An Experimental Investigation of Pressure Wave Celerity during the Transient Slurries Flow

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Ab ovo…

- Numerical analysis of pressure wave propagation in the pipes during the sludge hammer phenomenon for the selected elevation of the crest of Żelazny Most reservoir
  - Phase 1 - Theoretical analysis, **laboratory tests**, guidelines for the fieldwork.
  - Phase 2 - **Field study of pressure wave propagation**.
  - Phase 3 - Construction of the numerical model.
  - Phase 4 - Calibration of the numerical model.
- Presented paper – experimental analysis of wave celerity – part of Phase 2 and 3

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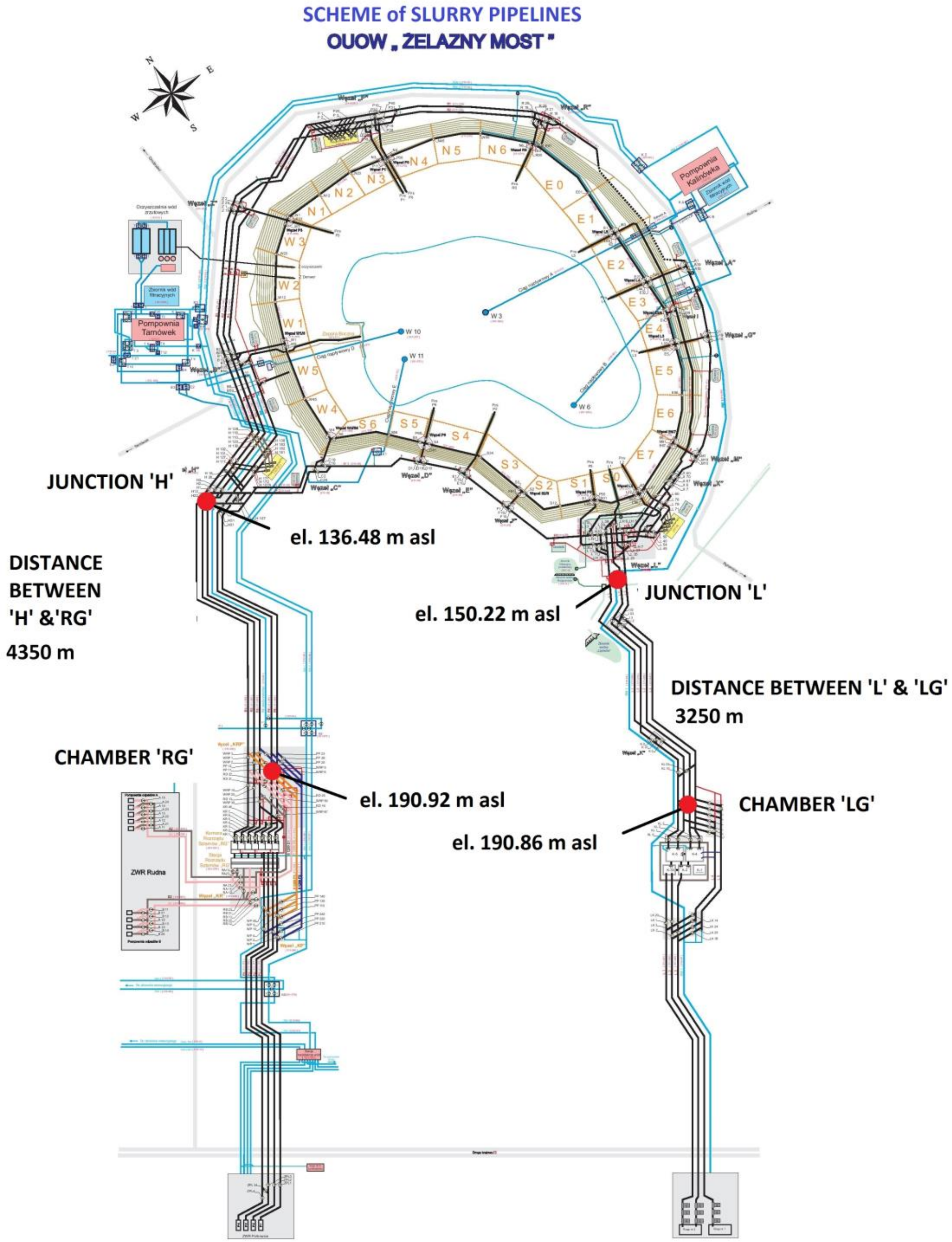
The problem

