Analysis of soil failure modes using flume tests

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INTRODUCTION

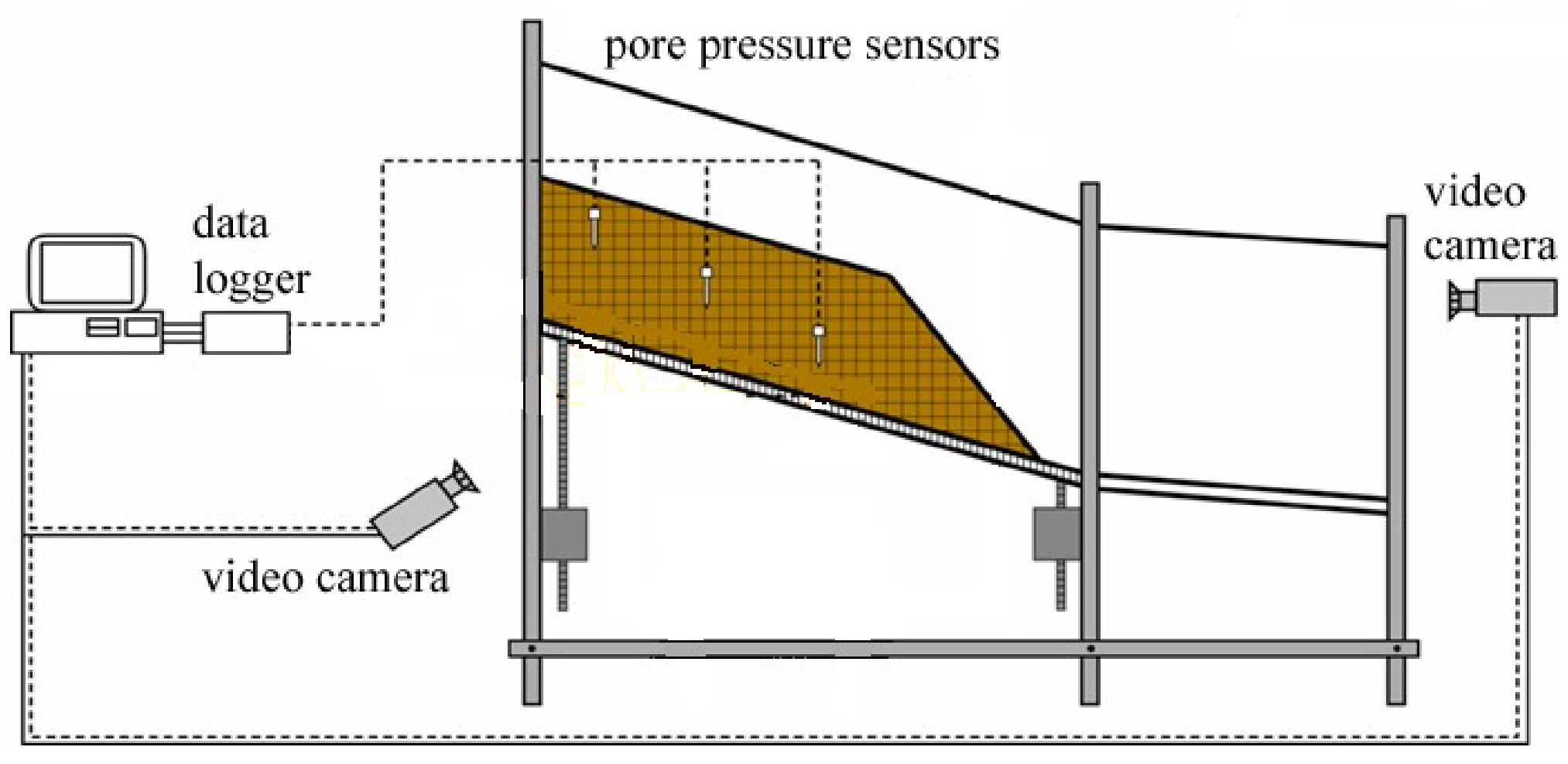
A basic requirement in landslide forecasting and in the design of early warning systems is the identification, qualification and the modelling of triggering mechanisms. The analysis of failure modes can give a better understanding of the processes governing landslide development. This study focuses on the investigation of landslide failure modes by performing flume tests in the laboratory.

OBJECTIVE

A landslide that is triggered by a hydrological process can show a variety of different failure modes which depend on the given conditions of the slope as geometry, material, joints and discontinuities. The objective of the study is to get a qualitative overview of the varying failure modes in dependency of the material with respect to 4 criteria, (1) the time displacement behaviour, (2) the total time of failure, (3) the kind of failure and (4) possible mechanisms leading to the observed failure.

FLUME TESTS

The test apparatus is depicted in Figure 1. Images are taken in defined intervals from the side and from the front. To investigate the hydrological trigger water infiltrates from the back bottom of the slope using a pump and a defined top water level that is kept constant (upward constant head infiltration).



Inner flume dimensions
Height: 60 cm
Width: 60 cm
Length: 13°

Fig. 1: Scheme of flume test apparatus.

Two materials are tested,

- loosely packed river sand (sandy material) and
- clay from Zoelen, the Netherlands (cohesive material).

a) RIVER SAND

To analyse the time displacement behaviour the movement of 4 points at the slope surface is measured (Figs. 2, 3, 4).

