

Uncontrolled air pocket release and geysering in upstream dropshafts in stormwater systems

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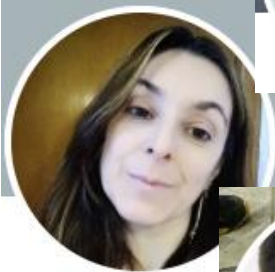
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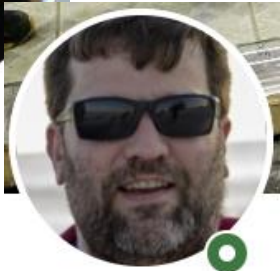
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Transient flows in stormwater systems and geysering

- Transient, air-water flows are observed in stormwater systems undergoing rapid filling
 - Significant changes in pressure and velocity, vibrations, reverse flows, and other situations
- May lead to unacceptable operational conditions such as geysering
- Research has been focusing on the causes, severity and characterization of geysers
 - Yet, geysering for some geometric configurations remain not well understood



Contributions to geysering research

Experimental/field scale research

- Laboratory-scale characterization of geysering
- Large-scale experiments on geysering
- Field-scale monitoring of geyser events
- Manhole cover displacements/shaft air pressurization

Numerical modeling

- Lumped-scale modeling of air pocket release
- CFD models representing laboratory scale
- CFD models representing large-scale, real-world shaft geometries

Knowledge gap: air release from an upstream shaft

Most experimental studies have involved air release from a vertical structures connected at upstream and downstream to conduits

- Muller et al. (2017) estimates from CFD indicate that a significant fraction of the air might sweep past a shaft and not be released during a geysering event

Upstream/terminal dropshafts might also be impacted by the release of entrapped air pockets (Vasconcelos et al. 2022)

- Entrapped air has no alternative route but being released through the shaft
- However, no experimental investigation has addressed this case

Objectives

This work presents results from large-scale experimental investigation performed on the release of entrapped air pockets from a dropshaft placed at a terminal point in the apparatus.

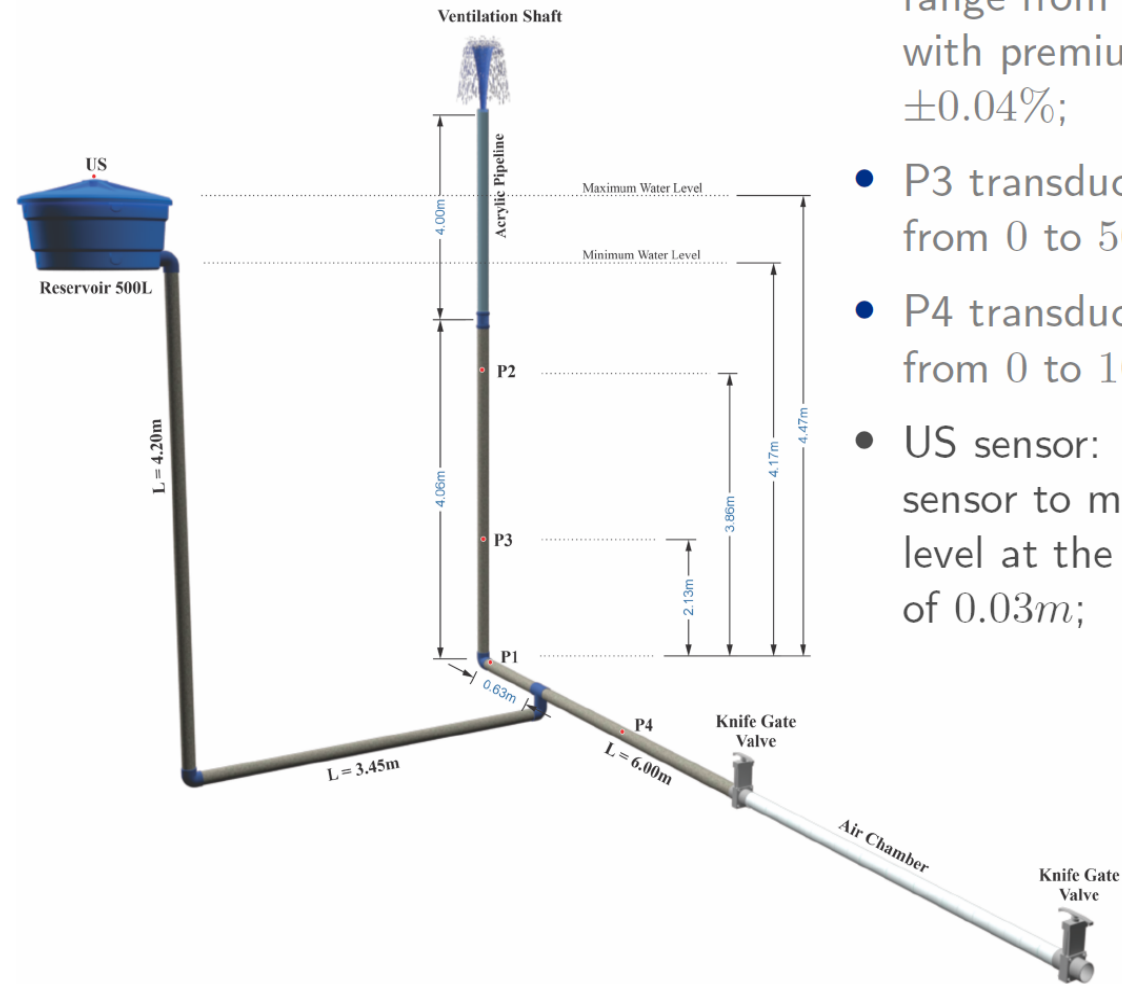
Goal is to compare the results with cases in which air pockets were release through intermediate shafts

