

# On the initiation of static liquefaction

KIVI TU Delft 2014

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3-12-2014

# Introduction

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# Introduction

## Terminology

Soil liquefaction = loss strength/stiffness resulting from excess pore pressures after shear deformation

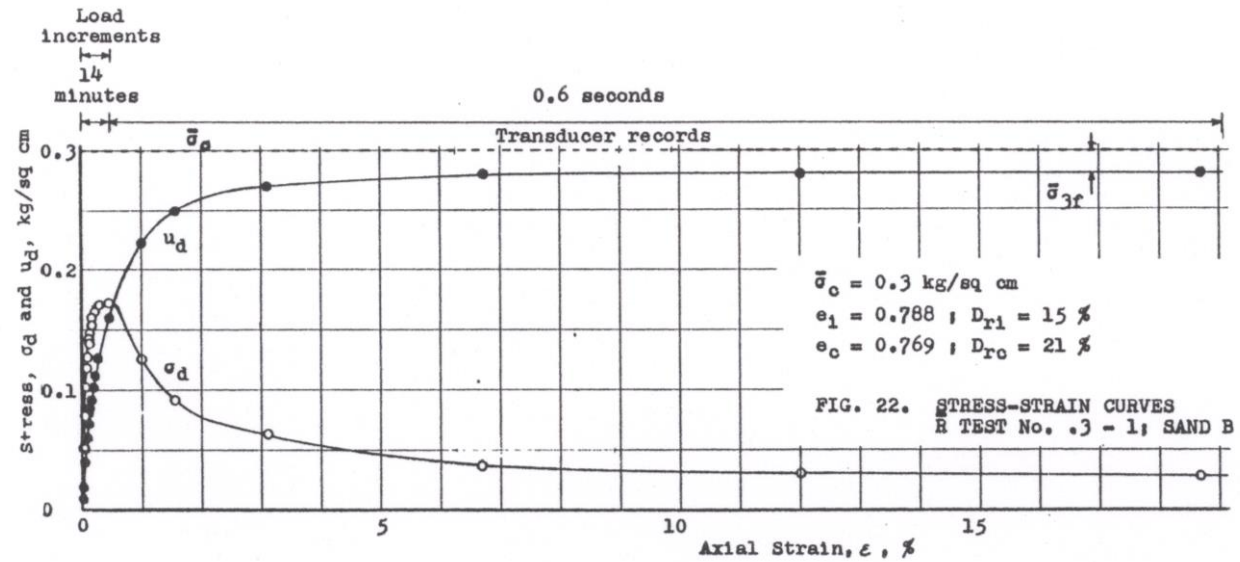
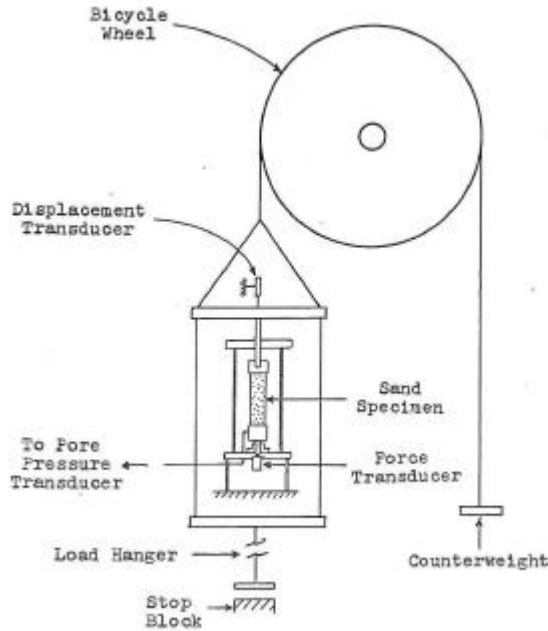
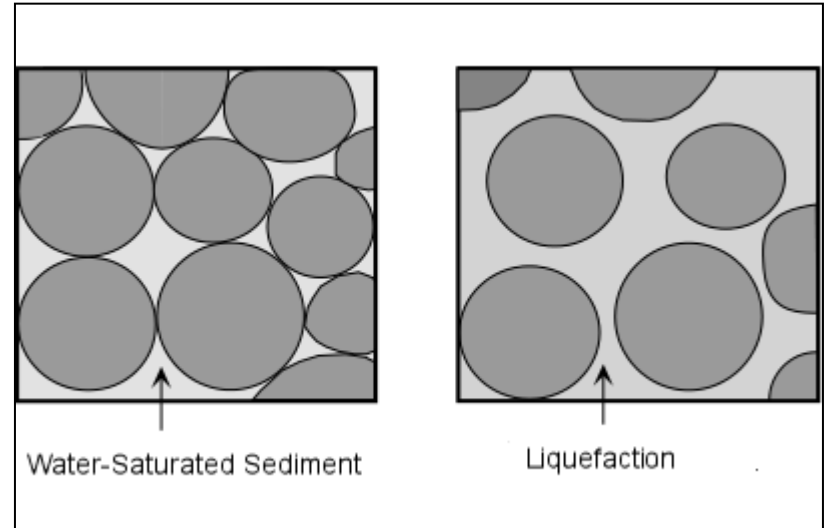
Flow liquefaction = runaway mechanism after triggering liquefaction driven by initial (static) shear: large deformations

Cyclic softening = gradual accumulation of deformations with (undrained) cyclic loading: small deformations

((Unstable) breaching = retrogressive mechanism during sand mining in dense sand (erosion/sedimentation))

# Flow slides

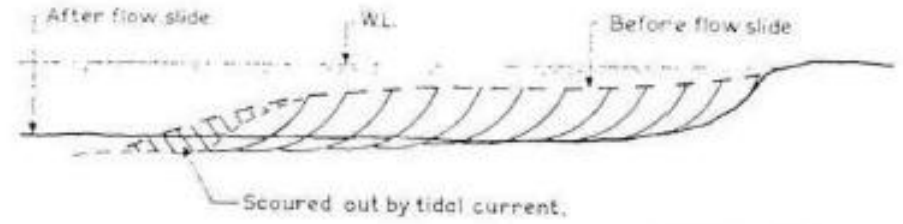
## Flow liquefaction



Castro (1969)

