Data Storage Report

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GEOLAB

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CONTENTS

List of Tables

List of Figures

List of Abbreviations	
CPT	Cone penetration test
DOI	Digital Object Identifiers
PPT	Pore pressure transducers
TSF	Tailings storage facilities

1 Introduction

1.1 Scientific background

Mine tailings represent an environmental liability to the mining industry and must be appropriately deposited in tailings storage facilities (TSF). Tailings are mostly formed by non-plastic sands and silts generally deposited in slurry form in very loose and saturated states being prone to liquefaction (Gens, 2019). When liquefaction is not contained and propagates throughout the deposit, a flow slide results. Since liquefaction propagates very fast, large structures may fail without warning in a matter of seconds. Sadly, several accidents due to liquefaction flow slides of catastrophic consequences have been a regular feature of tailing dams' history: e.g. Stava (Italy - 1984), Aznalcollar (Spain - 1998), Mount Polley (Canada - 2014), Fundao (Brasil - 2015), Brumadinho (Brasil – 2019; Viana da Fonseca et al., 2022).

The risk of physical instability due to tailings static liquefaction is a major obstacle to the sustainable supply of raw materials, including those critical for the green revolution. It is a major obstacle not only for new TSF but also for remediation and closure plans of existing TSF, which have to be reanalysed in terms of potential vulnerability and eventually stabilised or improved with structural zones. The lack of confidence in these deposits hinders any attempt at recycling and re-mining the resources accumulated during historical periods on such structures. The failure of these TSF is a geo-hazard, which can lead to serious disruptions in the secure supply of raw materials but also major direct effects on nearby communities due to damage, casualties, and significant environmental impacts. TSF can be considered as an energy critical infrastructure due to its strong impact on the metals supply necessary for renewable energy infrastructures, namely in terms of distribution and storage of electricity.

Most facilities have disposed tailings in wet form, transporting them by pumping and forming a tailings dam by hydraulic fill. Following recent accidents, other deposition modes have been pursued, namely the dry stacking disposal of filtered tailings (Davies, 2011), where the filtered material (will lower water content) is compacted in massive embankments. These structures still have large uncertainties like their height limits associated with very high overburden stress levels. Their design should take into account that the material strength will depend on the type of material, degree of saturation and compaction, as well as drainage conditions, effective stresses due to loading and/or excess pore pressure generation.

SAFETY analyses the behaviour of these earth structures when subjected to water percolation during heavy rainfall, towards the development of enhanced design methods.

1.2 Aims and Objectives

The objectives of this data storage report are to describe the testing set-up and procedure as well as to explain which data was obtained during the SAFETY centrifuge tests. In particular, this report provides a detailed explanation of:

1. experimental layout for the executed tests;
2. materials and model preparation procedures;
3. instrumentation of the model;
4. organization of data files.

Chapter 2 is dedicated to the description of the model layout, while Chapter 3 describes the material and model preparation procedures. Chapters 4, 5, and 6 comprise the specifications of the instrumentation components used in the model. Appendix A includes the logbook of the experiments.

2 Experimental setup

2.1 General description of experimental setup

The experimental setup considers a very simple slope prepared by moist tamping as described in section 3.2. At an acceleration of 100g, the slope is subjected to water percolation by raising the water table in the left boundary while keeping the drain open on the right boundary (Figure 2.1). On the left boundary, the water coming from the inlet pipe is distributed by a perforated plate with a geosynthetic (Figure 2.2a). On the right boundary, there is a drain to collect the percolated water which is also made by a perforated plate with geosynthetic (Figure 2.2b). The water level in the left boundary is controlled by a hydraulic pump that also assures the recirculation of water from the outlet to the inlet.

Before percolation, a cone penetration test (CPT) using a mini-CPT of 11 mm in diameter was conducted on the top of the slope to evaluate the soil state. Careful was taken to lower the CPT just on the top of the slope to avoid creating a preferential water path during the percolation stage. This test was repeated at the end of the centrifuge test (after percolation) to evaluate the change in soil state.

Before and after testing, the model surface was laser-scanned to better show the differences in the model shape due to the percolation. The tests were also instrumented with 10 pore pressure transducers (PPT) and 3 laser displacement sensors.

Figure 2.3 illustrates the SAFETY test setup onboard the platform of the Deltares GeoCentrifuge.

