td>P 1</td>
<td>0.060</td>
<td>0.014</td>
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<td>-0.068</td>
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<tr>
<td>P C Vx</td>
<td>-0.223</td>
<td>-0.034</td>
<td>-0.024</td>
<td>-0.009</td>
<td>0.186</td>
<td>-0.021</td>
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<tr>
<td>P 2</td>
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<td>Avg.</td>
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<td>Avg.</td>
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<tr>
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<td>0.993</td>
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<tr>
<td>P C Vx</td>
<td>0.817</td>
<td>0.964</td>
<td>0.974</td>
<td>0.998</td>
<td>0.931</td>
<td>0.937</td>
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<tr>
<td>P 2</td>
<td>0.994</td>
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<td>0.985</td>
<td>0.992</td>
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<tr>
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<td>0.274</td>
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<tr>
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<td>0.233</td>
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<tr>
<td>Avg.</td>
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<td>0.591</td>
<td>0.335</td>
<td>0.830</td>
<td>0.571</td>
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</tr>
</tbody>
</table>
Results

Pressure at the bottom

• The pressure at both the gully and manhole bottom are not uniform
• Higher pressure near the drain outlet and lower pressure at the inlet
• Difference between the max and min pressure is in the range of 300Pa and 200Pa at gully and manhole bottom respectively
Results

Wall shear stress at the bottom

- Like pressure map, the wall shear stress is not uniform
- The shear stress direction is opposite to the flow
- For gully, higher shear stress near the gully outlet
- For manhole, higher shear stress near the central axis
- The shear stress pattern is asymmetric for the manhole bottom, probably a result of gully inflow
Results

Streamline

- Flows coming from gully and manhole inlet becomes well mixed inside manhole
- Surcharge level has influence in the vortex formation
- Fraction of the flow from drain inlet goes inside the gully and later comes out to the drain
- The gully outlet flow occupies partial area of the pipe

<table>
<thead>
<tr>
<th>Flow distribution</th>
<th>Drain Inlet</th>
<th>Drain Outlet</th>
<th>Gully Pipe</th>
<th>Manhole Pipe Inlet</th>
<th>Manhole Pipe Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow (l/s)</td>
<td>19.80</td>
<td>11.80</td>
<td>8.0</td>
<td>43.70</td>
<td>51.70</td>
</tr>
</tbody>
</table>
Conclusion

• The work presented shows the first step numerical assessment of flow behaviour inside a gully-manhole drainage system

• OpenFOAM® v. 2.3.0 with solver interFOAM was used with RANS k-ε turbulence model

• Numerical model shows good agreement with measured velocity at the gully

• Flow streamline show different characteristics with change in surcharge level in the manhole.
Future Work

• The model will be validated with flow measurement inside the manhole

• The work will be further developed to better understand the particulate transport phenomena inside the drainage system
Thank you for your attention

Nazmul Azim Beg
Email: mnabeg@uc.pt
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