Comparison of manhole hydraulics using PIV and different RANS model

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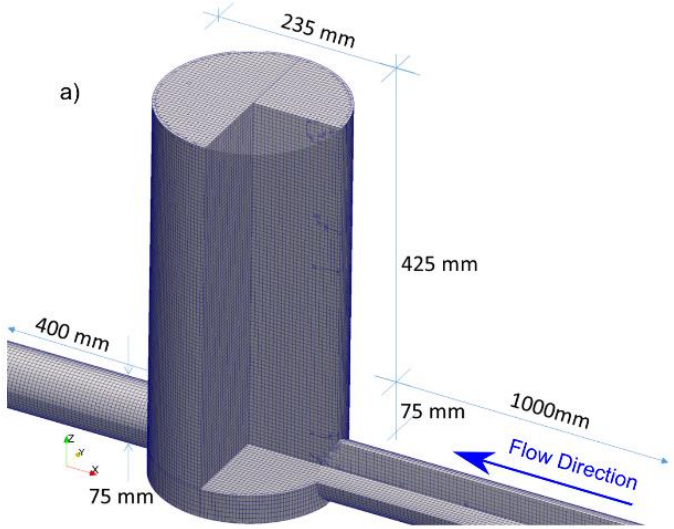
Introduction

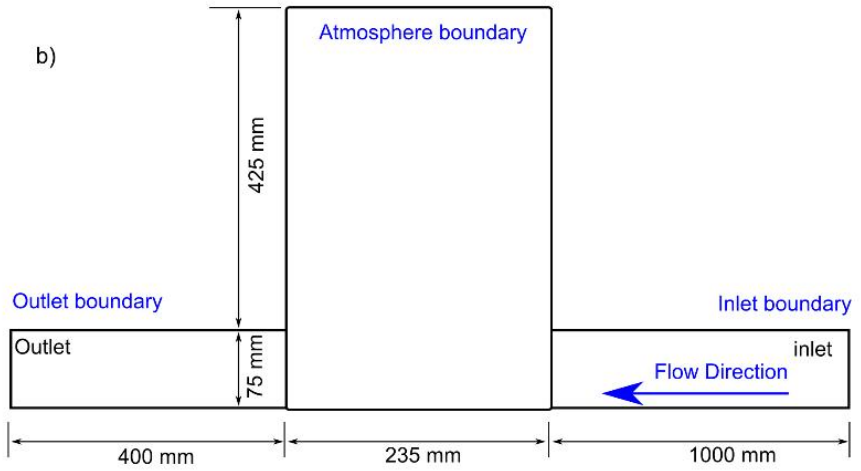
- Flows in manholes are complex and may include retardation, acceleration and rotation
- How these complex 3D flow patterns could affect flow quantity and quality in the wider network is as yet unknown
- A CFD model in OpenFOAM® using four different Reynolds Averaged Navier Stokes (RANS) turbulence modelling is constructed to represent flows in the manhole
- A 2D3C stereo Particle Image Velocimetry (PIV) measurements are made for the first time in a surcharged scaled circular manhole
- Using Laser light sheet to illuminate a 2D plane in the manhole and two cameras simultaneously to record the flow field from two different angles.
- Velocity profiles from CFD are compared with PIV data

Numerical Model

- Open source CFD model tool OpenFOAM®v4.1, with VOF based solver interFoam
- Cartesian mesh using *cfMesh*
- interior and the boundary mesh sizes were kept as 4 mm and 1 mm respectively
- One particular manhole flow condition was chosen: Q = 3.98 l/s and the water depth = 310 mm.

- Fixed velocity inlet
- Fixed pressure outlet
- No wall roughness
- *noSlip* condition at wall
- y+ value around 5



