ASIA TURBOMACHINERY & PUMP SYMPOSIUM
MARCH 2018 | SUNTEC SINGAPORE

Benefits of Installing Restrictive Orifice Plates on the Suction of Reciprocating Pumps: 1D Pulsation and CFD Studies

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Presenter/Author bios

Zixiang Chen, Wood (formerly **BETA Machinery Analysis**), PhD, EIT, Engineer – Zixiang has recently completed his doctoral work in the field of fluid dynamics. His academic research interest is on the sensor-based estimation of large-scale coherent structures in turbulent flows using optical flow diagnostics and numerical simulations. Prior to joining Wood Group in 2014, he worked on combustion modelling for the GT24/26 and compressor aerodynamics for the PT6.

Cajetan Ijeomah, Wood (formerly **BETA Machinery Analysis**), MSc, PEng, Senior Engineer
Cajetan is a professional engineer with over 14 years of industry experience, the majority of which is in dynamic engineering and vibration design. His responsibilities include acoustical (pulsation), mechanical and thermal analysis of reciprocating compressor and pump systems, evaluation of piping systems and related dynamic studies. Cajetan manages complex design projects involving multiple vibration disciplines and is proficient in the use of various engineering analysis software tools.

Presenter/Author bios

Jordan Grose, Wood (formerly **BETA Machinery Analysis**), PEng, MBA, Service Leader – Americas
Jordan is a mechanical engineer with extensive domestic and international design, field, and monitoring experience with compressors, pumps, pipelines, and other production machinery. He has specialized skills in vibration, liquid transient analysis, performance, and troubleshooting in onshore and offshore production facilities.

Jordan currently leads Wood Group's vibration integrity group in addressing plant-wide vibration risks in piping and machinery systems. He has been with Wood Group (formerly BETA Machinery Analysis) for over 14 years, during which time he has authored and co-authored several papers. Jordan was formerly responsible for BETA's Malaysia office in Kuala Lumpur.

Paul Crowther, Wood (formerly **BETA Machinery Analysis**), MSc, CEng, Principal Consultant

Paul is a technical authority in Wood Group's piping vibration and integrity team, which involves design, inspection, and consulting services related to static and transient piping vibration for onshore and offshore facilities. This includes requirements defined by the Energy Institute guideline (Avoidance of Vibration Induced Fatigue Failure), as well as many different advanced analysis services.

Paul is a principal consultant, with over 11 years of experience in advanced engineering analysis in Europe and the Middle East, where he has supervised large scale piping vibration projects. He has carried out numerous investigations and studies covering most vibration excitation mechanisms found in modern process plant operations across the world, both topsides and subsea. He is actively involved in industry committees, research, supervision, and specialized engineering projects.

Abstract

It is well understood that static pressure at the inlet of reciprocating pumps, quantified typically by Net Positive Suction Head Available (NPSHA), must be sufficient to avoid cavitation in the pump suction manifold and chamber. In an effort to conserve NPSHA, pump designers generally rely on rules of thumb that resist the addition of pressure drop elements such as restrictive orifice plates, choke tubes and line-size reductions to the inlet piping of all pumps, including reciprocating pumps.

Another design consideration of reciprocating pumps is the generation of pressure pulsations due to pump piston and valve motion. Uncontrolled pulsations can result in cavitation and vibration-related fatigue failures. In many cases, pressure drop elements are required to control pressure pulsations. Can there be a balance between the pulsation control benefits of pressure drop elements and the need to meet NPSHA?

This paper is of interest to designers and engineers working with reciprocating pump installations. It aims at challenging industry resistance to using pressure drop elements in the suction piping of reciprocating pumps by, first, outlining the virtues achieved in terms of pulsation and vibration control, and second, presenting results from numerical simulations (one-dimensional pulsation and detailed CFD modelling). Recent field data from a quintuplex pump installation were used to validate the 1-D pulsation model. The results show that well-designed orifice plates, and other pressure drop elements, are beneficial for reducing pulsations and cavitation risks; and can be used in the suction piping of reciprocating pumps.

Objective

- Demonstrate that proper use of orifice plates and other pressure drop elements (choke tubes and line-size reductions) in the suction piping of reciprocating pumps are beneficial for pulsation control and mitigation of cavitation risks.

Analysis approach

- Field-measured pulsations and numerical simulations (1-D pulsation model and CFD modelling).

