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

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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
Photo Source: http://www.raingain.eu/en/actualite/flood-solutions-north-south-europe

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

Introduction

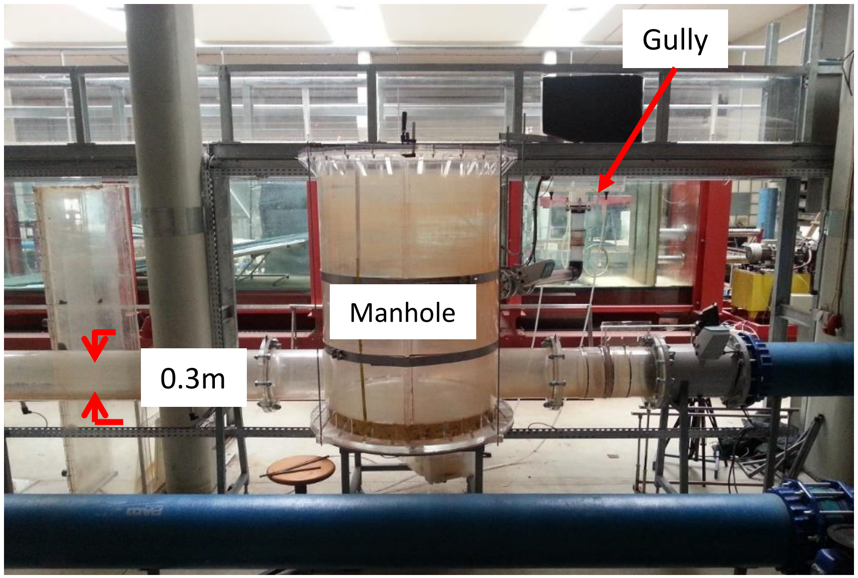
- Flooding is one the of biggest threats for a busy urban city
- The urban drainage system is responsible for safe routing of flood water; hence an efficient drainage is mandatory
- Drainage system efficiency is dependent on the individual efficiency of each element
- Gully and Manhole are two common element of an urban drainage system
- Flow analysis inside these structures can lead to a better understanding of the efficiency of a drainage system