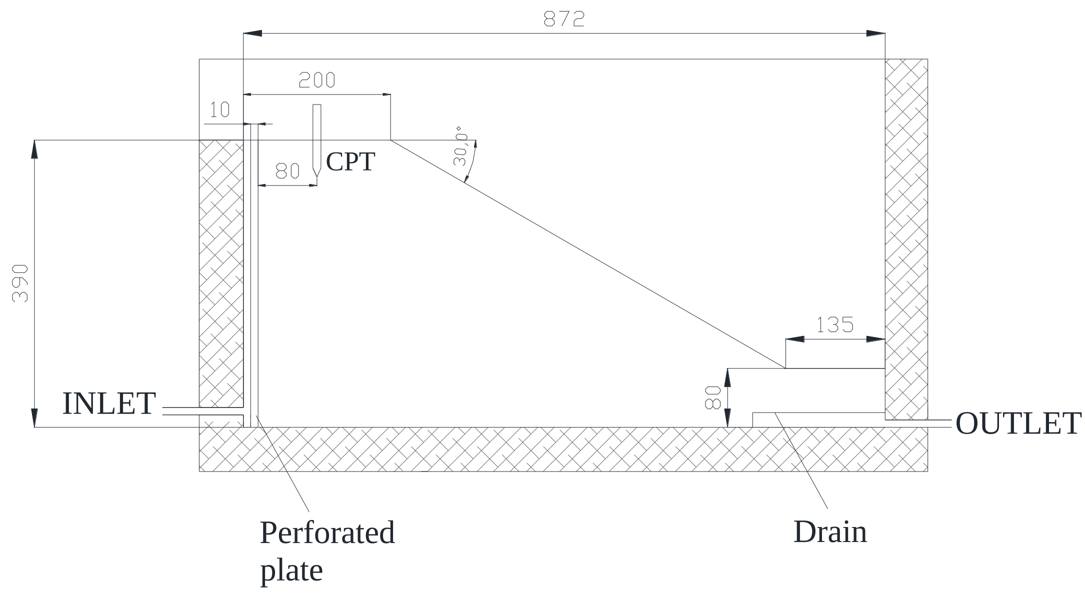
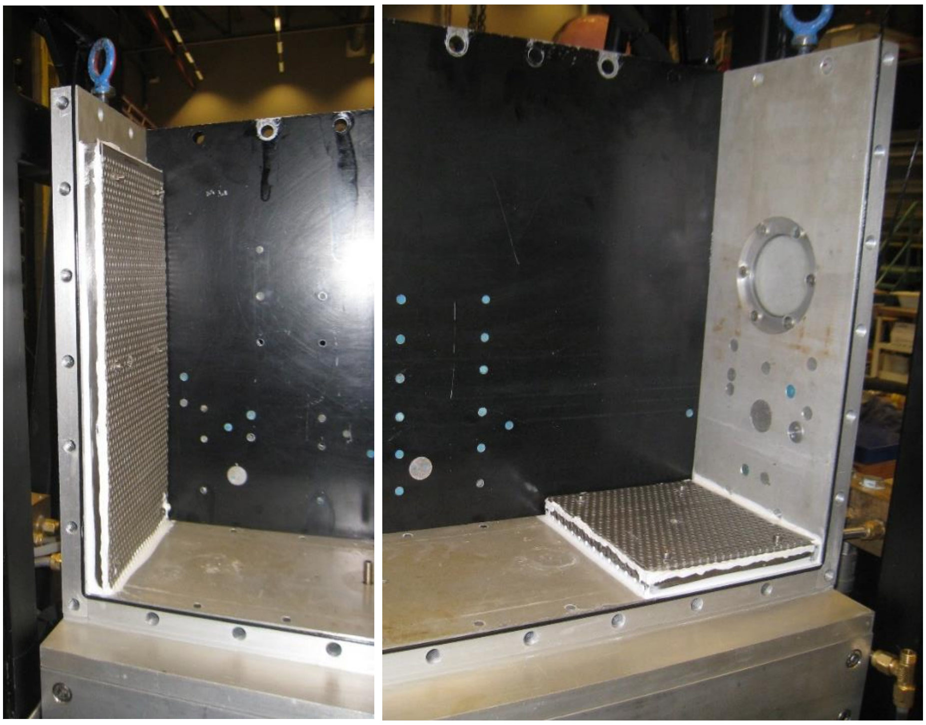


Figure 2.1: Drawing of the model geometry (dimensions in millimetres at model scale)



a) b)

Figure 2.2: Strongbox photos: a) perforated plate for the left boundary; b) drain

Figure 2.3: Strongbox inside Deltares GeoCentrifuge

2.2 General data storage principles and organization of data files

The data from SAFETY centrifuge tests are upload to the Zenodo platform (DOI: XXX). Two levels of data are provided:

- L0: raw data from all instruments (MAT format);
- L1: data processed for filtering with a decimation frequency of 100 Hz (CSV format).

