Development of Special and Advanced Laboratory Apparatus and Applications in Testing the Behaviour of Geo-materials

by

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DEPARTMENT OF
CIVIL AND ENVIRONMENTAL ENGINEERING
土木及環境工程學系

1. Geotechnical Laboratories

- Soil Mechanics Laboratory
  - JH Yin
- Rock Mechanics Laboratory
- Geology Laboratory

2. Rock and Geology Labs

- Rock Mechanics Laboratory

  (a) Large Size Rock Direct Shear Box

  (b) Acoustic Emission Apparatus

  (c) More …

- Geology Laboratory

  Geology info/models and samples

  Best collection of Hong Kong rocks

  Small-scale physical models

3. Soil Mechanics Laboratory

(a) GDS 2Hz Dynamic Triaxial Apparatus: stress-path control and bender elements (added by PolyU) for shear wave velocity measurement

(b) A large-size direct shear box with PolyU modification:
304mm wide x 304mm (or 450mm) long x 204mm high

(c) A new double cell triaxial system: continuous measurement of total volume changes of unsaturated soils in triaxial testing

(d) A Hollow Cylinder Apparatus: control of 4 independent parameters, simulation of pure shearing, the principal stress rotation, …

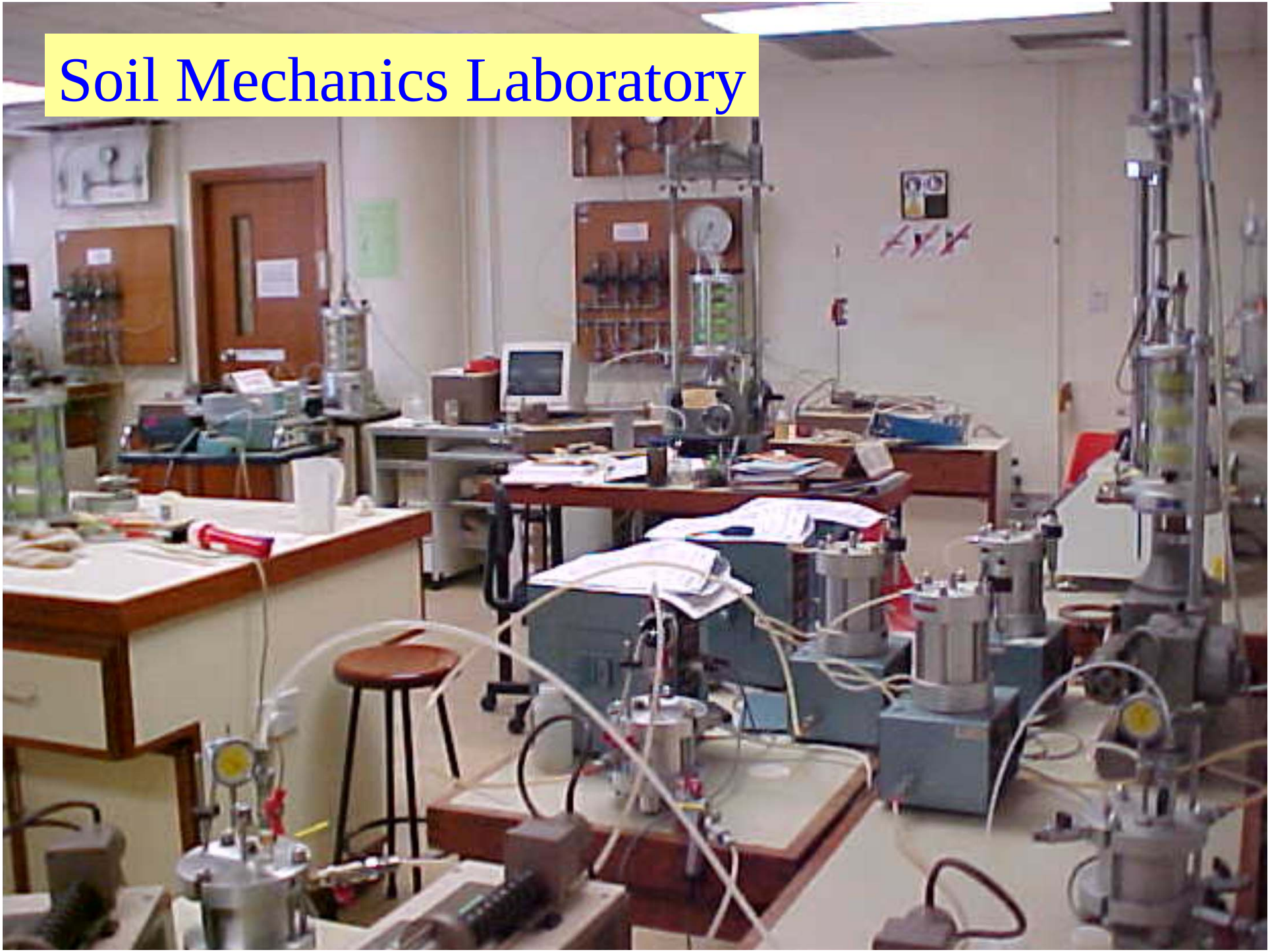
(e) A Truly Triaxial System with PolyU's new sliding loading plates: control of 3 principal stresses, study of middle principal influence …

(f) An innovative soil nail pullout box: for studying the interface shear strength between nail and soils under various controlled conditions

(g) A direct shear box for testing both saturated and unsaturated soils and interface with PolyU modification: 100mm wide x 100mm long x 40mm high

(h) Physical models …

Soil Mechanics Laboratory



Why triaxial tests and cyclic?

GDS 2Hz Dynamic Triaxial Apparatus – stress-path control and bender elements for shear wave velocity measurement

$$\tau_f = c' + \sigma'_f \tan\phi'$$

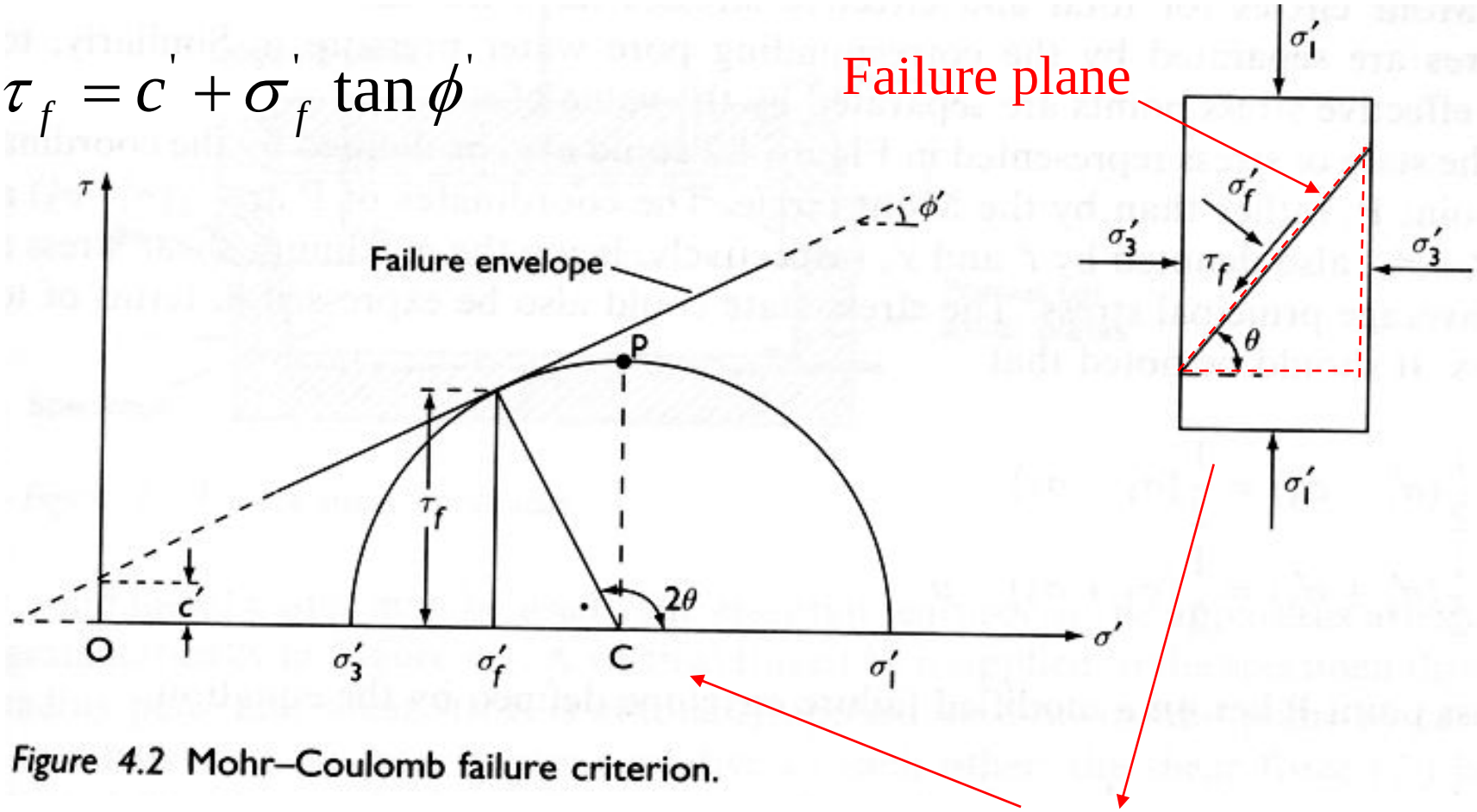


Figure 4.2 Mohr–Coulomb failure criterion.

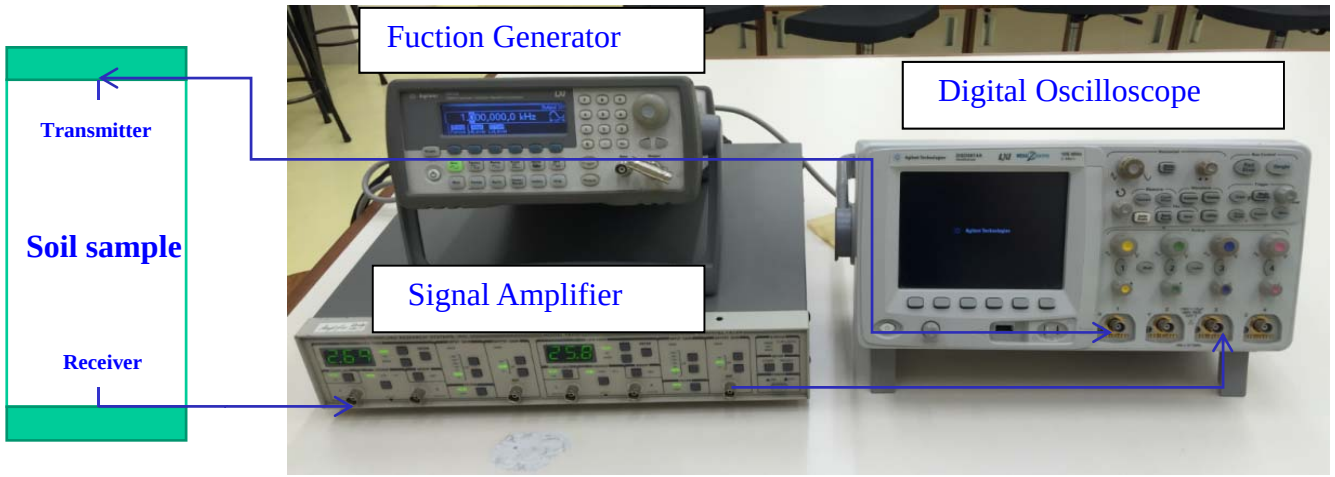
$$\tau_f = \frac{1}{2}(\sigma'_1 - \sigma'_3)\sin 2\theta; \quad \sigma'_f = \frac{1}{2}(\sigma'_1 + \sigma'_3) + \frac{1}{2}(\sigma'_1 - \sigma'_3)\cos 2\theta$$

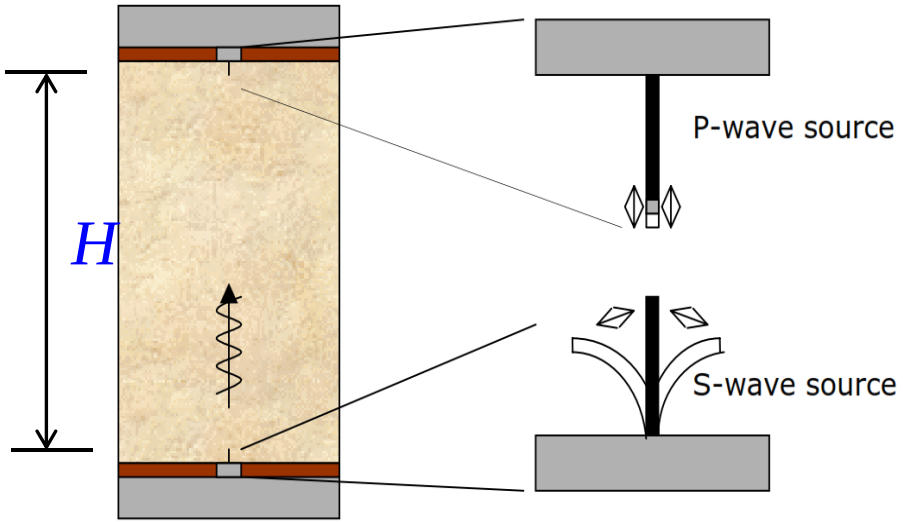
θ is the angle between major principal plane and the failure plane

$$\because 2\theta = 90^o + \phi'; \quad \therefore \theta = 45^o + \frac{\phi'}{2}$$

Methodologies

Bender element measurement system





$$V_s = \frac{H}{\Delta t_s} \quad V_p = \frac{H}{\Delta t_p}$$

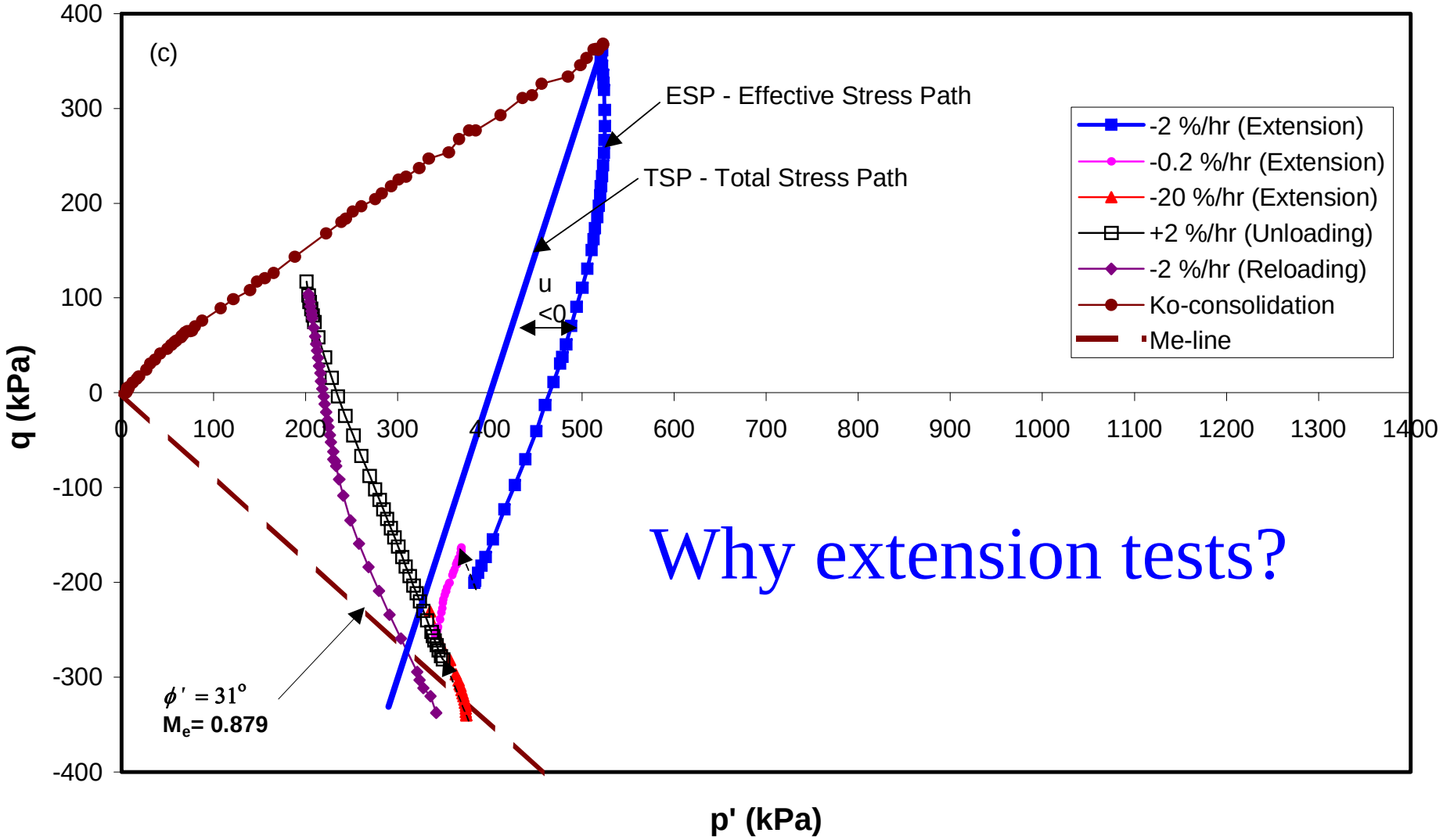
$$\nu = \frac{1}{2}\frac{\left(\frac{V_p}{V_s}\right)^2 - 2}{\left(\frac{V_p}{V_s}\right)^2 - 1}$$

$$G_{\max} = \rho V_s^2 \quad E_{\max} = 2G_{\max}(1+\nu)$$

Why bender element tests?

Failure of specimen C400 after K_o-consolidated compression testing and (c) failure of specimen E400 after K_o-consolidated extension testing

Why extension test?



Effective stress paths for test E400 – K_o-consolidation, step-changed axial extension and unloading/reloading

4. Large-size Direct Shear Box Tests on Interfaces and Findings

Why large size shear box?

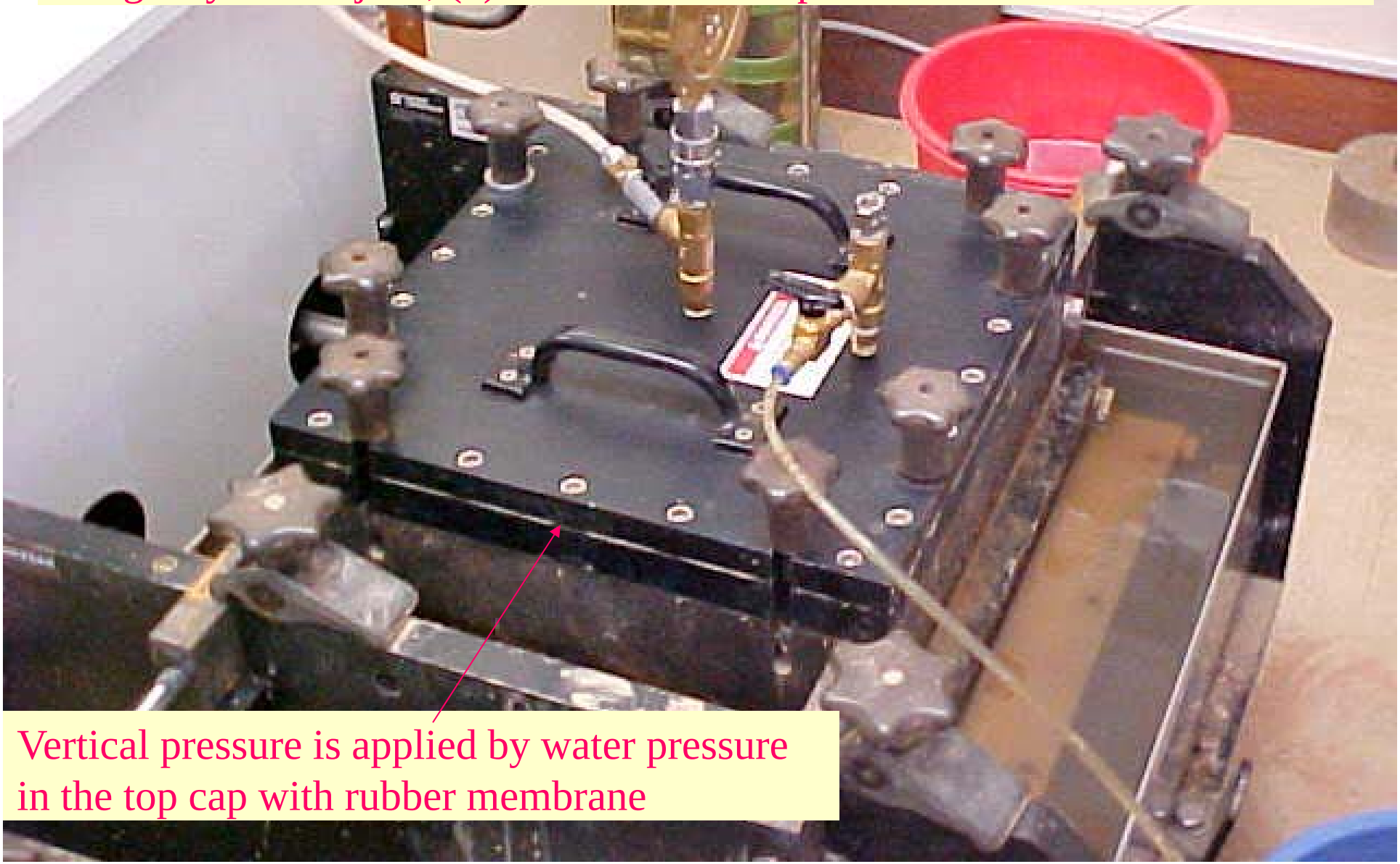
(a) Between metallic strips and fill

(b) Between geo-synthetics and fill

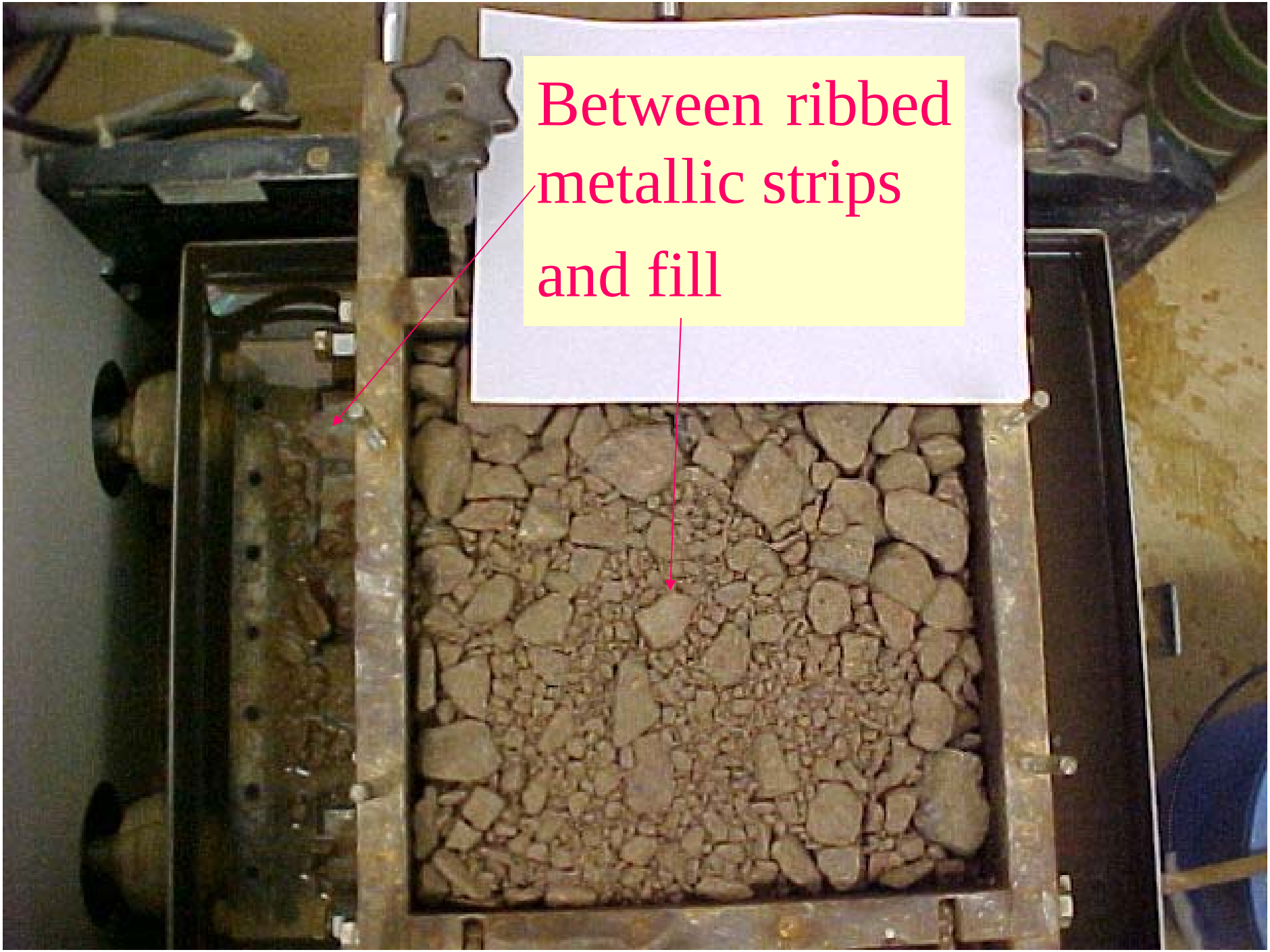
(c) Between pre-cast cement grout and soil

