Application of PIV technique in the model test of frost heave of unsaturated soil

Student: Meng Wang PHD Candidate
Supervisor: Prof. Xu Li

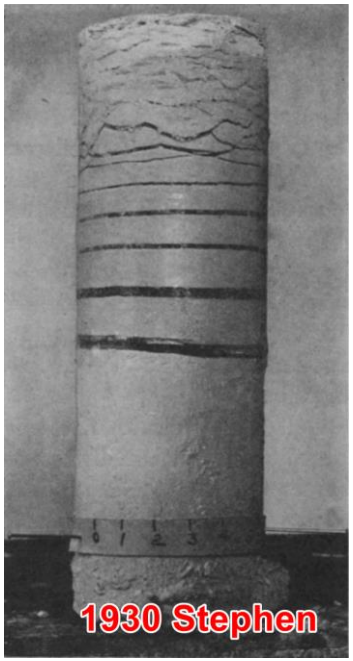
Department of Geotechnical Engineering
Beijing Jiaotong University

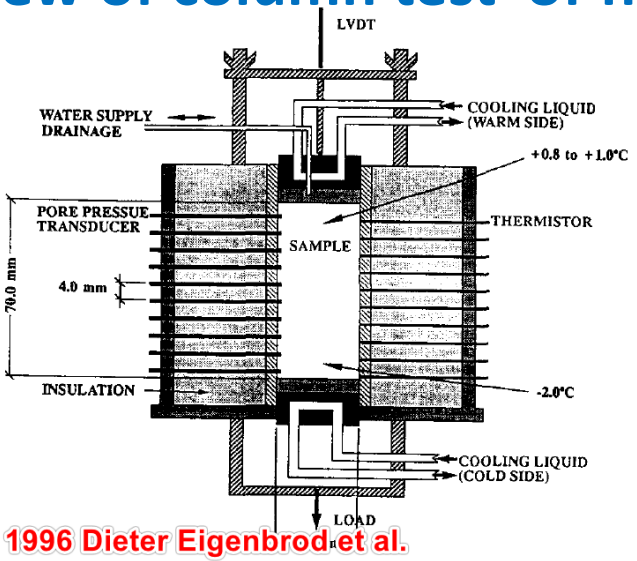
Special thanks to Prof. Jiankun Liu for support to the experiment

Content

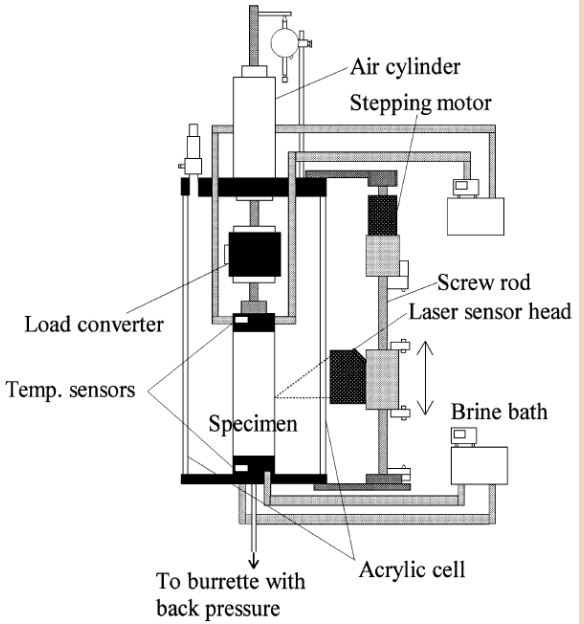
1. Research Background----

An overview of column test of frozen soil





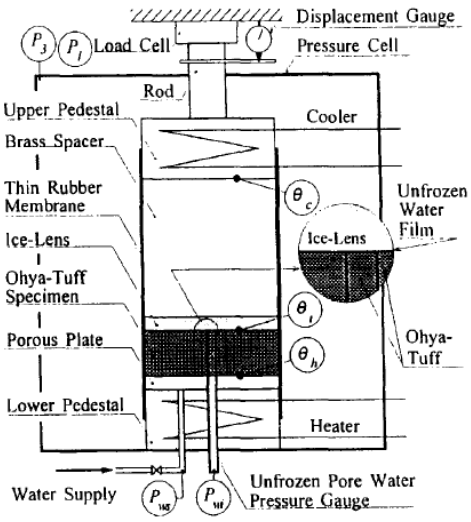
1996 Dieter Eigenbrod et al.



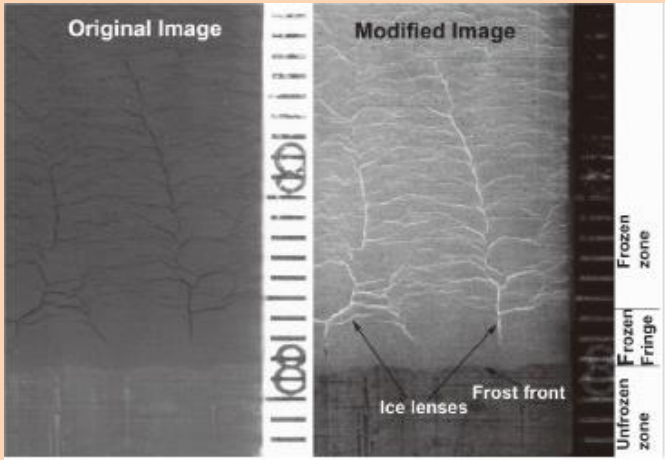
2002 Takashi Ono

Conventional soil column test

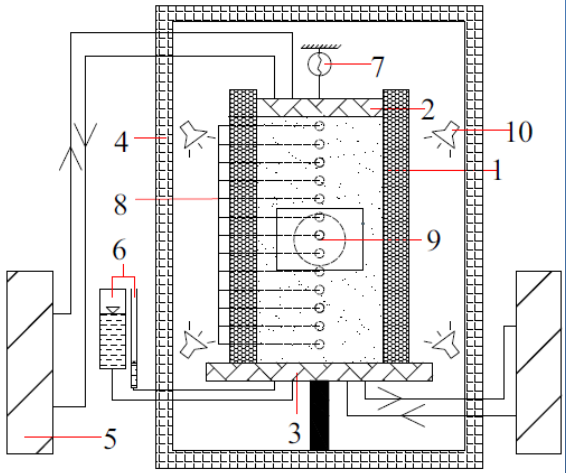
Soil column test with image analysis method



1997 Yoshiaki Miyata

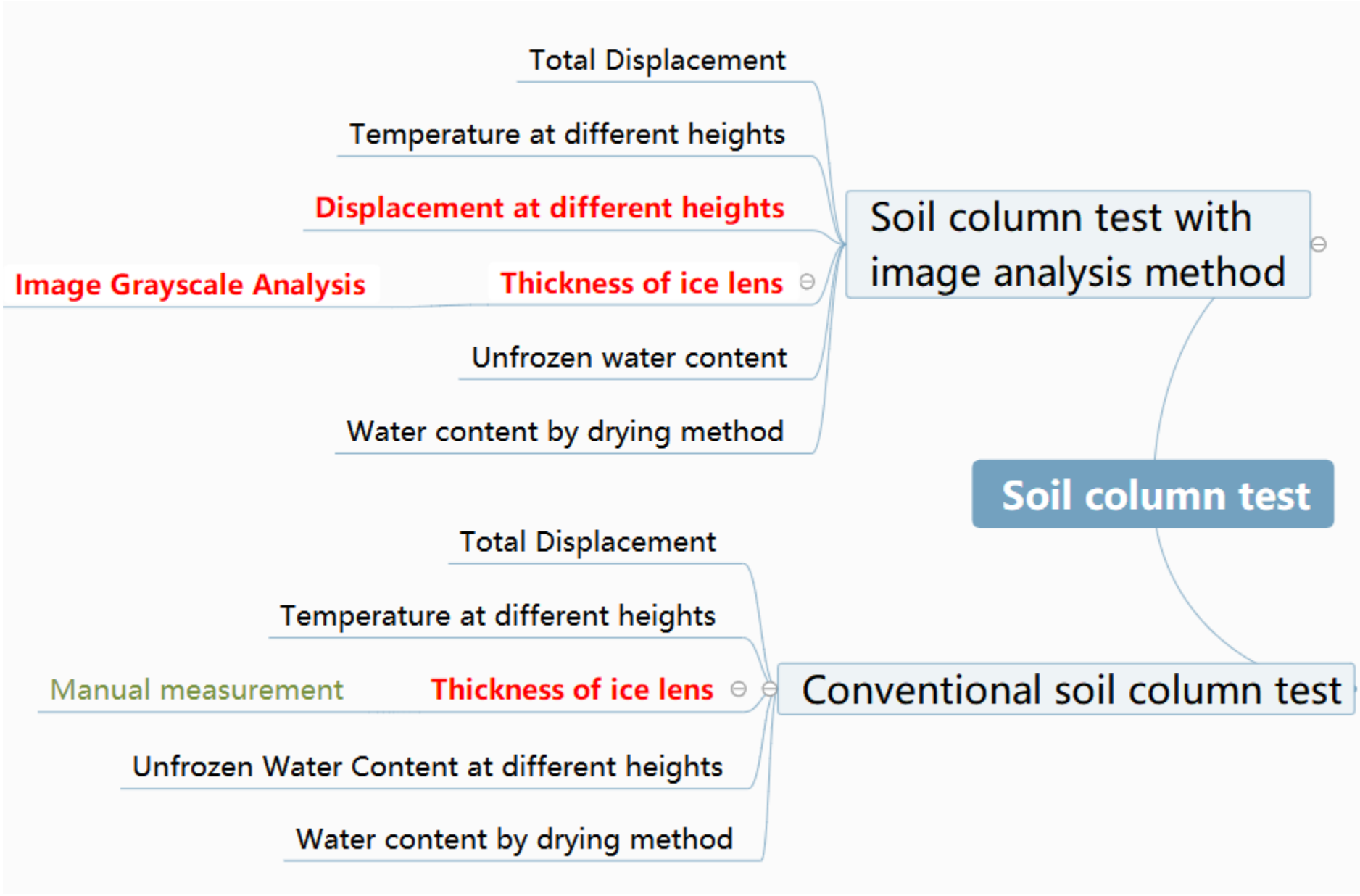


2008 Lukas U. Arenson



2018 Yongtao Wang

1. Research Background----
Comparison of test methods for soil columns

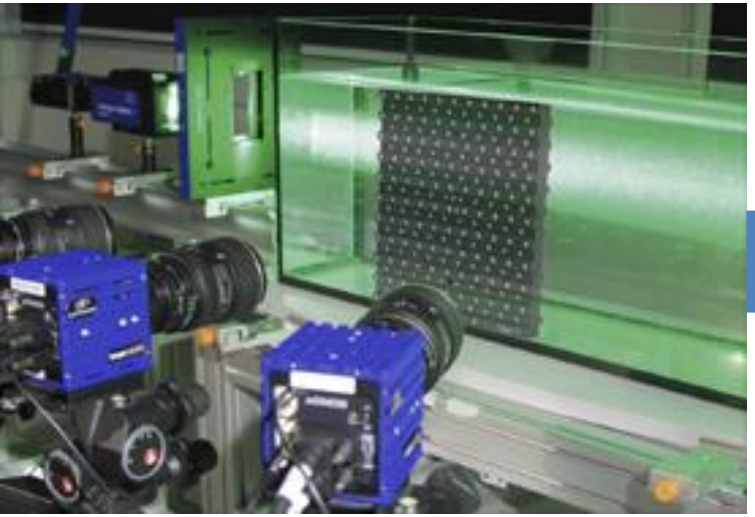


1. Research Background----
Reasons for choosing PIV (Particle Image Velocimetry) method

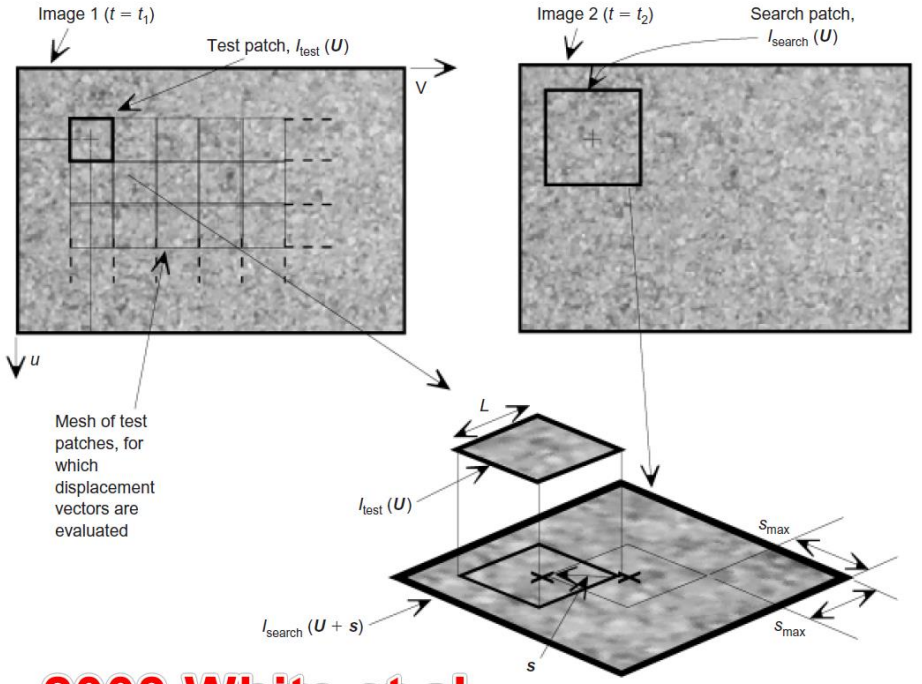
In summary, in the existing Soil column test method, the displacement measurement is limited to **a few observation points**, and there is a lack of a method to **measure the displacement field and strain field of the entire cross-section** of soil column.

