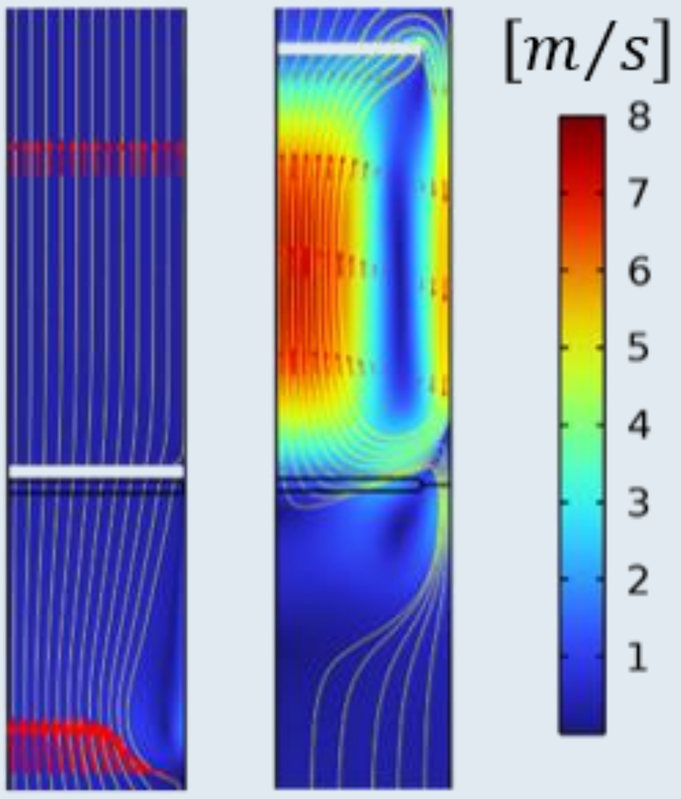

Assessment of hydrodynamic forces on a moving piston in a submerged cylinder

Understanding force interaction and relative motion of piston and tube water under oscillating flow conditions.

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Abstract

The WaveEL buoy is a point absorber with a 36 m vertical cylinder housing an oscillating water piston, (Ref. 1). Wave load estimation is complicated by narrow leakage gaps between the piston and cylinder walls, which introduce a phase shift affecting added mass and damping. Determining a favorable leakage width is hard to asses due to the criteria's: power uptake and end bumper impact in the water tube. A 2D axisymmetric model couples a k-ω turbulence fluid simulation with solid mechanics to capture piston motion through fluid structure interaction coupling. Phase angles between mean water flow and hydrodynamic forces on the piston were quantified using sample covariance. Simulations considered leakage widths from 1 to 25 cm under a 100 kN sinusoidal volume force load with a 6.28 s time period. Correlations between the Keulegan-Carpenter number and added mass, and between Reynolds number and added damping were established. Results show that increased leakage width reduces both added mass and damping, indicating lower water acceleration and decreased power absorption due to reduced drag.

