Università degli Studi di Padova

ICEA

INVESTIGATING LAND SUBSIDENCE OF TRANSITIONAL ENVIRONMENTS

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OUTLINE

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  - The test
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  - The recorded time series
- COUPLED MFE POROMECHANICAL MODEL FOR DATA INTERPRETATION
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  - Preliminary results
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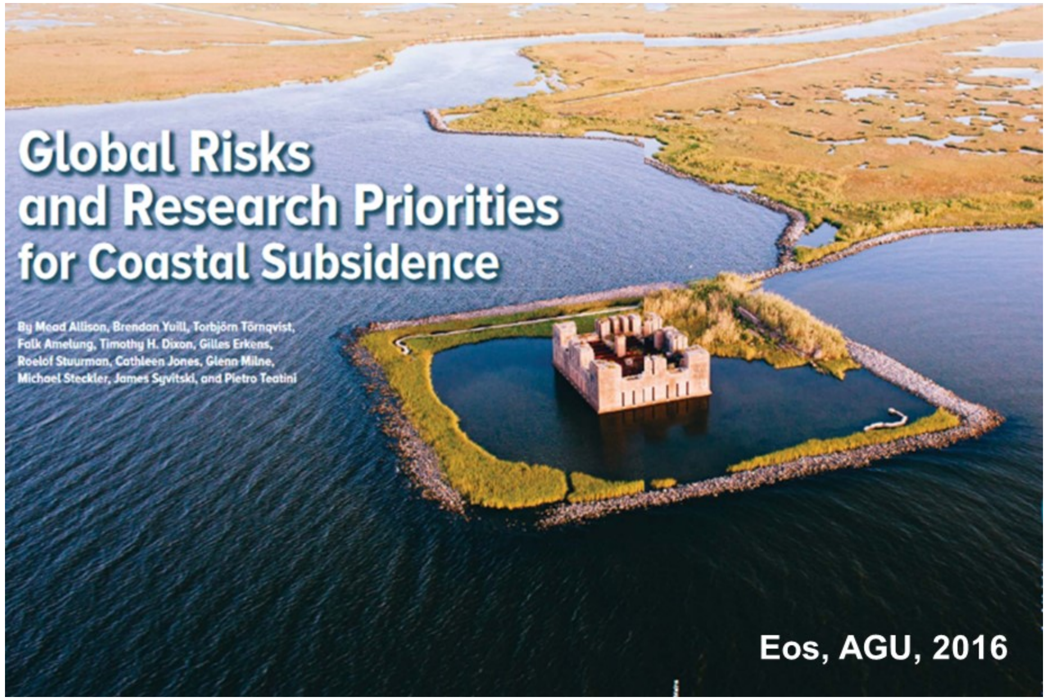
- **Transitional environments** provide biodiversity, recreational activities, protection of inland territories from storms, and many other ecosystem services.

- Fate of these morphological landforms is threatened by **rise of the mean sea level** (SLR) and **land subsidence** (LS). Loss of elevation relative to mean sea level, i.e. SLR plus LS, must be counterbalanced by **accretion of inorganic sediments** and **biodegradation of organic matter**.

- A large contribution to LS of transitional landforms is due to **auto-compaction** of the Holocene sediments.

$$\frac{\partial z}{\partial t} = Q_s(B,\mathbf{x},t) + Q_o(B,\mathbf{x},t) - E(B,\mathrm{MPB},\mathbf{x},t) + R(\mathbf{x},t)$$

relative sea level rise



$$R = SLR + SUB_{\mathrm{deep}} + \Delta z$$

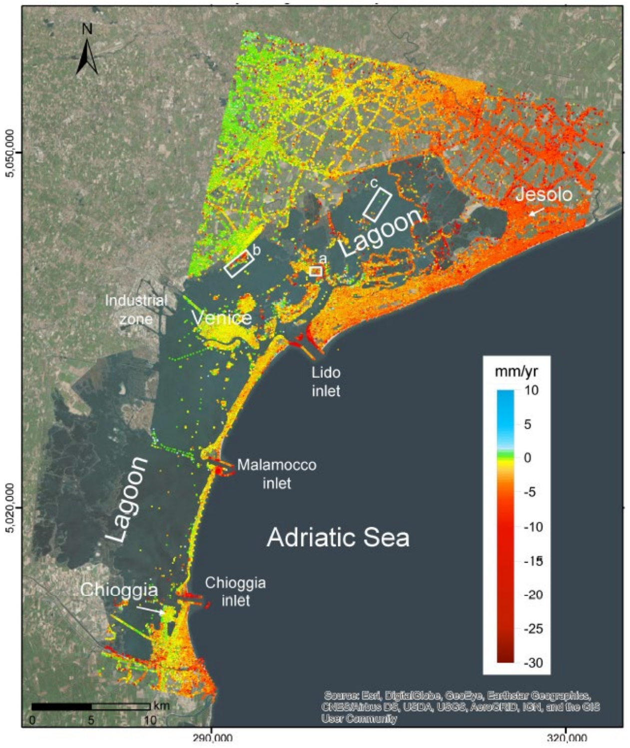
sea level rise

regional (deep) land sub.

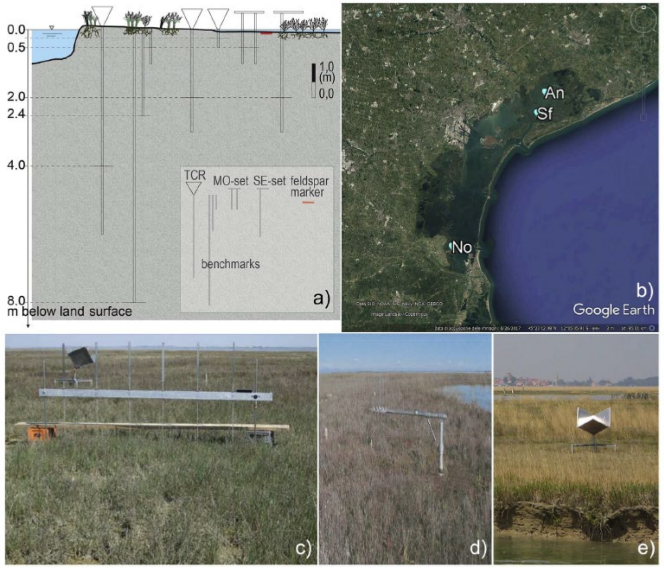
auto-compaction: reduction of the marsh thickness due to natural consolidation

INTRODUCTION

- **SAR interferometry** on deep-founded and surface radar scatterers, ground-based monitoring equipment (**deep levelling benchmarks**, **SET**, **accretion traps**) have been used in the **Venice Lagoon** (Italy) to distinguish between deep and shallow LS contributions, i.e. LS occurring below and above the Pleistocene / Holocene bound.

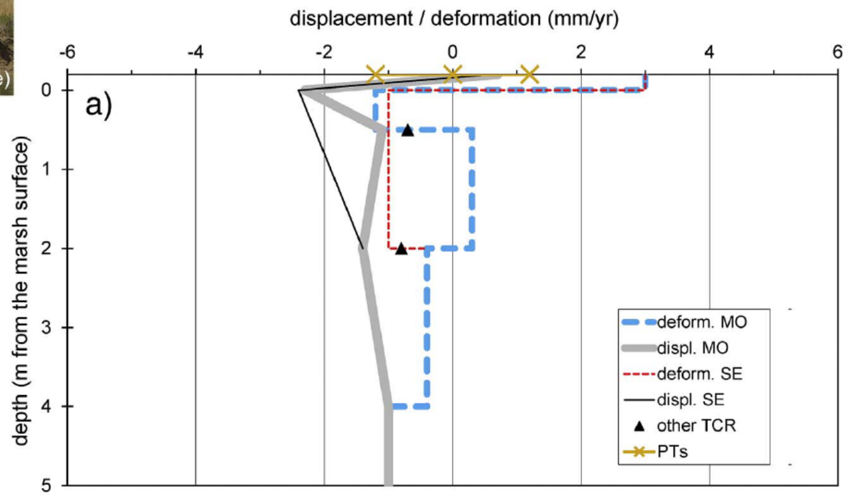


Average land displacements (mm/year) for the Venice coastland obtained by PSI on TerraSAR-X images. (Tosi et al., 2018)



Photos of MO-SET, SE-SET, and TCR (artificial radar corner reflectors) are shown in (c), (d), and (e), respectively. (Da Lio et al., 2018)

Displacement and compaction behavior vs depth at San Felice (Sf) marshland (Venice Lagoon, Italy). (After Da Lio et al., 2018).