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Introduction

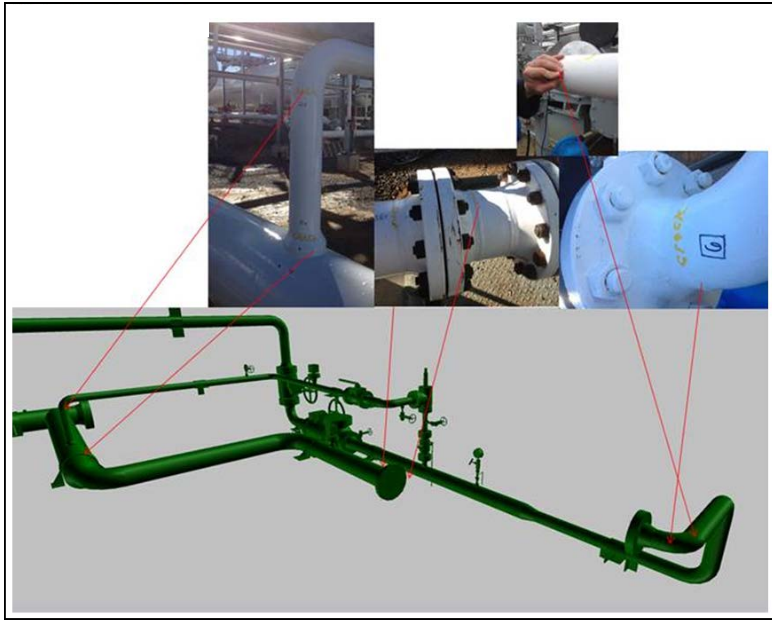
- Reciprocating pumps:
  - Widespread use in industry
  - Generate pressure pulsations
  - Uncontrolled pulsations → vibrations, cavitation, failures

- Orifice plates:
  - Reduced pressure under-spikes → lower cavitation risk
  - Pressure drop → reduced NPSHA → higher cavitation risk

Introduction, continued

Case study pump installation:

- Two 5-plunger propane pipeline pumps; 3.5” bore x 5” stroke
- 160 – 400 RPM, 416 GPM/pump; Ps = 98 – 282 psig; Pd = 1100 psig
- Elevated and inadequately supported piping
- High pulsations, vibrations and indications of cavitation
- Winter condition worse than summer due to higher liquid bulk modulus
- NDT showed several cracks in piping after six months of operation

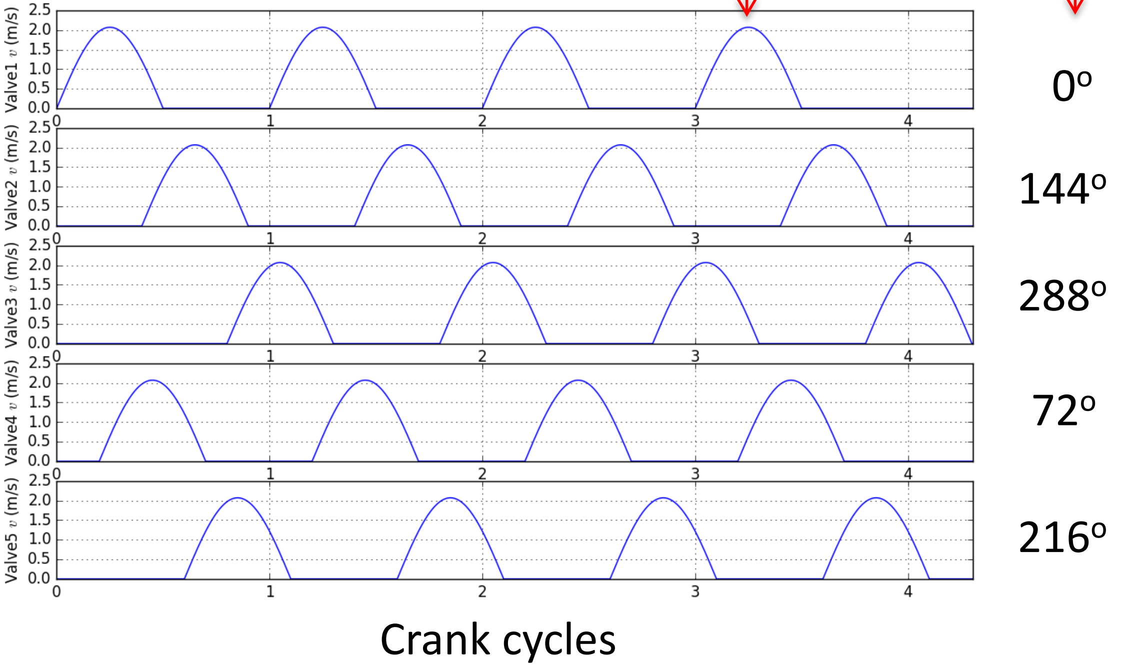


1-D model

- Applied method of characteristics to solve 1-D fluid dynamics equation
- Used empirical loss factors to calculate irreversible pressure losses
- Modelled from pump valves to known boundaries in piping

- Velocity peak from average flow rate.
- CFD: sinusoidal wave-form. No valve delay.

