ICCE 2018

36TH INTERNATIONAL CONFERENCE ON COASTAL ENGINEERING 2018

Baltimore, Maryland | July 30 – August 3, 2018

The State of the Art and Science of Coastal Engineering

LOADING ON PIPELINES DUE TO EXTREME HYDRODYNAMIC CONDITIONS

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Motivation

The design of pipelines to withstand external hydrodynamic loading exerted on them requires a proper understanding of the external hydrodynamic forces.

The Trans-Alaska Oil Pipeline, is designed to move 20-ft laterally and 5-ft vertically.
http://themilitaryengineer.com

https://www.oilandgaspeople.com

Submerging pipe- southern Norway
http://www.pipelife.no

Motivation (Cont`d.)

A new topic in pipeline design has emerged recently due to the recent **extreme events such as tsunami and storm surges**. Typical examples are the 2011 Tohoku Tsunami in Japan and the 2012 Typhoon Haiyan in the Philippines.

Miyako, Japan (national geographic)

(Japan,Photo courtesy Kyodo News/AP)

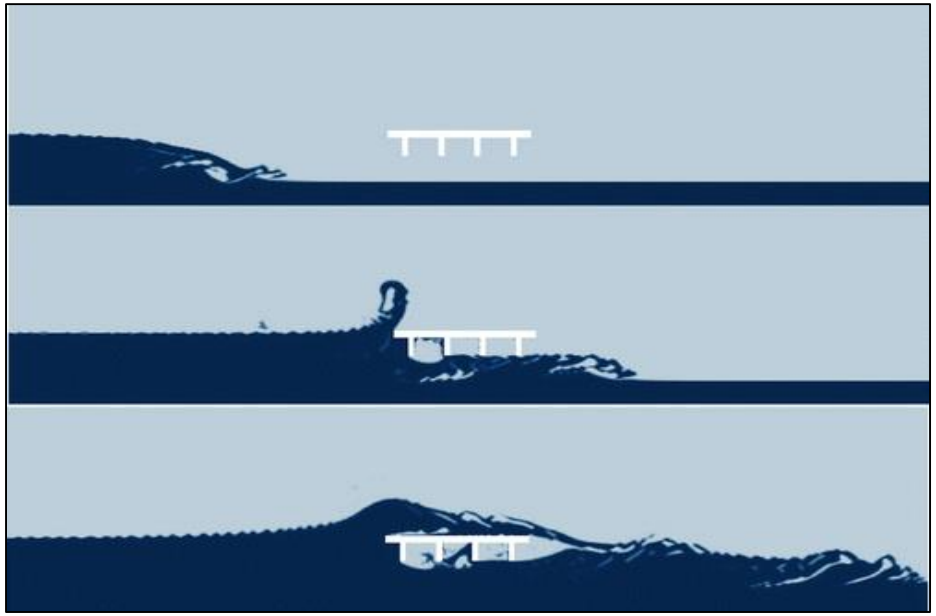
Tsunami damaged piping-Sendai treatment plant-Japan (Photo courtesy Peirpiekarz)

Introduction

Guidelines for Design of Structures for Vertical Evacuation from Tsunamis FEMA-P646 (2012) introduce different forces exerted on a body during a tsunami as drag and lift force:

$$F_d = \frac{1}{2}\rho_s C_d B(hu^2)_{max}$$

$$F_u = \frac{1}{2} C_u \rho_s A_f u_v^2$$



(Motley et al. 2015)

- **The 2017 ASCE7 Chapter 6,** Tsunami Loads and Effects **<u>emphasized the need to investigate tsunami loads on pipelines</u>** located in tsunami-prone areas.

Objectives and novelty

- Novel study focused on **measuring and analyzing the forces caused by extreme hydrodynamic loading on submerged and above-ground pipelines due to transient flow conditions** by combining a comprehensive experimental study and detailed CFD simulations.

- New proposed values for the **resistance coefficient** in the case of a transient dam break flow for different relative gap ratios (e/D).

- Recommendations from this study will hopefully be used for the **assessment and improvement of the current tsunami design guidelines.**