In addition to the instrument data, an Excel sheet is provided (labelled as Appendix_5_D10_2_GEOLAB_SAFETY_Test1_16May23) including:

- Test sequence with an indication of the file sequence;
- Sensor locations;
- Names of the instrument data files;
- Residual values.

2.3 Definition and application of spatial and temporal reference systems

For all transducer coordinates (pore pressure transducers, laser sensors, and CPT), the origin of the axis system is located in the inside corner (on the bottom left) of the strongbox front window.
All instrumentation is measured simultaneously by the same acquisition system. This system supplied by HBM has 56 channels with a simultaneous sampling rate of 100 kHz.

2.4 Test Programme

In the available data, only one centrifuge test is presented which provided relevant information. The instrumentation layout of that model is illustrated in Figure 2.4. The test sequence is summarised as follows:

- Spin up the centrifuge up to 100g in steps of 25 g at 1g/min;
- Execution of CPT test at 2 mm/s up to 90 mm penetration in the model;
- Increase the water level on the left boundary at 0.01 mm/s
- Execution of CPT test at 2 mm/s up to 180 mm penetration in the model;
- Spin down the centrifuge at 10g/min;
- Lower water level.

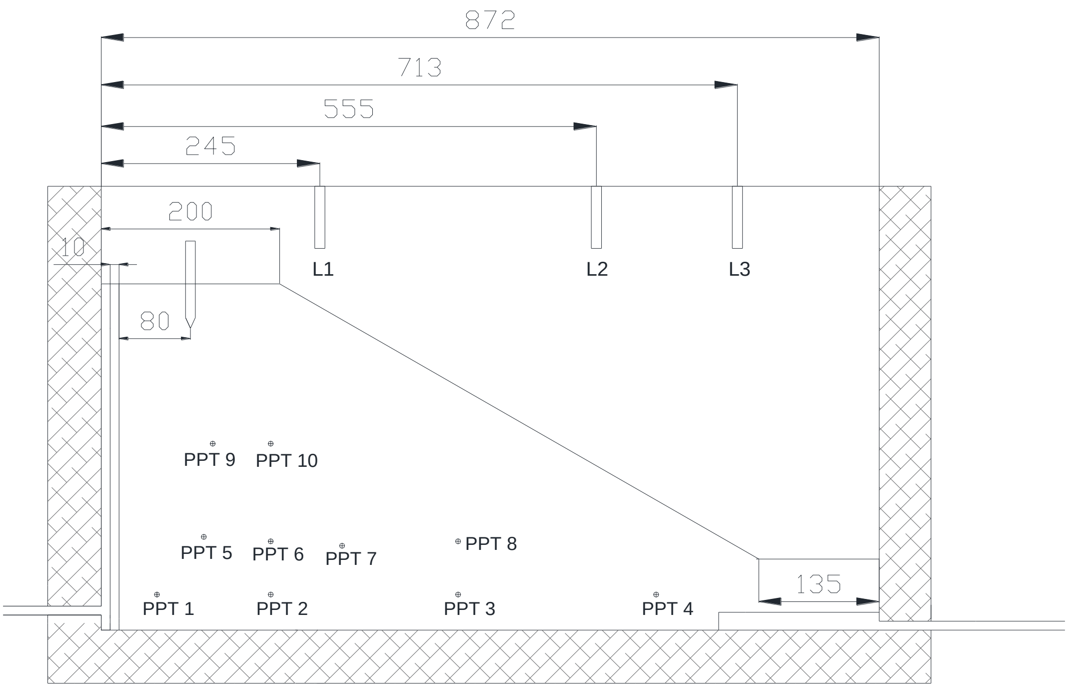


Figure 2.4: Instrumentation layout (dimensions in millimetres at model scale)

3 Materials and model preparation

3.1 Soil

A silty sand with a grain size distribution curve similar to an iron tailing material was used in the SAFETY experimental program. For this purpose, 56% of Geba sand together with 44% of Silt (sieved from Baskarp B15 sand) were mixed, which are two silica based natural soils. Figure 3.1 presents the grain size distributions of the two base soils that were mixed to simulate the mine tailings, together with the ones of the obtained mixture and original mine tailings. The complete geotechnical characterization of the silty sand is available in Viana da Fonseca et al. (2023).