Plunger phasing



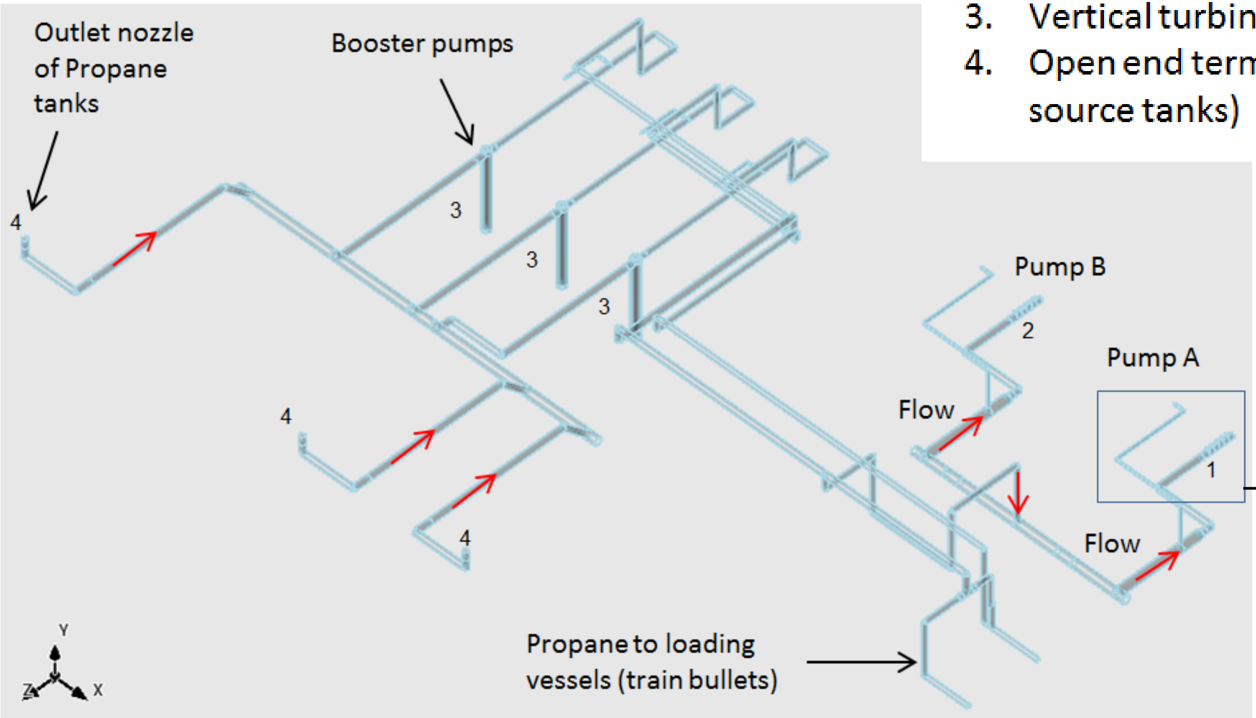
BC: Velocity profile at the pump valves

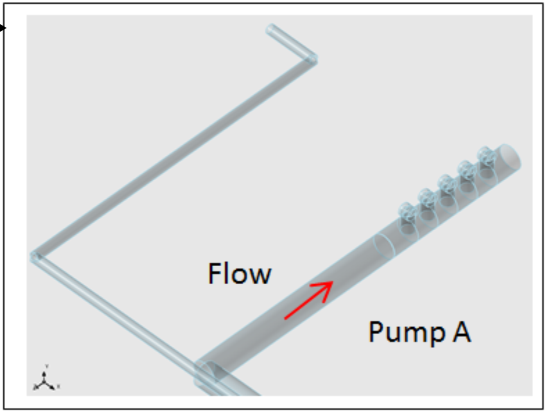
1-D model, continued

Pump suction: original design

<u>Legend</u>:

1. Pump A
2. Pump B
3. Vertical turbine booster pumps (limited space)
4. Open end terminations (outlet nozzles of the propane source tanks)