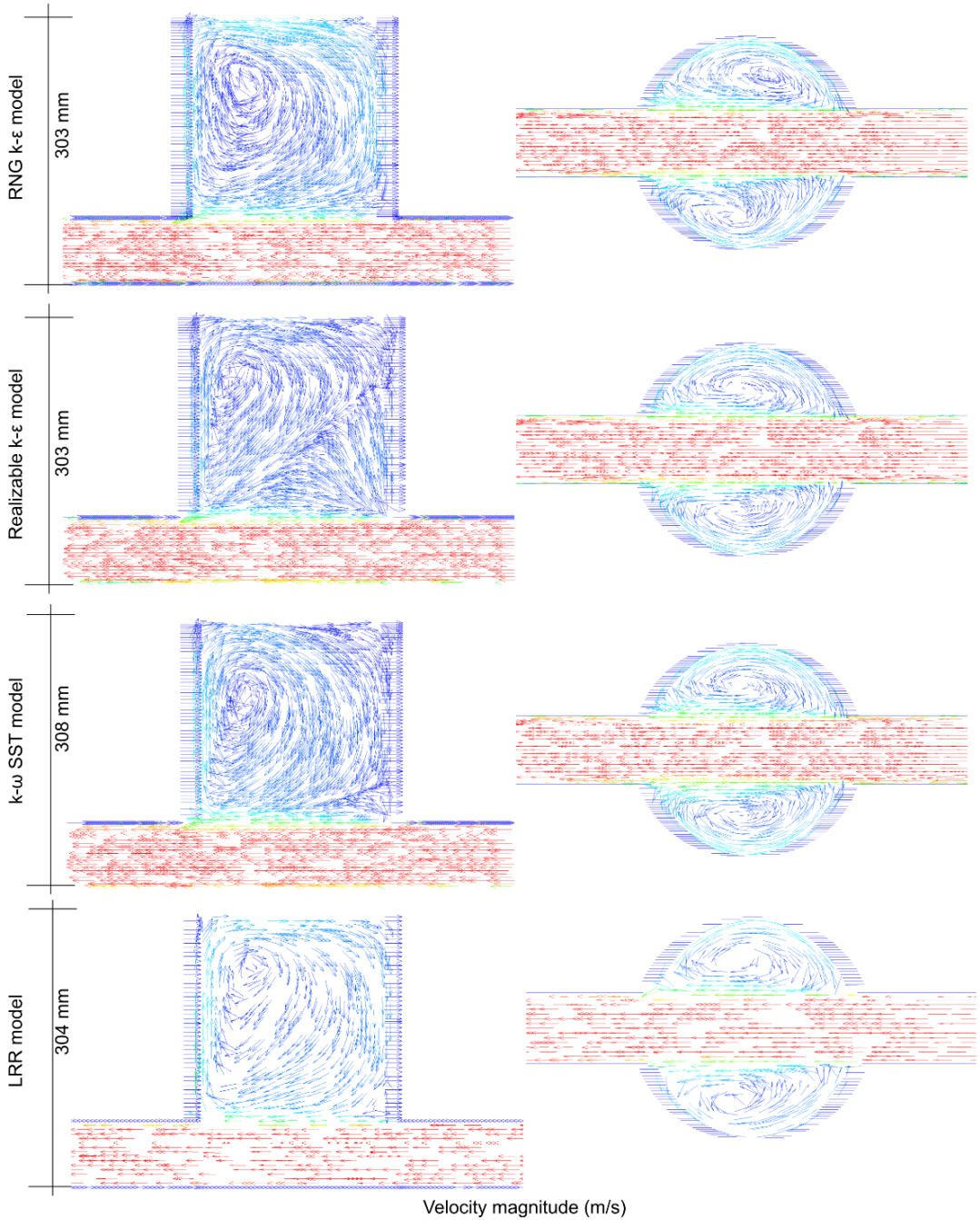


Four turbulence models:

1. RNG k-ε,
2. Realizable k-ε,
3. k-ω SST and
4. Launder-Reece-Rodi (LRR)

Comparison between models

- Velocity of central vertical and the horizontal planes through the pipe axis
- Two velocity zones: high velocity near the inlet-outlet pipe axis due to jet and low velocity due to recirculation
- The **jet flow is similar** at all the four models
- The **recirculation zone is different**
- Vertical plane velocity shows different size and locations of the vertical vortex
- **Realizable k-ε creates a separation zone** in the middle of the manhole and pushes the vertical vortex more towards the outlet wall
- Results do not show much variation in the vortex locations at horizontal sections



Comparison between models

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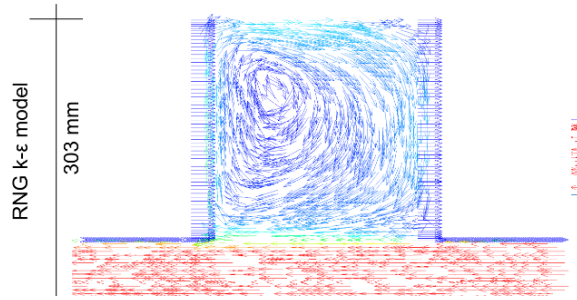
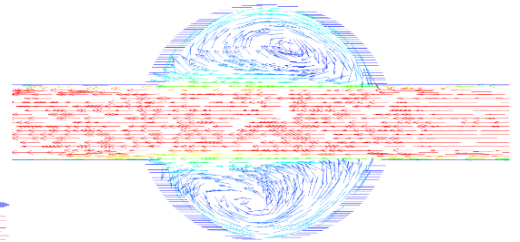
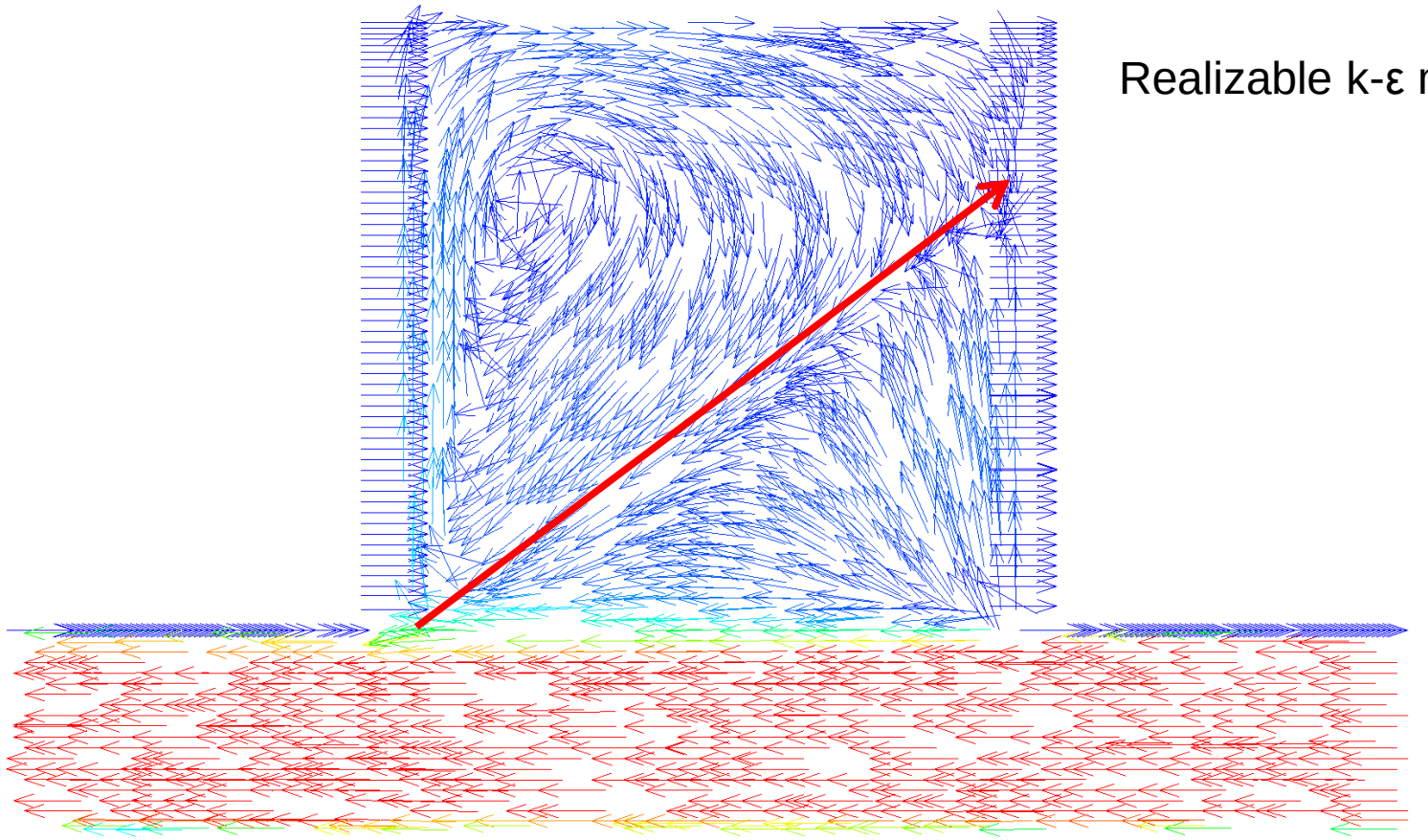
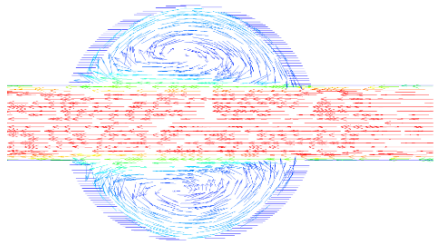
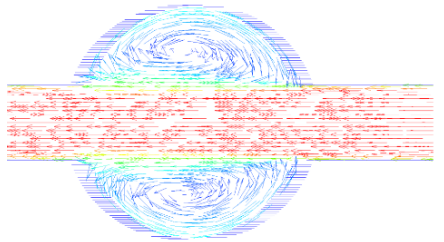