Experimental setup

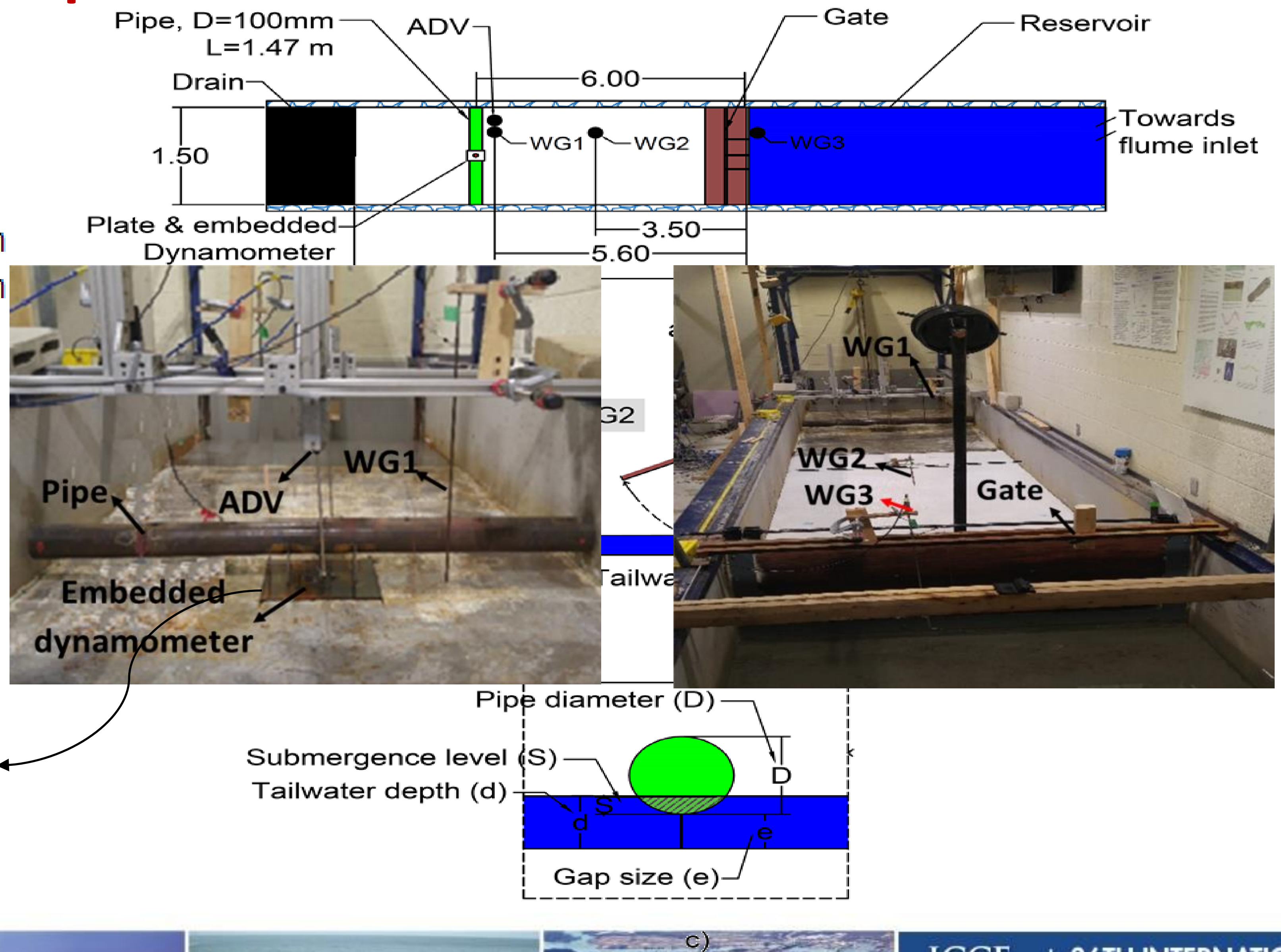
Interface 6A68E

Max Forces:

- F_x = 10 kN
- F_y = 10 kN
- F_z = 20 kN
- M_x = 500 Nm
- M_y = 500 Nm
- M_z = 500 Nm

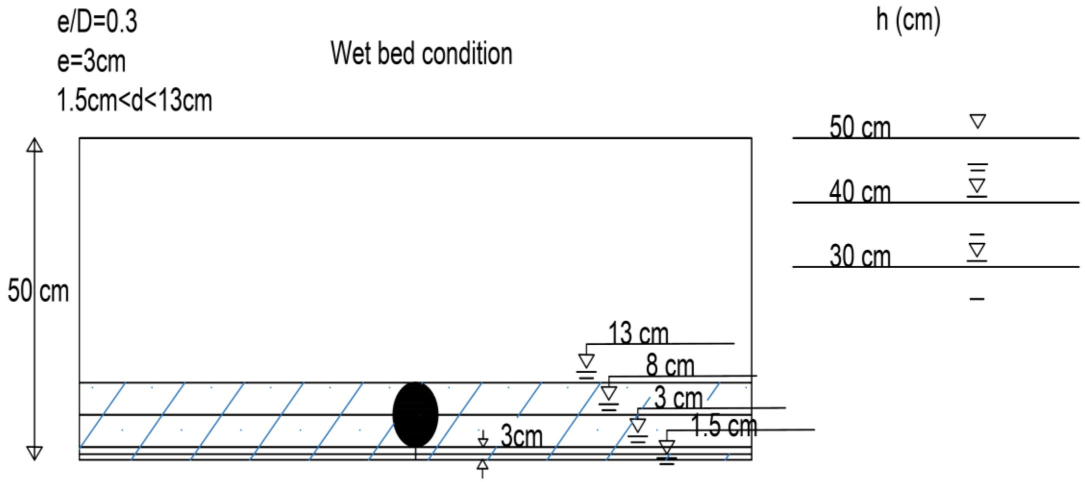
Dimensions:

