Experimental Investigation of Embankment Failure by Overtopping

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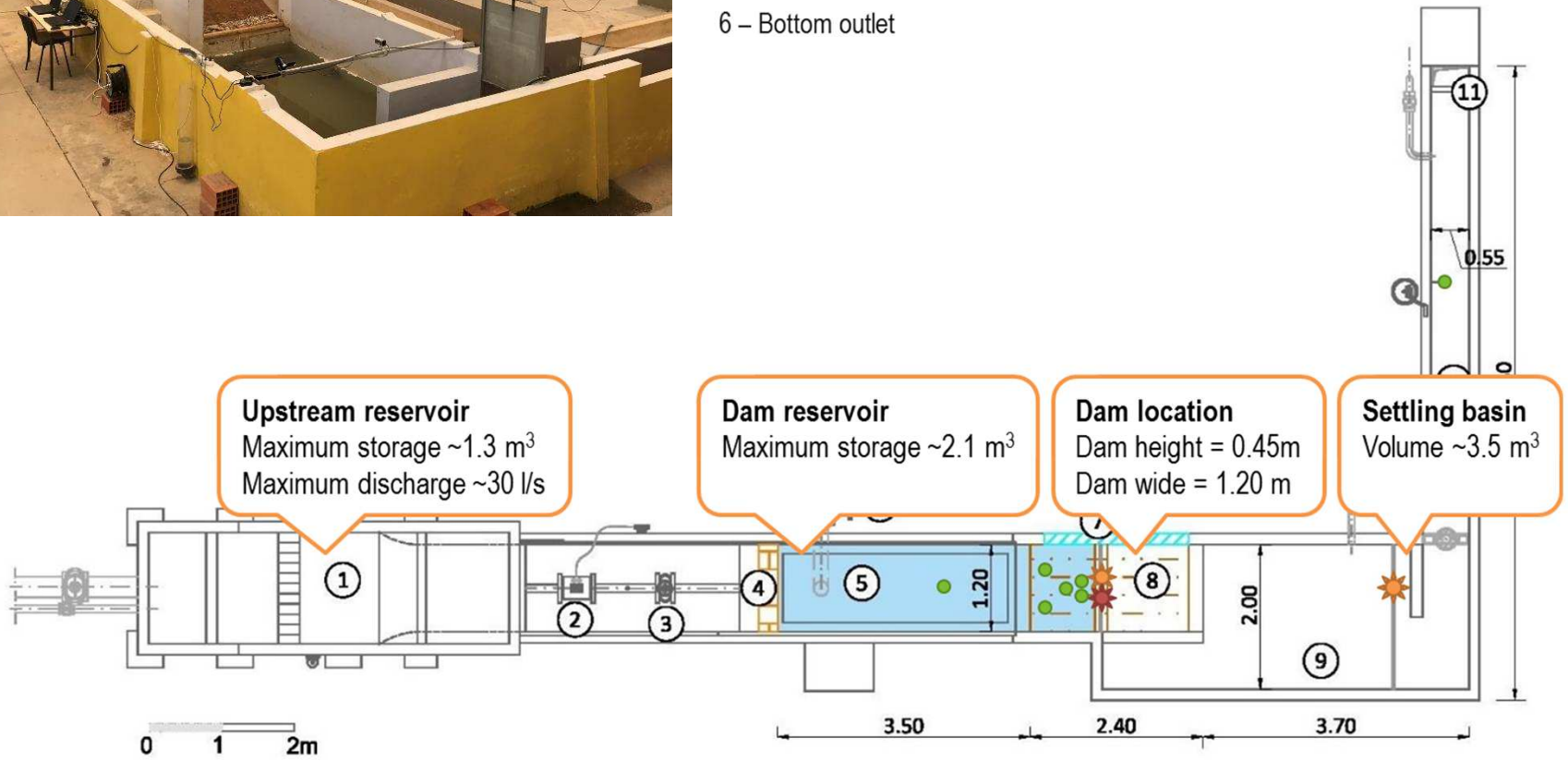
EXPERIMENTAL FACILITY