- Network of pressure pipelines – about 150 km total length of large pipelines (diameter > 800 mm)
- 4 pump stations
- Slurry transportation
- Continuous expansion - increasing level of crest



The request

- Continuous expansion of reservoir
- Increase of risk of water hammer occurrence
- Necessity of network development
- Proper description of water hammer phenomenon

A brief theory

- Pressure increase in water for rapid water hammer

$$\Delta p = \Delta \upsilon \cdot \rho \cdot a$$

- Wave celerity for water

$$a = \frac{\sqrt{\frac{K}{\rho}}}{\sqrt{1 + \frac{D}{e} \cdot \frac{K}{E}}}$$

Proposal for wave celerity definition for slurries

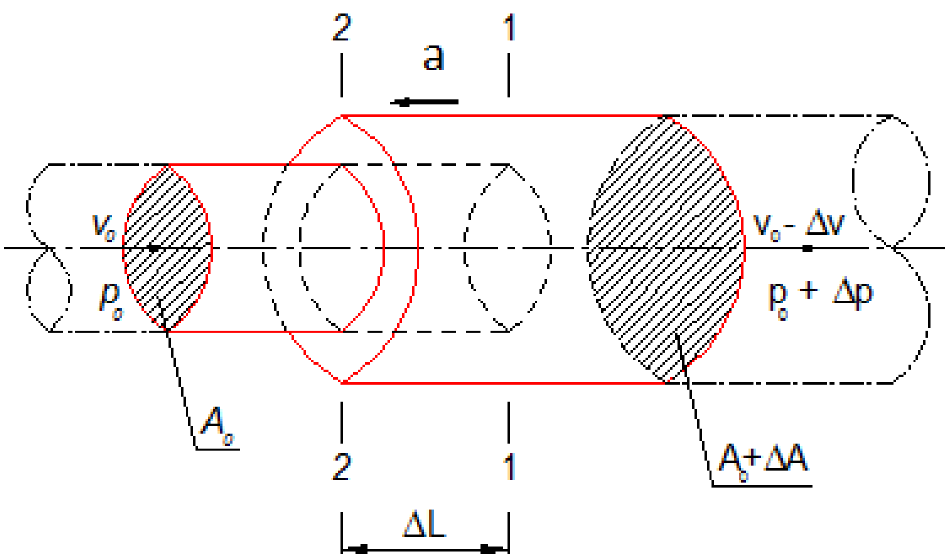
$$a_{he} = \frac{\sqrt{K \cdot \left(\frac{C_V}{\rho_S} + \frac{1 - C_V}{\rho_L} \right)}}{\sqrt{1 - C_V + \frac{K}{E_S} \cdot C_V + \frac{K}{E} \cdot \frac{D}{e}}}$$