Therefore, the PIV **(Particle Image Velocimetry)** method was added to the test of frozen soil column.

1. Research Background----PIV method in geotechnique



Derived from fluid mechanics

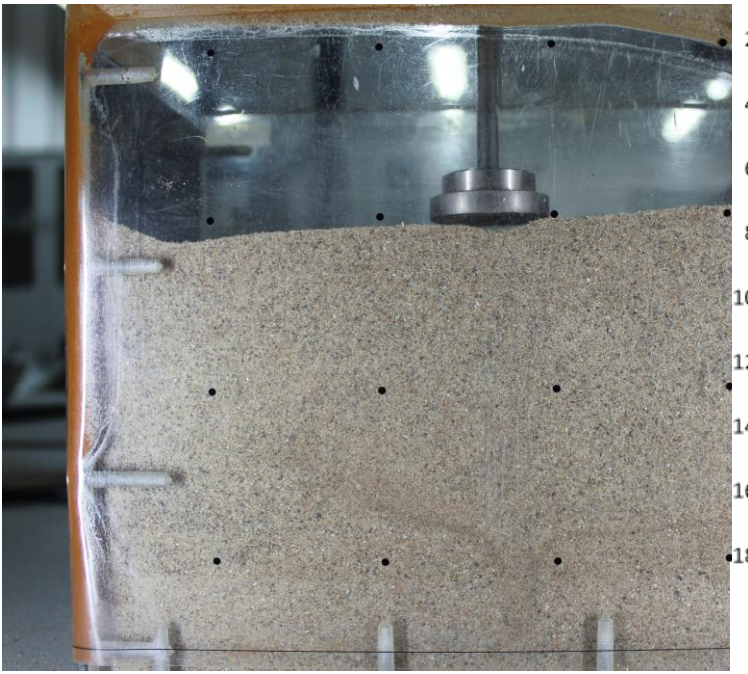


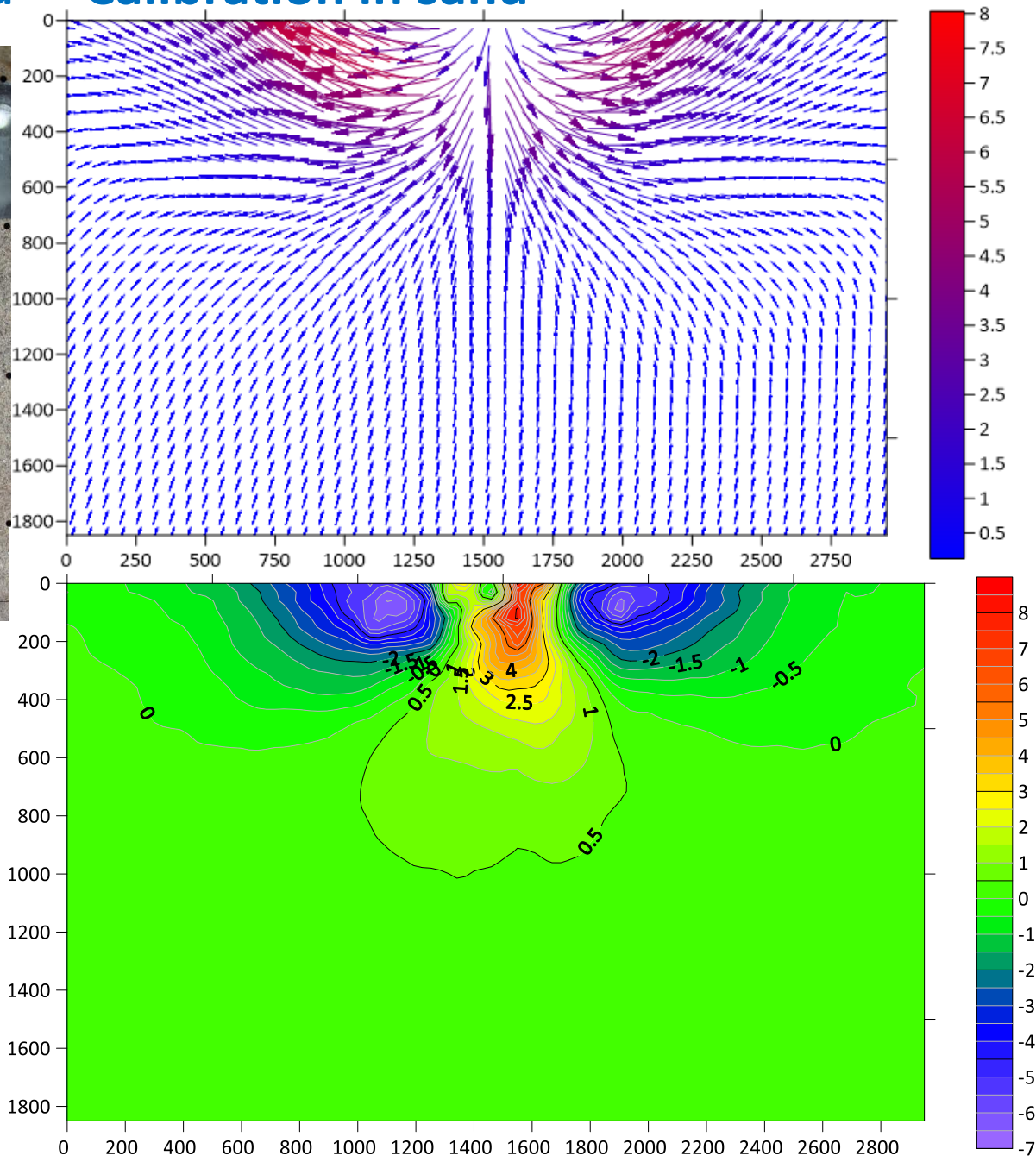
2003 White et al.

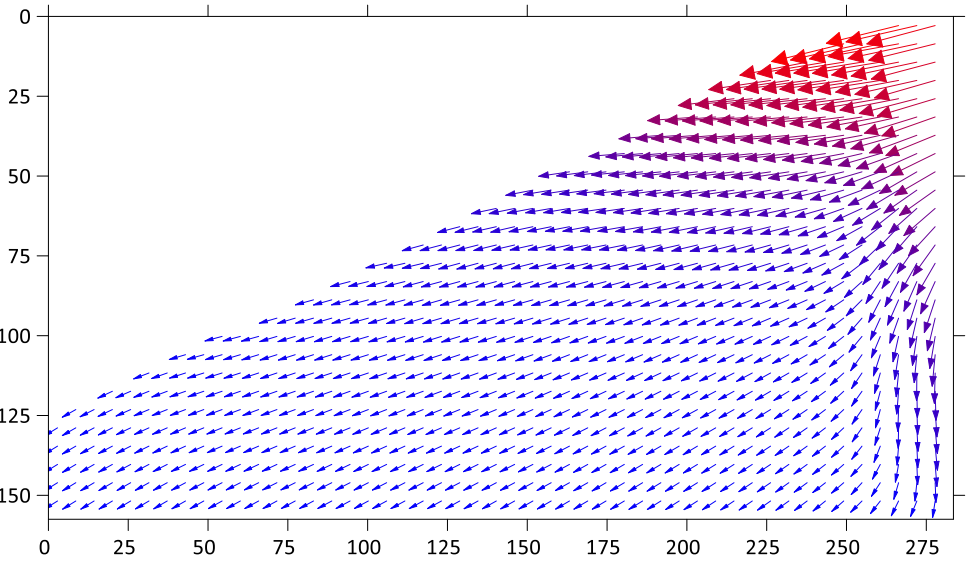
Improvement: Consider the coarse-grained soil as **low-speed fluid**; Also combined with open source program: **GeoPIV_RG (by White et al.)**

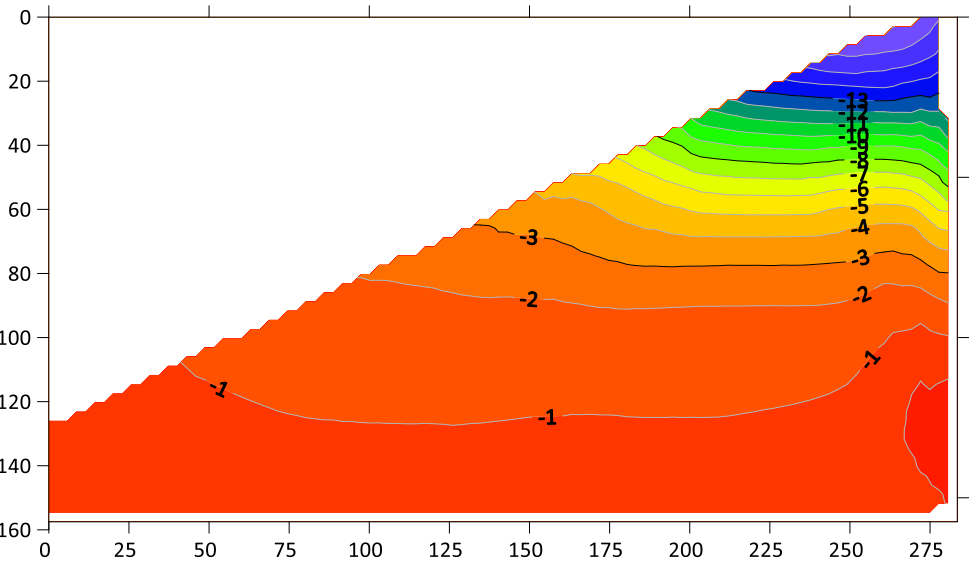
With the appropriate **tracer particles**, the whole displacement field of the **fine-grained** soil column can be obtained.