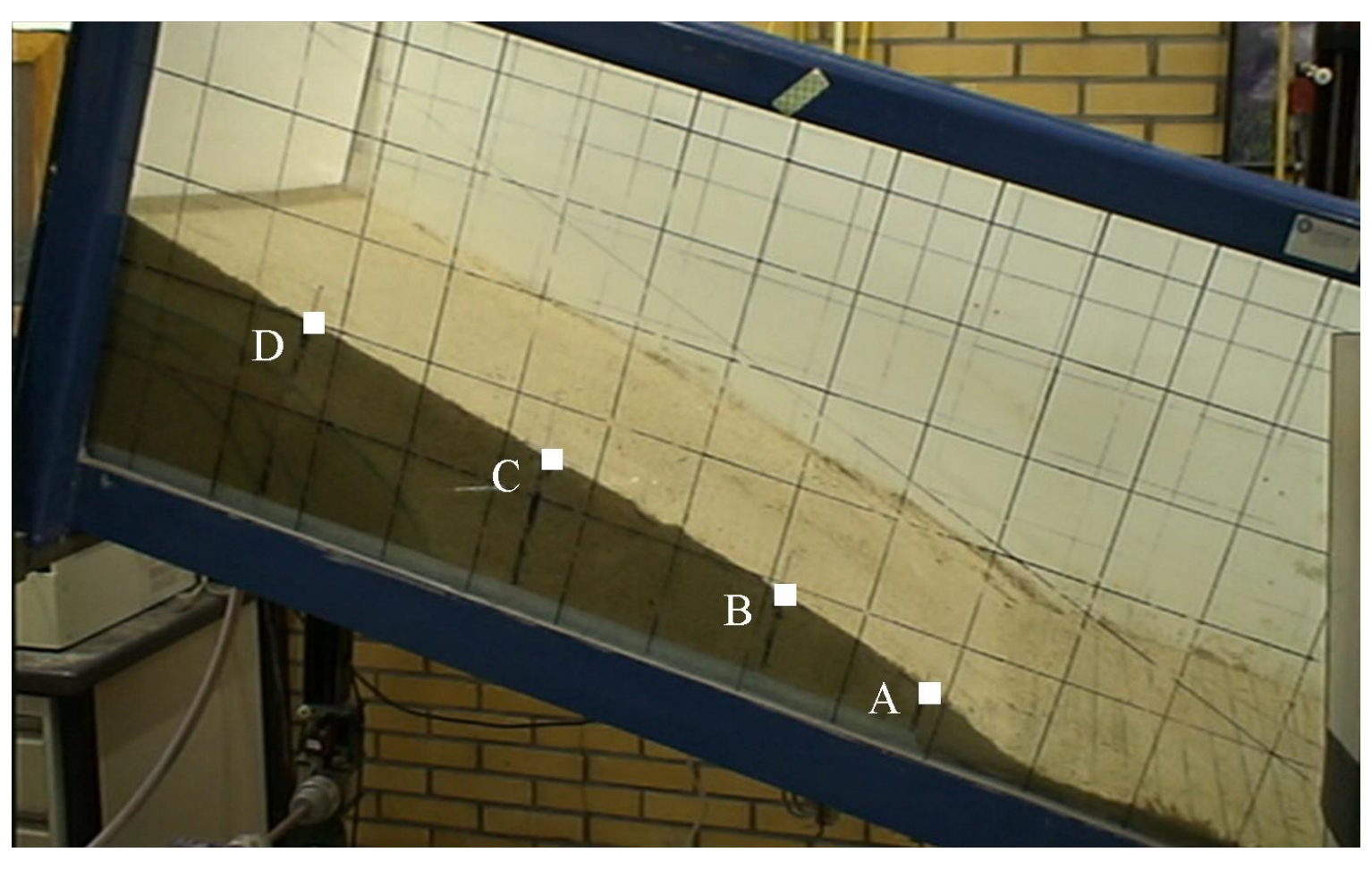


Fig. 2: Initial test conditions and observed points of test on River sand.

Slope dimensions
Slope height: 25 cm
Slope length: 110 cm
Slope angle: 13°
Flume inclination: 25°
Total slope angle: 38°.