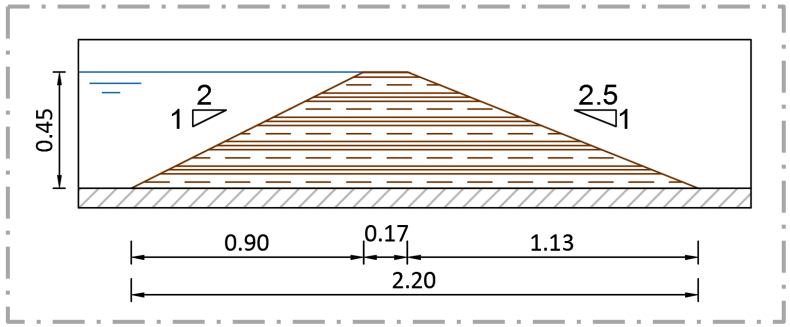
Legend:

1 – Upstream reservoir
2 – Flowmeter
3 – Flow control valve
4 – Brick wall (for flow stabilization)
5 – Dam reservoir
6 – Bottom outlet
7 – Glass wall
8 – Dam site
9 – Settling basin
10 – Outflow channel
11 – V-notch weir
– Acoustic probe
– Video camera
– Kinect sensor



EXPERIMENTAL TESTS

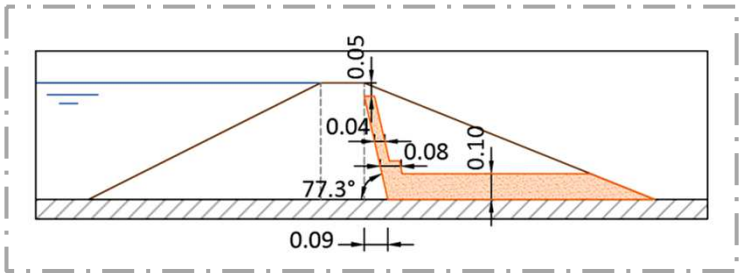
HOMOGENEOUS EMBANKMENT WITH TOE DRAIN



Soil: silty sand with 25% of fines content

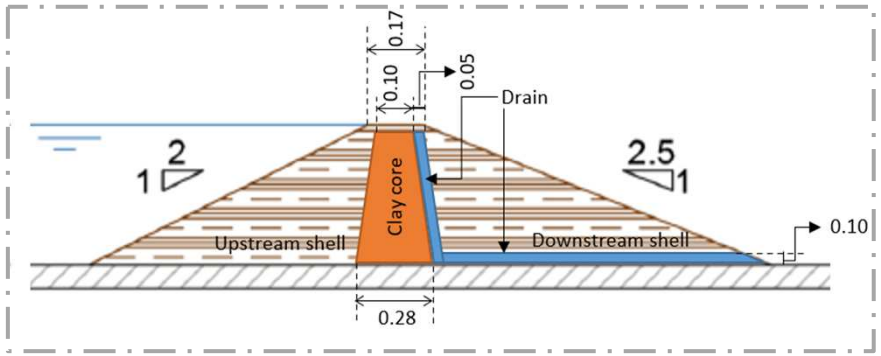
Cohesive embankments

HOMOGENEOUS EMBANKMENT WITH CHIMNEY FILTER AND TOE DRAIN



Filter and drain detail

ZONED EMBANKMENT WITH CLAY CORE AND DRAIN



Impervious core detail

Core soil:
clay with 40% of fines
Downstream and upstream shells soil:
silty sand with 27% of fines

