Characterizing Cracking Process in Clayey Soil Using Electrical Resistivity Method

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19th Annual NJDOT Research Showcase

October 13, 2017

Introduction

- Desiccation cracking

Sedimentary structures formed as clay-bearing soils dry and contract.



Introduction

Mechanical property change

- impaired strength
- excessive deformation
- increased compressibility

Hydraulic property change

- Increase hydraulic conductivity
- Create preferential pathways for fluids

Inspection of desiccation cracking

- Visual observation


- Excavation of trenches

Electrical resistivity of soil

A sensitive reflection of

- The nature of solid

(mineralogy, shape, fabric, and size distribution)

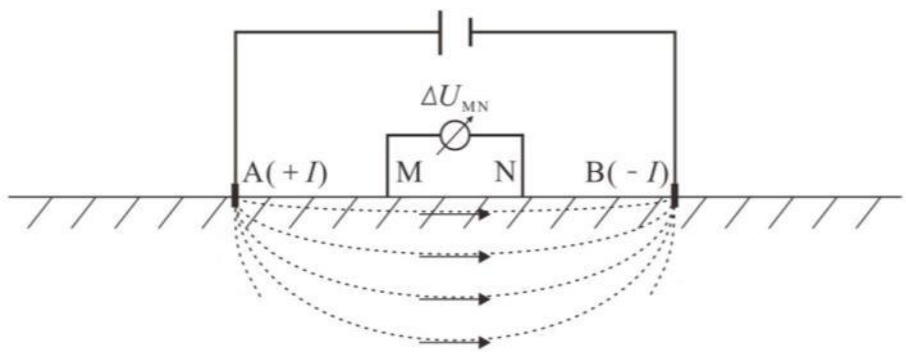
- Arrangement of voids

(porosity, tortuosity, connectivity, pore structure)

- Properties of fluid

(water content, electrical resistivity, solute concentration)

Electrical resistivity measurement



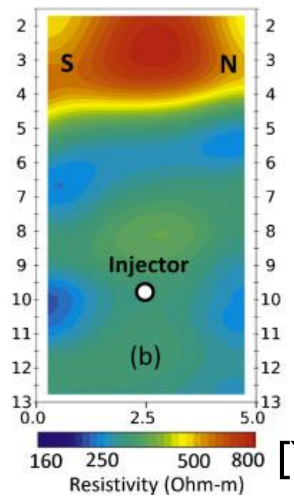
Schematic view of electrical resistivity method

$$\rho = \frac{\Delta U_{MN}}{I}\left(\frac{2\pi}{\frac{1}{MA}-\frac{1}{MB}+\frac{1}{NB}-\frac{1}{NA}}\right) = K\frac{\Delta U_{MN}}{I}$$

- *I* is the injected current (A)
- ΔU_{MN} is the measured electrical potential (V) between M and N
- *K* is a geometrical coefficient
- MA, MB, NA and NB represent the relative spacing (m) between electrodes

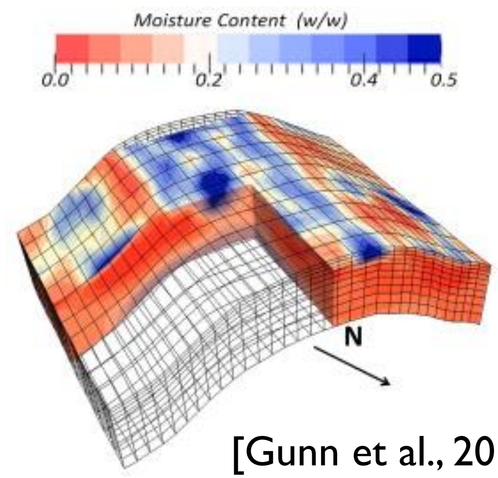
Applications of electrical resistivity tomography (ERT)

Monitoring CO_2 migration in shallow sand aquifer



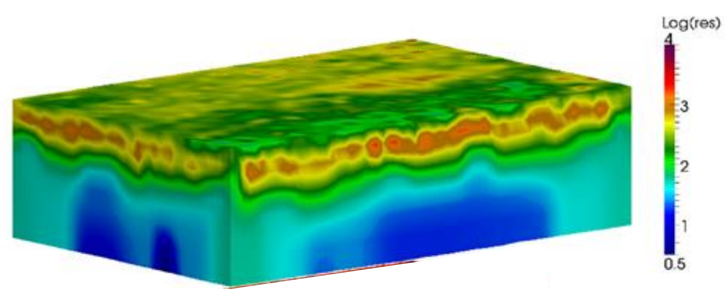
[Yang et al., 2015]

Monitoring moisture change in clay embankments



[Gunn et al., 2015]