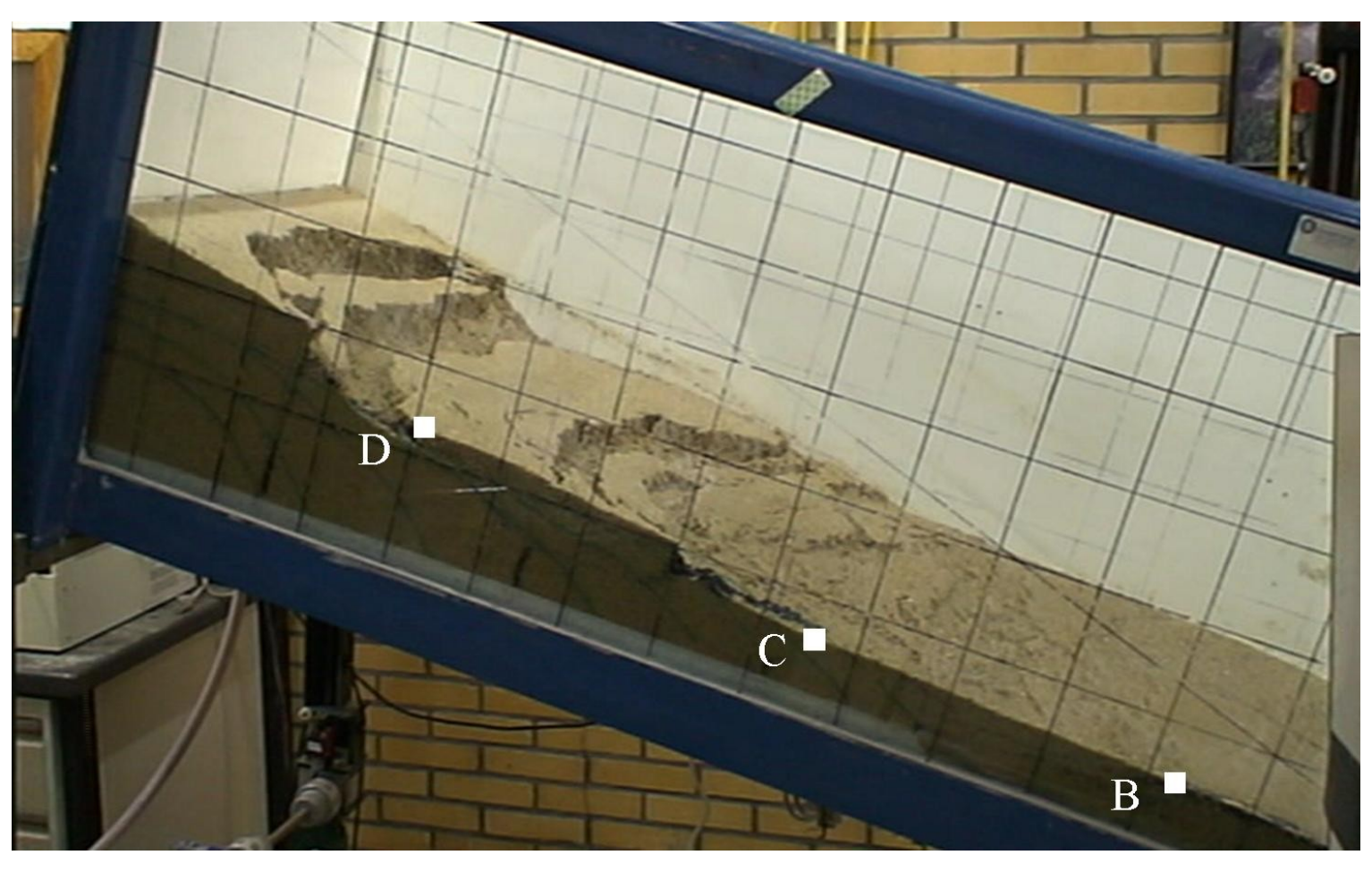


Fig. 3: Final phase of retrogressive failure (12:05:49) inclusive observed points B, C, D.