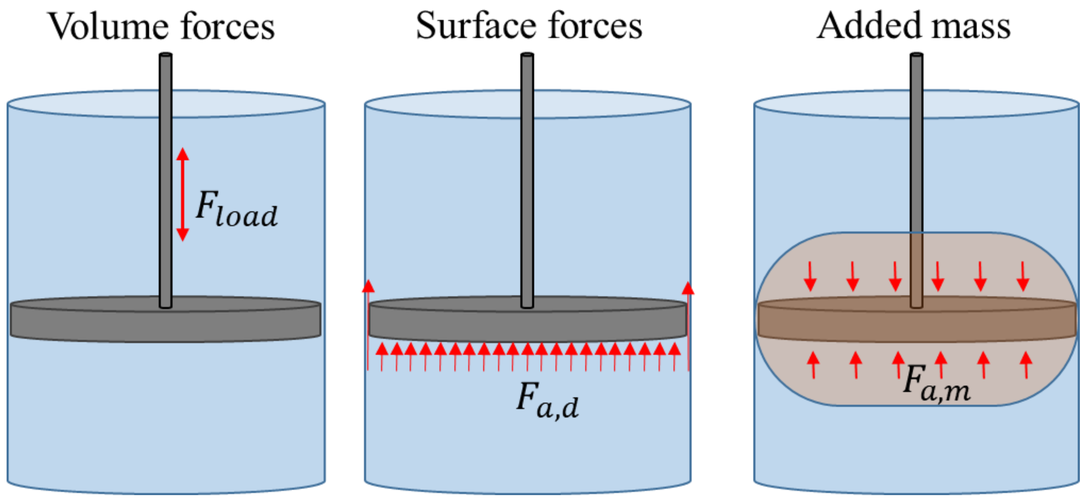

Figure 1. Schematic representation of the hydrodynamic forces in the piston. $F_{a,d}$ represent added damping force contributions and $F_{a,m}$ represent added mass due to acceleration.

Methodology

A 2-dimensional axial-symmetric reference frame was used to observe the motion of the piston and water mass through the fluid-structure interaction feature, see Figure 1. The piston is set in motion due to the exposed forces transmitted from the buoy. The piston and water motion are analysed for leakage widths 1, 2, 3, 5, 7, 10, 15 and 25cm. Sample covariance is used with tube water velocity and hydrodynamic forces as input data sets to estimate added damping and added mass force contributions. Scalable expressions of the added damping and mass coefficients are established:

$$C_d = f\left(Re, F_{a,d}\right)$$
$$C_m = f\left(KC, m_{add}, F_{a,m}\right)$$

Results

The results reveal that increasing the leakage width amplifies the difference between piston and water velocity. For small leakage (1 cm), piston and water velocities remain closely aligned, whereas for larger leakage widths (10 cm and 25 cm) the water velocity deviates substantially, such that the relative velocity approaches the piston velocity. This trend explains the observed increase in Reynolds and Keulegan–Carpenter numbers with increasing leakage width and the corresponding decrease in drag and added mass coefficients. In conclusion, larger leaking widths leads to high Re flows which minimize drag effects, while high KC flows diminish the relative contribution of inertia. Such insights are crucial for decision making which, in this case, revolves optimal leakage widths in terms of power uptake and end bumper impacts.

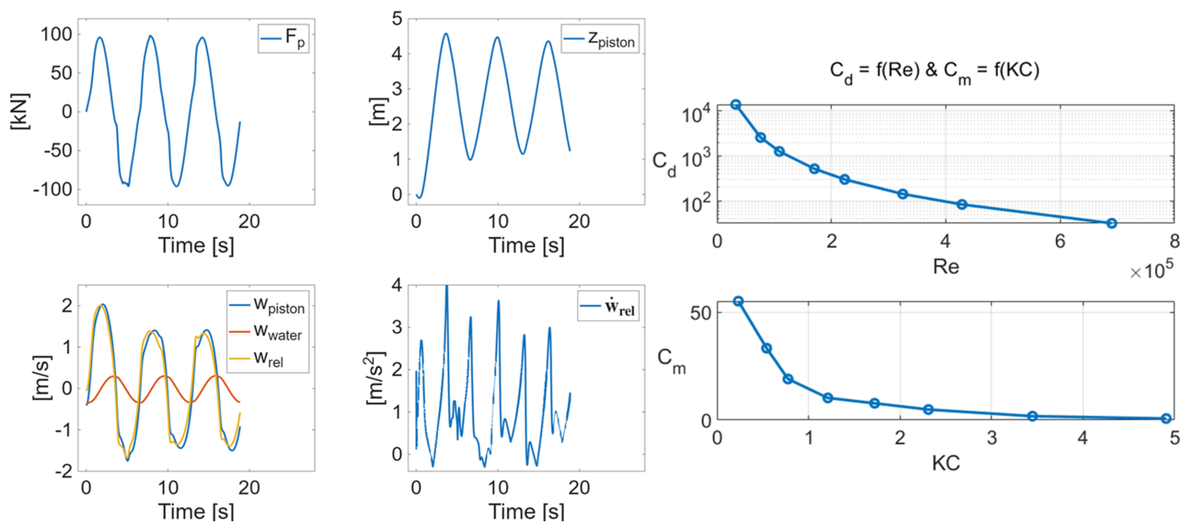

Figure 2. Oscillating motion of tube water and piston to the left. The drag and added mass coefficient as a function of the Re- and KC-number respectively to the right.

REFERENCES

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