NTNU
Norwegian University of Science and Technology

Landslides triggered by hydro-meteorological processes

Development of analytical and numerical codes

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Co-supervisor: Dr. José Cepeda (NGI)

Outline

- Background
- Debris flows challenges
- Possible approaches
- Current work
- Future plans

Background

- MSc. Geotechnical Engineering, NTNU, 2011
- 5 years at NGI
- FEM (offshore foundations, landslides)

- PhD project Klima 2050:
  - Started spring 2016
  - WP3 Landslides triggered by hydro-meteorological processes
  - WP3.1 Development of analytical and numerical codes

THE ACTIVITIES

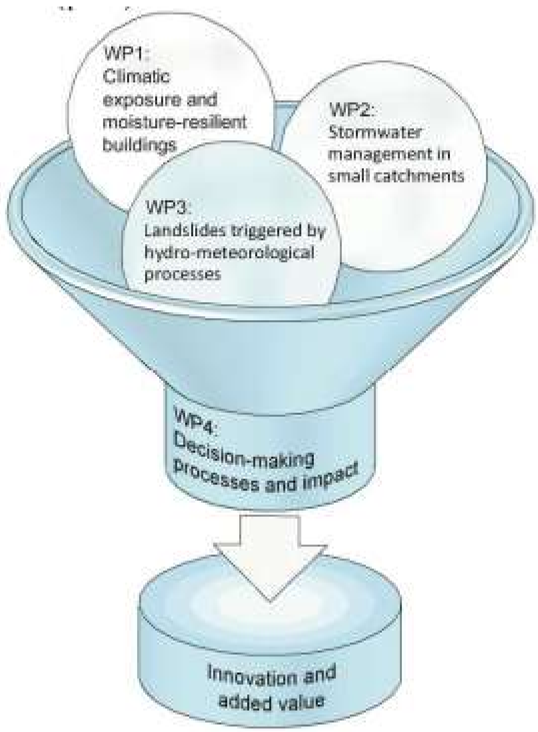
Klima 2050 will focus on four main research areas (work packages) WP1-4. The fourth work package, WP4: Decision-making processes and impact, is an important premise for research and innovation and will form a "societal funnel" bringing together the first three work packages of research into implementable and sustainable solutions leading to innovation and added value for the consortium and the building, construction and transportation sector

WP 1: Climate exposure and moisture-resilient buildings

WP2: Stormwater management in small catchments

WP3: Landslides triggered by hydro-meterological processes

WP4: Decision-making processes and impact



Klima2050

- WP3, organized by NGI (José Cepeda)
  - **WP3.1 Development of analytical and numerical codes**
  - WP3.2 Environmentally sustainable methods for improving drainage and stabilizing slopes
  - WP3.3 Protection of critical infrastructures (CI) from landslides
  - WP3.4 Early warning systems based on short-term weather forecasts (now-casting)
  - WP3.5 Procedures for managing landslide risk

- Goals:
  - Physical understanding of debris flow phenomena
  - Better prediction of run-out distance
  - Design tool for mitigation measures

News extended info

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PhD project: Landslides triggered by hydro-meteorological processes

Landslides triggered by hydro-meteorological processes are expected to occur more frequently in the future, due to increased frequency of extreme precipitation associated with climate change. Landslides termed as debris flows are composed of coarse-grained soil and water, and are usually highly mobile (high velocities and long runout distances). In Norway, debris flows are typically triggered during local extreme rainfall events, and by groundwater and runoff exceeding normal conditions.