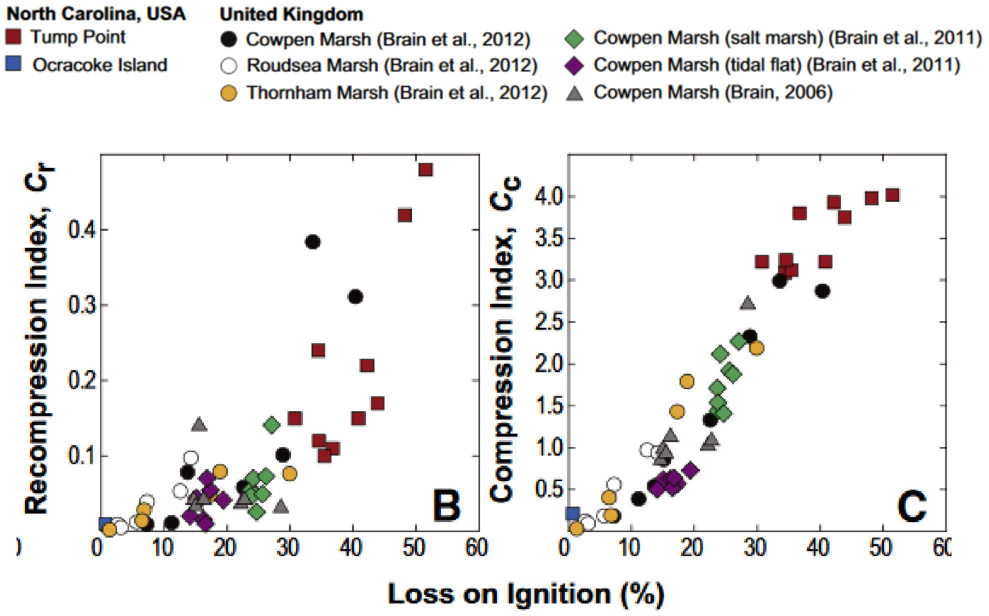
- A **novel in-situ loading test** is here discuss to integrate previous results and better understand the geomechanical behavior of these deposits

- We focus on the characterization of the **soil compressibility**

- The in-situ test can overcome the main challenges of indirect evaluations or lab-tests related to **sampling of loose soils**, **soil heterogeneity** and **low stress range**

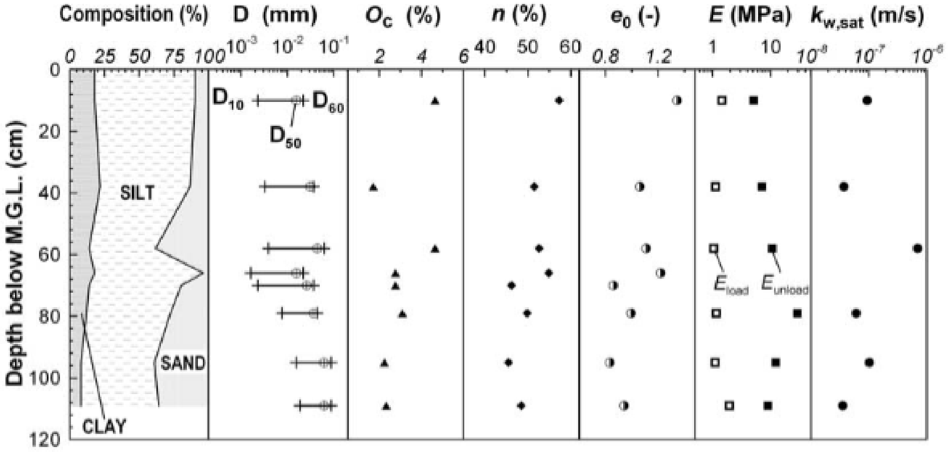
Indirect evaluations

Compression / recompression indices vs LOI (After Brain et al, QR, 2015)

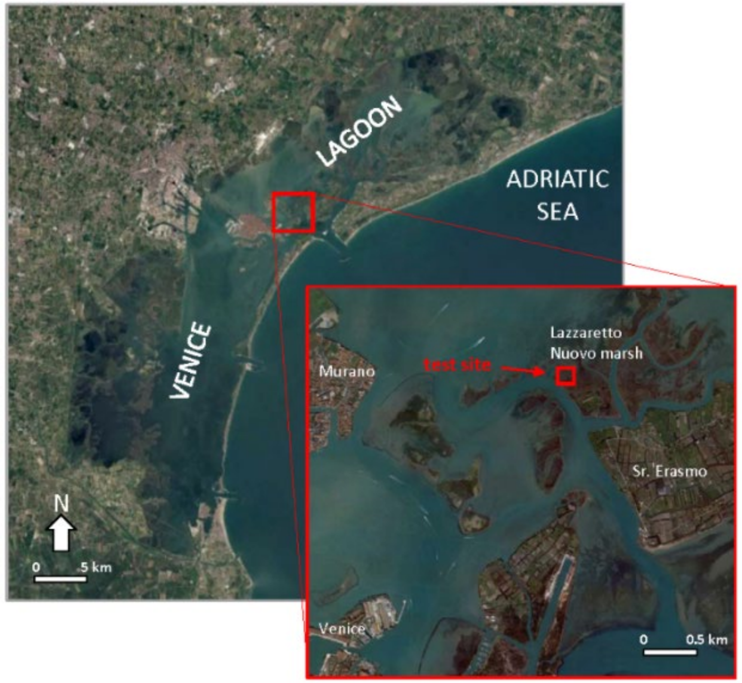


Lab tests on cored samples

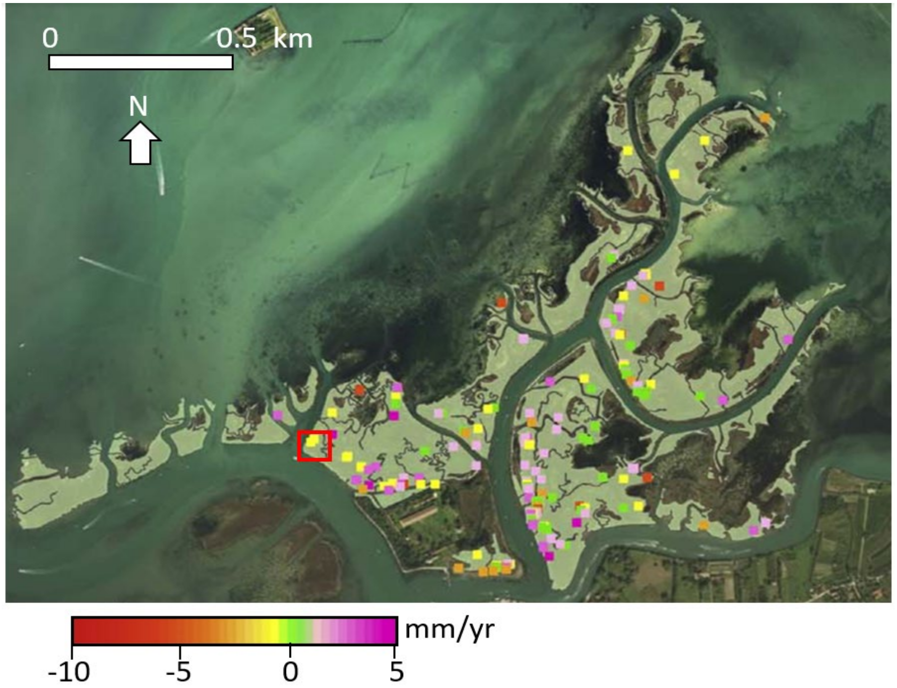
Young modulus vs depth (After Cola et al, WRR, 2008)



THE SITE (Lazzaretto Nuovo marsh)



Location of the Lazzaretto Nuovo salt-marsh and the site where the loading test has been carried out