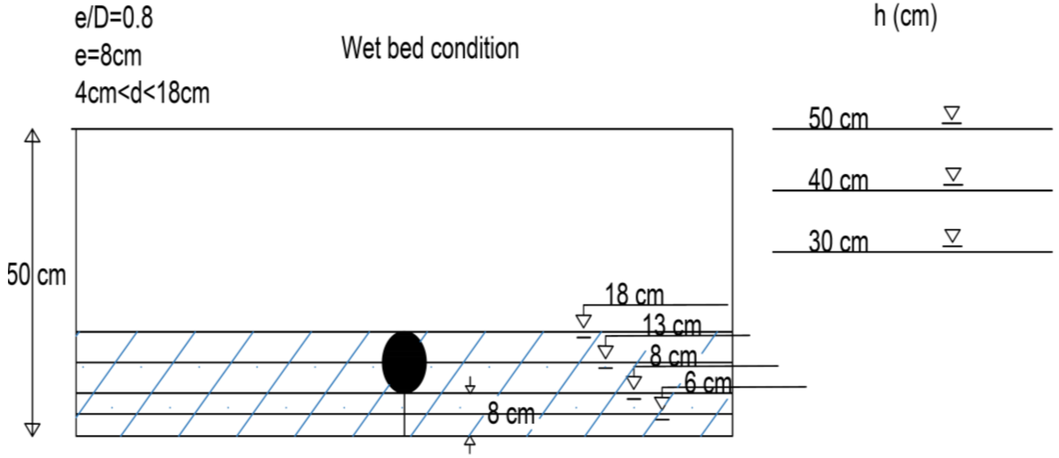
- D = 83 mm
- H = 64 mm

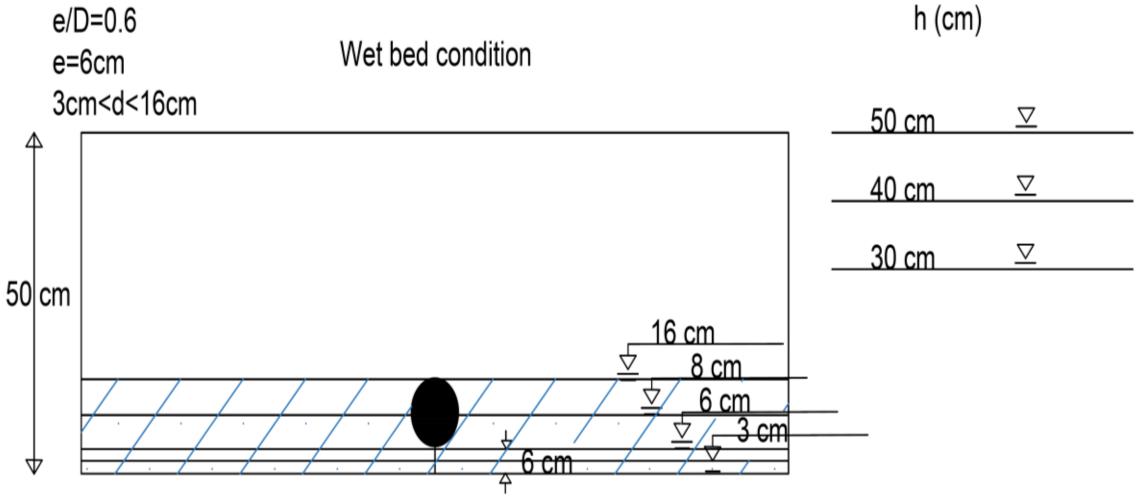


Experimental conditions:

e/D=0.3,0.6,0.8
h=50,40,30

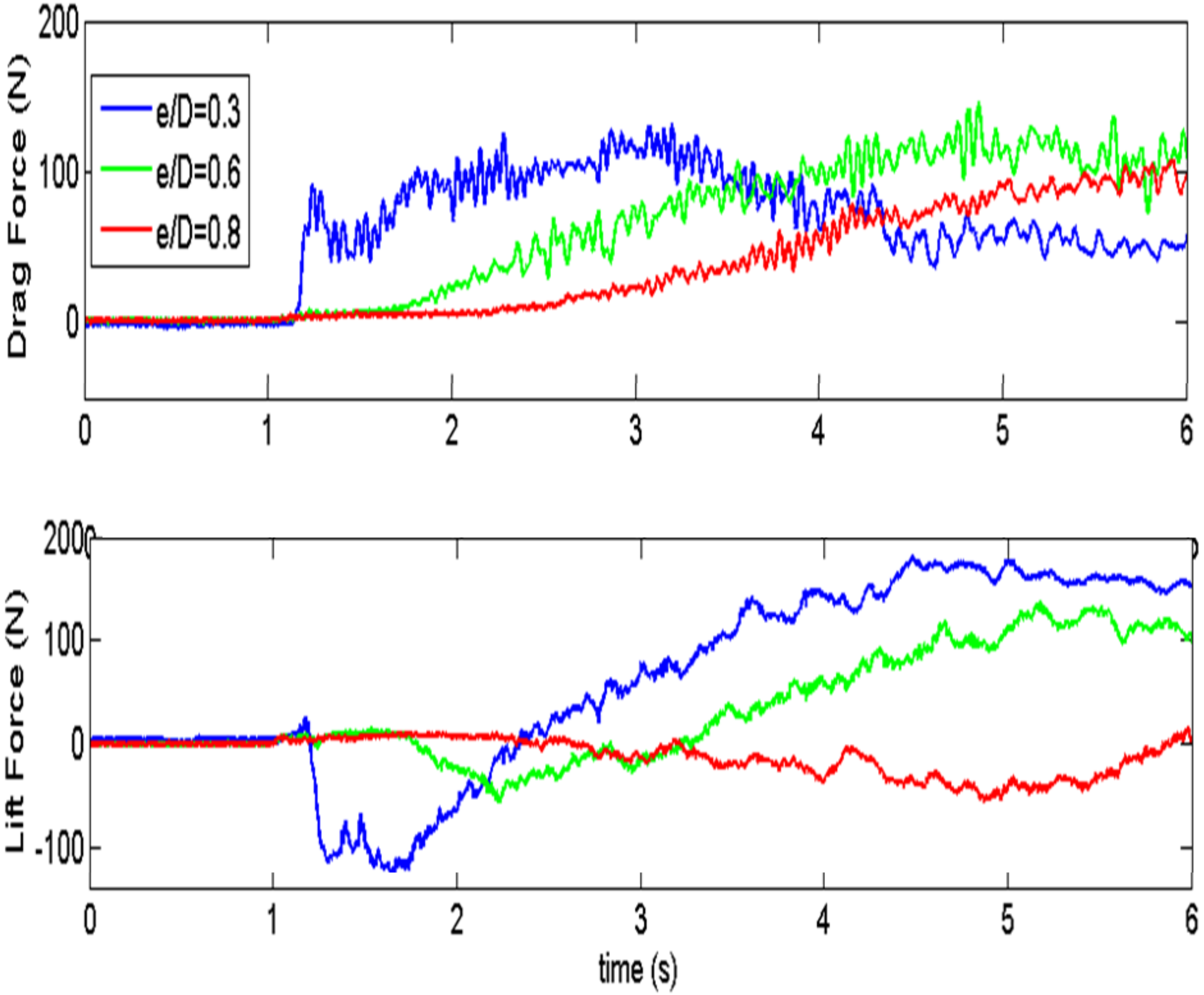






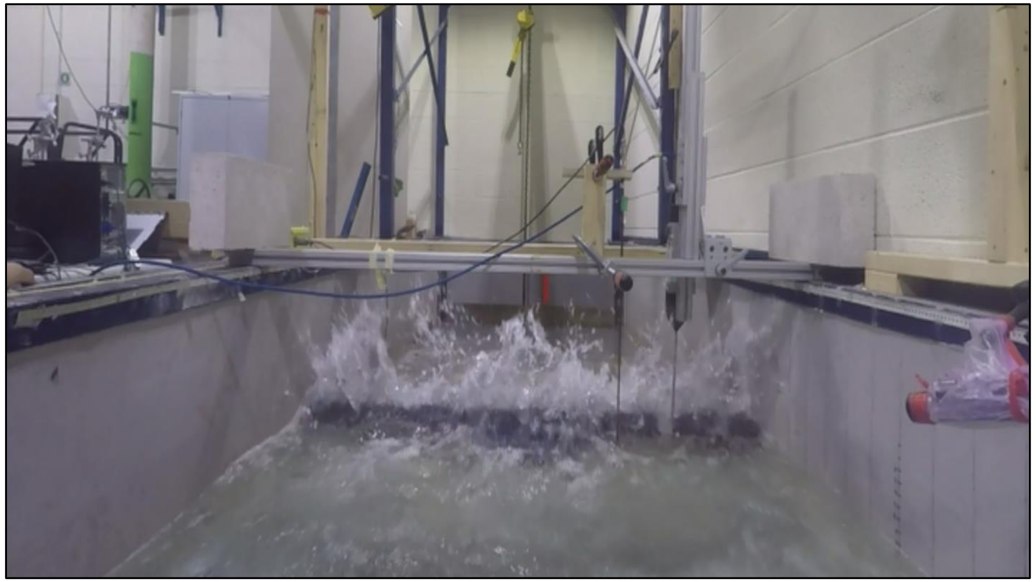
Sample video:
e/D=0.3, h=40

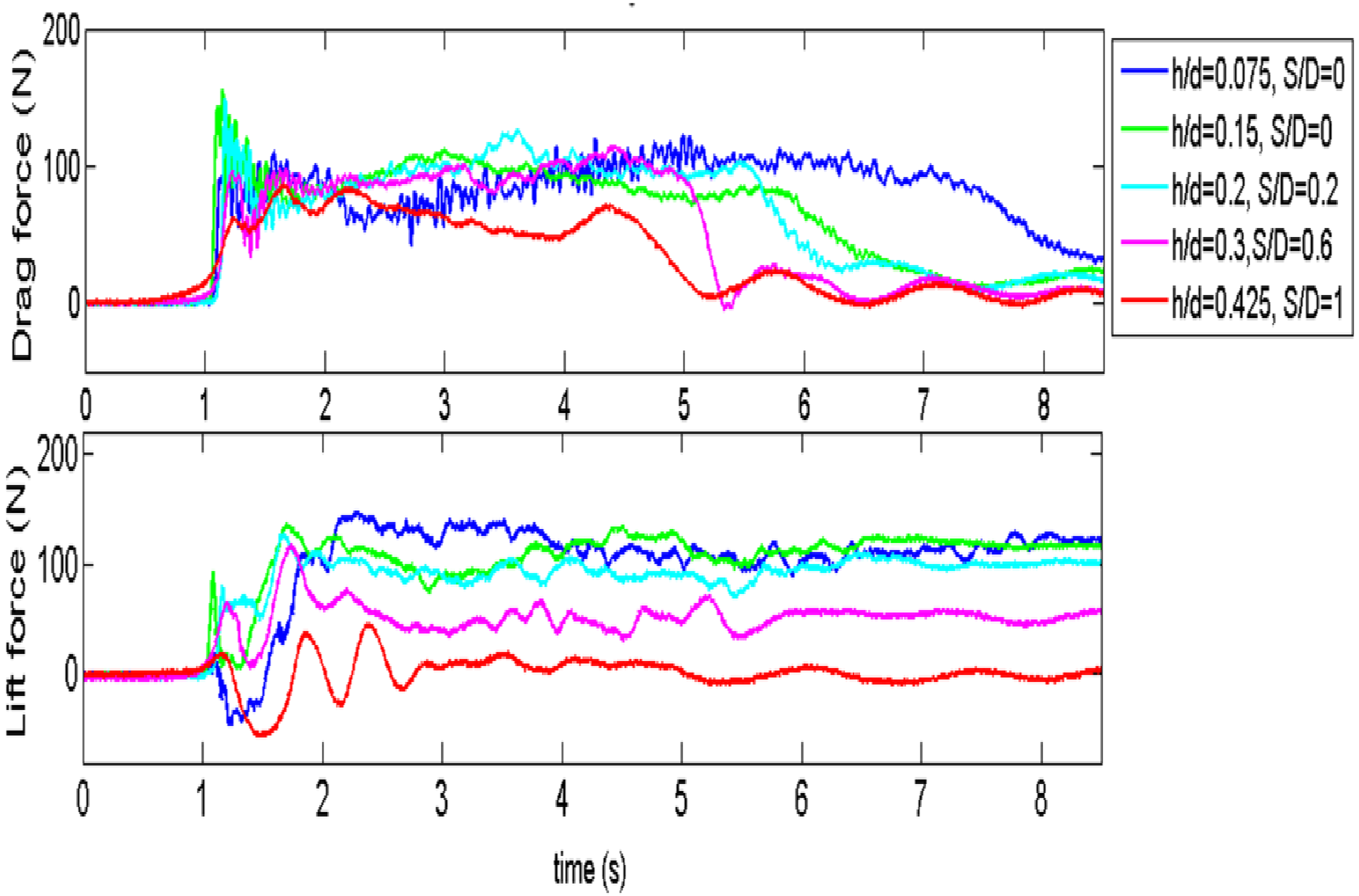
Force components
Dry bed conditions and varying (e/D) ratio



- For e/D=0.3 an impulse force as well as run-up force are noticeable while for e/D=0.6 and for e/D=0.8 no distinct impulse peak was noticed.
- Lift force is larger for smaller e/D values.