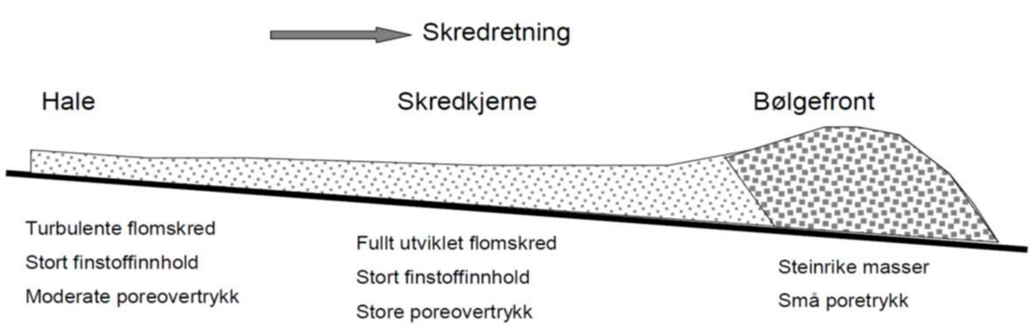
A debris flow usually starts with local erosion, which can make ravines and riverbanks unstable, triggering small local failures, and gradually increasing the flow density and give potential for further erosion. As the flow progresses, more material is entrained from the base and sides along the path, and the final volume can be several orders of magnitude higher than initial failure volumes. Due to high pore water pressures, the internal friction is low and debris flows can travel very long distances. The potential consequences of this type of landslide include damage to infrastructure like roads and railways, damage to buildings and casualties.

To reduce the consequences of precipitation-induced landslides, a better understanding of the physical mechanisms of debris flows is required. This PhD research work will focus on numerical modelling of debris flows for improving both the prediction of run-out distance and the evaluation of mitigation measures that aim to reduce consequences.

Debris flow challenges

- Extreme precipitation events
- Soil (particles) and water (fluid)
- Debris avalanche → debris flow

- Excess pore pressure
- Entrainment
- Separation



Possible approaches

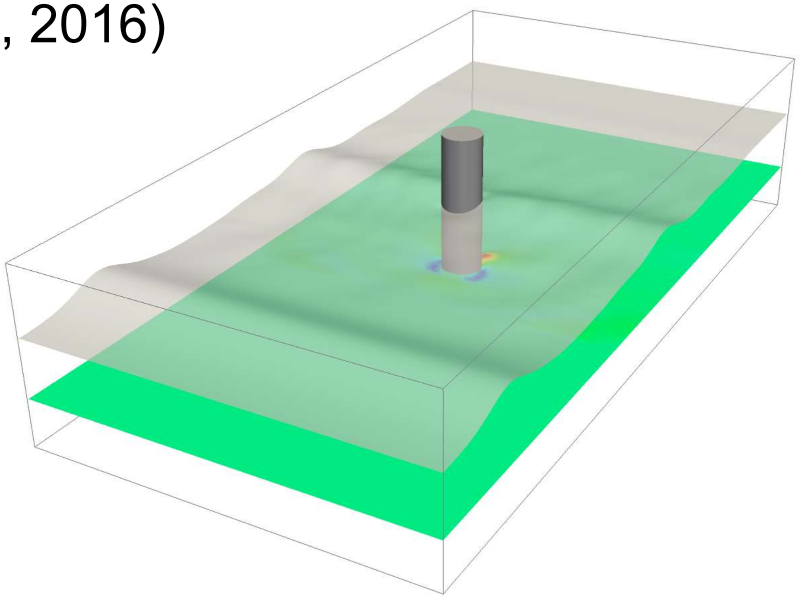
- Debris flow initiation, propagation and structure interaction

- Methods
  – Depth averaged (2.5D)
  – CFD
  – SPH
  – DEM

- CFD:
  – Better physical understanding
  – Pressure, forces on structures
  – Continuum fluid

Current work

- Computational Fluid Dynamics (CFD)
  - 3D general solution of Navier-Stokes equations
  - Open source: REEF3D (Bihs et al., 2016)
  - Finite Difference Method
  - Parallelization
  - Newtonian rheology
  - (DEM+CFD coupling)



- Navier-Stokes equations:

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\nu + \nu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + g_i$$

Rheology

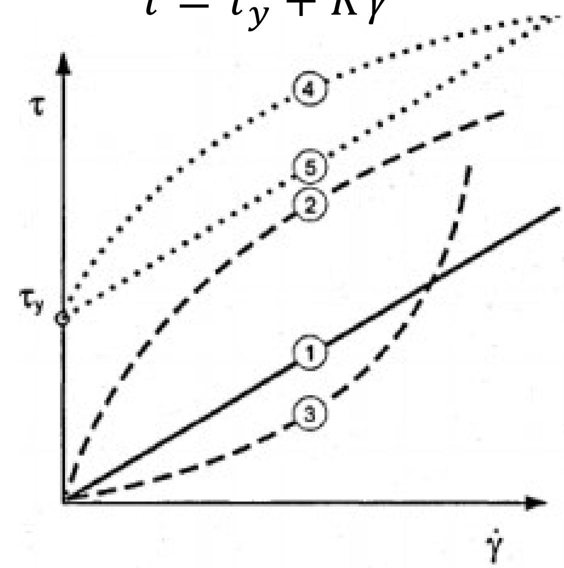
- Debris flow as continuum
- Viscoplastic Herschel-Bulkley rheology
- Water with fines in suspension (not debris flow)
  - Interstitial fluid phase, mudflows