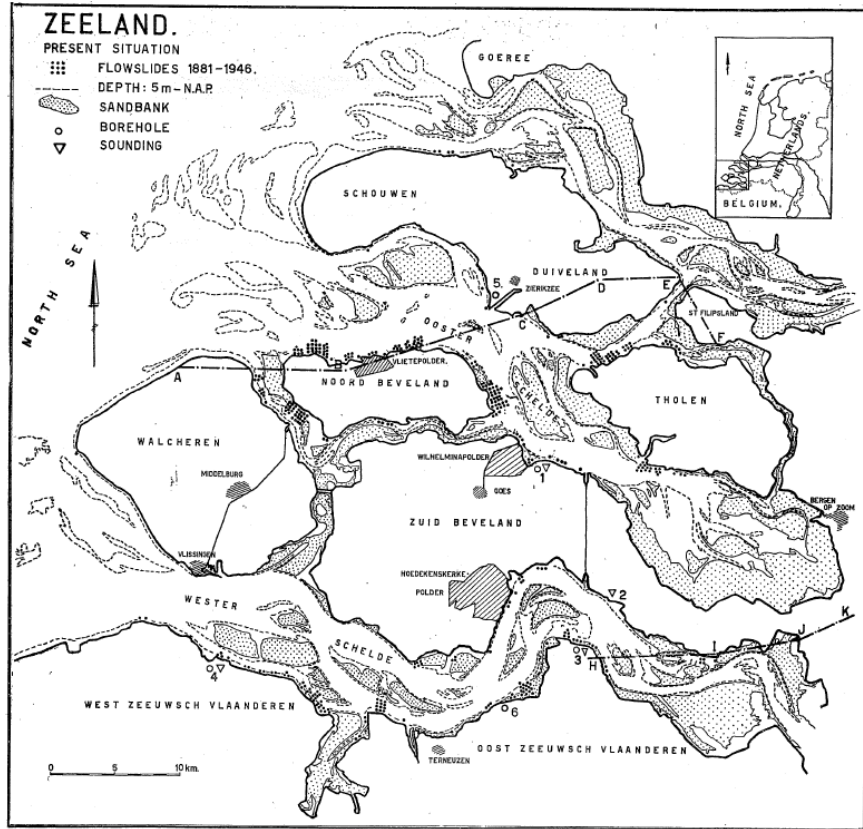
# Flow slides

## Zeeland



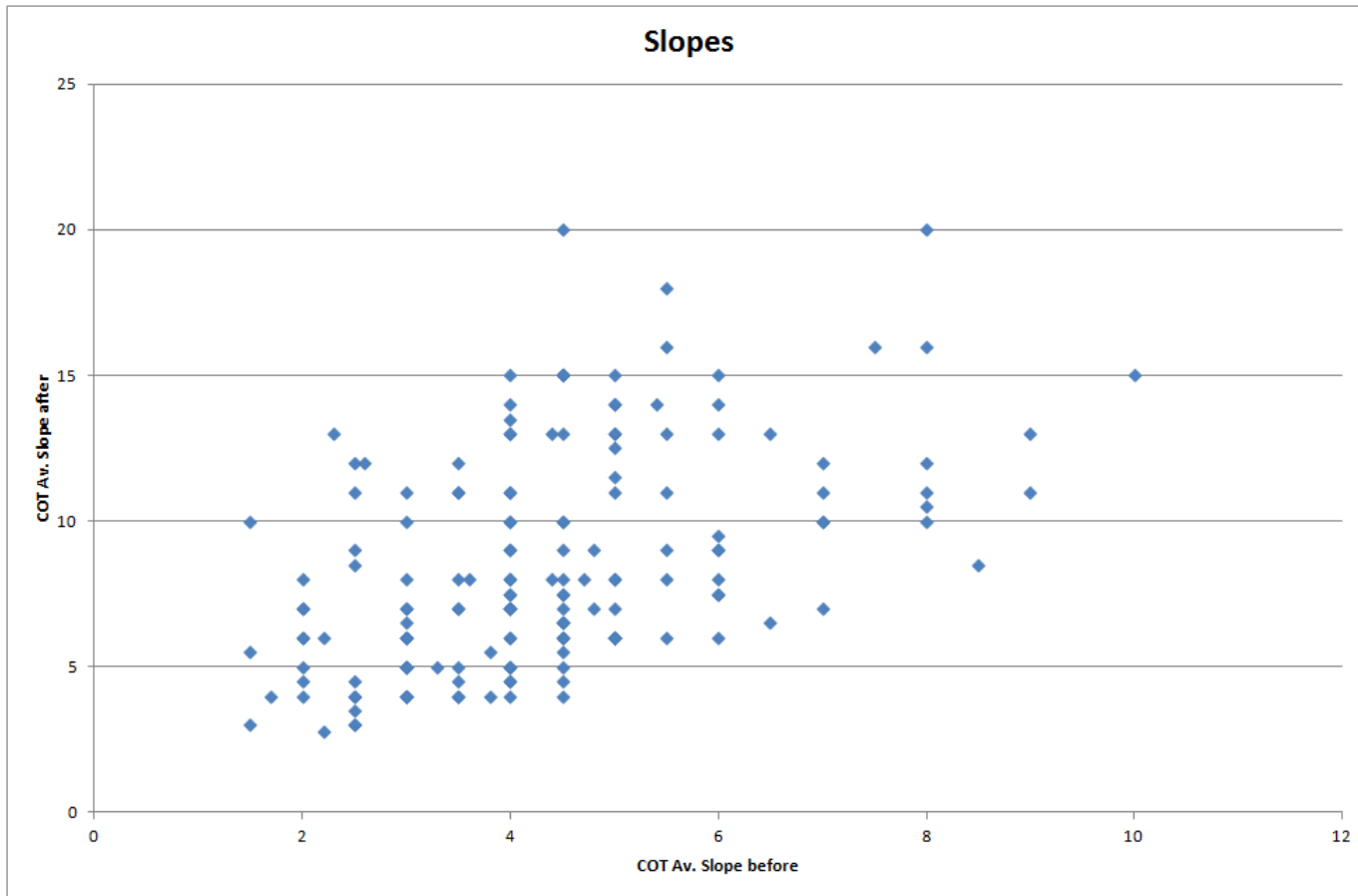
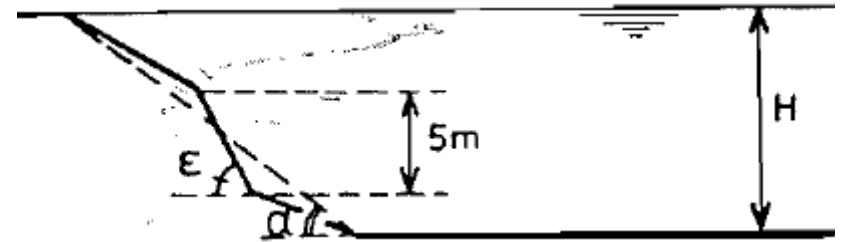
**RETROGRESSIVE FLOW SLIDE**  
Mechanism after Koppejan et al 1948