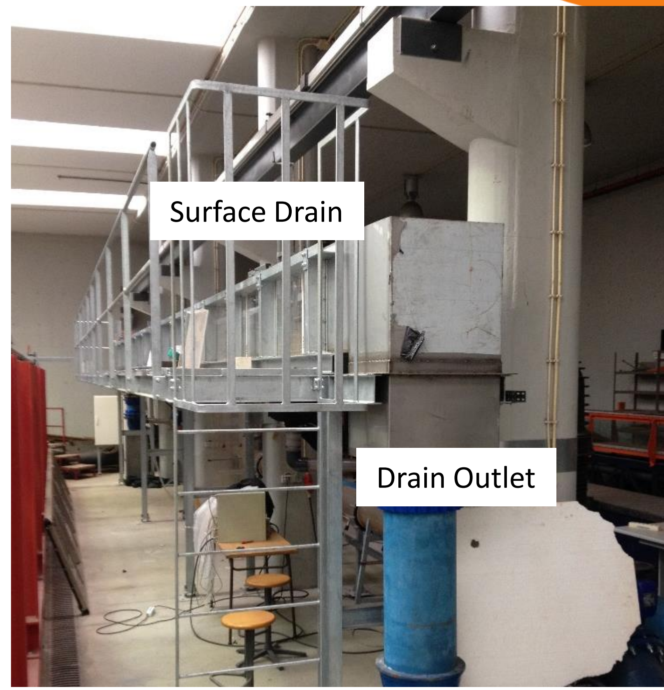
Objective

- 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



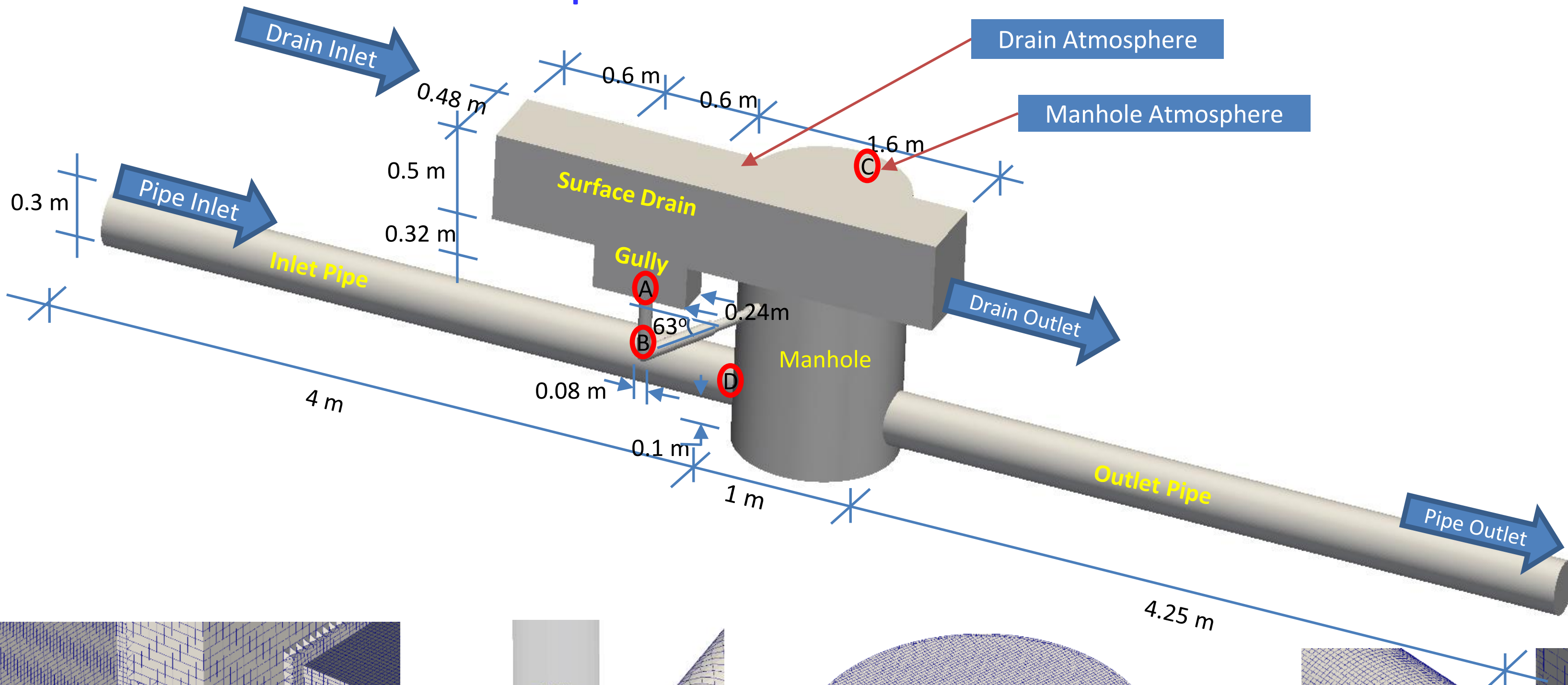


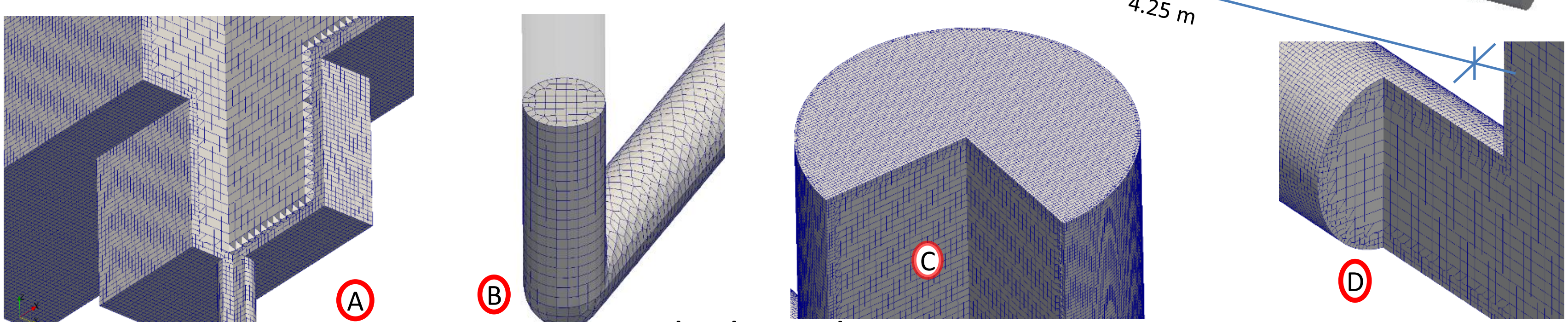
The physical model facility is installed at the Department of Civil Engineering, University of Coimbra.

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

Methodology

Numerical Model set up





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

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

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho \boldsymbol{u}) = 0$$