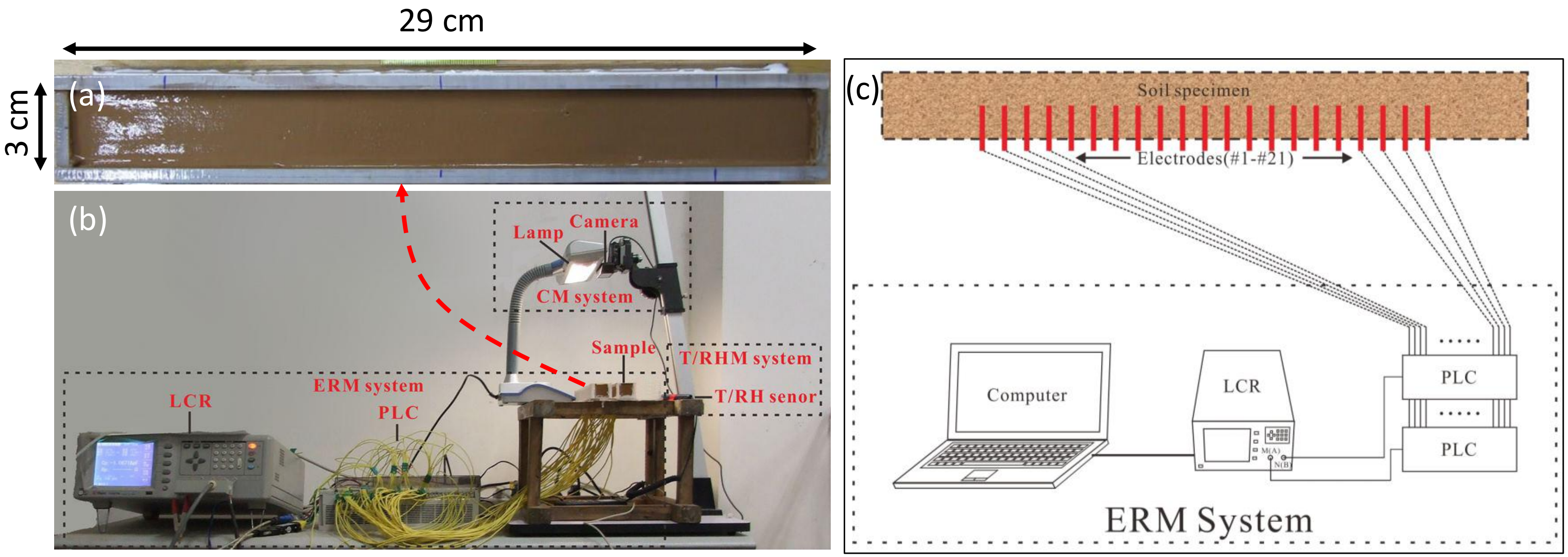
Detecting sand-bedrock interface



[Ward et al., 2014]

Experimental set up

- Electrical Resistivity Measurement (ERM) system
- Crack Monitoring (CM) system
- Temperature and Relative Humidity (RH) Monitoring (T/RHM) system



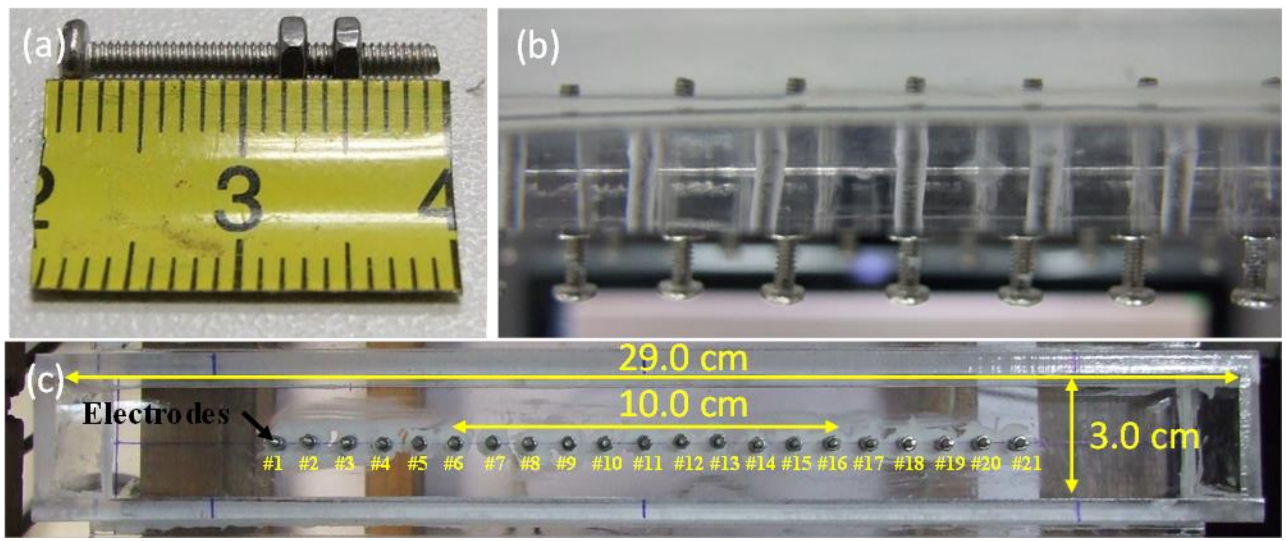
Soil specimen

- Low plasticity clay (CL)