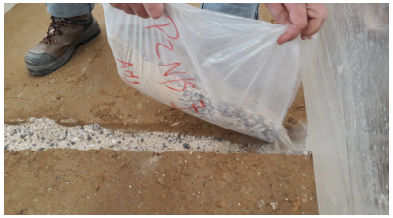
EXPERIMENTAL TESTS

	Objective	Dam profile
Test 1	Facility stet up / main erosion mechanisms	Homogeneous dam with toe drain
Test 2	Initial conditions: pilot channel dimension	
Test 3	Initial conditions: water content	
Test 4	Trial / Procedure for filter construction	Homogeneous dam with chimney filter and toe drain
Test 5	Trial / Procedure for filter construction	
Test 6	Influence of non-cohesive elements (filter / drain)	
Test 7	Repeatability of Test 6	
Test 8	Trial / Procedure for core construction	Zoned dam with clay core
Test 9	Influence of clay core	

EMBANKMENT CONSTRUCTION

Soil homogenization and humidification

Embankment compaction (5 cm layers)



Chimney filter

Sand replacement test

Embankment final cut

Toe drain

EMBANKMENT CONSTRUCTION

Soil homogenization and humidification

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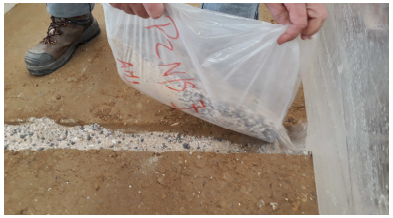

Chimney filter

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Embankment final cut

Toe drain

EXPERIMENTAL PROCEDURE

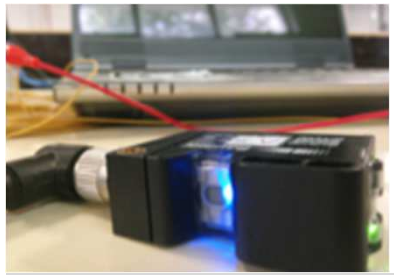
1. Approximately 24 h before the beginning of the test, the reservoir was filled up to 0.38 m;
2. The pilot channel was carved in the center of the crest and blocked, by a plate or soil;
3. The upstream water level was slowly raised up to the crest level (the upper 0.07 m);
4. The block of the pilot channel is instantly removed and the overtopping begins (*t = 0 s*);
5. The water level inside the reservoir was maintained reasonably constant and equal to the crest level, the inflow discharge was increased whenever the water level in the reservoir became lower than the crest level;
6. The tests were interrupted almost instantly for the breach characterization with the Kinect sensor 3 times. To halt the breaching process:
   - the inflow was cut-off, and simultaneously
   - the reservoir bottom valve is opened

MONITORED VARIABLES

1. Reservoir inflow
   ⇨ digital flowmeter
2. Reservoir water level
   ⇨ 6 acoustic probes

Breach hydrograph
(mass balance in the reservoir)

3. Channel outflow, using water level measurements in the channel
   ⇨ 1 acoustic probe
4. Breach morphologic evolution
   ⇨ 2 HD video cameras (one above the crest and one downstream the dam)
5. 3D breach morphology
   ⇨ 2 KINECT sensors (one above the crest and one mobile)