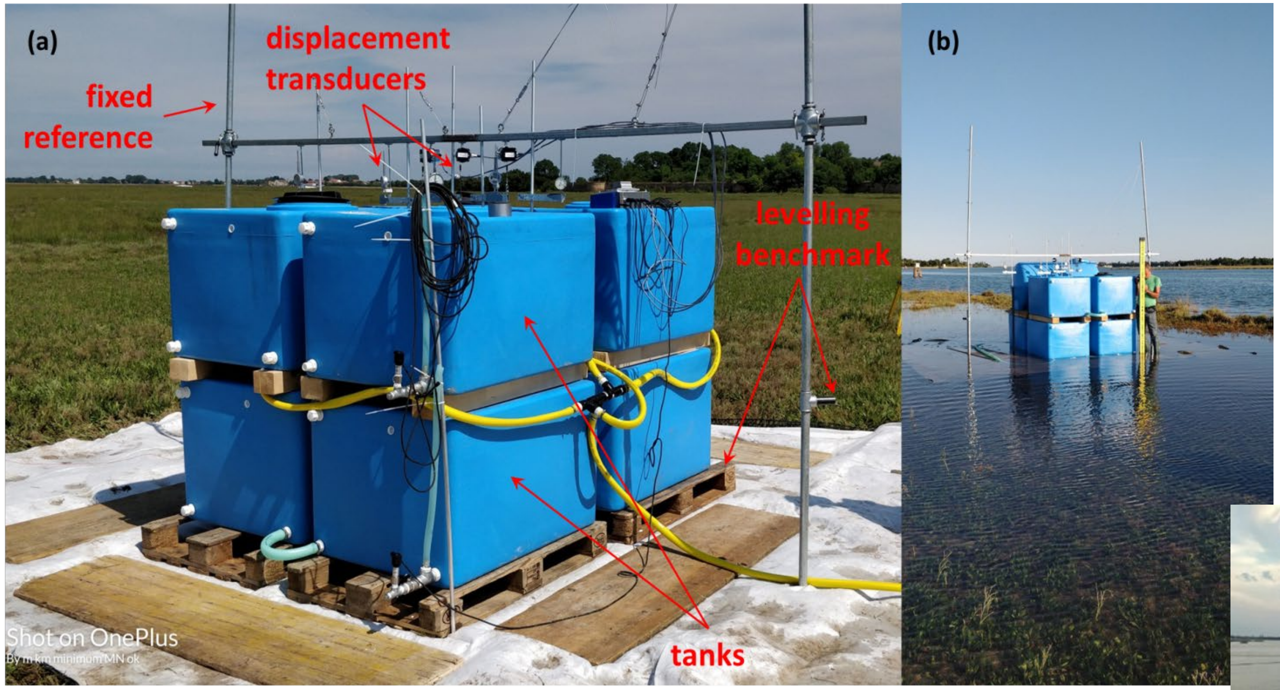


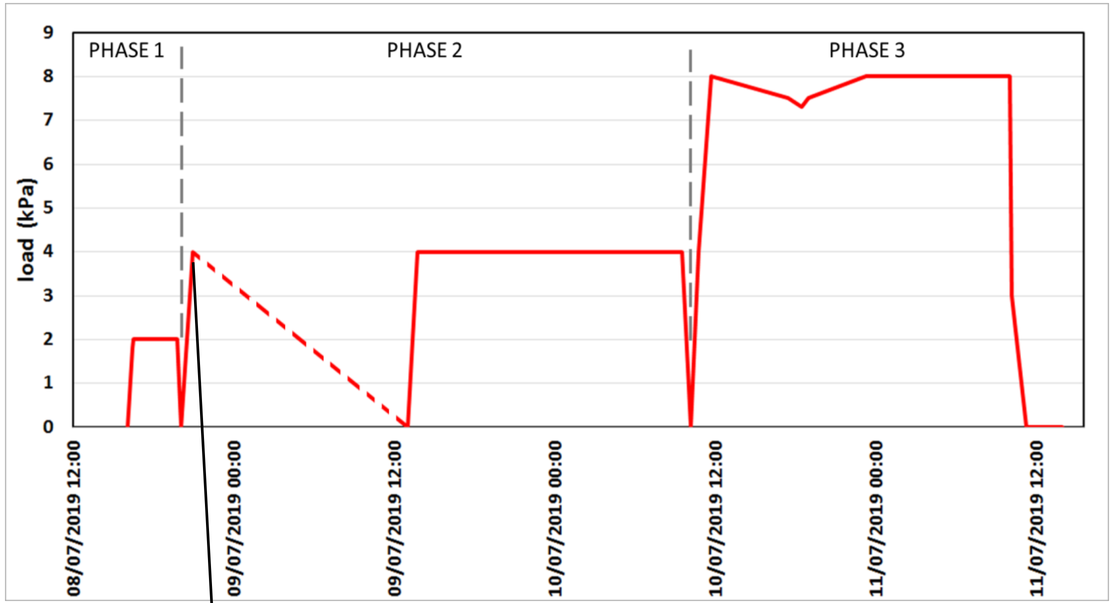
Lazzaretto Nuovo salt-marsh: average land displacement between 2008 and 2013 measured by PSI

THE IN-SITU LOADING TEST

THE TEST (July 2019)

(a) Picture of the loading and monitoring equipment and (b) the experimental equipment in high-tide conditions with the marsh flooded by approximately 0.2 m sea water. Each polyethylene tank contains 500 l

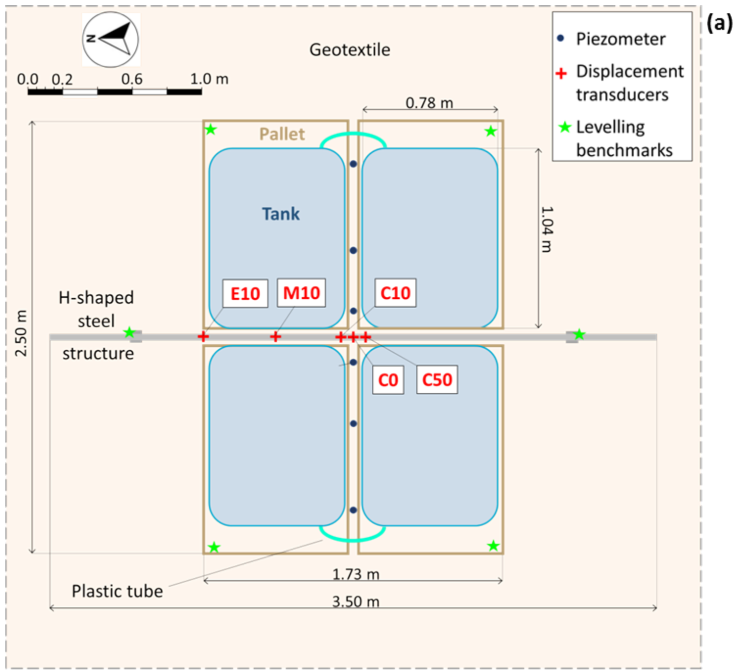




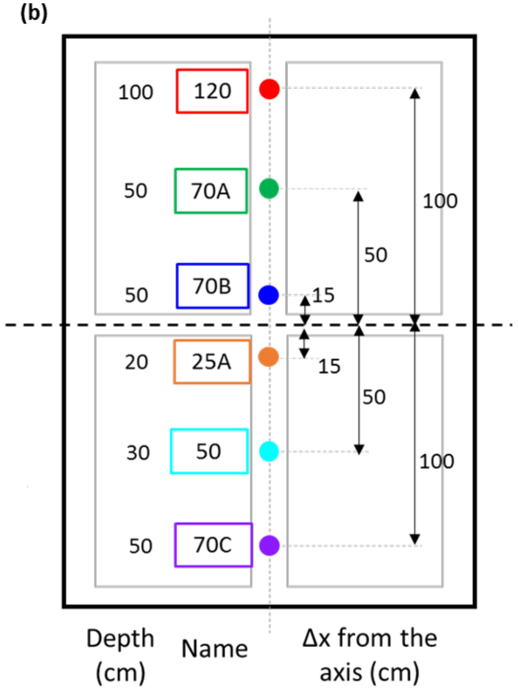
Behavior of the load applied on the marsh surface between July 8 and July 11