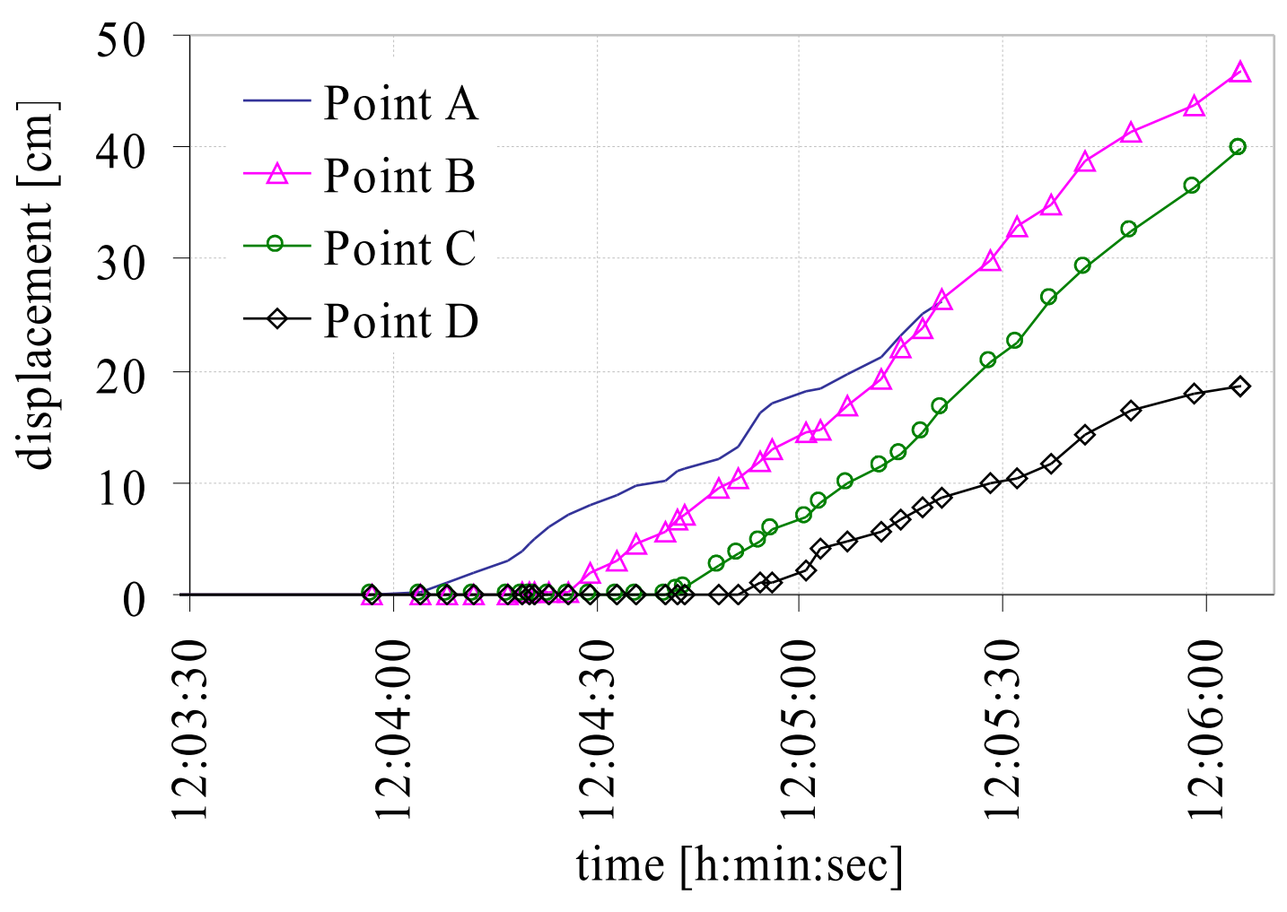


Fig. 4: Time displacement curves of points A, B, C, D at the slope surface (the ending points of the graphs are limited because of observation reasons, it does not mean that the soil mass stops to move).

After about 15 min of water supply failure starts at the toe (point A) and it continues in direction of the crest. In Figure 5 the geometry and sequence of slumps are displayed and Figure 6 gives the development of slumps in time. It is assumed that due to liquefaction of the soil at the toe a first slip surface (slump 1) is formed.