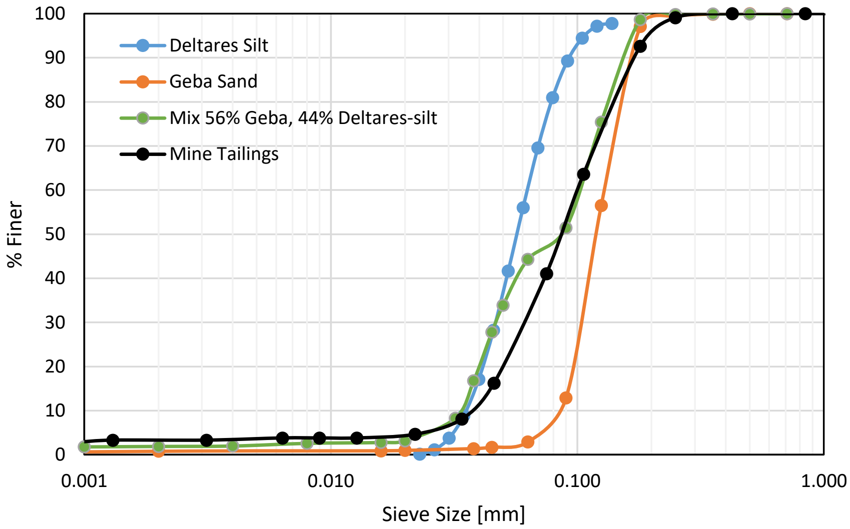


Figure 3.1 Grain size distribution curves of the two base soils, the mixture, and the mine tailings

3.2 Model preparation

The model was prepared by moist tamping in four layers. The following procedure was applied:
1) the shape of the slope was drawn in the strongbox window as well as the separation between layers;
2) the amount of soil and water for each layer were calculated targeting a void ratio of 1.1 and a water content of 6%;
3) the soil and water for each layer were mixed;
4) the wetted soil was gently compacted manually inside the strongbox following the desired shape of the slope.

4 Instrumentation – Pore pressure transducers

4.1 Instruments

Ten pore pressure transducers (PPT) of type EPB-PW-7BS by StrainSense (UK) with a maximum measurement range of 700 kPa (Figure 4.1) were installed in the back wall of the strongbox, in the positions indicated in Table 4.1.

Figure 4.1 Pore pressure transducer

Table 4.1:Location of pore pressure transducers in relation to the bottom left corner of the strongbox (values in millimetres at model scale)

PPT location	Coordinates in relation to the inside corner of the box		Coordinates in relation to the outside corner of the box	
	x	y	x	y
1	62,5	40	87,5	65
2	190	40	215	65
3	400	40	425	65
4	622	40	647	65
5	115	105	150	130
6	190	100	215	125
7	270	95	295	120
8	400	100	425	125
9	125	210	150	235
10	190	210	215	235

4.2 Measured parameters

PPTs are installed to measure the evolution of pore pressure during water percolation throughout the model. All pore pressure measurements given in the data files are in kPa.

4.3 Experimental procedure

Pore-water pressure sensors were calibrated with a pressure regulator with a rated output. The pressure regulator itself was calibrated at the national metrology institute of the Netherlands. Data was recorded at a sampling rate of 100 Hz.

4.4 Available data

Both L0 and L1 data files provide the PPT measurements in kPa. While for L0 data files in MAT format no filtering or processing was done, for the L1 data files in CSV format the data was filtered with a decimation frequency of 100 Hz.

4.5 Organization of data files

See section 2.2.

4.6 Remarks

PPT 8 was not working properly.

5 Instrumentation – Laser displacement sensors

5.1 Instruments

Three laser distance sensors from SICK, model OD1-B100H50I14, were used to measure the distance from the sensor to specific points of the slope. The sensors were installed in a beam above the model (see coordinates in Table 5.1) facing the slope face.