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \nabla . (\rho \boldsymbol{u}\boldsymbol{u}) = -\nabla p^{*} + \nabla . \tau + \boldsymbol{g} . \boldsymbol{x} \nabla \rho + \boldsymbol{f_{\sigma}}$$

- Uses Volume of Fluid (VOF) method (Hirt and Nichols 1981) to track the free surface or interface location
- RAS k-ε 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

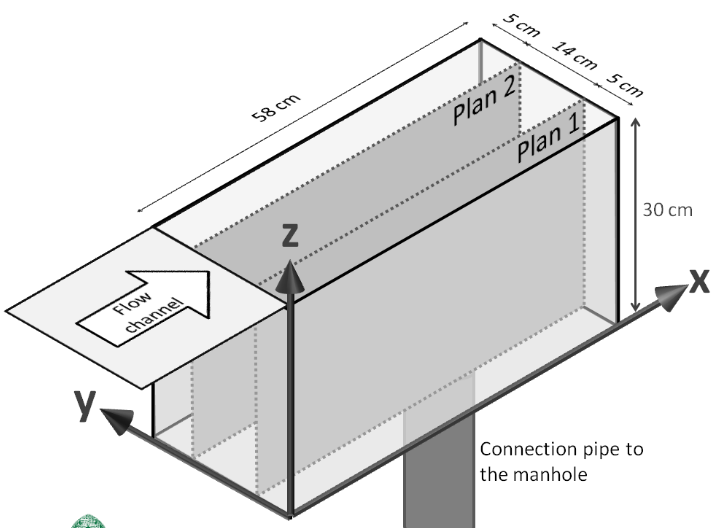
	Drain inlet Q (l/s)	Manhole inlet Q (l/s)	Manhole surcharge level (m)	Remarks
Simulation 1	19.8	43.7	0.67	Experimental case scenario
Simulation 2	19.8	43.7	1.29	Additional scenario

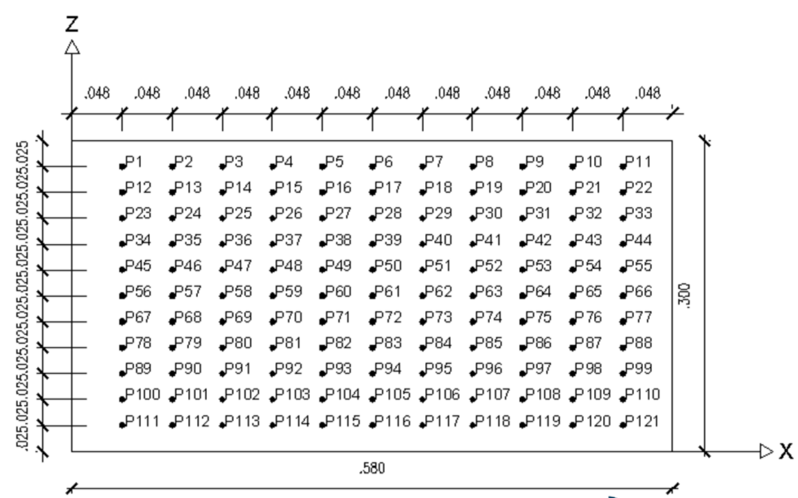
- 40seconds of run to reach steady state condition
- Each steady state simulation took 138hrs using 16 processors