Thunderstorm arriving on evening July 8

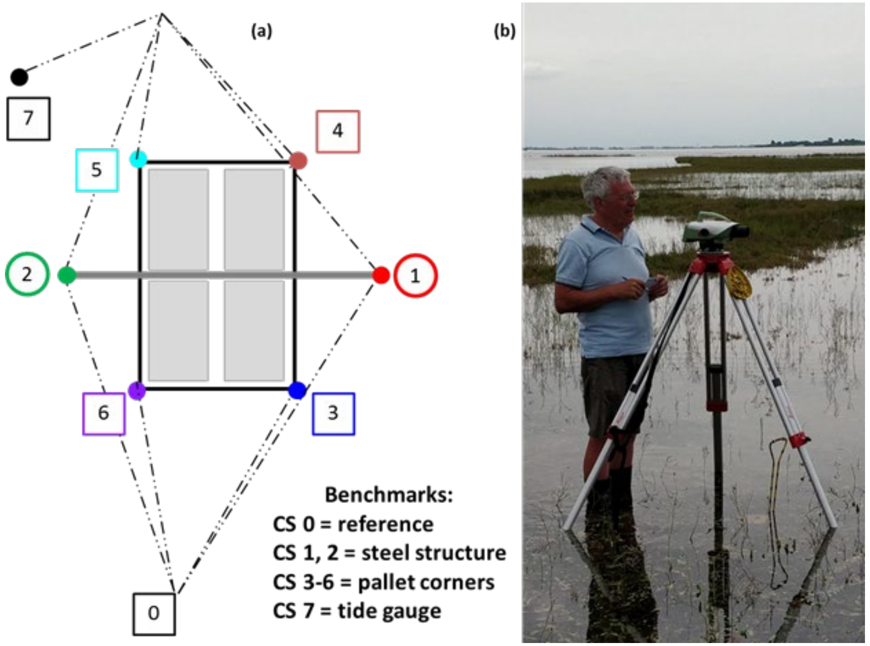
THE INSTRUMENTATION



Sketch of the loading with dimensions and location of the displacement transducers (micrometers)



Sketch of the loading with dimensions and location of the pressure transducers

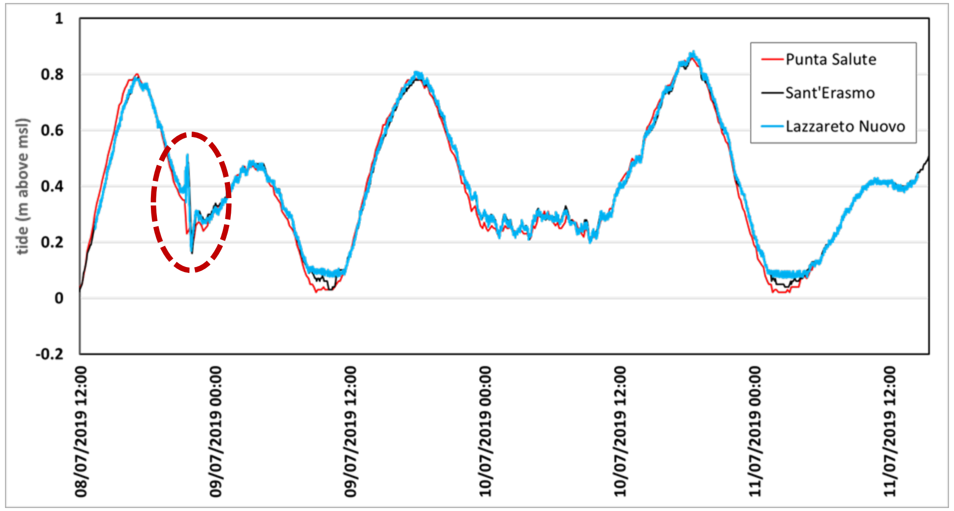


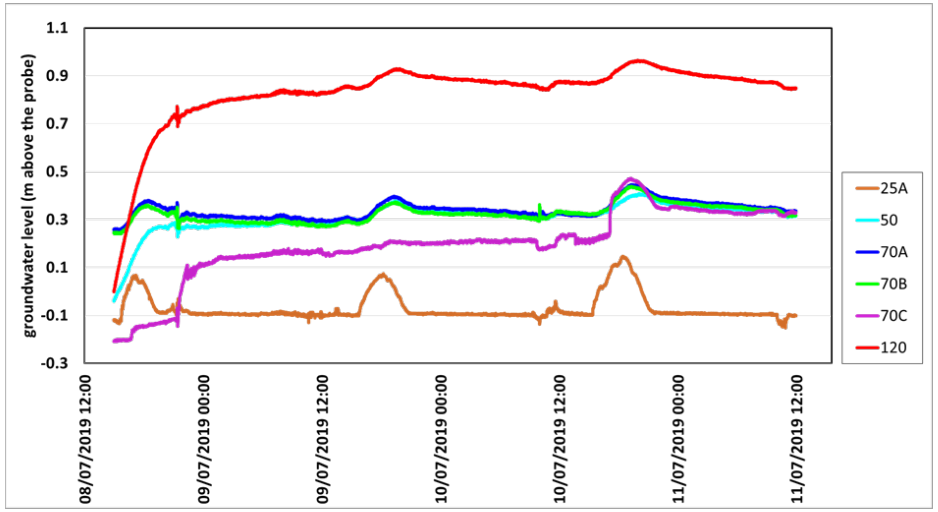
Levelling network and levelling survey

RECORDED ENVIRONMENTAL PARAMETERS

THE RECORDED TIME SERIES

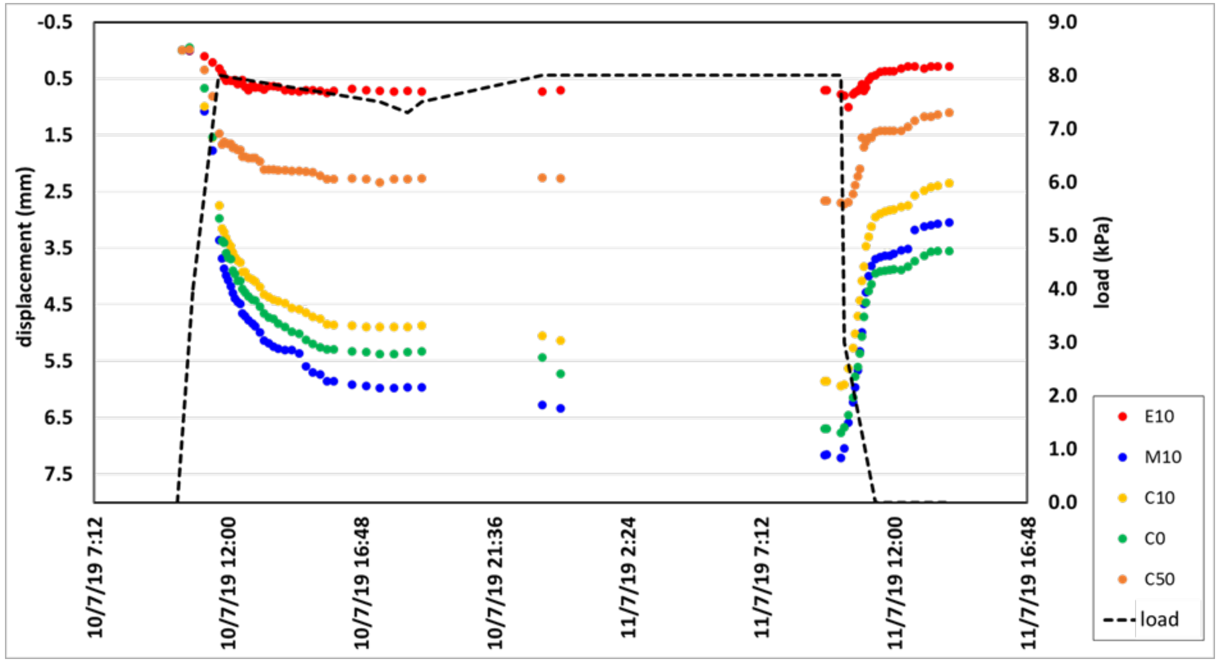
Tidal level





Pore pressure

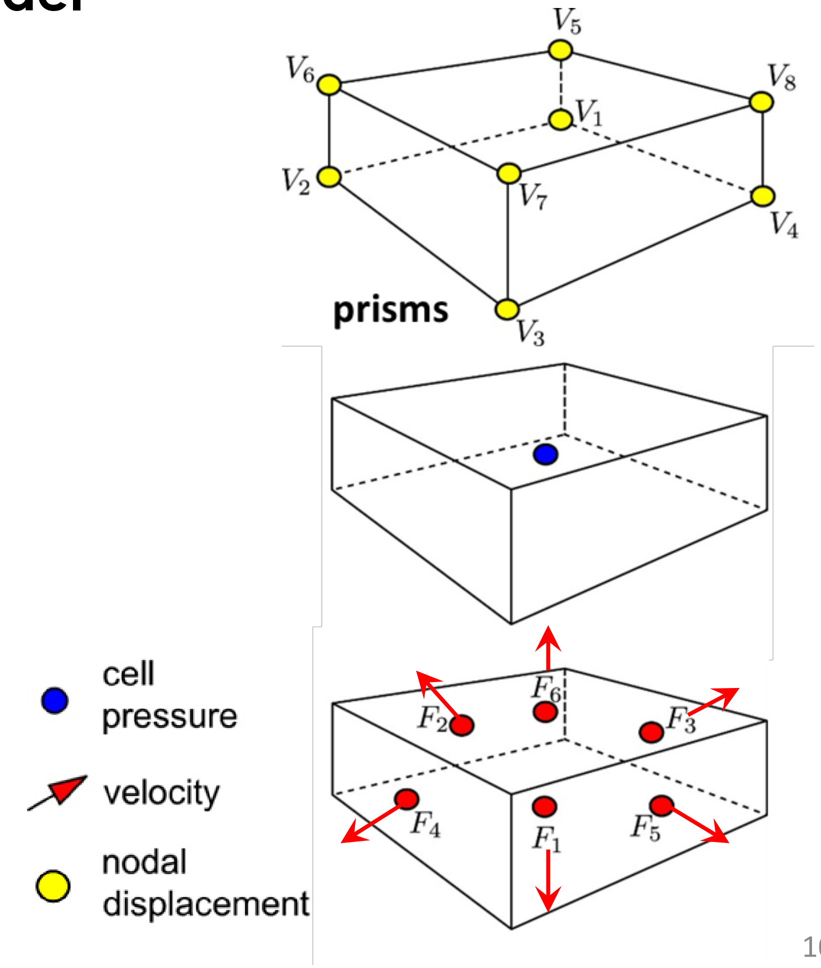
Displacements vs load (phase 3)