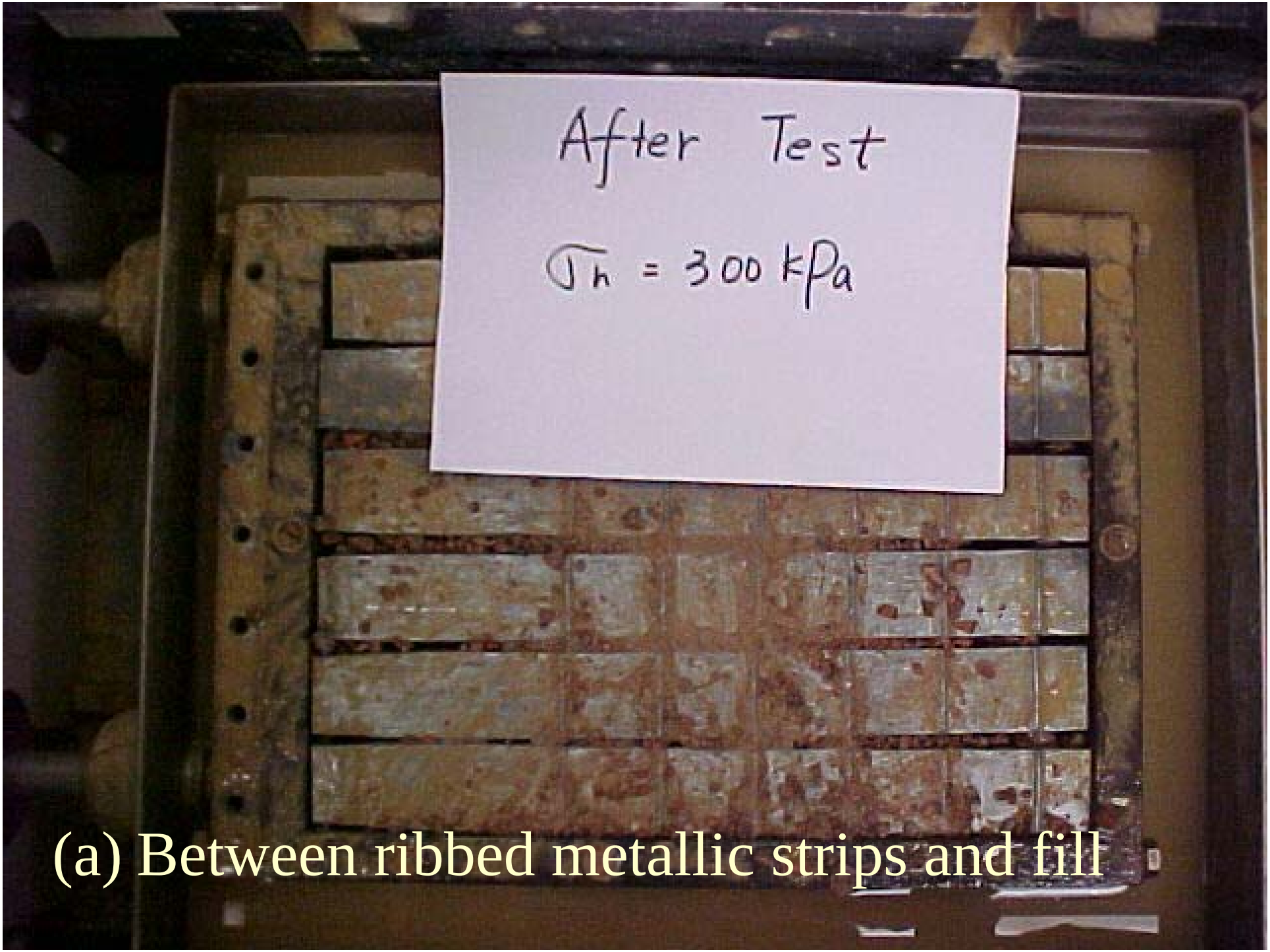
(d) Between cement grout and soil

Large-size direct shear box： 304mm wide x 304mm (or 450mm) long x 204mm high - (a) increase horizontal load capacity using a hydraulic jack, (b) increase vertical pressure to 700 kPa



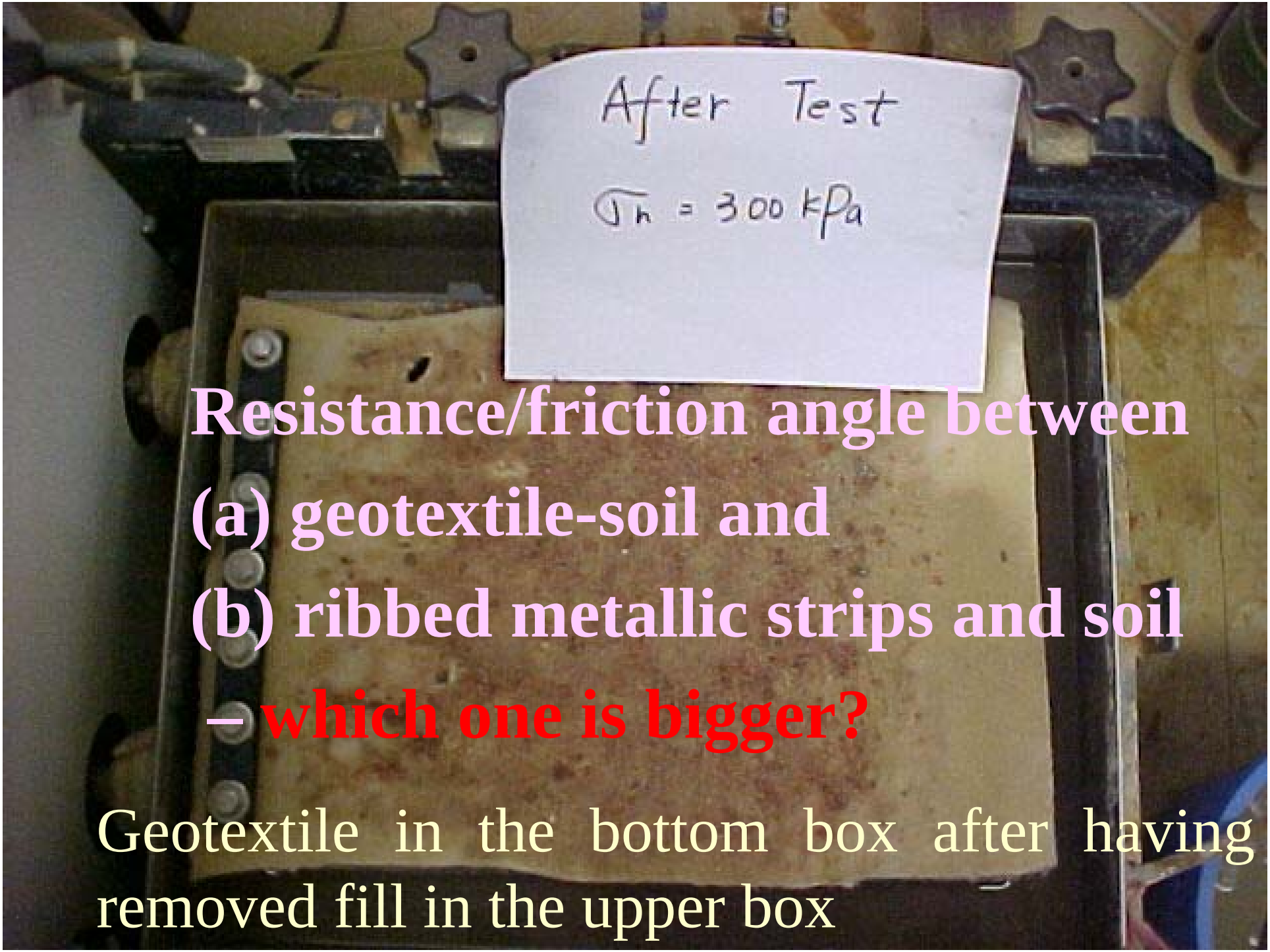
Vertical pressure is applied by water pressure in the top cap with rubber membrane


Between ribbed
metallic strips
and fill



(a) Between ribbed metallic strips and fill

Between
geotextile
and fill



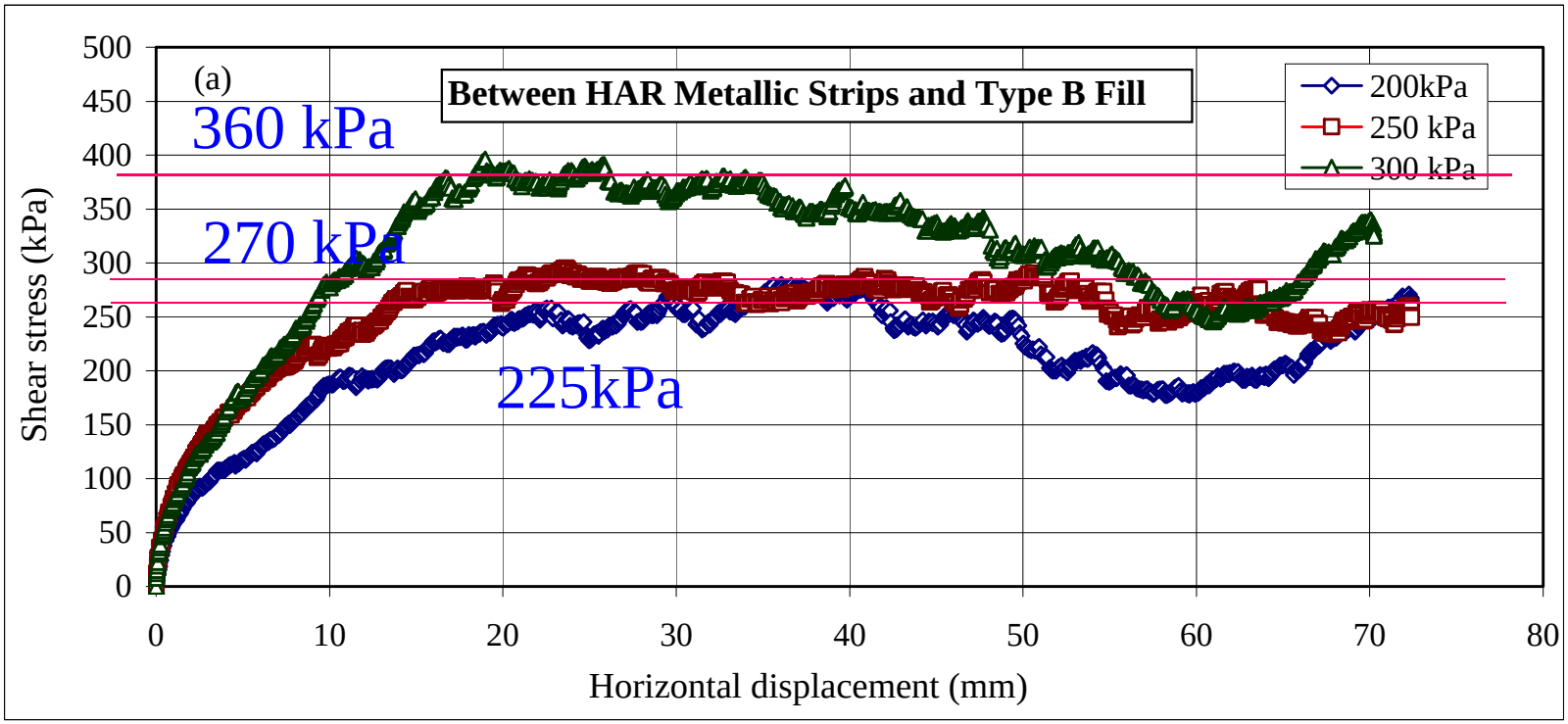
Resistance/friction angle between

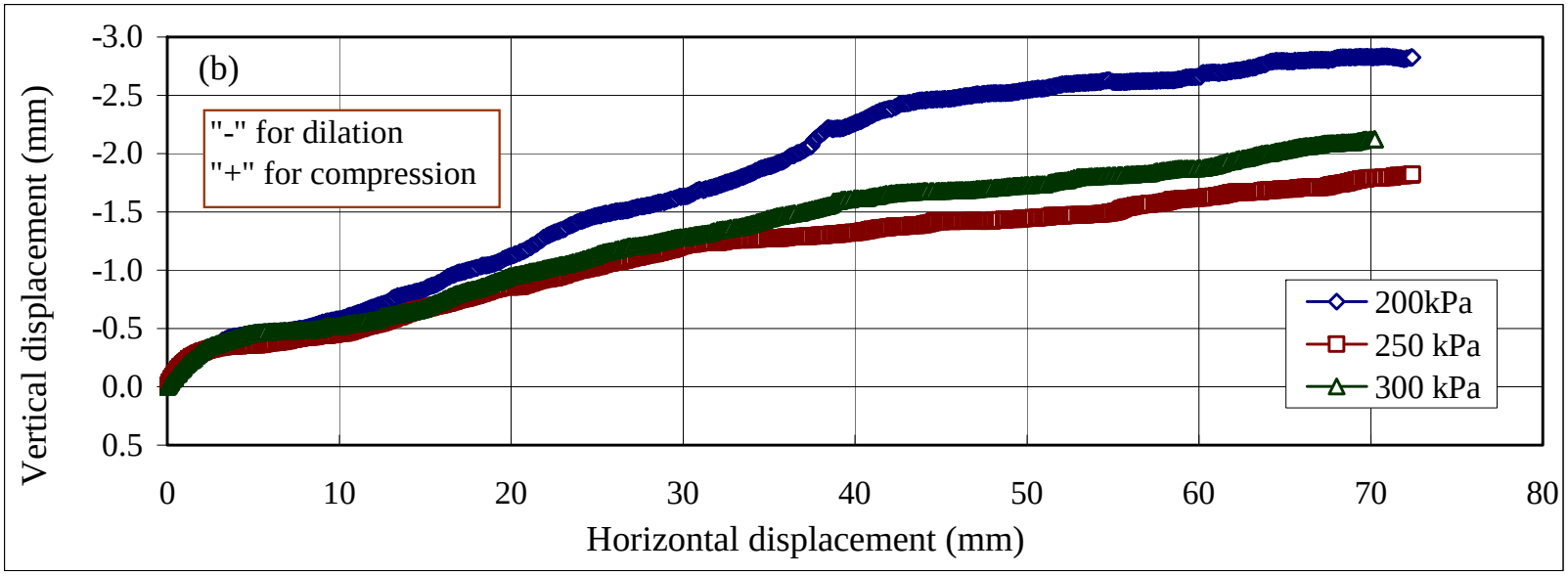
(a) geotextile-soil and

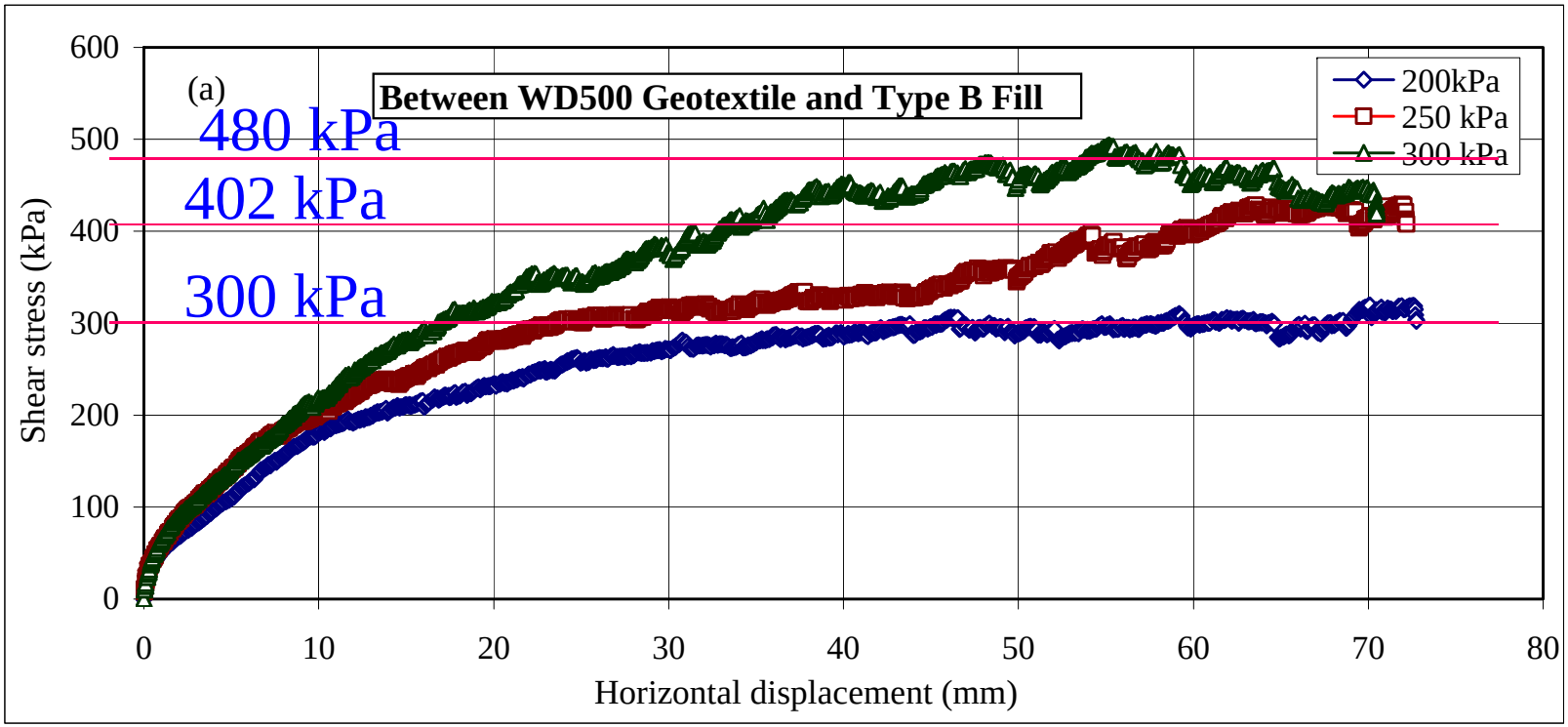
(b) ribbed metallic strips and soil

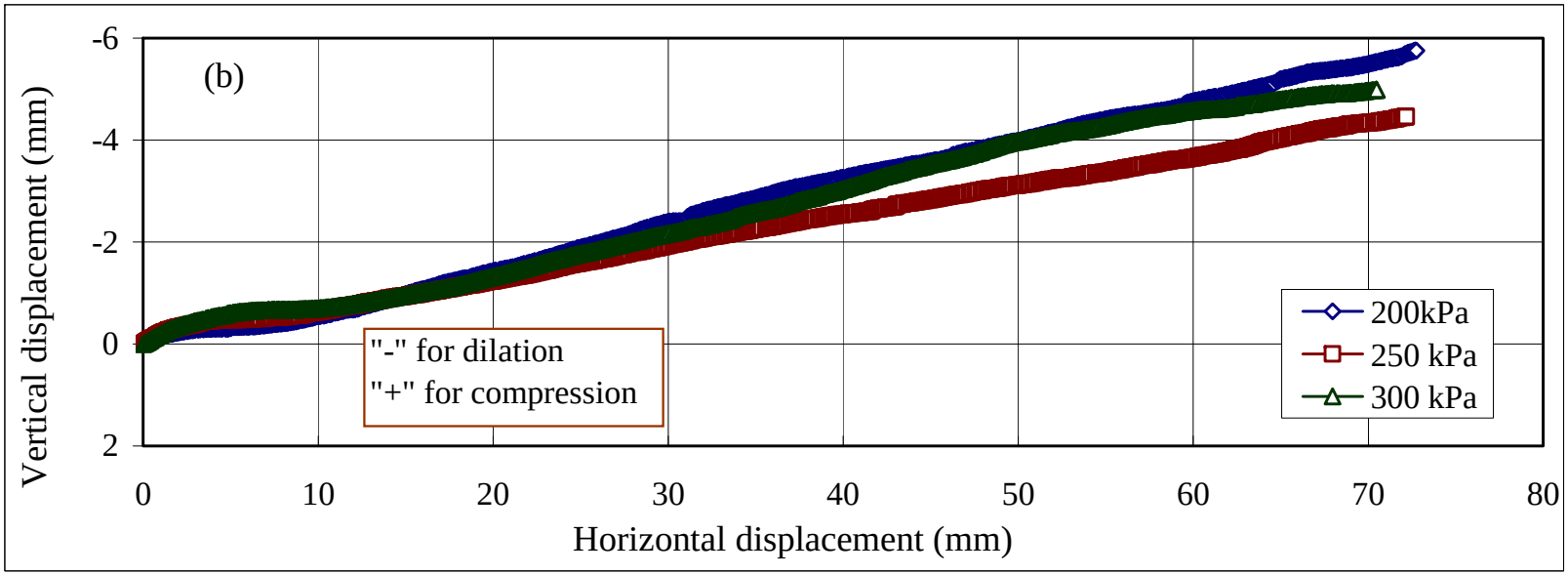
– which one is bigger?