The target

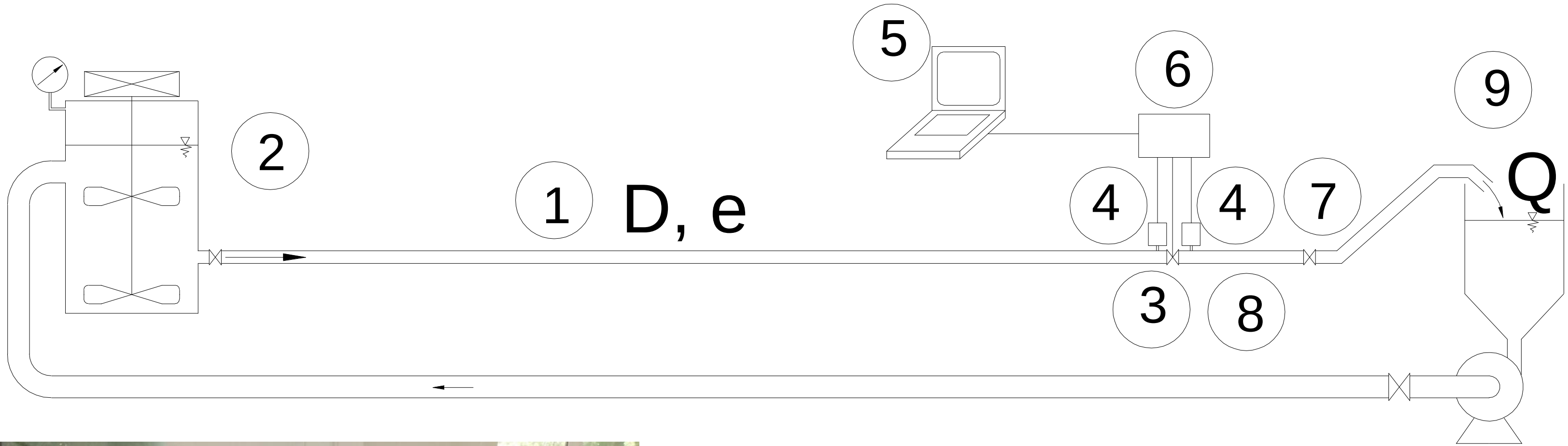
- A numerical model of transient flow dedicated to a particular network
  - Laboratory experiments to investigate the phenomenon
  - Field tests to analyze phenomenon in real system
  - Determination of experiment-based wave celerity