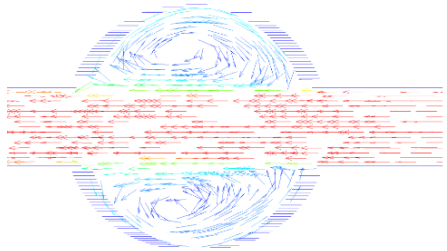


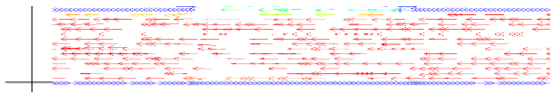


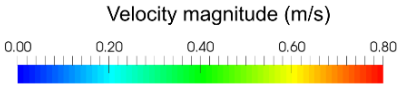
Realizable k-ε model







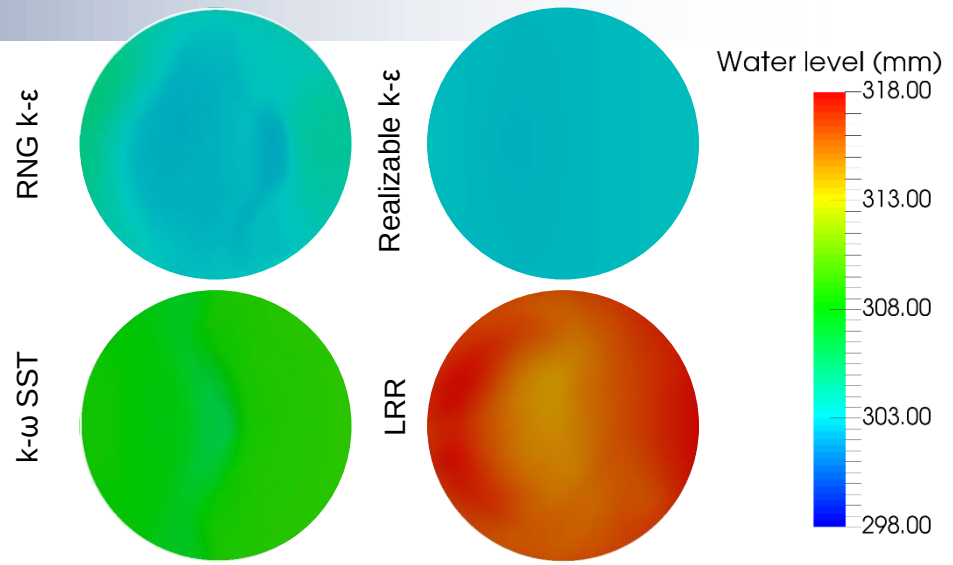




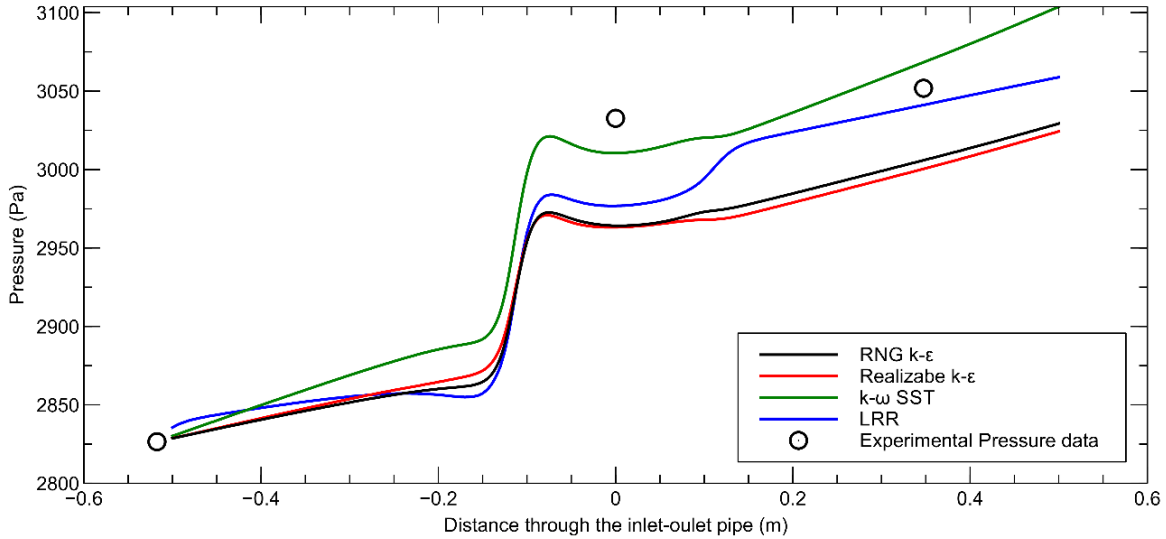
Comparison between models

- Water depth was also found a little different at the manhole centre
  - RNG k-ε: 303mm
  - Realizable k-ε: 303mm
  - k-ω SST: 308 mm (Closest approximation)
  - LRR: 304mm
  - Experimental: 310mm

- The hydraulic grade line (HGL) of the manhole and throughout the length of inlet-outlet pipe is slightly different
  - RNG k-ε and Realizable k-ε models produce a similar pattern
  - No model could represent the same pressure pattern (few mm's different)