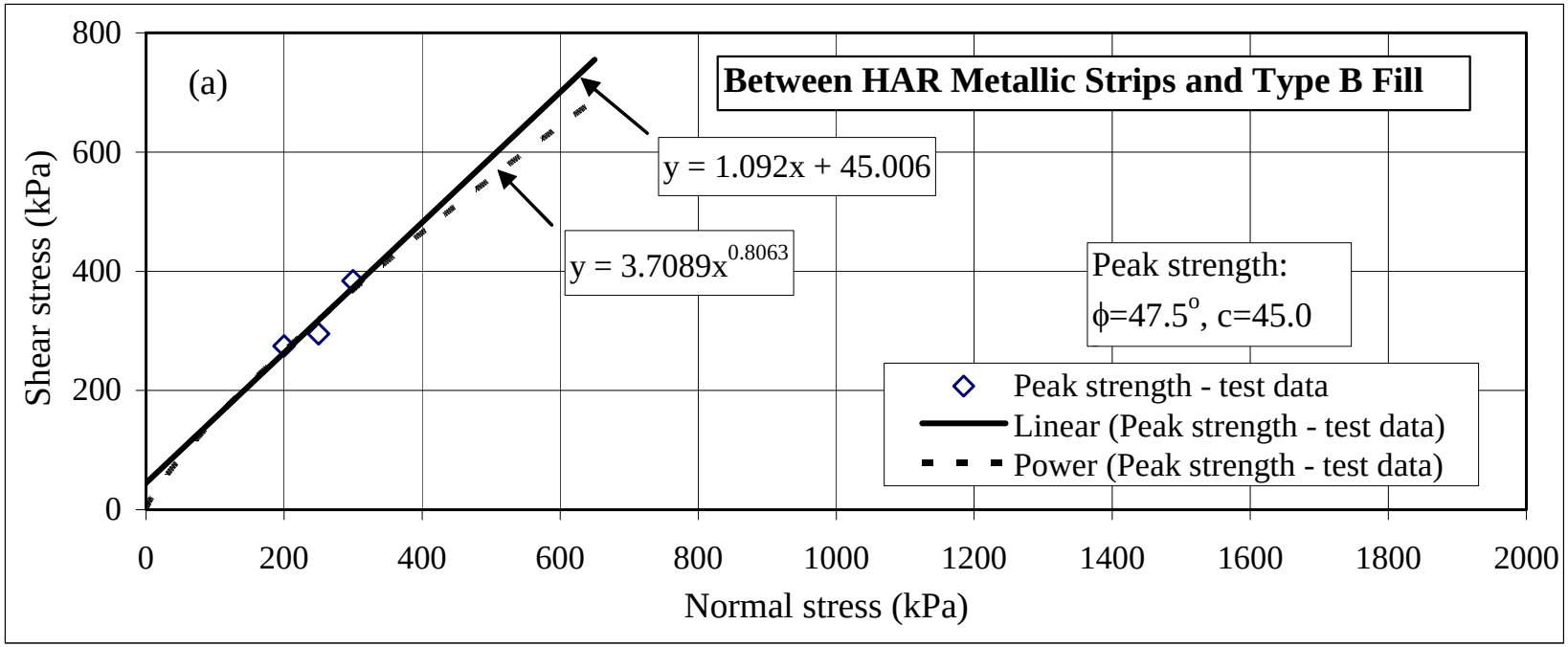
Geotextile in the bottom box after having removed fill in the upper box

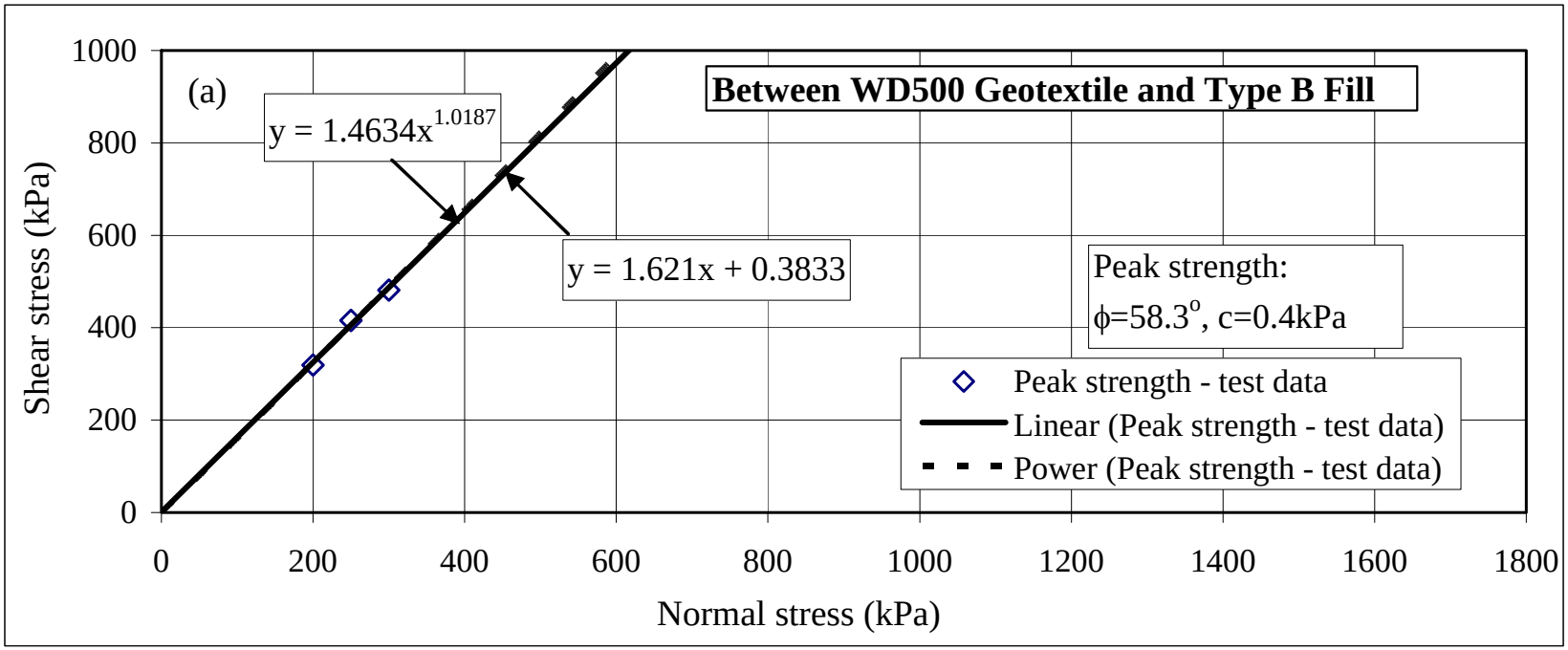

(a)
Between HAR Metallic Strips and Type B Fill
360 kPa
270 kPa
225kPa
200kPa
250 kPa
300 kPa
Shear stress (kPa)
Horizontal displacement (mm)
0
50
100
150
200
250
300
350
400
450
500
0
10
20
30
40
50
60
70
80


(b)
"-" for dilation
"+" for compression
200kPa
250 kPa
300 kPa
Vertical displacement (mm)
Horizontal displacement (mm)
-3.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
0
10
20
30
40
50
60
70
80


(a)
Between WD500 Geotextile and Type B Fill
480 kPa
402 kPa
300 kPa
200kPa
250 kPa
300 kPa
Shear stress (kPa)
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
Horizontal displacement (mm)


(b)
"-" for dilation
"+" for compression
200kPa
250 kPa
300 kPa
Vertical displacement (mm)
-6
-4
-2
0
2
0
10
20
30
40
50
60
70
80
Horizontal displacement (mm)


(a)
Between HAR Metallic Strips and Type B Fill
y = 1.092x + 45.006
y = 3.7089x^0.8063
Peak strength:
ϕ=47.5°, c=45.0
Peak strength - test data
Linear (Peak strength - test data)
Power (Peak strength - test data)
Shear stress (kPa)
Normal stress (kPa)
0
200
400
600
800
1000
1200
1400
1600
1800
2000


(a)
Between WD500 Geotextile and Type B Fill
y = 1.4634x^1.0187
y = 1.621x + 0.3833
Peak strength:
ϕ=58.3°, c=0.4kPa
Peak strength - test data
Linear (Peak strength - test data)
Power (Peak strength - test data)
Shear stress (kPa)
Normal stress (kPa)
0
200
400
600
800
1000
1200
1400
1600
1800

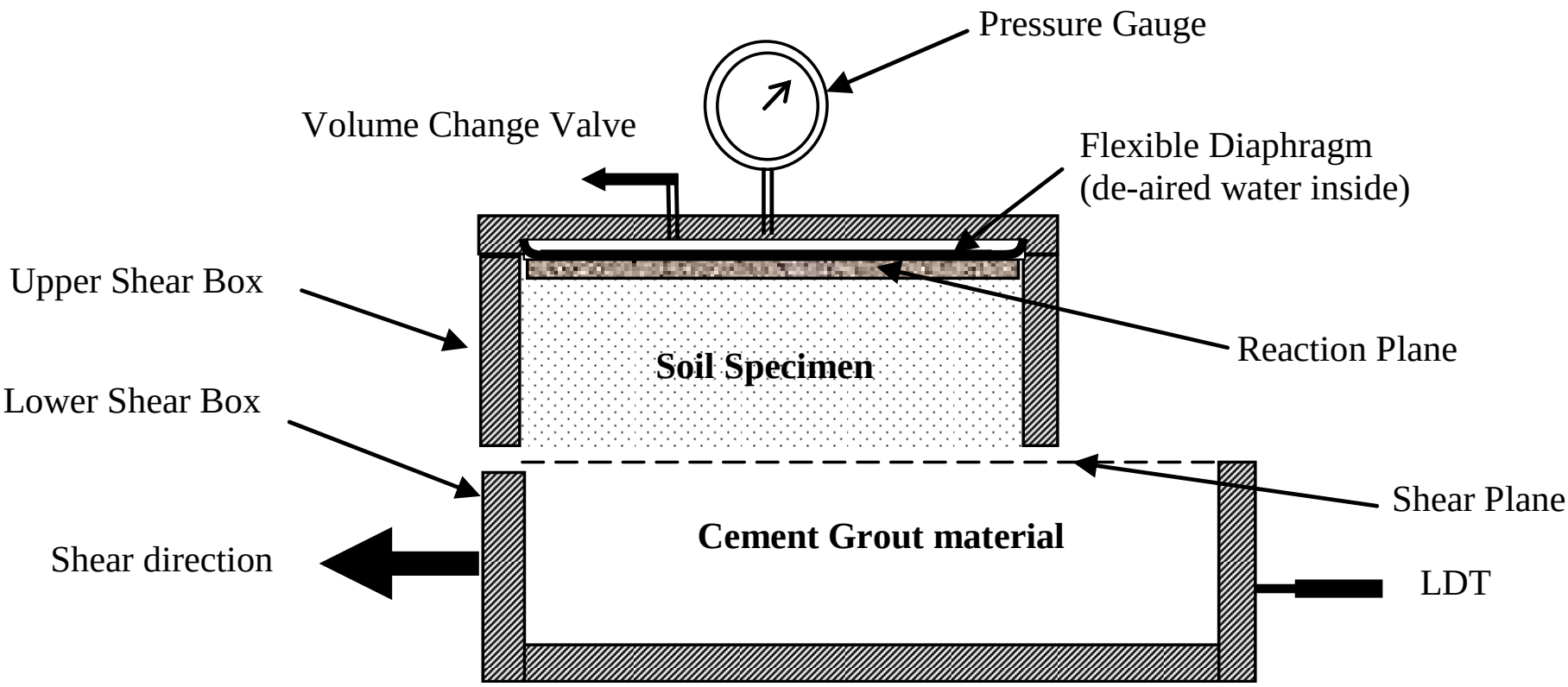
Comparison and Why:

(a) Between ribbed metallic strips and fill – smaller friction angle due to sliding on the metallic strips

(b) Between geo-textile and fill – higher frictional angle – interlocking of particles which penetrate through the geo-textile

(c) Test results give you the fact !

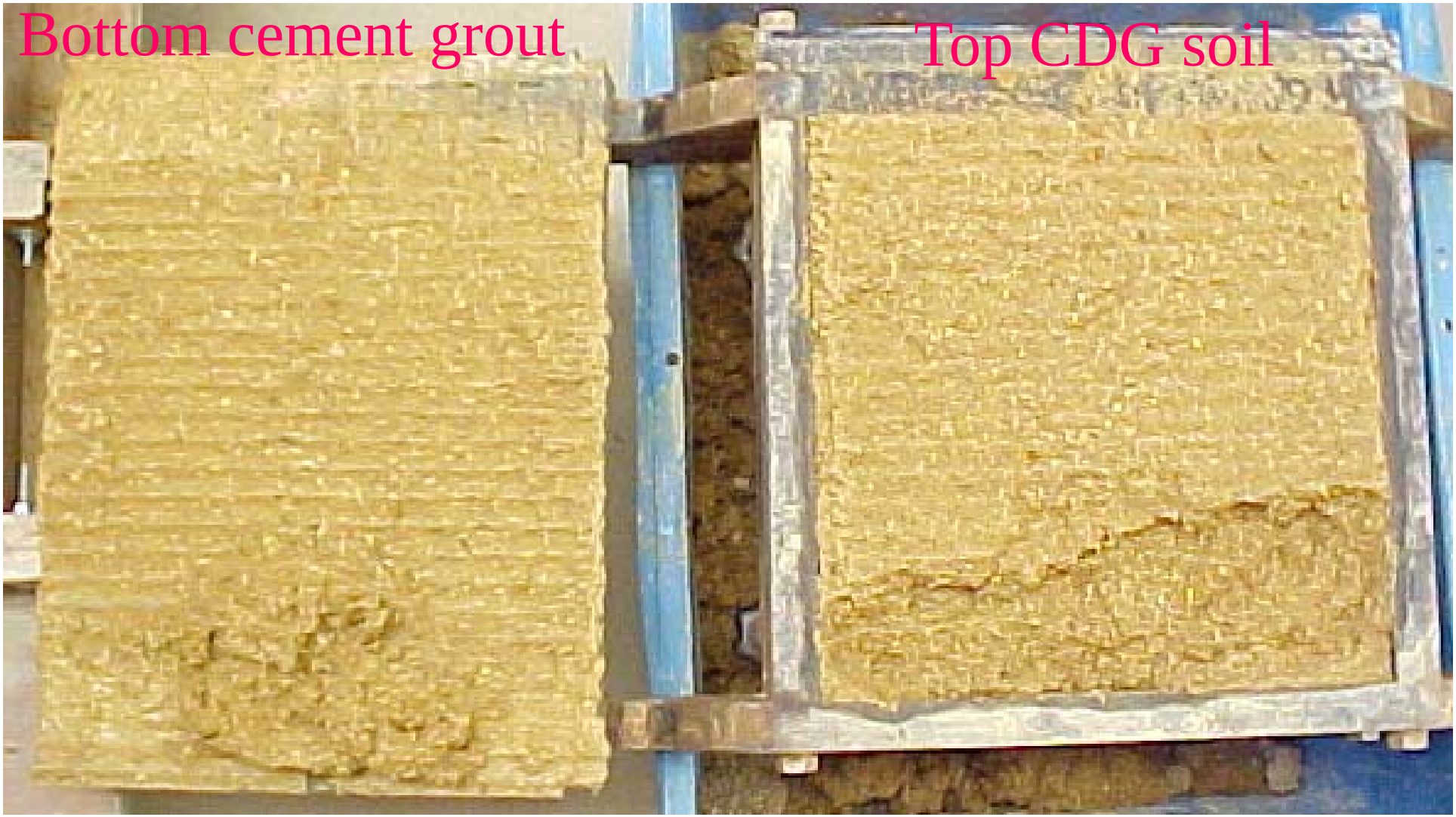
(c) Between cement grout and soil –
grouted/cast-in-place pile/nail and soil interface

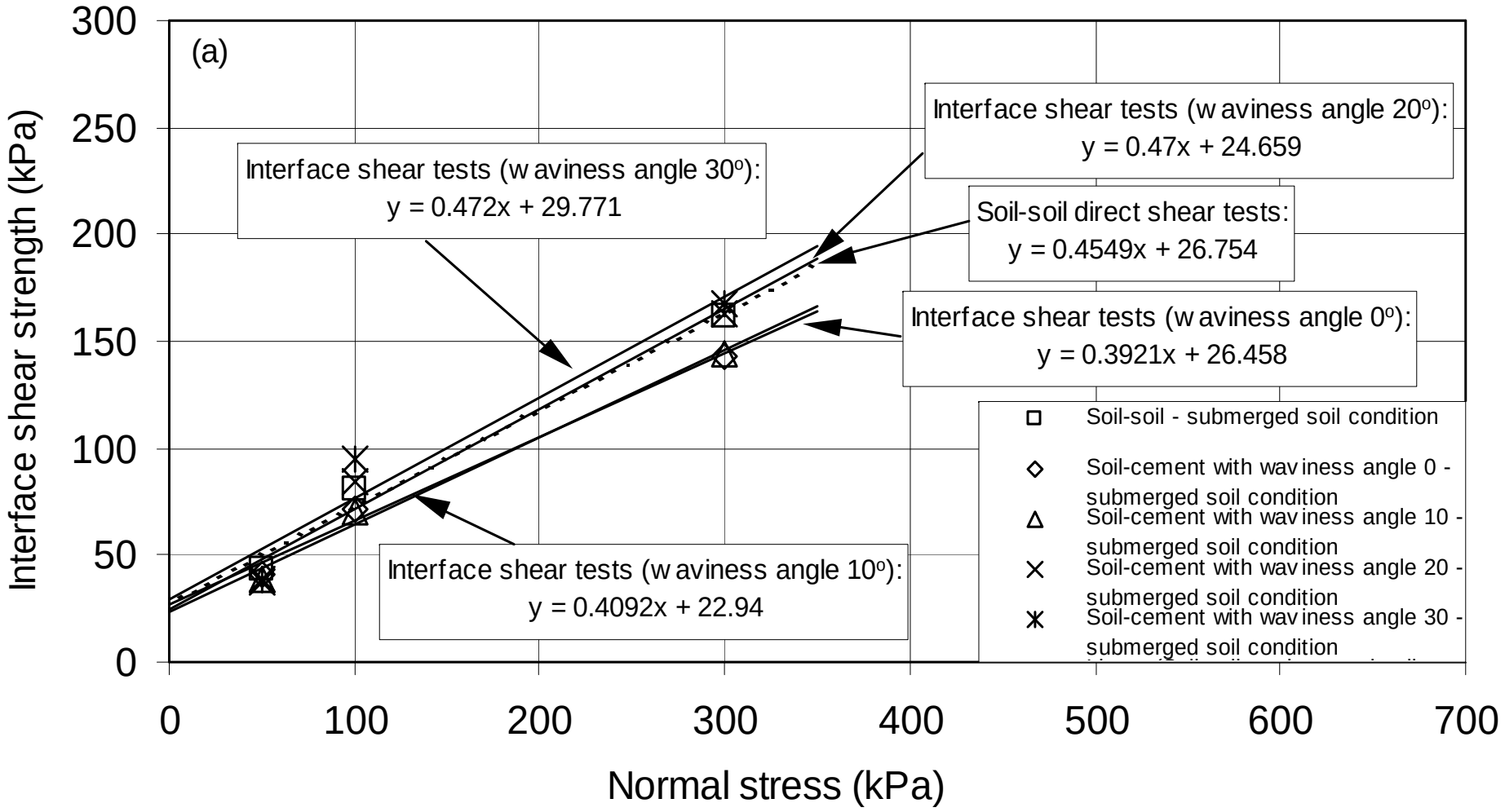


(c) Between pre-cast cement grout and soil
- existing pile/nail/retaining wall and soil interface

(c) Between cement grout and soil –

grouted/cast-in-place pile/nail and soil interface





Comparison of shear strength parameters between the soil-soil direct shear tests and the soil-grout interface shear tests of different waviness angles in the submerged condition – peak shear strength and

5. A New Double Cell Triaxial System

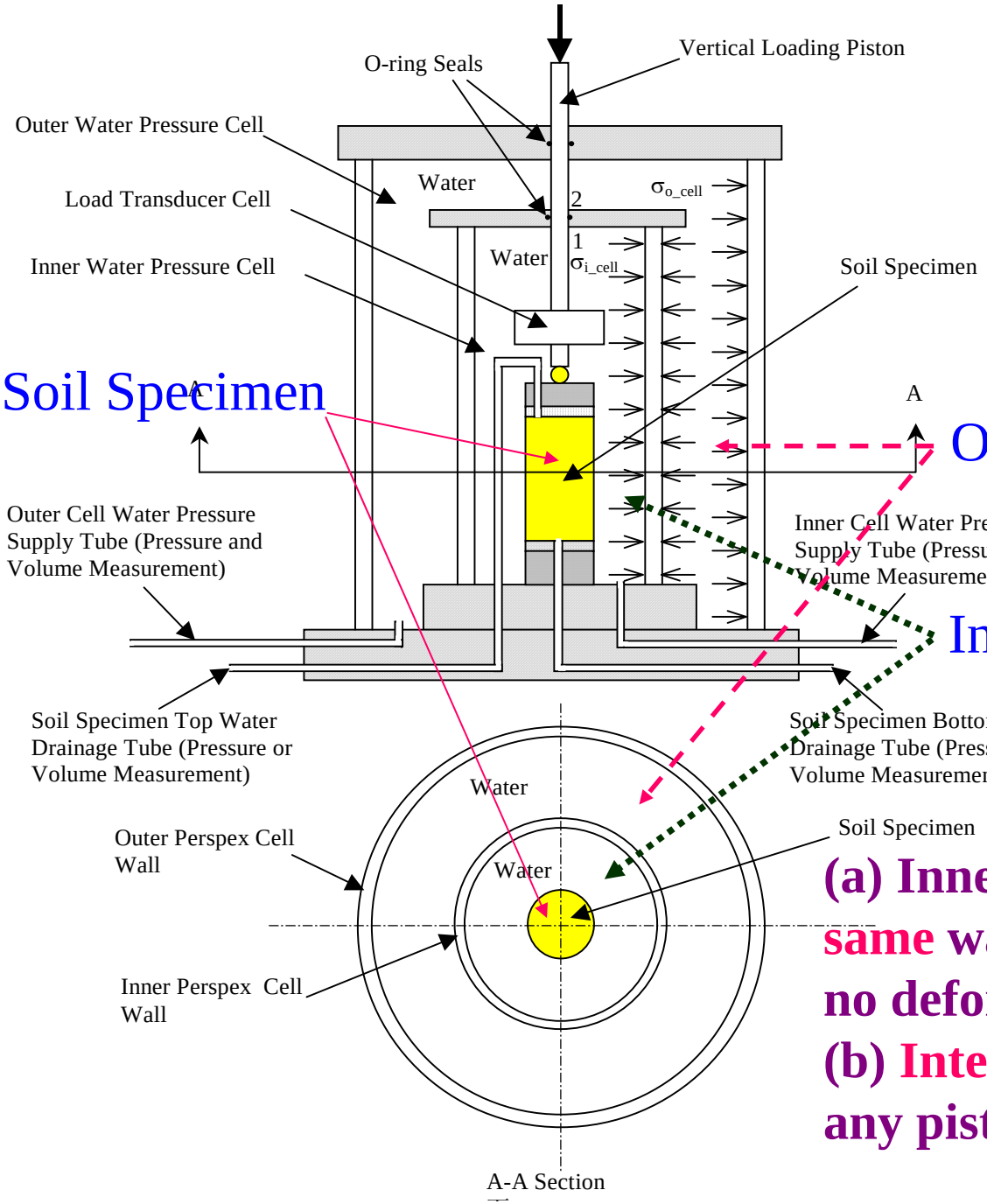
Why double cell triaxial tests?

(a) Continuous measurement of total volume changes of unsaturated soils in triaxial testing – PolyU's contribution

(b) Calibrations: How ? Results?