Experimental conditions and variables

Apparatus constructed at the Federal University of Santa Maria, with a horizontal apparatus comprised by 100-mm PVC.

Total of 16 unique geometric conditions:

- Two vertical shaft geometries
 - 8.1 m, 100-mm tower with last 4 m in acrylic
 - 4.1 m, 100-mm followed by 6.0-m, 50-mm PVC
- Valve opening
 - Quick and complete (Q), following the approach of most experimental studies
 - Gradual to enable air pressurization, followed by complete release
- Two air pocket volumes were released: 25 L and 45 L
- Two levels in the water reservoir that sustained the pressure in the experiments



- P1 and P2 transducers: Pressure range from -34.47 to $68.95kPa$ with premium precision of $\pm 0.04\%$;
- P3 transducer: Pressure range from 0 to $50kPa$;
- P4 transducer: Pressure range from 0 to $100kPa$
- US sensor: Ultrasonic ranging sensor to monitoring the water level at the resevoir, with accuracy of $0.03m$;

Experimental apparatus

Normalized range of experimental tests

| No. tested condition | Valve Opening | D^* | $Y_{FS,0}^*$ | \forall_a^* | \forall_a^{**} |
|----------------------|---------------|-------|--------------|---------------|------------------|
| 1 | G | 0.50 | 0.44 | 25.0 | 2.85 |
| 2 | Q | 0.50 | 0.44 | 25.0 | 2.85 |
| 3 | G | 0.50 | 0.44 | 45.0 | 5.13 |
| 3 | G | 0.50 | 0.44 | 45.0 | 5.13 |
| 4 | Q | 0.50 | 0.44 | 45.0 | 5.13 |
| 5 | G | 1.00 | 0.56 | 25.0 | 0.71 |
| 6 | Q | 1.00 | 0.56 | 25.0 | 0.71 |
| 7 | G | 1.00 | 0.56 | 45.0 | 1.28 |
| 8 | Q | 1.00 | 0.56 | 45.0 | 1.28 |
| 9 | G | 0.50 | 0.42 | 25.0 | 2.85 |
| 10 | Q | 0.50 | 0.42 | 25.0 | 2.85 |
| 11 | G | 0.50 | 0.42 | 45.0 | 5.13 |
| 12 | Q | 0.50 | 0.42 | 45.0 | 5.13 |
| 13 | G | 1.00 | 0.52 | 25.0 | 0.71 |
| 14 | Q | 1.00 | 0.52 | 25.0 | 0.71 |
| 15 | G | 1.00 | 0.52 | 45.0 | 1.28 |
| 16 | Q | 1.00 | 0.52 | 45.0 | 1.28 |

$$D^* = \frac{D}{D_t}$$

$$Y_{FS,0}^* = \frac{Y_{FS,0}}{L}$$

$$\forall_a^* = \frac{\forall_a}{D_t^3}$$

$$\forall_a^{**} = \frac{4\forall_a}{Y_{FS,0}\pi D^2}$$

Results were benchmarked with conditions presented in Muller et al. (2017)