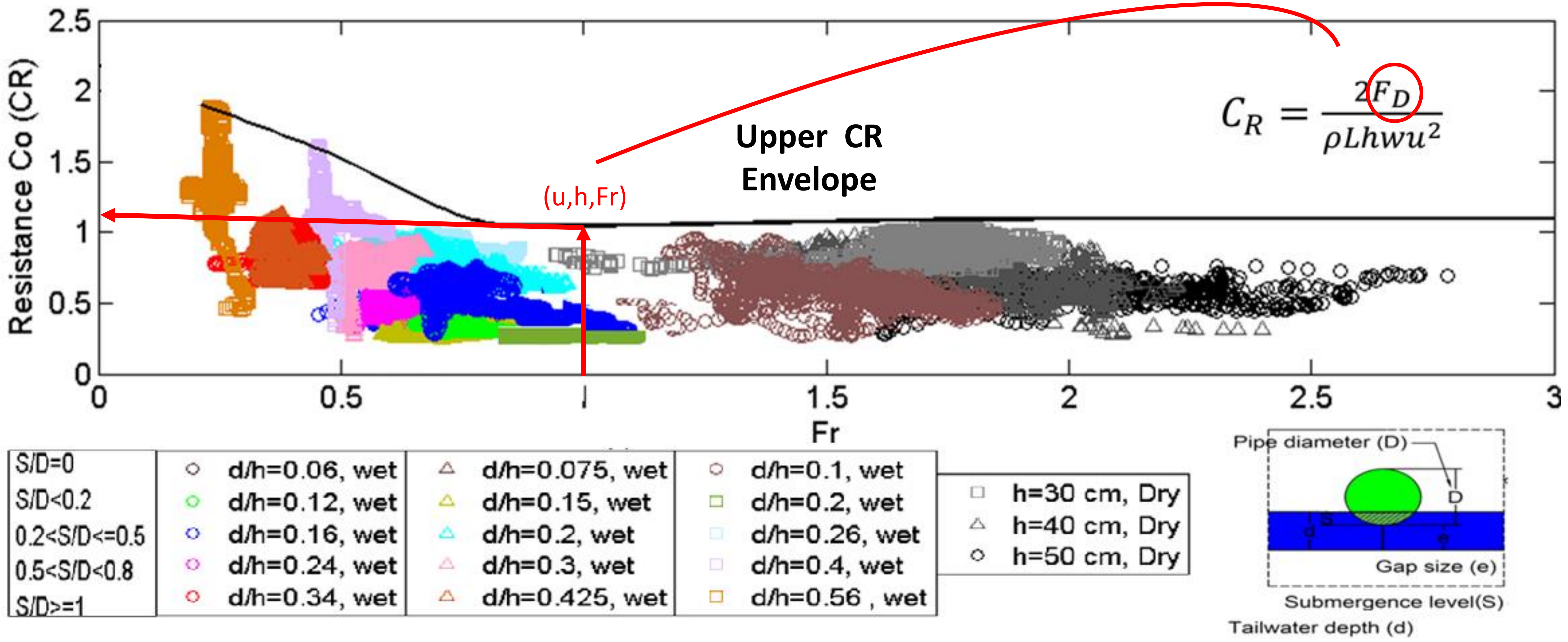
Force components
Wet bed conditions and varying (e/D) ratio





- Smaller level of pipe submergence results in larger impulse drag force.
- Lift force decreases by increasing the level of pipe submergence.