Large strain velocities 50 – several thousand meters/hour



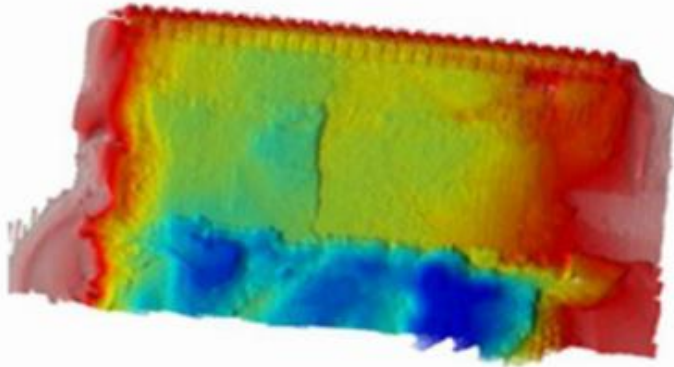
# Flow slides

Zeeland

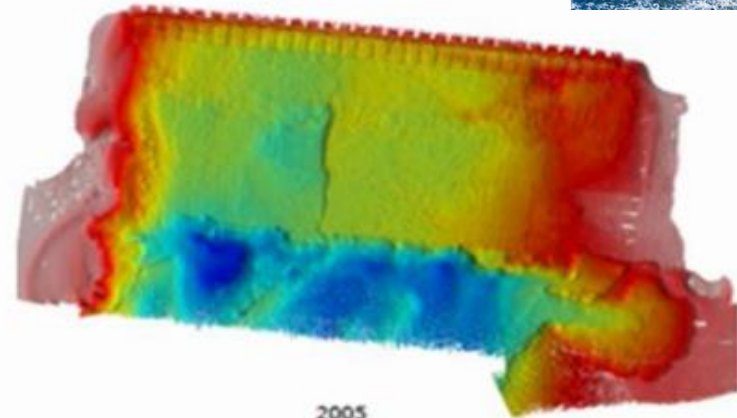


# Flow slides

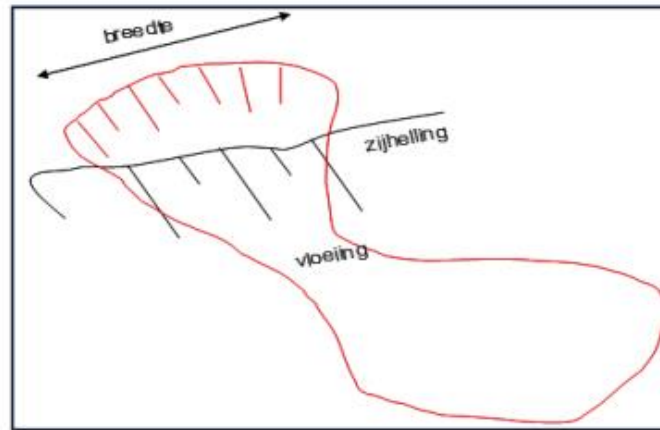
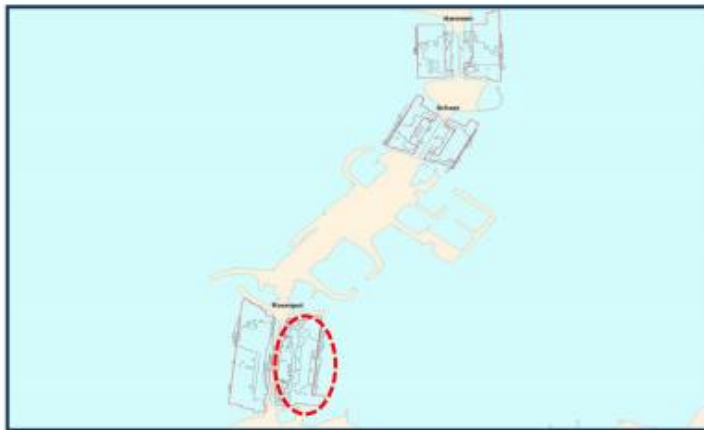
Oosterscheldekering



2004



2005



# Flow slides

What do we know about liquefaction flow slides?

- Liquefaction flow slides occur unexpectedly; a minor trigger may be sufficient to initiate liquefaction, even at mild slopes
- Liquefaction flow slides develop rapidly; there is little time to respond
- Liquefaction flow slides affect large areas; large volumes of soils are displaced over large distances (retrogressively)



# Flow slides

What is unknown/uncertain?

- The in-situ state (density)
- The in-situ material behaviour (reconstitution)
- The in-situ (horizontal) stress conditions
- The (quantified) trigger
- The development of the mechanism: retrogressive, erosion/sedimentation, entrainment water etc.

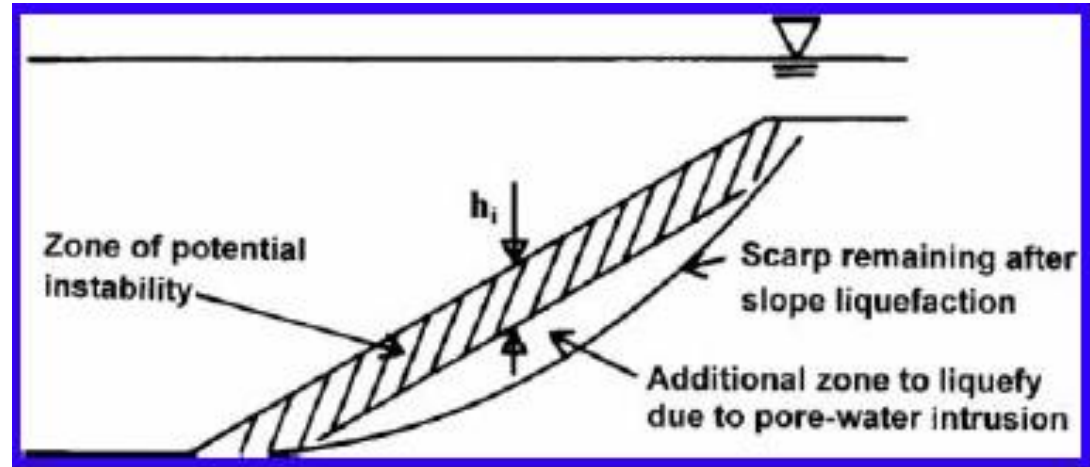
→ Direct relation with CPT ( $q_{cr}$ ,  $f_s$ )