MODELLING APPROACH

Complexity of the forcing factors ➡ interpretation of the recorded data through an advanced numerical model

Prismatic MFE and unknowns



Standard Finite Elements for displacements and **Mixed Finite Elements for pressures** with the aim at alleviating numerical instabilities and developing a mass conservative approach

- **Mechanical equilibrium** of the elastic bulk

$$\mu\nabla^2\hat{\mathbf{u}} + (\lambda + \mu)\nabla(\nabla \cdot \hat{\mathbf{u}}) - \alpha\nabla p = \mathbf{b}$$

- **Fluid mass balance**

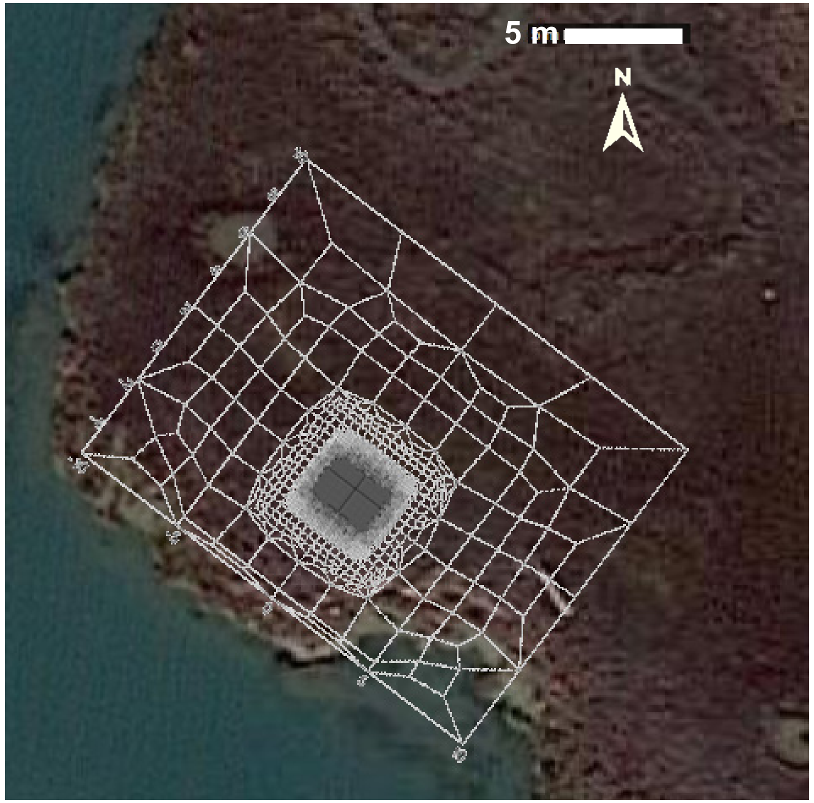
$$\nabla \cdot \mathbf{v} + \frac{\partial}{\partial t}(\phi\beta p + \alpha\nabla \cdot \hat{\mathbf{u}}) = f$$

- **Darcy's law**

$$\bar{\mathbf{k}}^{-1}\mathbf{v} + \nabla p = 0$$

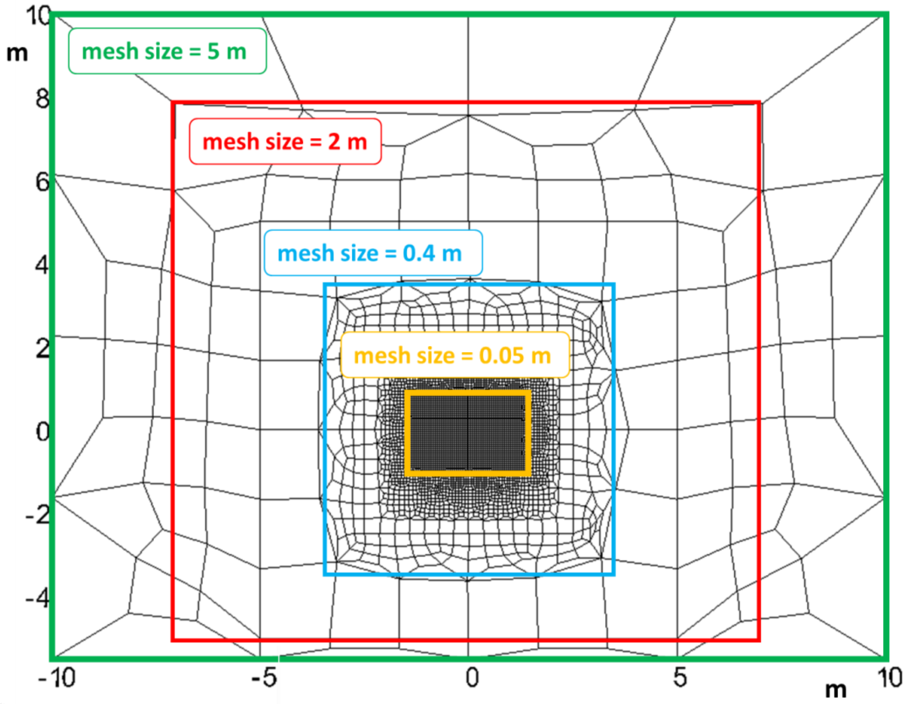
COUPLED MFE POROMECHANICAL MODEL

DOMAIN DISCRETIZATION

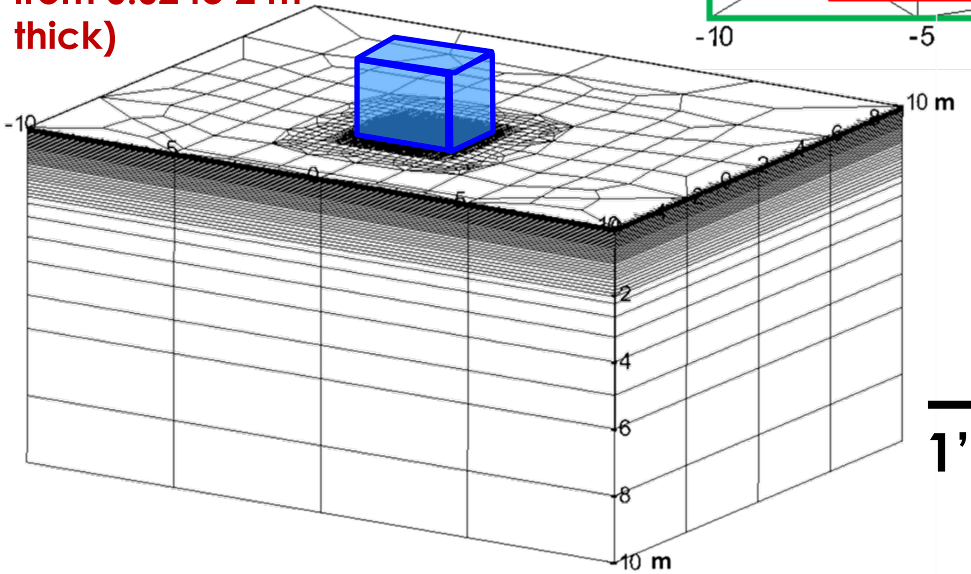


Horizontal view of the MFE mesh superposed to the Lazzaretto marsh

Horizontal view of the MFE mesh with the characteristic mesh dimensions



3D axonometric view of the MFE mesh with the load (47 layers from 0.02 to 2 m thick)