Soil properties	Value
Specific gravity	2.73
Consistency limit	
Liquid limit (%)	36.5
Plastic limit (%)	19.5
Plasticity index (%)	17.0
USCS classification	CL
Compaction study	
Optimum moisture content (%)	16.5
Maximum dry density (Mg/m^3)	1.7
Grain size analysis	
Sand (%)	2
Silt (%)	76
Clay (%)	22

Installation of electrode

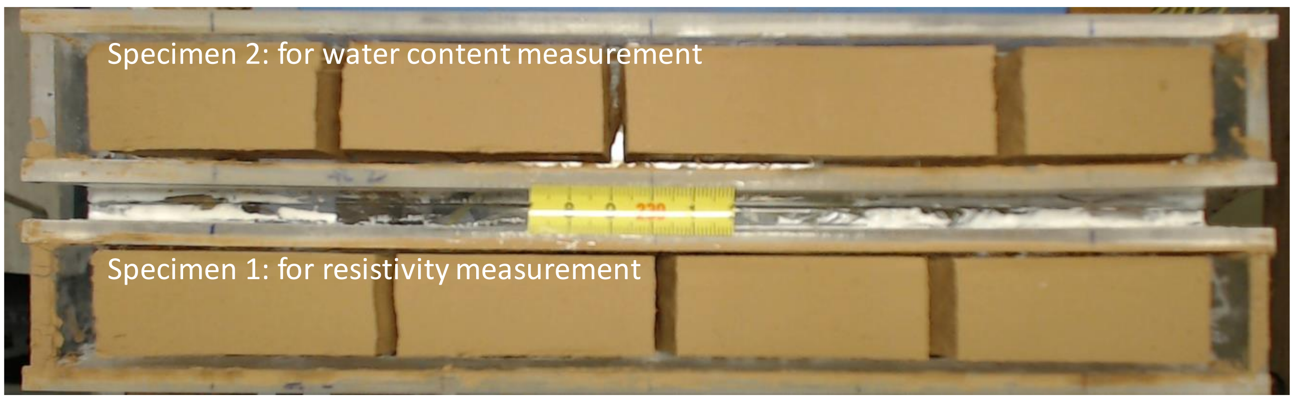
- Twenty-one electrodes were fabricated using stainless steel bolts with a length of 19.0 mm and a diameter of 2.0 mm.



- 3 mm penetration depth: to ensure sufficient soil-electrode interfacial contact.
- The electrode length to electrode spacing ratio is 0.3, a reasonably small value.

Final crack pattern

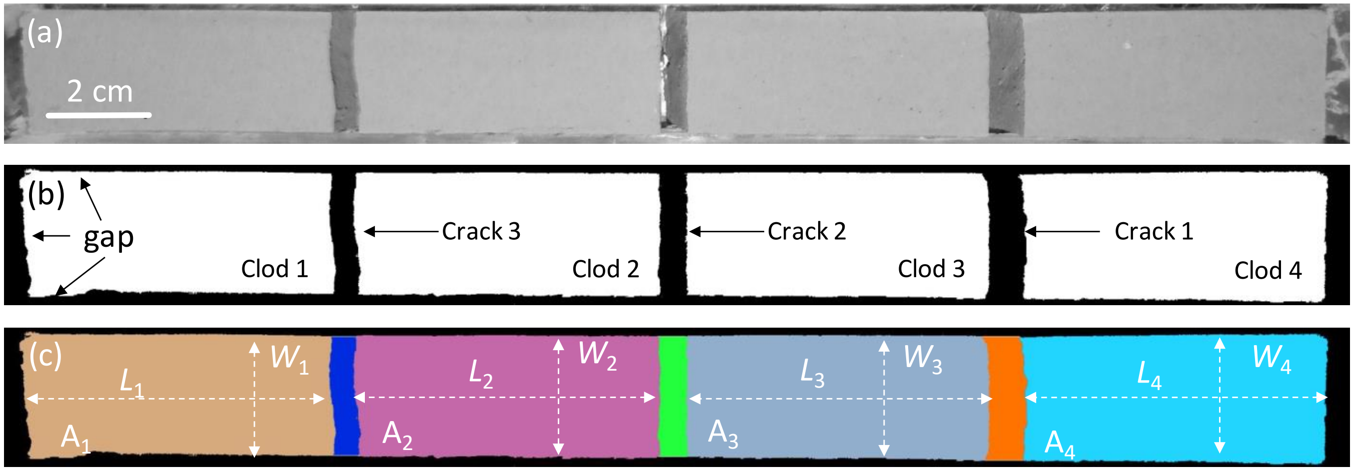
- Specimen 1: electrical resistivity
- Specimen 2: water content measurement