→ Undrained behaviour

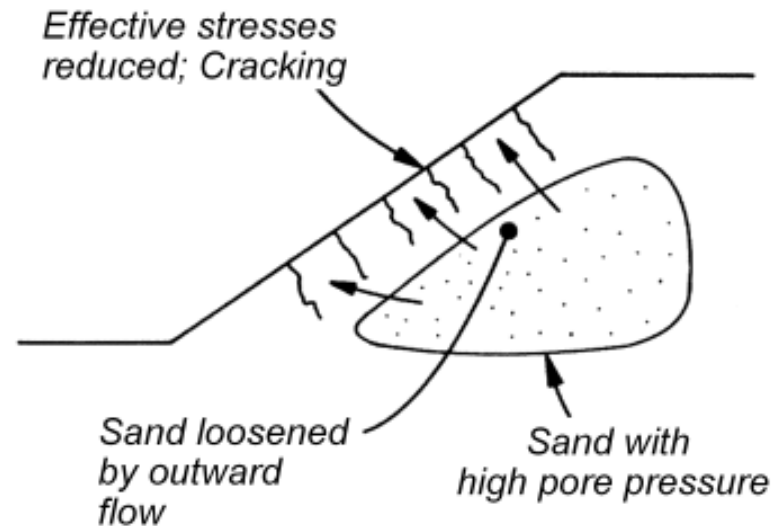
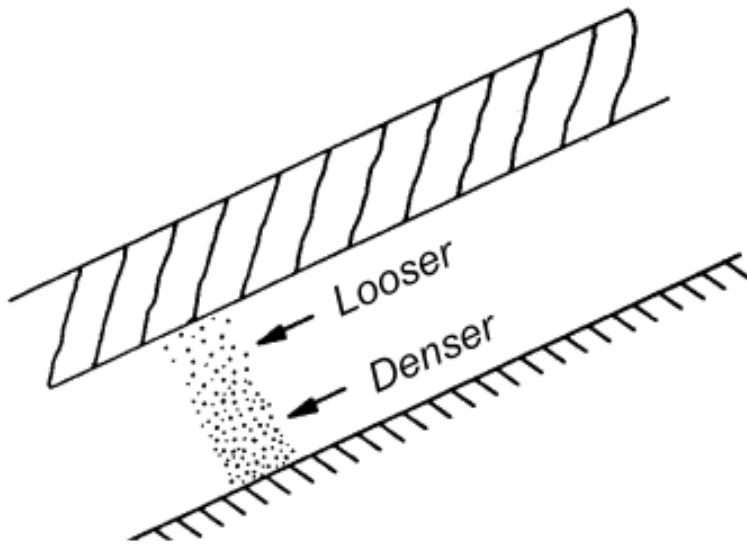
→ Liquefied strength (ratio)