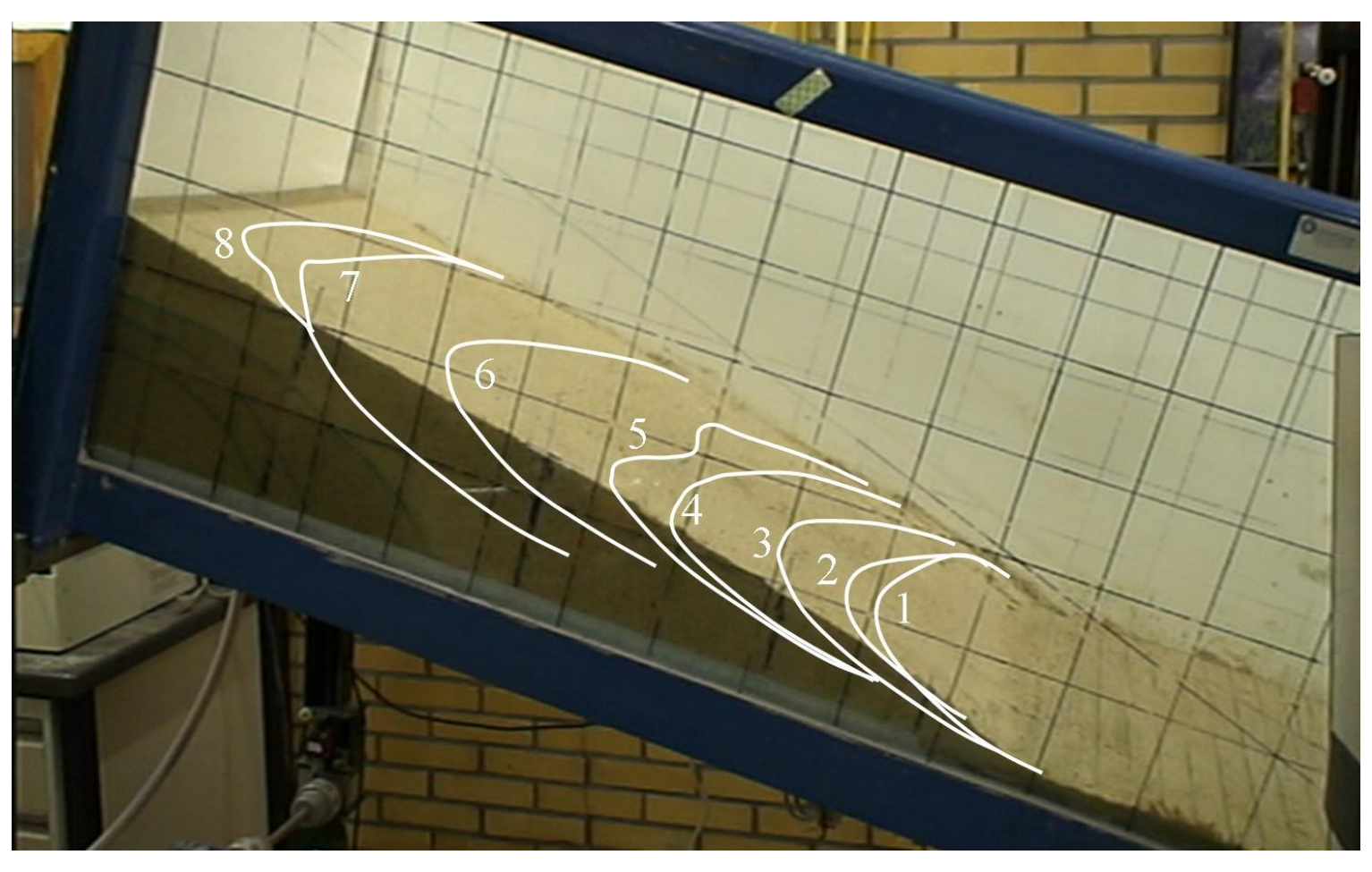


Fig. 5: Geometry and sequence of slumps during retrogressive