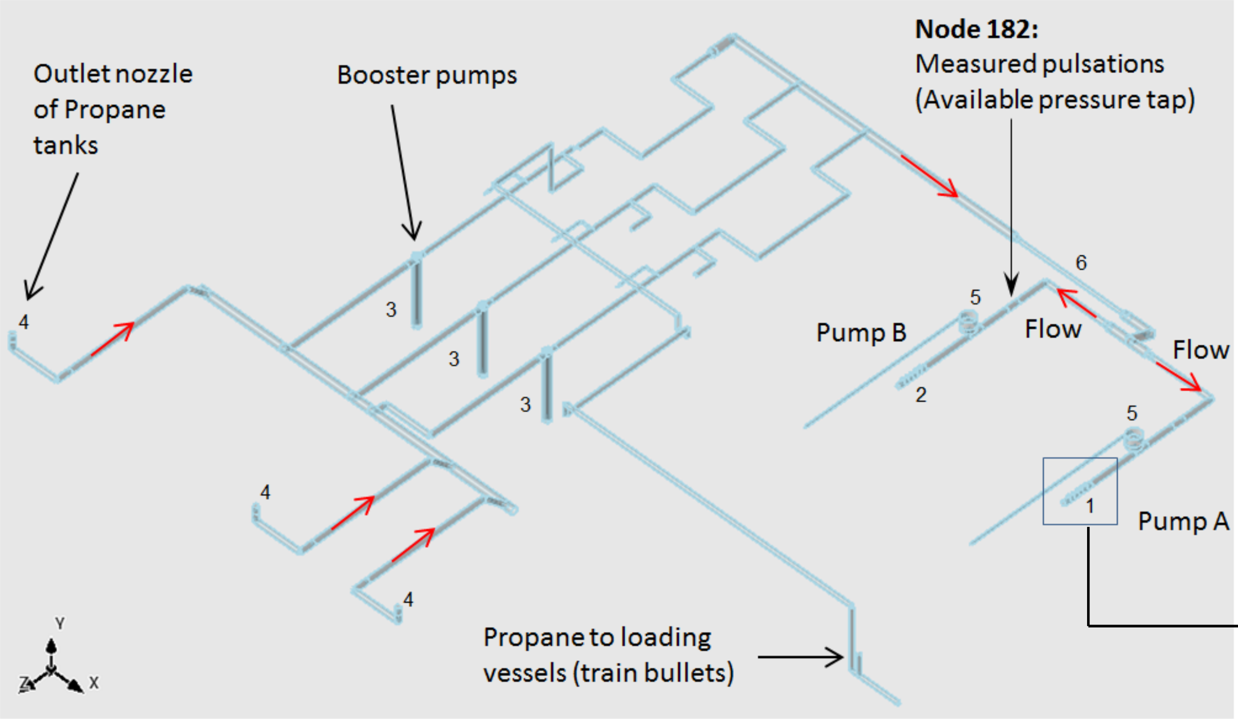


1-D model, continued

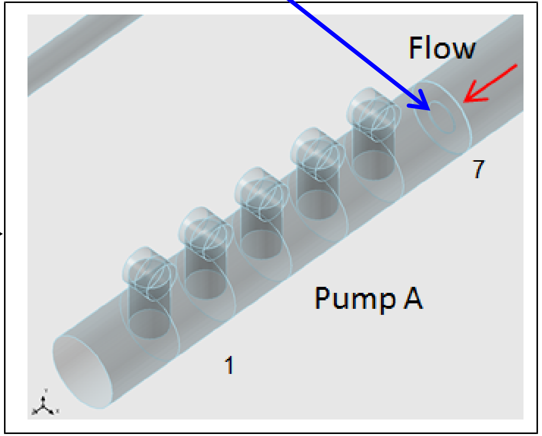
Pump suction: modified design

Legend:

1. Pump A
2. Pump B
3. Vertical turbine booster pumps
4. Open end terminations (outlet nozzles of the propane source tanks)
5. 20 gallon gas-charged dampener
6. 6" Sch. 160 line reduction (external choke tube)
7. 3.125" ID restriction orifice plate (40% beta ratio)