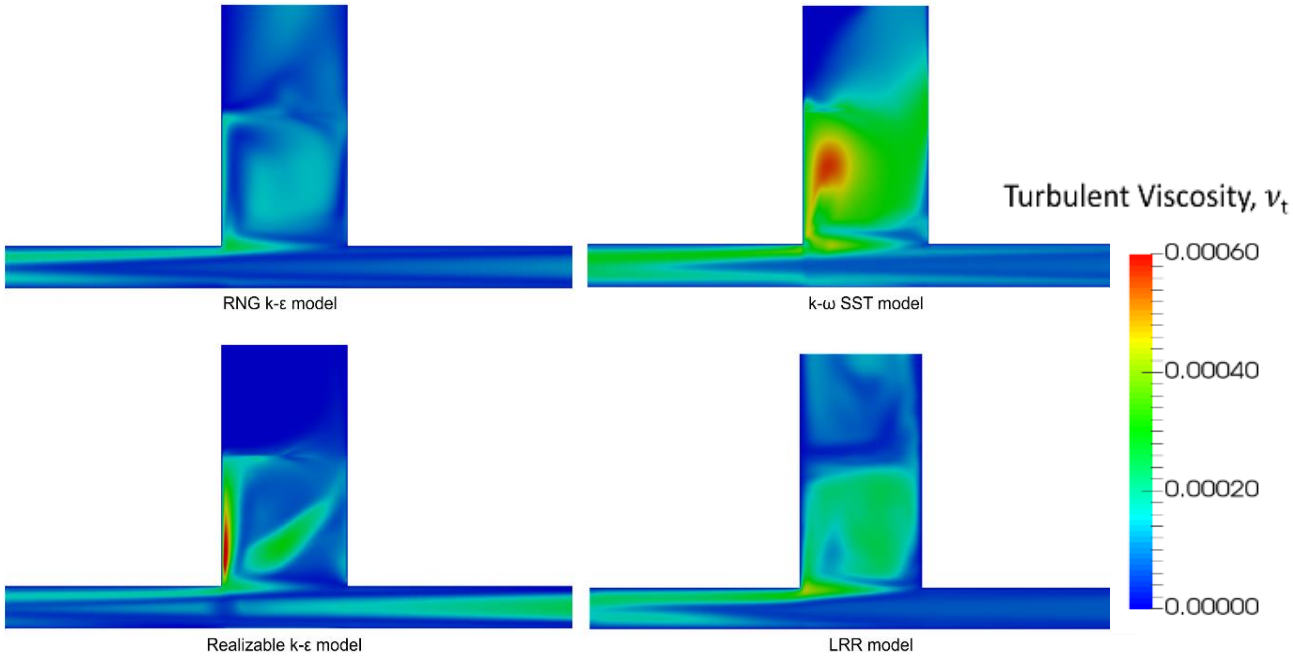


Bottom pressure at the manhole and inlet-outlet pipe



Comparison between models

- RNG k-ε model showed the lowest turbulent viscosity (νt)
- Realizable k-ε model showed very high νt at the mid-section of the inlet pipe



- The coefficient of head loss (k) in the manhole is calculated as the ratio between head loss and the velocity head

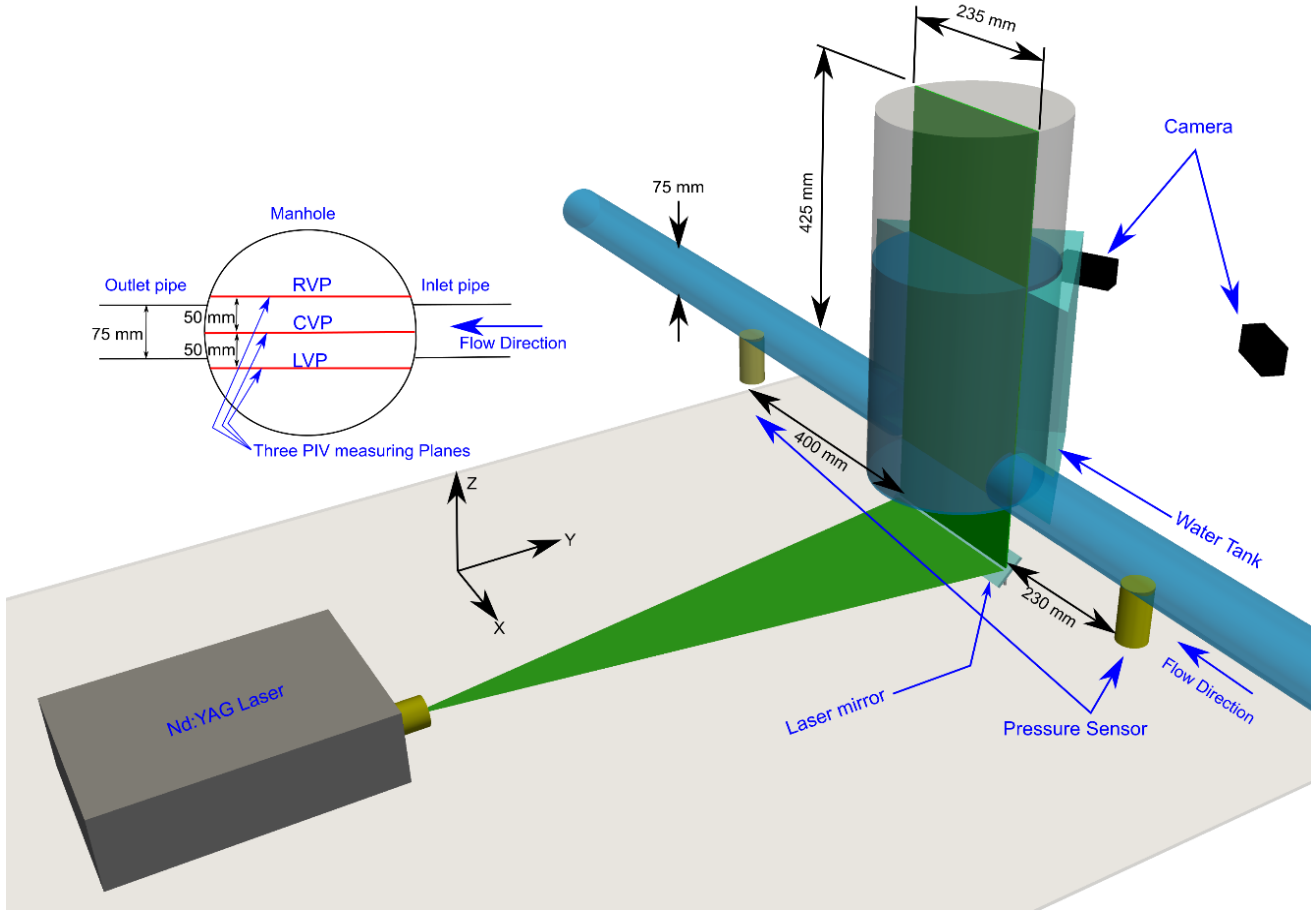
$$k = \Delta H / \left(\frac{v^2}{2g} \right)$$