$$a = \frac{2 \cdot L}{T_R}$$

$$a = \frac{\Delta L}{t}$$



Laboratory experiments



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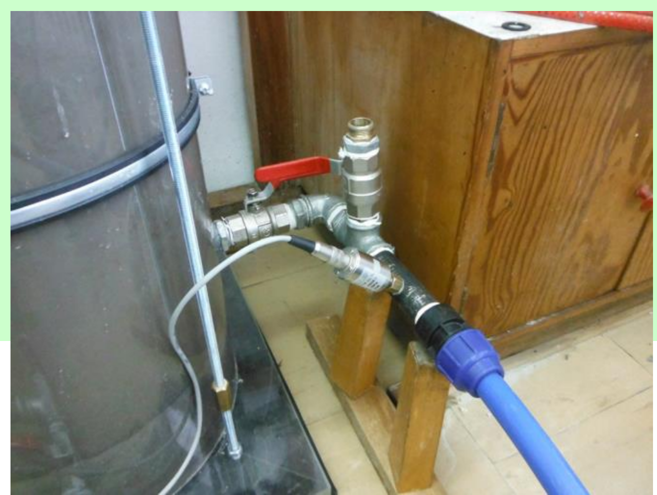
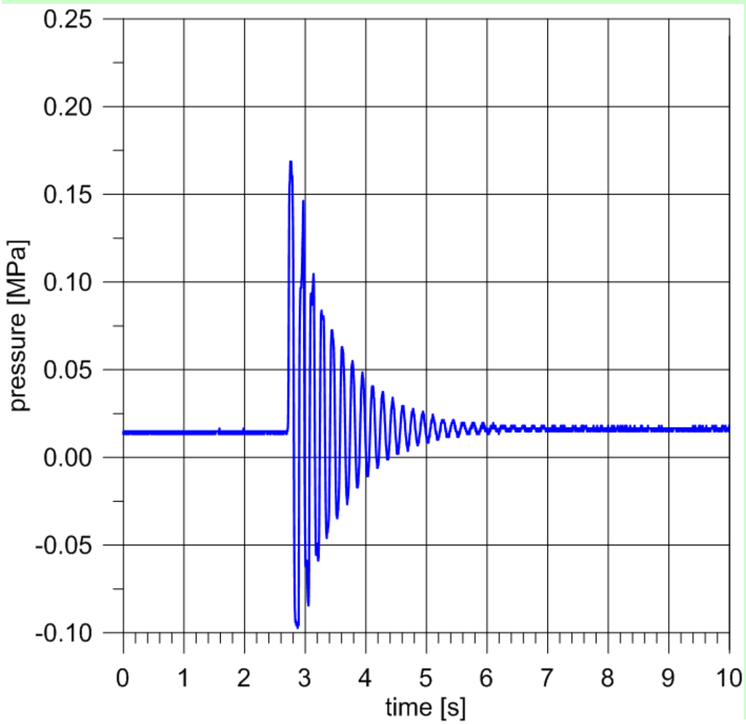
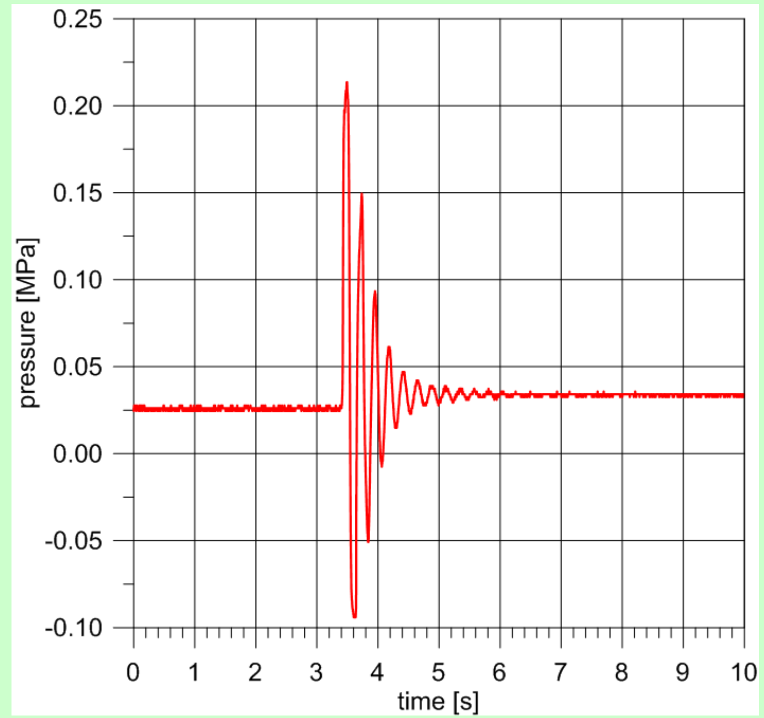


