Interaction between storm water conduit flow and overland flow for numerical modelling of urban area inundation

Author:

Jakub Hakiel

Michał Szydłowski

Department of Hydraulic Engineering
Faculty of Civil and Environmental Engineering
Gdańsk University of Technology

Urban flooding

Pluvial (surface) flooding.

Caused by extreme rainfall events that cannot be absorbed by drainage system.

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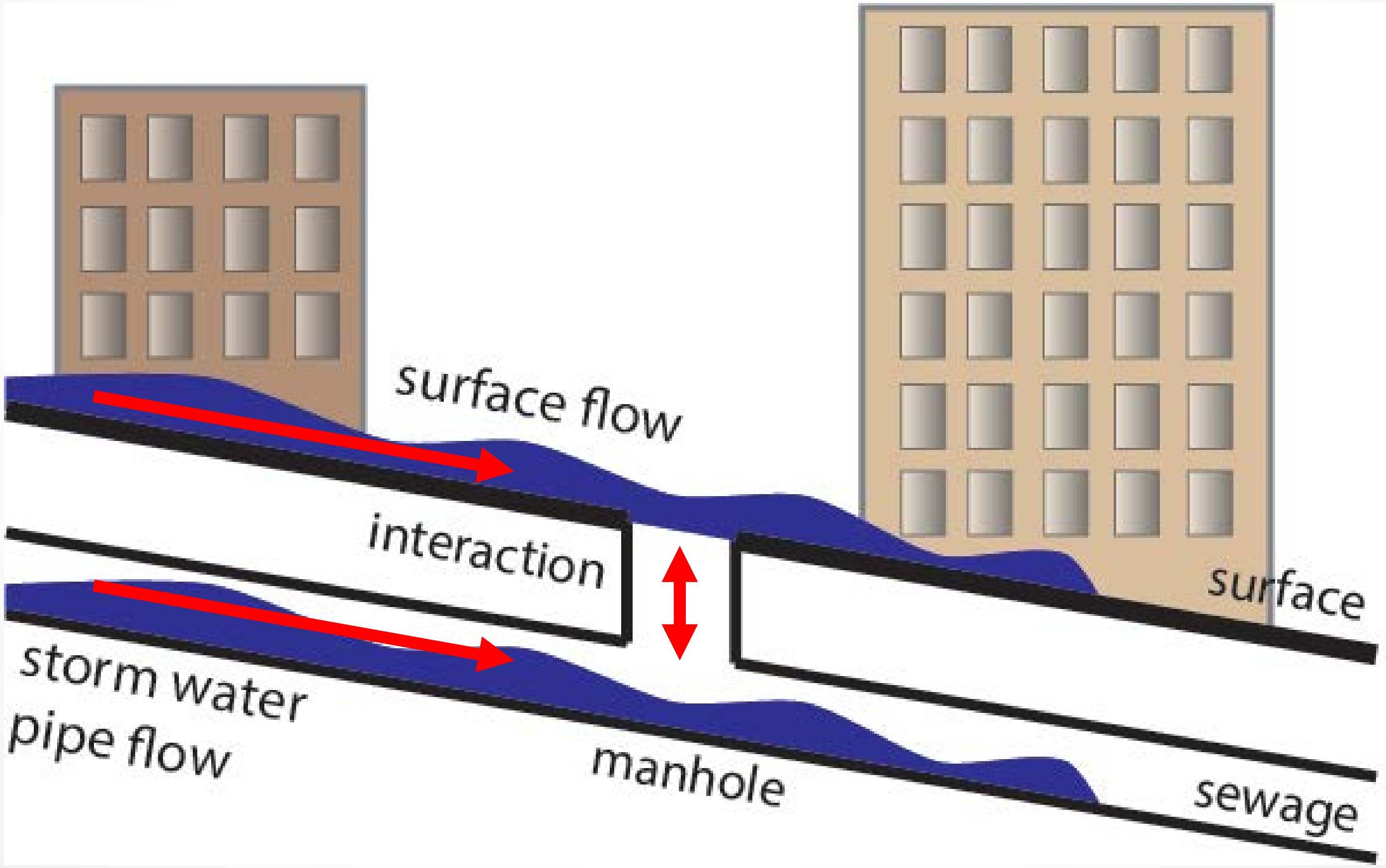
Modelling of urban flooding

Dual drainage modelling (1D+2D):



Storm water pipe flow (1D)

The Saint-Venant Equations

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{F}}{\partial x} = \mathbf{S}$$

$$\mathbf{U} = \begin{pmatrix} A \\ Q \end{pmatrix} \qquad \mathbf{F} = \begin{pmatrix} Q \\ Q^2 / A + I \end{pmatrix} \qquad \mathbf{S} = \begin{pmatrix} 0 \\ gA\left(S_o - S_f\right) \end{pmatrix}$$

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Solving:

- finite differences method,
- finite elements method.

Surface flow (2D)

Shallow Water Equations (SWE)

$$\frac{\partial \mathbf{U}}{\partial t} + \frac{\partial \mathbf{E}}{\partial x} + \frac{\partial \mathbf{G}}{\partial y} + \mathbf{S} = 0$$

$$\mathbf{U} = \begin{pmatrix} h \\ uh \\ vh \end{pmatrix}, \quad \mathbf{S} = \begin{pmatrix} 0 \\ -gh\left(S_{ox} - S_{fx}\right) \\ -gh\left(S_{oy} - S_{fy}\right) \end{pmatrix} \quad \mathbf{E} = \begin{pmatrix} uh \\ u^2 h + 0.5 g h^2 \\ uvh \end{pmatrix}, \quad \mathbf{G} = \begin{pmatrix} vh \\ uvh \\ v^2 h + 0.5 g h^2 \end{pmatrix}$$