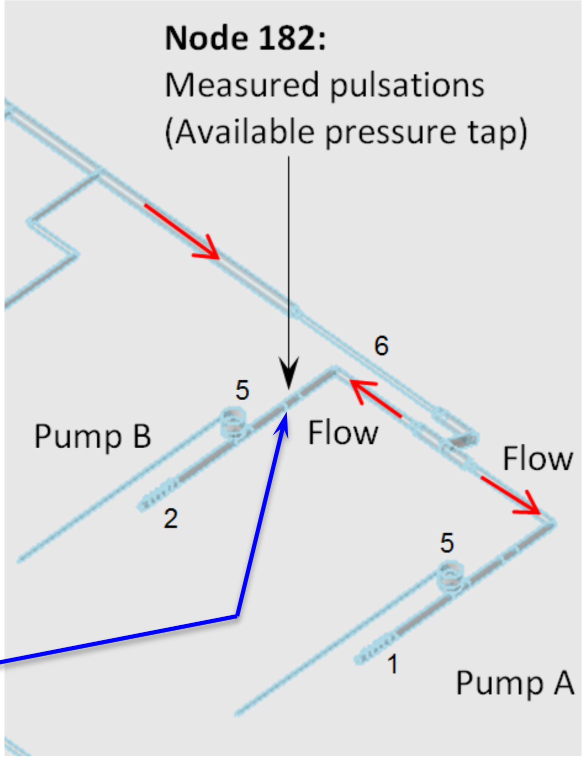


3.125" ID orifice plate



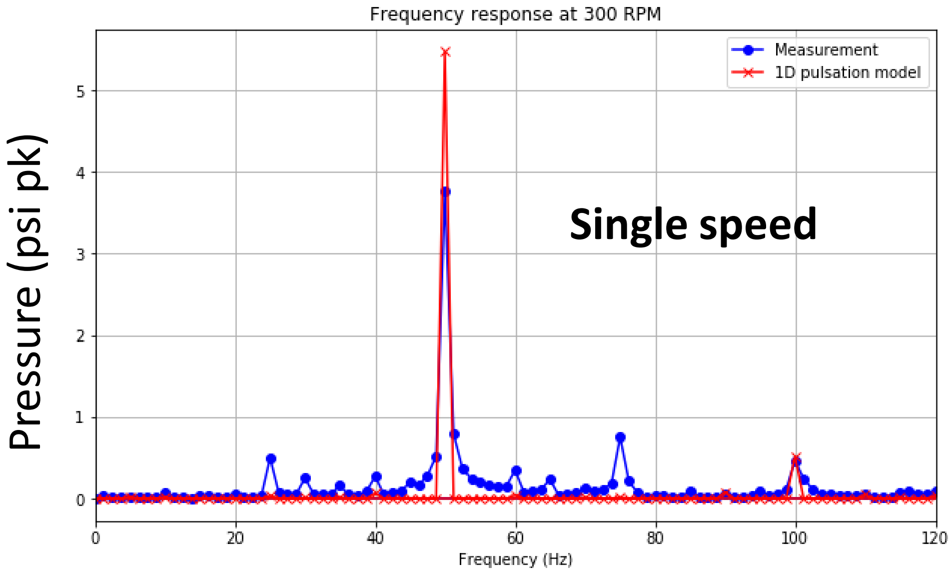
Validation of 1-D model

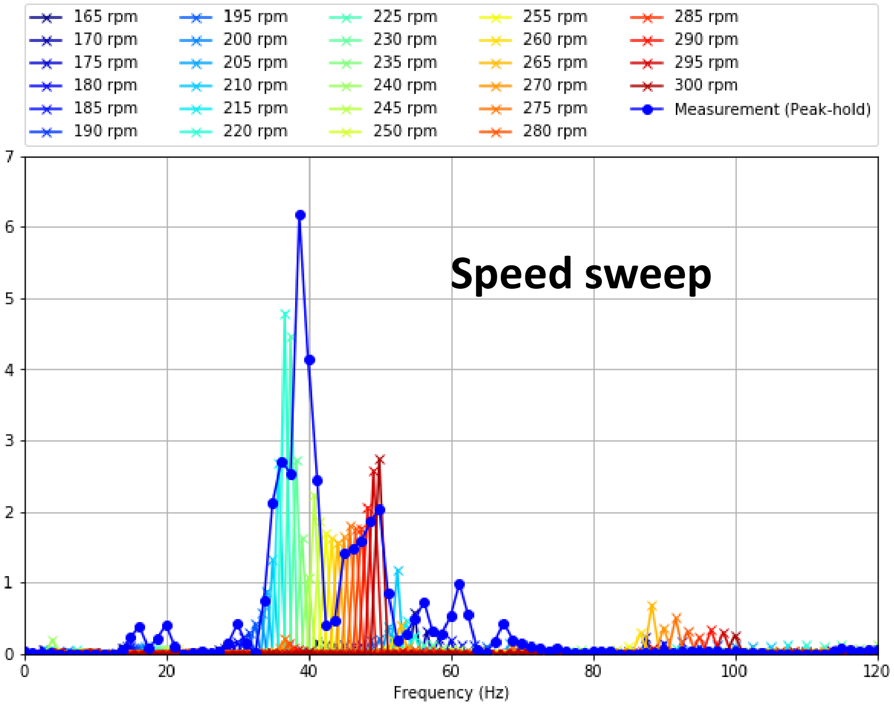
- Field: pulsations measured at Node 182
- Field data vs 1-D model:
  - Field visit during summer
  - Frequency spectra at 300 RPM
  - Frequency spectra at 165 – 300 RPM



Validation of 1-D model, continued

Summer condition





Pulsations at node 180 (without orifice plate installed)

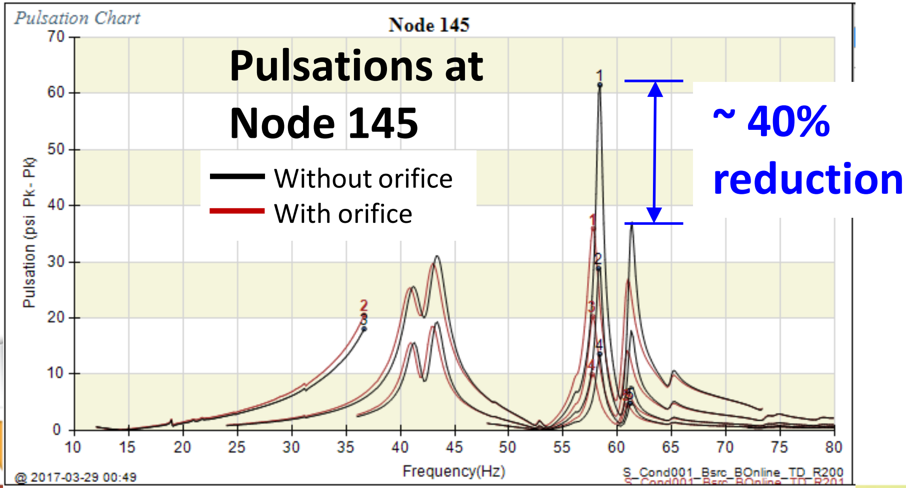
1-D model results

Key result:

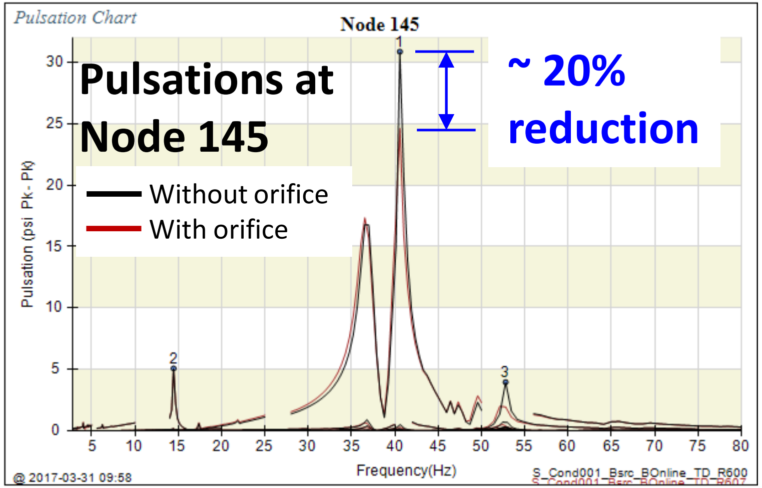
Orifice plate will improve reliability.