ments

Laboratory experiments – example of pressure characteristic



water



slurry

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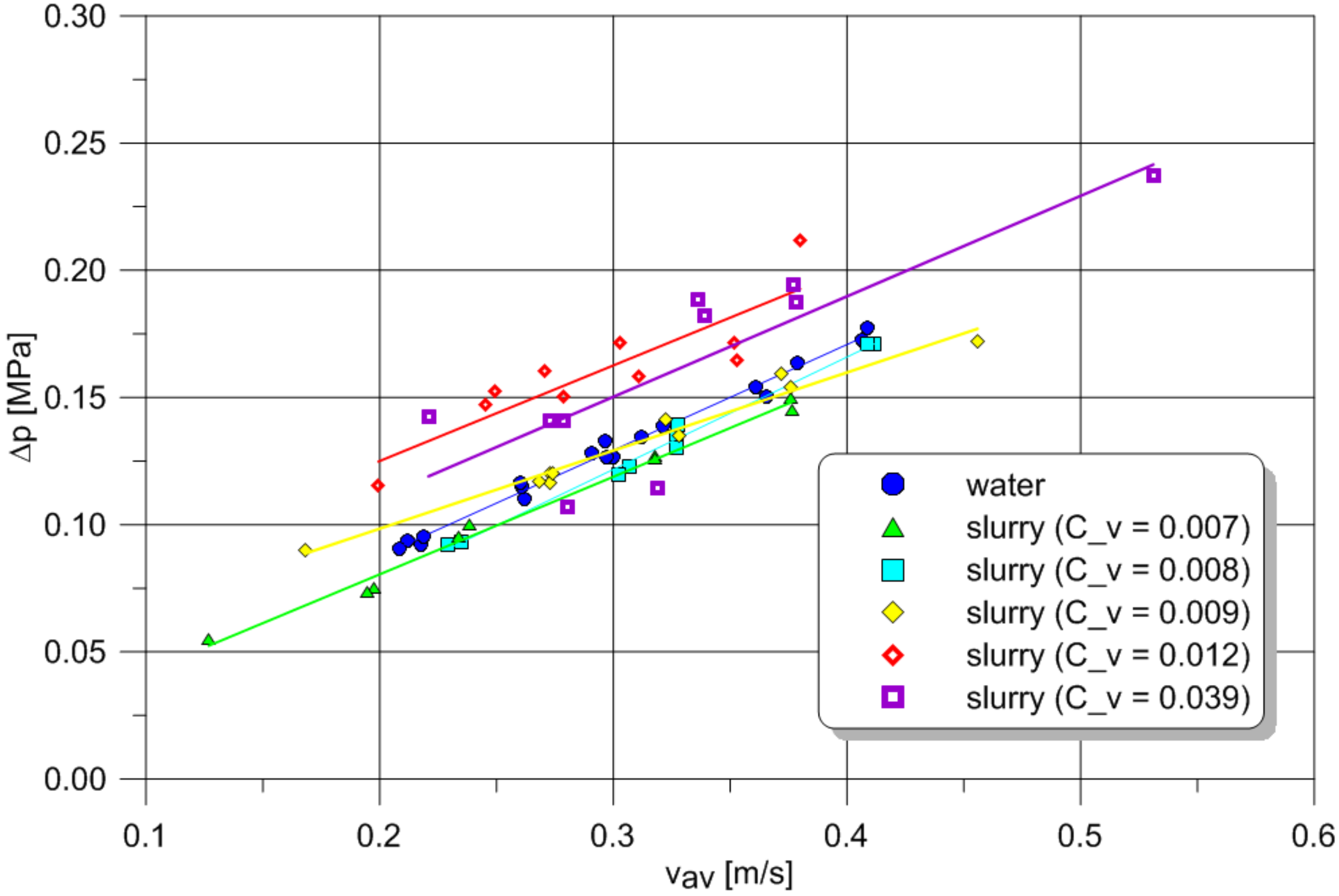
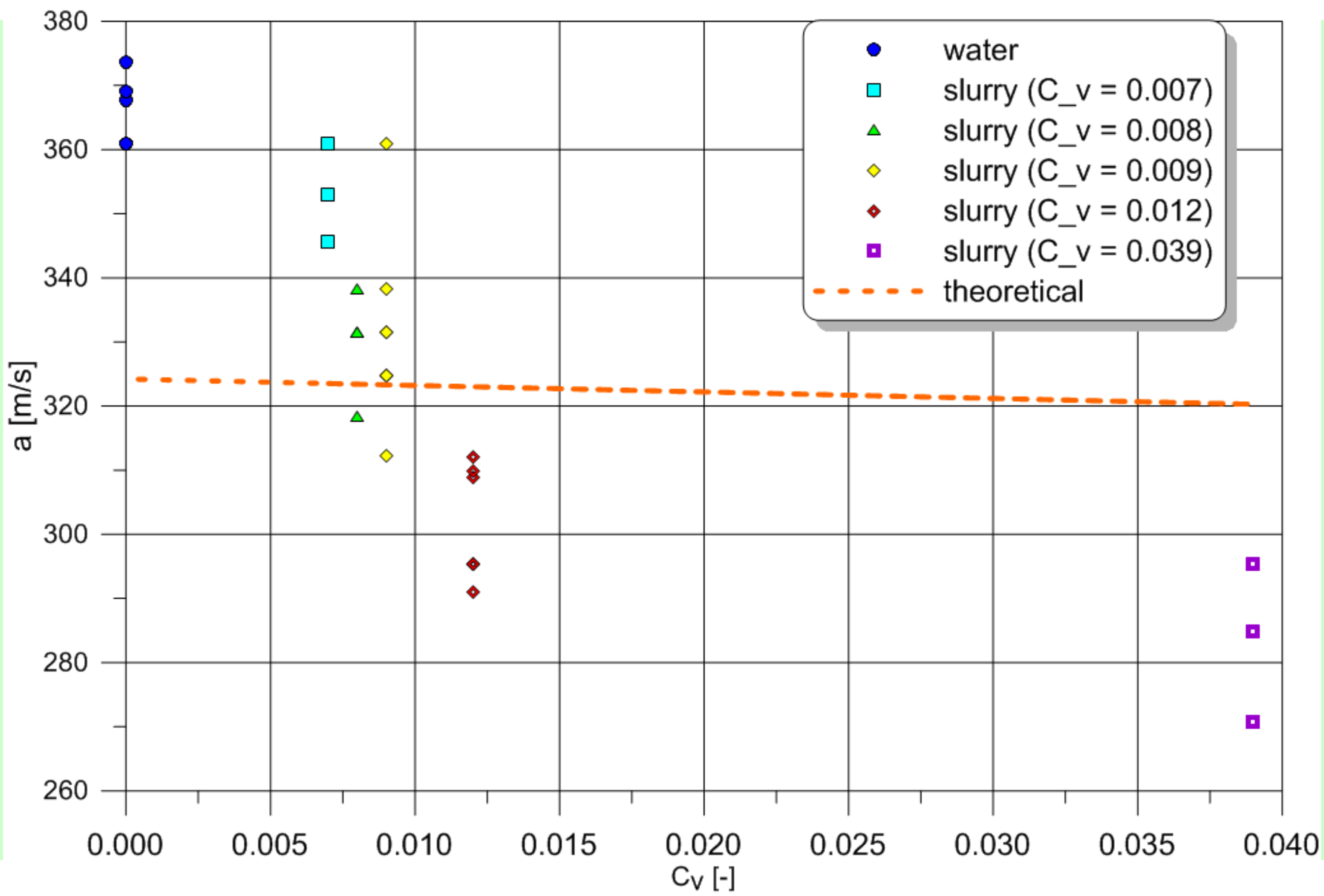
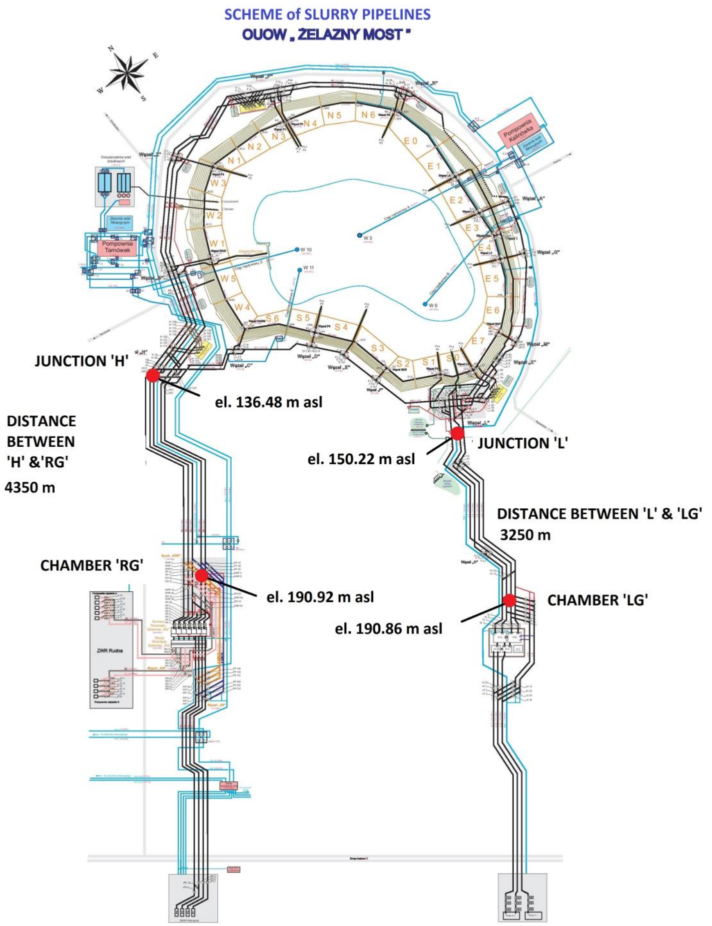
Laboratory experiments