Simulation	Pressure drop ΔP (Pa)	ΔH	k (=ΔH /(v^2/2g))
RNG k-ε	67.3	0.0069	**0.171**
Realizable k-ε	55.1	0.0056	**0.140**
k-ω SST	61.6	0.0063	**0.156**
LRR	121.4	0.0140	**0.307**

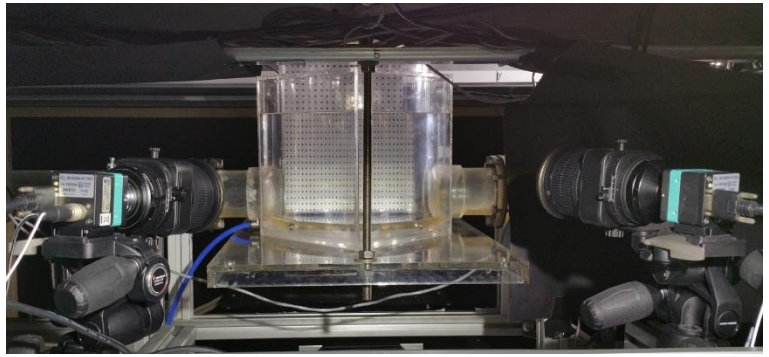
Experimental Setup

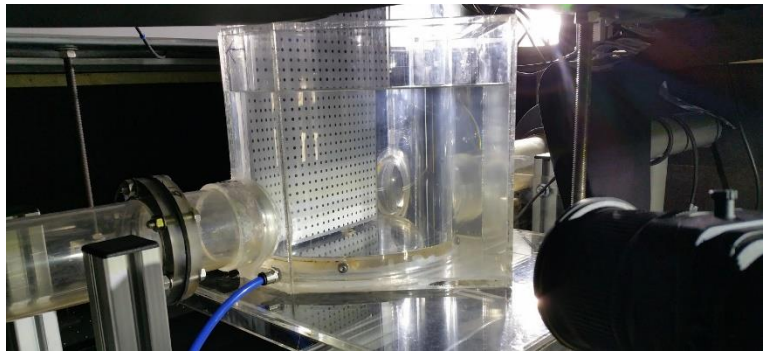
- The experimental facility is installed at the hydraulic laboratory of University of Sheffield

- Transparent Perspex circular scaled manhole with inner diameter of 235 mm
- Connected with a 75 mm co-axial inlet-outlet pipe
- Pipe axis passes through the centre of the manhole axis.
- Two valves at the inlet and outlet that control the flow
- The inflow can be monitored using an electromagnetic flow meter.
- Two pressure sensors installed at the inlet and outlet pipes measure piezometric pressures

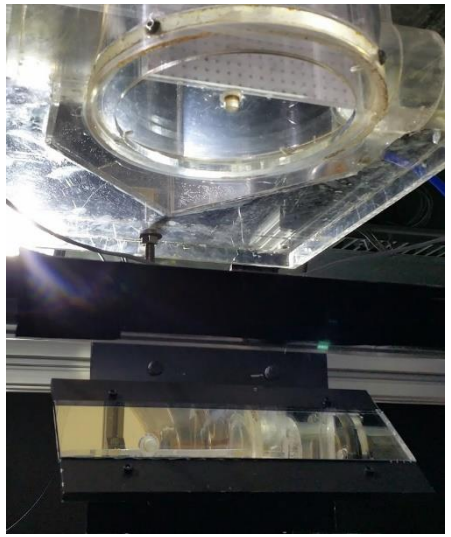


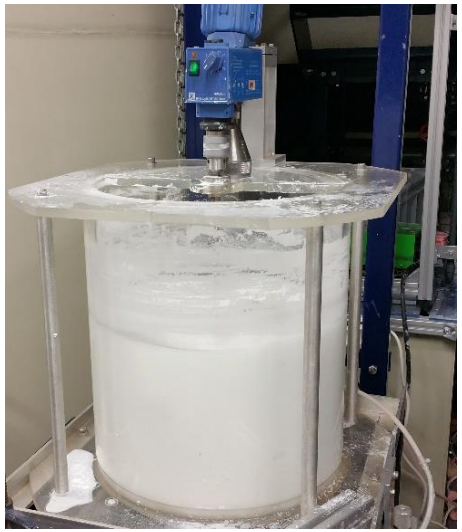
PIV Setup





- Recently installed stereo PIV measurement consists of two Dantec FlowSense EO 2M cameras and a Nd:YAG pulsed laser
- Camera resolution is **1600x1200 pixels**
- Angle between the two cameras were more than 45^{o}
- To reduce error due to refraction at the curved manhole wall, a transparent acrylic tank was constructed around it and filled with water, keeping flat surfaces to both camera lenses.

