INVESTIGATING LAND SUBSIDENCE OF TRANSITIONAL ENVIRONMENTS

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INTRODUCTION

THE IN-SITU LOADING TEST
- Main aims
- The site
- The test

RECORDED ENVIRONMENTAL PARAMETERS
- The instrumentation
- The recorded time series

COUPLED MFE POROMECHANICAL MODEL FOR DATA INTERPRETATION
- Modelling approach
- Preliminary results

CONCLUSIONS
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.

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

\[
R = SLR + \text{SUB}_{\text{deep}} + \Delta z
\]

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

Displacement and compaction behavior vs depth at San Felice (Sf) marshland (Venice Lagoon, Italy). (After Da Lio 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)
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
(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 \[ \rightarrow \] interpretation of the recorded data through an advanced numerical model

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
  \[ \mu \nabla^2 \hat{u} + \left( \lambda + \mu \right) \nabla (\nabla \cdot \hat{u}) - \alpha \nabla p = b \]

- Fluid mass balance
  \[ \nabla \cdot \mathbf{v} + \frac{\partial}{\partial t} \left( \phi \beta p + \alpha \nabla \cdot \hat{u} \right) = f \]

- Darcy’s law
  \[ k^{-1} \mathbf{v} + \nabla p = 0 \]
COUPLED MFE POROMECHANICAL MODEL

DOMAIN DISCRETIZATION

Horizontal view of the MFE mesh superposed to the Lazzaretto marsh

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

Horizontal view of the MFE mesh with the characteristic mesh dimensions

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

\[ \mathbf{E} = 0.46 \text{ MPa} \]
\[ \mathbf{\nu} = 0.25 \]
\[ \mathbf{K} = 3 \times 10^{-6} \text{ m/s} \]
PRELIMINARY RESULTS

Constant and uniform parameters:

\[ E = 0.46 \text{ MPa} \]
\[ v = 0.25 \]
\[ K = 3 \times 10^{-6} \text{ m/s} \]

Vertical displacements at the land surface

Pore over-pressure at the land surface

Pore over-pressure along a vertical section

\( t = 10 \text{ min} \)
COUPLED MFE POROMECHANICAL MODEL

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

\( t = 1.5 \text{ hours} \)

\( t = 1.5 \text{ hours} \)
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

\[ t = 24 \text{ hours} \]
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.
REFERENCES


Thank you for your attention

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