(c) Applications to test CDG soils

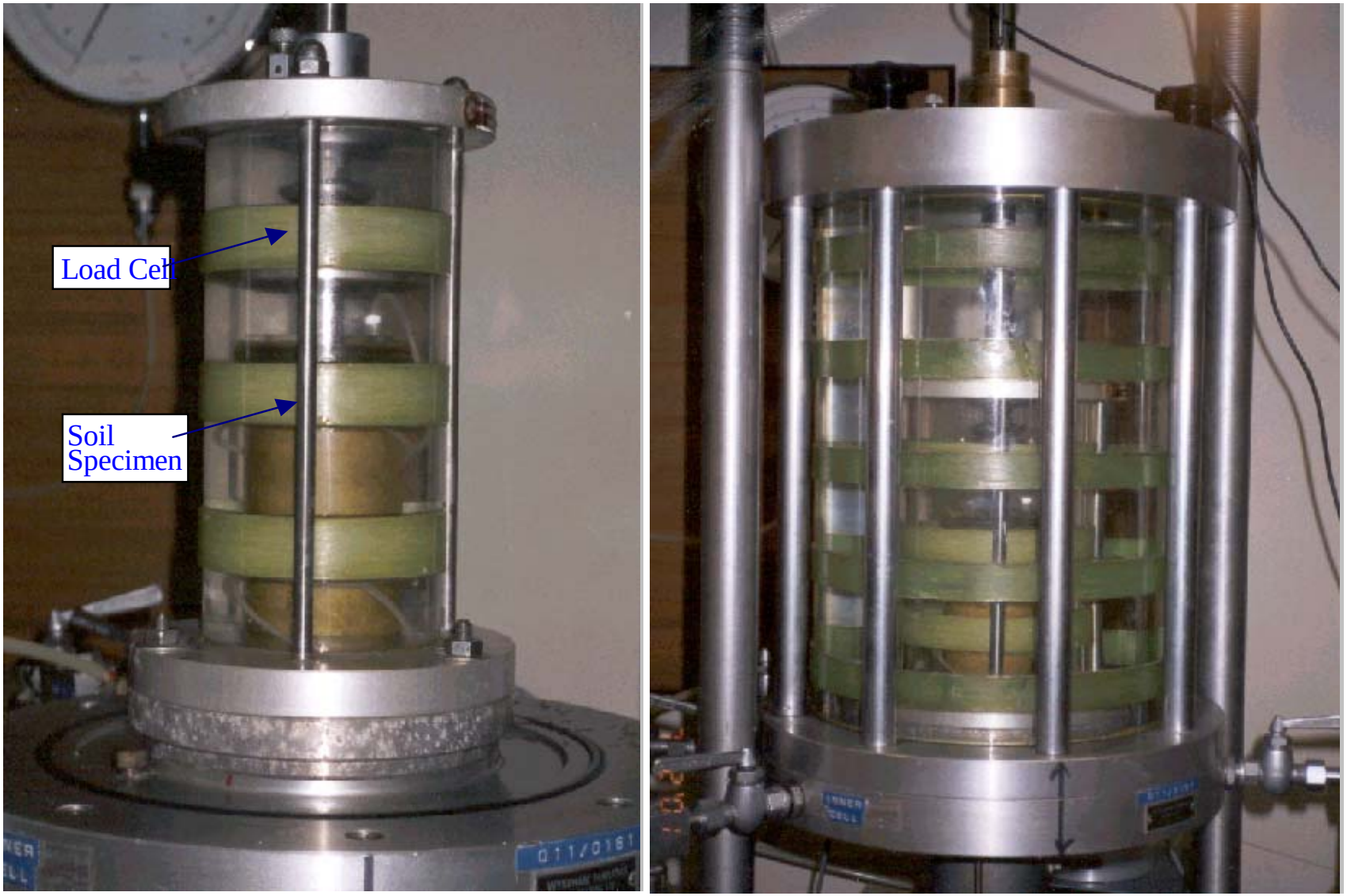
New double cell triaxial system for unsaturated soil testing



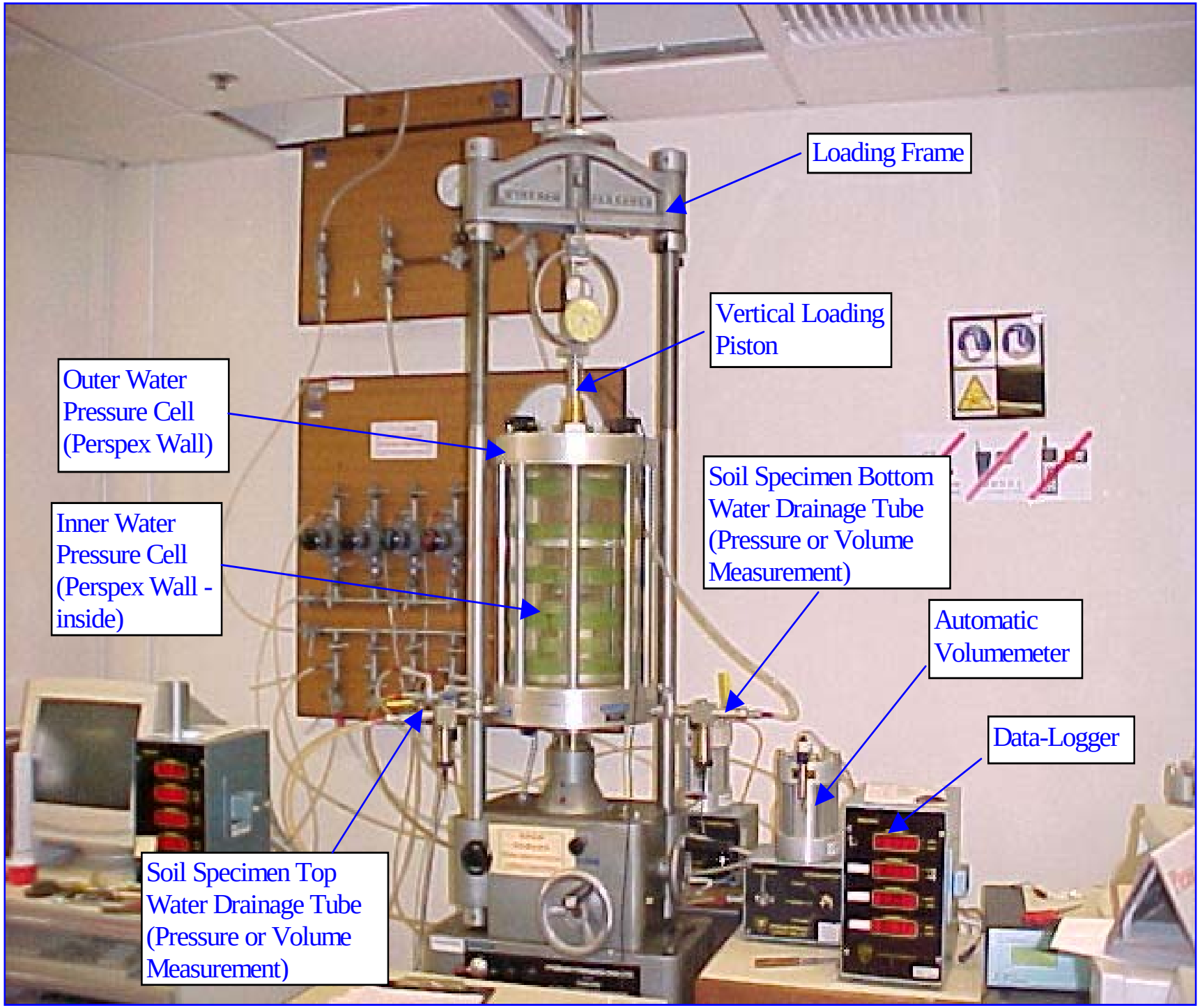
Why double cell is needed?

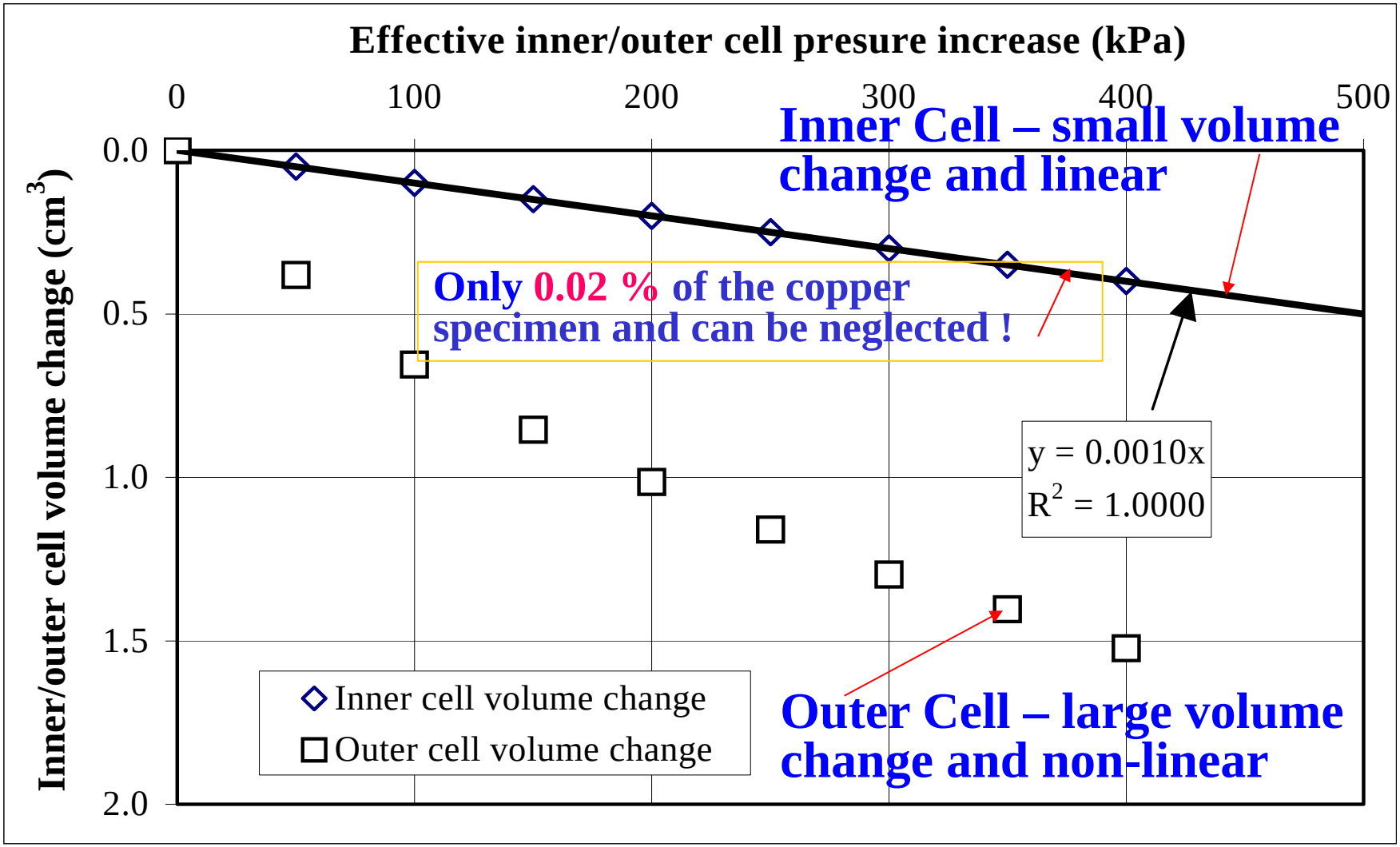
(a) Inner cell is fully balanced by the same water pressure – no leaking and no deformation of perspex cell wall

(b) Internal load cell is used to avoid any piston friction influence

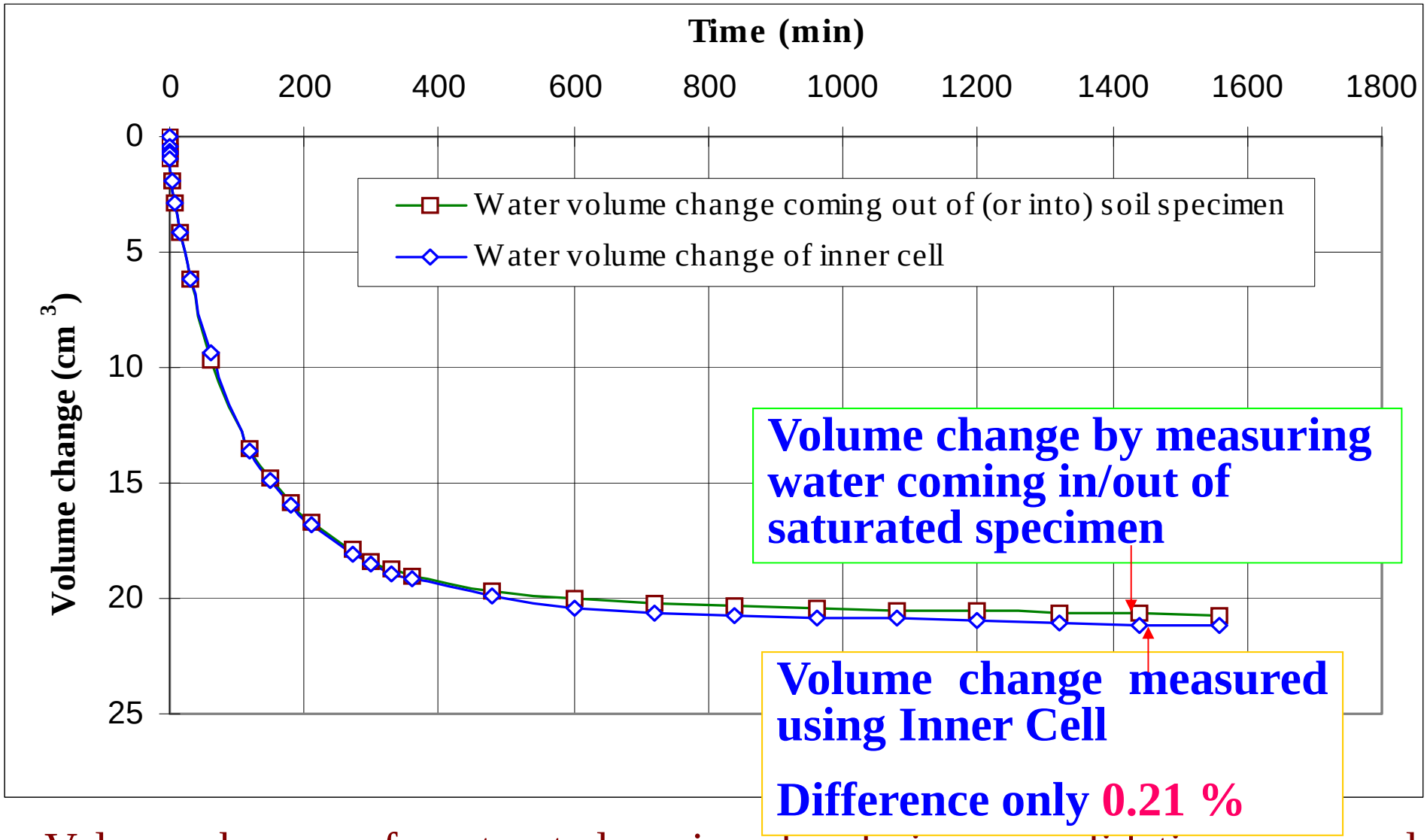


(a) Left photo - a close-up view of the inner cell (left) and
(b) right photo - a close-up view of the outer cell (right)

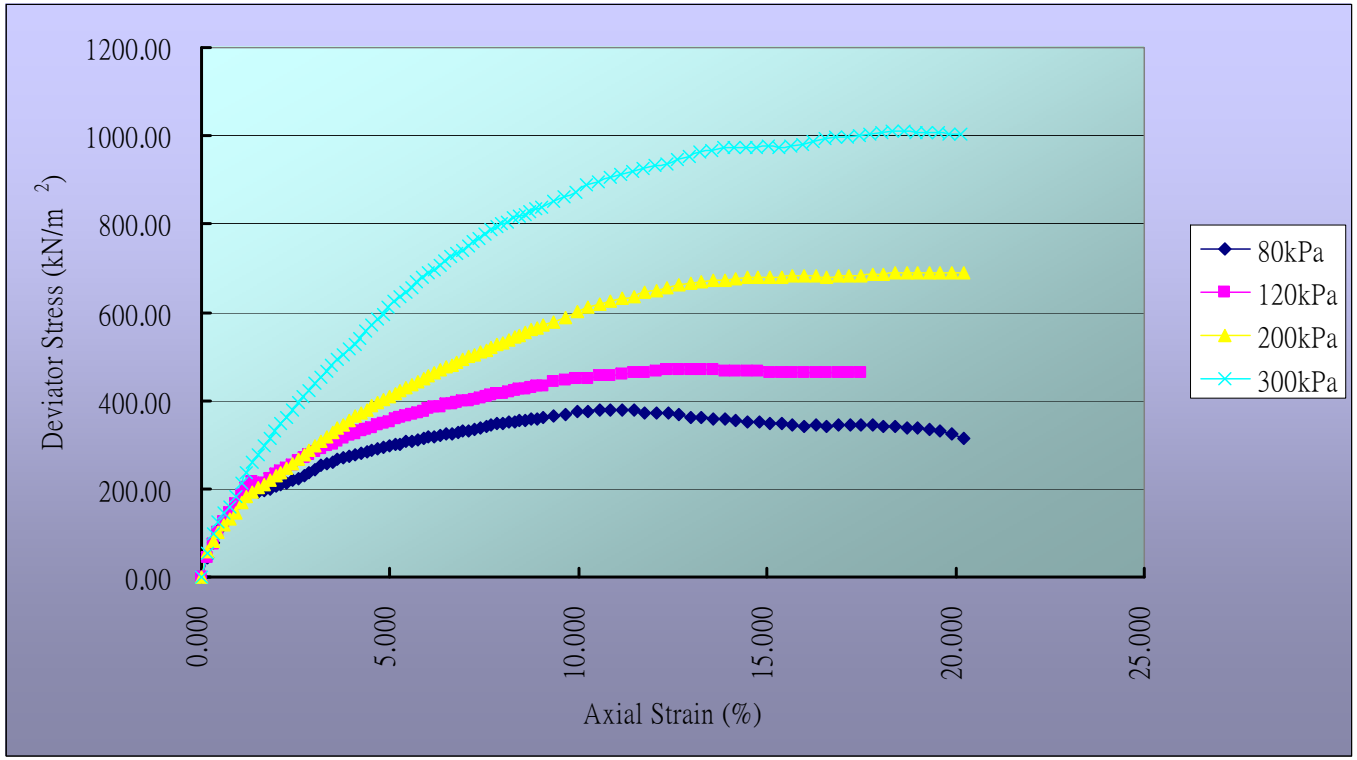

Loading Frame
Vertical Loading Piston
Outer Water Pressure Cell (Perspex Wall)
Inner Water Pressure Cell (Perspex Wall - inside)
Soil Specimen Bottom Water Drainage Tube (Pressure or Volume Measurement)
Automatic Volumemeter
Data-Logger
Soil Specimen Top Water Drainage Tube (Pressure or Volume Measurement)

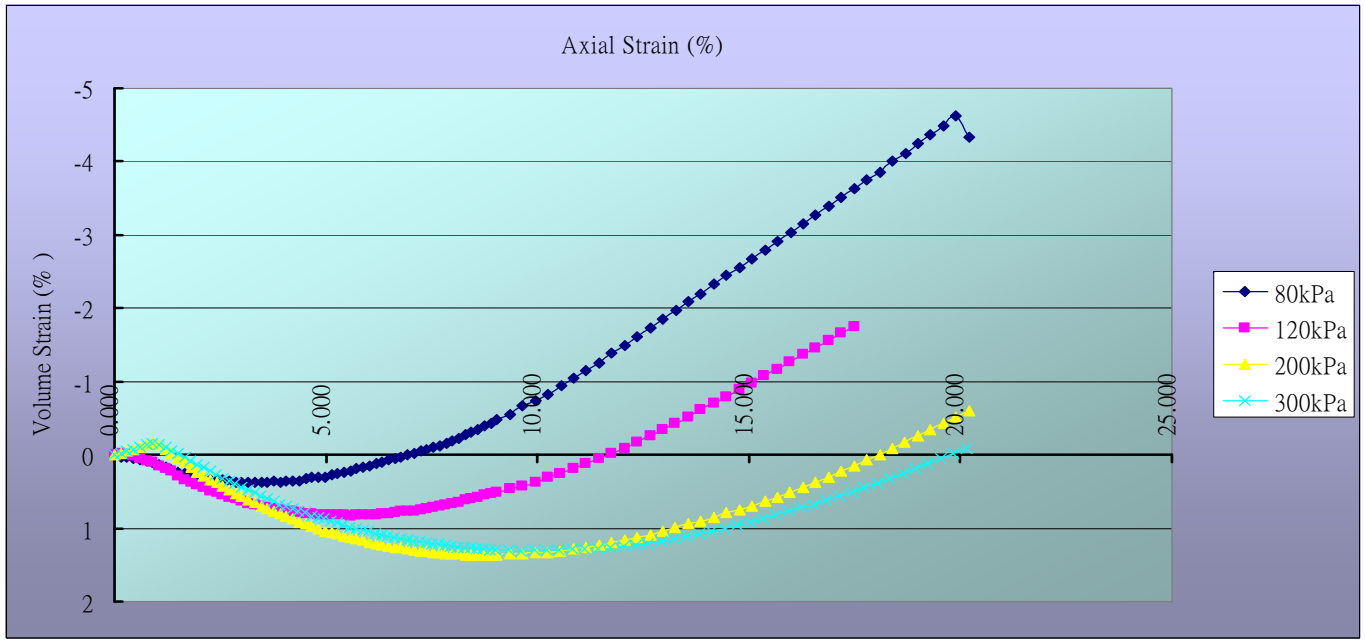


Volume changes of a **copper specimen** under isotropic compression measured by the changes of (a) water volume of the inner cell and (b) the water volume of the outer cell with back pressure equal to 100kPa and the specimen drainage valve closed (Yin 2002a,b)



Volume changes of a saturated marine clay during consolidation measured by the changes of (a) the water coming out of (or into) the clay specimen and (b) water volume of the inner cell (Yin 2002a,b)





Double Cell Triaxial compression tests on a CDG soil with initial degree of saturation of 35%

6. A Hollow Cylinder Apparatus (HCA) for Soil Testing

Why HCA?