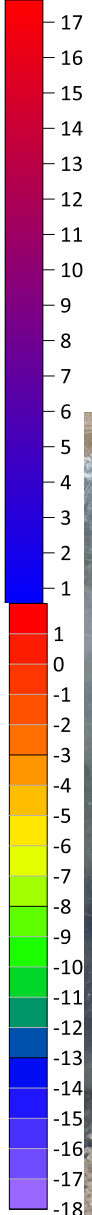
1. Research Background----Calibration in sand

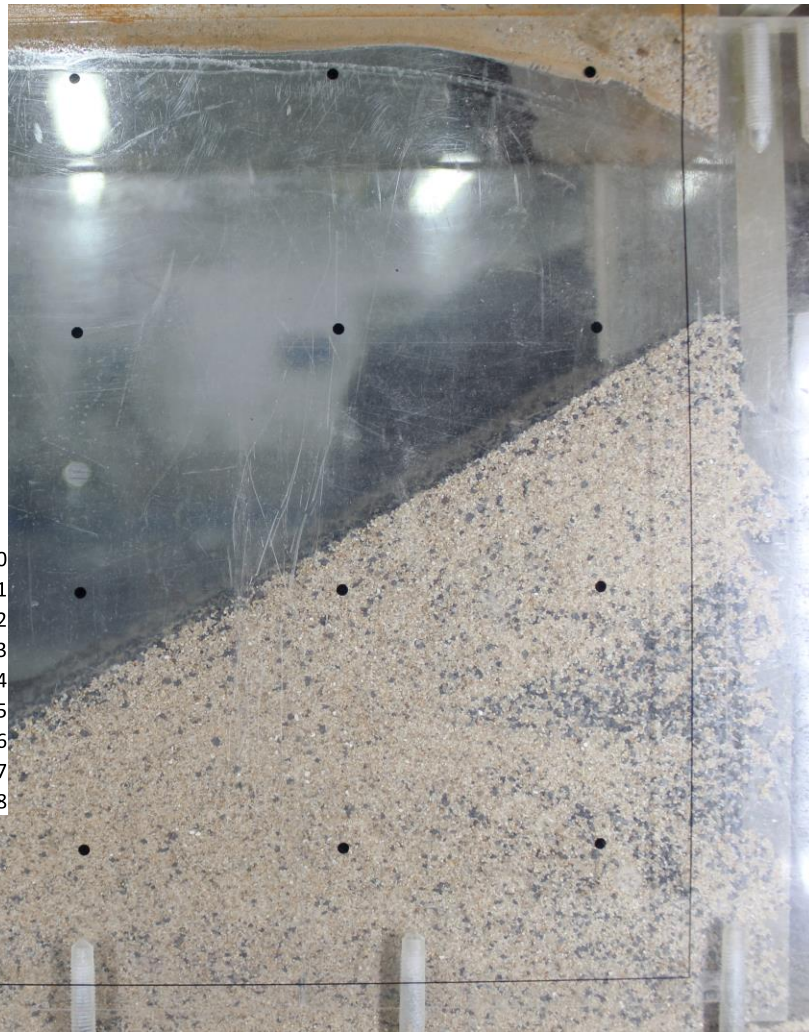





0
25
50
75
100
125
150
0
25
50
75
100
125
150
175
200
225
250
275


0
20
40
60
80
100
120
140
160
0
25
50
75
100
125
150
175
200
225
250
275
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13


17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18



1. Research Background---PIV methods in frost heave test

Principles for selecting tracer particles

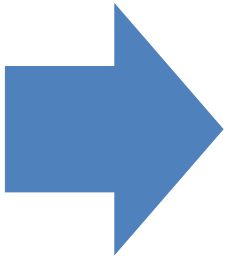
a) Have a significant **grayscale contrast**;

b) Less disturbance to the soil for experimental use

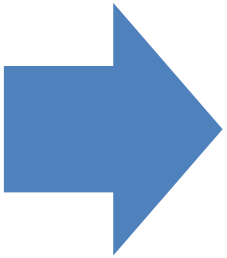
c) The ability to resist the influence of **ice-water phase change** on soil gray scale

Test procedure

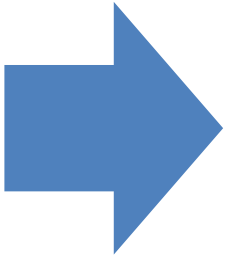
Preparation of tracer particles



Preparing the soil column; **Adding tracer particles**; Setting up the sensors

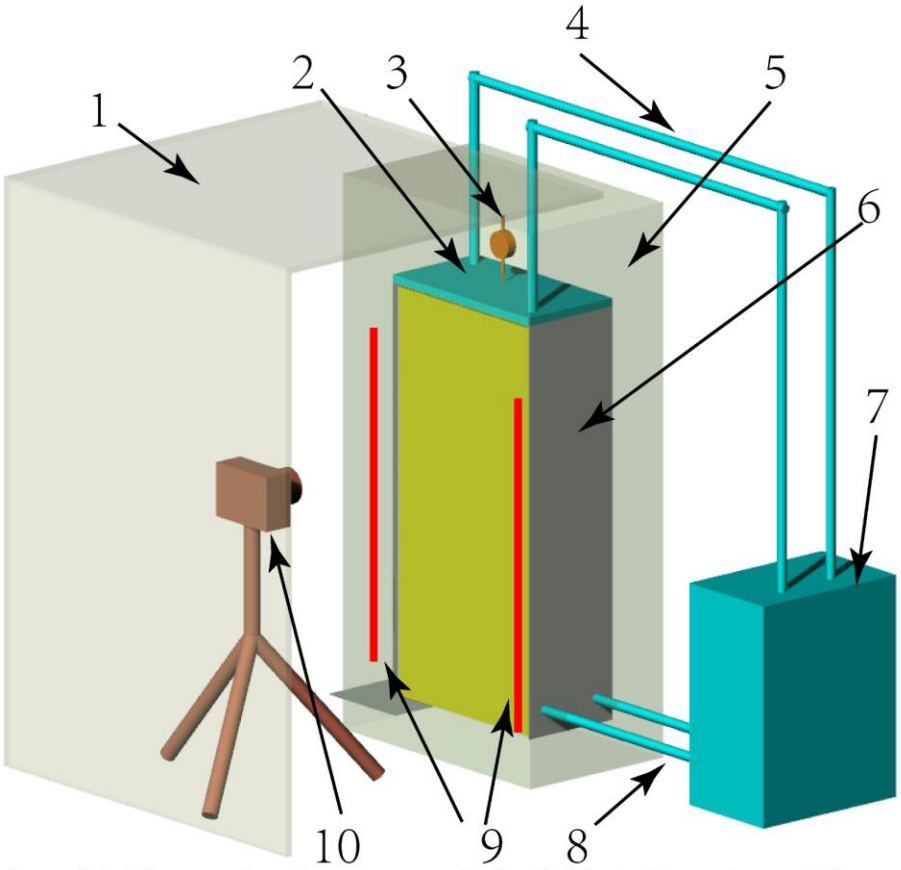


Using **OpenPIV's analysis kernel** to derive the displacement of each patch center



Post-processing: **programming by python to draw contours** of displacement and strain

2. Experimental method--- Equipment



1. Shadow shield to maintain constant light field; 2. Top plate of the cold bath;
3. Displacement meter; 4. Coolant delivery line of the top plate
5. Thermotank (the front side is transparent for image acquisition);
6. Stainless steel cuboid model box, image acquisition surface using tempered glass;
7. Cold bath; 8. Coolant delivery line of the bottom plate;
9. Lighting device; 10. Image acquisition equipment (Canon 1300D)

Self-developed test equipment

2. Experimental method --- Soil type and sensors

Physical Property soil

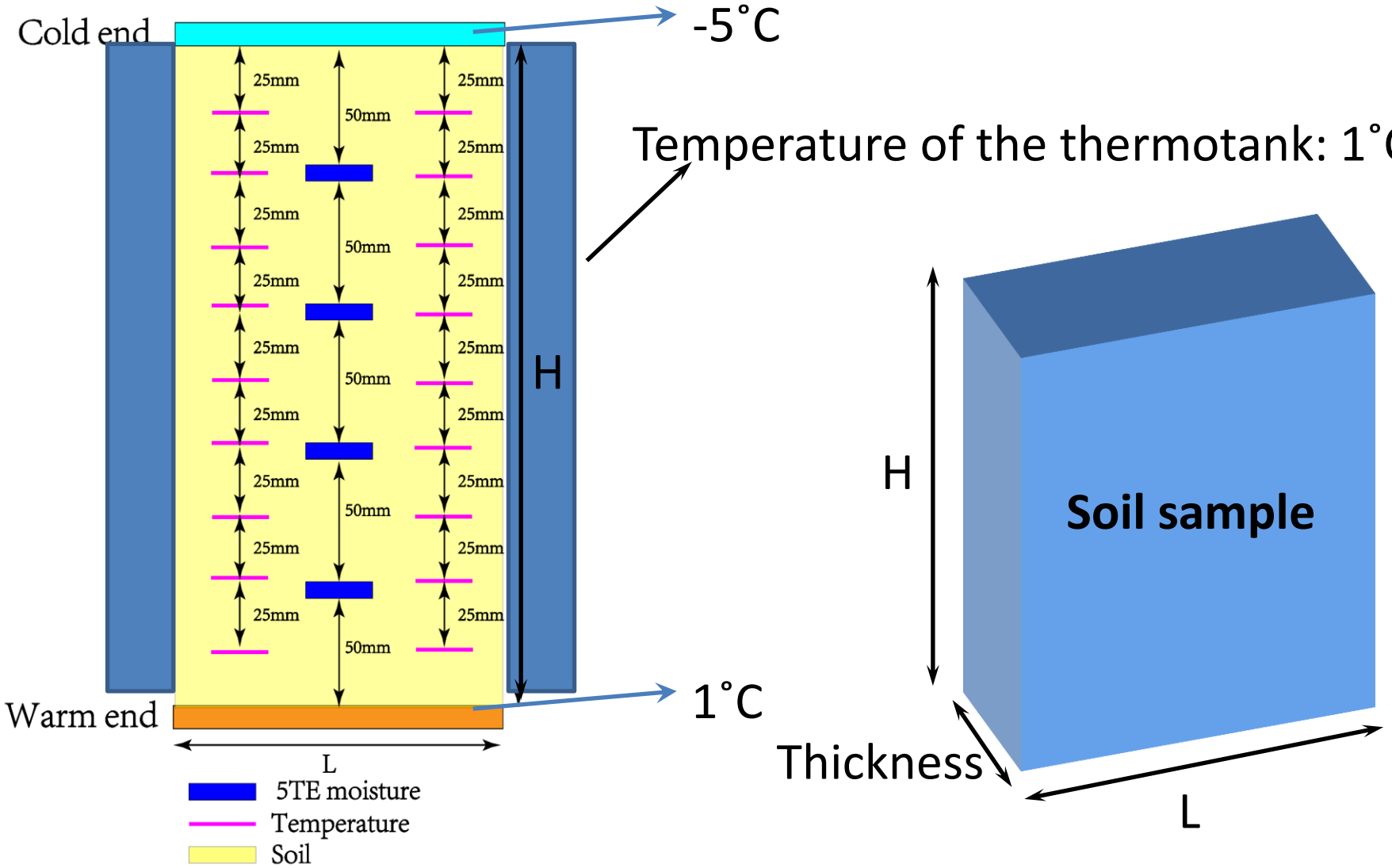
Specific surface area (m^2/g)	Maximum dry density (g/cm^3)	optimum moisture content (w_{op})	Liquid limit	Plastic limit	specific gravity
17.62	1.75	15.5%	27.15	15.1	2.72
Grain composition					
	0.25~0.075mm		0.075~0.005mm		<0.005mm
	6.33%		80.42%		13.26%

Sensors

Soil moisture sensor: **5TE(Decagon)**, accuracy： $\pm 0.03 m^3/m^3$

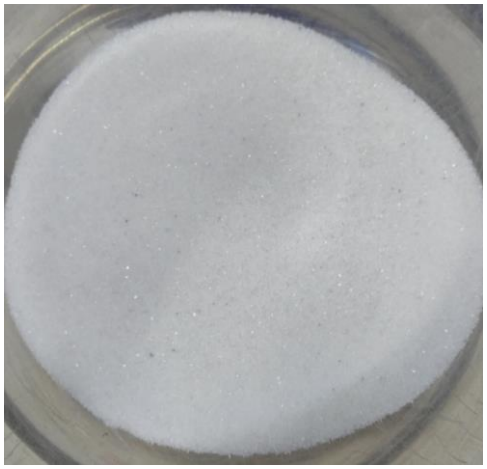
Temperature sensor： **PT-100 (JUMO, Germany)**,
accuracy： $(0.15 \pm 0.002*|t|)^\circ C$， (t is the measuring temperature)

2. Experimental method --- sensors and soil column



L x H x Thickness = 280 x 250 x140 mm

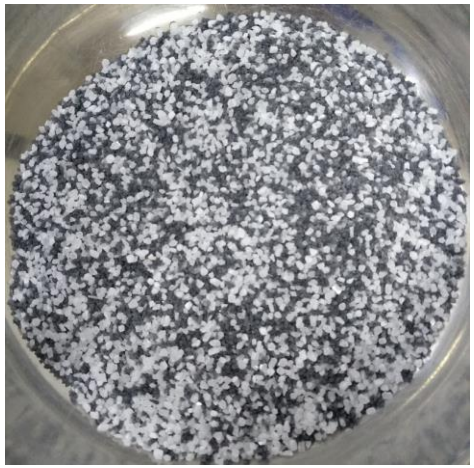
2. Experimental method --- selection of tracer particles