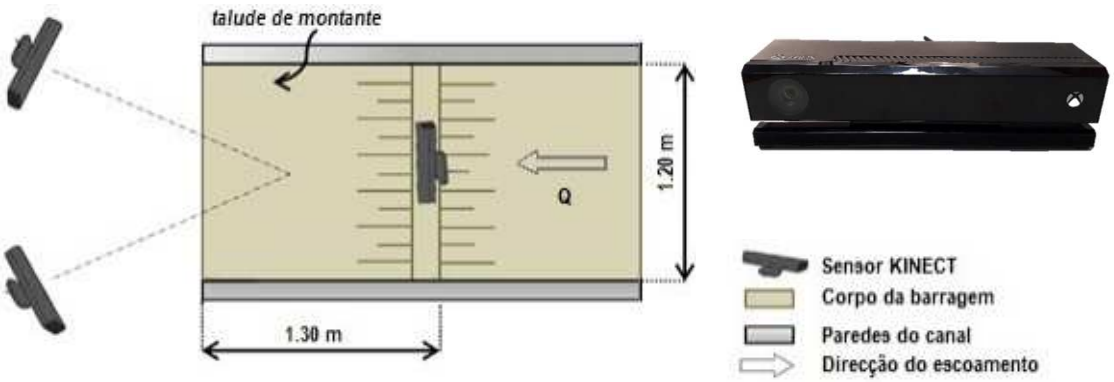
Acoustic probes

KINECT sensor and video camera above the crest

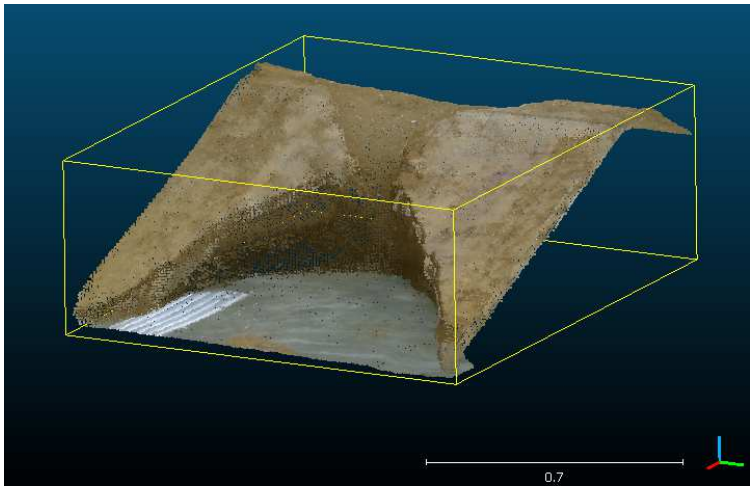
Downstream video camera

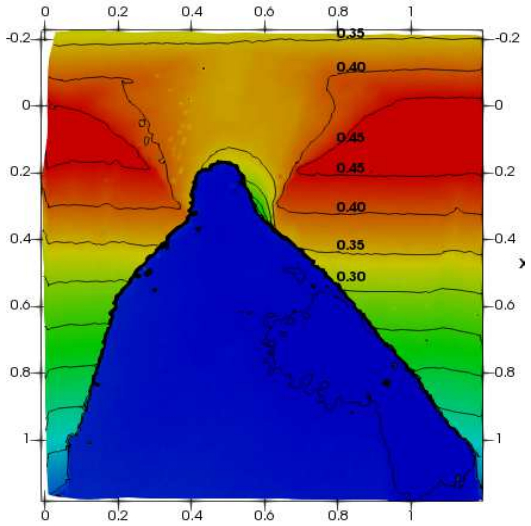
KINECT sensor

3D BREACH MORPHOLOGY



- **Depth images acquisition with KINECT sensor**





- **Image alignment and removal of "no significance areas" with the software CloudCompare**
- **Contour maps and cross sections obtained with the software ParaView**

HOMOGENEOUS EMBANKMENT WITH TOE DRAIN

Main Erosion Mechanisms:

homogeneous dams without filter

On the experimental tests, it was possible to fully reproduce the main breaching mechanisms:

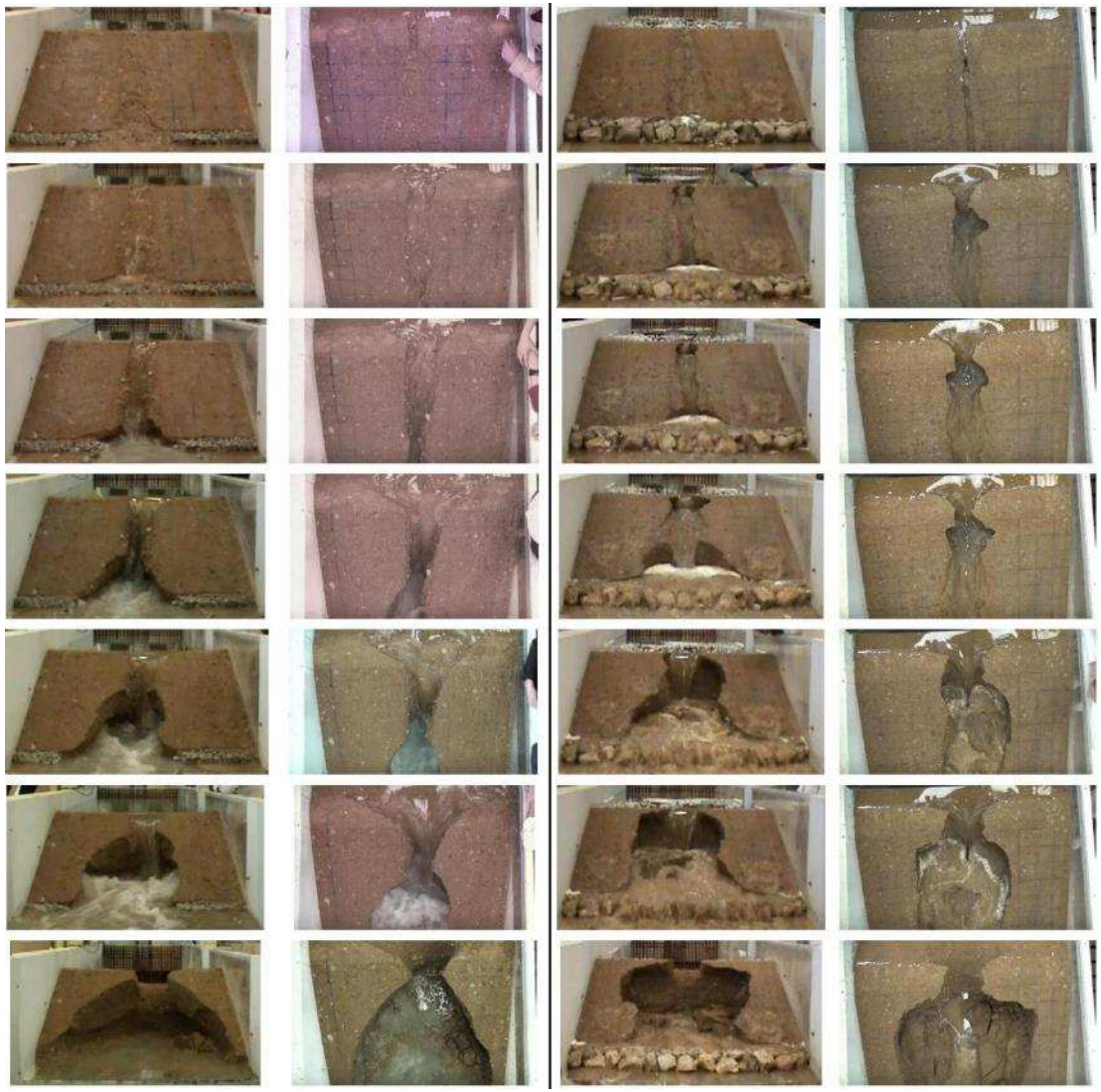
- Hydraulic erosion
- Headcut erosion
- Underscouring

Test 1: Homogeneous dam with toe drain

Test 1 – small pilot channel

Test 3 – large pilot channel

HOMOGENEOUS EMBANKMENT WITH CHIMNEY FILTER AND TOE DRAIN



Major differences in the breaching mechanisms were observed

Erosion cavities inside the dam body start to develop, due to faster sand erosion

The creation of cavities in the dam's body induce a faster rate of failure of the downstream slope, with the rapid failure of the side walls

When the underscouring and filter cavities in-duce the failure by mass detachment of the breach side walls, the filter location is clearly visible