failure.

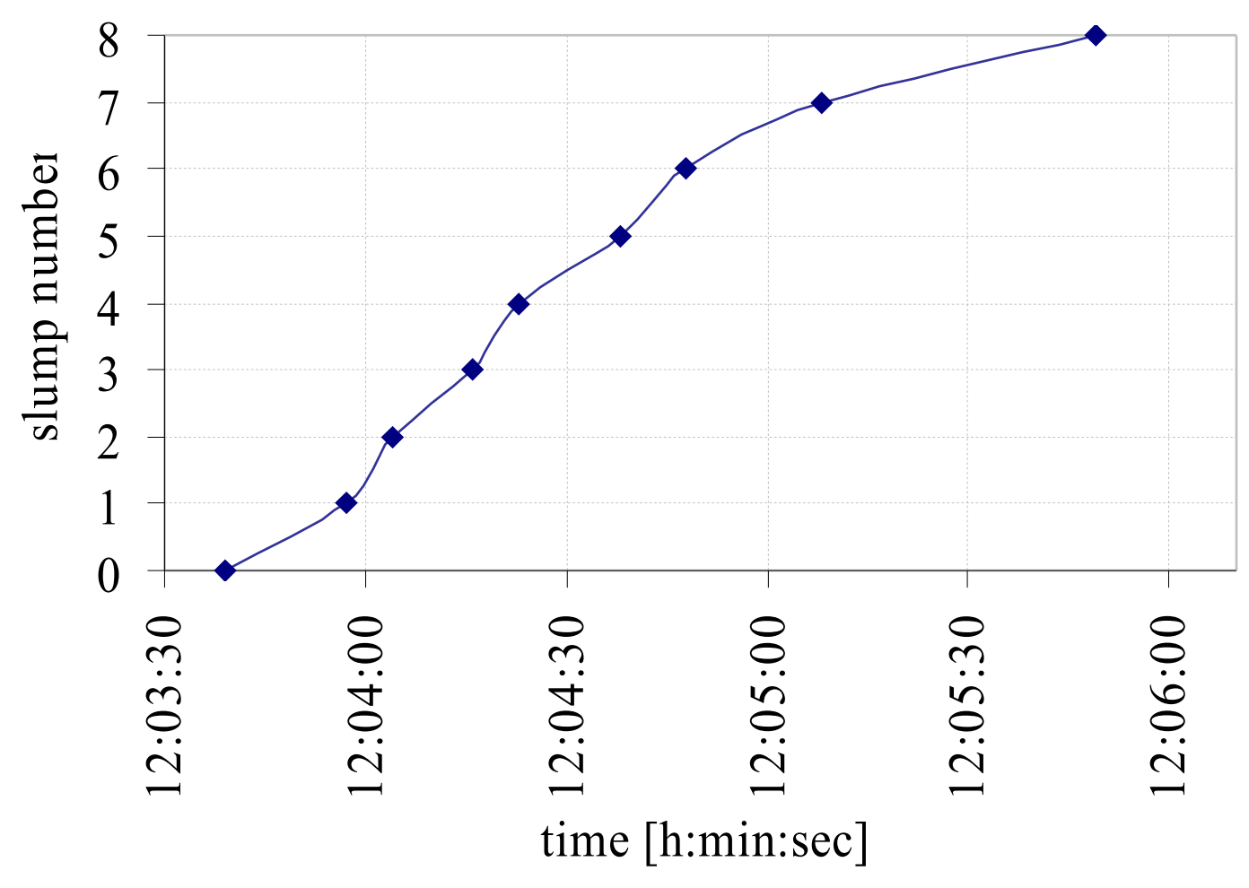
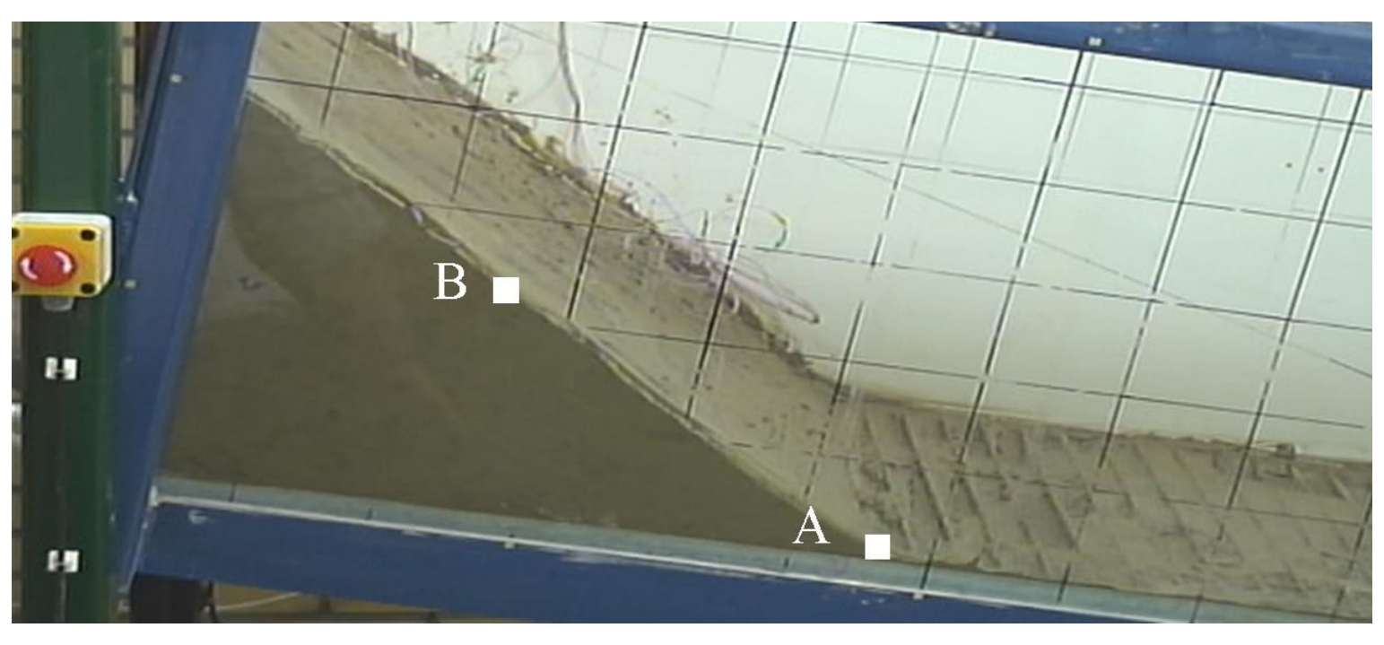