0.4mm
White quartz sand

2mm
White quartz sand

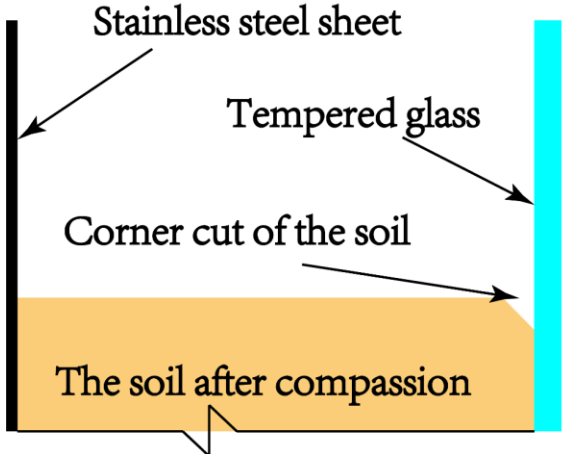
2mm
Black quartz sand

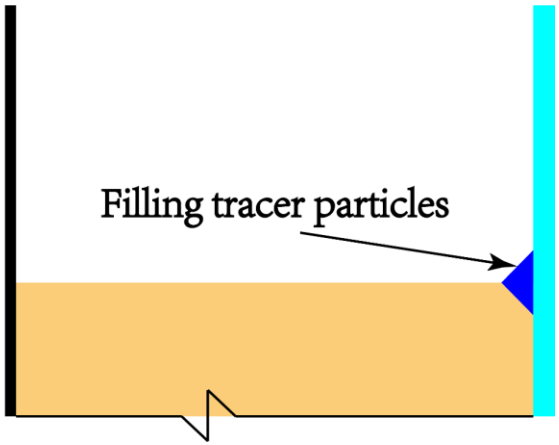


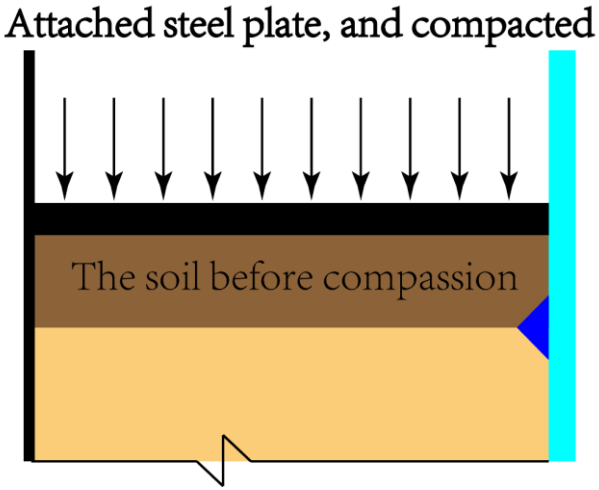
2mm
Mixed quartz sand

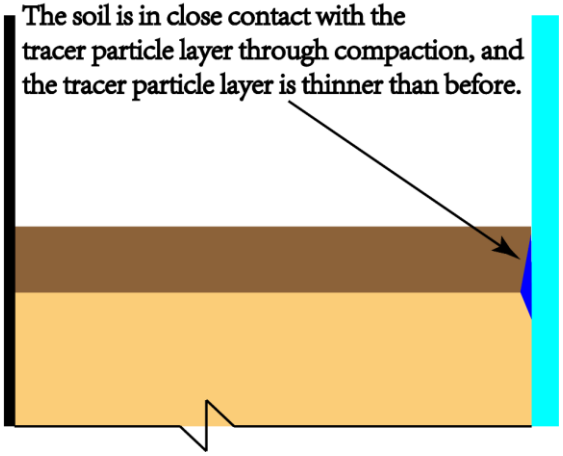
Principle:
Increase soil texture;
Minimize the impact on the test soil.

2. Experimental method --- Adding tracer particles



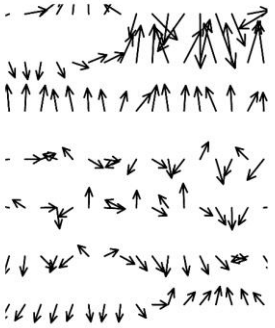






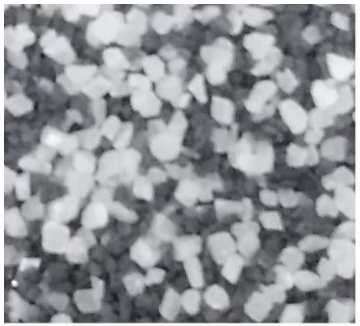
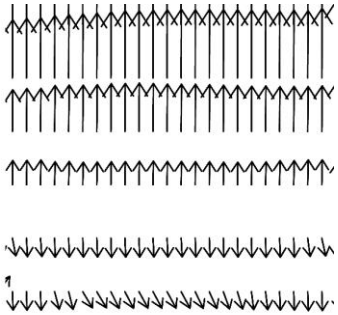
Example !

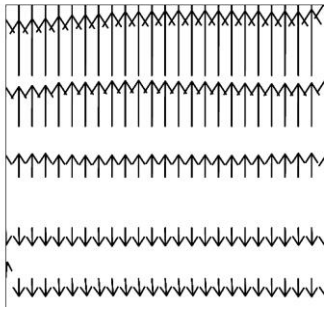
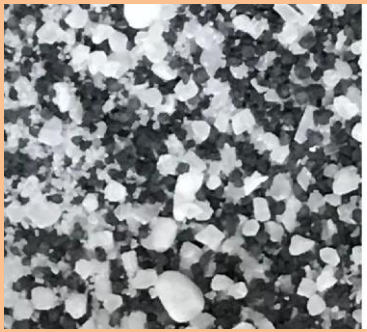
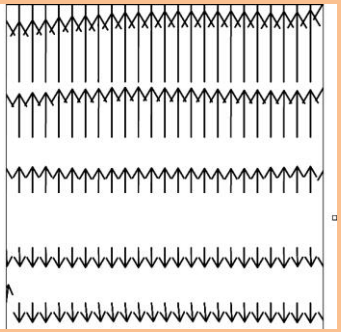
3. Results --- The verification of tracer particle