Same crack pattern with similar morphological characteristics

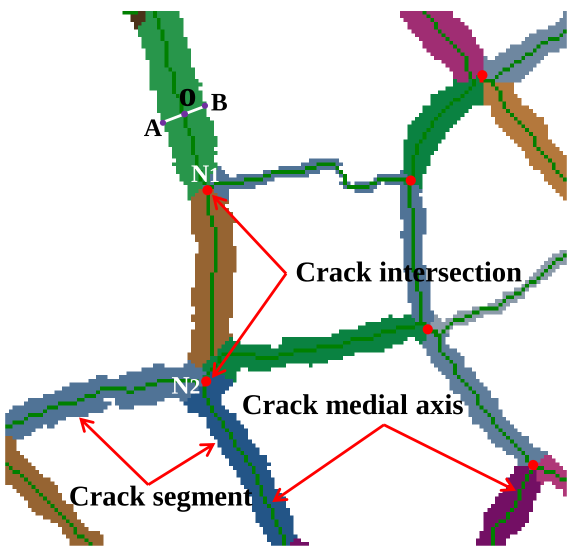
Image processing procedures

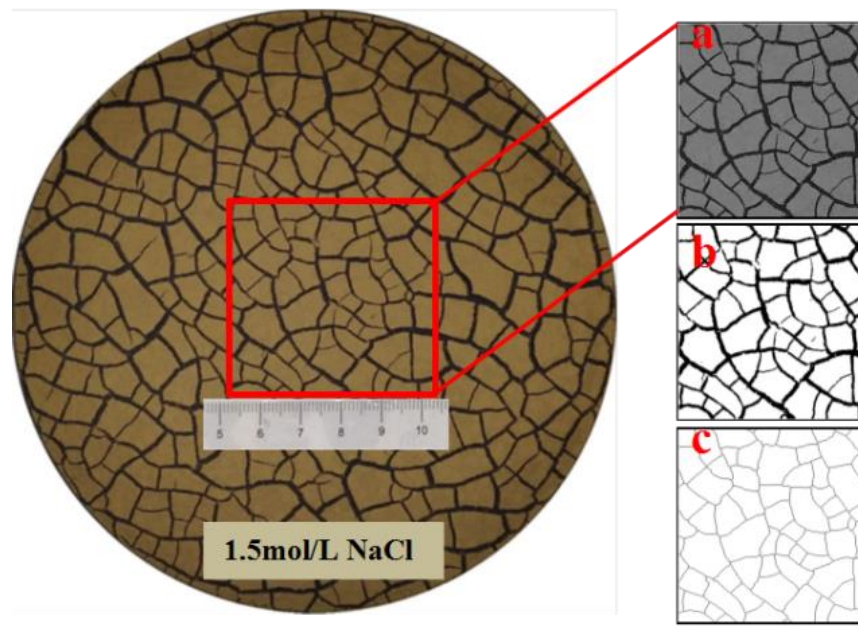
1) Convert original image to grey level
2) Noise removal through filter and binarization
3) Clod and crack recognition and analysis



Crack pattern characterization

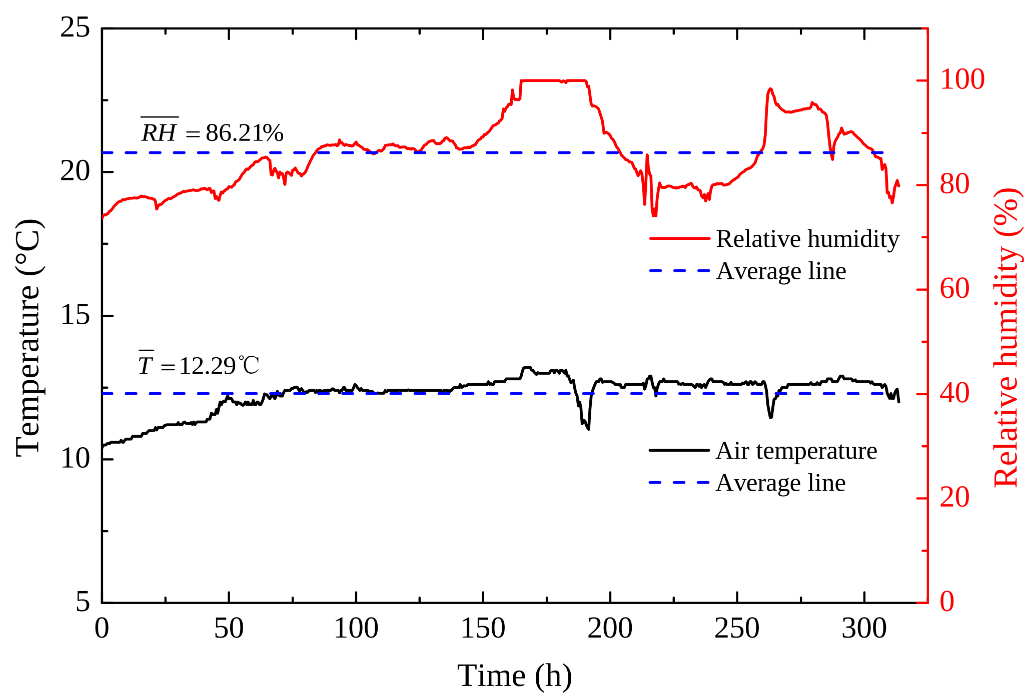
- Number of crack segments N_{seg}
- Number of clods N_c
- Average width of cracks W_{av}
- Average area of clods A_{av}
- Longitudinal shrinkage strain e_{Lon}
- Lateral shrinkage strain e_{Lat}
- Surface shrinkage strain e_{Sur}





Laboratory T & RH conditions

- The time histories of temperature and relative humidity exhibit minor fluctuations.