# Flow slides

## Mechanisms

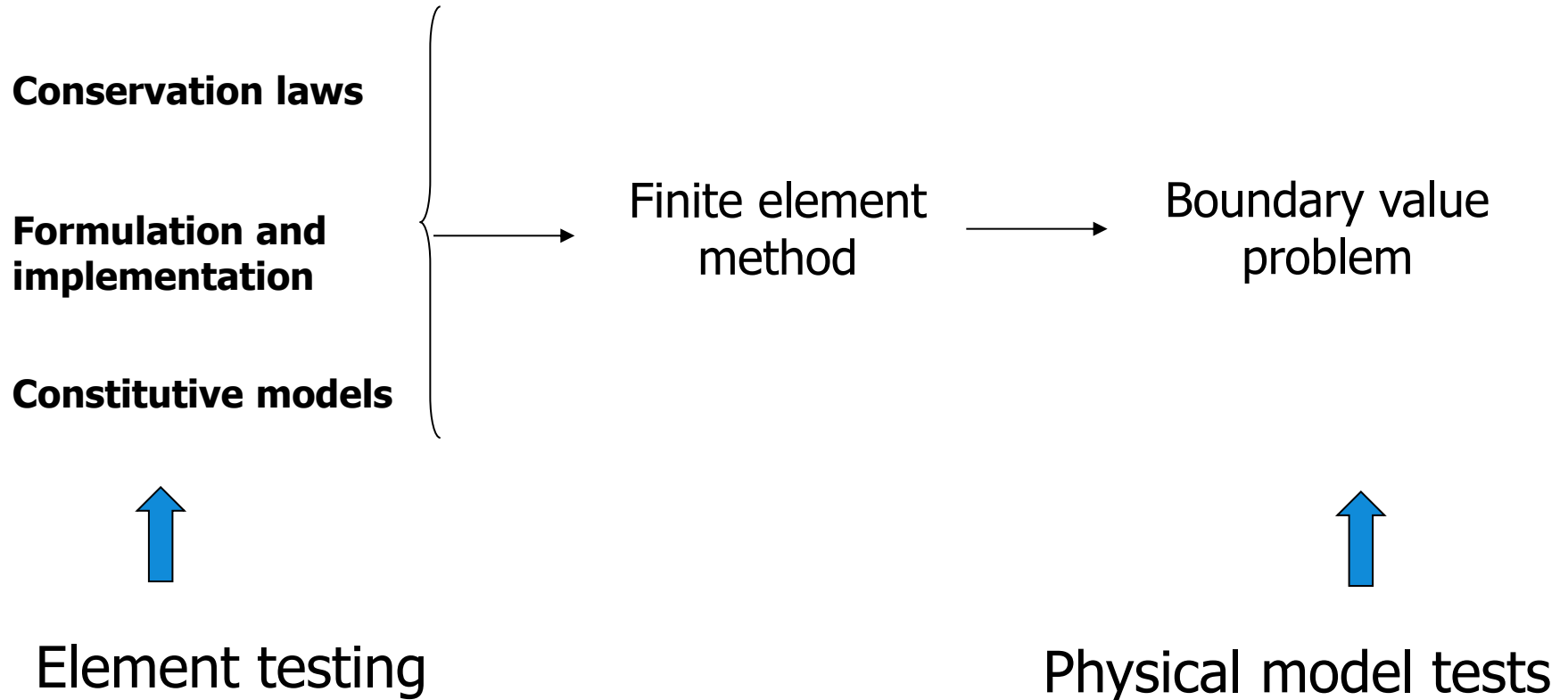


*Lade & Yamamuro, 2011*



*Whitman, 1985*

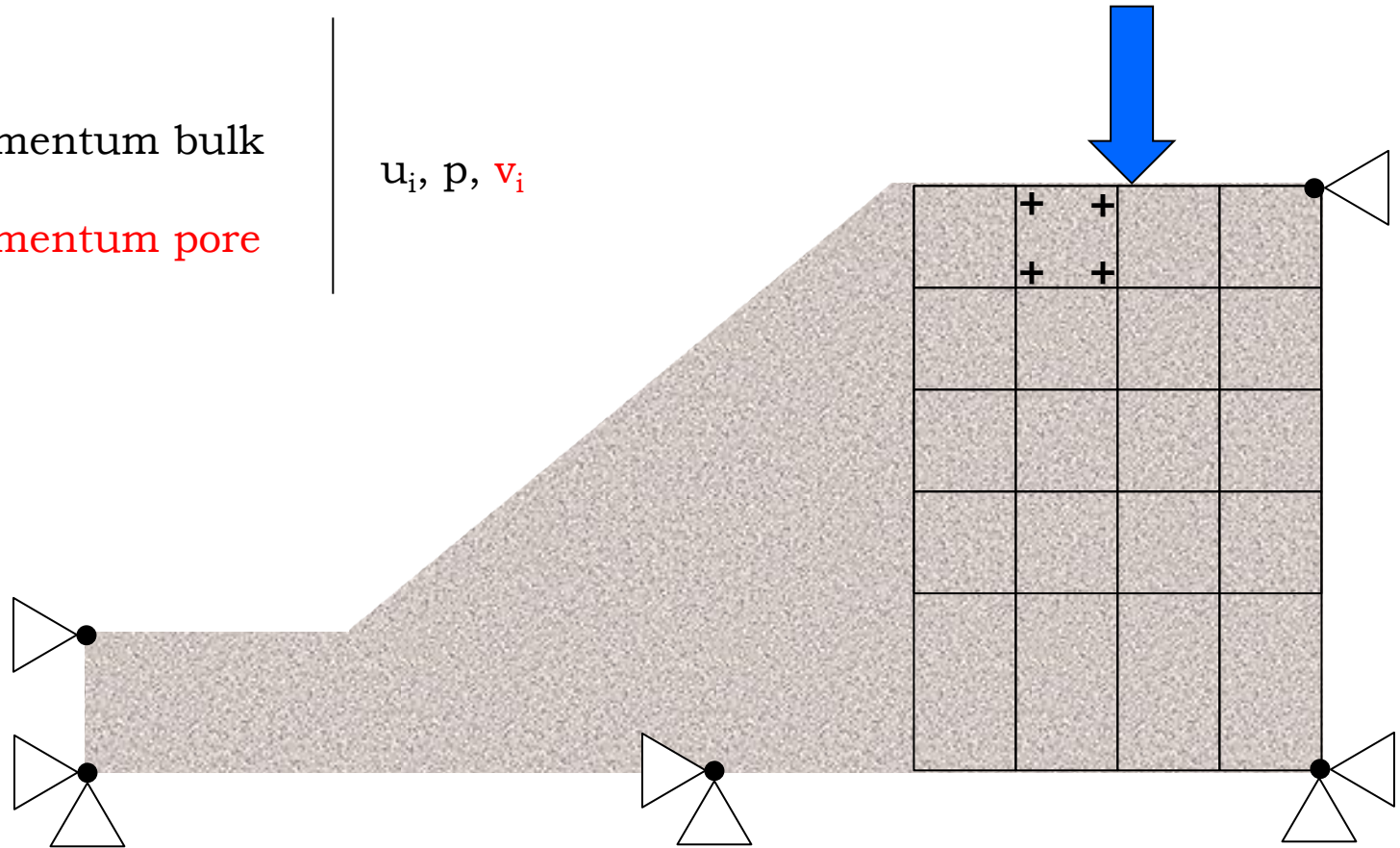
# Research



# Modelling

## Finite element method

1. Linear momentum bulk
2. Mass bulk
3. Linear momentum pore fluid



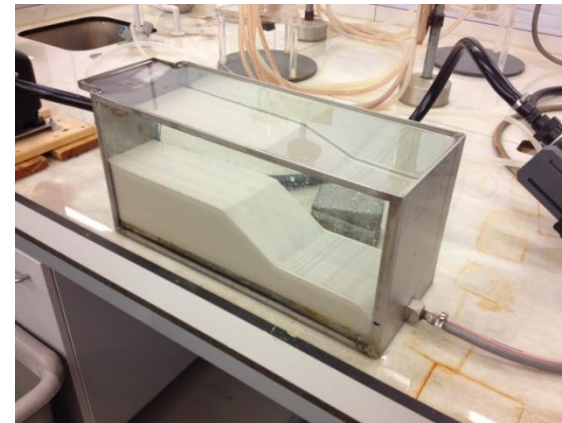
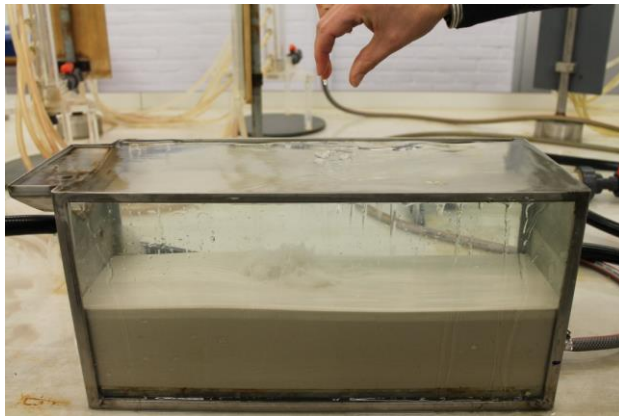
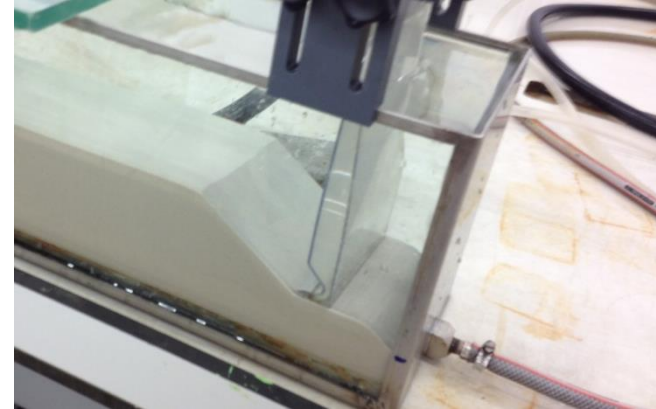
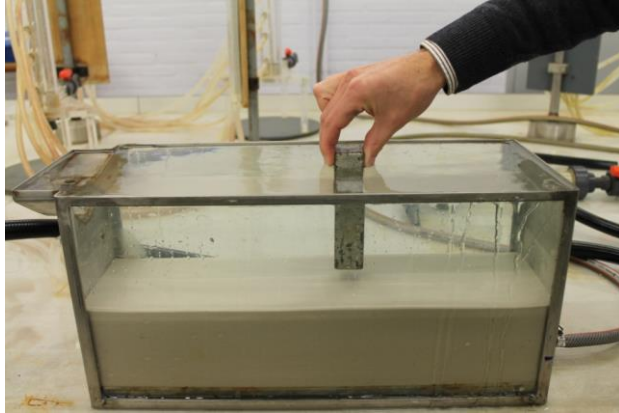
# Liquefaction tank