| No. tested condition | Valve Opening | D^* | $Y_{FS,0}^*$ | V_a^* | V_a^{**} |
|----------------------|---------------|-------|--------------|---------|------------|
| 17 | Q | 0.34 | 0.55 | 3.63 | 4.53 |
| 18 | Q | 0.51 | 0.55 | 3.63 | 2.01 |
| 19 | Q | 0.67 | 0.55 | 3.63 | 1.16 |
| 20 | Q | 0.34 | 0.55 | 7.26 | 9.07 |
| 21 | Q | 0.51 | 0.55 | 7.26 | 4.03 |
| 22 | Q | 0.67 | 0.55 | 7.26 | 2.31 |
| 23 | Q | 0.50 | 0.33 | 5.00 | 0.51 |
| 24 | Q | 1.00 | 0.33 | 5.00 | 0.13 |
| 25 | Q | 0.50 | 0.33 | 10.0 | 1.02 |
| 26 | Q | 1.00 | 0.33 | 10.0 | 0.26 |
| 27 | Q | 1.00 | 0.33 | 50.0 | 1.27 |

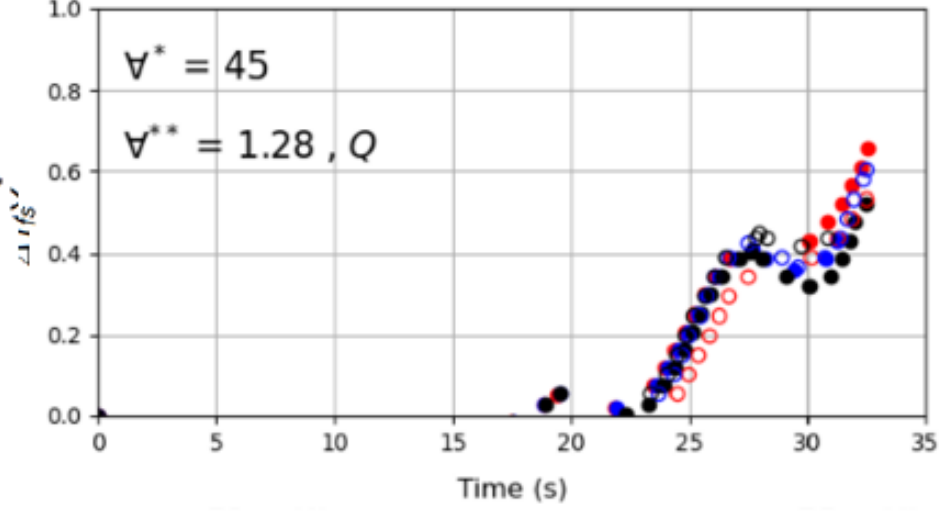
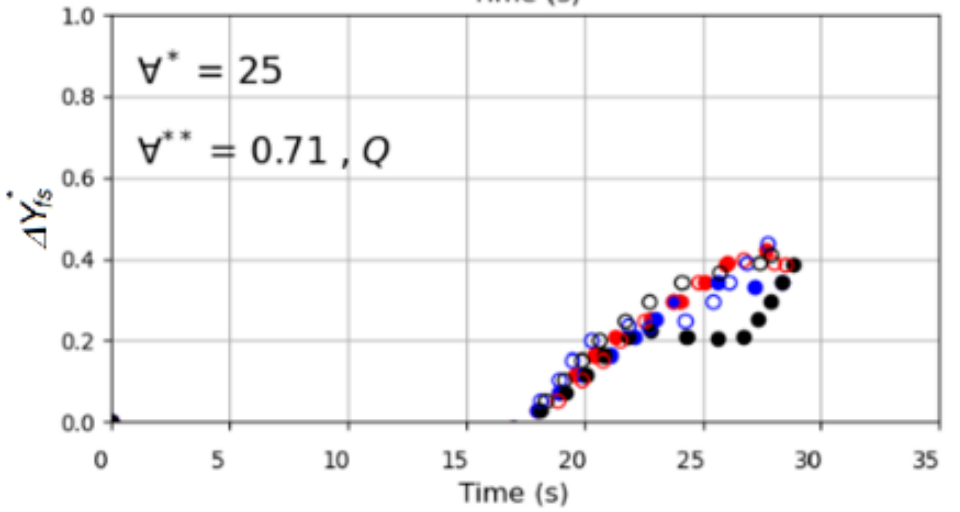
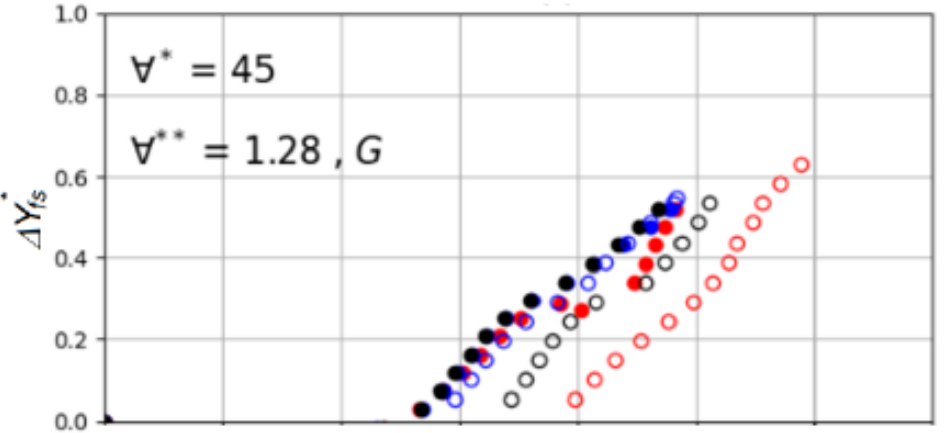
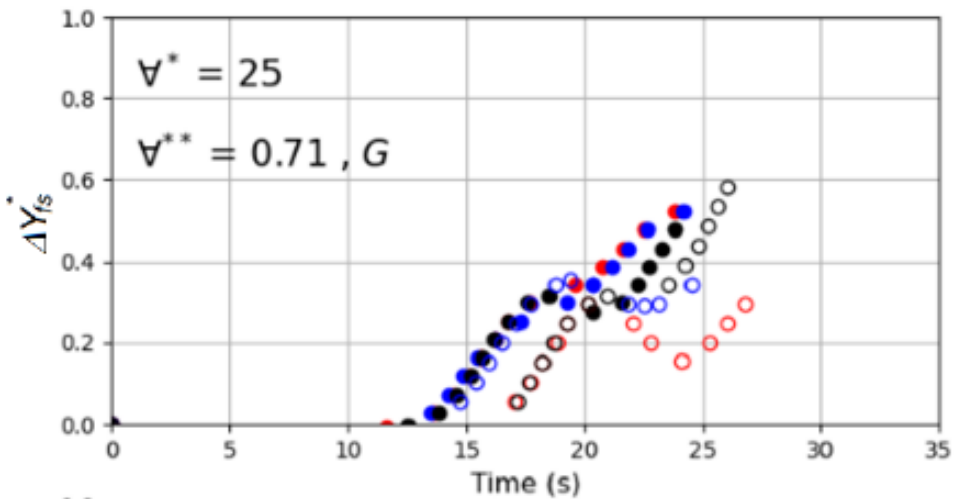
$$D^* = \frac{D}{D_t}$$