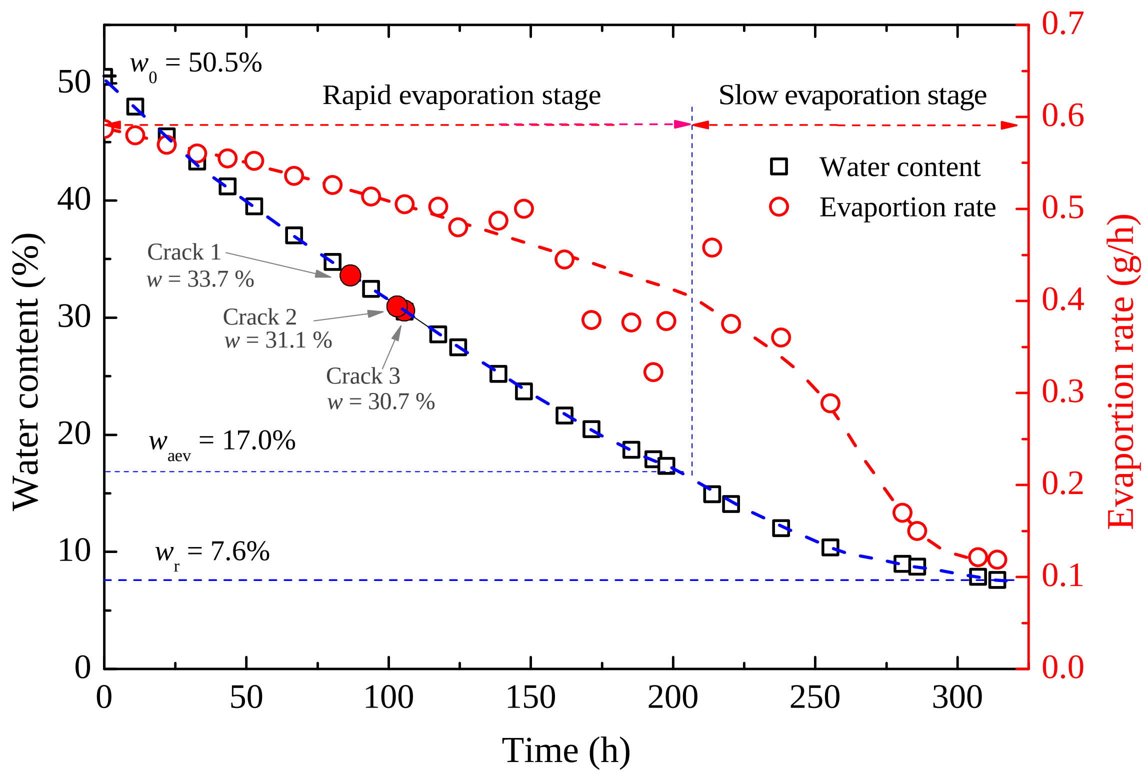


relative humidity varying within 86.21 ± 13.8%

temperature varying within 12.29 ± 1.85 °C

Water evaporation

- Water content decreases with drying time.
- Evaporation rate decreases with drying time.