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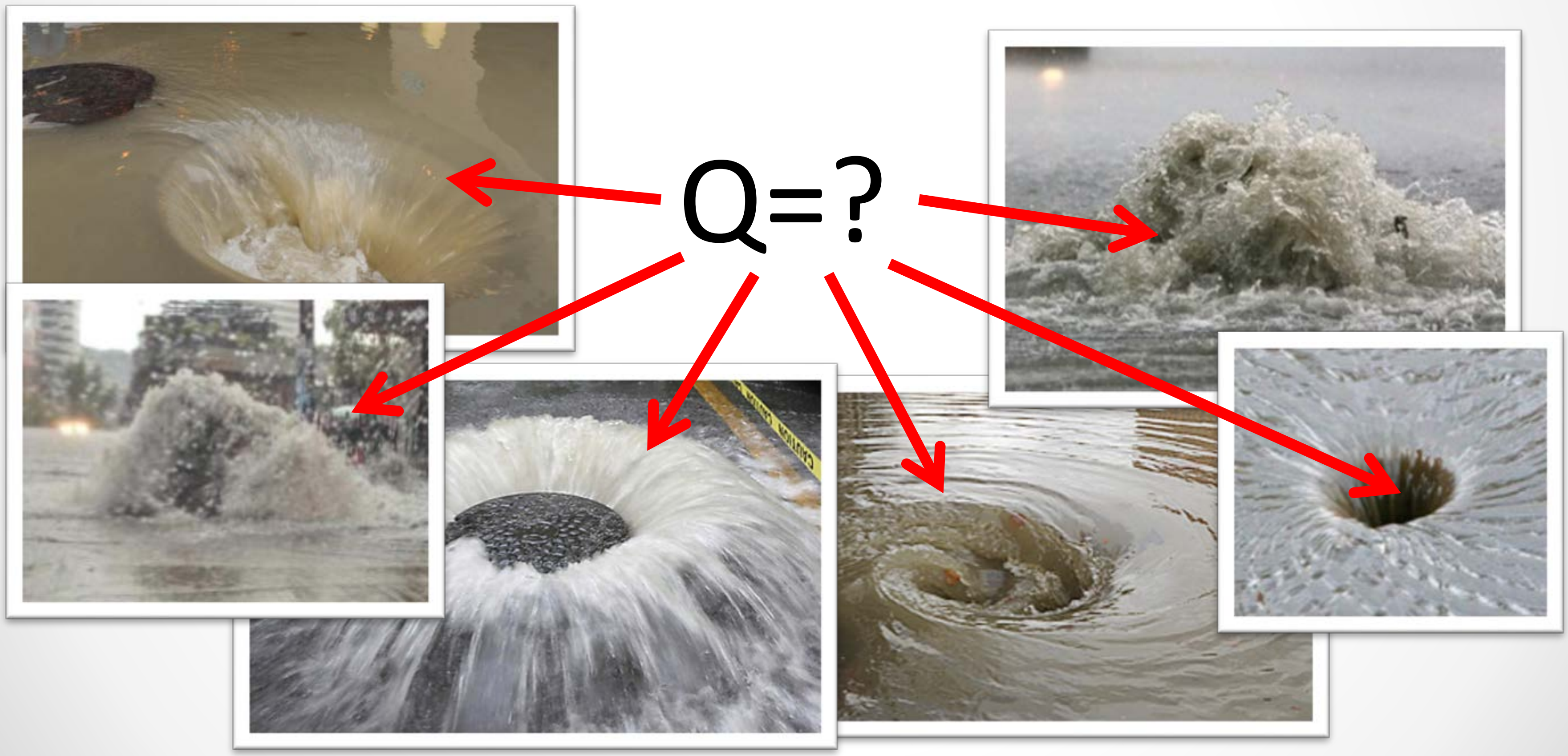
Solving:

- finite volume method,
- finite element method,
- finite difference method.

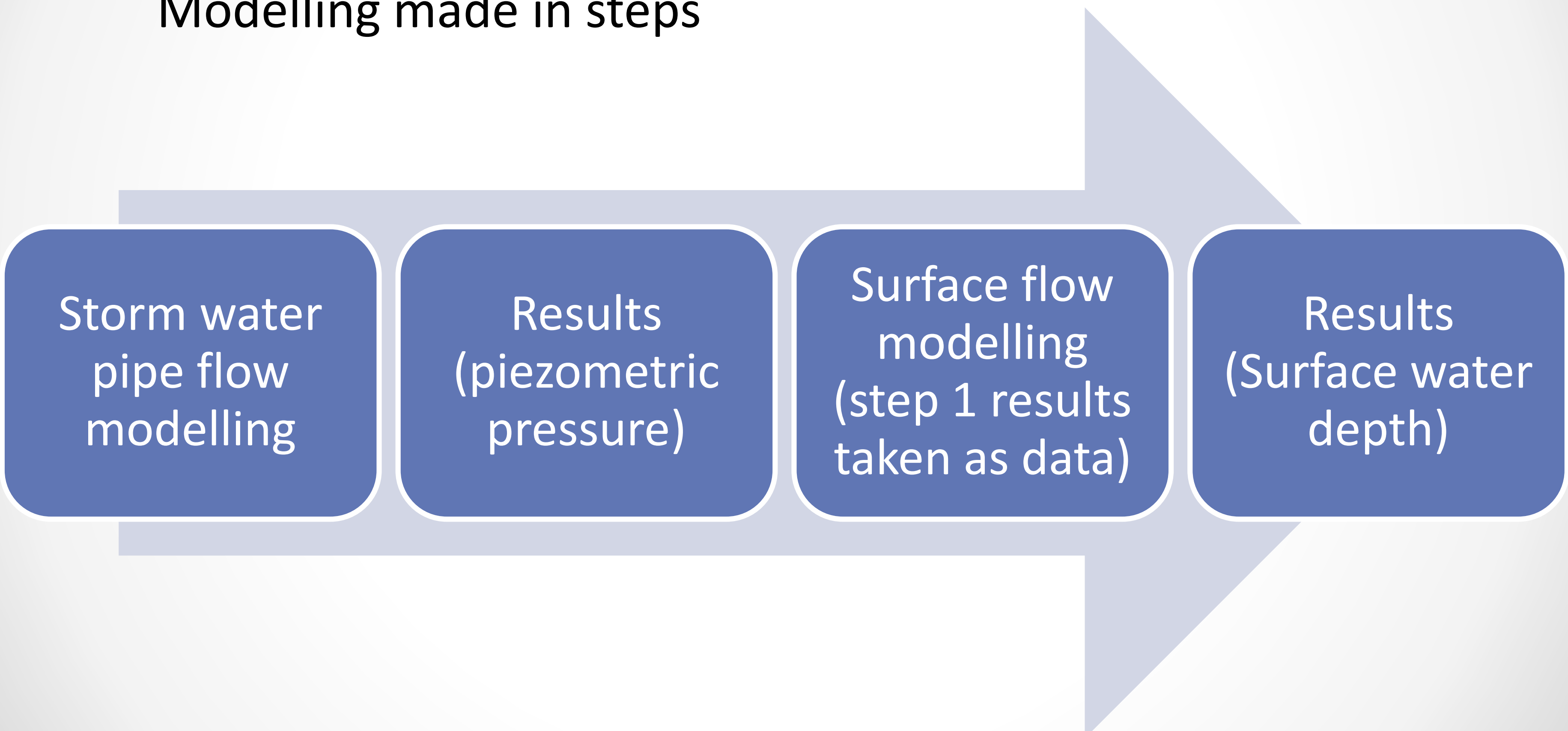
Concept of dual drainage modelling

Problem of interaction!