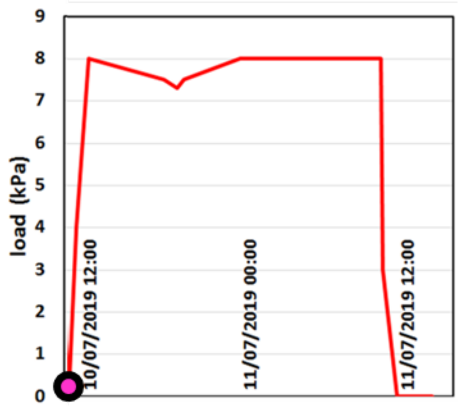
217’392 nodes
212’440 elements
642’216 faces

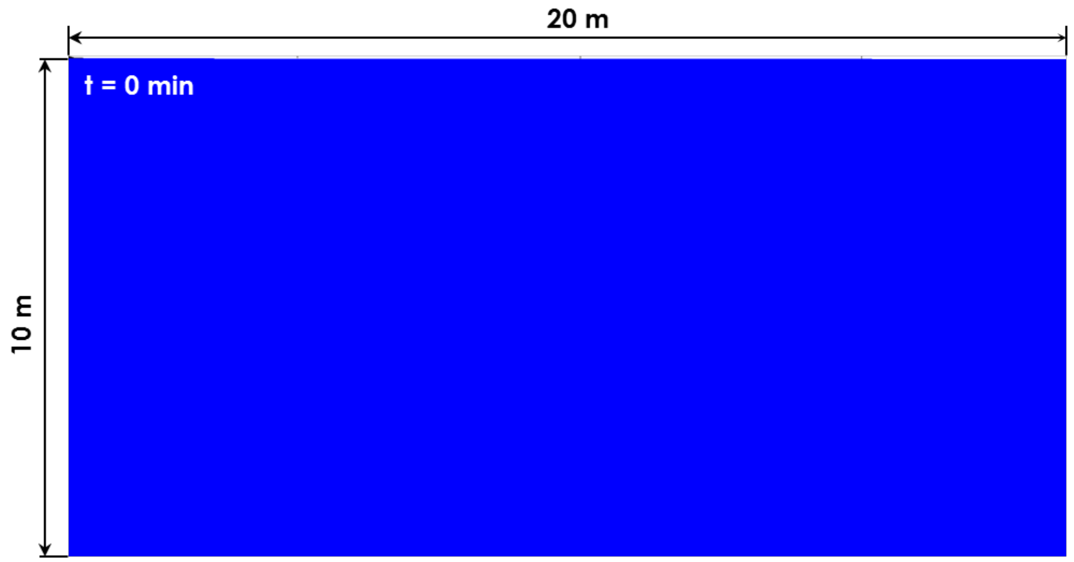
1’072’048 unknowns

PRELIMINARY RESULTS

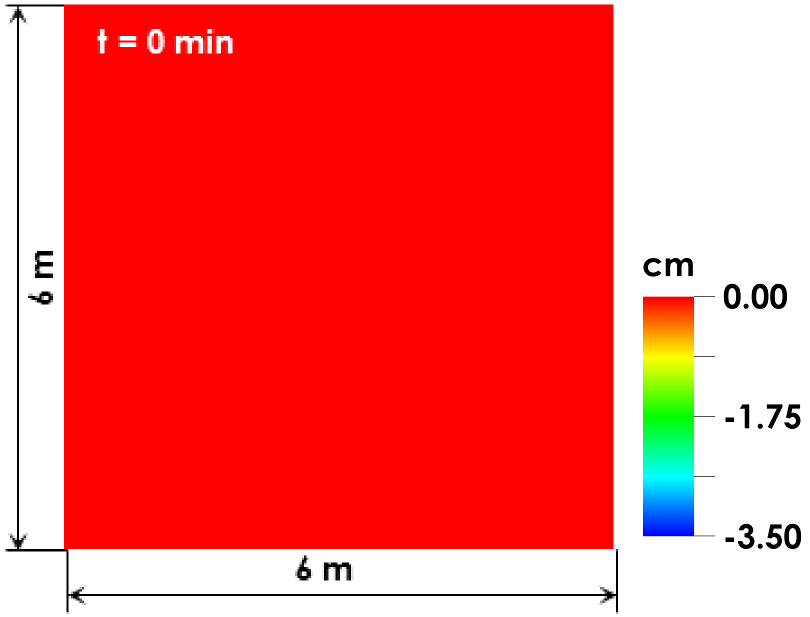
Constant and uniform parameters:

$$E = 0.46\ \text{MPa}$$
$$\nu = 0.25$$
$$K = 3 \times 10^{-6}\ \text{m/s}$$

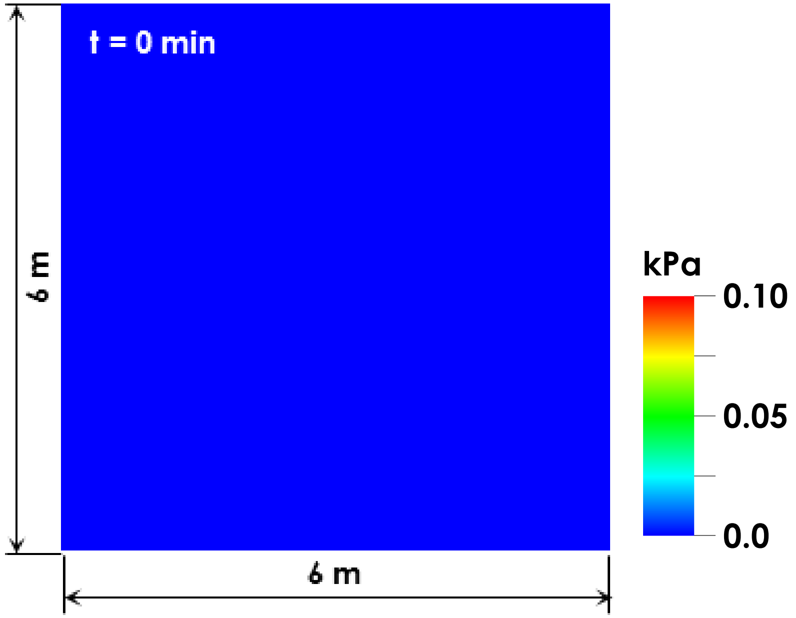




Vertical displacements at the land surface



Pore over-pressure at the land surface



Pore over-pressure along a vertical section

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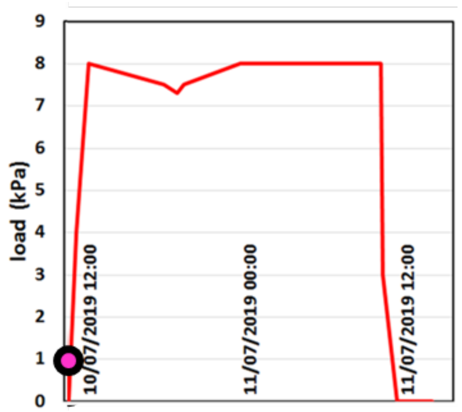
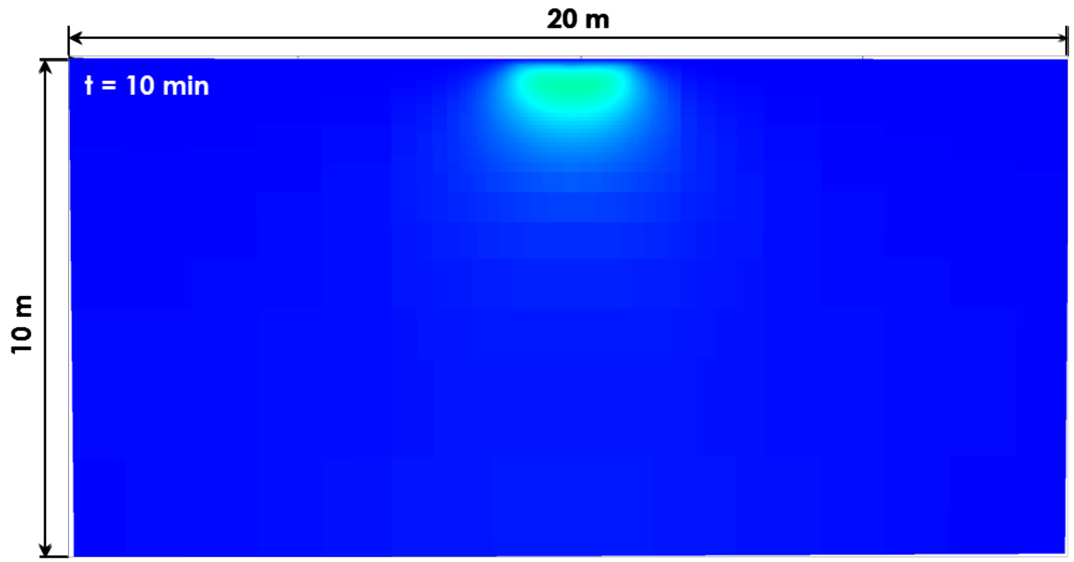
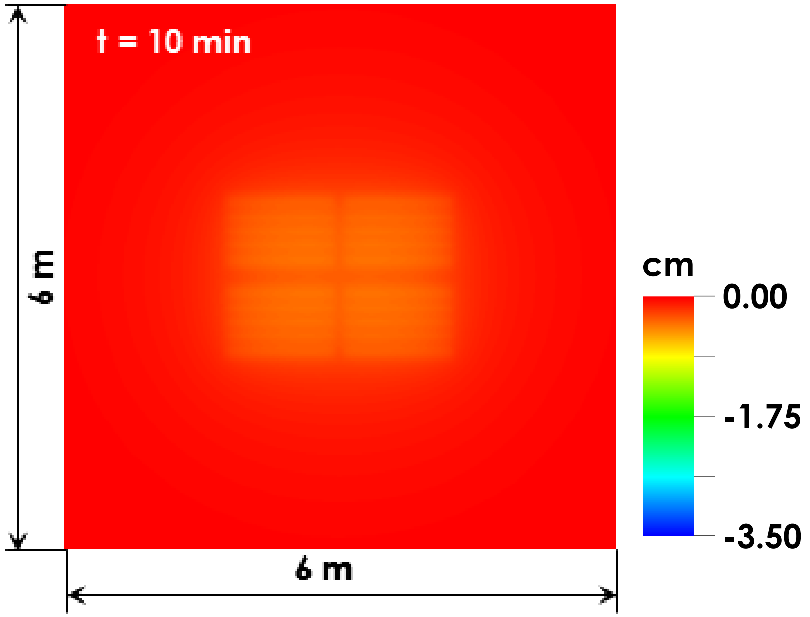


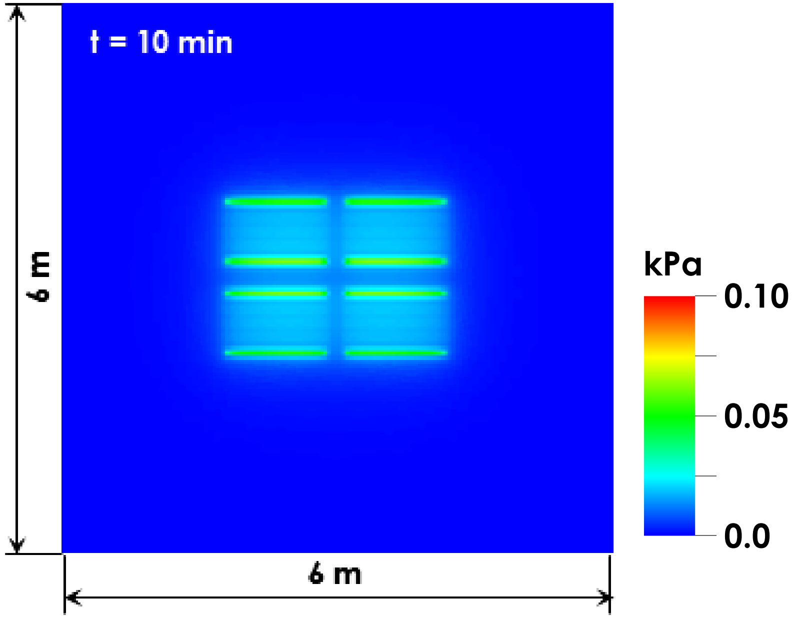


Pore over-pressure along a vertical section

Vertical displacements at the land surface



Pore over-pressure at the land surface



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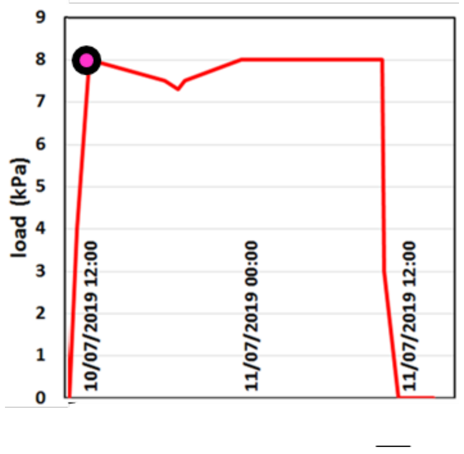

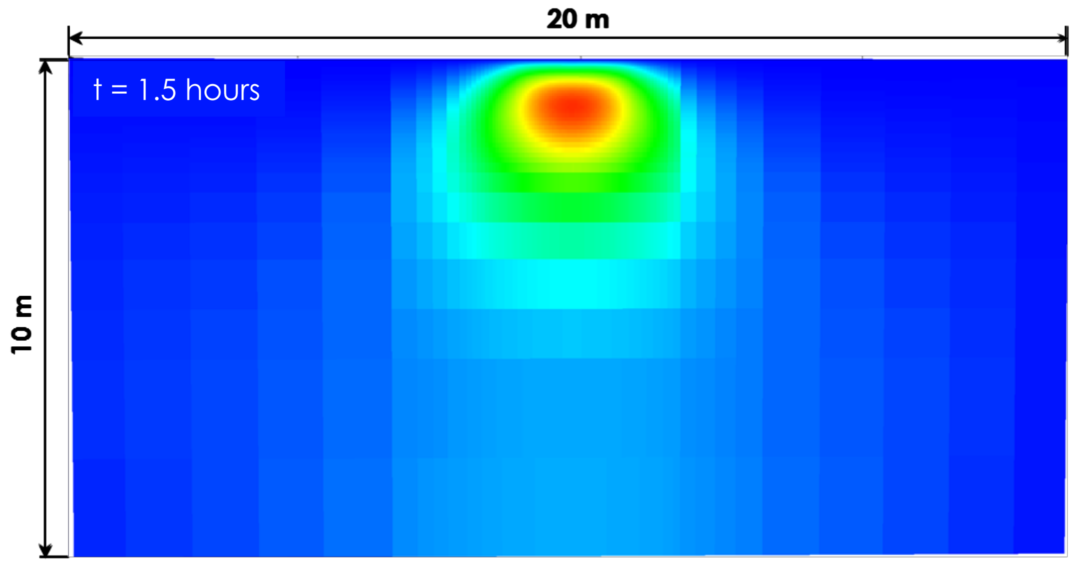

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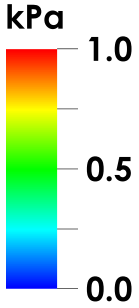

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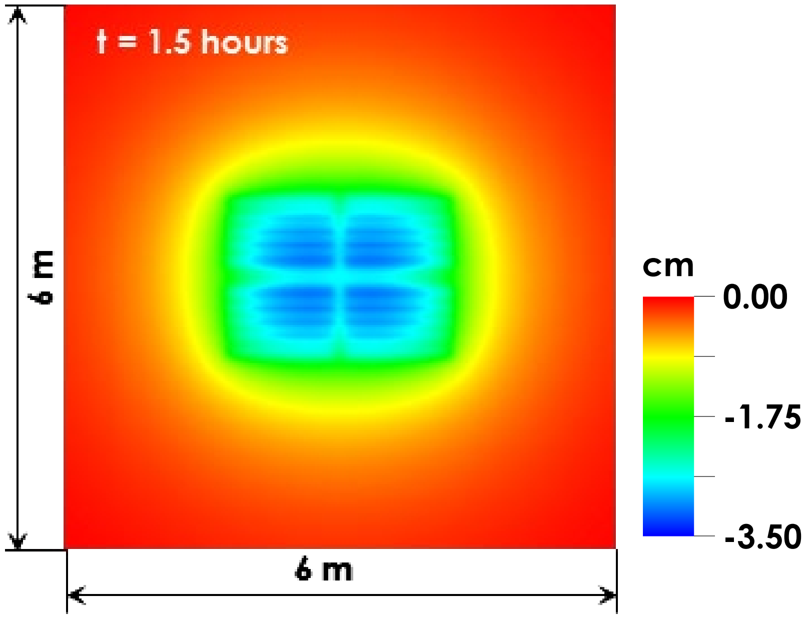