- Generalized Newtonian fluid

$$\nu = \mu/\rho = (\tau_y/\dot{\gamma} + K\dot{\gamma}^{n-1})/\rho$$

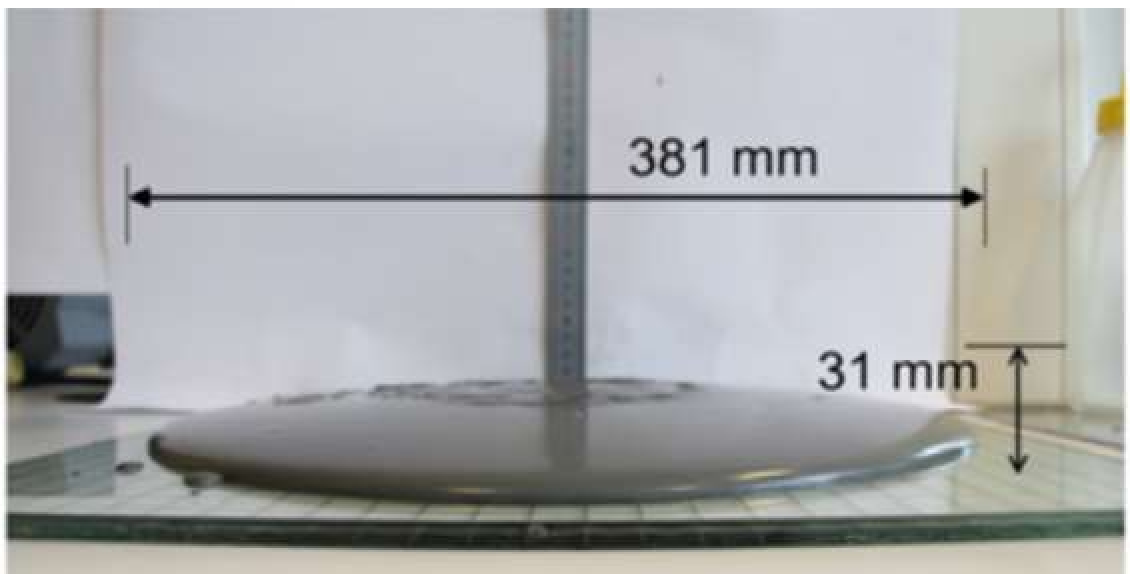
$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3}\dot{\gamma}_{ij}\dot{\gamma}_{ij}}$$

$$\tau = \tau_y + K\dot{\gamma}^n$$



Benchmark test

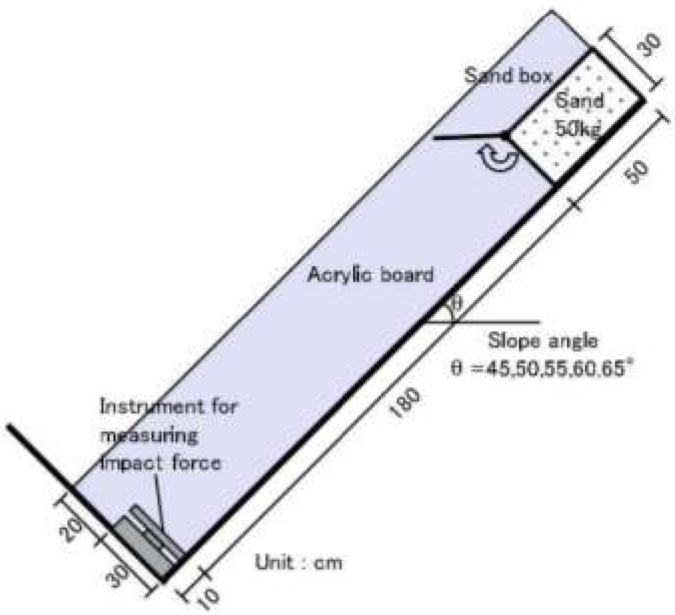
- Quickness test - remoulded sensitive clay
  - Rheological data, viscometer (Grue, 2015)
  - Cylindrical dambreak (Thakur et al., 2013)