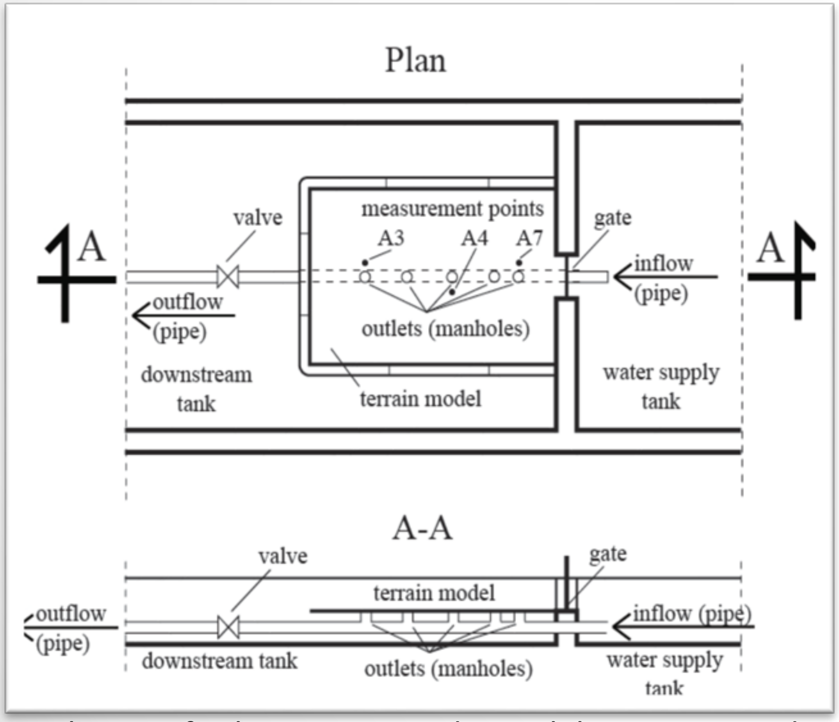
Quasi coupled models

Modelling made in steps

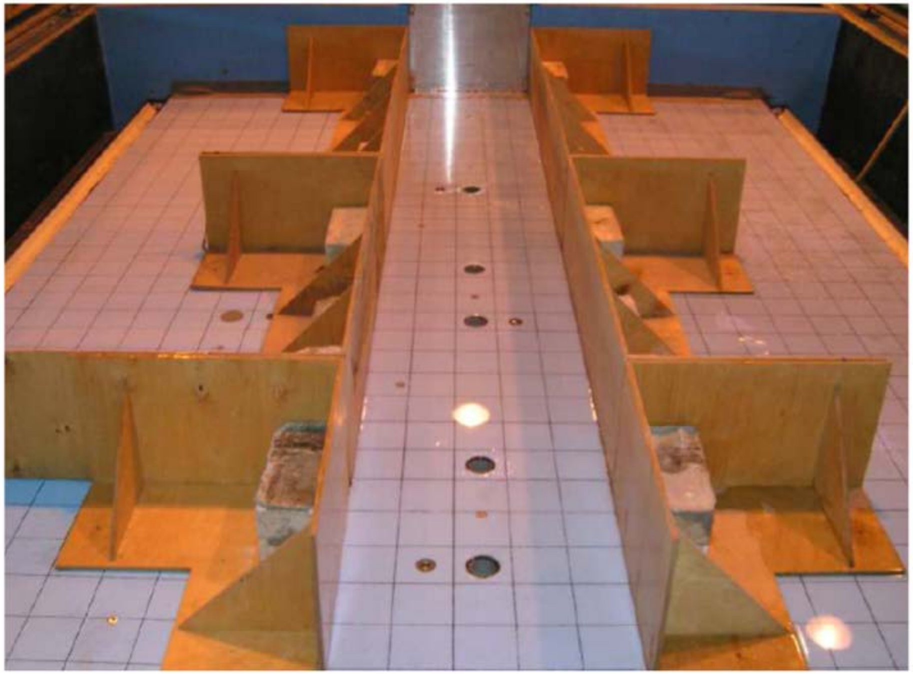


Quasi coupled models

Test held at hydraulic laboratory of the Gdańsk University of Technology



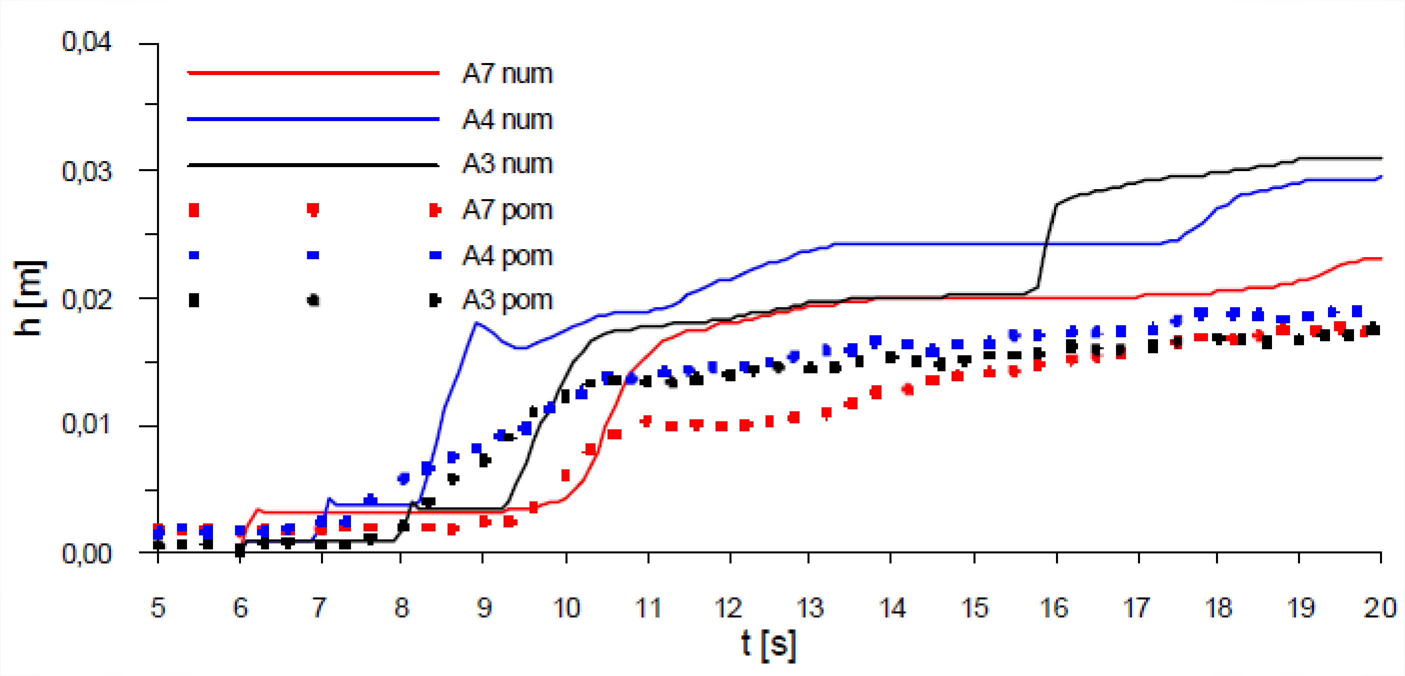
Scheme of urban area inundation laboratory stand