Fig. 6: Development of slumps in time.

a) ZOELEN CLAY

The displacements in time are measured using two points at the slope surface (Figs. 7, 8, 9, 10). Figure 8 presents the time displacement curves of the whole failure process (25 days). The curve can be divided into two parts, where the first part is characterized by a very slow movement that took place from 01-10-2008 until 24-10-2008. In the second part the movement velocity increases and final failure occurs. In Figure 9 the second phase of the time displacement behaviour is illustrated in detail.



Slope dimensions
Slope height: 40 cm
Slope length: 57 cm
Slope angle: 35°
Flume inclination: 11°
Total slope angle: 46°.

Fig. 7: Initial test conditions and observed points of test on Zoelen clay. Before the slope was built the material was saturated in buckets what leads to a strong compacted slope.

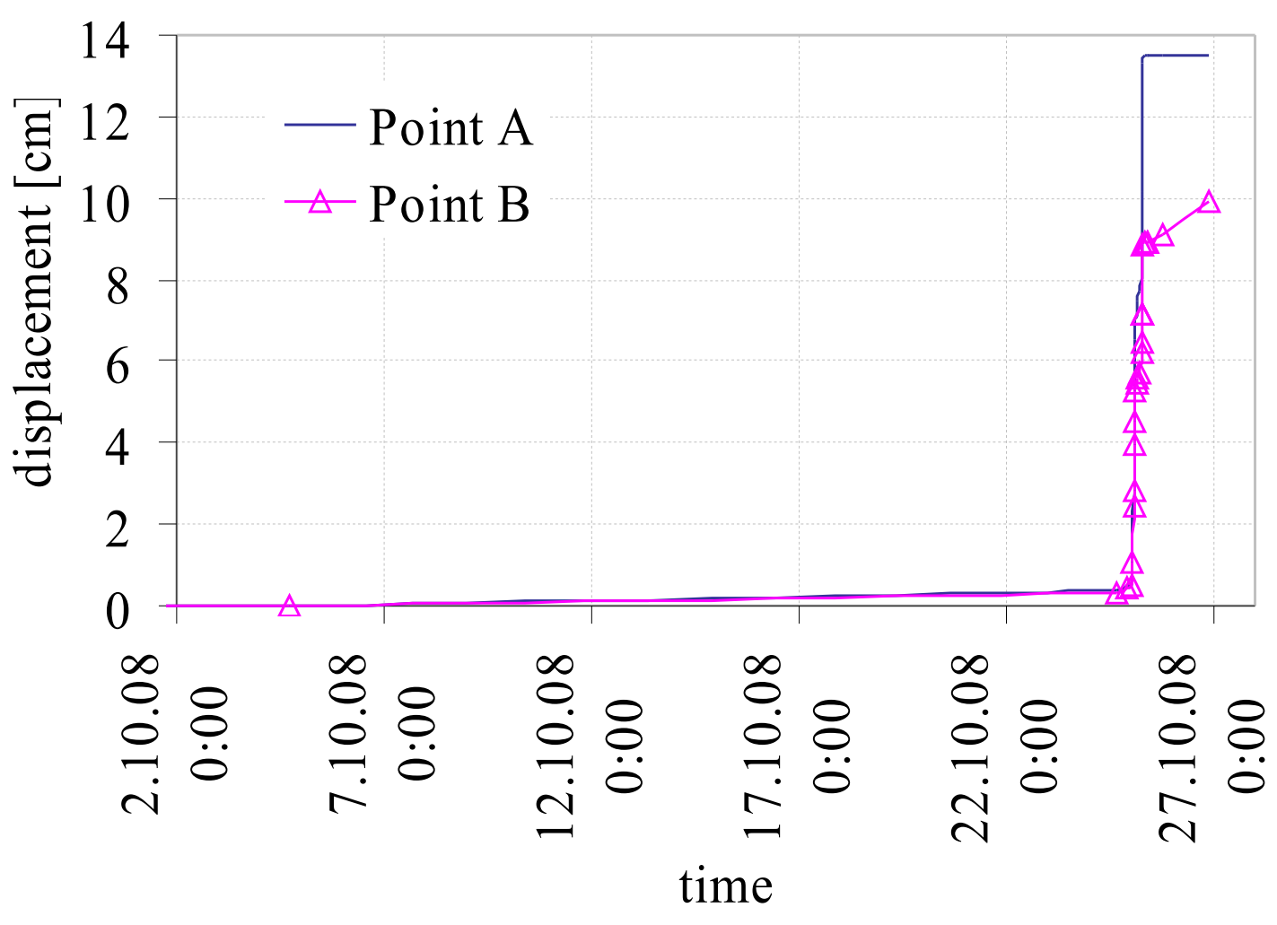


Fig. 8: Time displacement curves of points A, B at the slope surface.

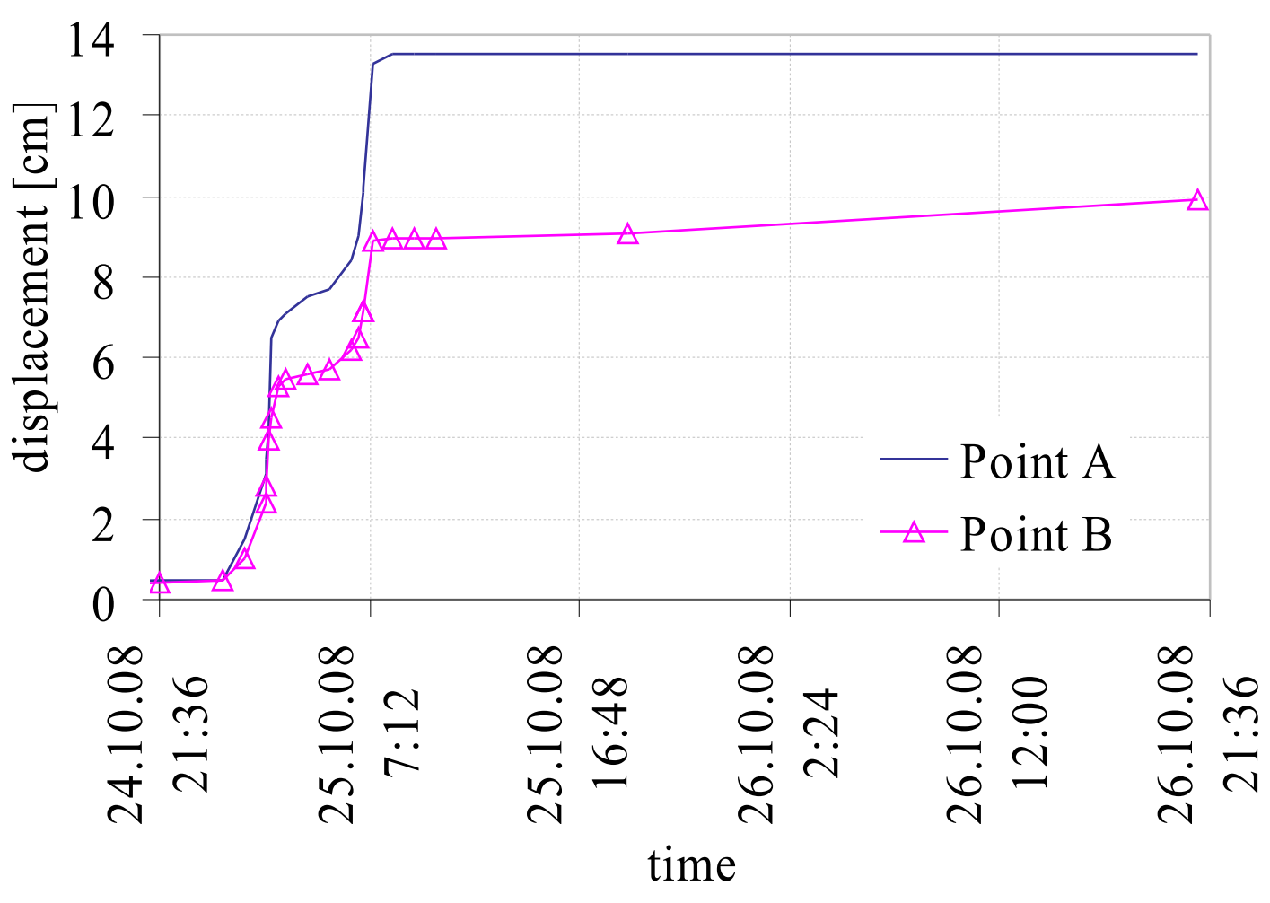


Fig. 9: Time displacement curves of the last phase of failure.