Resistance Coefficient

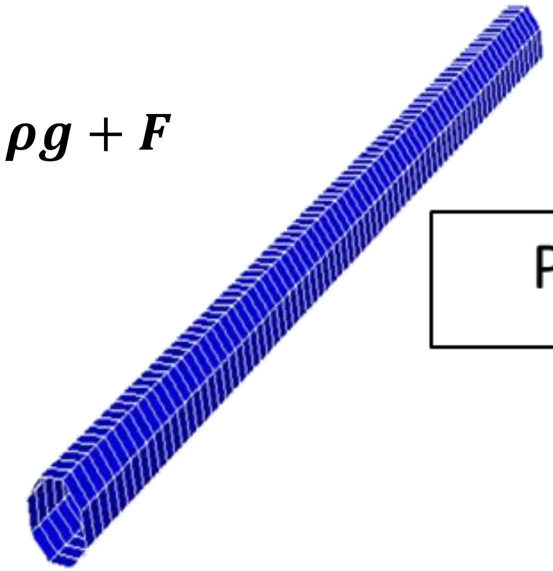


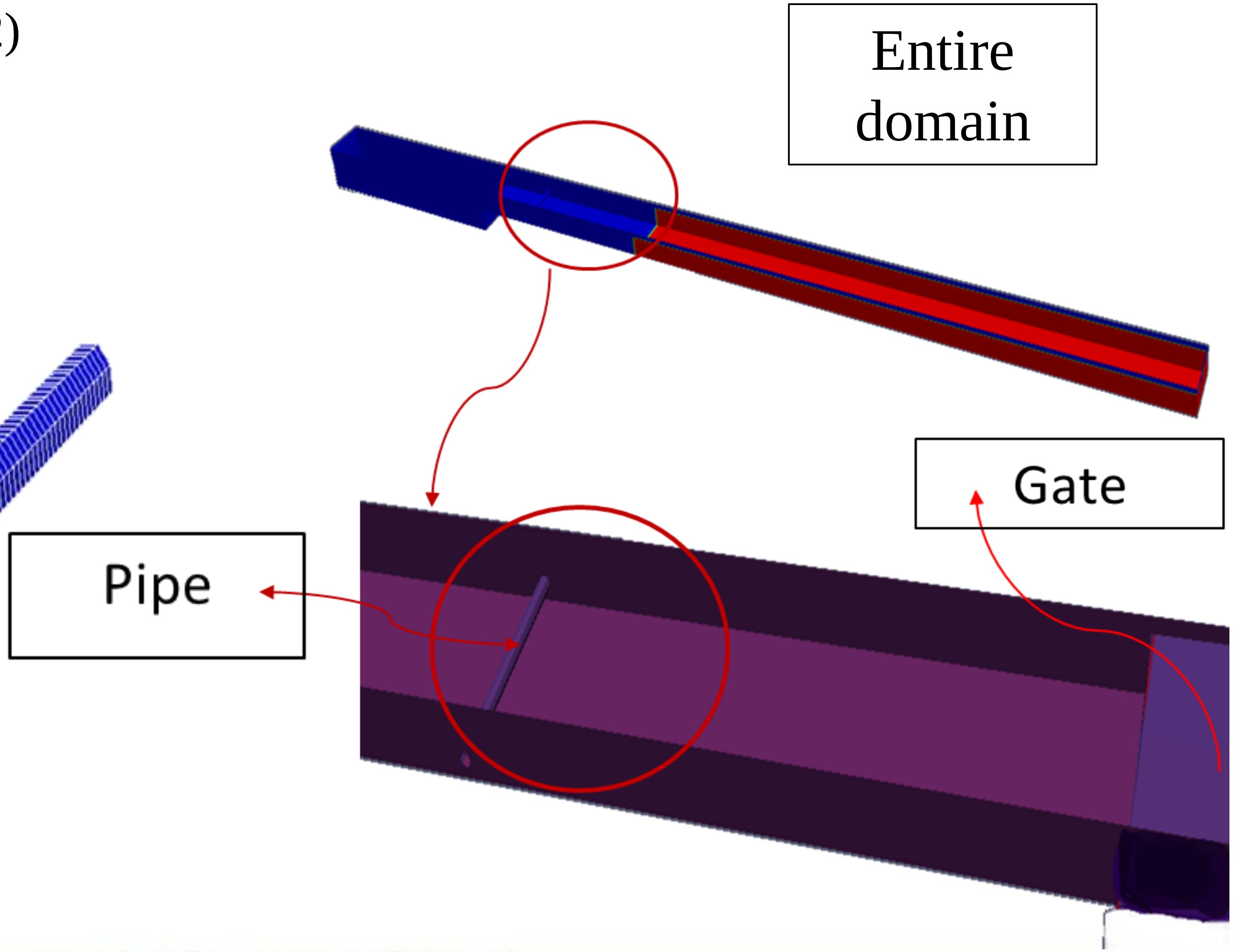
Numerical model

OpenFoam CFD Modeling tool - uses the Finite Volume Method to solve the 3-D Navier-Stokes equations (Rusche, 2002)

$$\nabla . U = 0$$

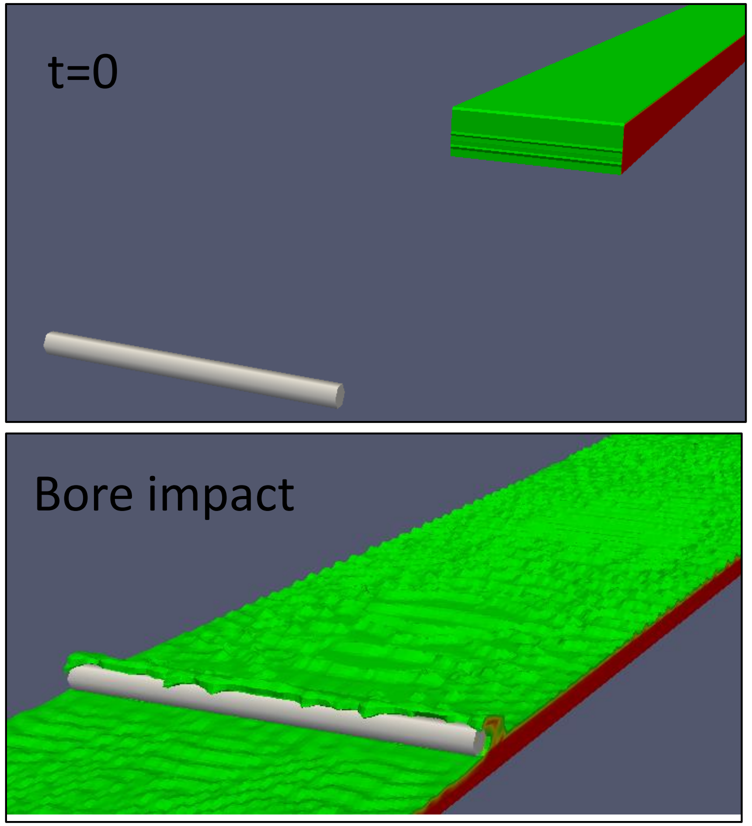
$$\frac{\partial \rho u}{\partial t} + \nabla . (\rho U U) = -\nabla P + \nabla . \tau + \rho g + F$$