Photography of urban area inundation laboratory stand

Quasi coupled models

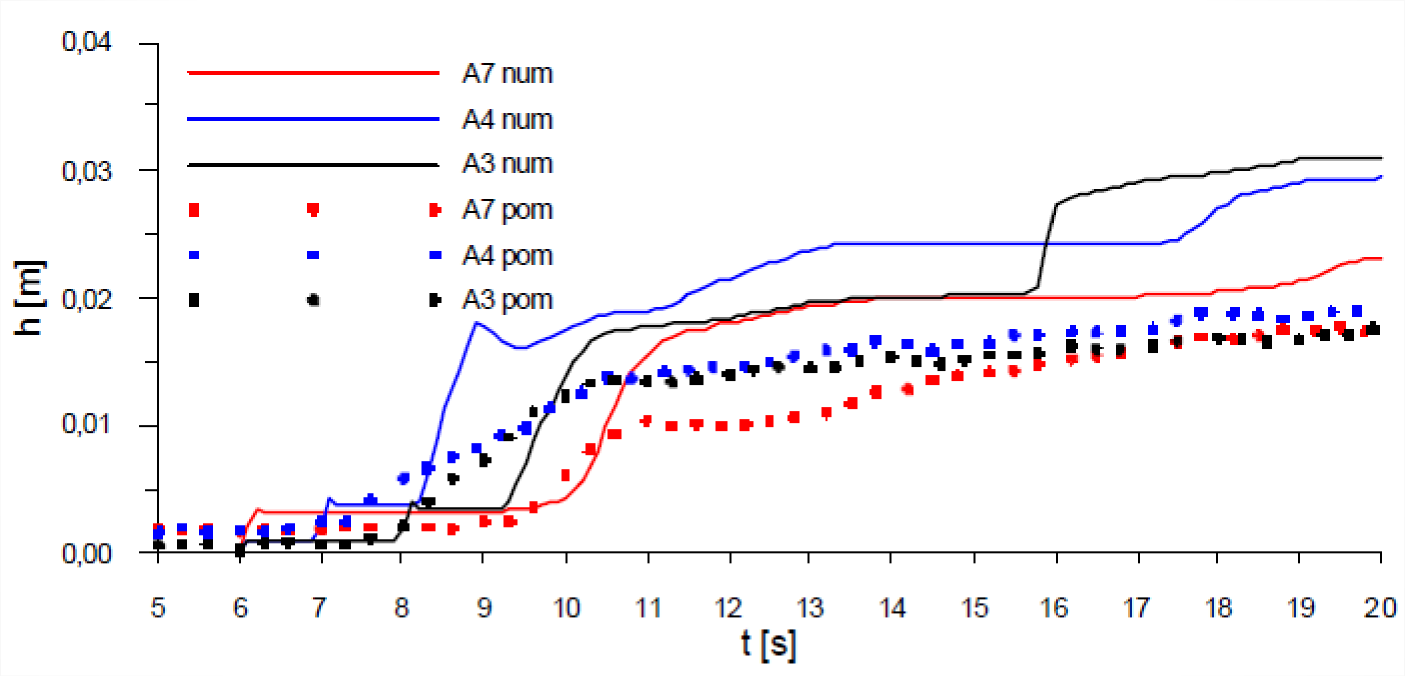
Results



Comparison of measurements and calculations for urban area inundation experiment

Quasi coupled models

Results



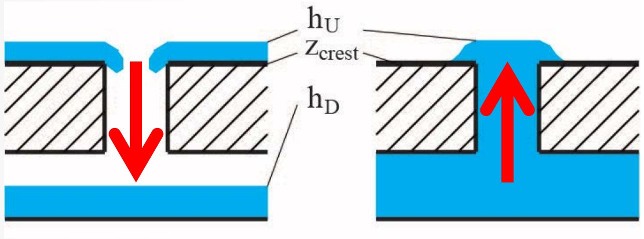
Comparison of measurements and calculations for urban area inundation experiment

Conclusion: interaction is needed in calculations

Integrated models

Interaction between pipe and surface flow

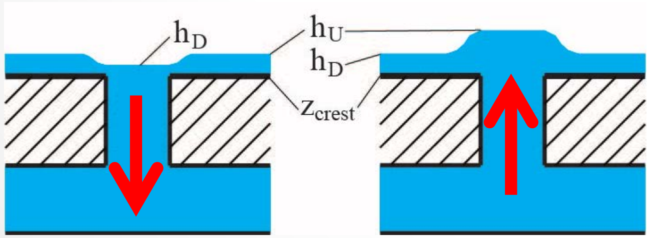
Free weir:



Inflow outflow

$$Q = sign[h_{mh} - h_{2d}]c_w w\sqrt{2g}(h_U - z_{crest})^{3/2}$$

Submerged weir and orifice:



Inflow outflow

$(h_U - z_{crest}) < A_{mh}/w$

$$Q = sign[h_{mh} - h_{2d}]c_w w\sqrt{2g}(h_U - z_{crest})(h_U - h_D)^{1/2}$$

$(h_U - z_{crest}) \geq A_{mh}/w$

$$Q = sign[h_{mh} - h_{2d}]c_o A_{mh}\sqrt{2g}(h_U - h_D)^{1/2}$$

Interaction

Questions and problems?

No verification presented (why we need it?):

Interaction

Questions and problems?