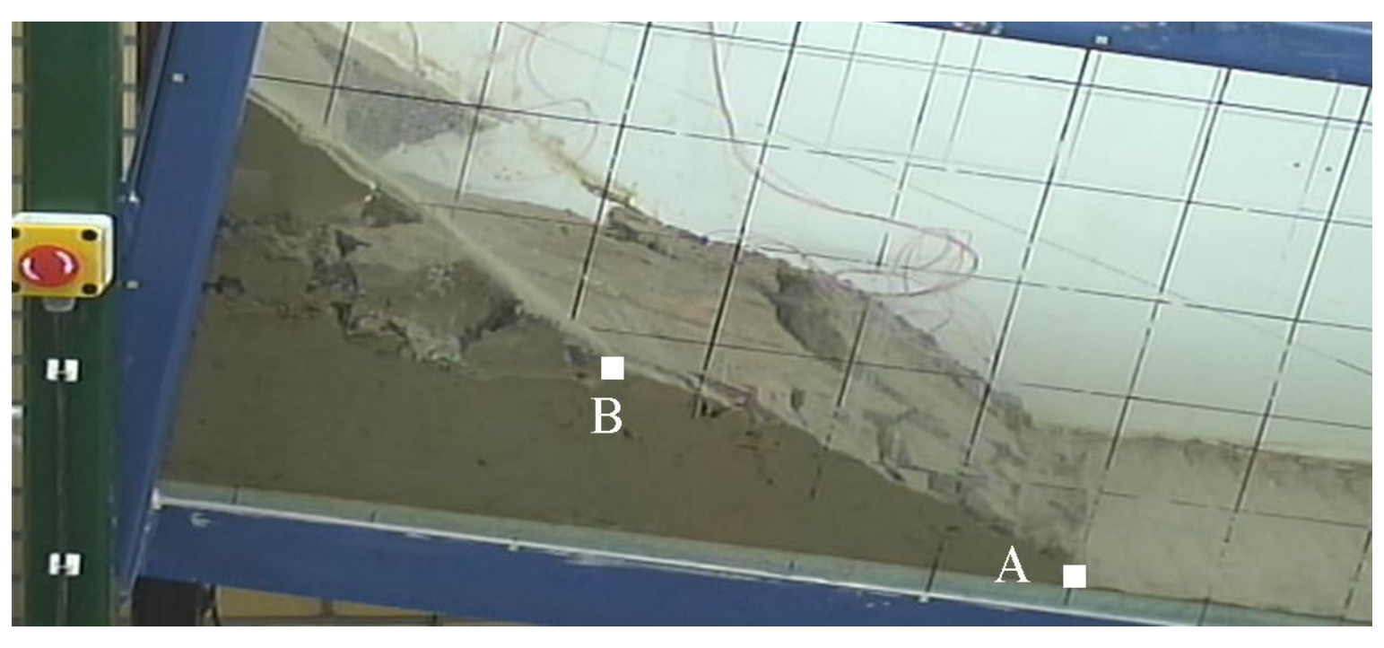


Fig. 10: Slope after failure, 26-10-2008, inclusive final positions of observed points A, B.

The first part of the failure process is characterised by the development of fissures and cracks. Final failure occurs within one slump in two stages. The whole process is characterised as progressive failure that is typical for cohesive materials.

To characterize failure modes four criteria are taken into account,

- the time displacement behaviour,
- the total time of the failure,
- the kind of failure and
- possible mechanisms leading to the observed failure.

	a) River sand	**b) Zoelen clay**
(1)	failure occurs suddenly, without any visible precursor; associated with a high and constant velocity	time displacement graphs are divided into 2 parts; 1st part: very slow and constant movement; 2nd part: movement velocity increases and final failure occurs
(1)	ca. 5 min	ca. 3 weeks
(1)	retrogressive failure that proceeds as a series of multiple slide events; connected to fluidization processes	final failure is initialized over a long time period and occurs progressively; after a shearing surface is formed the soil slumps down along the surface in several stages, with different velocities, that could be related to a renewed building up of pore pressure in opening fissures
(1)	failure starts with liquefaction at the toe; possible mechanisms leading to liquefaction: - seepage forces caused by the infiltration of water, - material is near the liquid limit	shear surface growth starts with microcracking; after point interaction and coalescence of microcracks further shear surface development leads to stress concentration and acceleration of sliding movements

CONCLUSIONS

The long term failure initialization in cohesive slopes showing progressive failure can be used in forecasting potential catastrophic failure. Due to the sudden occurrence of landslides in sandy material the measurements of displacements as indicator of failure is assessed to be insufficiently. It has to be studied if pore pressure measurements can be a useful tool to predict potential failure.

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