Results

Comparison with experimental tests performed

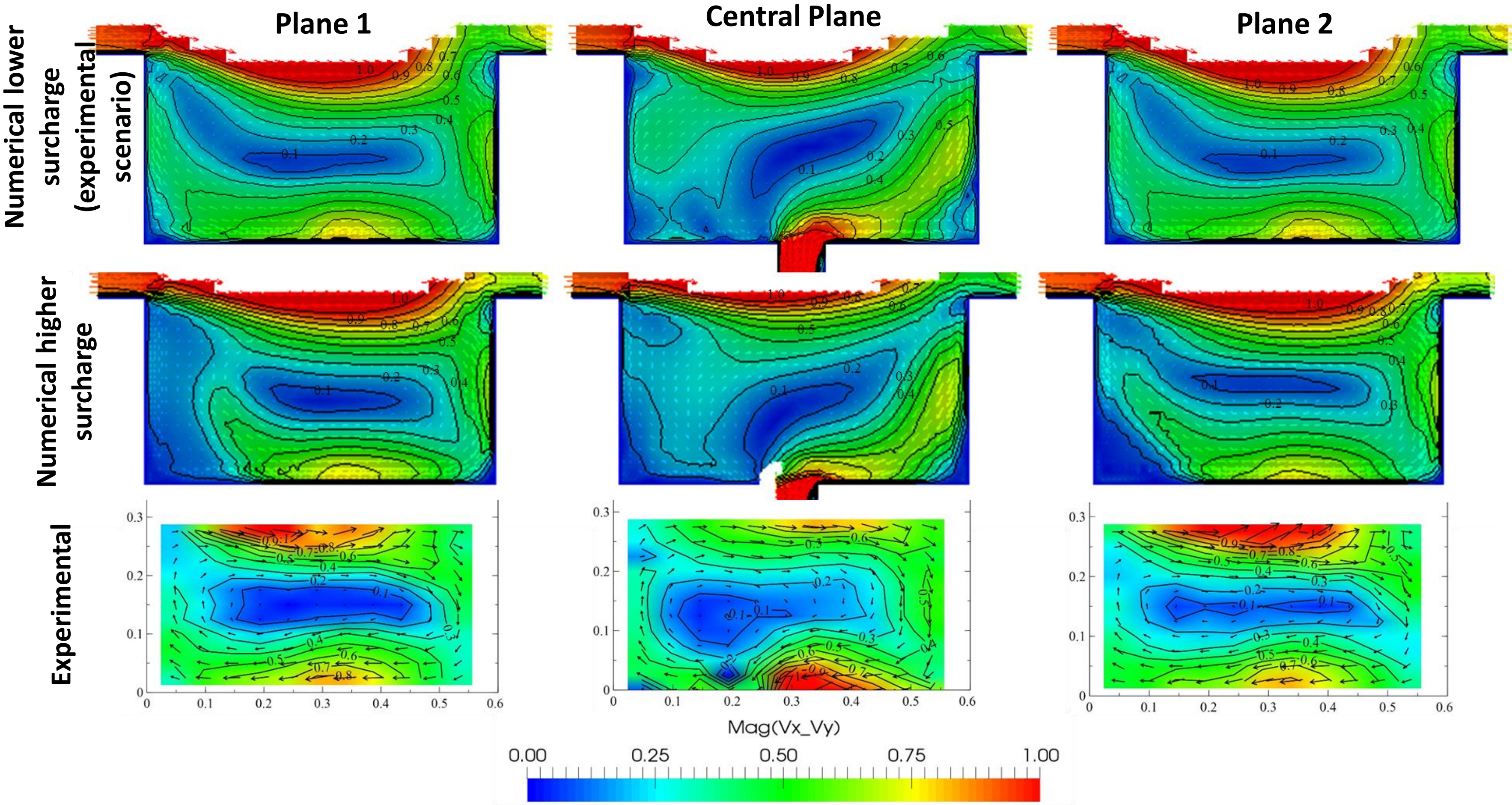
- During the experimental study, velocity at the gully was observed at three plane using Nortec Vectrino acoustic velocimeter
- The first and the third plane are at 5 cm distance from the longitudinal walls of the gully
- The second plane is the central plane
- Each plane contained 121 velocity measurements