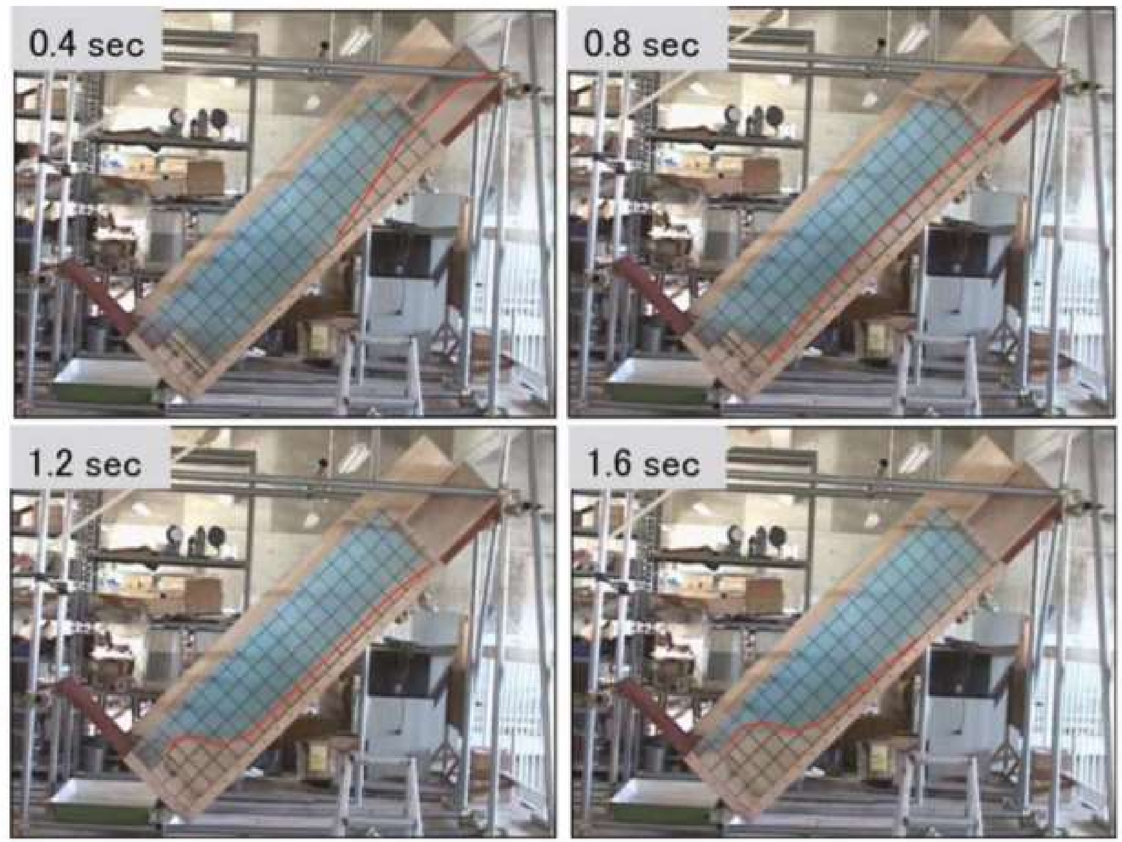


(Thakur et al., 2013)