For measuring the behaviour of a hollow soil specimen (100mm height by 100mm external diameter by 50mm inner diameter) under conditions of

(a) pure shearing

(b) plane strain

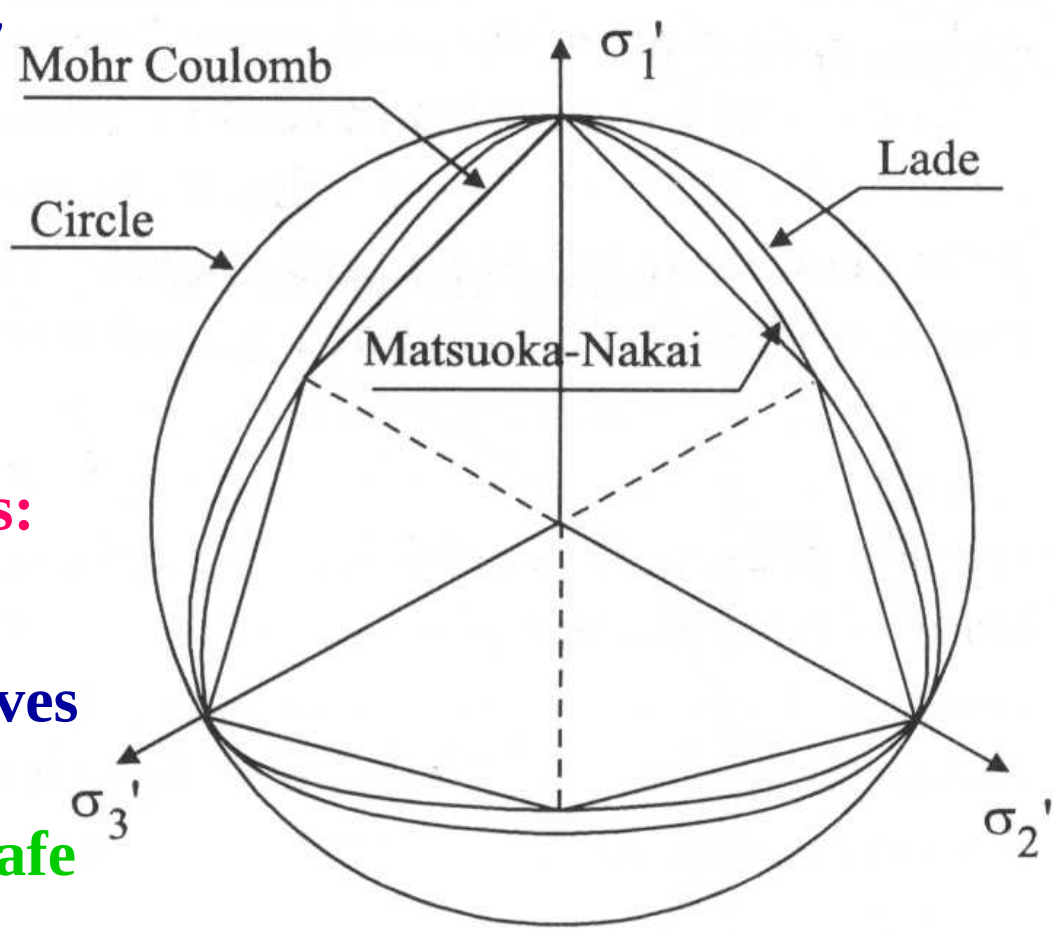
(c) rotation of the principal stress

(d) influence of the middle principal stress

(e) …

Development of failure criteria and constitutive models

Extension to/study in a general stress space: advanced lab facilities are needed

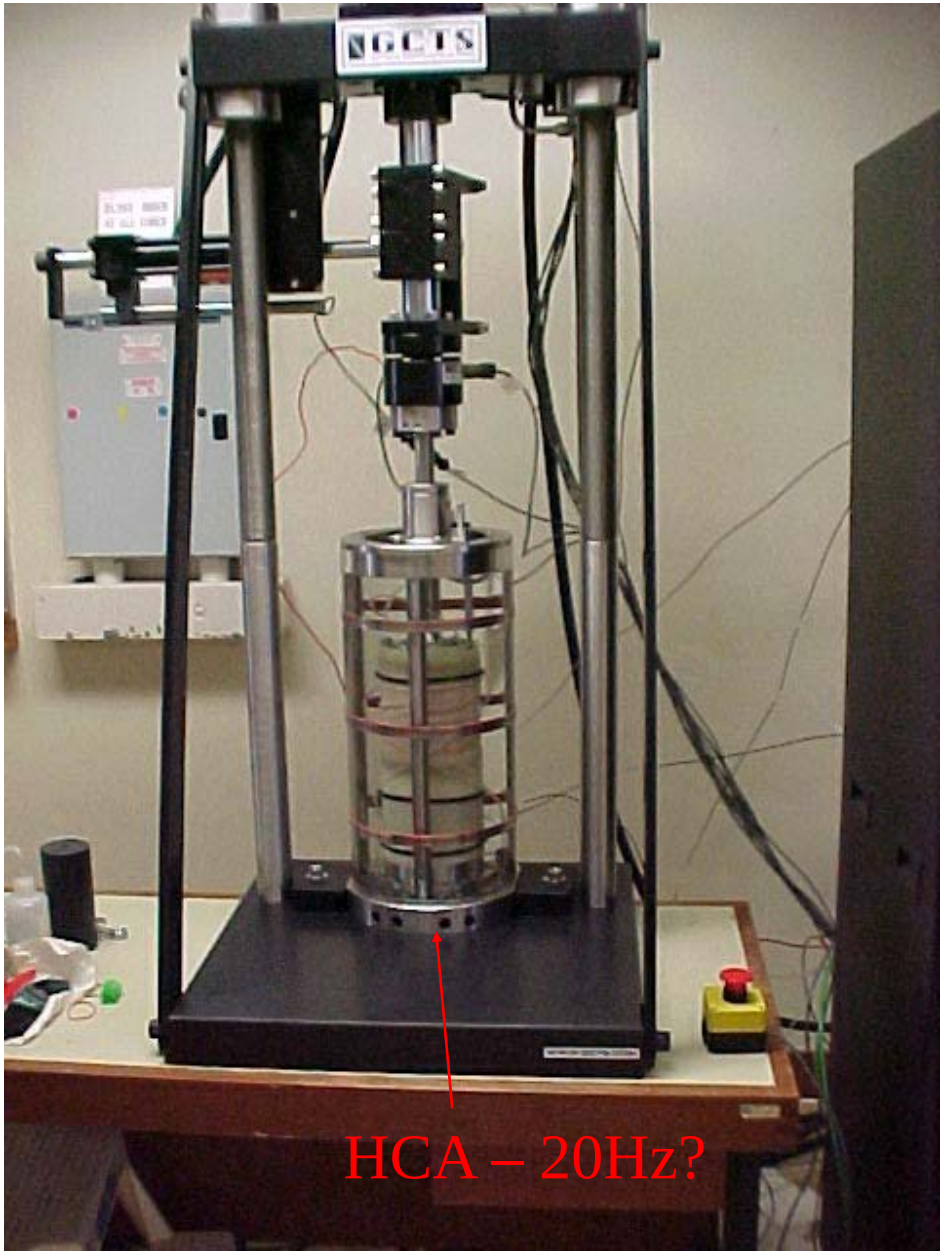


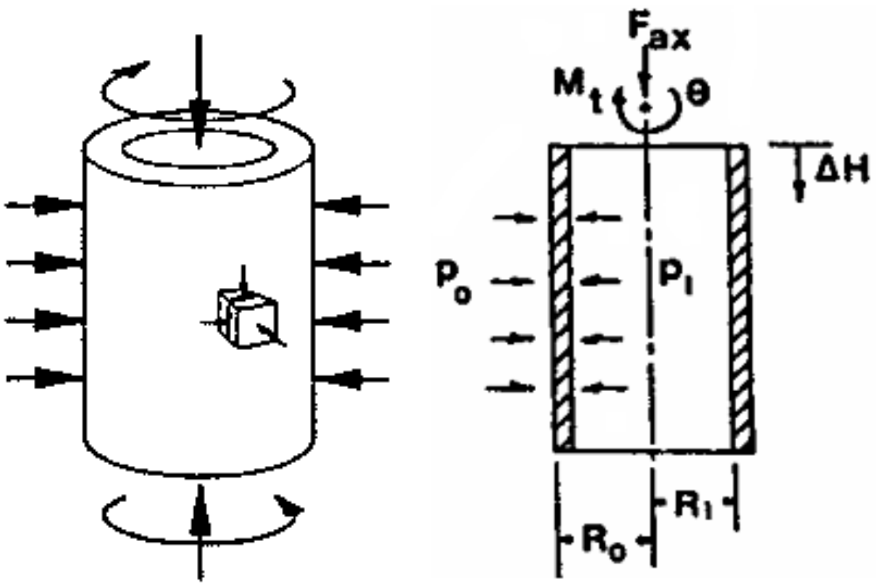
Failure surfaces in π–plane

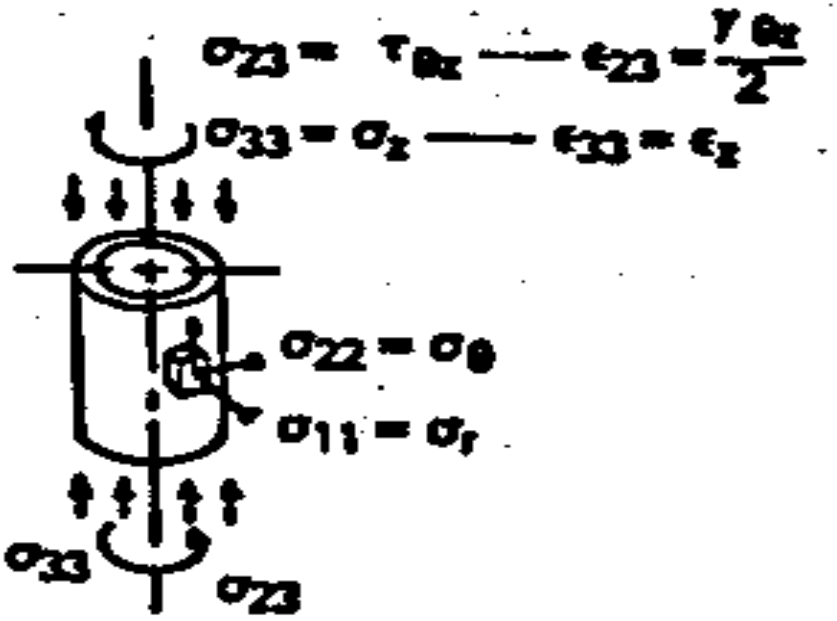
Useful to engineers:

Mohr-Coulomb failure criterion gives more conservative strength – on the safe side !

Hollow Cylinder Apparatus (HCA): control of **4** independent parameters







Hong Kong Marine Clay
Hollow Cylinder Test

7. A Truly Triaxial System (TTS) for Soil Testing

For measuring the behaviour of a “brick” soil specimen (70mm by 70mm by 140mm) under conditions of

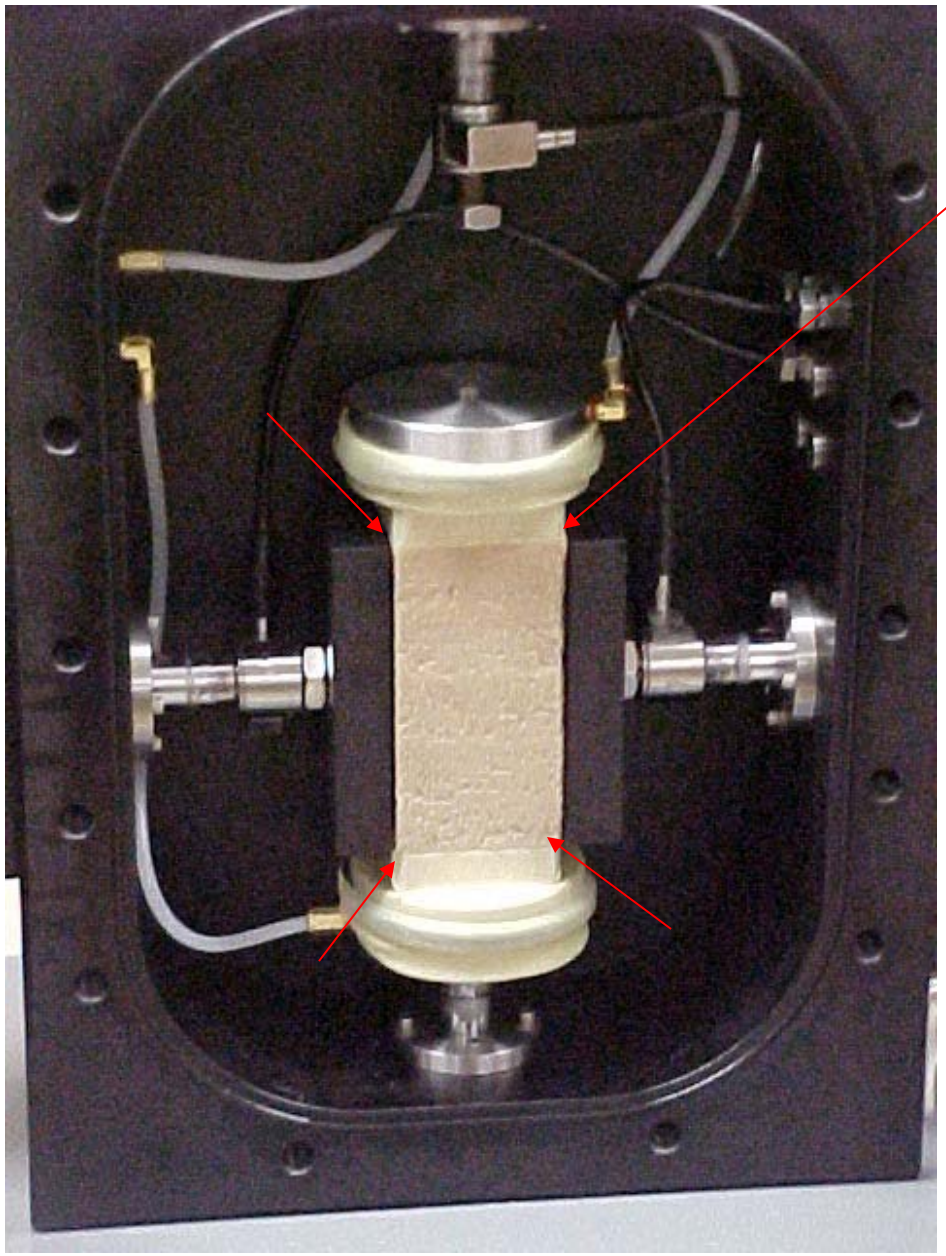
(a) plane strain,

(b) influence of the middle principal stress

(c) …

Development of **new sliding loading plates** and setup

Truly Triaxial System (TTS): control of **3** independent parameters

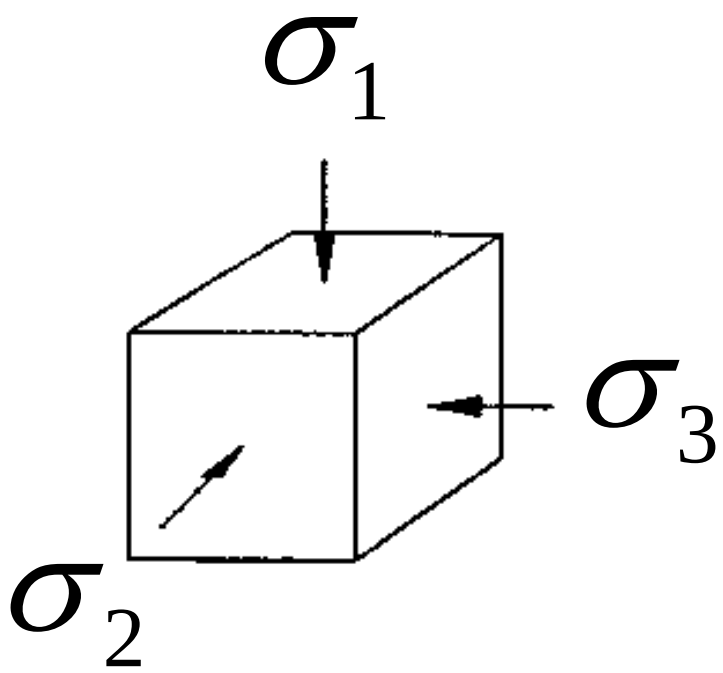


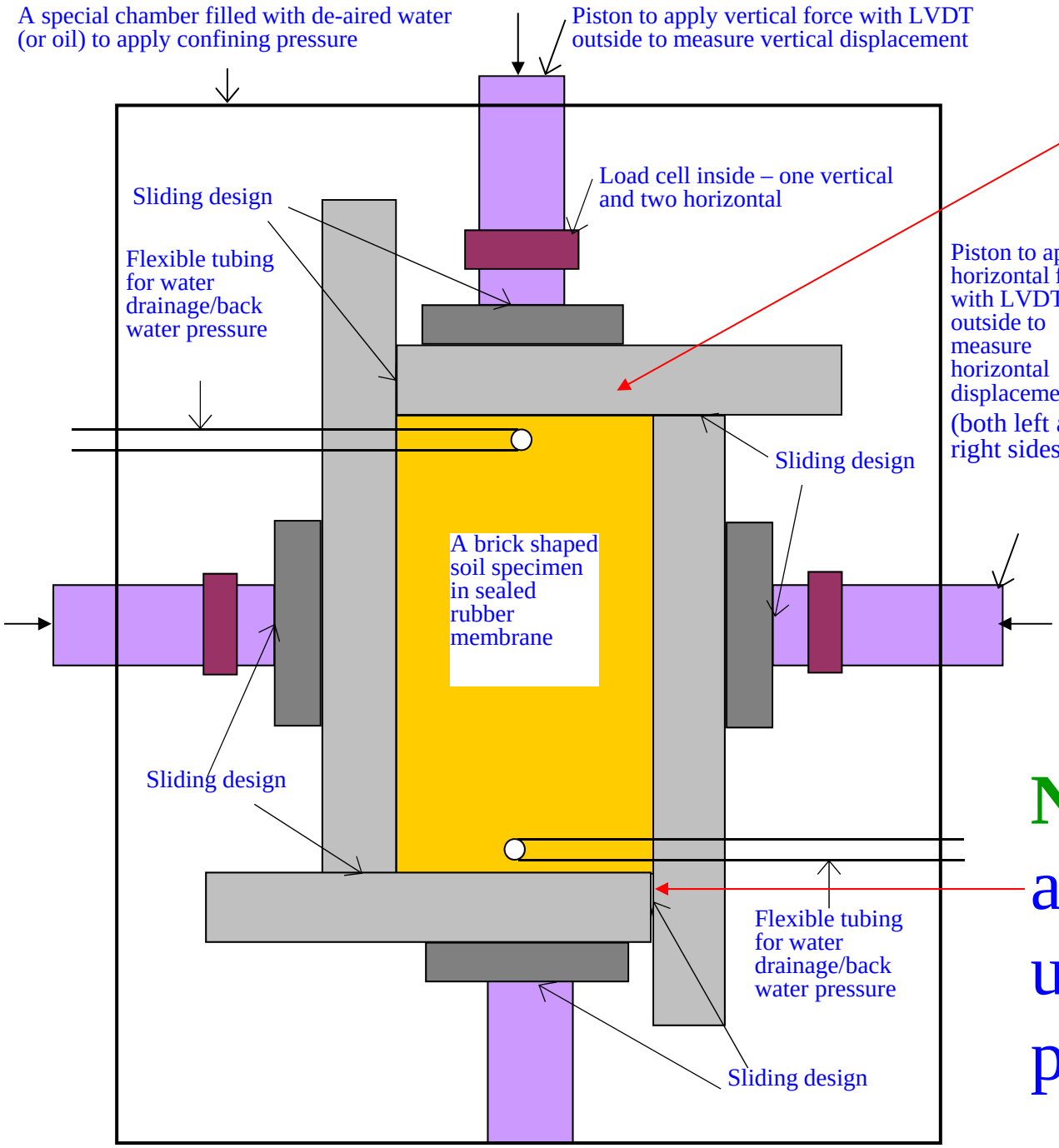
Problems:

Interference at the corners

(a) non-uniform stresses

(b) small compression

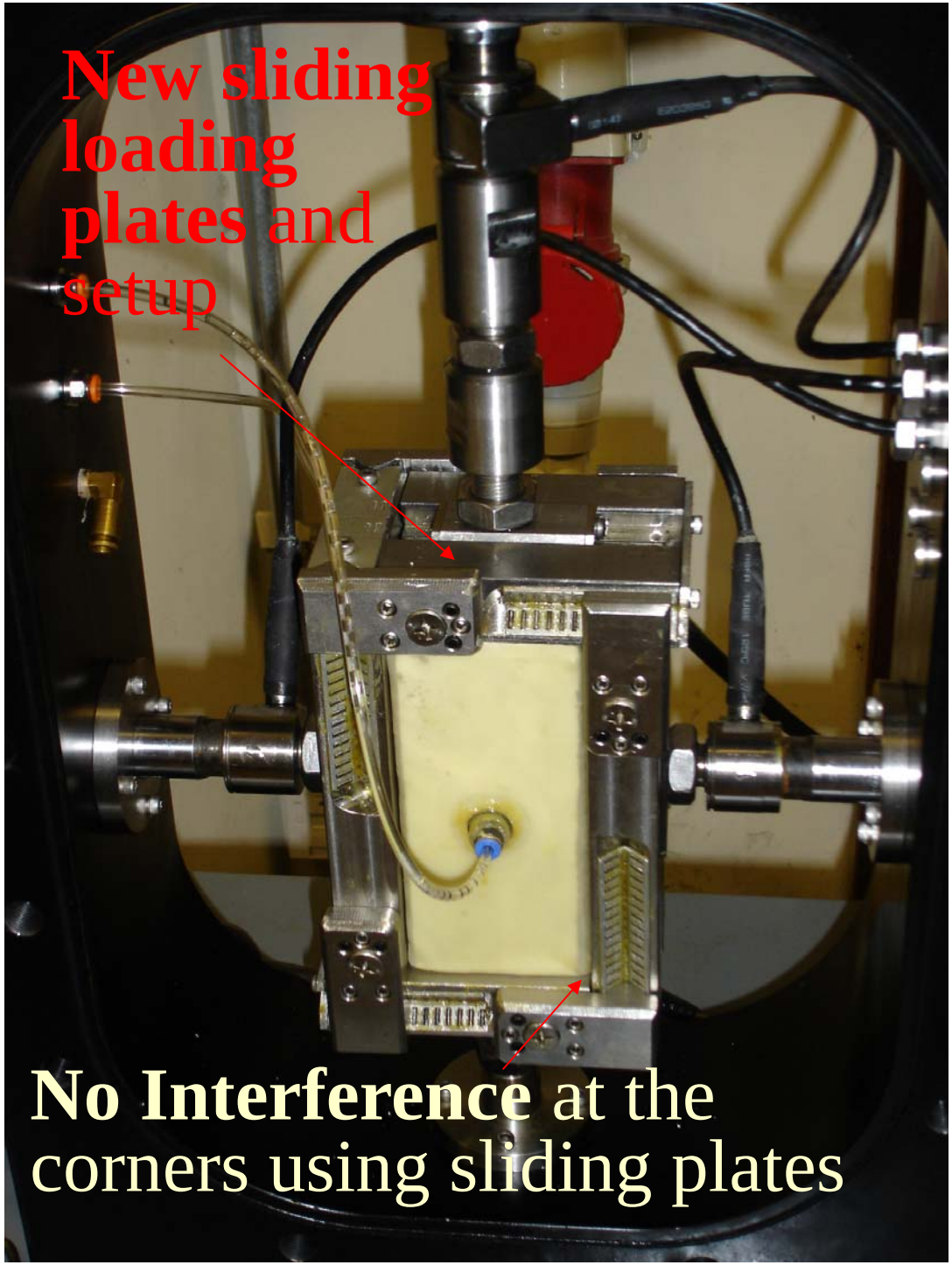




New sliding loading plates and setup

创新的设计

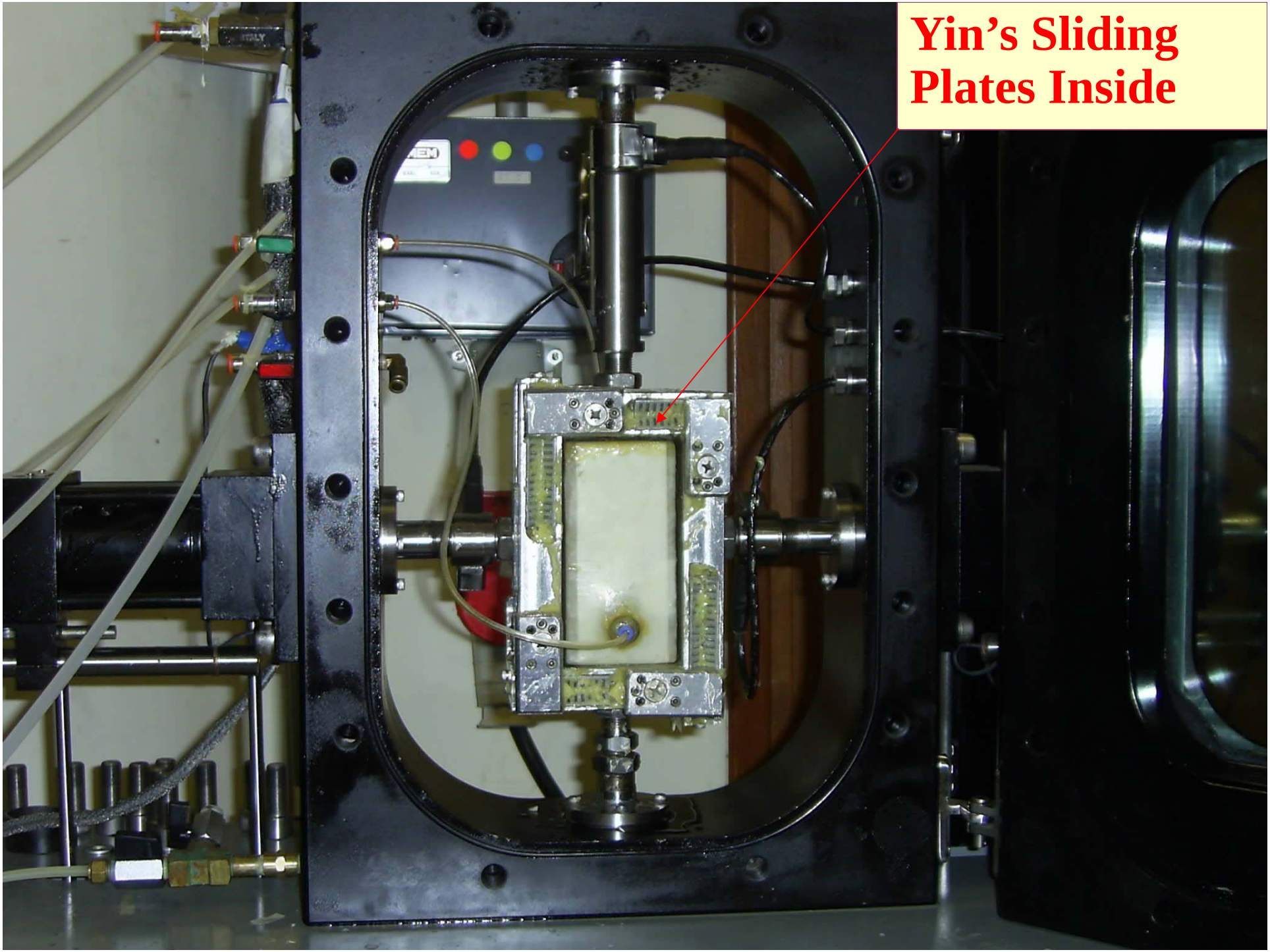
No Interference at the corners using sliding plates