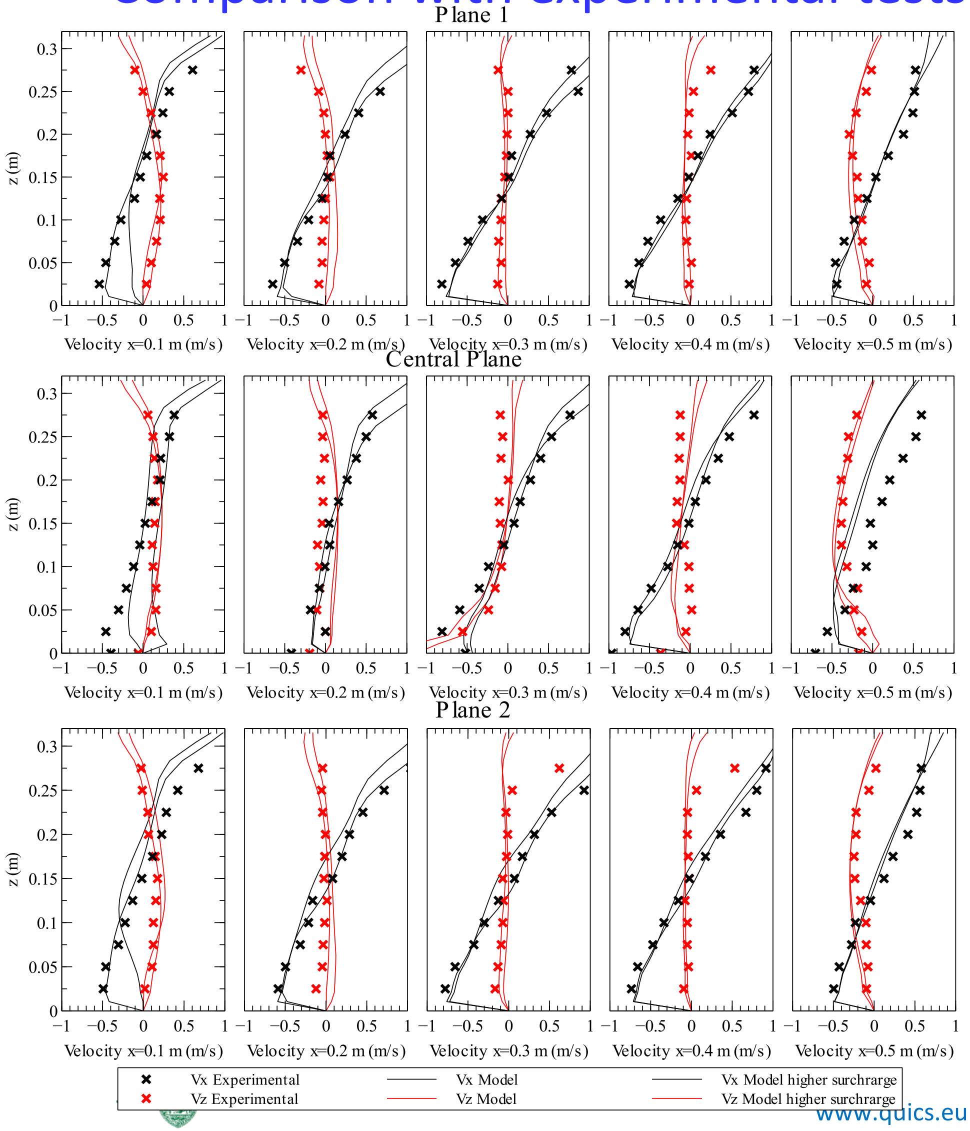
Results

Comparison with experimental tests performed



Results

Comparison with experimental tests performed



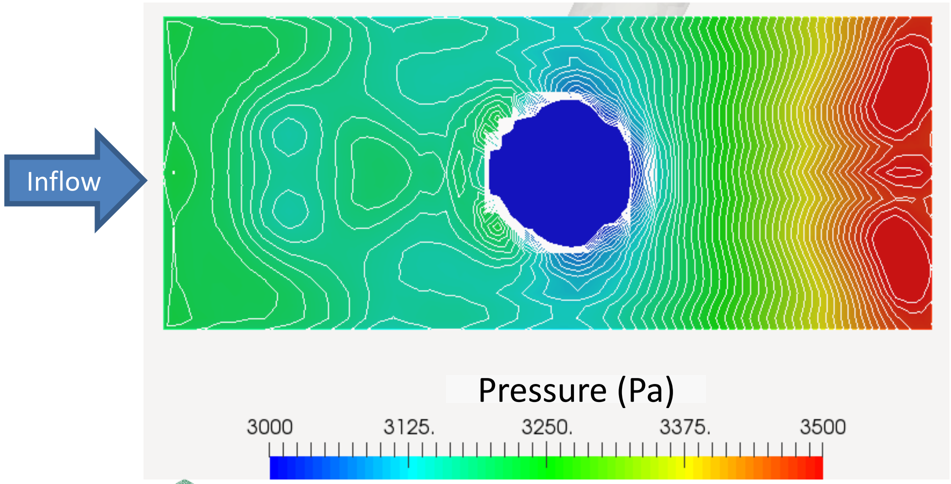
		BIAS					
		X=0.1m	X=0.2m	X=0.3m	X=0.4m	X=0.5m	Avg.
P 1	Vx	0.060	0.014	-0.078	-0.068	-0.007	**-0.016**
P C		-0.223	-0.034	-0.024	-0.009	0.186	**-0.021**
P 2		0.096	0.023	-0.010	-0.016	0.028	**0.024**
Avg.		-0.023	0.001	-0.037	-0.031	0.069	**-0.004**
P 1	Vz	0.004	-0.031	0.009	0.072	0.073	**0.025**
P C		-0.020	-0.141	0.015	-0.020	0.021	**-0.029**
P 2		-0.029	-0.021	0.069	0.079	0.089	**0.037**
Avg.		**-0.015**	**-0.064**	**0.031**	**0.044**	**0.061**	**0.011**