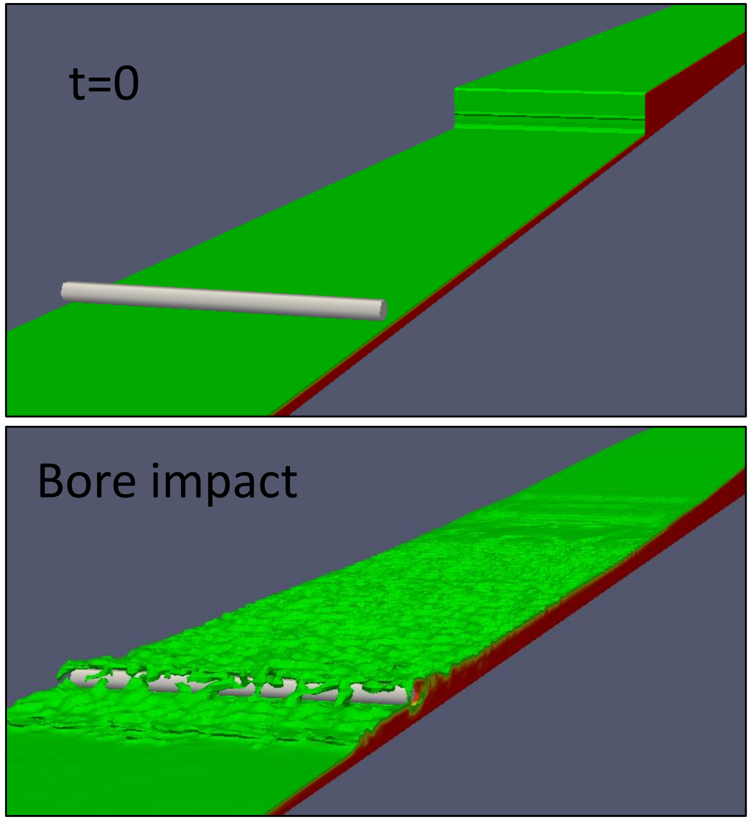


Numerical model results - water level

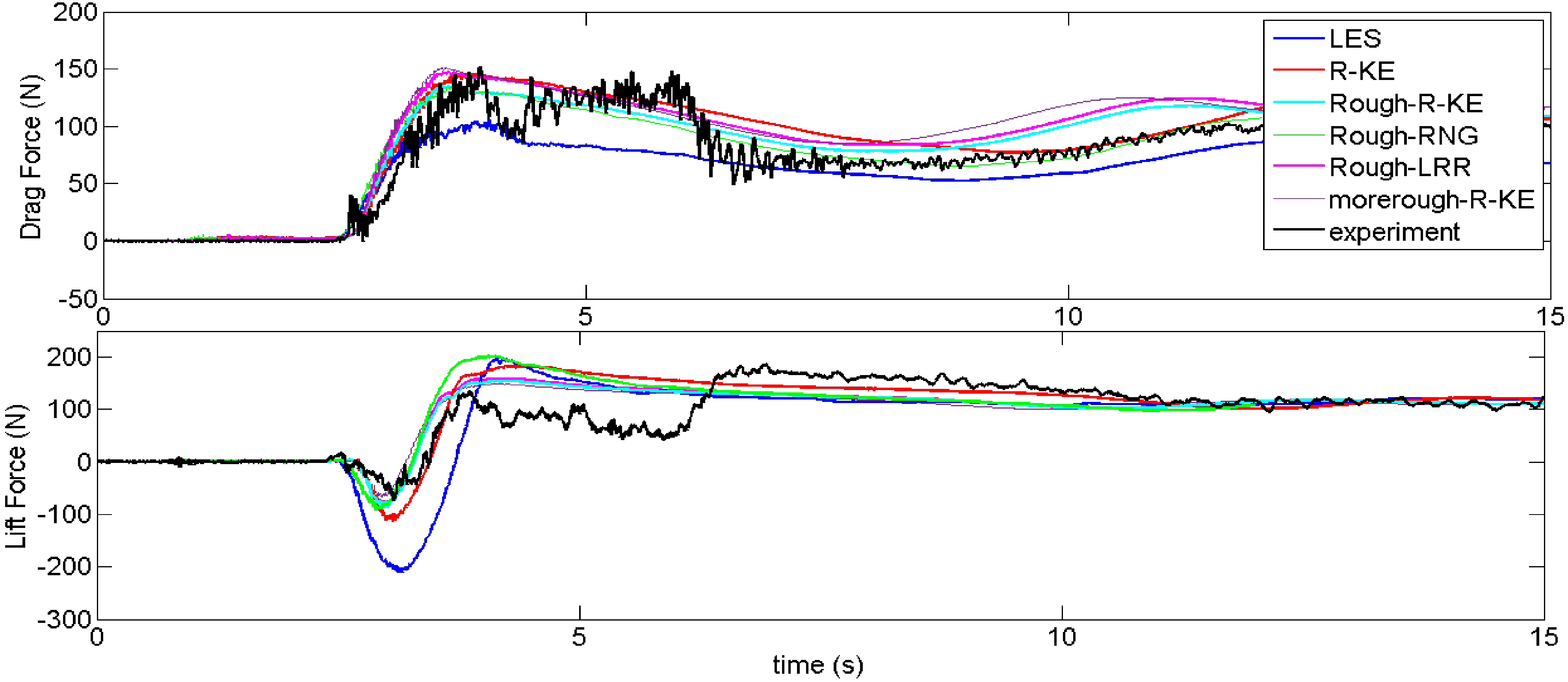
Dry bed condition



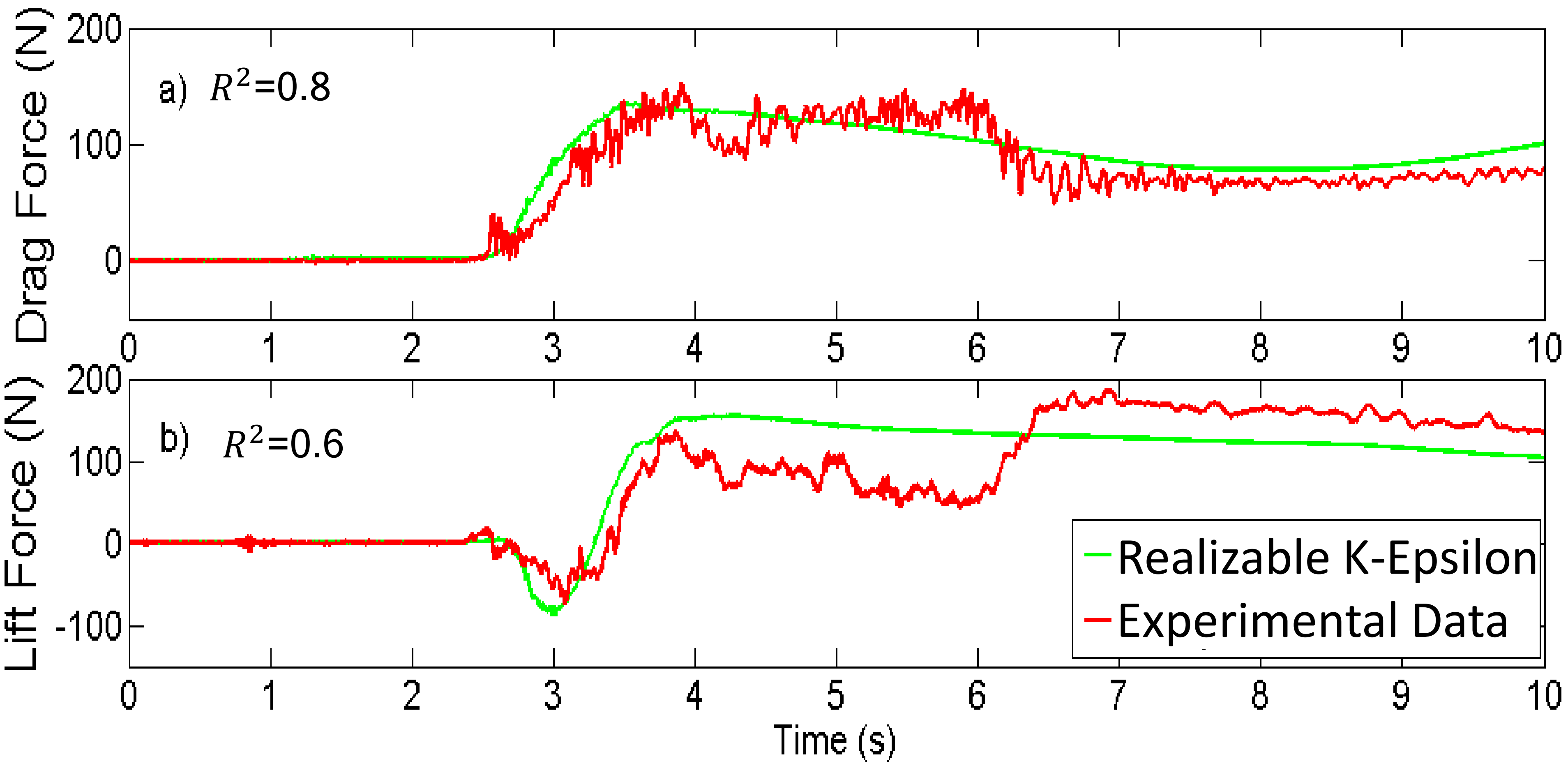
Wet bed condition



Effect of turbulence models & Effect of surface roughness



Experimental and numerical results-force components



Conclusions

Force time history

- **Dry bed condition**: Beginning of bore surge: Larger drag force for e/D≤0.3.
  - After the pipe got fully submerged : Smaller drag force for smaller e/D ratios due to vortex shedding suppression. Larger lift force magnitudes for smaller e/D ratios during the entire time history due to the asymmetry in pressure distribution in presence of plane boundary.
- **Wet bed condition:**
  - Smaller initial level of submergence (S/D<0.3): larger impulse force.
  - Submerged pipe (S/D=1): No impulse lift force was observed.

Resistance coefficient

- **Wet bed condition**: Increase in initial **level of submergence** ⇨ Resistance coefficient increase
- **Dry bed condition**: Increase in **relative gap ratio value** (e/D) ⇨ Resistance coefficient decrease