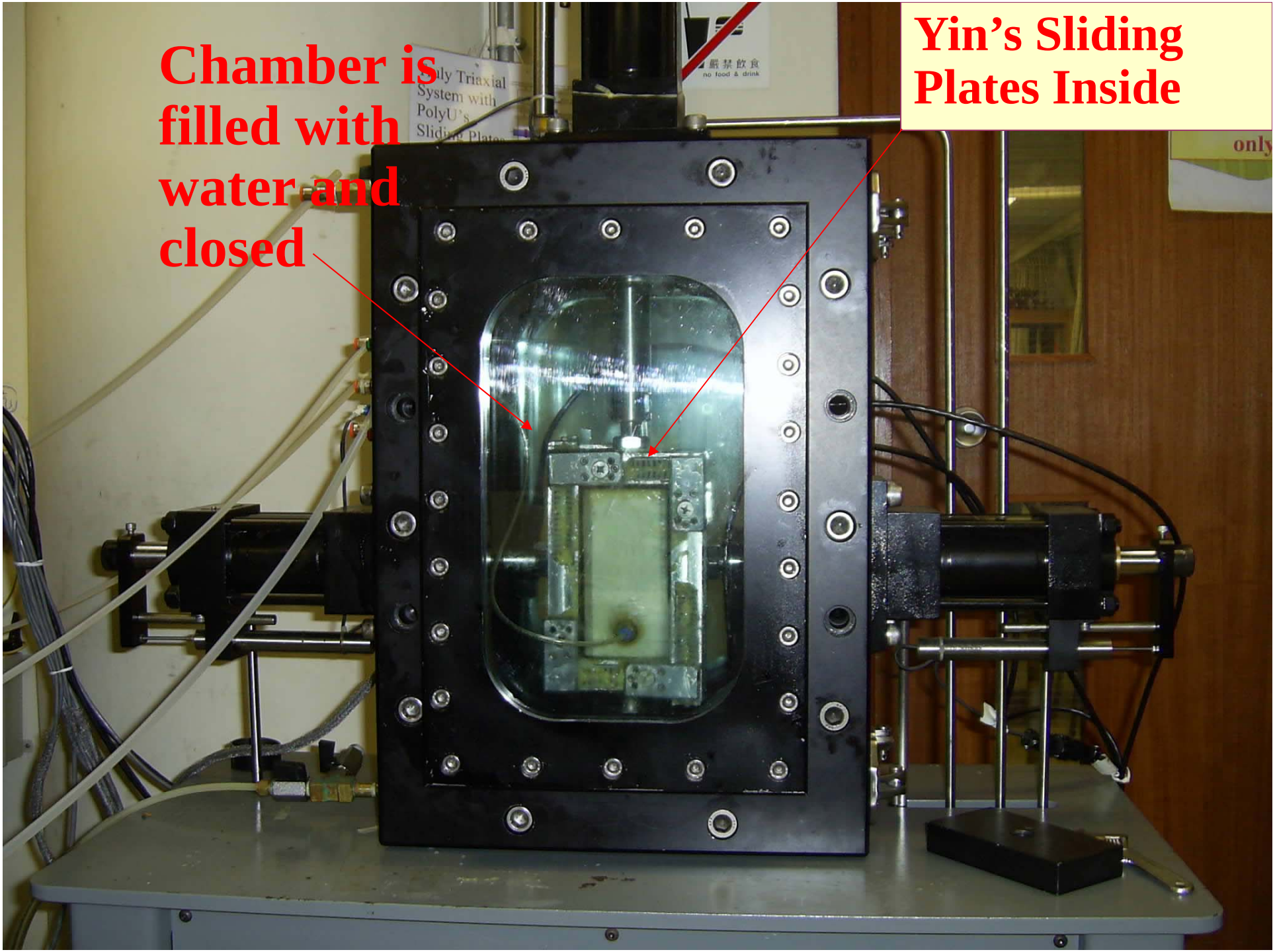


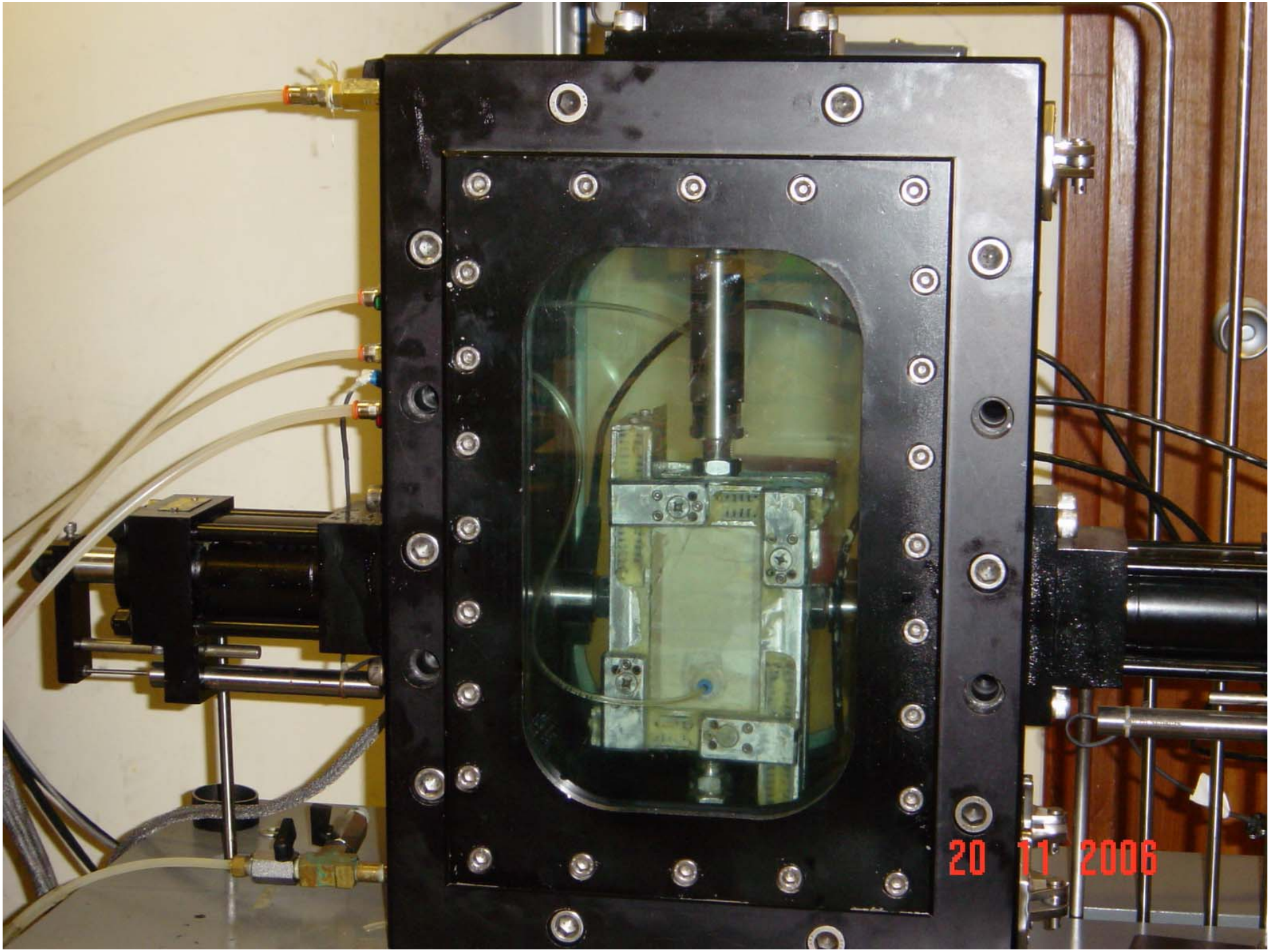
The best in the World?

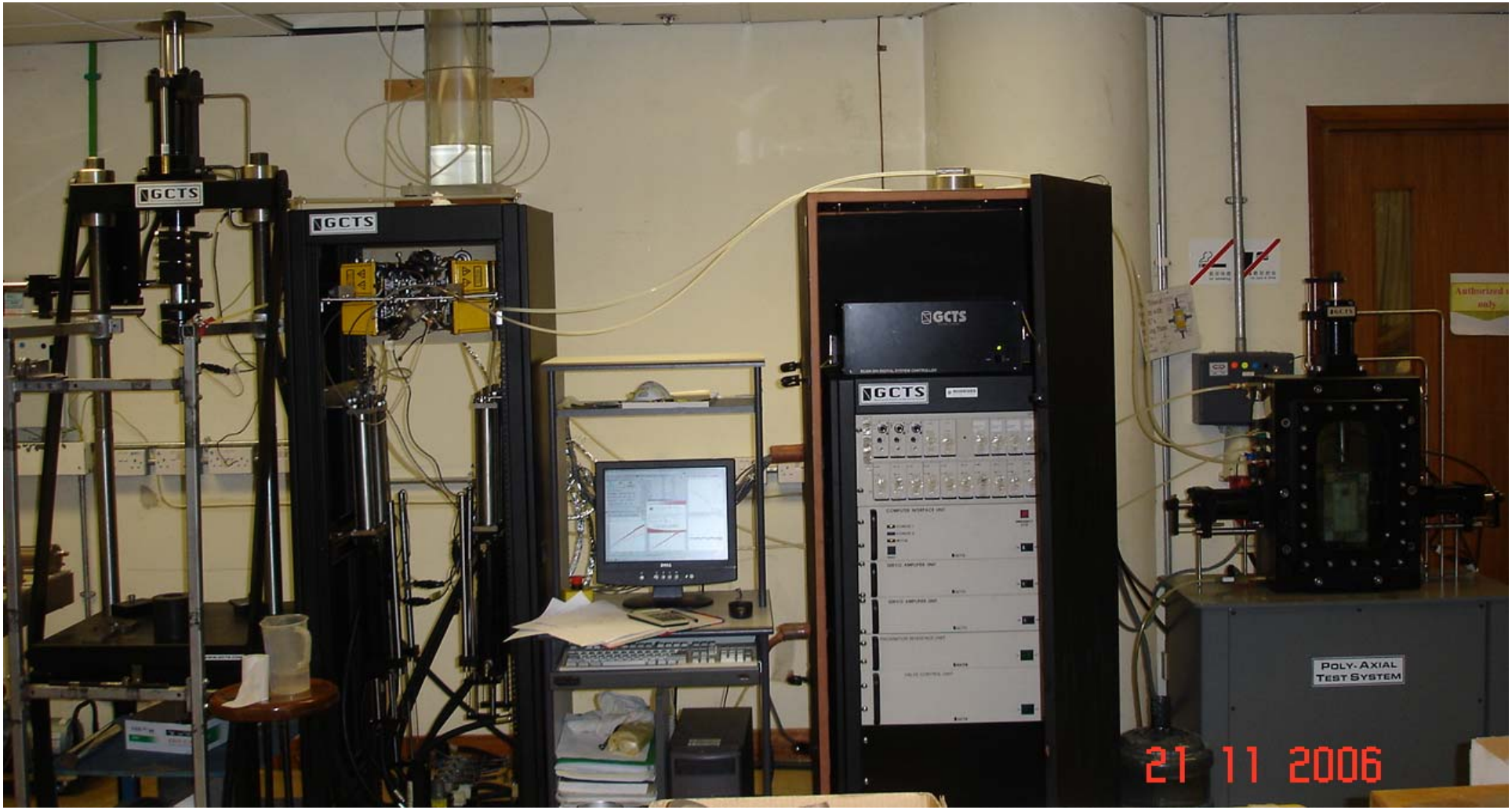
世界上最佳？

由你评价！


Yin's Sliding
Plates Inside


Chamber is filled with water and closed
Yin's Sliding Plates Inside


20 11 2006



电子控制仪器、油压系统、软件、
静与动态(20Hz) 试验等

香港风化花岗岩土
P=400
b=0.2
D
P=400
b=0
T-2
P=400
b=0.4
P=400
b=0.6
NO-1
NO-1
P=400
b=0.2
P=400
b=0.2
NO-2
P=400
b=0.4
NO-2
P=400
b=0.6
NO-2
D=200
b=0.0
P=100
b=0.6
P=100
b=0.4
P=100kPa
b=0.2
P=200
b=0.6
21 11 2006

塑料泡沫材料 –软土填料，挡土墙填料等

塑料泡沫材料 –应力-应变-强度如何？

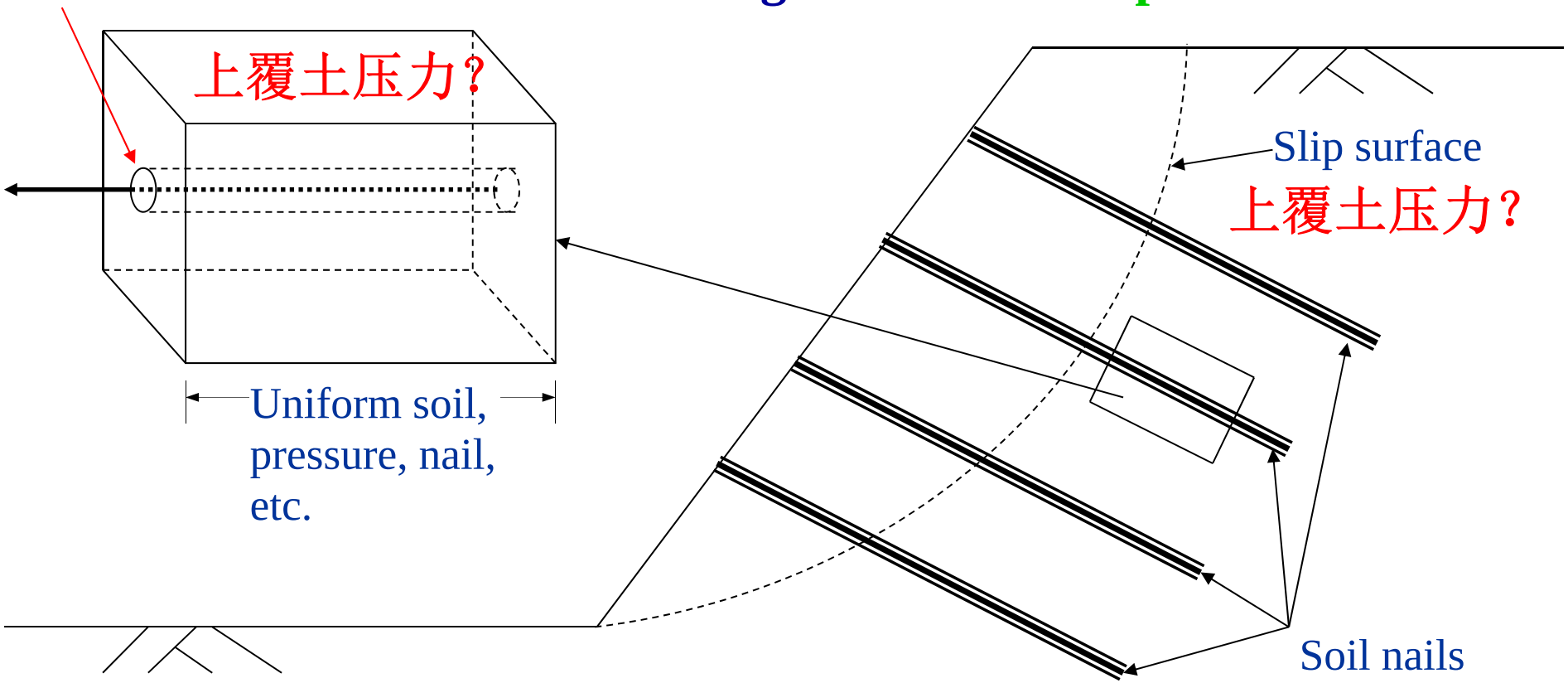
8. An Innovative Soil Nail Pullout Box with Instrumentation

- For studying the interface shear strength of soil nail and soil under various controlled conditions
- Saturated or unsaturated soils, stress release, grouting pressure, *etc.*
  (simulating real construction process)

New soil nail pullout box testing – simulating a segment of a soil nail in a slope

Useful to engineers:

Know the influences of a few key factors and make better designs and safer slopes !

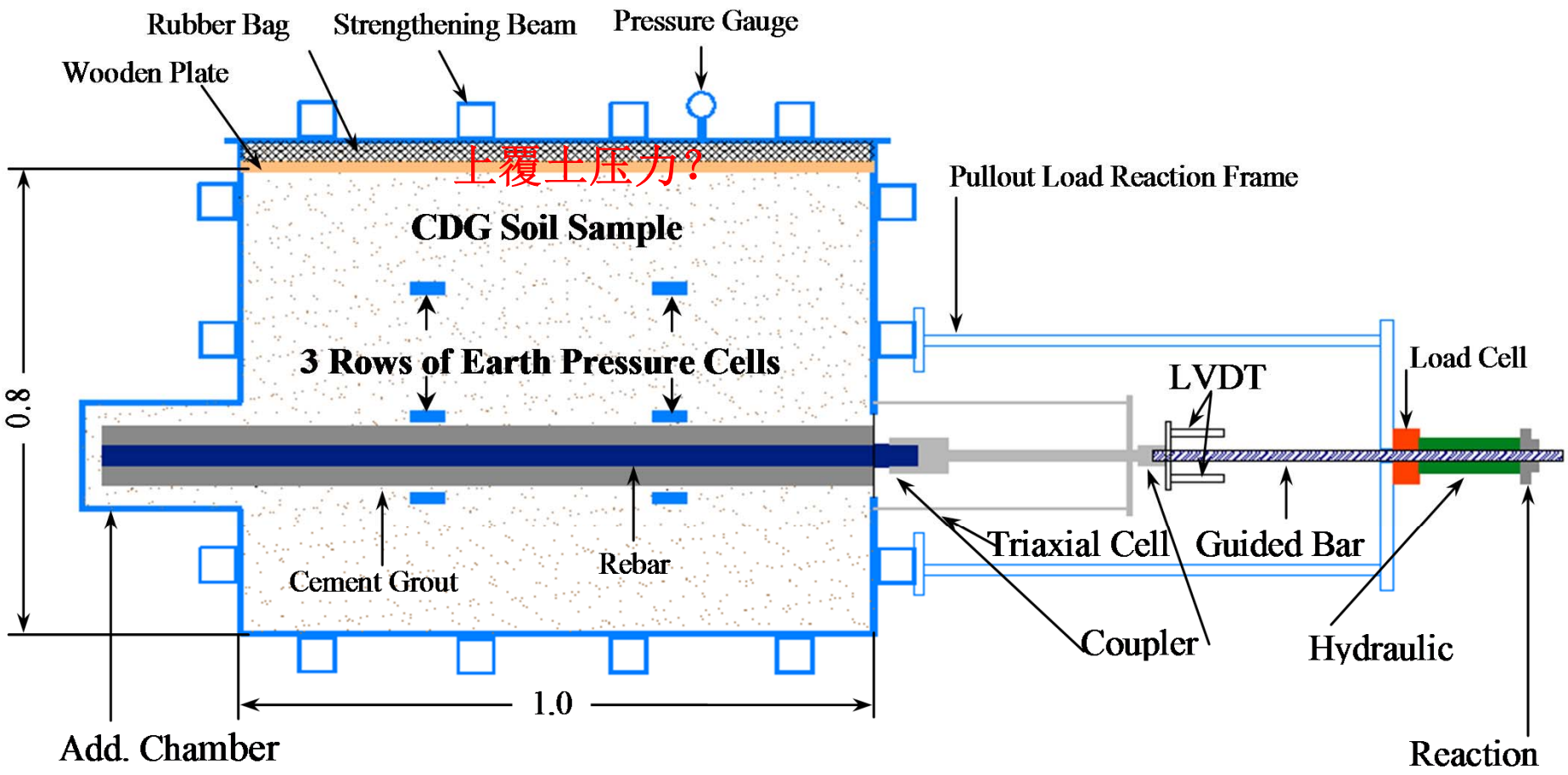


Soil nail pullout test studies on:

(a) Overburden pressure? 上覆土压力?
(b) Water saturation/suction/water table rising?
(c) Cement slurry grouting pressure?
(d) Drill hole roughness/dilation?
(e) Different soil types?
(f) Different nail materials (fibre/carbon-glass)?
(g) Block soil samples *vs* compacted samples?
(h) Comparison of lab pullout test results with field pullout test results?

…

Studies in (a), (b) and (c) have been done.

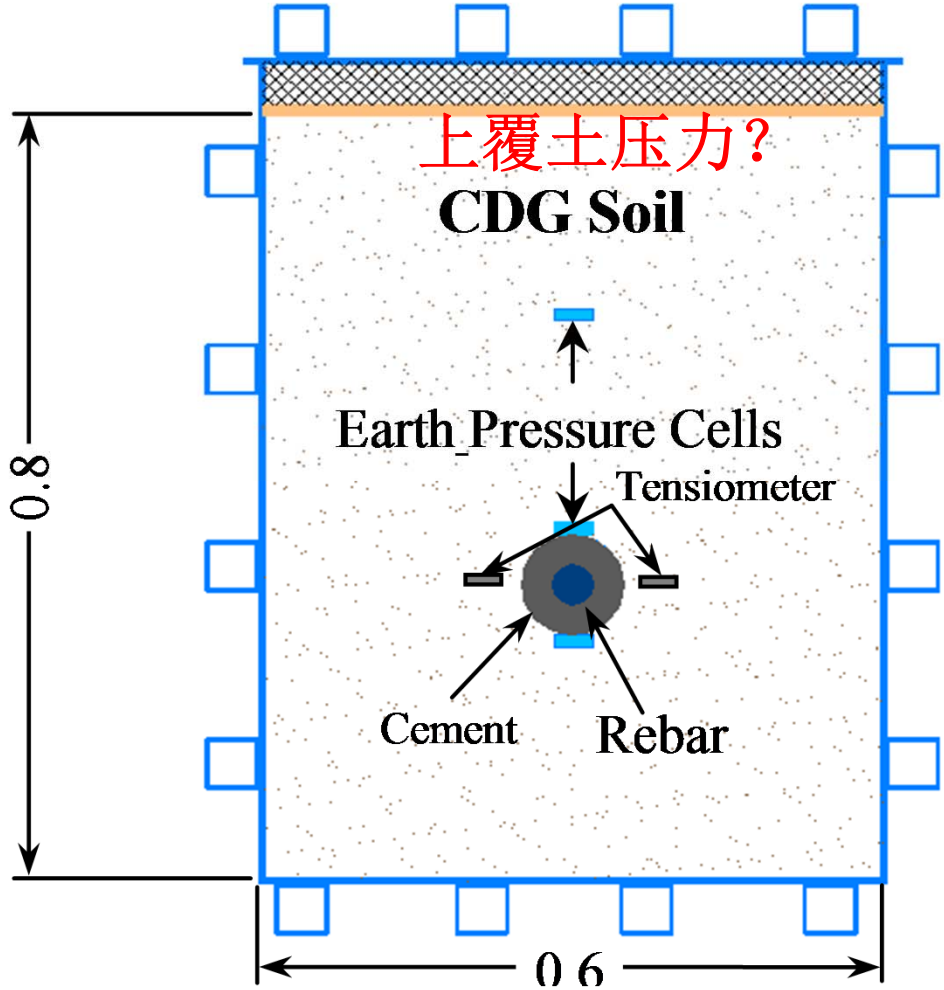


(i) Six earth pressure cells for measuring total earth pressures

(ii) Four strain gauges on the re-bar for measuring nail axial strains

(iii) Pressure gauges and volume change meter in the top cover cap for water pressure control and vertical soil movement

(iv) Two LVDTs and one load cell for measuring pullout displacement and load.