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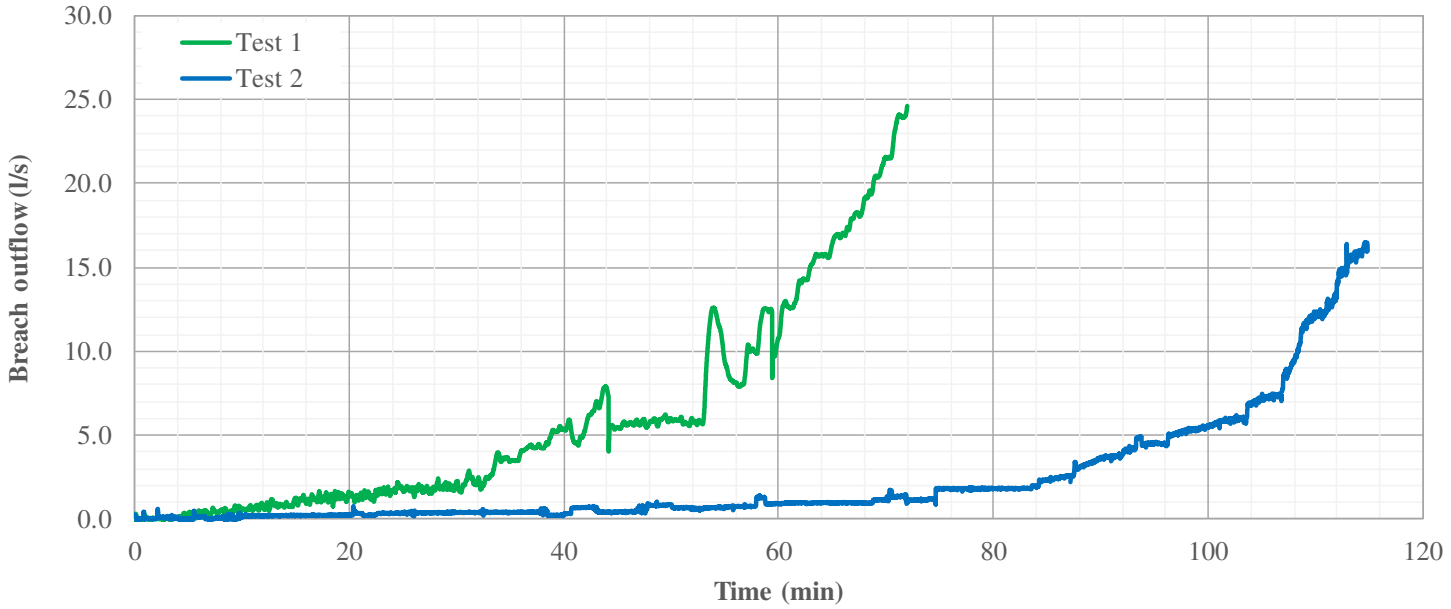


The discharge has a very slow increase rate in the first stage of the erosion, while the filter erodes and control the progression of the erosion upstream. After a while, when the dam downstream slope has mostly disappeared the breach discharge increases at a higher rate, similarly to the one of the dam without drainage system.

The breach discharge increases in a slower way, compared with the dam with only toe drain. Large amounts of body material are removed from the downstream slope due to the fragility induced by the filter but this seem seems to be able to occur at mild discharges and to limit the rate of increase of hydraulic erosion at the breach entrance.

HOMOGENEOUS EMBANKMENT WITH CHIMNEY FILTER AND TOE DRAIN

- Major novelty in the conceptual model of dam erosion by overtopping that should be incorporated in simulation models
- The filter erosion causes a delay in the discharge increase that needs to be accounted in the dam's safety plans.
- This is especially in relevant for the flood warnings for the communities immediately downstream of a dam, that will have more time for a proper evacuation warning that what is estimated with the current models.