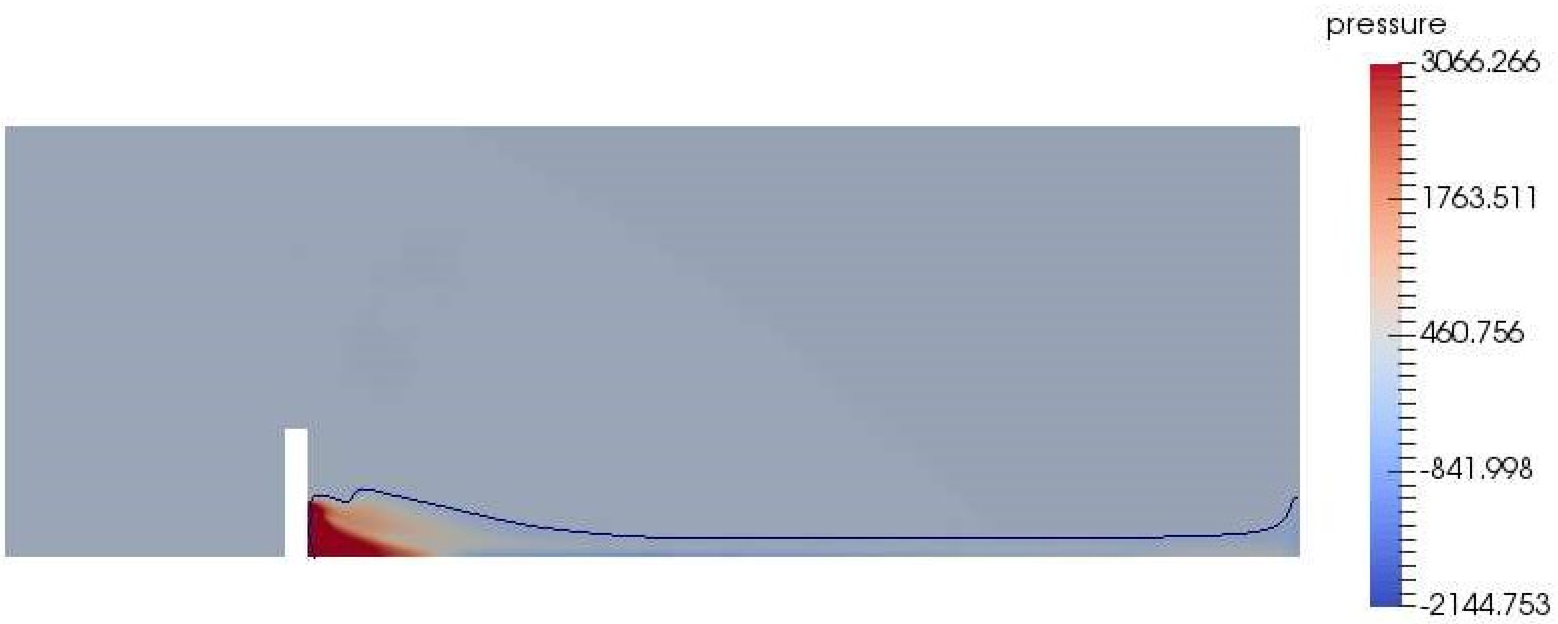
Benchmark test

Moriguchi et al. (2009)





Simulations



Yield stress

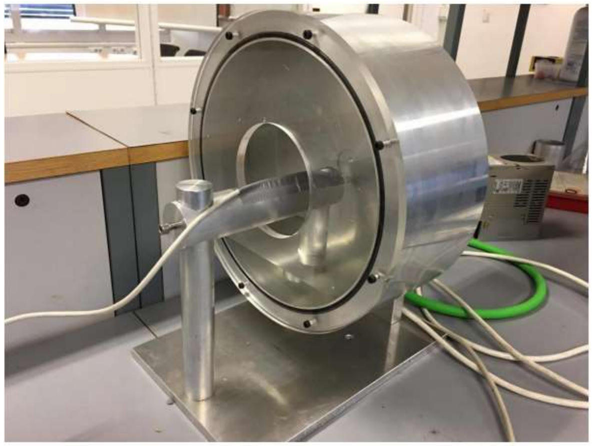
- Coulomb friction:
  - $\tau_0 = c + \sigma' \cdot \tan(\phi)$,
- Dry granular soils:
  - zero excess pore pressure
  - $\sigma' \rightarrow$ hydrostatic pressure p
- Debris flows:
  - Excess pore pressure generation
- Implemented as high viscosity, ν_0