$$Y_{FS,0}^* = \frac{Y_{FS,0}}{L}$$

$$V_a^* = \frac{V_a}{D_t^3}$$

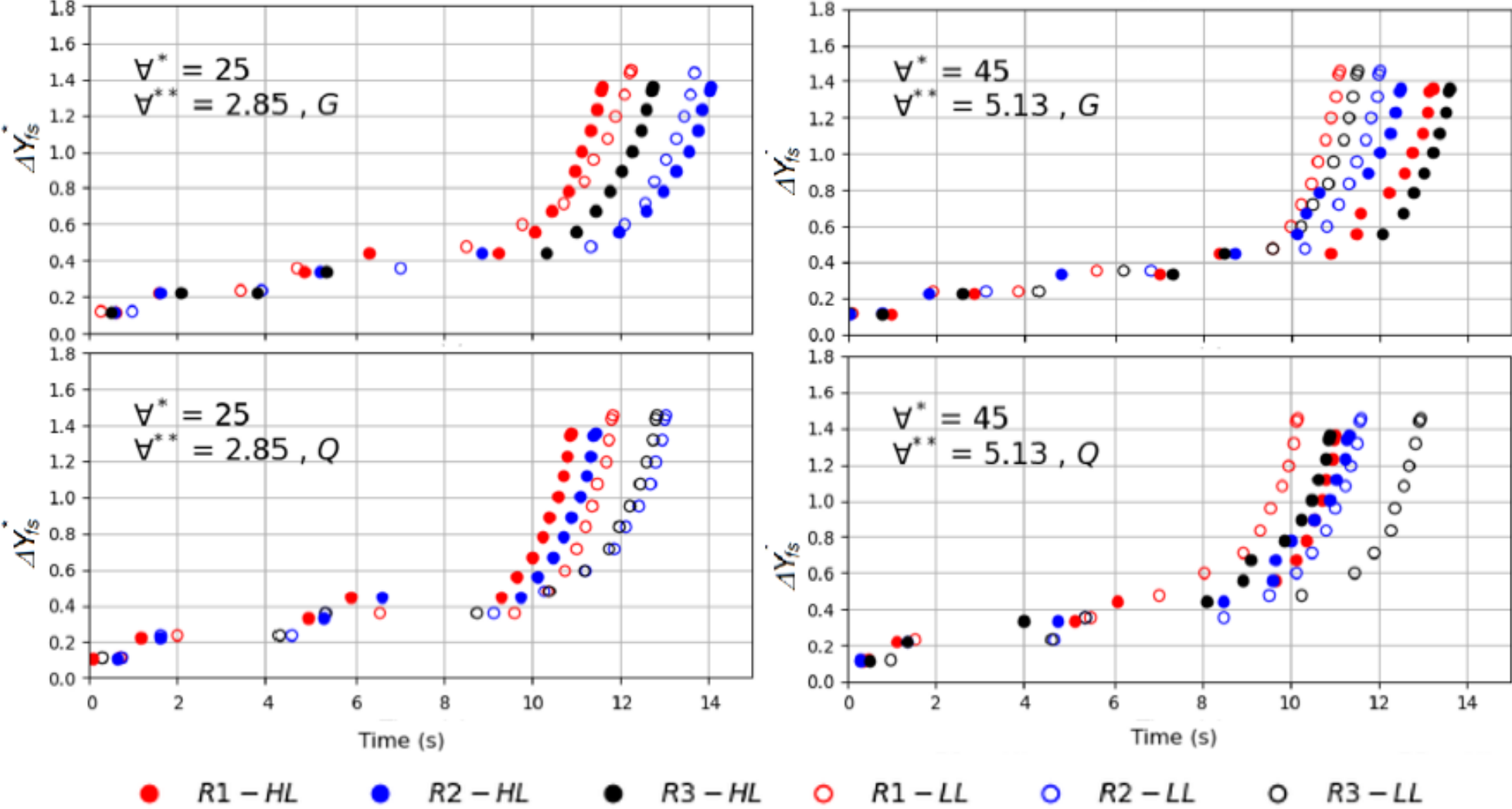
$$V_a^{**} = \frac{4V_a}{Y_{FS,0}\pi D^2}$$