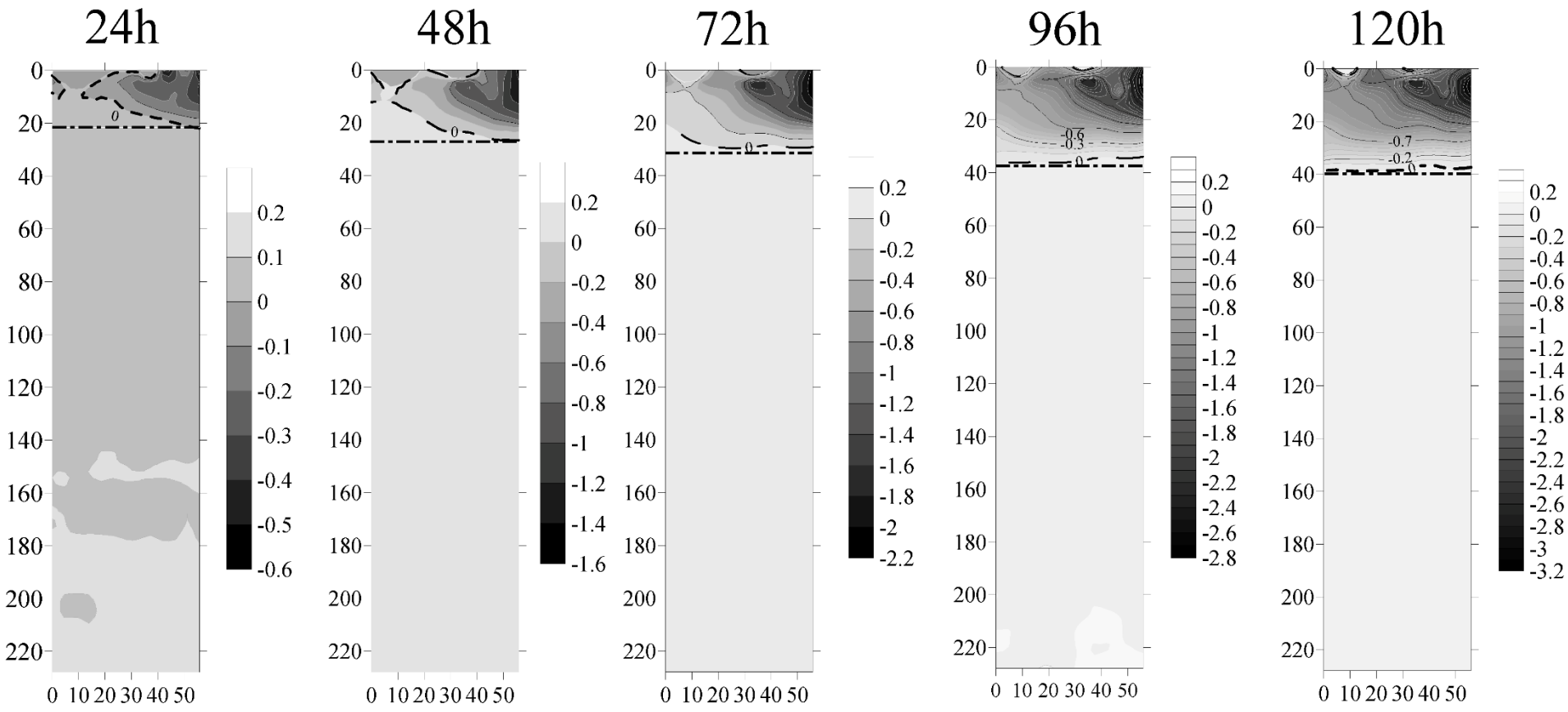


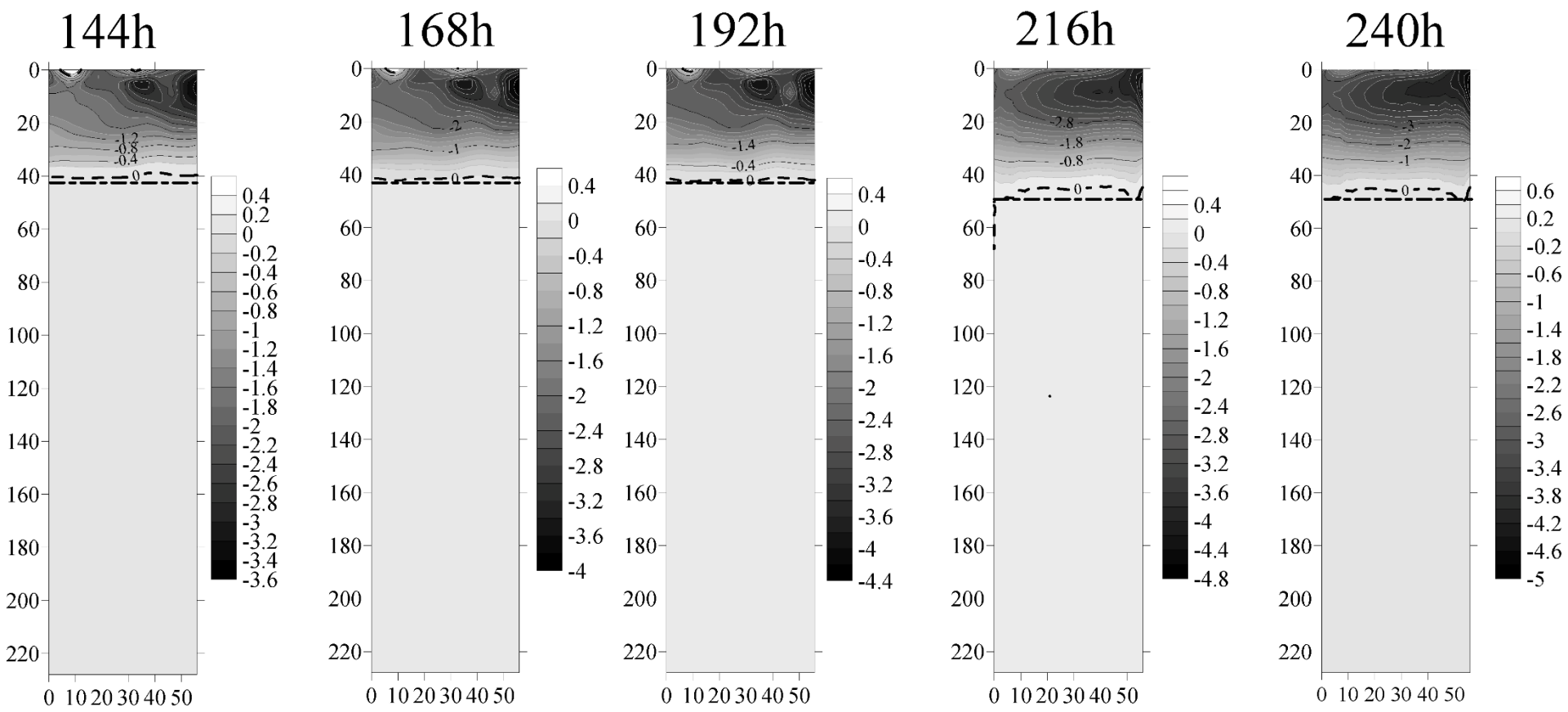

3. Results --- The y-directional displacement field (Unit: mm)

Negative value: frost heave positive value: settlement

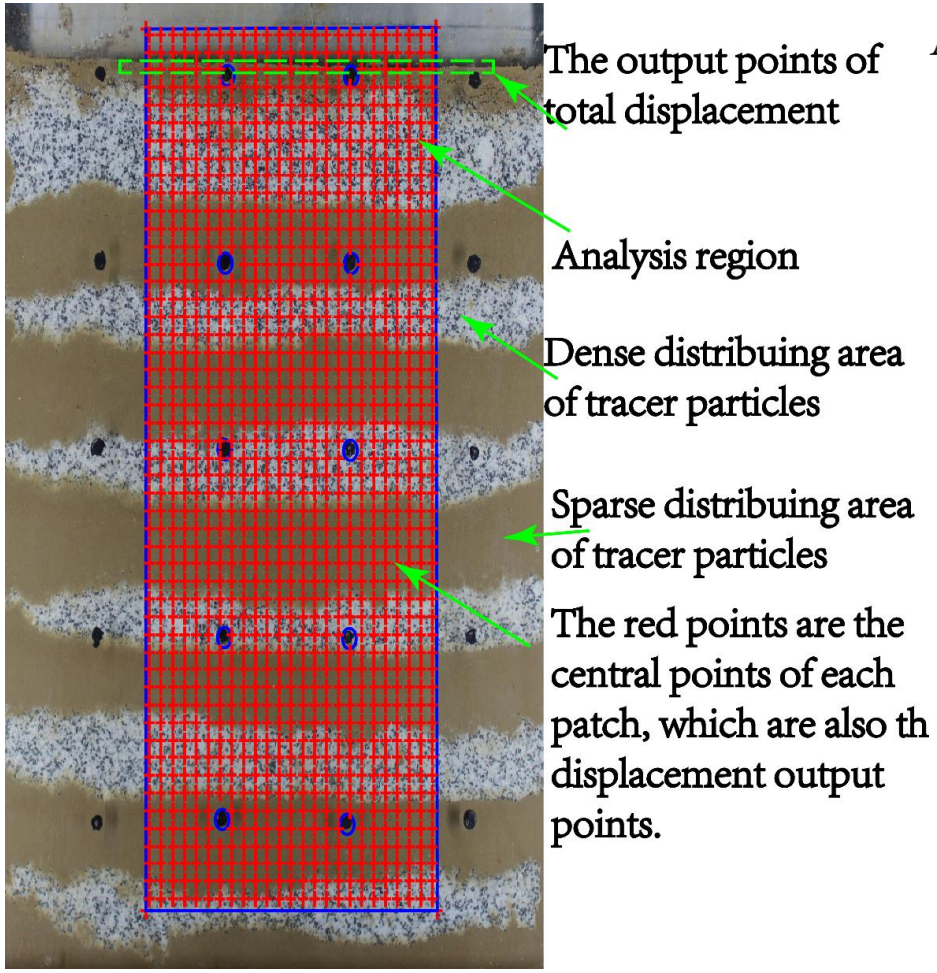


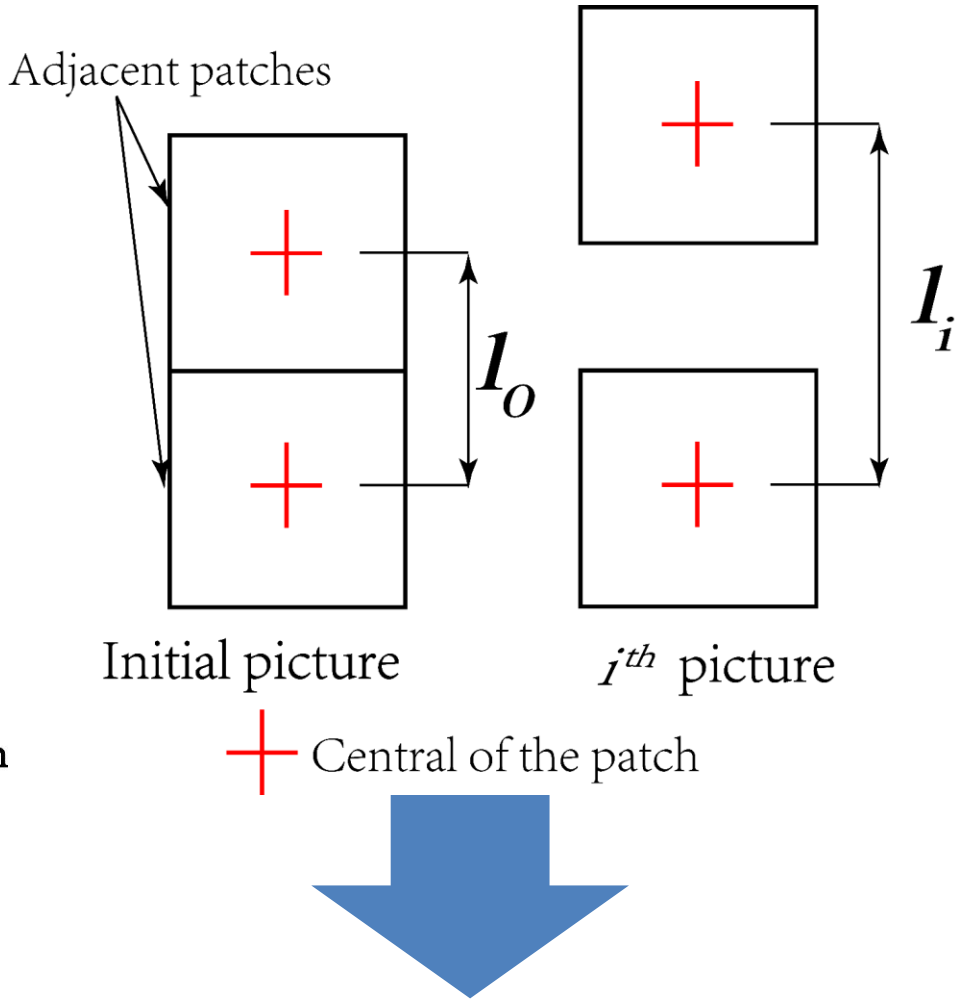
3. Results --- The y-directional displacement field

Phenomenon: There is a zero contour in each map, and the relationship between the zero contour and the frozen fringe is worth exploring.



3. Results --- The y-directional strain field

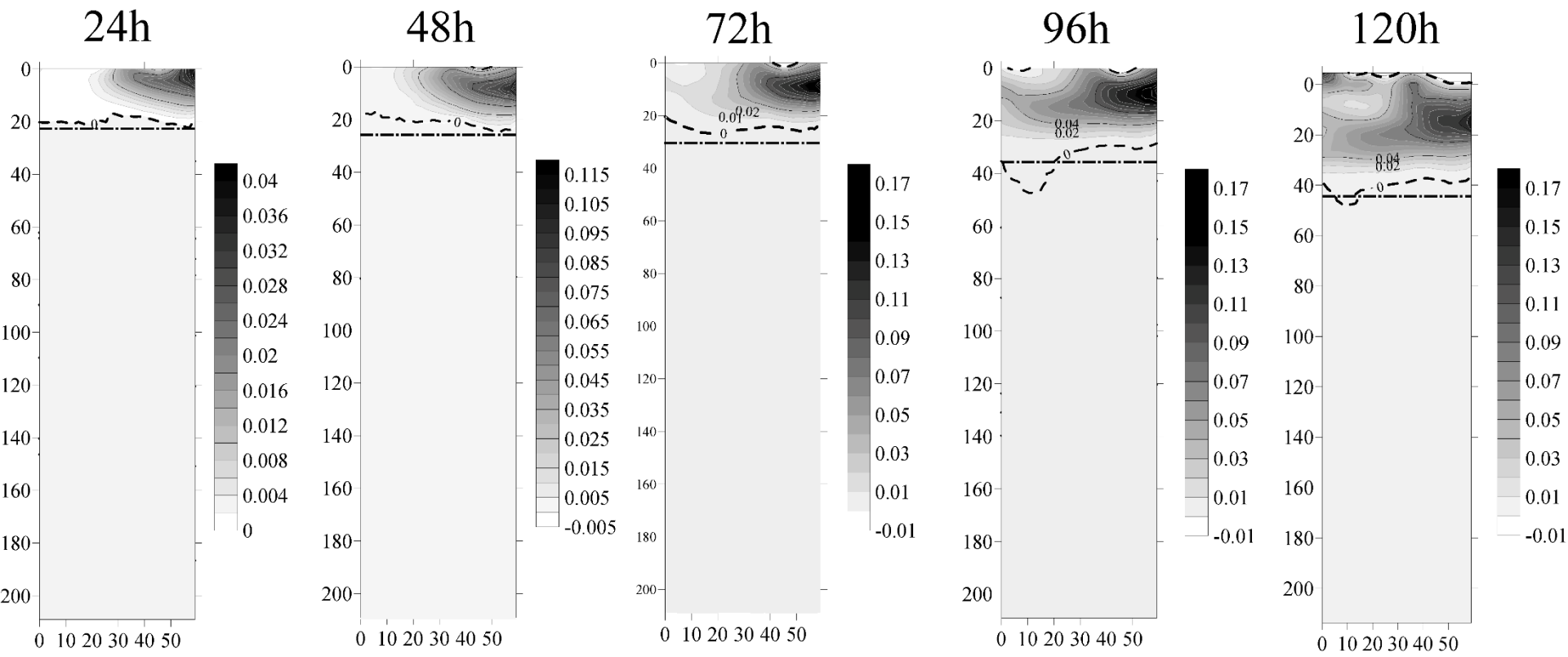




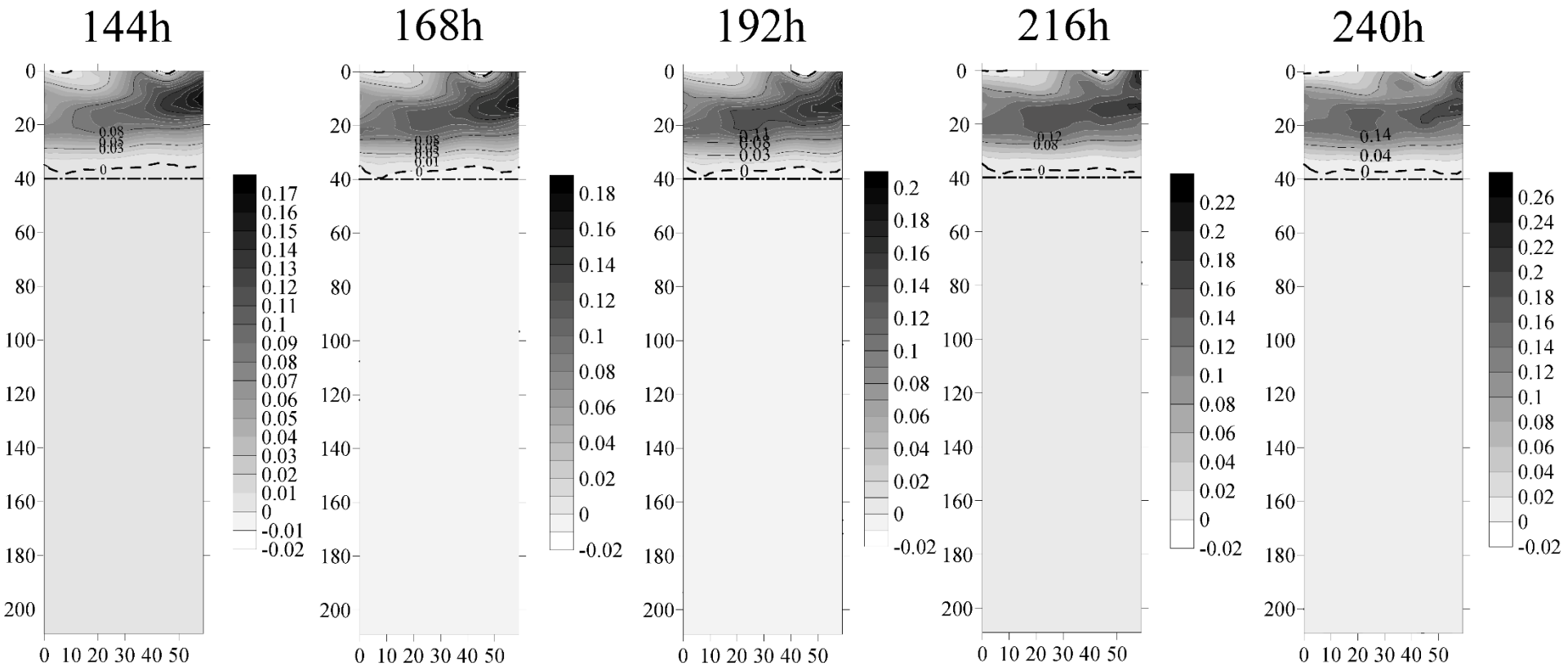
Calculation formula of vertical strain :