Operator concerned with pressure drop.

Winter condition



Summer condition

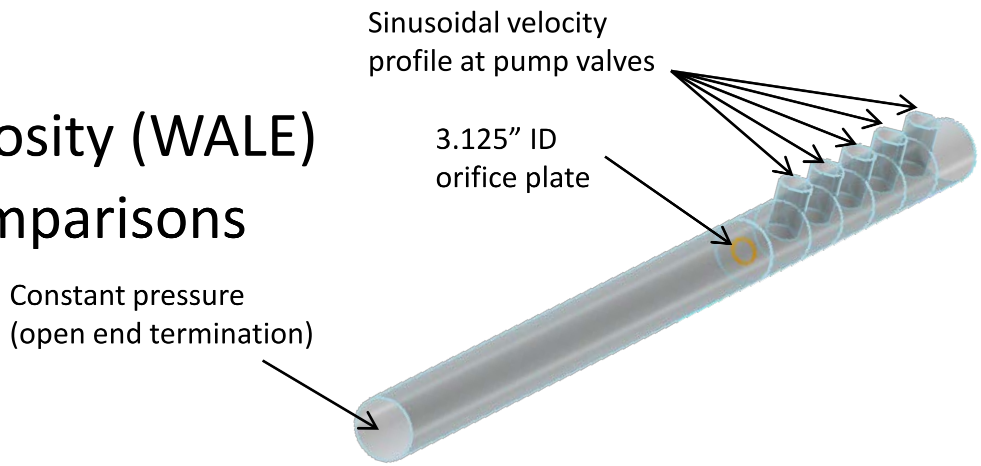


CFD model

- Solved 3-D Navier-Stokes equation
- Modelled from pump valves to small part of suction piping
- Assumed ideal pump valve opening and closing (no valve delays)
- BC: velocity profile at valves; constant pressure at suction pipe
- Turbulence model:

  → Large-eddy simulation (LES)

  → Wall adapting local eddy-viscosity (WALE)
- Used reduced 1-D model for comparisons with CFD model

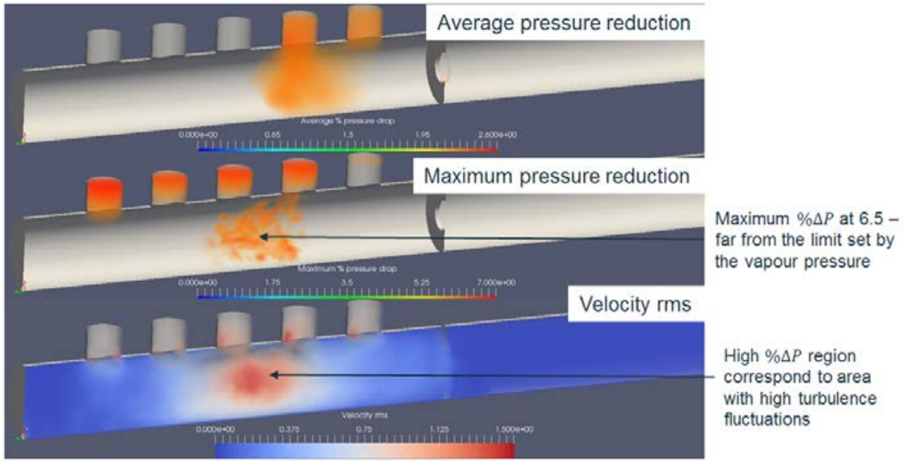


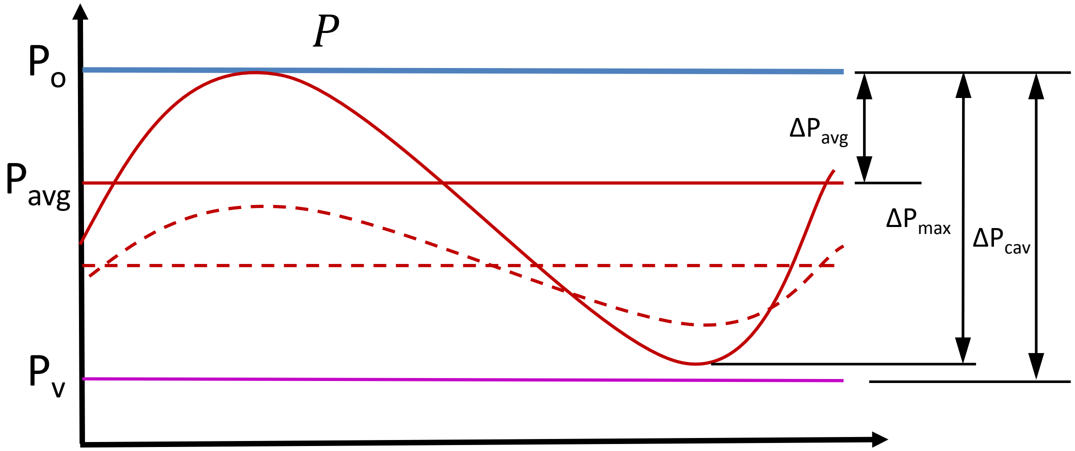
Definition of pressure loss terms

- ΔP_{avg} : Average pressure loss
- ΔP_{max} : Maximum pressure loss
- ΔP_{cav} : Pressure loss for cavitation
- P_o : Static pressure at pump inlet
- P_{avg} : Time-average static pressure (time: ~ 2 sec.)
- P_v: : Vapour pressure