Experimental results: displacements $D^*=1$



- R1 - HL
- R2 - HL
- R3 - HL
- R1 - LL
- R2 - LL
- R3 - LL

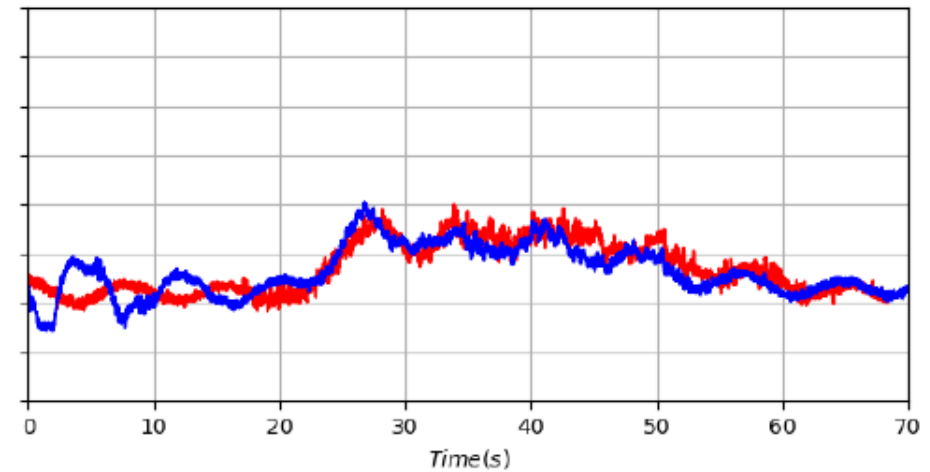
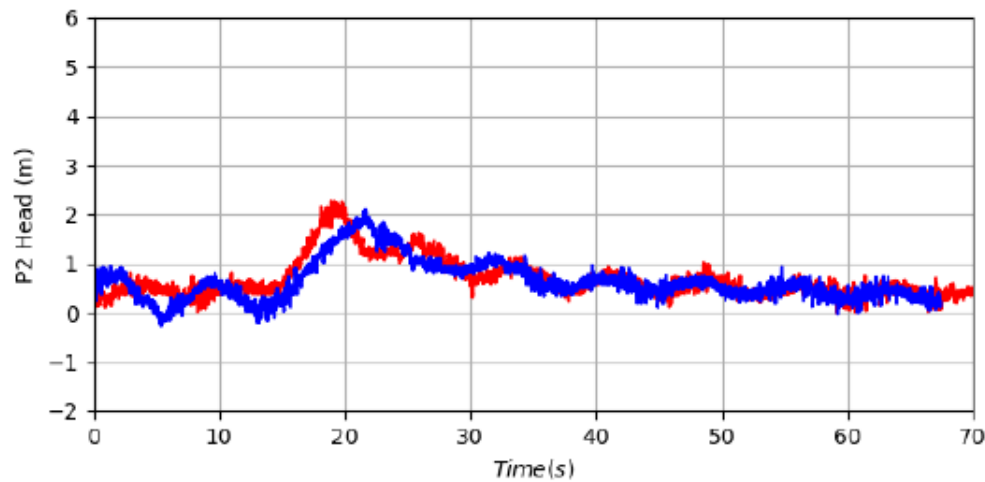
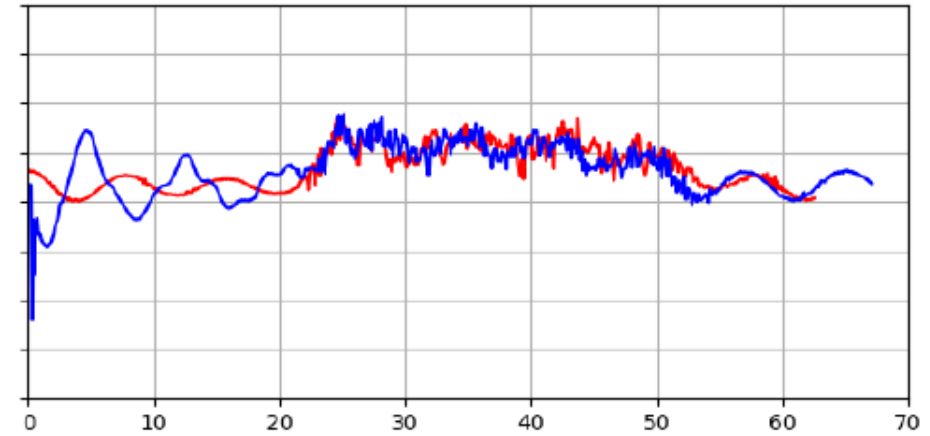
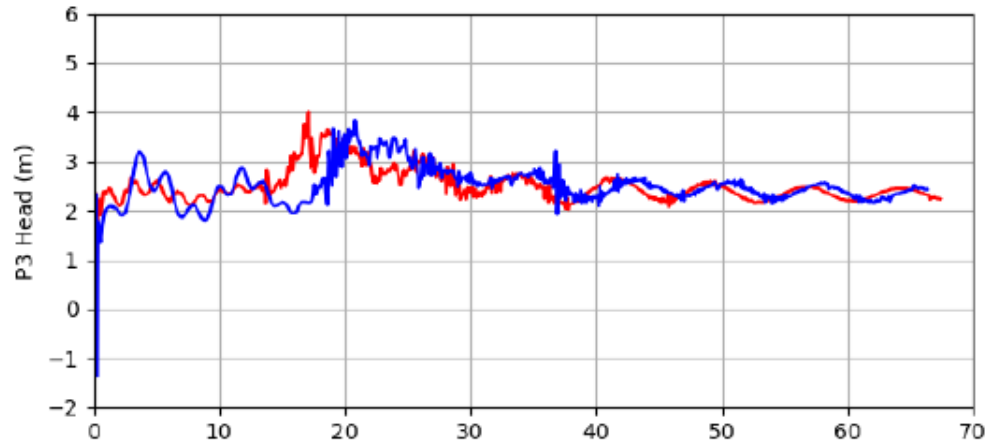
Experimental results: displacements $D^*=0.5$