Future implementation

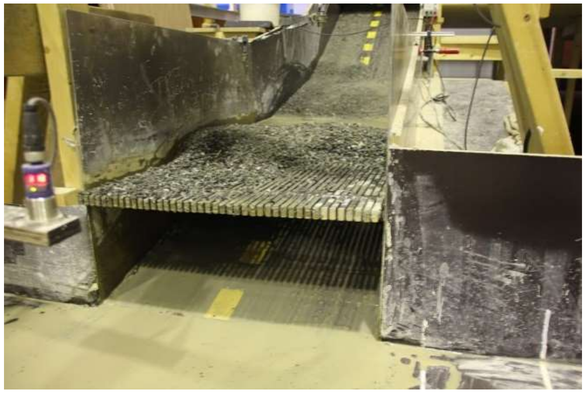
- Multiphase continuum material
  - Fluid representing both particle and water phases
  - Solid volume content, $m - \rho$
  - Excess pore pressure by shear deformation, $p_{excess} - \dot{\gamma}$
  - Coulomb friction, $\tau_y - \phi - p_{excess}$
  - Dissipation of pore pressure, $p_{excess} - k - t - m$
  - Grain size curve dependent rheology, $[D_{10}, D_{50}, D_{90}] - k - \dot{\gamma}$

Validation

- Ashenafi Yifru (PhD, E39)
- Laboratory tests
- Model tests
- Field cases
- More data!



(Yang, 2106)