## Design

- Type of test
- Size
- Preparation
- Triggering
- Measurements
- Infrastructure

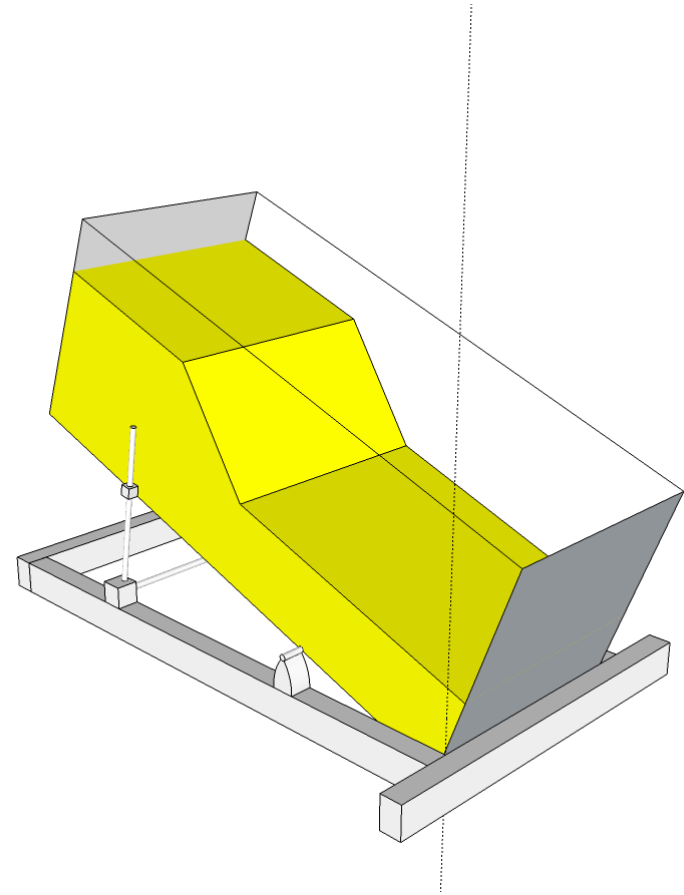
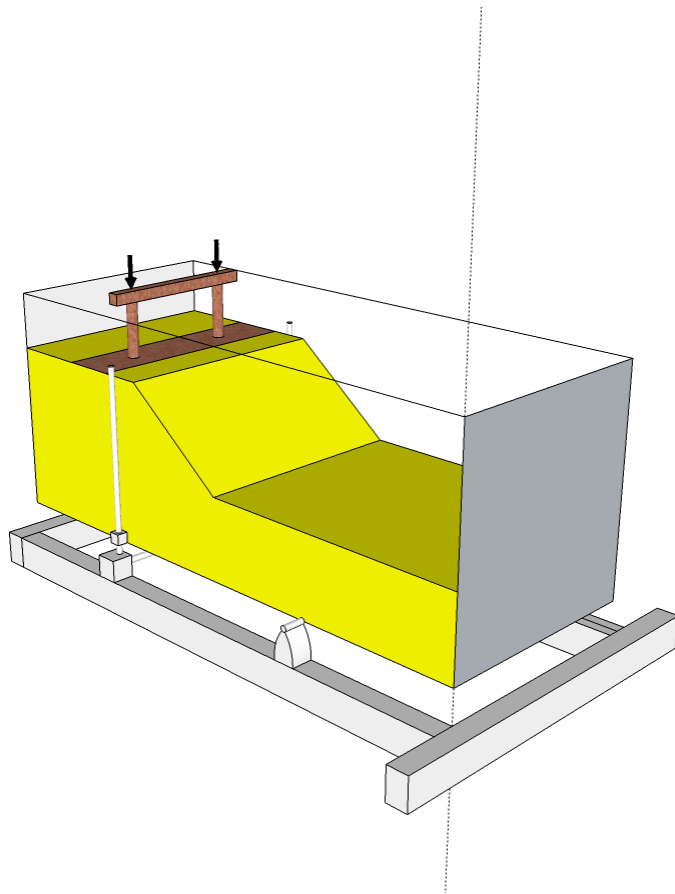
# Liquefaction tank experiments