$$\varepsilon_y = \frac{l_i - l_0}{l_0}$$

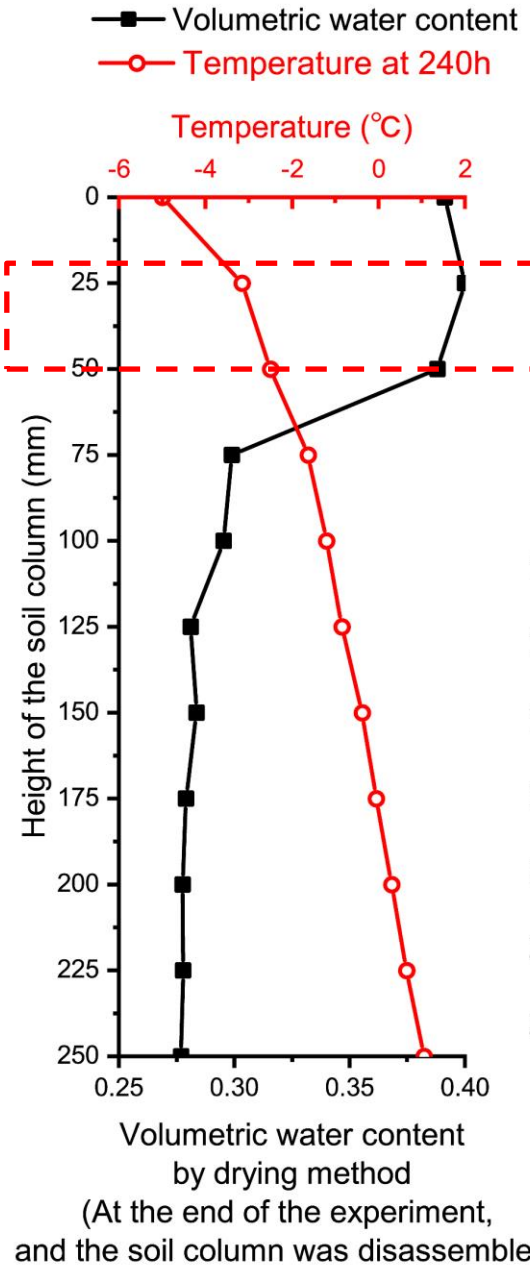
3. Results --- The y-directional strain field

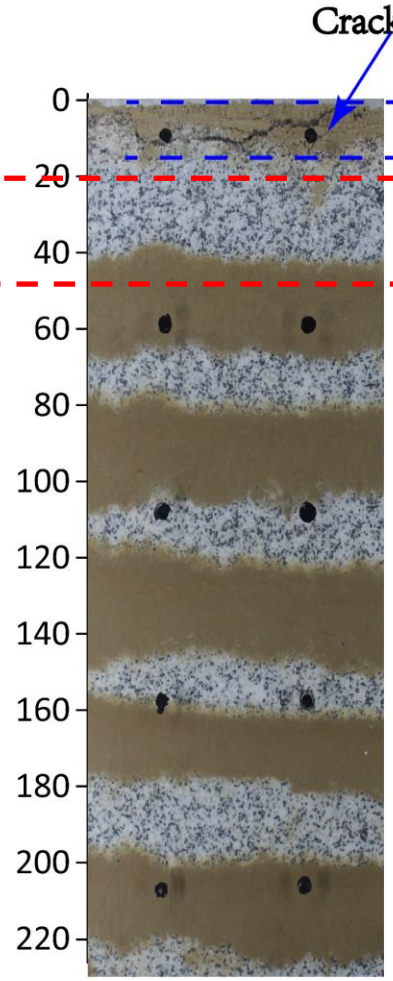


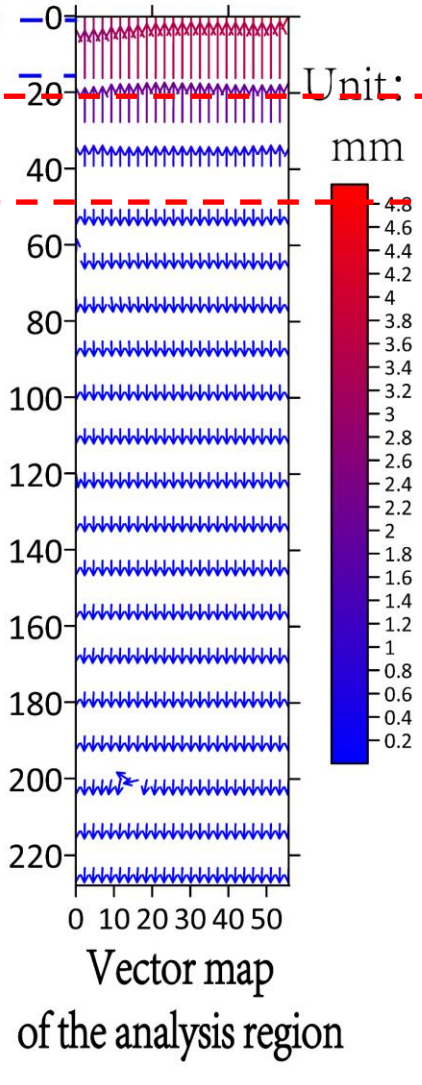
3. Results --- The y-directional strain field