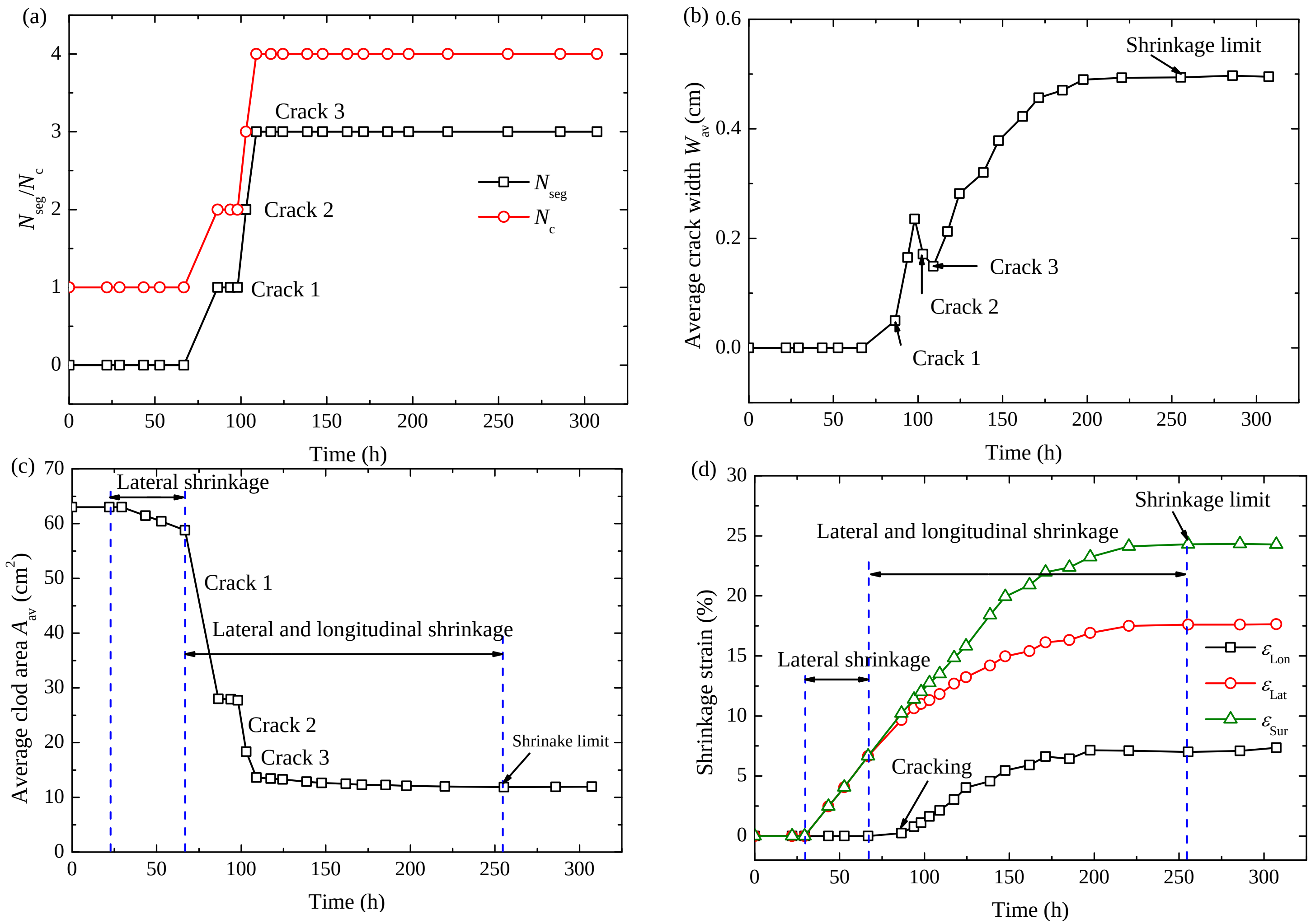
Temporal variations of water content and evaporation rate

Desiccation cracking process

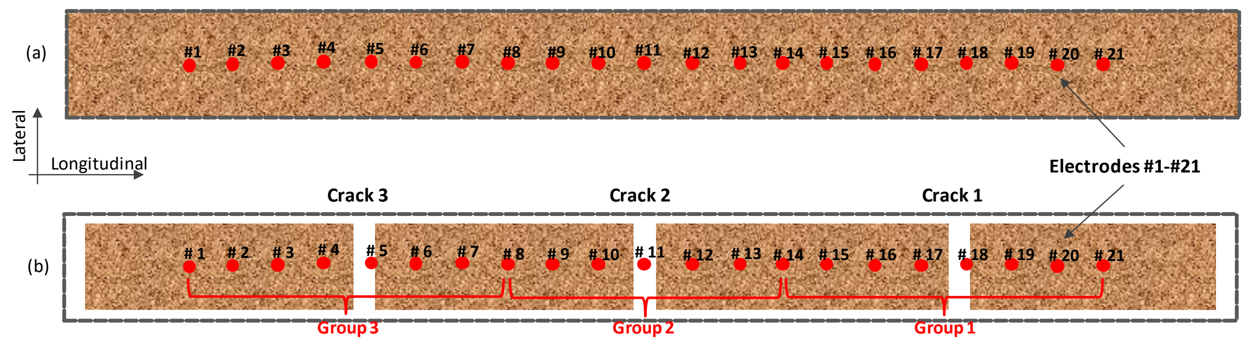
A total of three cracks were formed nearly parallel to each other and perpendicular to the longitudinal direction of the specimen.