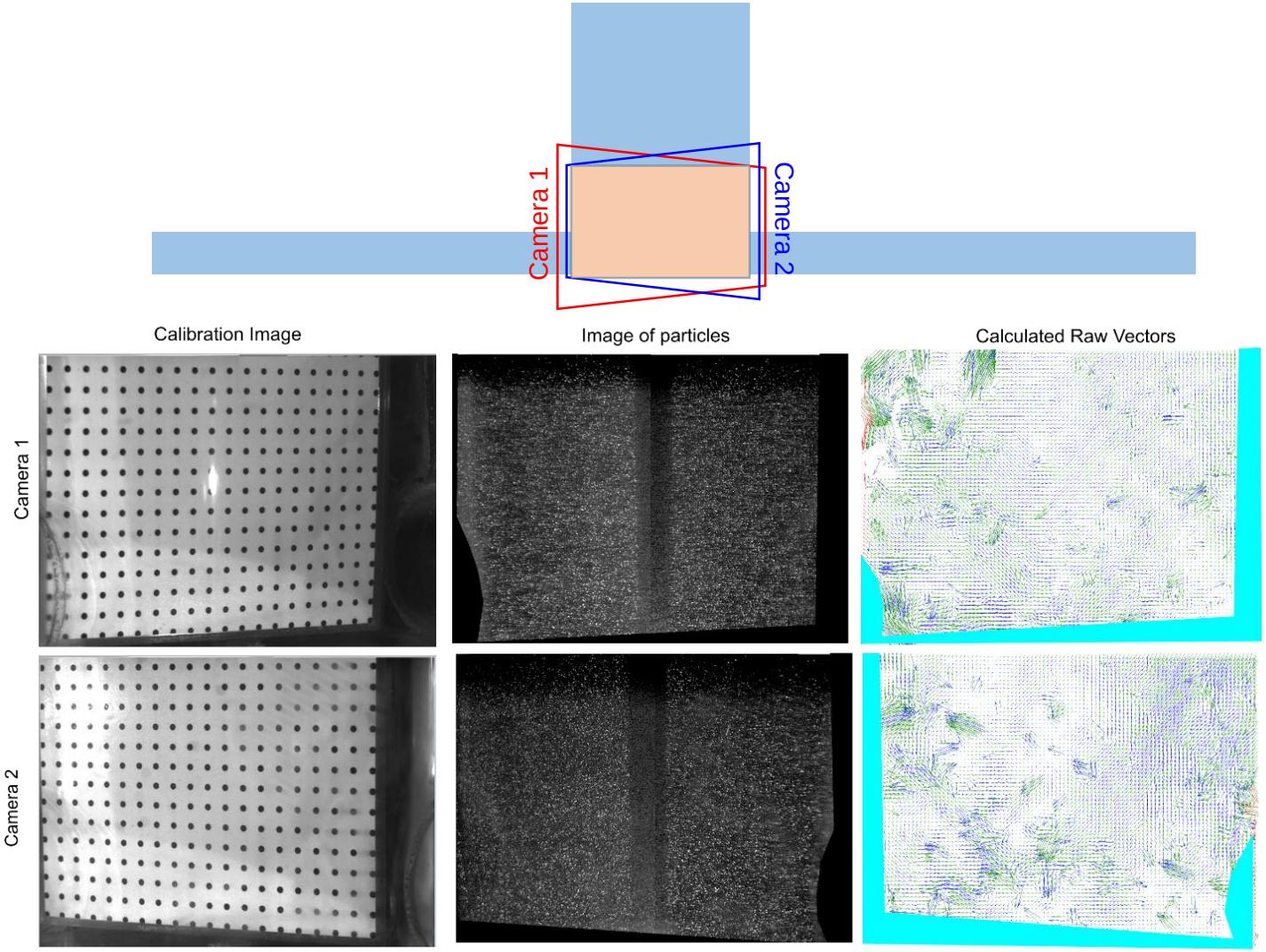




- Laser was sent through the bottom of the manhole
- A laser mirror was used at 45^{o} to the horizontal direction
- **100 µm polyamide 12** particles were chosen for seeding

PIV Measurement

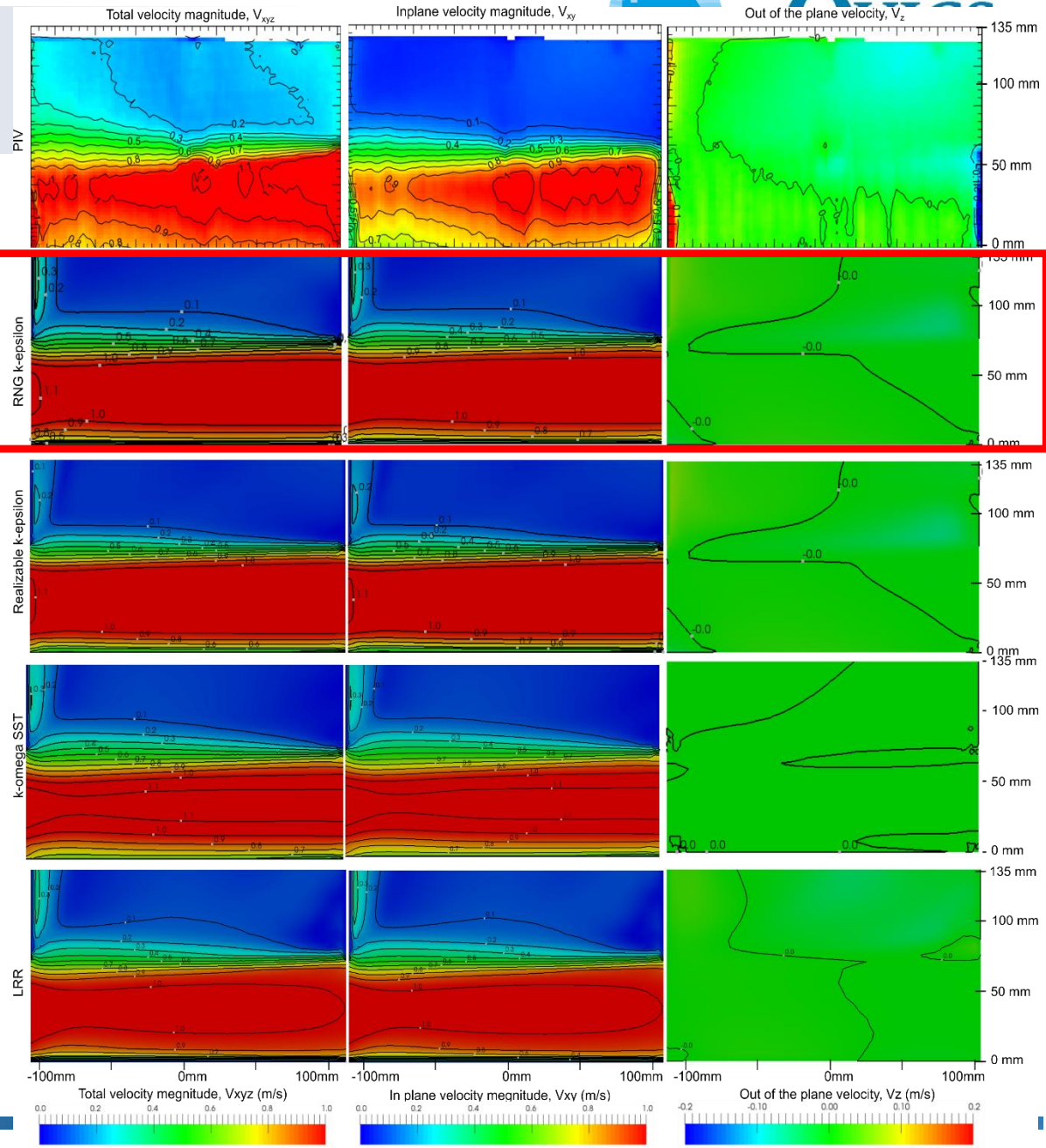
- Data was taken using DynamicStudio v3.31
- Pre-processed using masking the area of interest
- Adaptive cross correlation technique was used to calculate the vectors
- Median correction post processing was applied to remove erroneous vectors.
- Neither of the cameras was able to cover the whole manhole height
- Only the core jet velocity zone was recorded