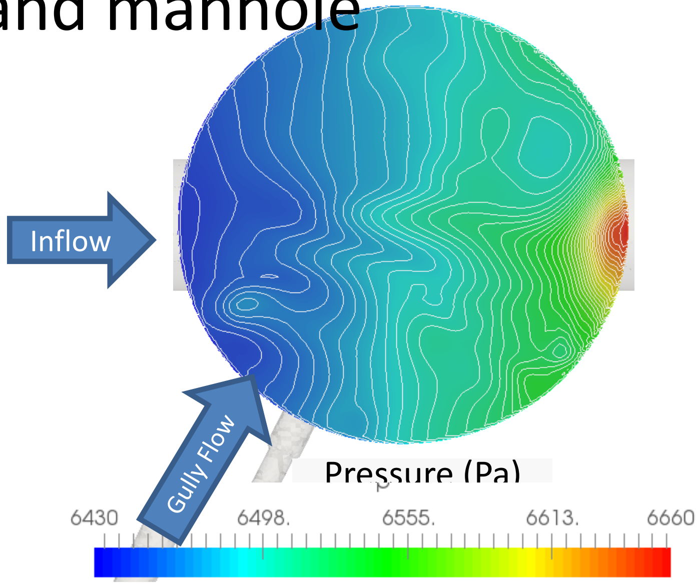
		r					
		X=0.1m	X=0.2m	X=0.3m	X=0.4m	X=0.5m	Avg.
P 1	Vx	0.993	0.985	0.988	0.996	0.981	**0.988**
P C		0.817	0.964	0.974	0.998	0.931	**0.937**
P 2		0.994	0.993	0.996	0.992	0.985	**0.992**
Avg.		0.935	0.981	0.986	0.995	0.966	**0.972**
P 1	Vz	0.932	0.834	0.728	0.891	0.845	**0.846**
P C		0.600	-0.221	0.917	-0.731	0.806	**0.274**
P 2		0.920	0.233	0.129	0.845	0.840	**0.593**
Avg.		**0.817**	**0.282**	**0.591**	**0.335**	**0.830**	**0.571**