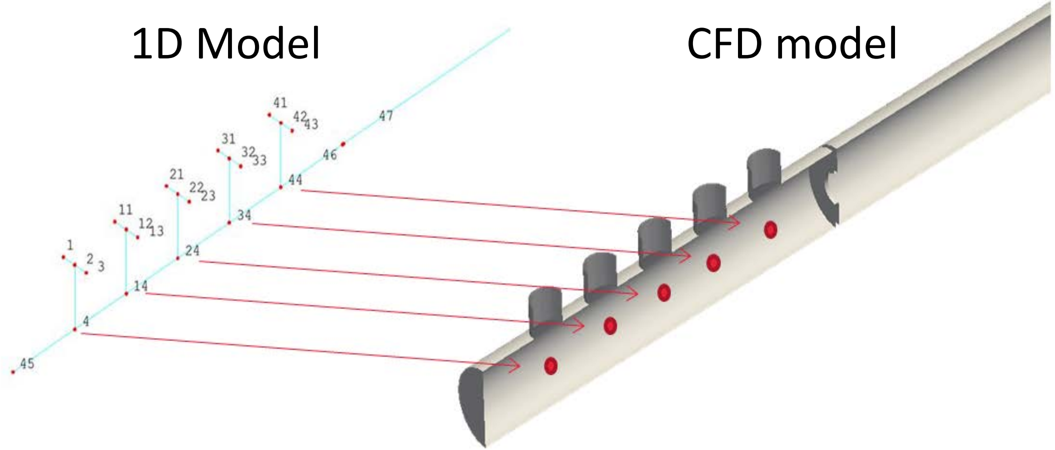
—— Pressure without orifice plate

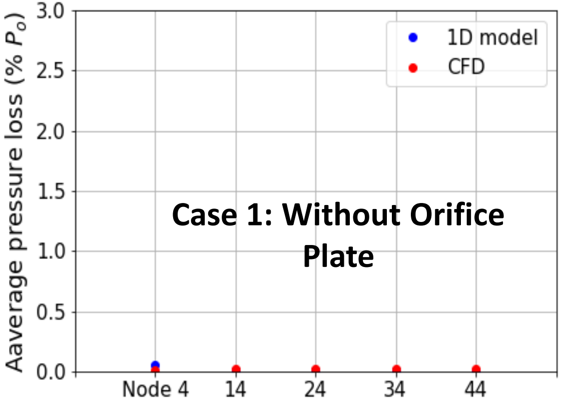
- - - Pressure with orifice plate

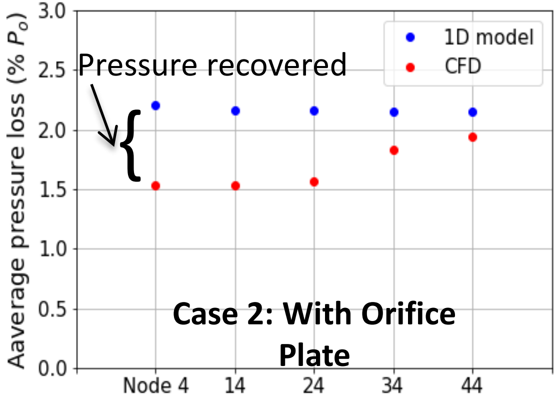




Average pressure loss: 1-D vs CFD model



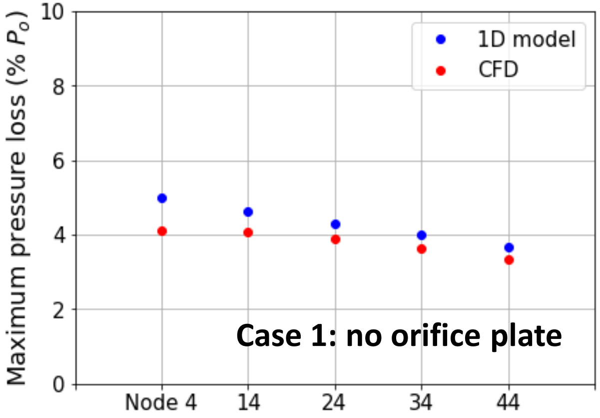


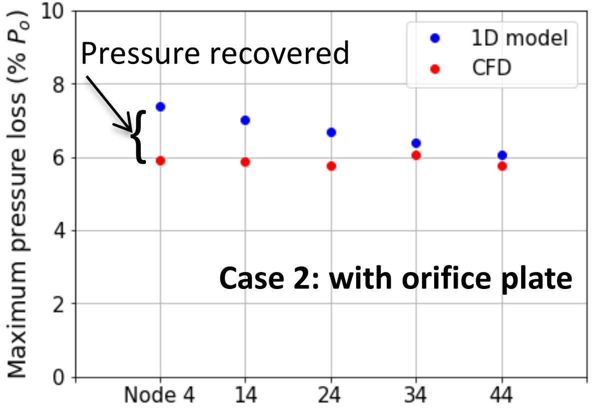


- The same geometry for 1-D and CFD models
- Average pressure loss (recoverable + irreversible)
  - → Effect of pulsations not included
  - → Higher loss with orifice plate
    - → Pressure recovery with CFD model