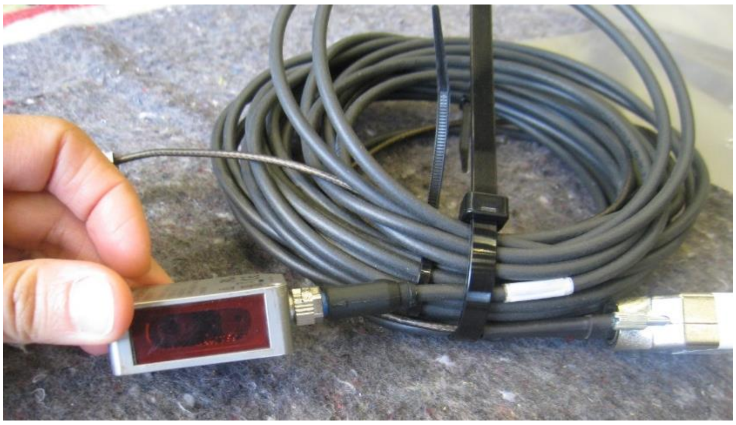


Figure 5.1 Laser distance sensors

Table 5.1:Position of displacement laser sensors in relation to the bottom left corner of the strongbox (values in millimetres at model scale)

Laser sensors location	Coordinates in relation to the inside corner of the box		Coordinates in relation to the outside corner of the box	
	x	y	x	y
1	245	400	270	425
2	555	400	580	425
3	713	400	738	425

5.2 Measured parameters

These sensors measure the distance from the sensor to the next visible point (in the model). The distance is measured in millimetres so this is the unit presented in all data files.

5.3 Experimental procedure

Distance measurements in millimetres were taken at a sampling rate of 100 Hz. From these distances, it is possible to calculate the soil settlements/heave in specific points during the experiment by the difference between the measured distance in a given instant and the initial distance.

5.4 Data post-processing

Both L0 and L1 data files provide the measurements at model scale in millimetres. While for L0 data files in MAT format no filtering or processing was done, for the L1 data files in CSV format the data was filtered with a decimation frequency of 100 Hz.

5.5 Organization of data files

See section 2.2.

6 Instrumentation – CPT probe

6.1 Instruments

CPT tests were performed before and after water percolation throughout the model. The mini CPT probe has a diameter of 11 mm and was designed by Fugro (cone type: A01F0.5CKEW2) specifically for the Deltares Centrifuge. The dimensions of the probe are given in Table 6.1.
The CPT probe was introduced in the model at the following coordinates in relation to the bottom lower corner of the strongbox: x: 80 mm, y: 390 mm, z: 100 mm.

Table 6.1:Dimensions of CPT probe

Parameter	Unit	value
Cone diameter	mm	11.3
Apex angle of cone	degrees	60
Distance tip and base of cone	mm	9.8
Sleeve diameter	mm	11.35
Diameter of CPT in gap between sleeve and cone	mm	8.3
Diameter of CPT above sleeve	mm	9.7
Length sleeve	mm	42.5
Cone net area ratio	[-]	0.54
Sleeve net area ratio	[-]	±0.013
Distance between base of cone and centre of u_2 filter	mm	1.35
Distance between base of cone and bottom of sleeve	mm	2.7
Distance between base of cone and centre of sleeve	mm	23.95

6.2 Measured parameters

The CPT probe is a subtraction-type cone, measuring the tip force (in N), the tip and sleeve friction force (in N), and the pore water pressure (in kPa).

6.3 Experimental procedure

All sensors were calibrated with expert knowledge based on the manufacturer's calibration certification. The linearity of each sensor was checked. Data was recorded at a sampling rate of 100 Hz. At the beginning of the experiment, the soil was not saturated so it was not possible to ensure that the porous stone remained saturated during the CPT test.

6.4 Data post-processing

The data provided in L0 and L1 versions corresponds to raw data at the model scale.

To obtain the cone tip stress and sleeve friction stress the following procedure is recommended:

1) Calculate the effective cone area and sleeve surface area of the CPTU taking into account the dimensions indicated in Table 6.1;
2) The sleeve friction force can be obtained by subtracting the tip force at an equal depth from the soil surface, which requires manually shifting the data in time;
3) The sleeve friction stress can be obtained by dividing the sleeve friction force by the sleeve surface area;
4) The tip cone stress can be obtained by dividing the cone tip force by the effective cone area.

6.5 Organization of data files

See section 2.2.

7 References

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8 Appendices

Appendix A: Logbook


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