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

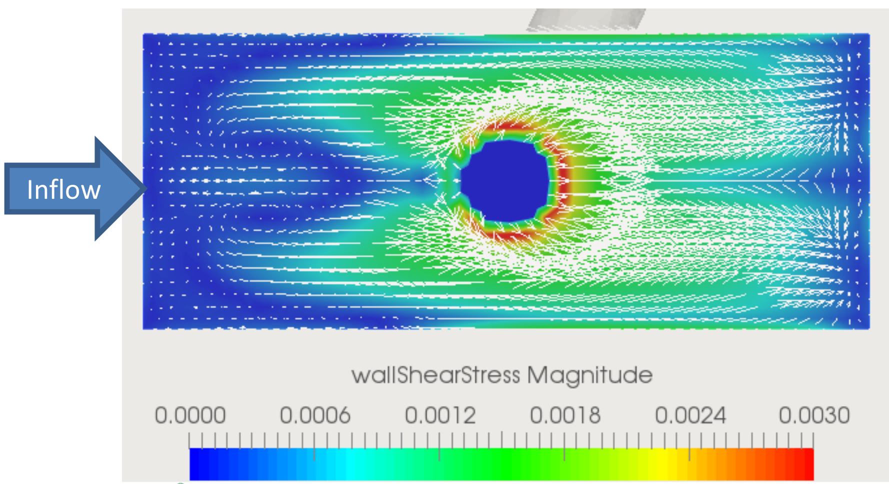


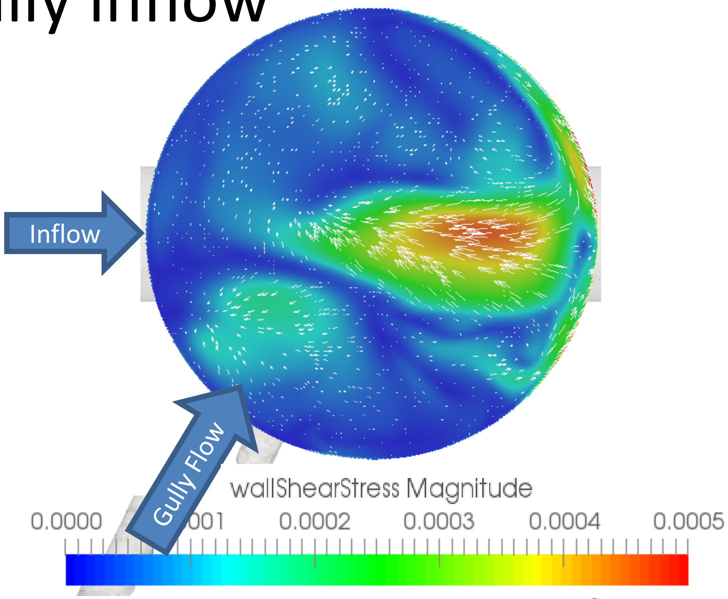


Results

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



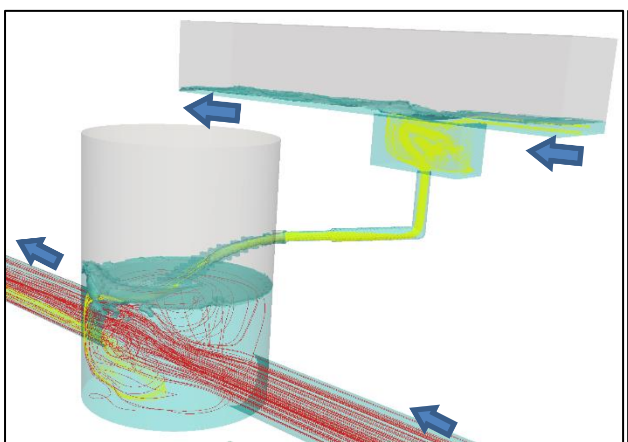


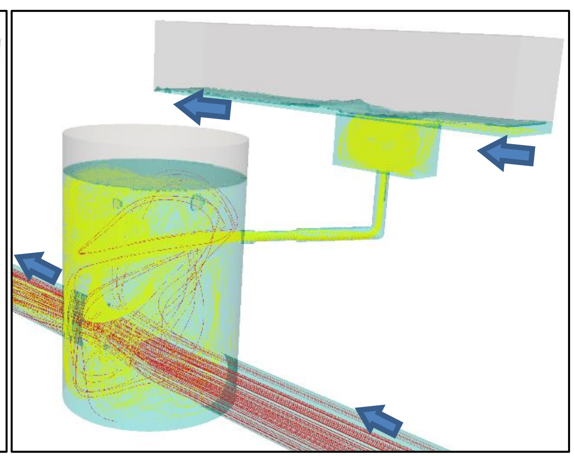
Results

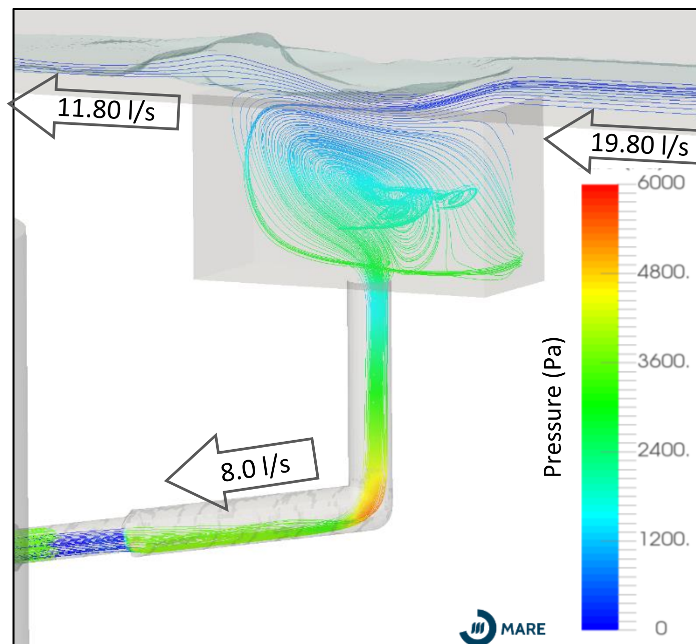
Streamline

- 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

Flow distribution	Drain Inlet	Drain Outlet	Gully Pipe	Manhole Pipe Inlet	Manhole Pipe Outlet
Flow (l/s)	19.80	11.80	8.0	43.70	51.70







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

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