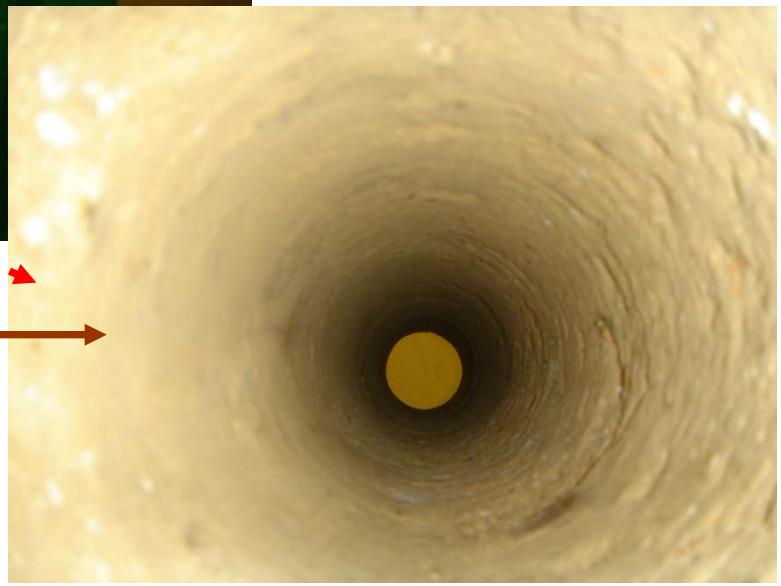


(v) Four miniature tensiometers for measuring suctions and small pressure transducers for measuring positive pore water pressures

上覆土压力？

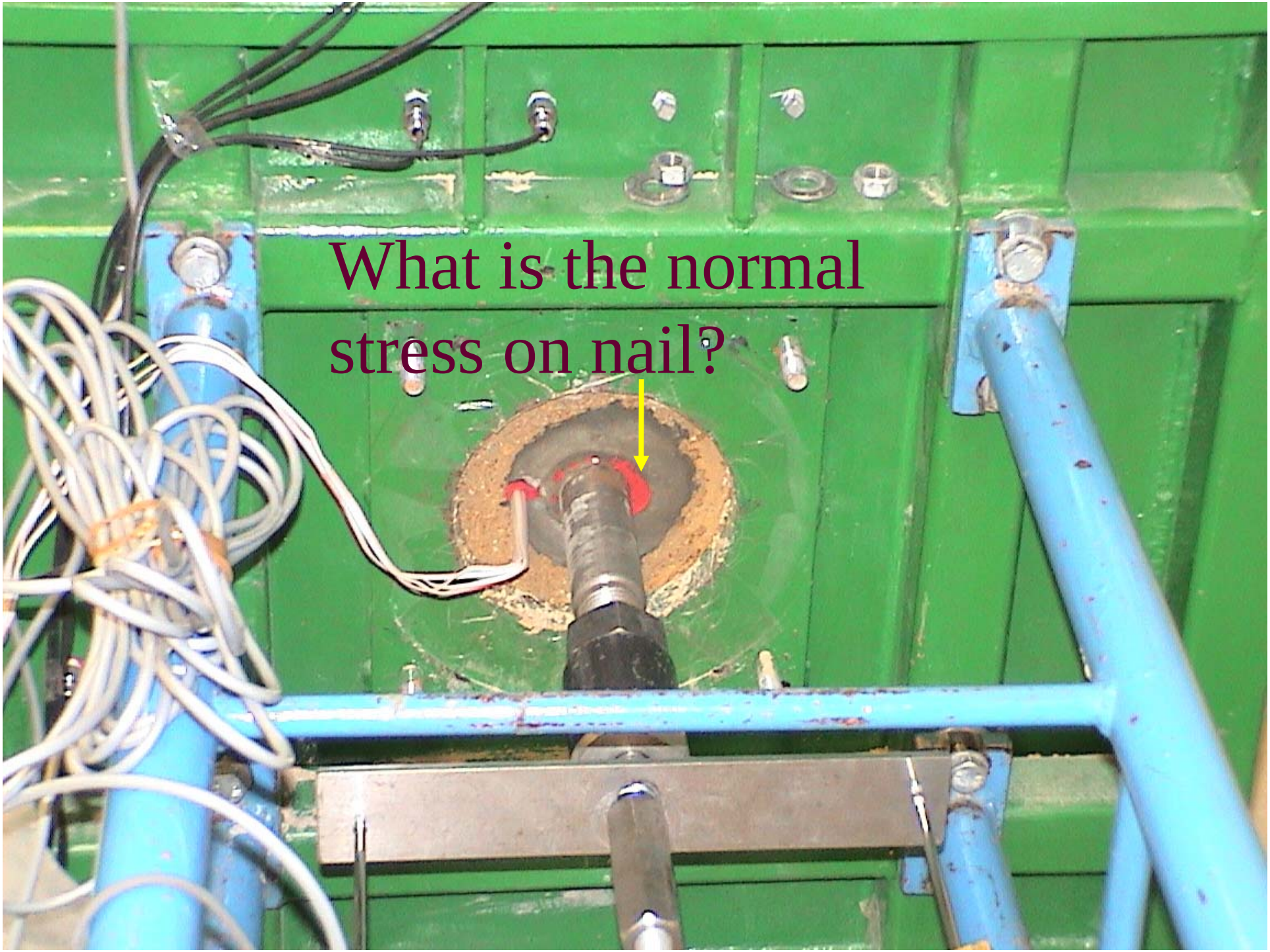
应力释放了

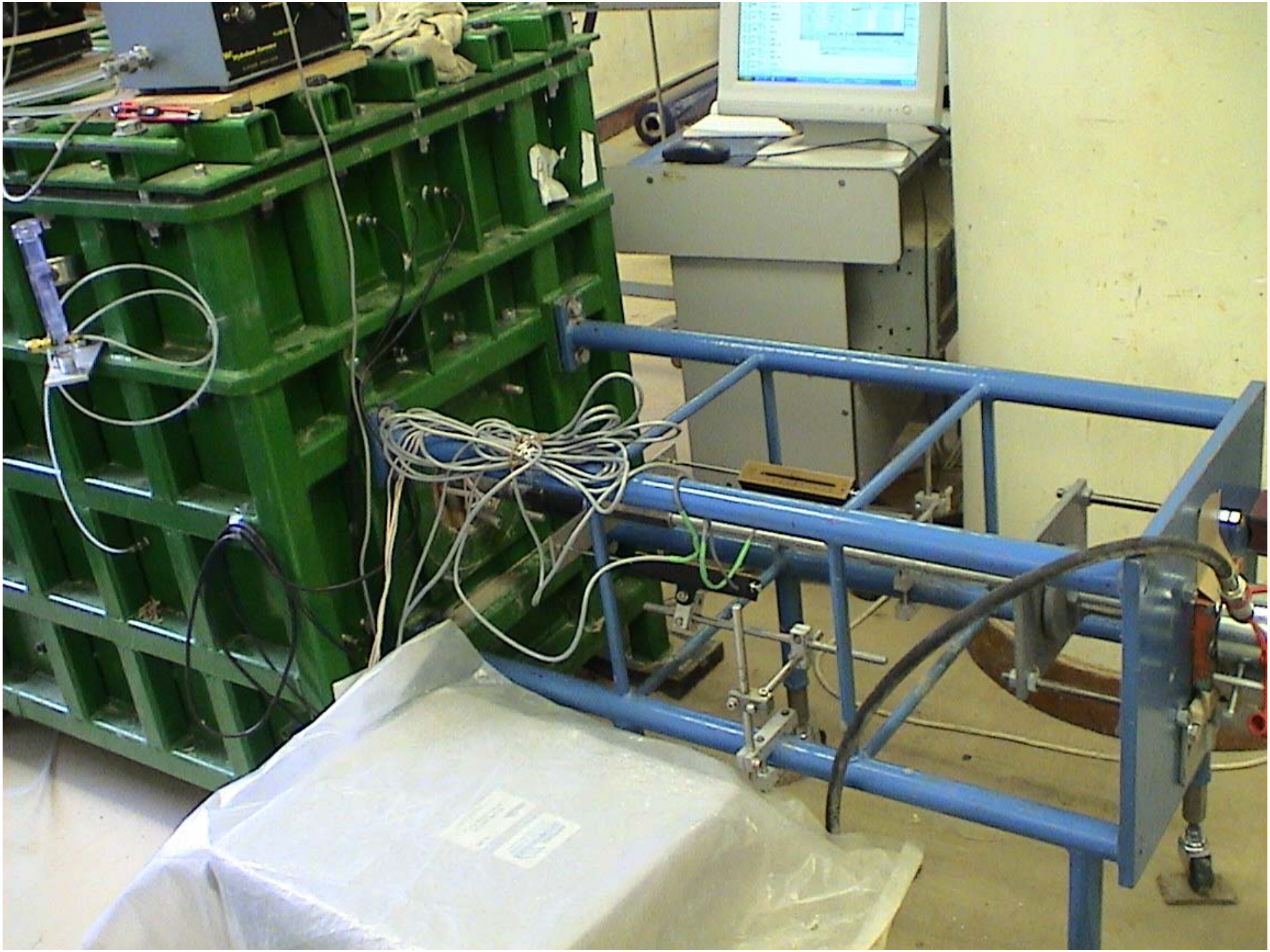
土钉上的应力为零



Stress is released (to zero).

What is the normal stress on nail?

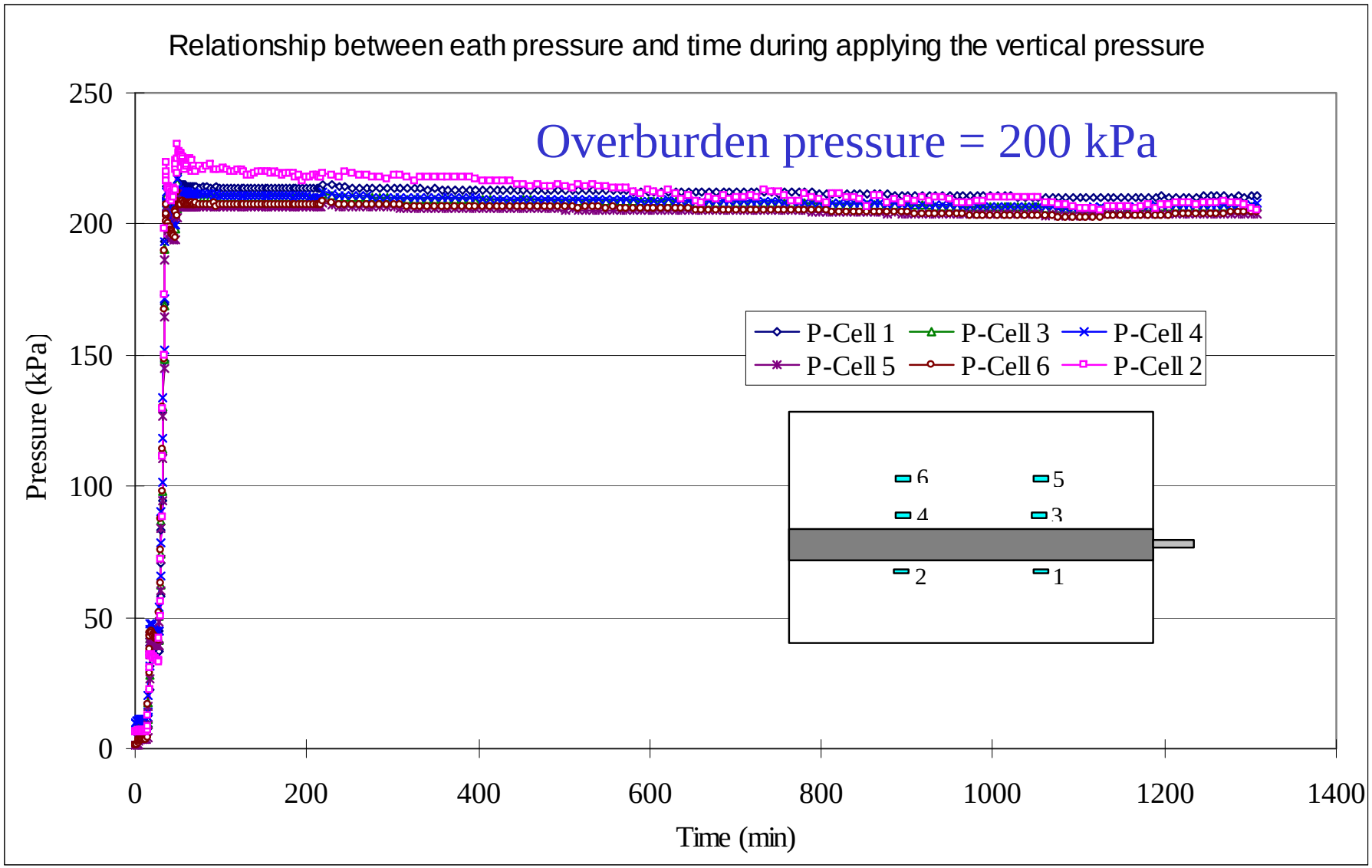

What is the normal stress on nail?



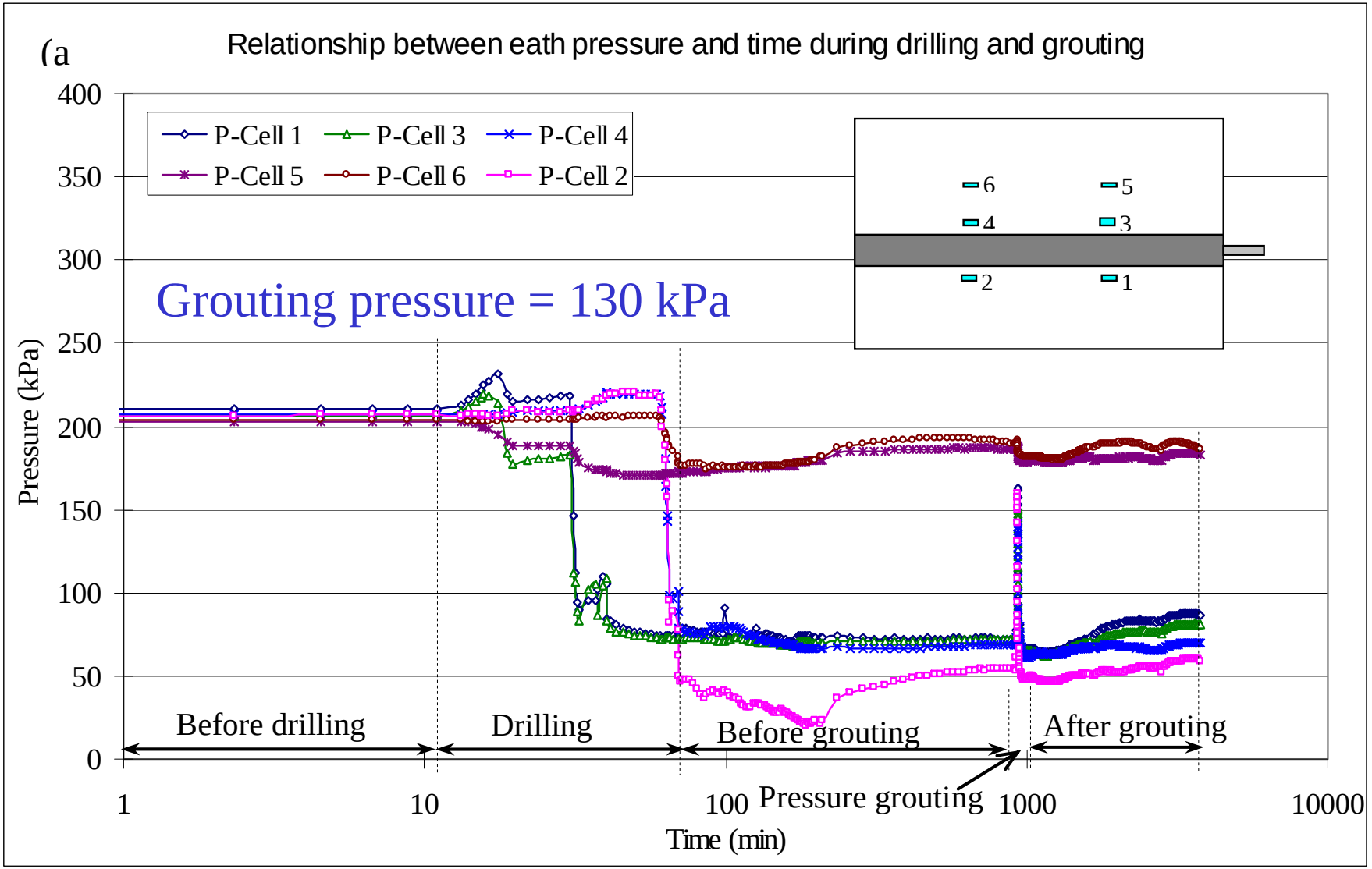
Example data from a pressure grouted soil nail pullout test :

Vertical Pressure (VP) = 200 kPa
Degree of saturation S_r = 50%
Cement grouting pressure = 130 kPa

Step 1: Establishment of field overburden pressure

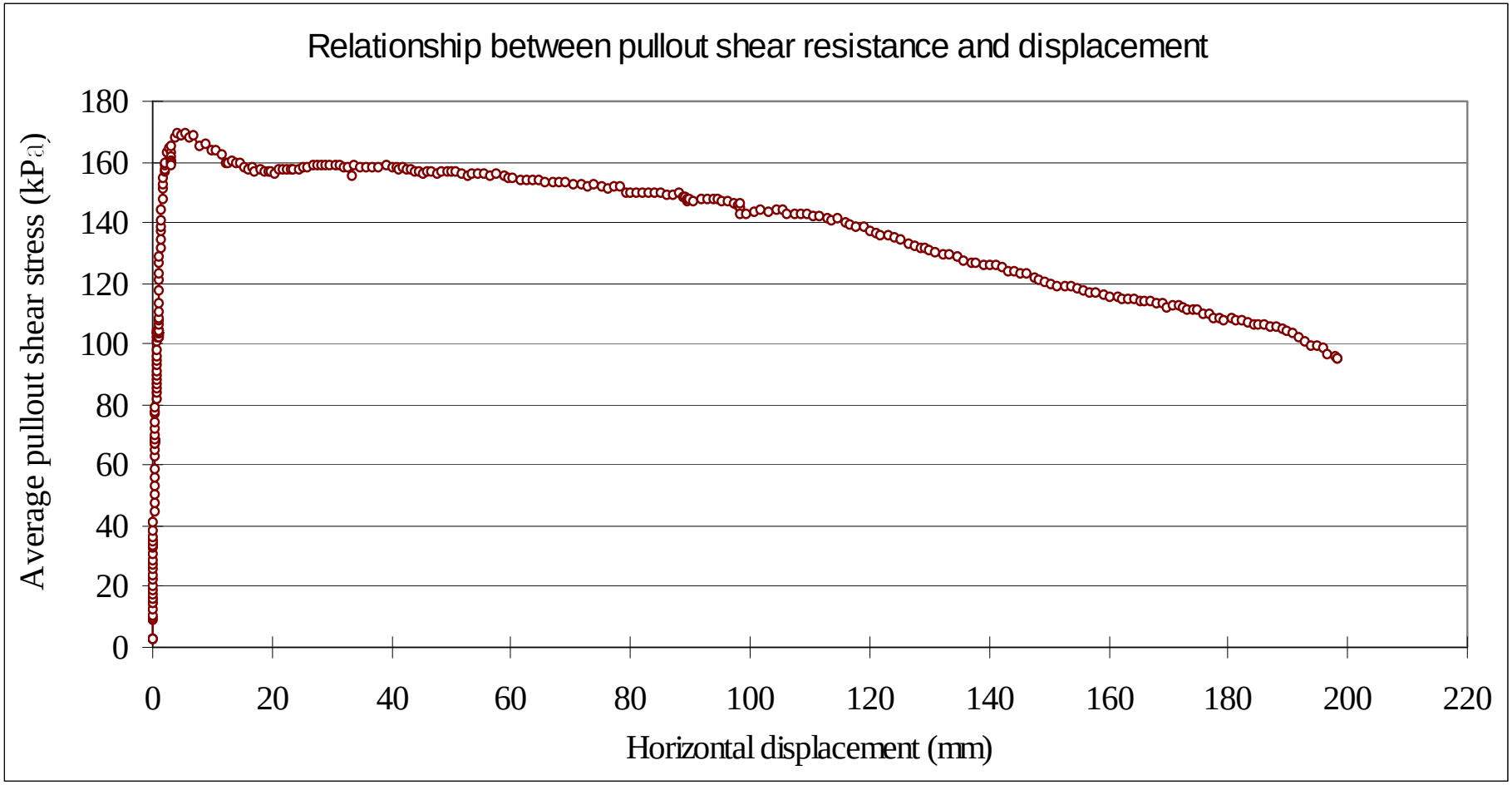


Step 2: Drilling and nail installation with cement slurry pressure grouting



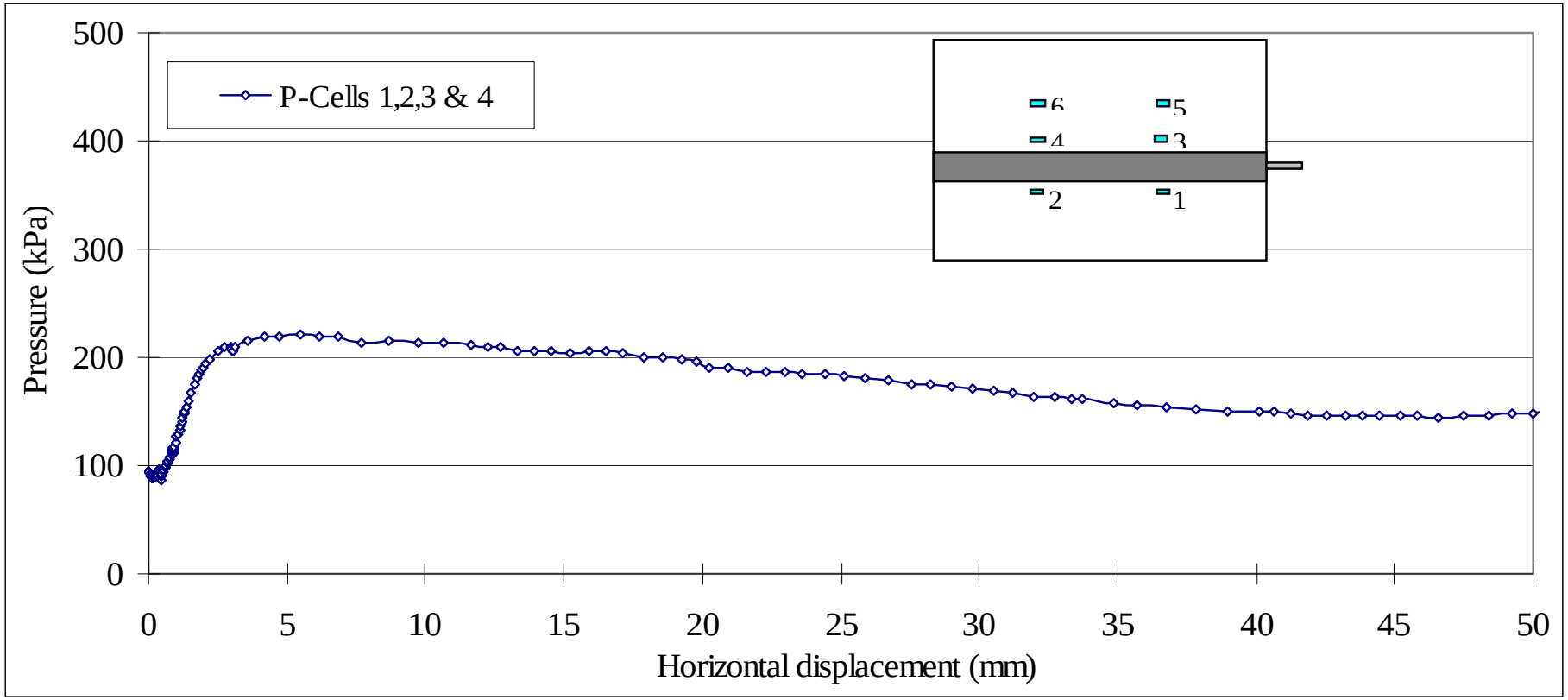
Step 3: Soil nail pull-out with full monitoring