No verification presented (why we need it?):

Verification if equations are valid for:

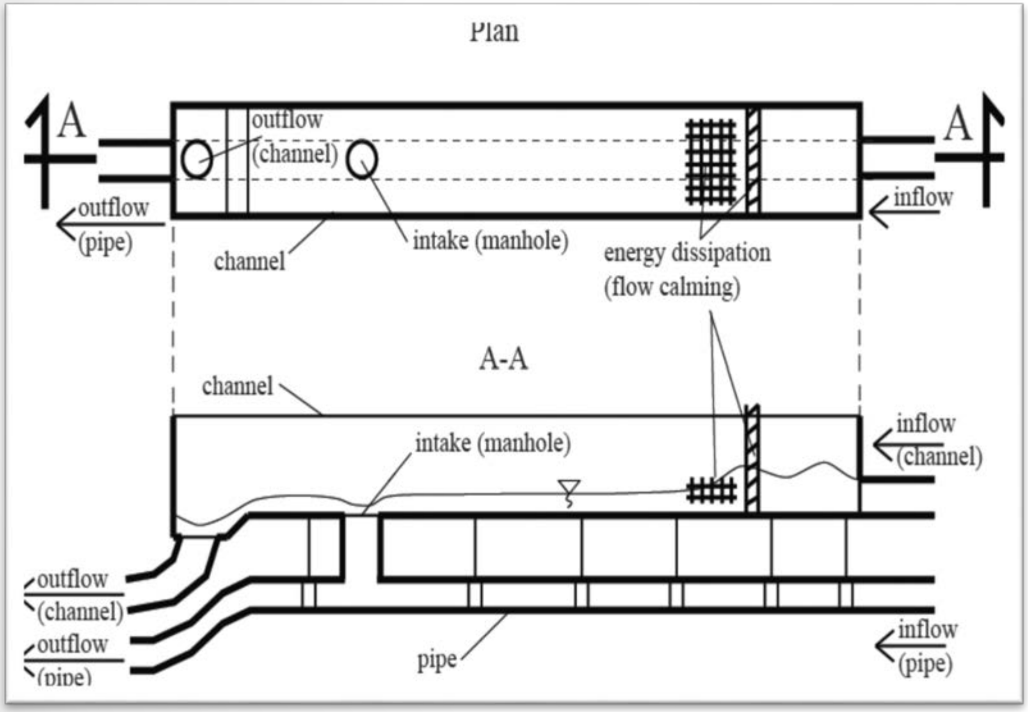
- high surface slopes,
- high values of velocity,

Is there a need to include velocity in calculations?

How can we do that?

Experiment to verify interaction formulas

Test stand



Scheme of laboratory stand for surface and sewage flow interaction experiments

channel:

- length: 5.5m
- width: 0.4m

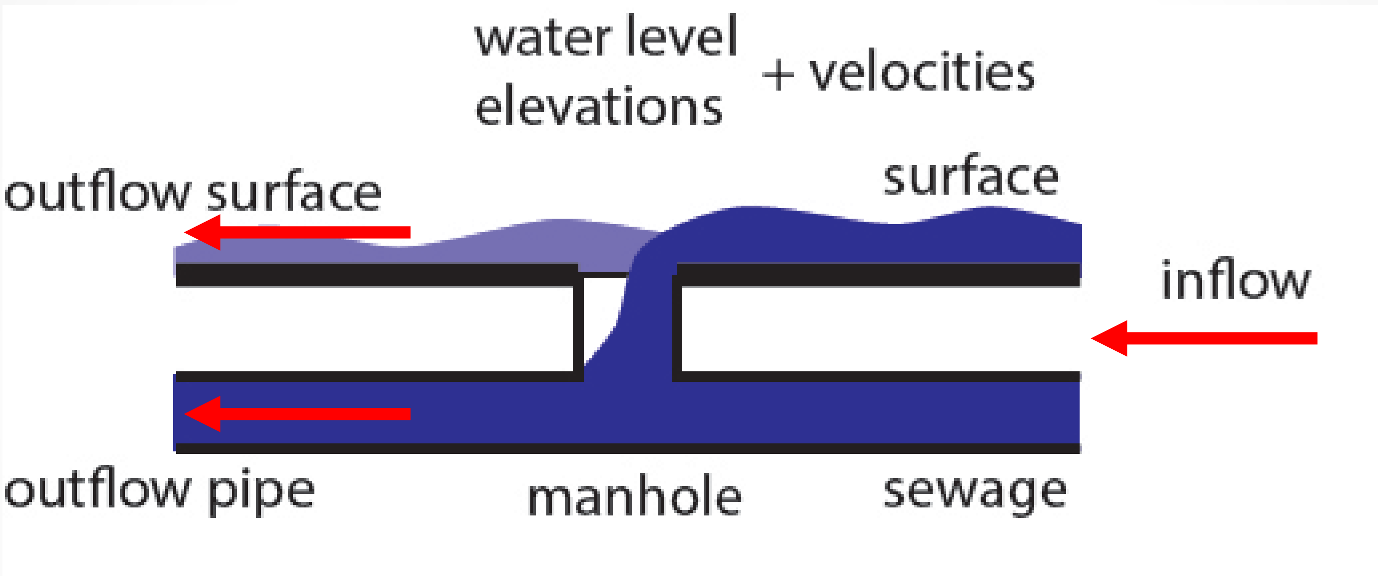
pipe:

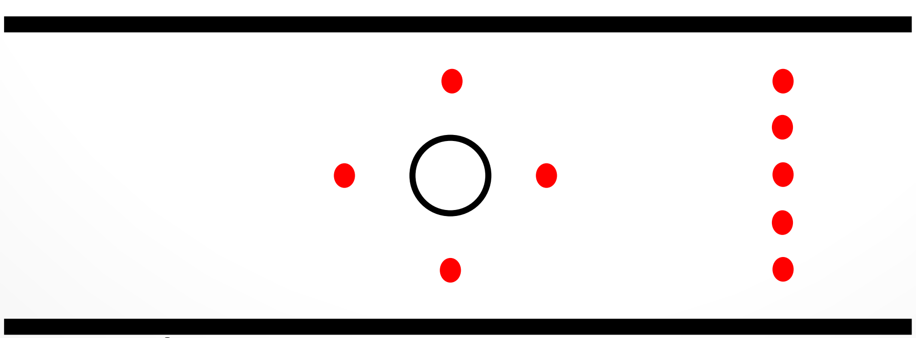
- diameter: 110mm

Photography of laboratory stand for surface and sewage flow interaction experiments