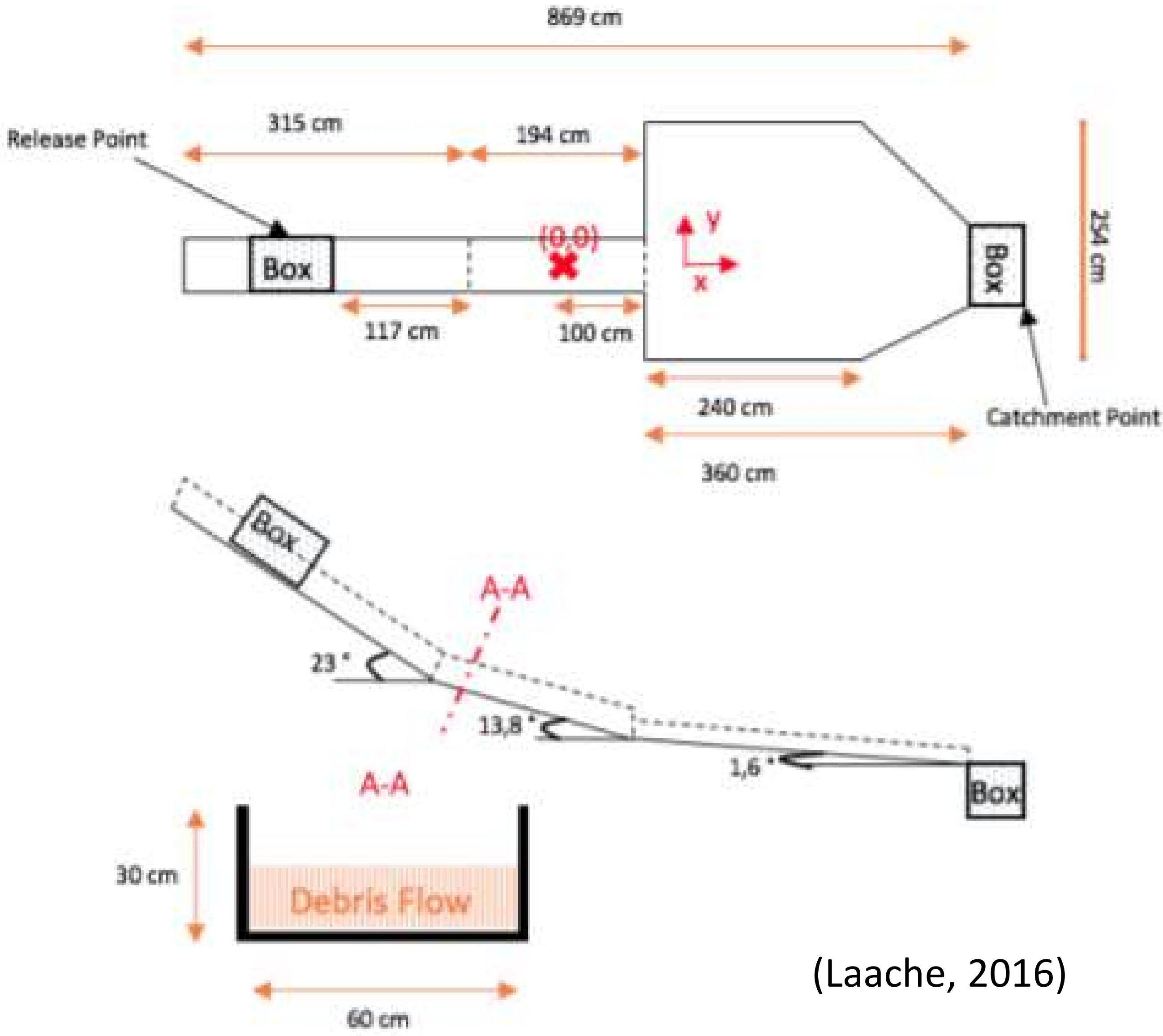


(Laache, 2106)

Flume test

(Laache, 2016)

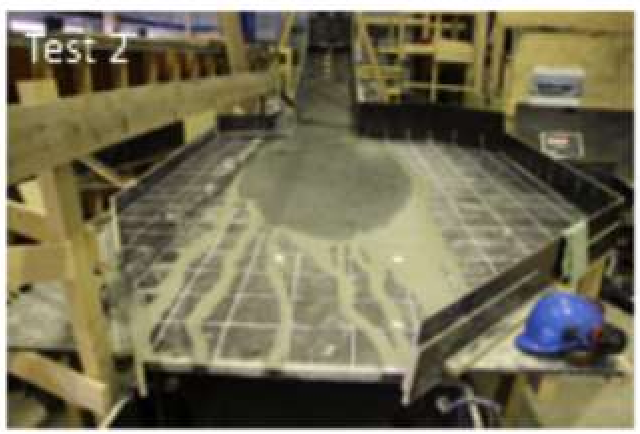
Flume test



(Laache, 2016)

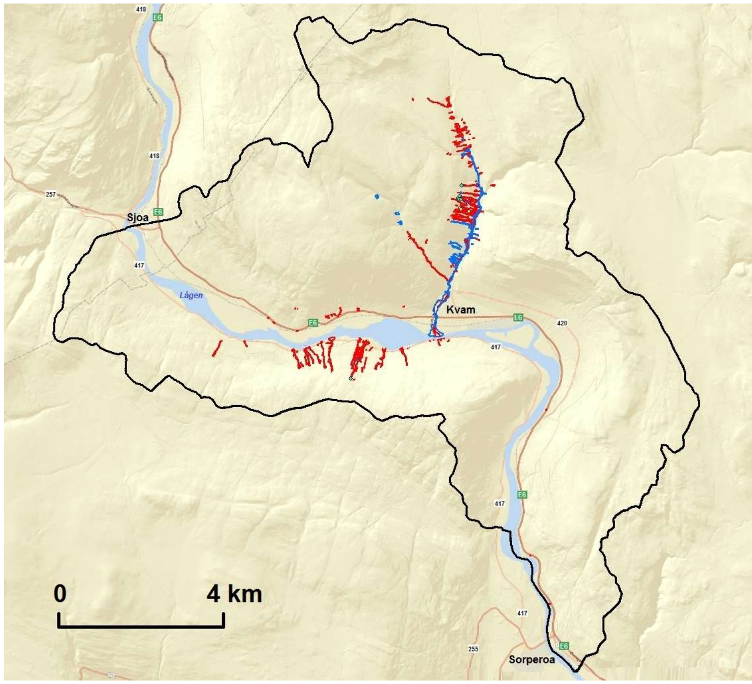
Flume test

- Natural soils (well graded sand)
- 2 ultrasound sensors (height)
- Video cameras
- Pore pressure measurements



(Laache, 2016)

Field case: Kvam, 2011 and 2013



Landslides (10 June, 2011)

Landslides (22-23 May, 2013)

Other activities

- Field trips:
  - Gråfonfjellet (NGU)
  - Norangsdalen (Klima2050, NGI)
  - Kvam (NGI)

- ETH Winter School, Switzerland

Collaborations

- NTNU, Marine Civil Engineering – REEF3D CFD code
- NGI – Soil characterization, field measurements
- SVV/NPRA – E39 project, PhD candidate
- Sintef – Kvam case study
- WP2 – Case studies?
- Abroad?

Thank you!