(i) Average pullout shear stress (or load) *vs* horizontal displacement



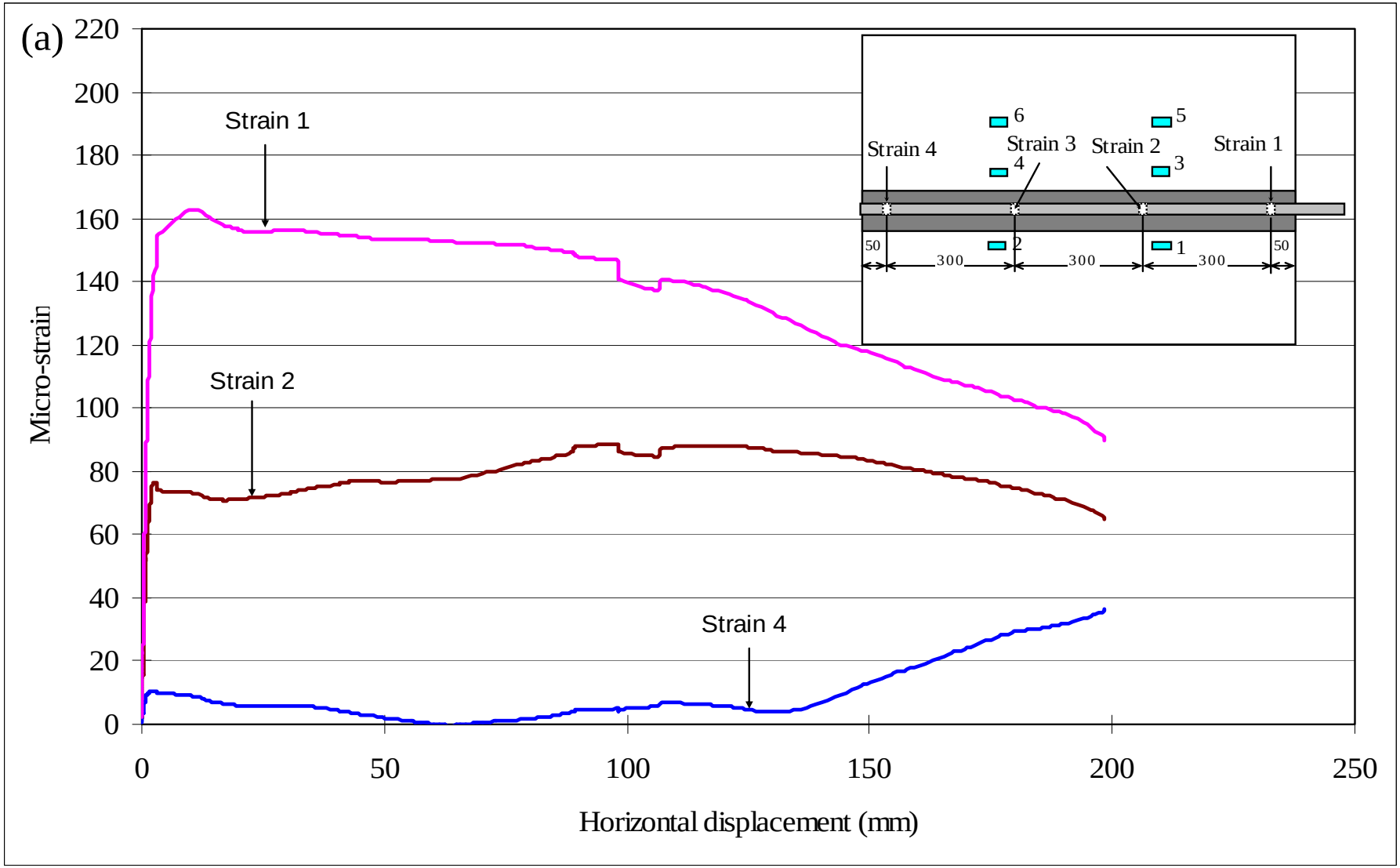
Step 3: Soil nail pull-out with full monitoring

(ii) Average earth pressure on the nail surface *vs* horizontal displacement



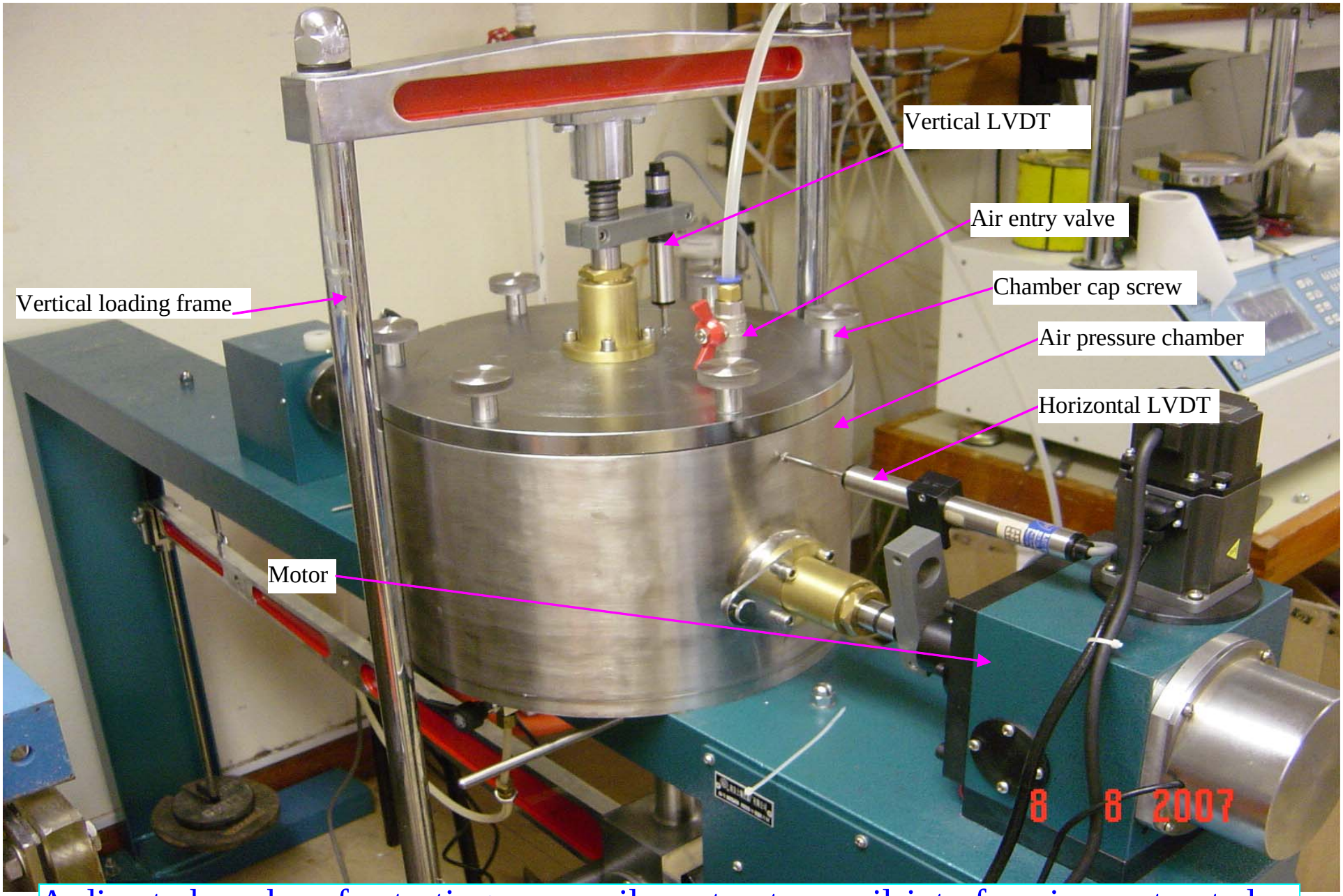
Step 3: Soil nail pull-out with full monitoring

(iii) Strains on re-bar *vs* horizontal displacement



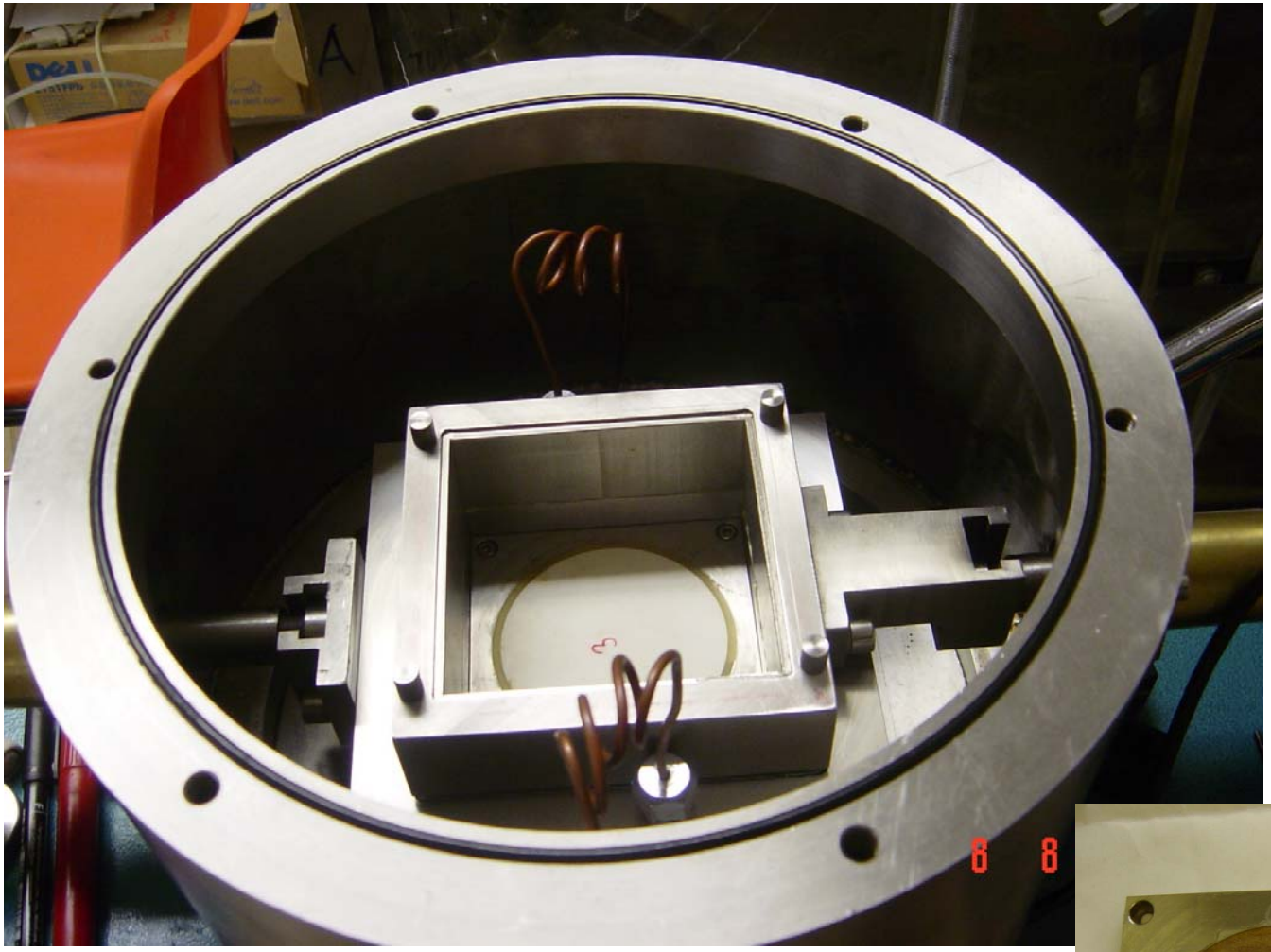
9. A direct shear box for testing both saturated and unsaturated soils and interface

- For studying shear strength of pure soil or the interface with soil in unsaturated (or saturated) state
- Size： 100mm wide x 100mm long x 40mm



A direct shear box for testing pure soil or structure-soil interface in a saturated or unsaturated state with suction control and measurement (modified from Gan 1986, Gan *et al.* 1988, and Gan and Fredlund, 1992)

ZFY-1A型非饱和土应变控制式直剪仪
enter
shear
forward/stop
backward/stop
南京土壤仪
香港理工大学
8 8 2007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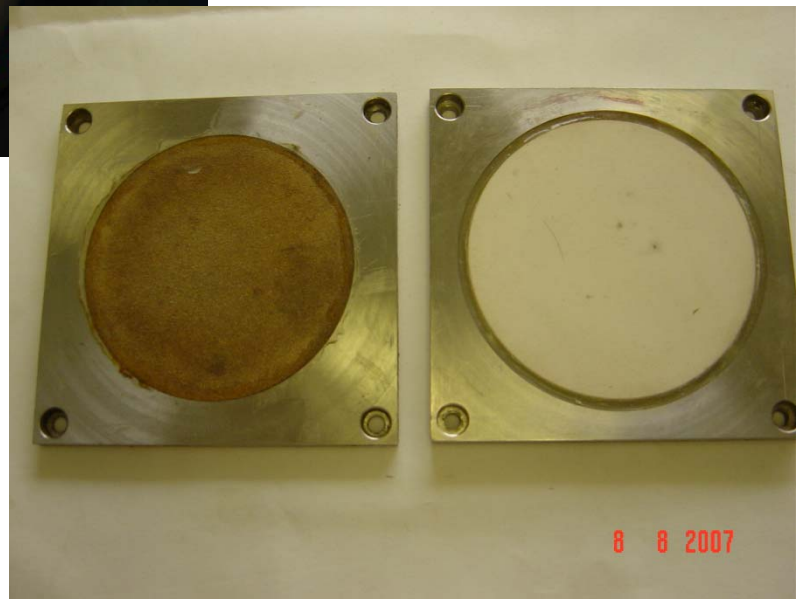

8 8 2007

10. Study of Debris Flow Impact on Flexible Barrier Using a Large-scale Physical Model

Background of Proposal and Motivation

- **Geo-hazards:** Landslides, debris flows, rock falls, failure of retaining walls and seawalls, collapse of dams/dikes, large ground subsidence, *etc*.
- **Problems:** Geo-hazards have caused the loss of human life and property in Hong Kong, Chinese Mainland, and many other regions or countries.
- **Examples** in Hong Kong, Chinese Mainland, and the world:

  (i) Landslides of Sau Mau Ping of Hong Kong: 1972 landslide caused 71 casualties and in 1976 another one caused 16 casualties

  (ii) On 8 August 2010, the large debris flow in Zhouqu, Gansu Province of Chinese Mainland caused death of 1471 persons and 294 persons missing

Examples in Chinese Mainland and the World:

(i) Debris flow, 16 May 2008 (273 dead) after Wenchuan Earthquake, 12 May 2008, 8.0 Richter magnitude scale (69227 dead and 18923 missing) - photos by Yin and videos in Korea

Debris flow video in Korea

(ii) (a) Left below - debris flow of Fully, Switzerland, 2000 and (b) during the 1980 eruption of Mount St. Helens, a debris flow traveled about 14 miles down the valley of the North Fork Toutle River. It destroyed nine highway bridges, many miles of highways and roads, and about 200 homes on the flood plain of the Toutle River (Photo: D. Crandell, USGS).

A large debris flow in Zhouqu, Gansu Province of Chinese Mainland caused 1471 causalities and 294 persons missing in on 8 August 2010

Why a Large-scale Multi-function Facility?

Iverson (1997) and Iverson *et. al.* (2010): physical model tests (95m flume and with debris volume of $10m^3$ ~ $20m^3$) (USA: USGS) (not for the impact of debris flow on flexible barriers) (right)

Volkwein et al. (2006), Bugnion *et. al.* (2012), and Wendeler *et. al.* (2006, 2008, 2012) (below)

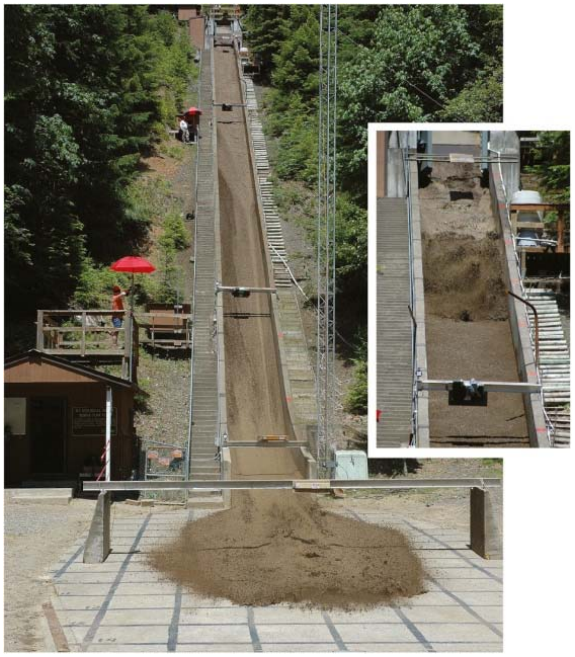
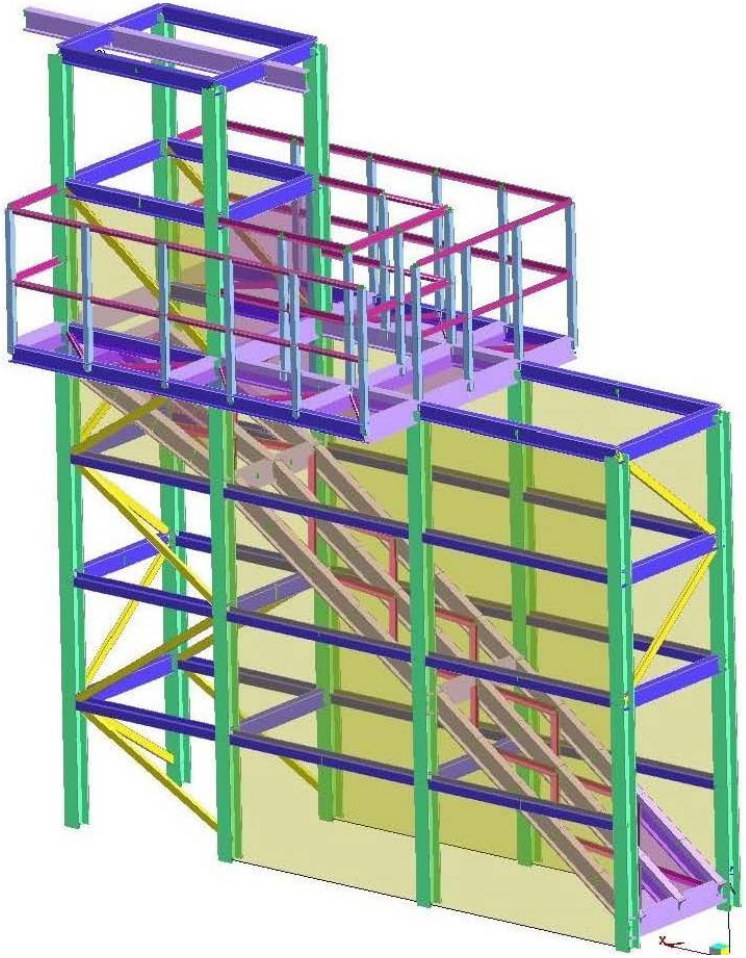


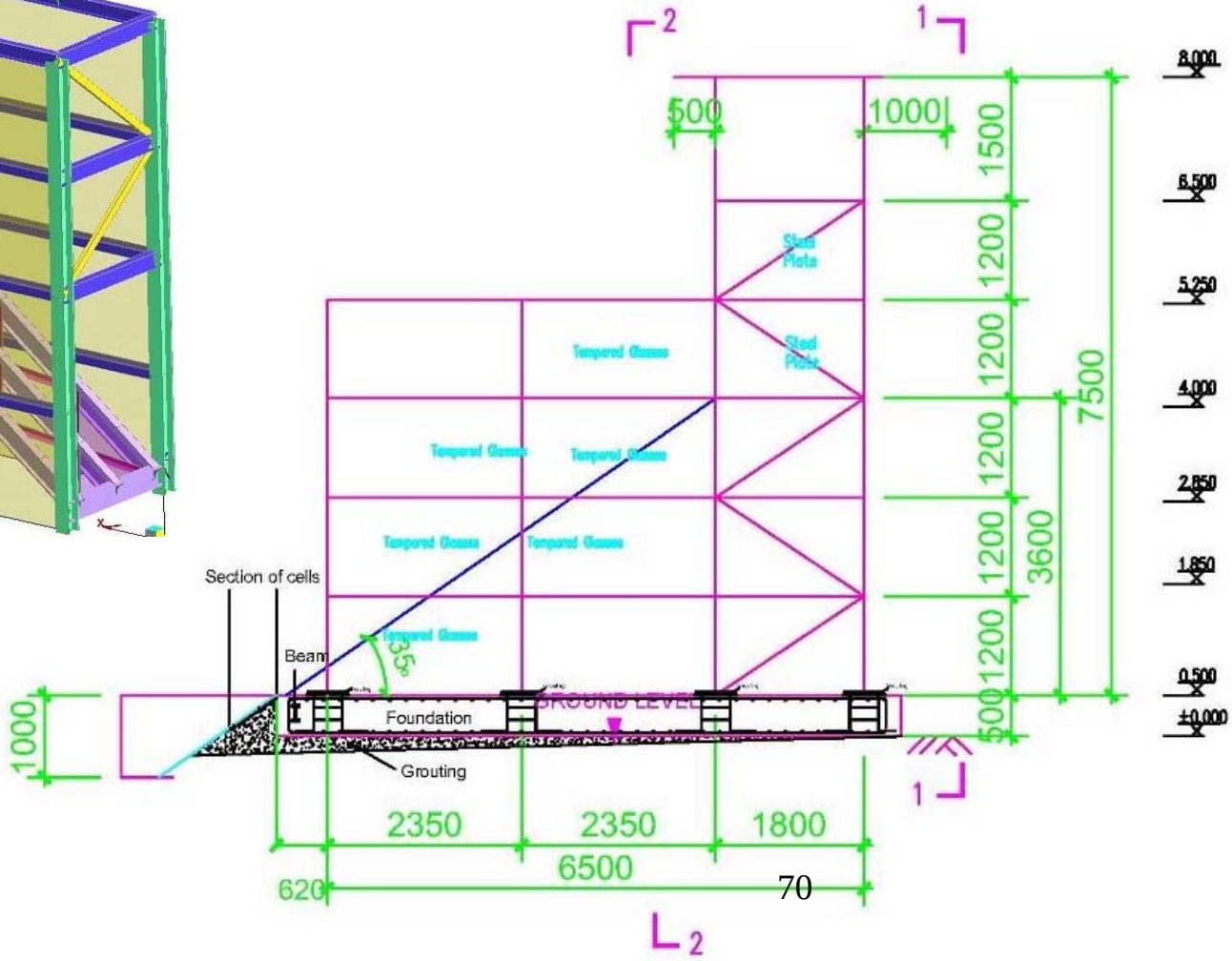
Figure 1: Debris flow deposit directly in front of a building and a filled flexible barrier system.

Why:

- The behavior of debris is highly non-linear, gravity driven, and stress-level dependent
- The volume of debris in HK design - $150m^3$
- Small-scale model: scale effects; field tests: problems of repeatability,

A Large-scale Multi-function Facility to be built in PolyU





Thank You