  - Study suggests using **resistance coefficient** values of $(1.2 < C_R < 2)$

Numerical model

- Comparing results between different RANS and LES turbulent models with those obtained from experimental tests showed that the **RANS** models reproduced most accurately the dam break wave flow field.
- The **realizable K-ε** model results provided the most accurate results compared to other RANS turbulence models.

Other Pipe configurations

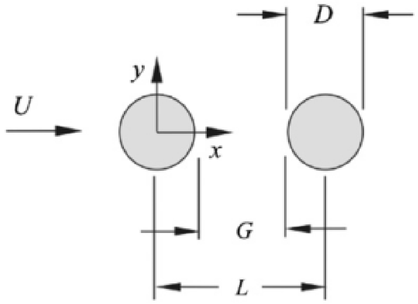
Pipe with angle to the flow: θ=30 & 45

θ =45

θ =30

Tandem configuration

L=1D & 2D

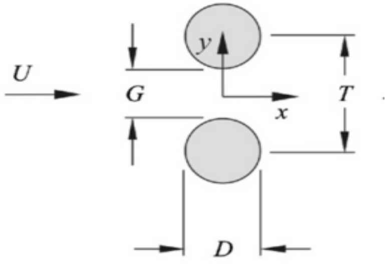


L=1D

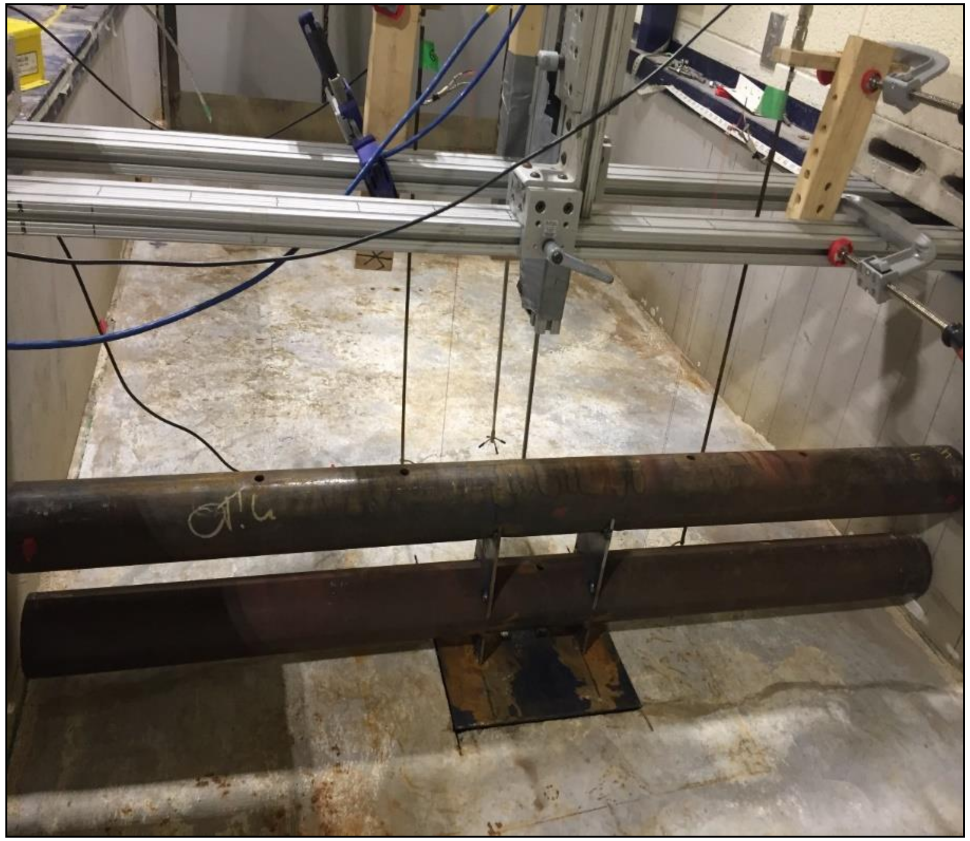
L=2D

Side by Side Configuration

T=1D & 2D



T=1D



T=2D

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Motley, M.R., Wong, H.K., Qin, X., Winter, A.O. and Eberhard, M.O., 2015. Tsunami-induced forces on skewed bridges. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, *142*(3), p.04015025.

Rusche, H. (2002). Computational fluid dynamics of dispersed two-phase flows at high phase fractions. *PhD thesis, Imperial College*, London, UK. .

Thank You

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