Pressure results, $D^*=1.0$

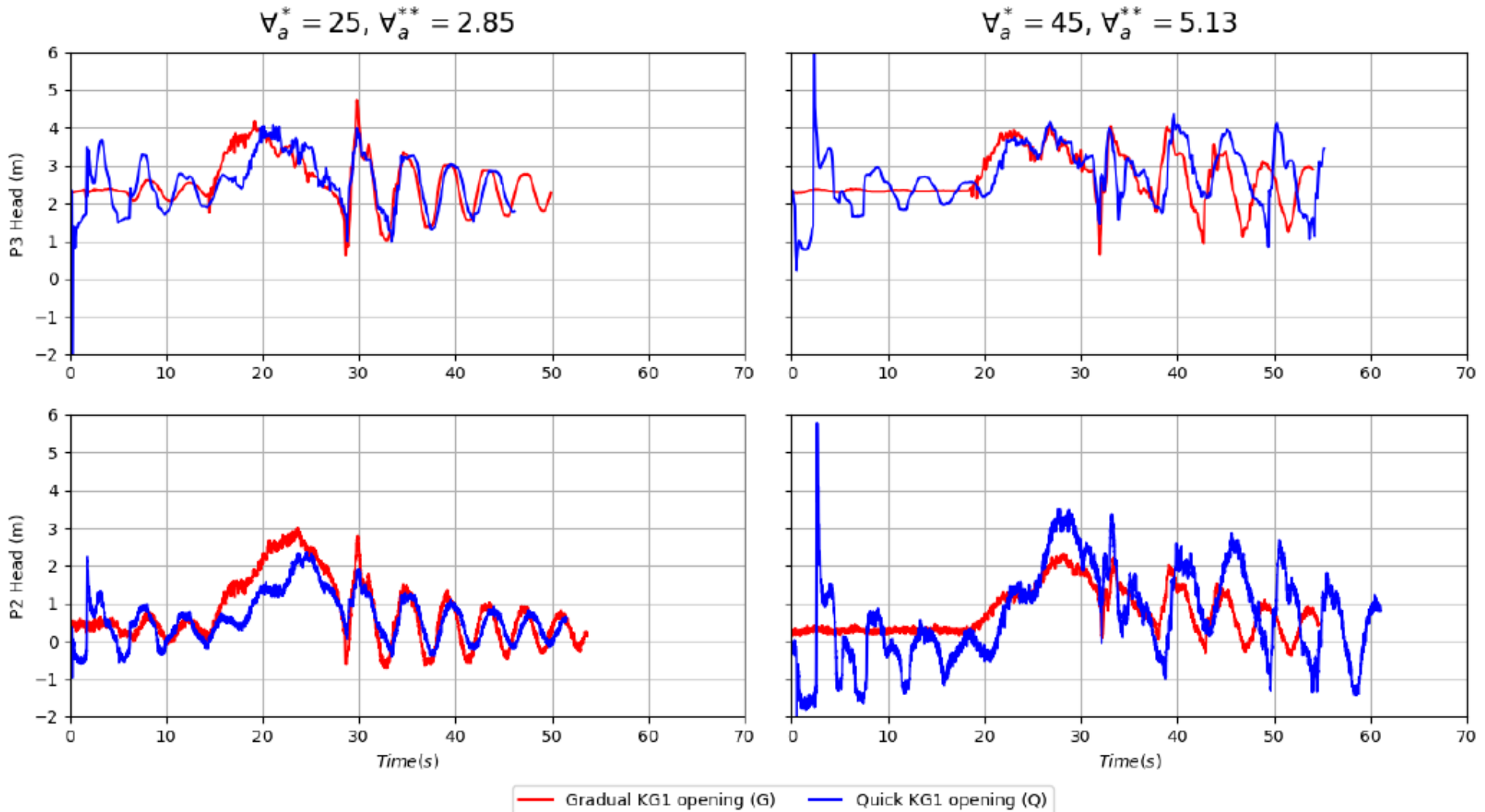
$$V_a^* = 25, V_a^{**} = 0.71$$

$$V_a^* = 45, V_a^{**} = 1.28$$



— Gradual KG1 opening (G) — Quick KG1 opening (Q)