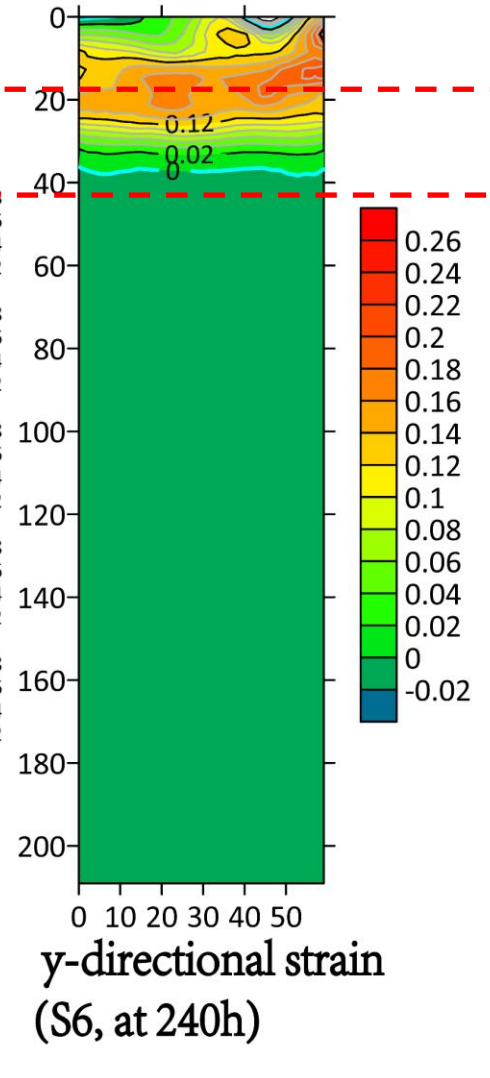


3. Results --- Comparison of displacement multiphysics

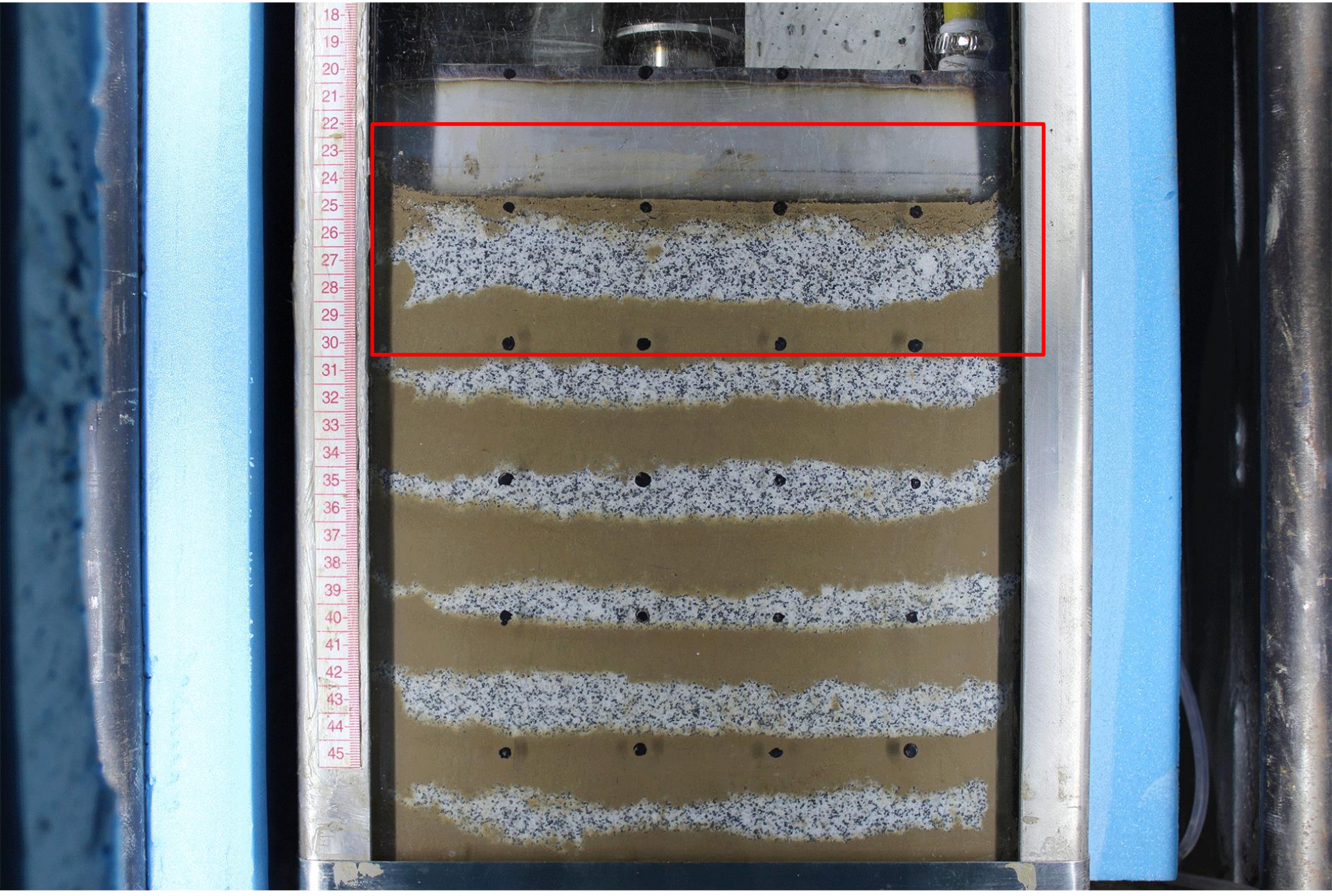




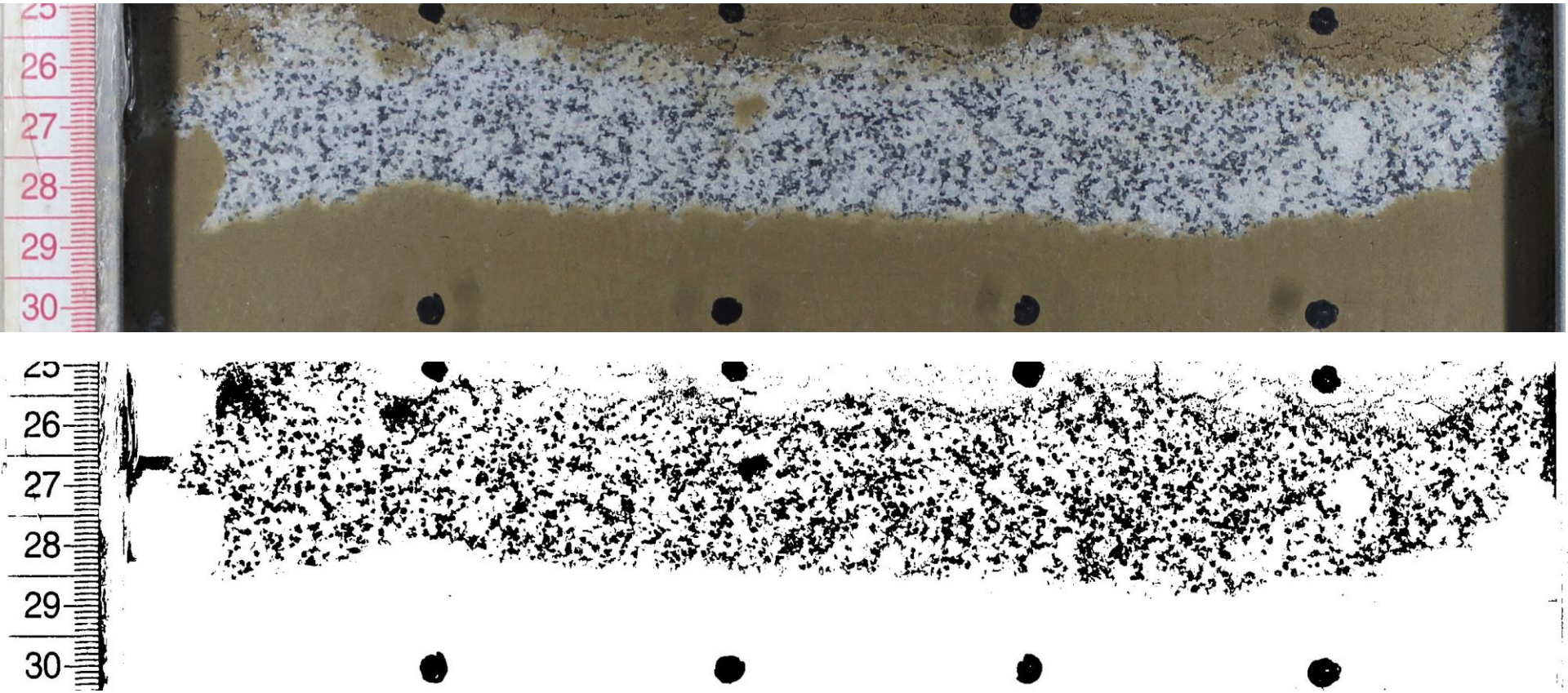




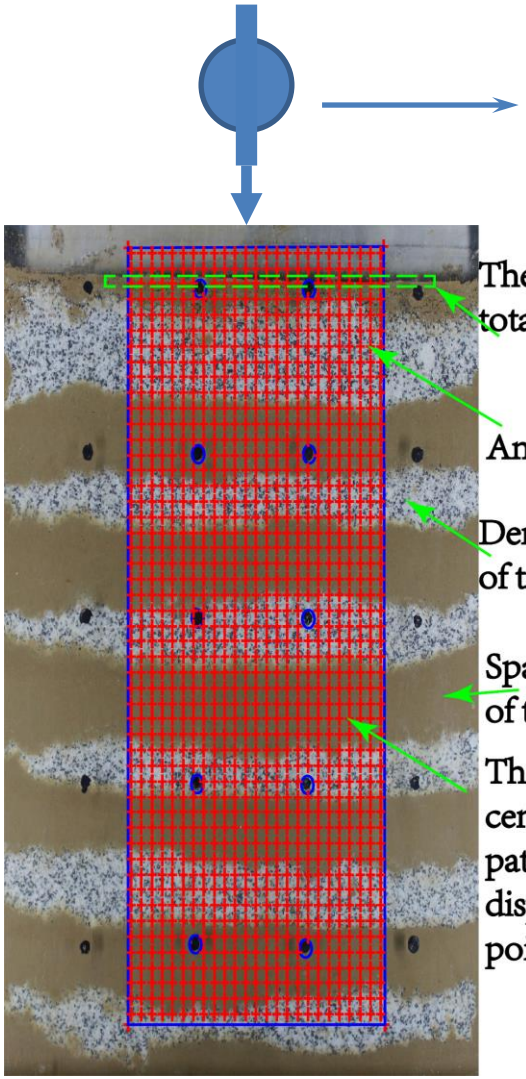
3. Results --- GIFs

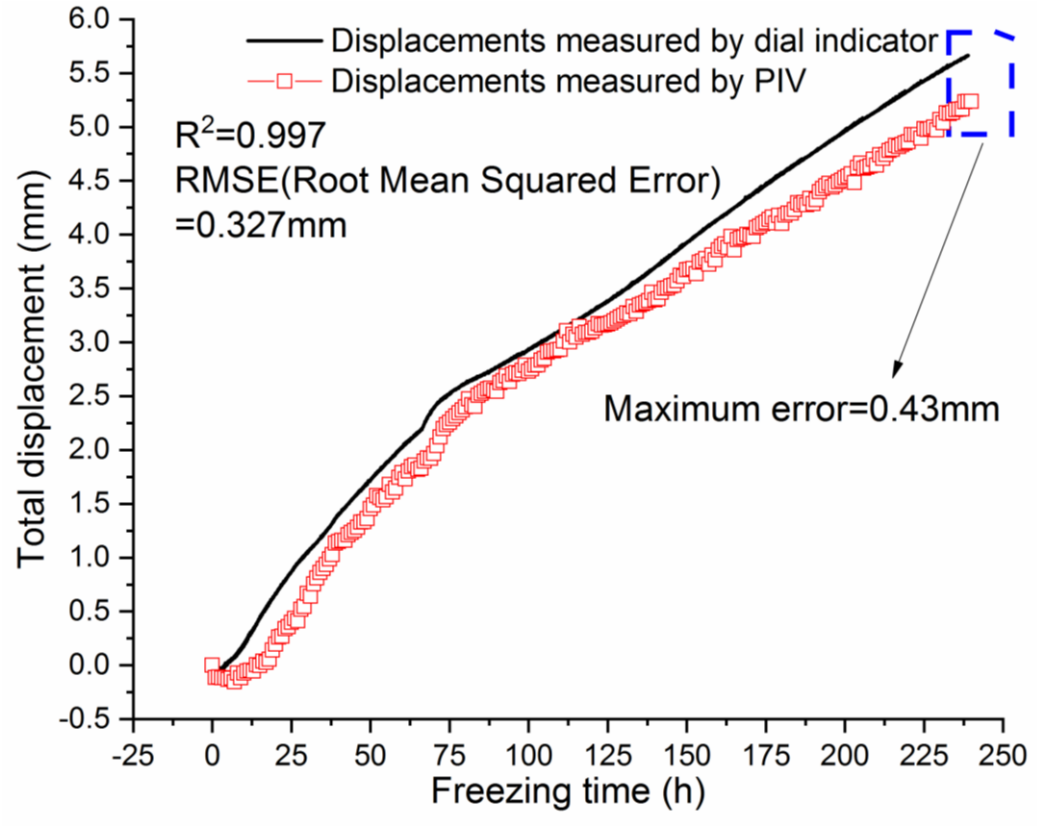


3. Results --- Crack evolution by binary images analysis

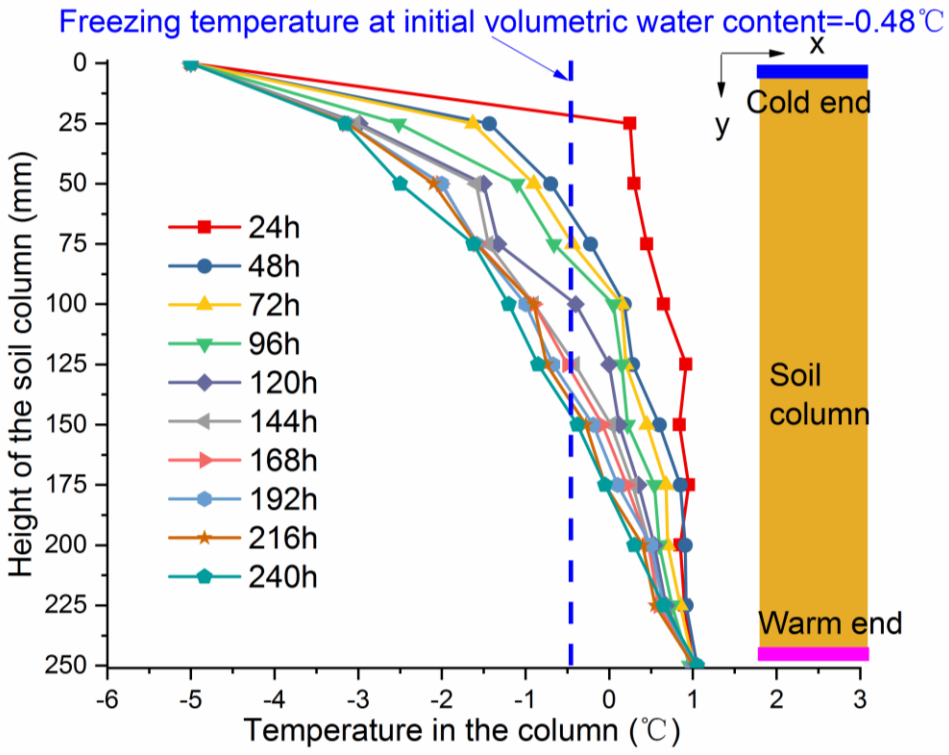


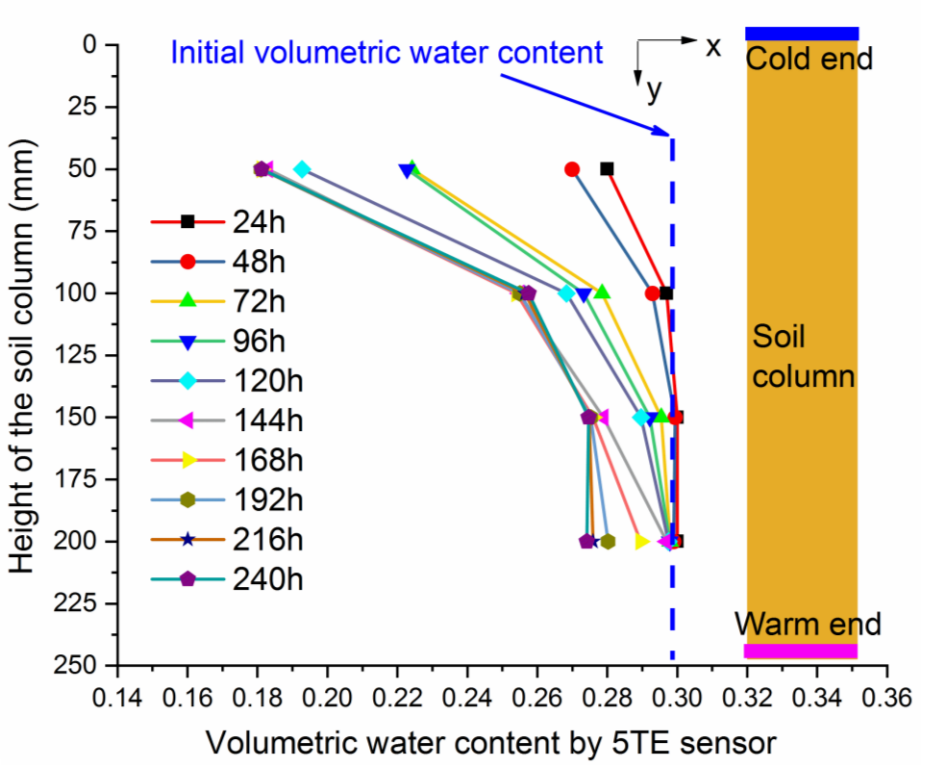
4. Discussion --- Displacement of the cold end