Experiment to verify interaction formulas

Test stand - measurements



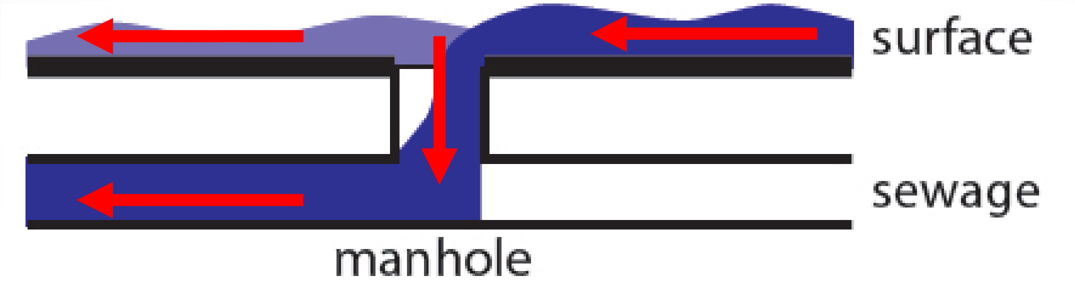


velocity measurements point

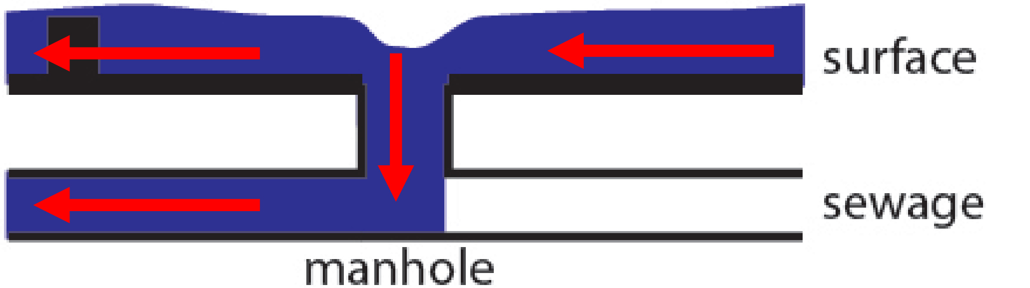
Experiment to verify interaction formulas

Test scenarios

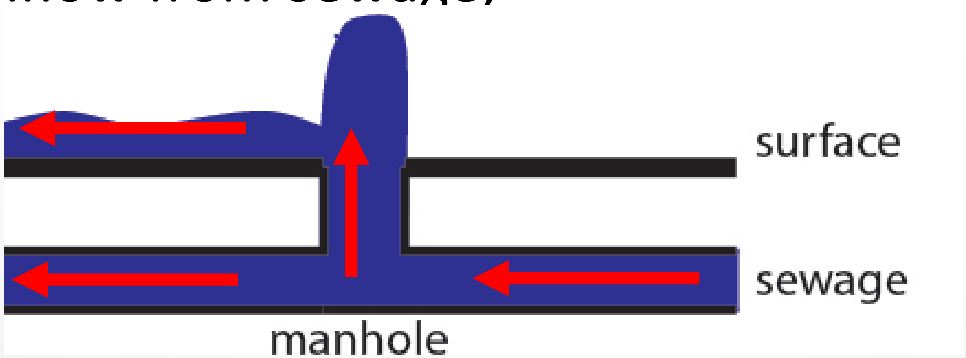
- inflow from surface,



- Inflow from surface with increased water depth,



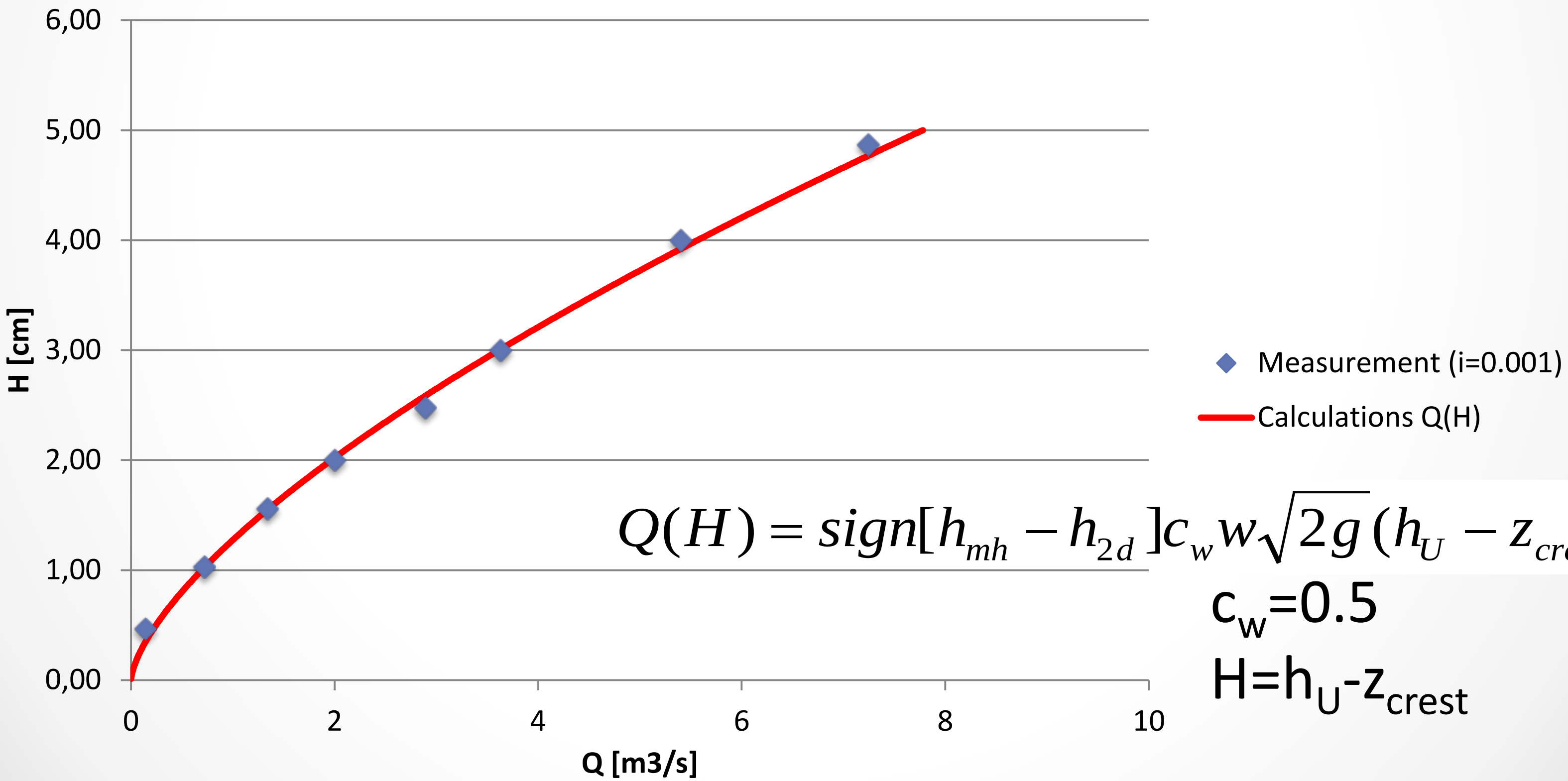
- free inflow from sewage,



Experiment to verify interaction formulas

Results

Verifying formula for free weir with 1‰ surface slope:



$$Q(H) = sign[h_{mh} - h_{2d}]c_w w\sqrt{2g}(h_U - z_{crest})^{3/2}$$

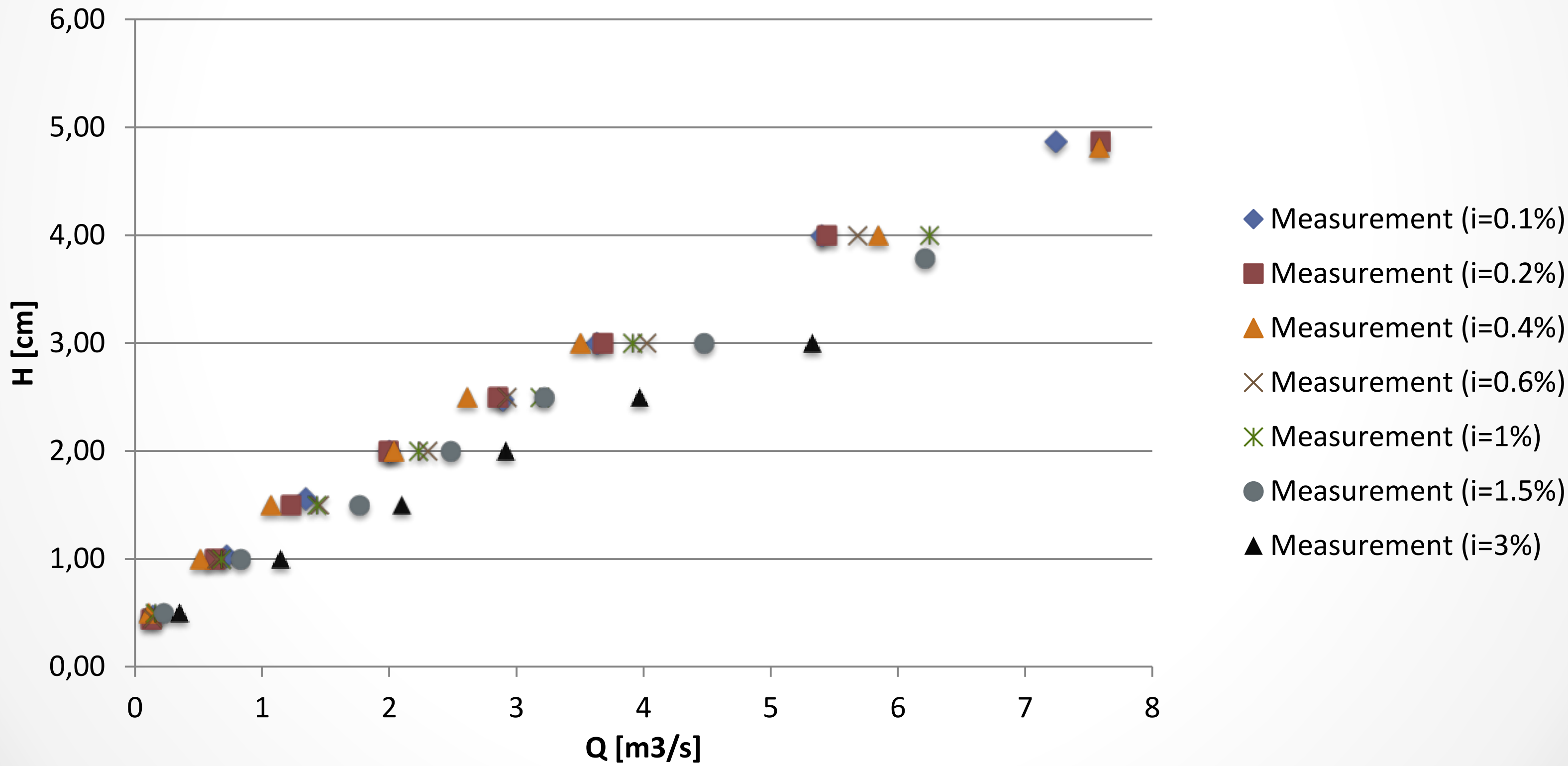
$c_w=0.5$

$H=h_U-z_{crest}$

Experiment to verify interaction formulas

Results

Comparing inflow values for different slope:



Experiment to verify interaction formulas

First approach based on elevation and velocity:

Basic free weir formula:

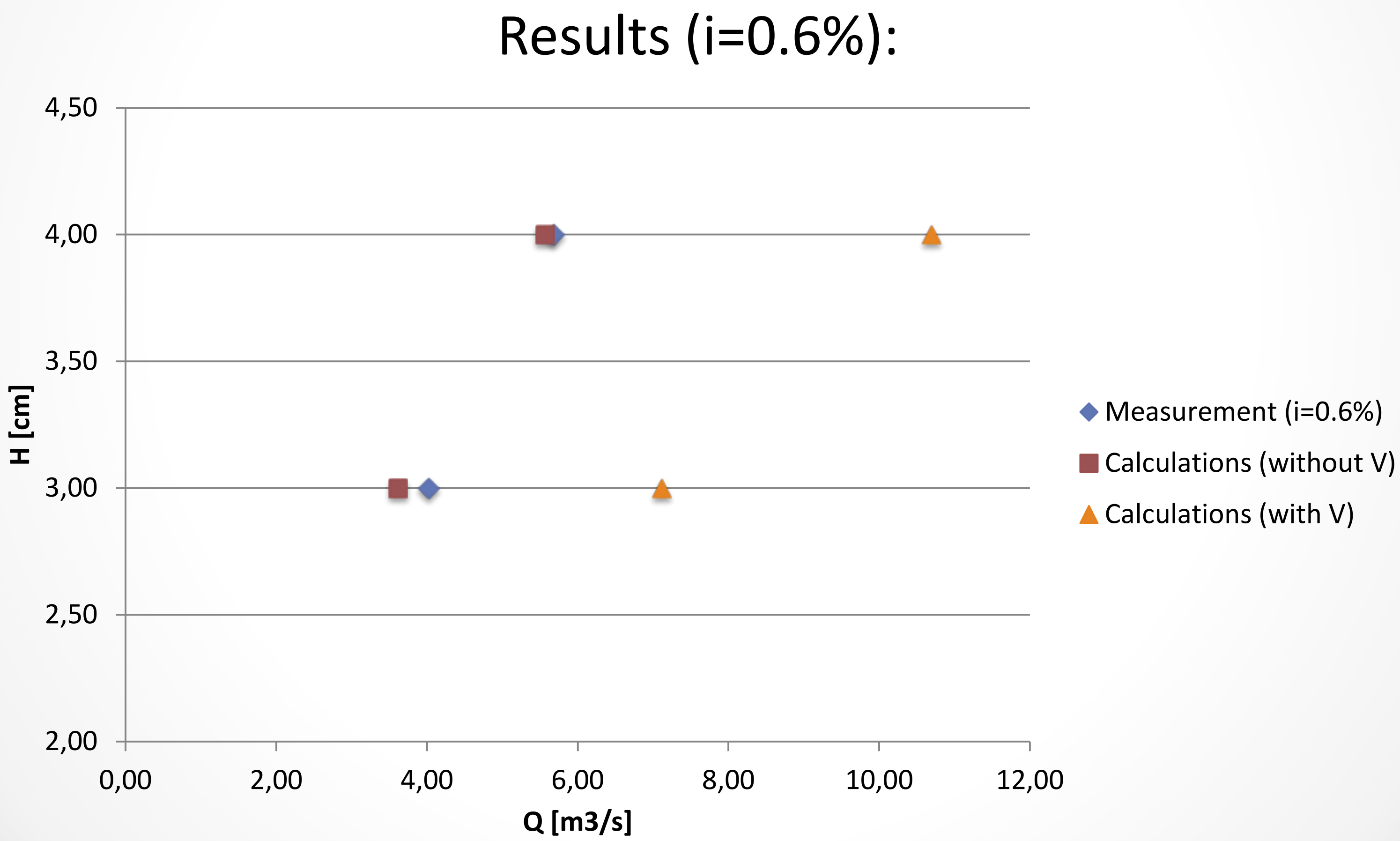
$$Q = sign[h_{mh} - h_{2d}]c_w w \sqrt{2g}(h_U - z_{crest})^{3/2}$$