Pressure results, $D^*=0.5$



Comparing displacements and velocities

$D^* = 1.0$

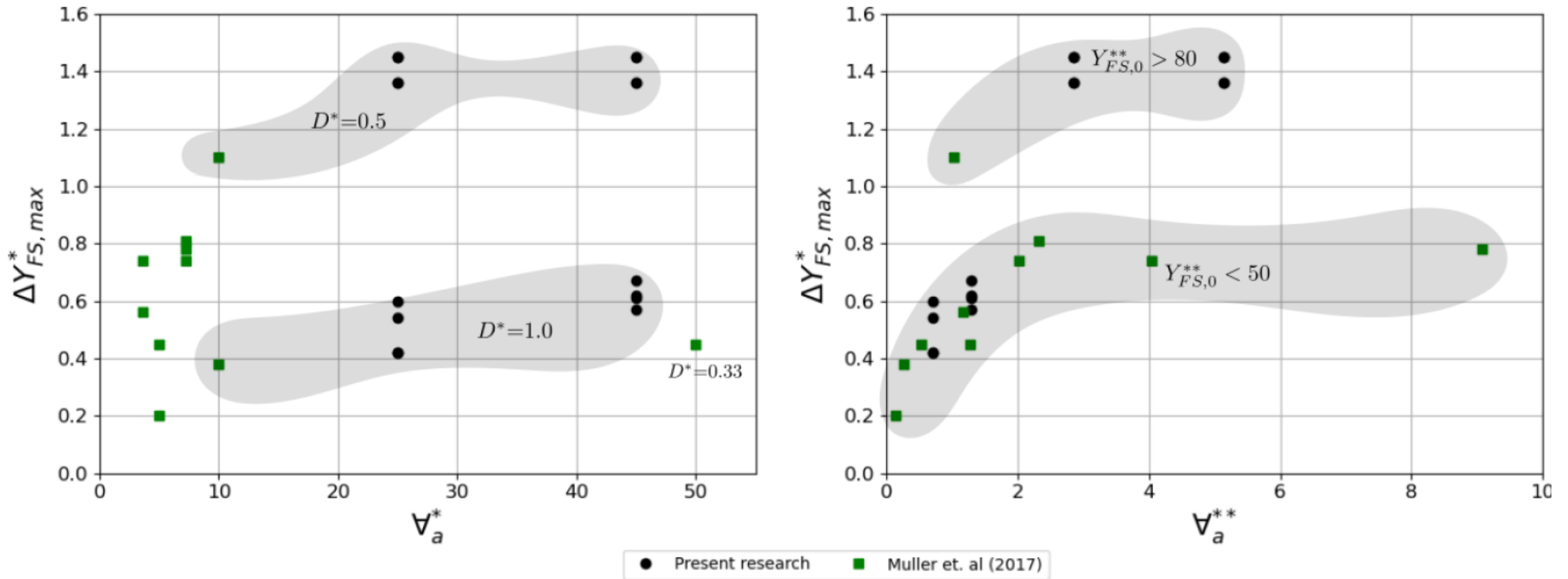
| Tested condition | Valve Opening | D^* | $Y_{FS,0}^*$ | V_a^* | V_a^{**} | $\Delta Y_{FS,max}^*$ | $V_{FS,max}^*$ |
|------------------|---------------|-------|--------------|---------|------------|-----------------------|----------------|
| 6 | Q | 1.00 | 0.56 | 25.0 | 0.712 | 0.42 | 0.43 |
| 8 | Q | 1.00 | 0.56 | 45.0 | 1.28 | 0.67 | 0.78 |
| 14 | Q | 1.00 | 0.52 | 25.0 | 0.712 | 0.42 | 0.21 |
| 16 | Q | 1.00 | 0.52 | 45.0 | 1.28 | 0.61 | 0.78 |
| 24 | Q | 1.00 | 0.33 | 5.00 | 0.127 | 0.20 | 0.50 |
| 26 | Q | 1.00 | 0.33 | 10.0 | 0.255 | 0.38 | 0.70 |
| 27 | Q | 1.00 | 0.33 | 50.0 | 1.273 | 0.45 | 1.00 |

Comparing displacements and velocities

$D^*=0.5$

| Tested condition | Valve Opening | D^* | $Y_{FS,0}^*$ | V_a^* | V_a^{**} | $\Delta Y_{FS,max}^*$ | $V_{FS,max}^*$ |
|------------------|---------------|-------|--------------|---------|------------|-----------------------|----------------|
| 2 | Q | 0.50 | 0.44 | 25.0 | 2.85 | >1.36 | 8.6 |
| 4 | Q | 0.50 | 0.44 | 45.0 | 5.13 | >1.36 | 8.3 |
| 10 | Q | 0.50 | 0.42 | 25.0 | 2.85 | >1.45 | 11 |
| 12 | Q | 0.50 | 0.42 | 45.0 | 5.13 | >1.45 | 8.5 |
| 18 | Q | 0.51 | 0.55 | 3.63 | 2.01 | >0.74 | 3 |
| 21 | Q | 0.51 | 0.55 | 7.26 | 4.03 | >0.74 | 3 |
| 23 | Q | 0.50 | 0.33 | 5.00 | 0.519 | 0.45 | 2.70 |

Displacement in terms of the proposed V_a^{**} normalization



Discussion and Conclusions

Indication that geyser intensity, measured in terms of the displacement of water in shafts, increased for a terminal shaft

Displacement velocities were larger, particularly for the cases when $D^*=0.5$, which can be relevant for the case of air pressurization in shafts and manhole cover displacement.

Gradual opening of air reservoir during experiments helped to eliminate initial oscillations that could interfere with the experimental observations

Discussion and Conclusions

Studies should be complemented involving a single air release point but with more geometries (i.e., $D^*=0.33$)

CFD modeling of these results is planned to assess additional changes in the flow created by a single air discharge point.

**56th INTERNATIONAL CONFERENCE
ON WATER MANAGEMENT MODELING**

Mar 1 & 2, 2023

Thank you
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