## Minitank



# Liquefaction tank

## Triggering

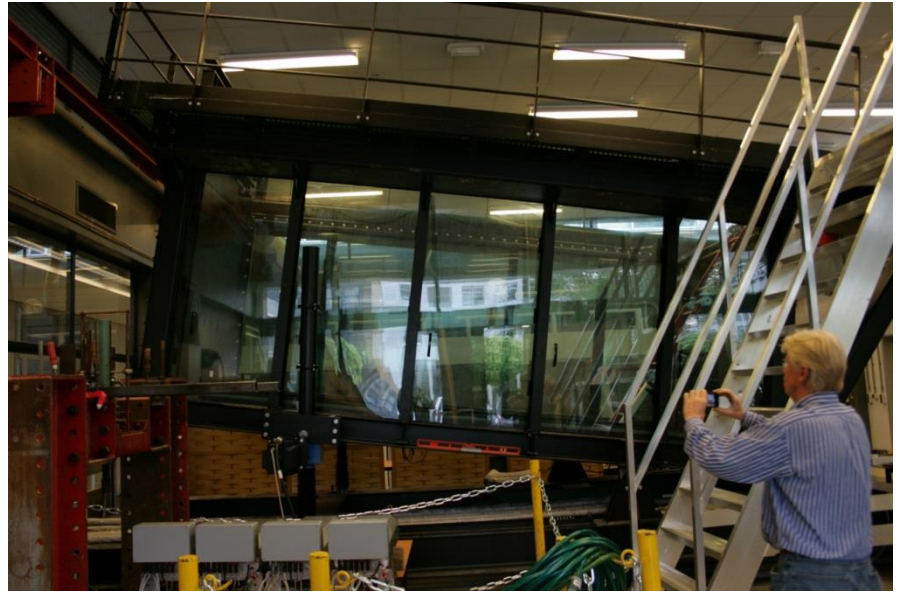


# Liquefaction tank experiments



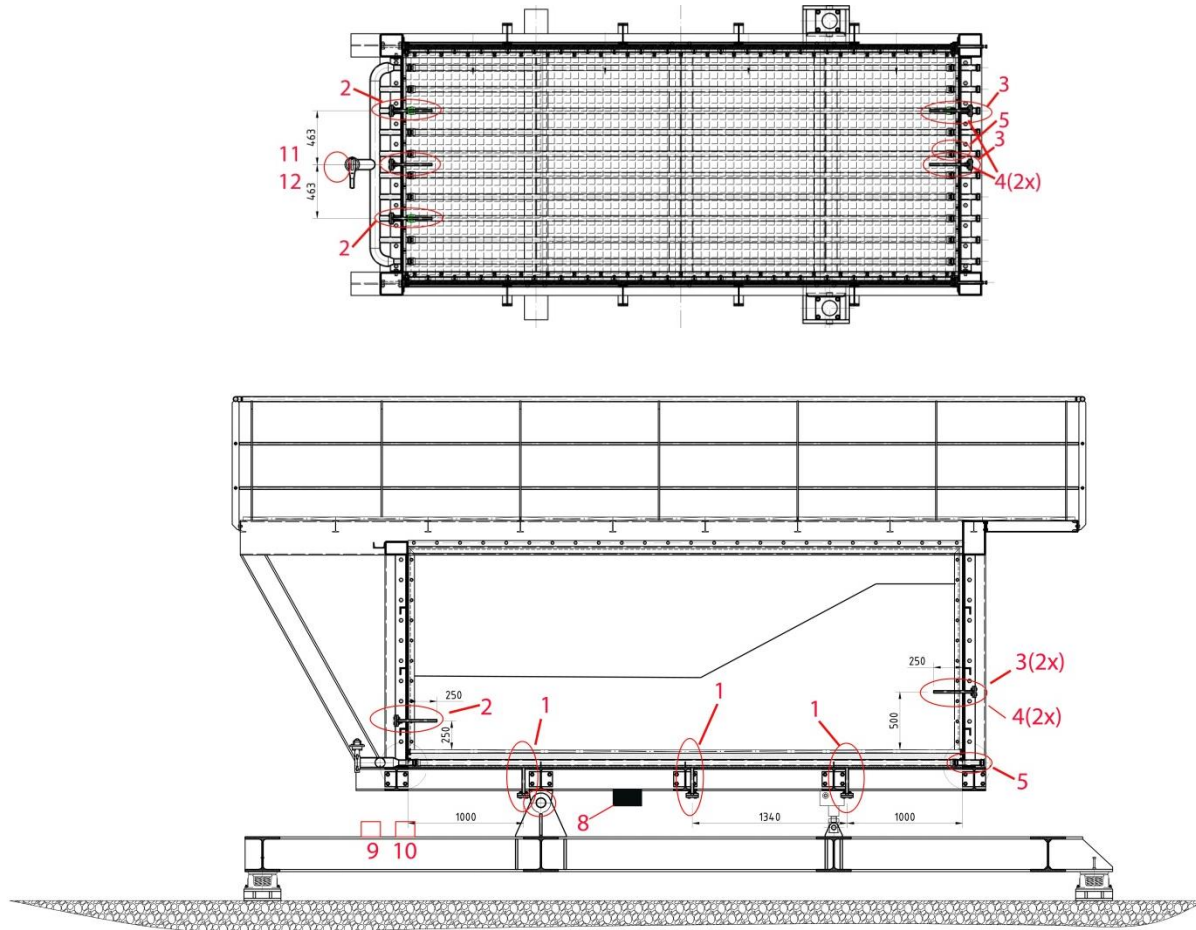


# Liquefaction tank experiments



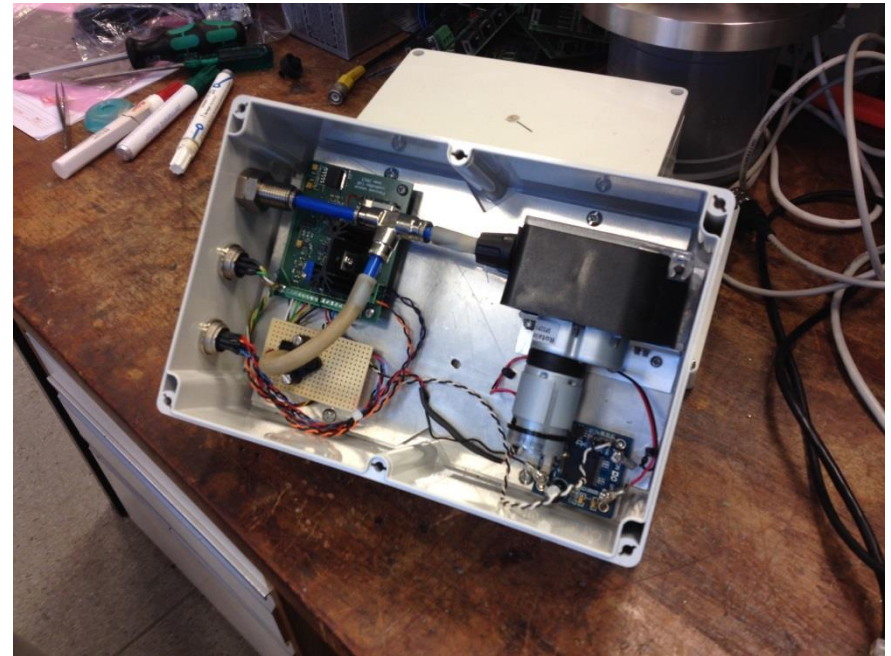
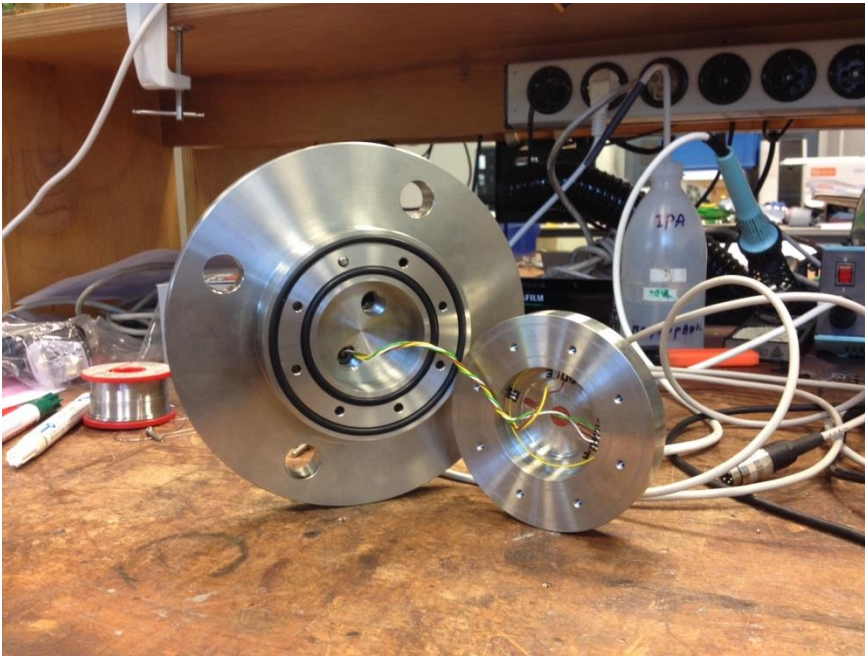
# Liquefaction tank experiments