Comparison with PIV

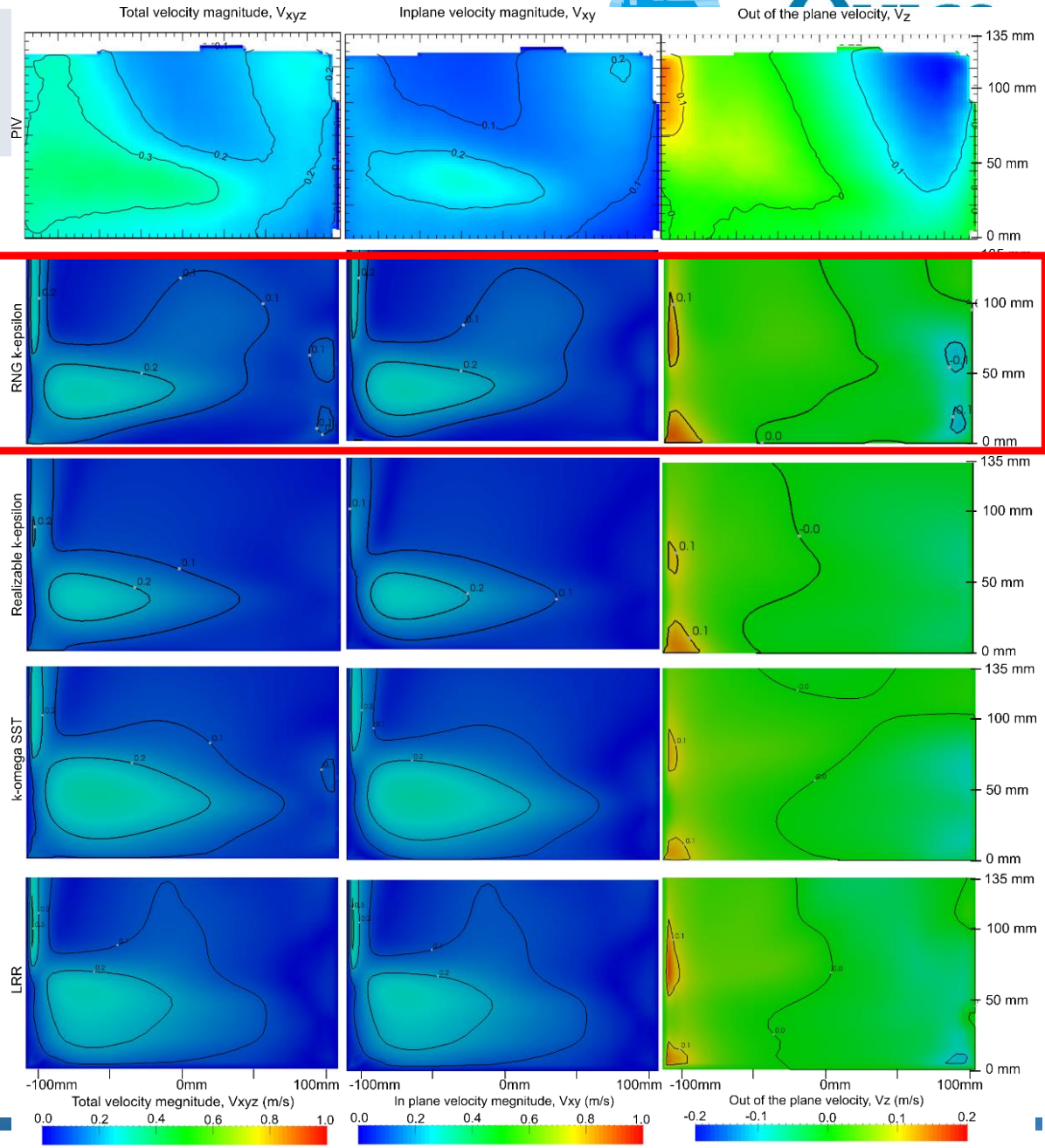
- PIV measurements were taken at the central vertical plane (CVP) along with the left vertical plane (LVP) and right vertical plane (RVP)
- At CVP, the core jet velocity zone in the RANS models were almost similar to PIV
- The diffusive velocity zone was also found similar

- CVP did not have much out of the plane velocity component (Vz)
- RNG k-ε and Realizable k-ε model show good match with PIV data at the CVP



Comparison with PIV

- At LVP, The velocities measured through PIV was found higher than CFD models
- PIV measurement shows **higher the spread of the inlet jet velocity zone**
- At LVP, the highest jet velocity measured at PIV was up to 0.3 m/s and 0.2 m/s in CFD models
- The out of the plane velocity measurement (Vz) at PIV is observed between -0.1 m/s to 0.2 m/s (Negative values Vz means direction towards the camera and positive value represents away from the camera)
- Similar Vz near the outlet of the manhole shown by numerical models
- RNG k-ε model creates the closest approximation of the velocity at the manhole.



Conclusions

- A **scaled inline manhole** to **pipe diameter ratio** was **3.13** was studied
- Numerical simulations using **CFD with four different RANS** models
- Two dimensional plane with **three component (2D3C) stereo PIV measurement**
- Each model calculates the **velocity inside manhole** slightly differently
- Numerical models calculated marginally lower velocities towards all the three directions in compared to the PIV data
- Velocity structures and locations of vortex centres were found marginally different among the models
- The **RNG k-ε model showed the closest approximation of velocity contour** while **k-ω SST model showed the closest approximation of the water and pressure level** at the manhole

Acknowledgement

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Thanks for your attention!