Free weir formula with velocity head:

$$Q = sign[h_{mh} - h_{2d}]c_w w \sqrt{2g}[(h_U - z_{crest} + \frac{V^2}{2g})^{3/2} - (\frac{V^2}{2g})^{3/2}]$$

Experiment to verify interaction formulas

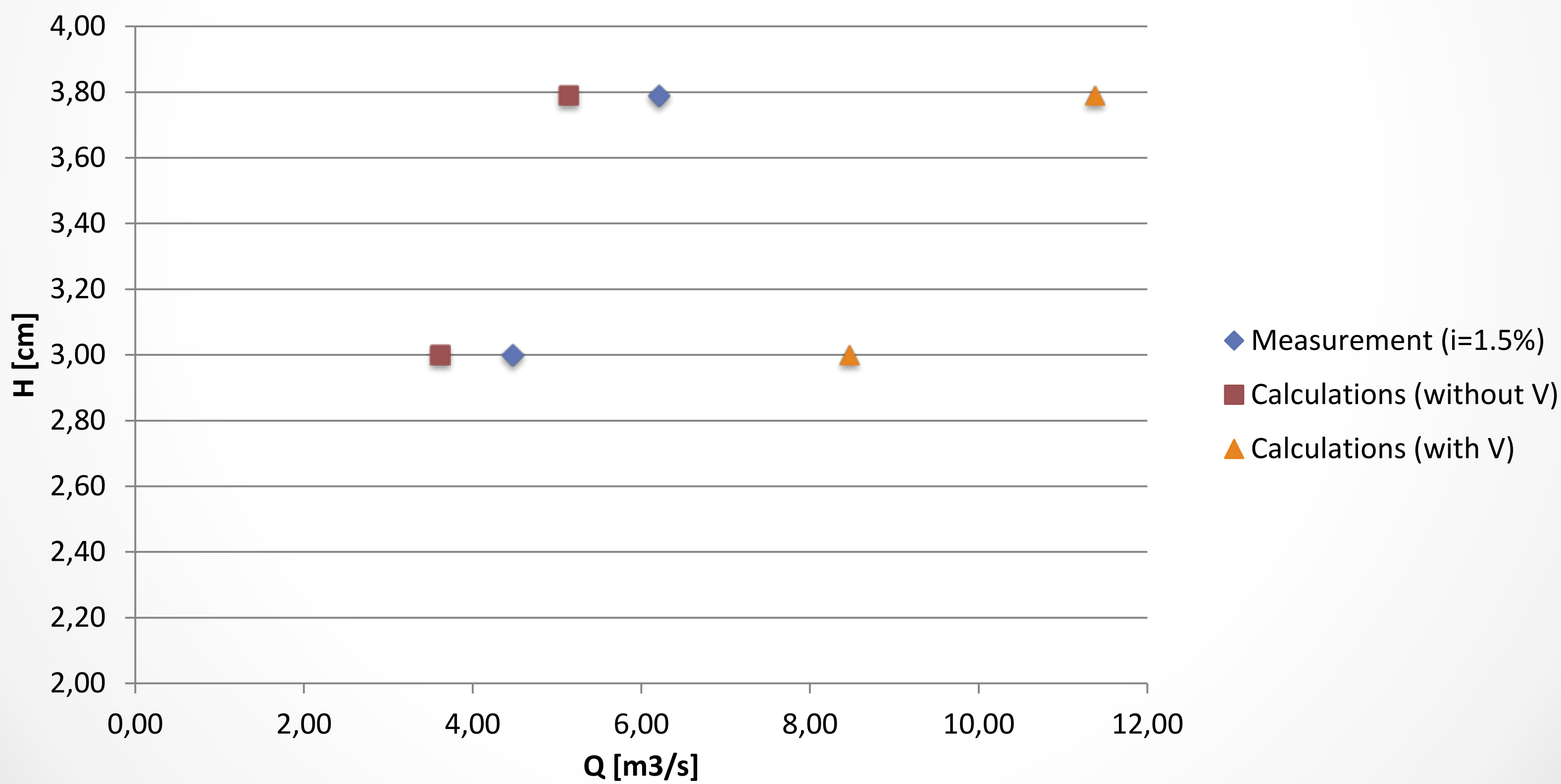
First approach based on elevation and velocity:



Experiment to verify interaction formulas

First approach based on elevation and velocity:

Results (i=1.5%):



Experiment to verify interaction formulas

Conclusion of current results:

- for not sloped channels basic free weir formula is correct,
- with slope increase we observe higher values of inflow into manhole,
- there is a need for including velocity values into equations,
- approach using basic hydraulic formulas for free weir including velocity head is not suitable for this case.

Thank You
for your attention