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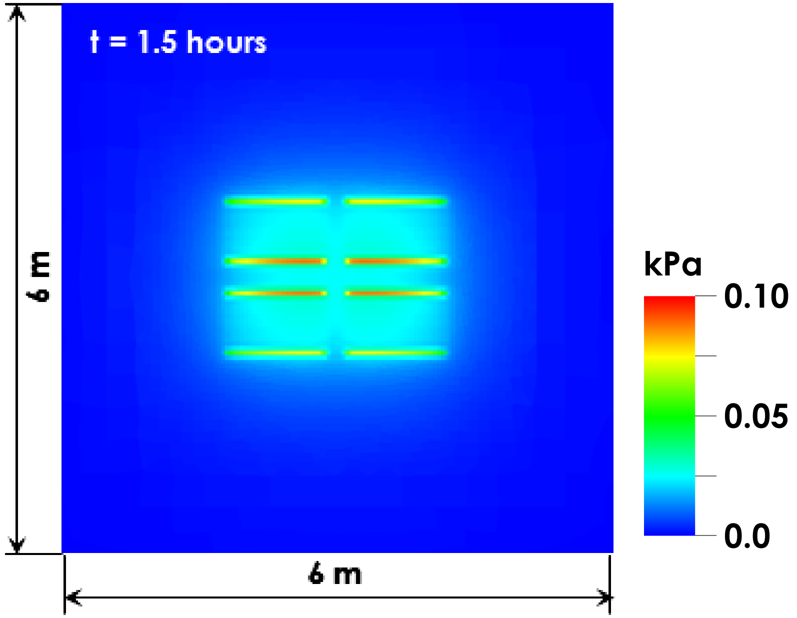

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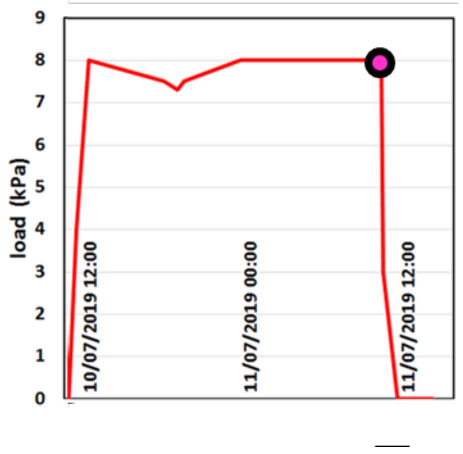

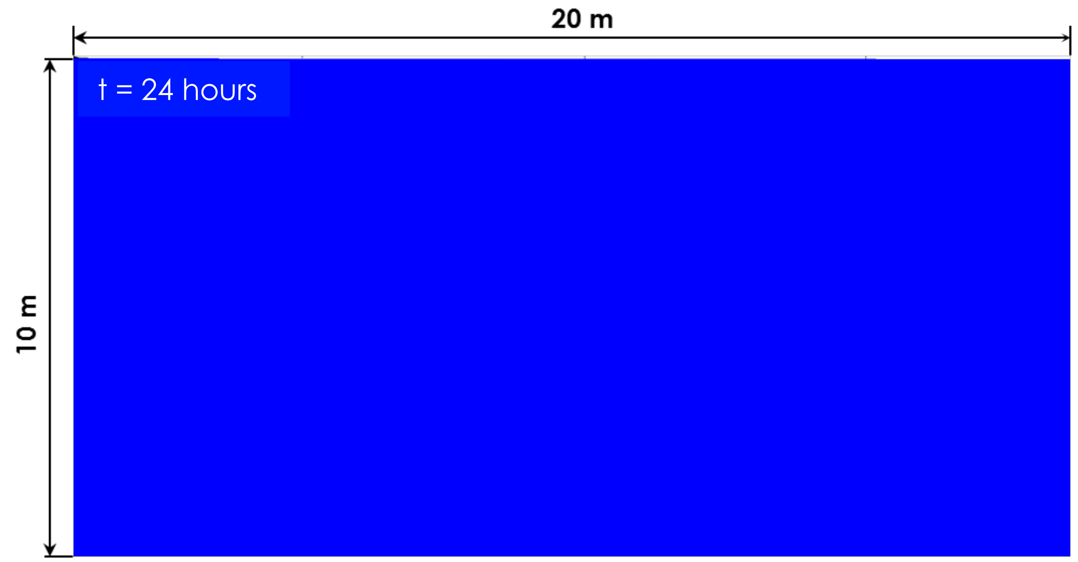

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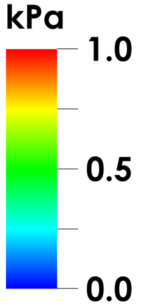

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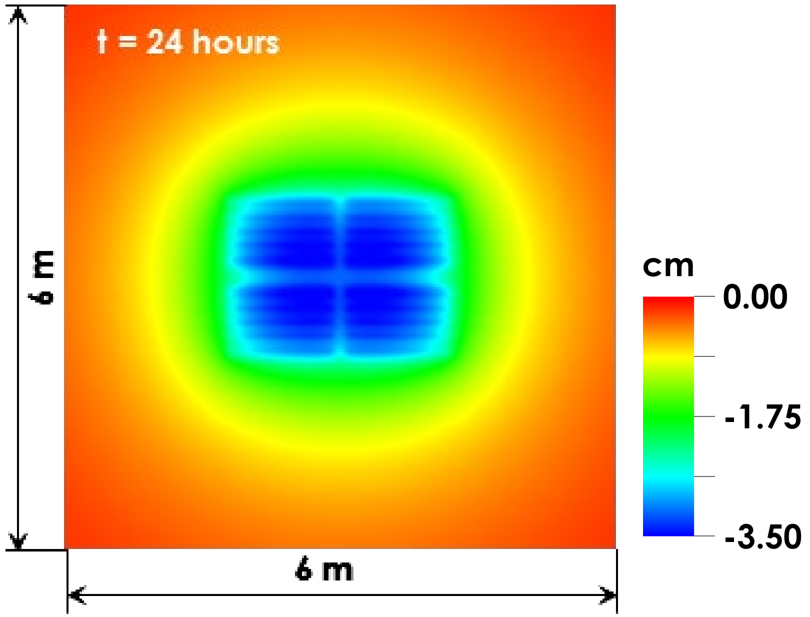

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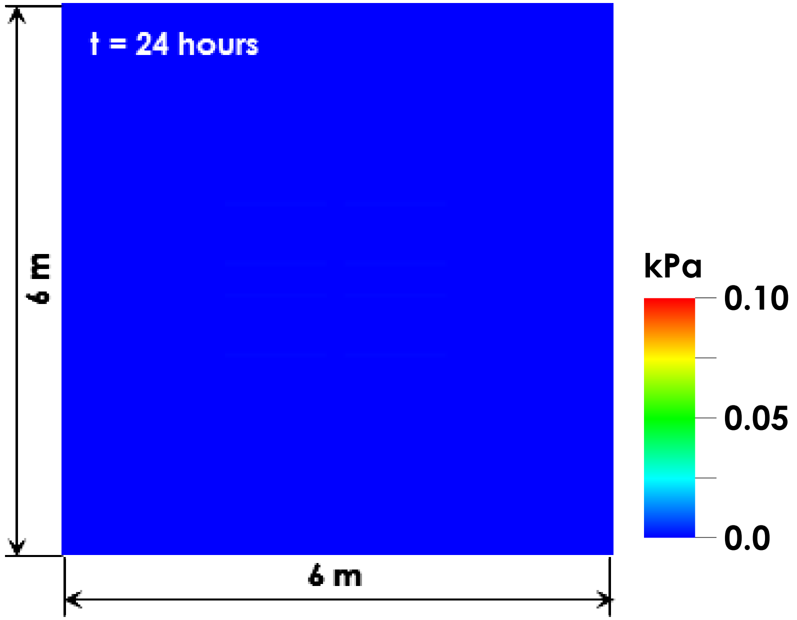

CONCLUSIONS

- Because of their large porosity and compressibility, Holocene deposits forming marsh bodies are subjected to significant auto-compaction
- Auto-compaction is a major factor threatening the resilience of transitional environments
- Soil compressibility is the key hydro-geomechanical parameter
- An original loading test is carried out in July 2019 to reliably characterize c_M of shallow loose soils
- An advanced poro-mechanical modelling activity is ongoing for the test interpretation
- The calibrated c_M will be used for long-term modelling of lagoon evolution

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Thank you for your attention

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