4. Discussion --- Temperature and unfrozen water content

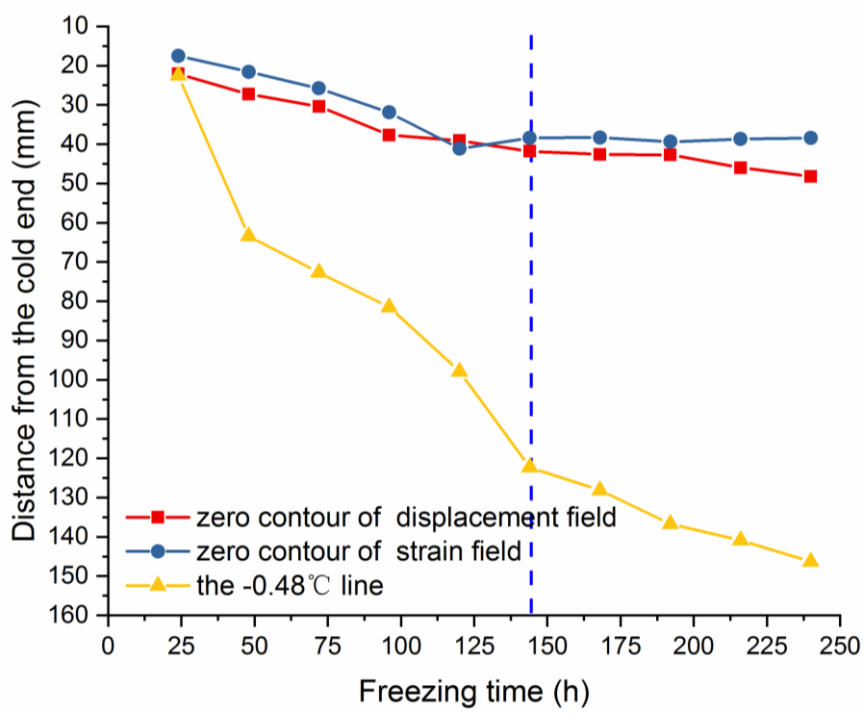




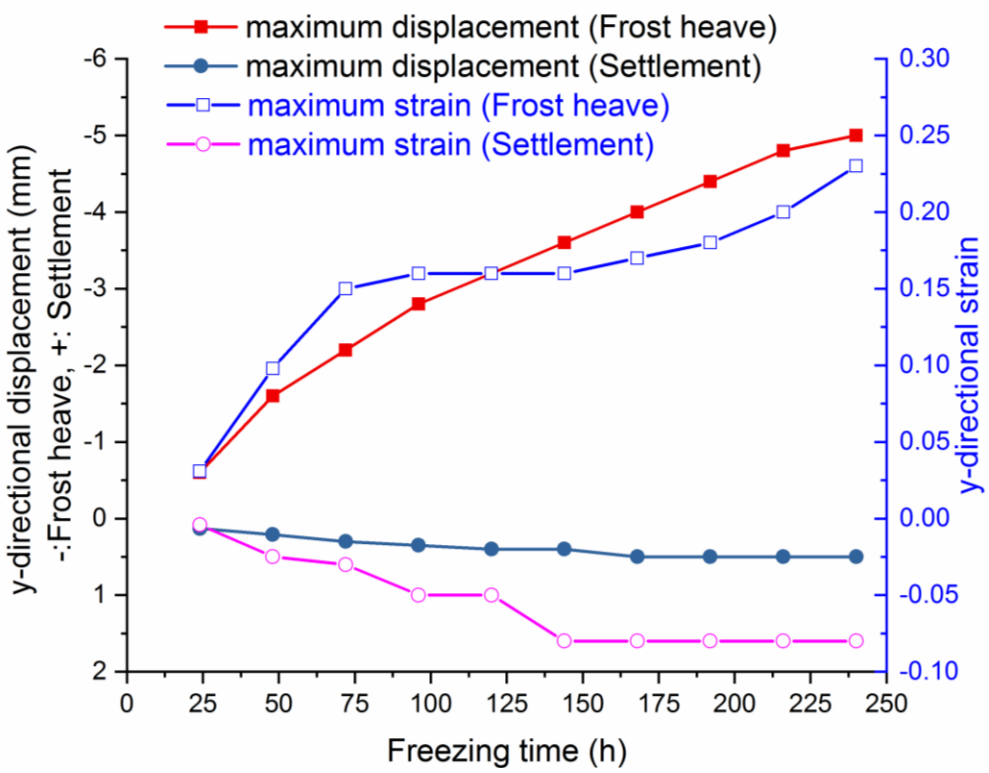
Temperature in each height

Unfrozen water content in each height

4. Discussion --- the evolution of zero contours and the position of the zone with maximum value

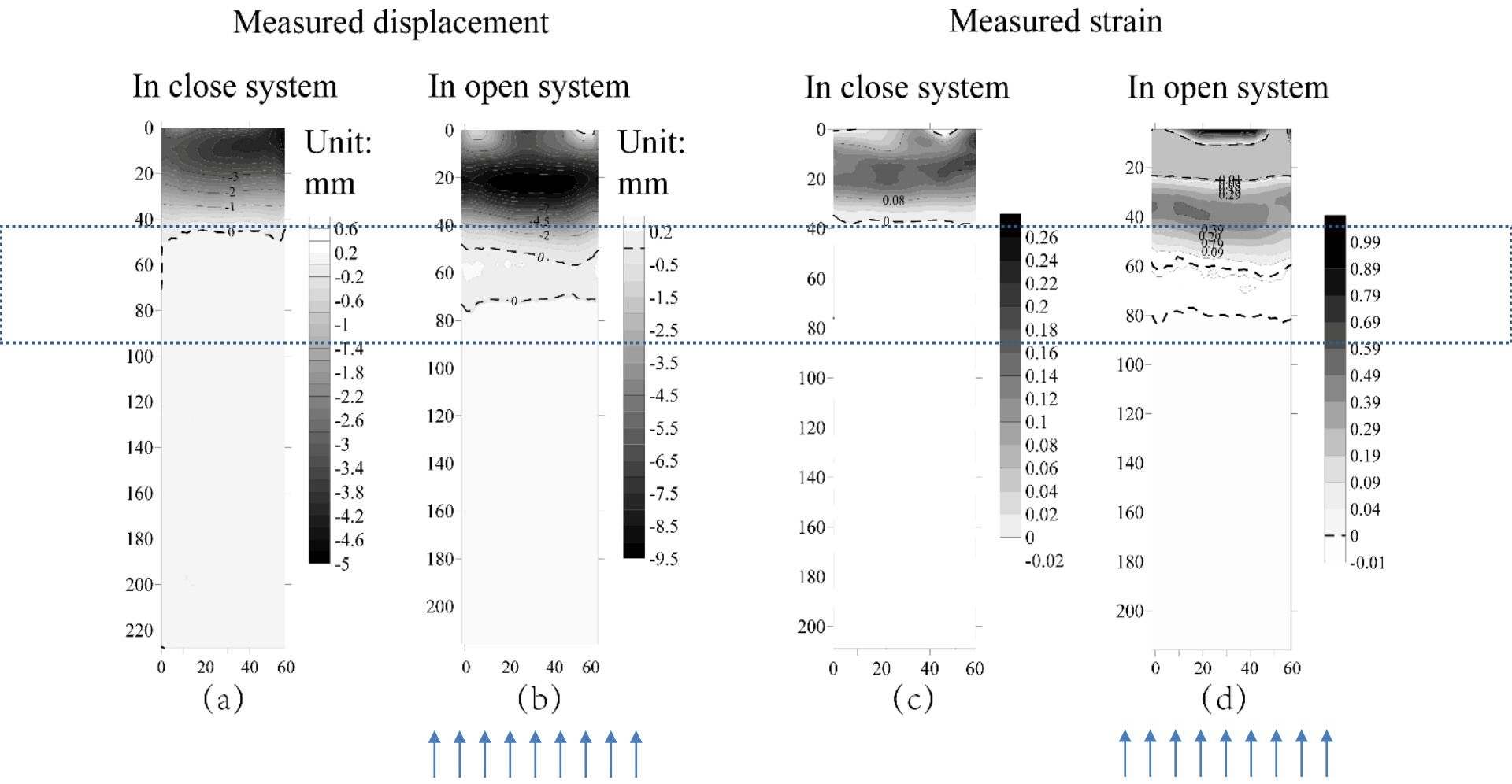


The position of the zero contour



The position of the maximum zone

Impact of open and closed systems



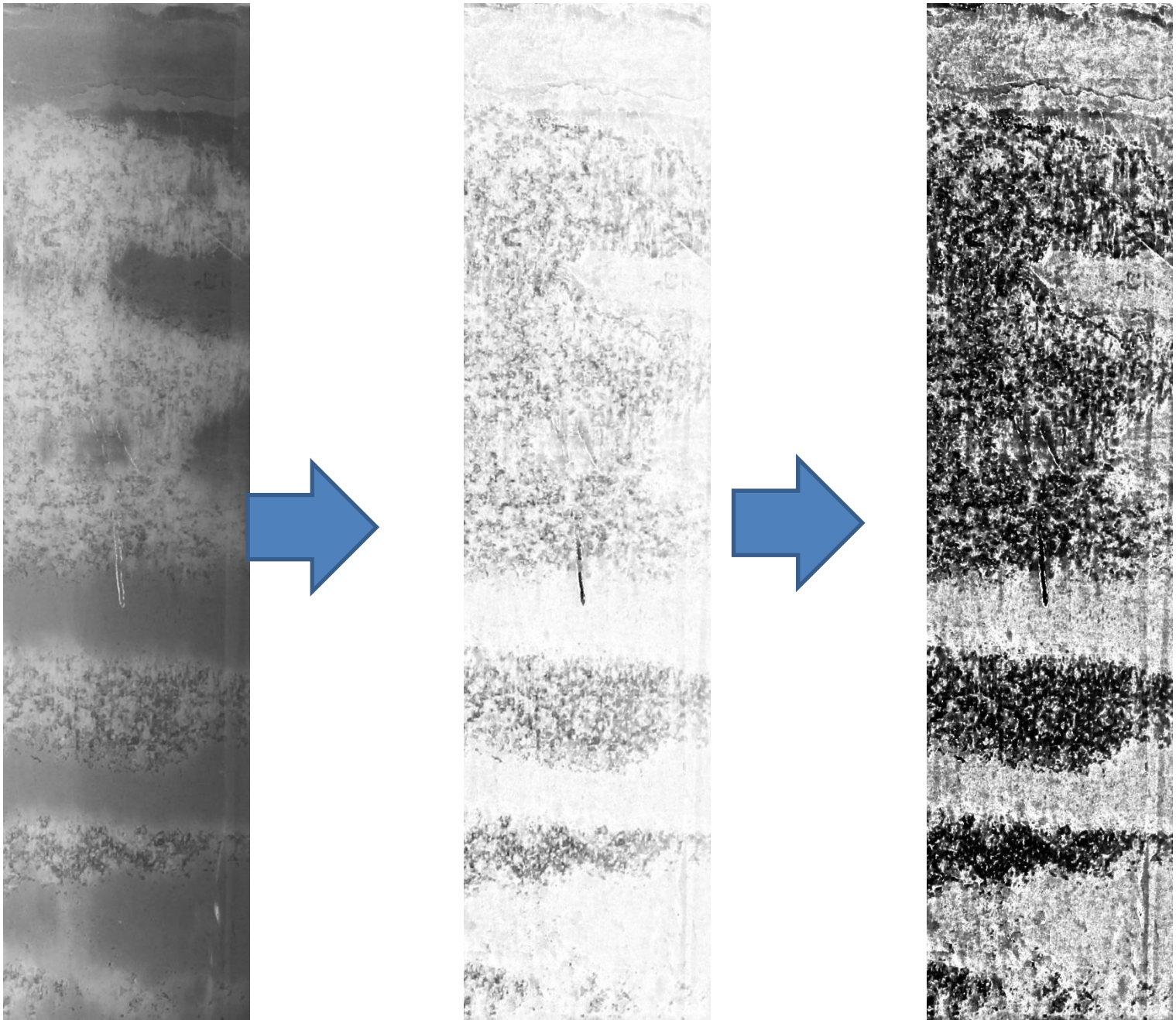
4. Discussion --- Conclusion

1. **Mixed quartz sand** is suitable for PIV analysis for indoor frost heave test, and the recommended mix ratio is： **2mm white : 2mm black : 4mm white : 0.4mm white = 1 : 1 : 0.2 : 0.8**；
2. In **closed system**, there was **an obvious zero contour** in each map which was the **dividing line** of soil **expansion and contraction**. Based on the strain map, it can be found that both the soil shrinkage under the frozen fringe and the soil expansion at the front of frozen fringe are **layered**；

Deficiencies and improvements：

1. Experiments **in open system** will be carried out in subsequent studies;
2. The strain is related to the **patch size**. In the subsequent experiments, the **relationship between patch size and strain calculation accuracy** will be discussed in detail, and an appropriate error estimation will be given;
3. The relationship between **ice lens formation** and **local strain** will be explored in subsequent experiments.

At the end



Thanks