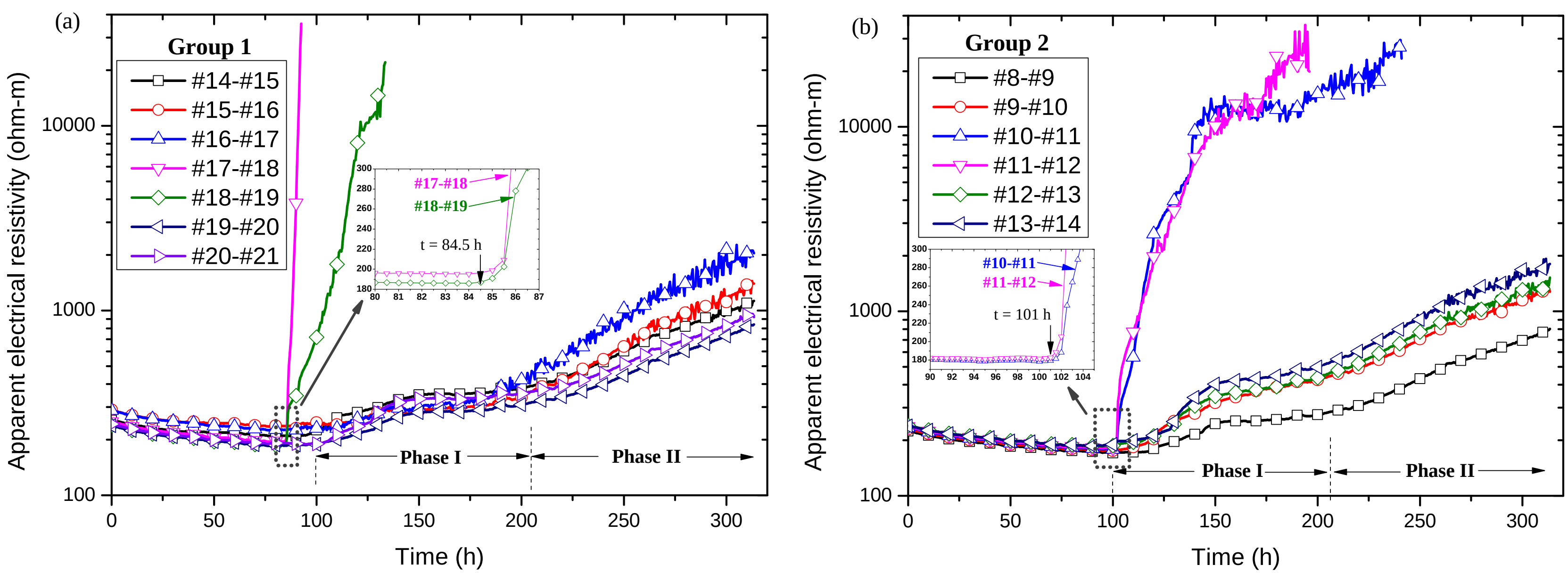
Crack 1: formed at 86.5 h
Crack 2: formed at 102.8 h
Crack 3: formed at 103.0 h

Geometrical parameters of crack patterns



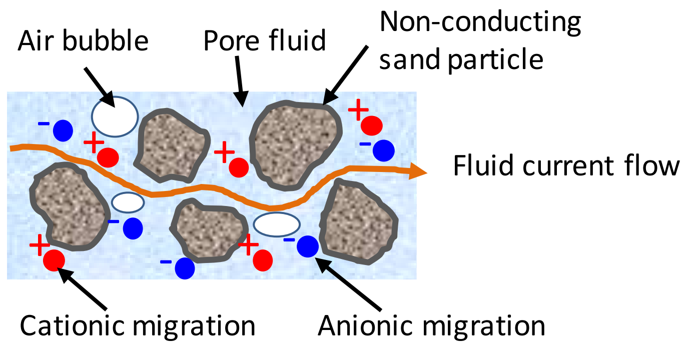
Temporal variation of ρ





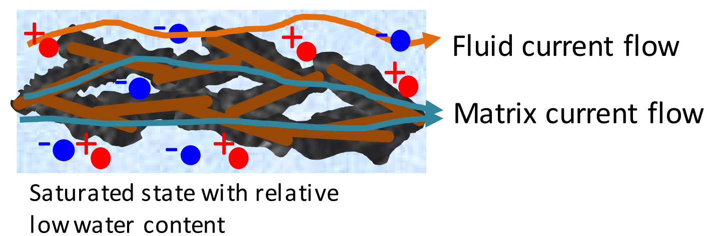
Electrical conduction behavior of different soils

(a)



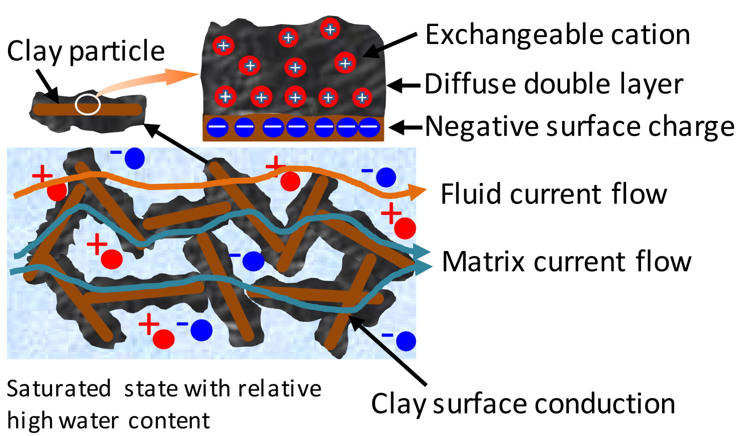
sand

(c)