Comparison with theoretical calculations



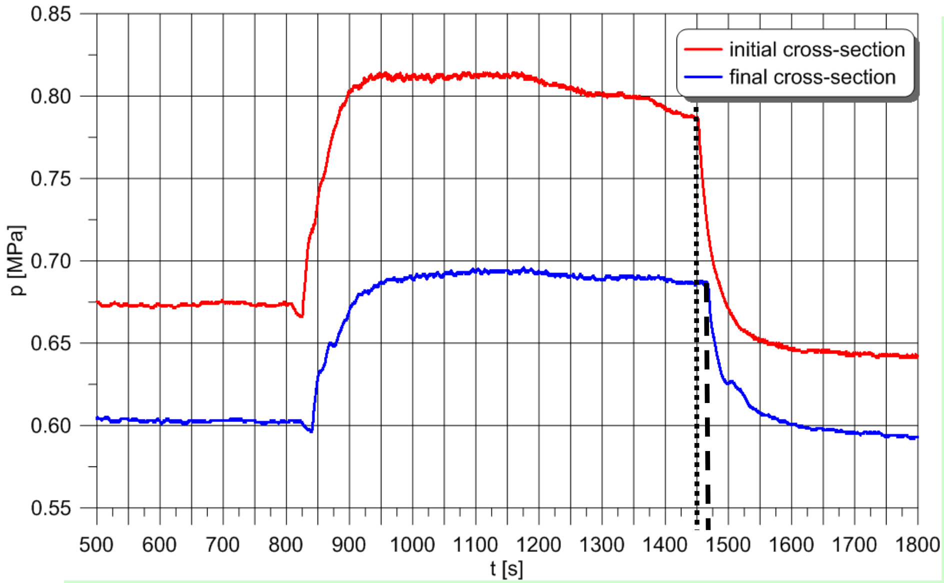
Fields tests

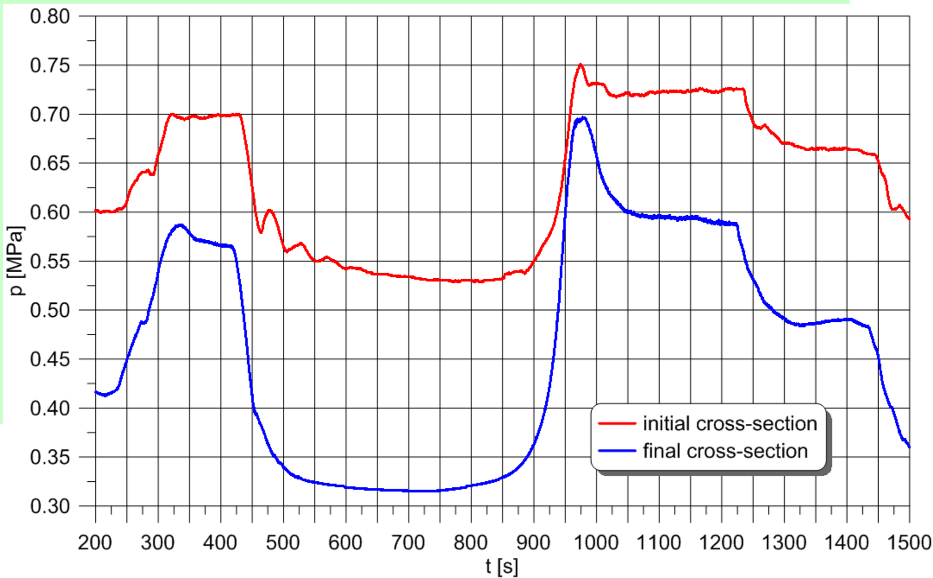


What's going on???
Where are the results?!?

Fields tests

Fields tests - pressure characteristic





Fields tests - results

Pumping station	Average measured wave celerity [m/s]	Volumetric concentration	Calculated wave celerity [m/s]
Lubin	374.8	0.046	307.2
Polkowice	461.8	0.071	305.2
Rudna	269.4	0.065	305.8

Conclusions

- **The pressure increase** during the transient flow **is in linear relationship to the steady-flow velocity**, as well for water and slurries.
- The observed **pressure raise for slurries increases** with the **raising volumetric concentration**.
- The similar influence of the flow velocity on the pressure increase **allows the use of Joukovsky formula to determine the maximum pressure change**.

Conclusions

- An **significant influence of volumetric concentration** of slurry on the **wave celerity** was observed.
- The **wave celerity** calculated from the field test results is higher than obtained during the laboratory tests.
- During the field test, the significant influence of slight amount of air on pressure wave decrease was observed.

Conclusions

- The **relationship between the wave celerity and the volumetric concentration** obtained during the field test is different than observed during the laboratory experiments.
- **Formulation of a new equation enabling determination of the wave celerity for slurries is a challenge for scientists. At the moment it is advisable to determine the celerity each time in the way of experiments.**

Thank you for your attention

- **Acknowledgements:**

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