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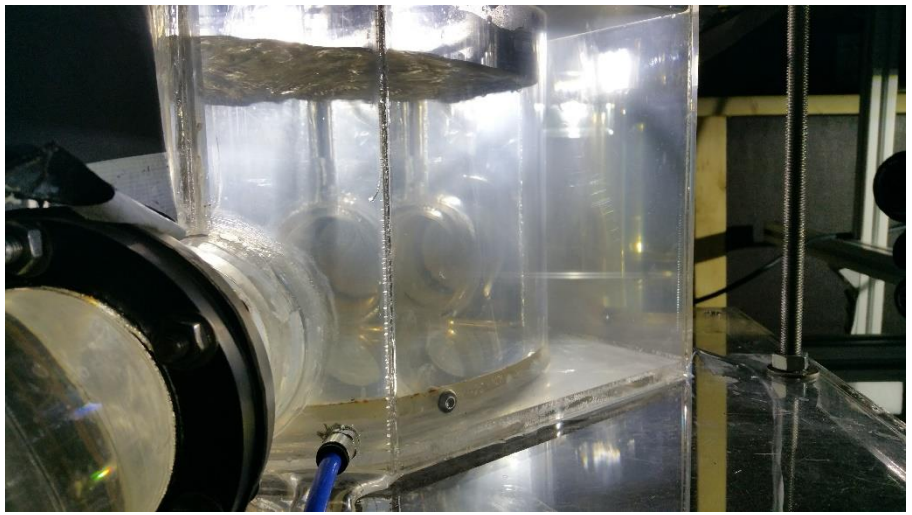
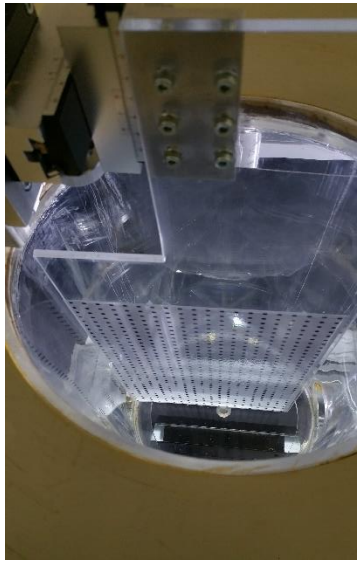
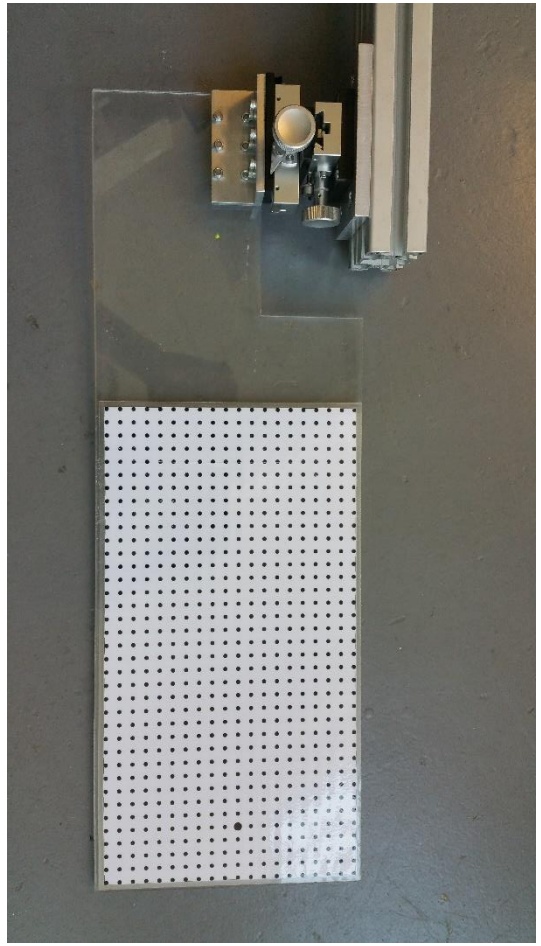
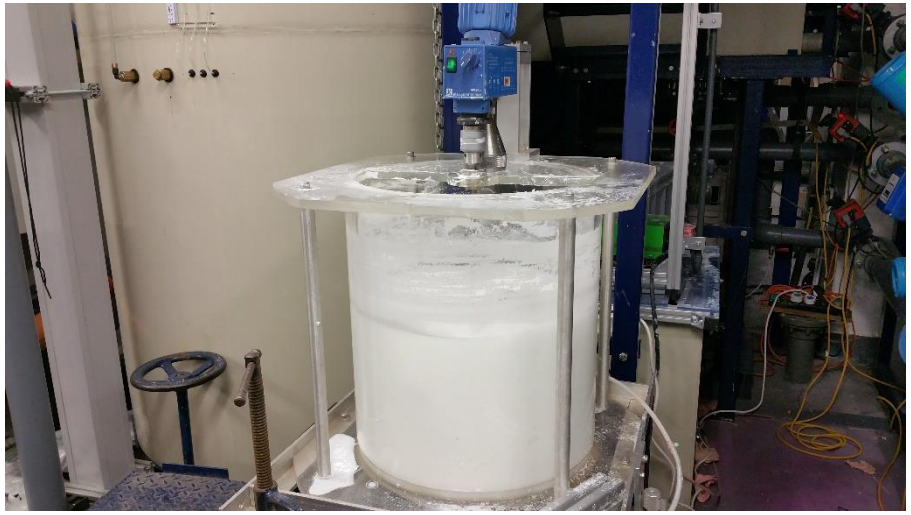
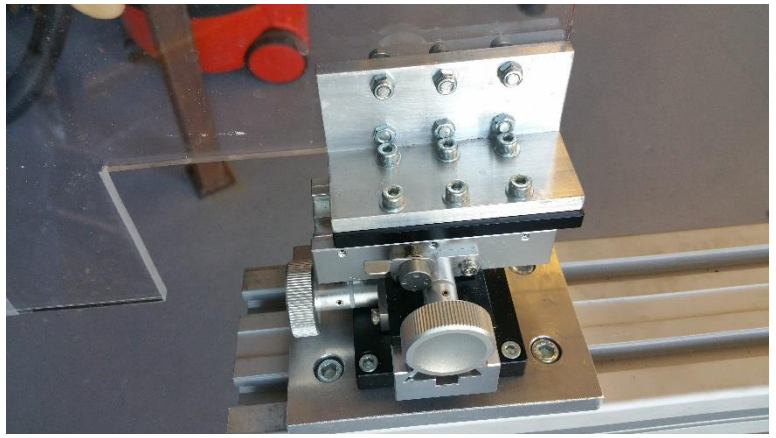
Experimental Setup











Comparison between models