Total pressure loss: 1-D vs CFD model

- Maximum pressure loss (pulsations + recoverable + irreversible)
  → Mainly due to pulsations
  → Higher with orifice plate
  → Pressure recovery with CFD model
  → Same trend in both models.
    ❖ Increases towards closed end





Key result:

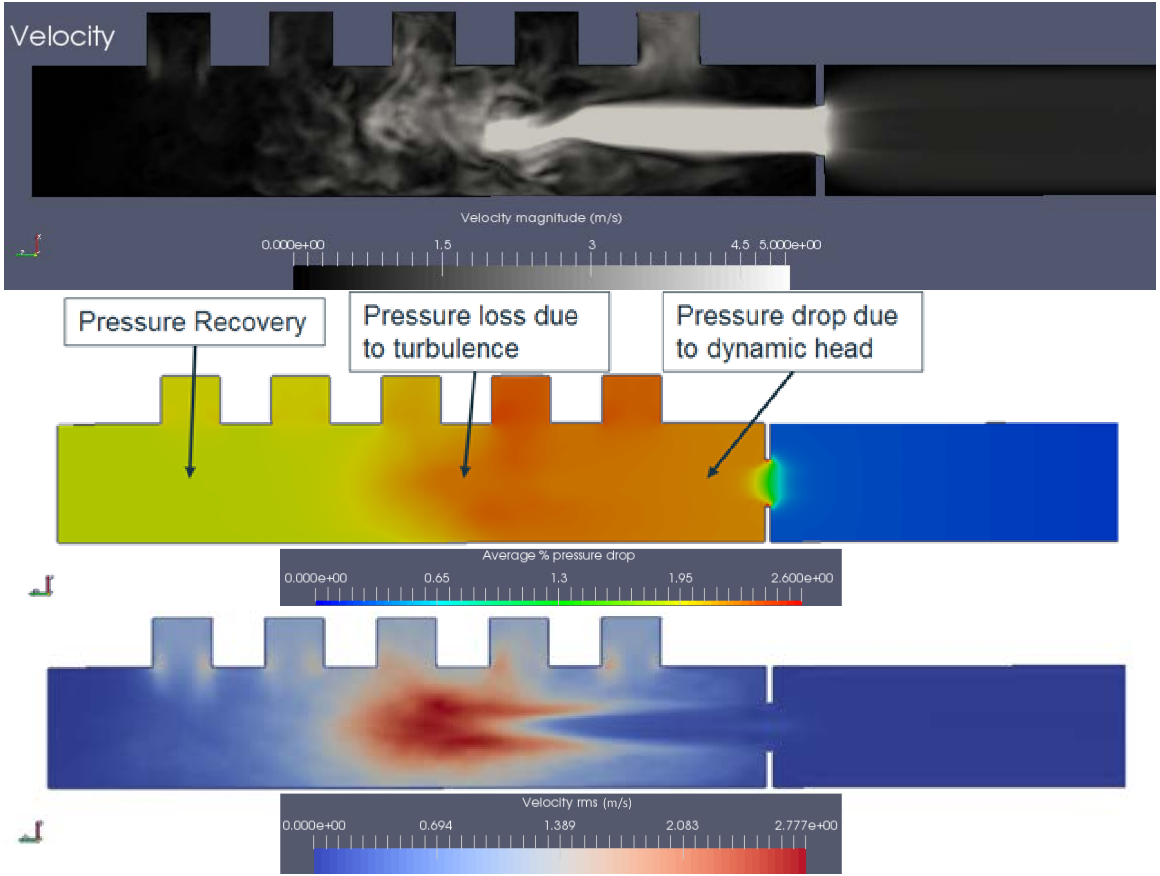
- Average pressure loss in 1D model is irreversible (no pressure recovery)
  → more conservative

CFD visualization: pressure recovery

(a) Instantaneous velocity field

(b) Average pressure reduction

(c) Velocity rms



CFD animation **with** orifice

CFD animation
without orifice

Conclusions

- 1D pulsation model validated with field data: good agreement
- Predicted pressure losses consistent between 1-D and CFD models
- CFD simulation provided more information, incl recovered pressure loss
- Well-designed orifice plates and other pressure drop elements:
  - → Are beneficial for reducing pulsations, vibrations and cavitation risks
  - → Can be used in the suction piping of reciprocating pumps if properly sized for mean and dynamic pressure losses
- Orifices not yet implemented for this project. Have been used in others.

Questions