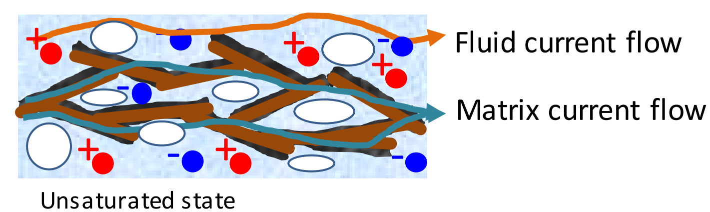
Saturated clay with relatively low water content

(b)



Saturated clay with relatively high water content

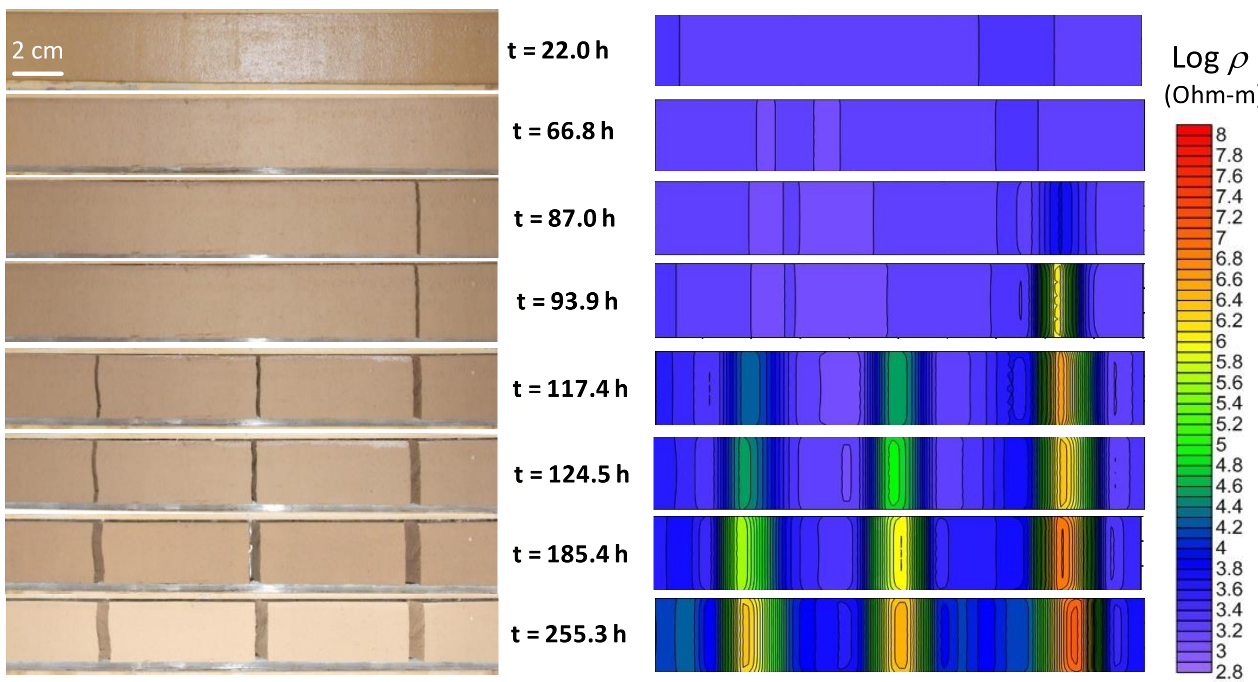
(d)



Unsaturated clayey soil

Electrical resistivity tomography

- Crack initiation and growth
- Crack pattern (location, width, geometry)



Crack patterns

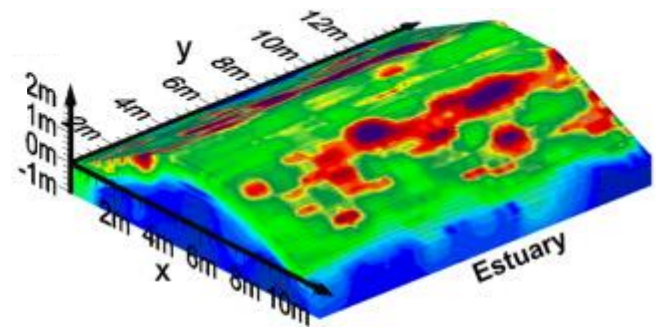
Apparent resistivity images

Conclusions

- Water evaporation is governed by the temperature and relative humidity at the soil-air interface.
- The volumetric shrinkage of the specimen shows evident anisotropic characteristics.
- The evolution of electrical resistivity in clay is dominated by two competing effects: (1) closer packing of soil fabric and higher concentration of ions in pore fluids, and (2) the evaporation-induced water loss associated with hydration film contraction and desiccation crack insulation.
- ERT is reliable to map the potential cracks' positions.

Future study

- Future works will be carried out to improve our fundamental understanding of the correlations between physical and electrical properties of soil in a higher dimensional space at larger scale during the desiccation cracking process.



Thank you!

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