PAPERS IN CONFERENCE PROCEEDINGS

4th year

Alvarez, T., Valente, S., Amaral, S., Viseu, T., Ferreira, R.M.L. (2020). Dam breach hydraulics and morphodynamics in overtopped earth dams with chimney filter. *River Flow 2020 - 10th Conference on Fluvial Hydraulics*. IAHR. Evento online

3rd year

Alvarez, T., Valente, S., Amaral, S., Viseu, T., Ferreira, R.M.L. (2019). Sensitivity analysis to the pilot channel geometry in dam breach by overtopping. *38th IARH World Congess – Water Connecting the World.* Panamá City, Panamá, 1-6 September 2019

Alvarez, T., Valente, S., Amaral, S., Viseu, T., Ferreira, R.M.L. (2019). Influência do teor de humidade na rotura de barragens de aterro por galgamento. 14º *SILUSBA.* Praia, Cabo Verde, 19-20 September 2019

Alvarez, T., Valente, S., Amaral, S., Viseu, T., Ferreira, R.M.L. (2019). Análise de sensibilidade à geometria do canal piloto na rotura de barragens por galgamento. *TESTE&E 2019 – Monitorizar e Preservar. 2º Congresso de Ensaios e Experimentação em Engenharia Civil*. Porto, Portugal, 19-21 February 2019

Amaral, S., **Alvarez, T.**, Caldeira, L., Viseu, T., Ferreira, R.M.L. (2019). *Recent advances on experimental dam breach studies*. Mecânica Experimental, 31:11-25.

Amaral, S., **Alvarez, T.,** Viseu, T., Ferreira, R.M.L. (2019). Técnicas de análise e pós-processamento de imagem aplicada à extração de dados locais de ensaios de rotura de barragens. *TESTE&E 2019 – Monitorizar e Preservar. 2º Congresso de Ensaios e Experimentação em Engenharia Civil.* Porto, Portugal, 19-21 February 2019

2nd year

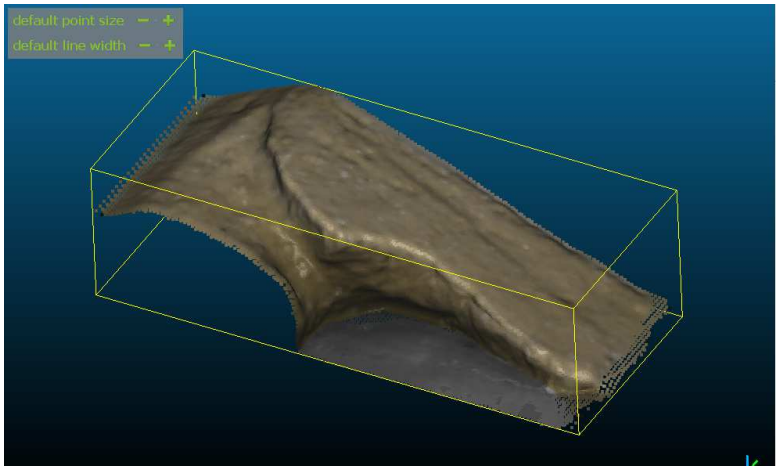
Alvarez; T., Conde, D., Amaral, S., Viseu, T., Ferreira, R.M.L. (2018). 2D numerical modelling of fluvial dike breach by overtopping. *5th IAHR Europe Congress - New challenges in hydraulic research and engineering*, Trento, 12-14 June

Amaral, S., **Alvarez; T.,** Viseu, T., Ferreira, R.M.L. (2018). Image analysis detection applied to dam breach experiments. *5th IAHR Europe Congress - New challenges in hydraulic research and engineering*, Trento, 12-14 June

Amaral, S., **Alvarez, T.,** Viseu, T., Ferreira, R. (2018). Modelação Física da rotura de barragens de terra. Instrumentação e métodos de monitorização. *14º Congresso da Água*, Évora, 7-9 March

FUTURE DEVELOPMENTS

- Laboratorial work regarding the hydrodynamic field near the breach: the velocity field near the breach will be characterized in a new facility using a 3D print of one of the breach morphology obtained in the dam breach tests already performed.
- Write the PhD thesis!



Thank You!