## Sensors



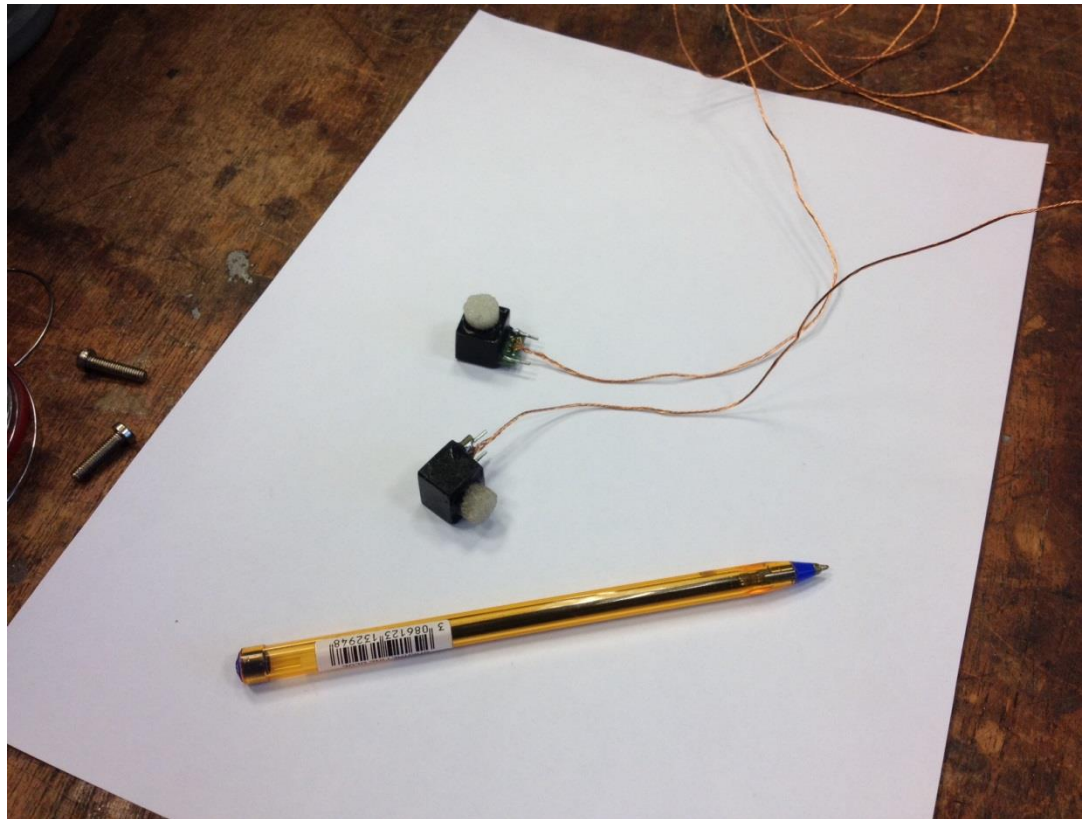
# Liquefaction tank experiments

## Sensors (1)



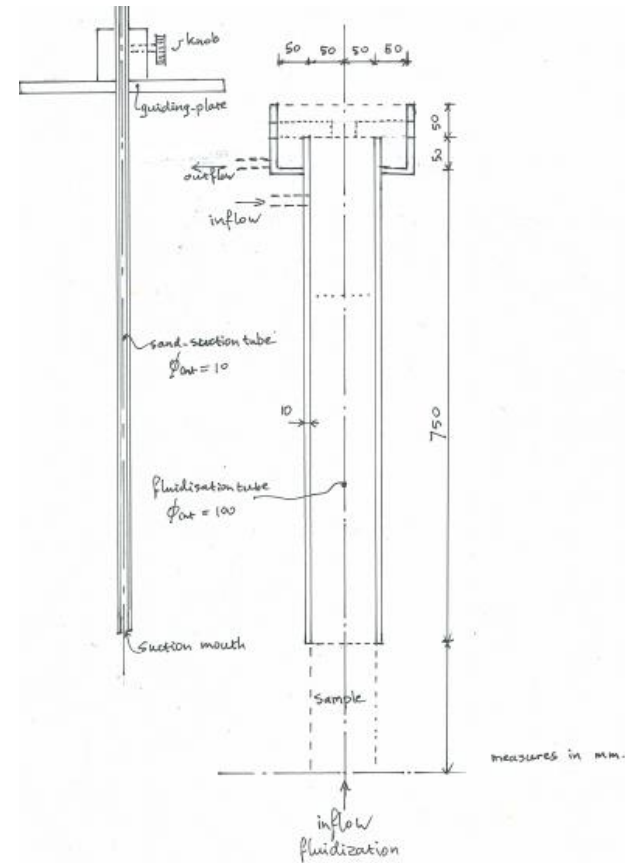
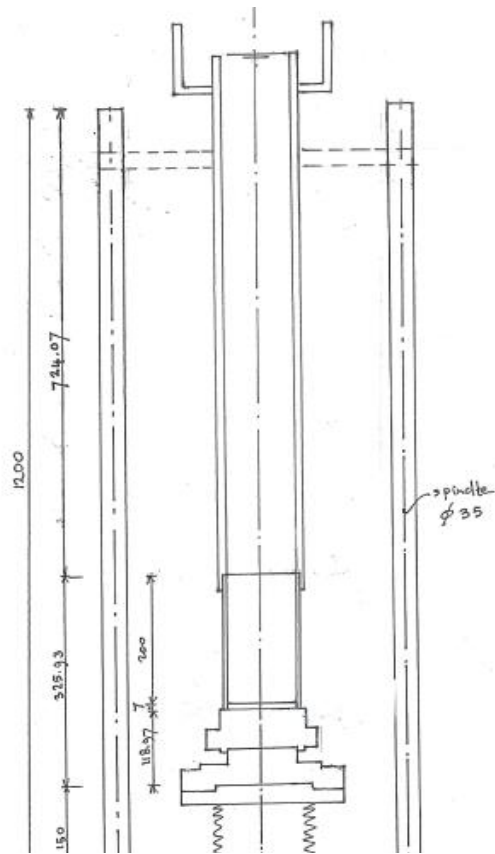
# Liquefaction tank experiments

## Sensors



# Liquefaction tank experiments

## Material modelling: triaxial testing



# Concluding remarks

- Importance of flow slides in engineering practice
- Liquefaction tank: unique experimental facility for (future) validation of models
- (Validated) FEM: assessment of flow liquefaction slides
- Future: compose database by varying:
  - Density
  - Trigger
  - Grain size/properties
  - Conditions (unsaturated → saturation)
  - ..