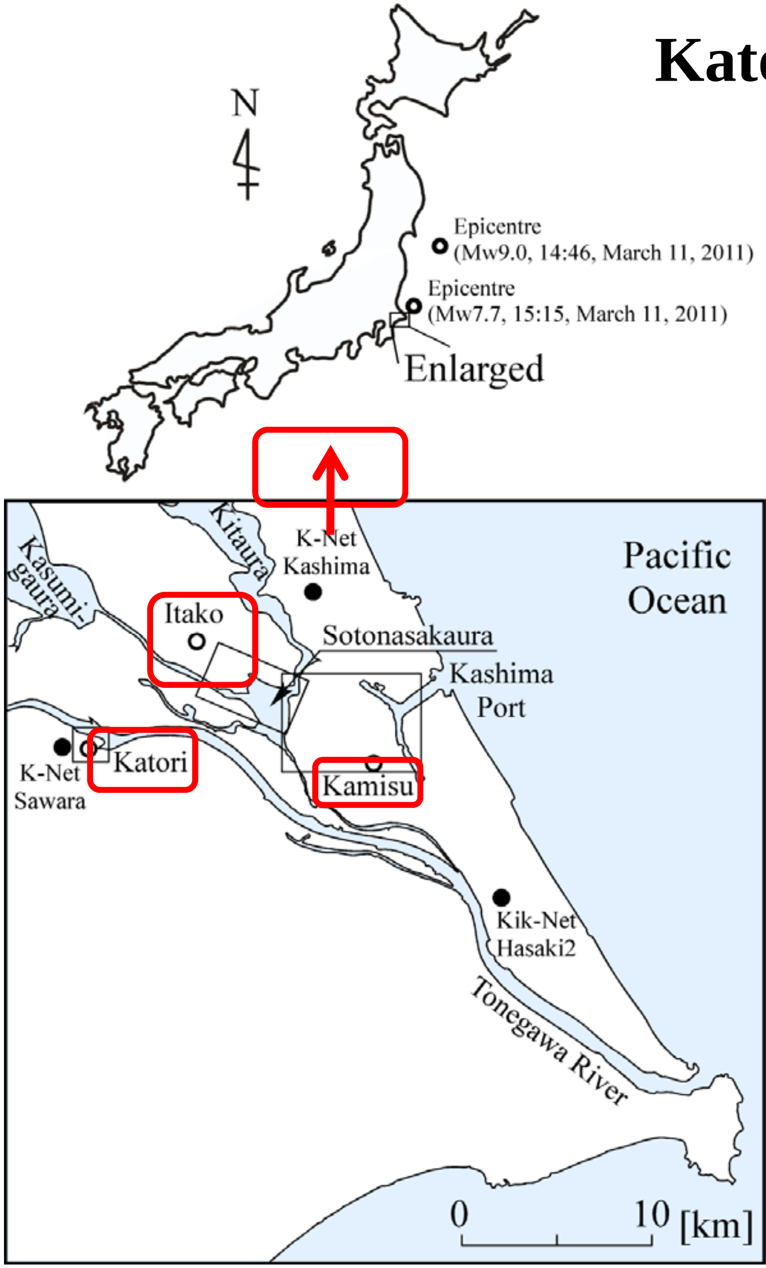
Ageing of soils affecting liquefaction triggering and undrained shear strength of soils

LIQUEFACTION EFFECTS CHALLENGE:
1 – Development and effects of **liquefaction-induced flow slides** that are governed by the **undrained residual shear strength** of liquefied soil

Yoshimichi Tsukamoto
Department of Civil Engineering,
Tokyo University of Science,
Chiba, Japan

Earthquake geotechnical reconnaissance investigations for 2011 Great East Japan Earthquake



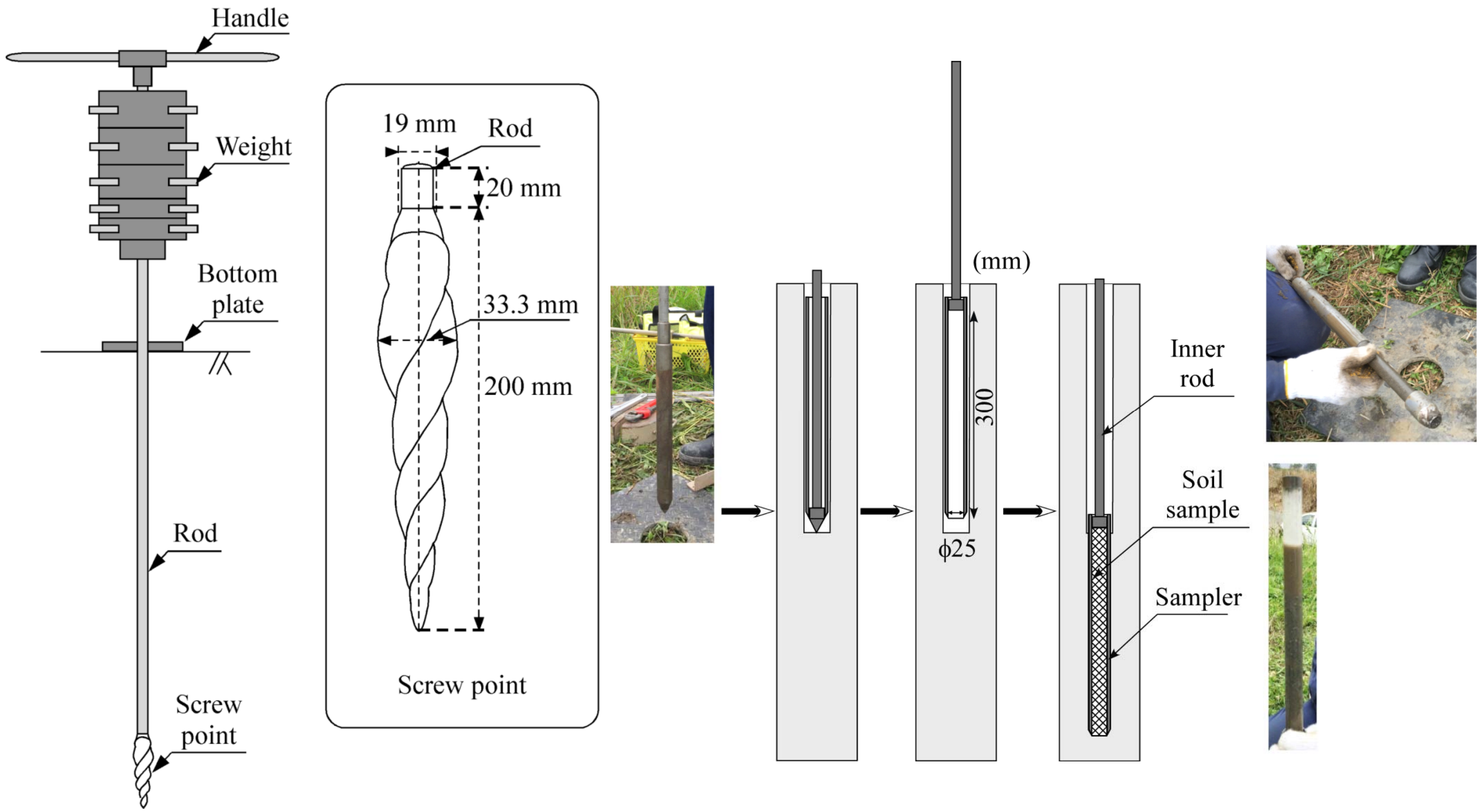
Katori

Itako

Kamisu

Hitachi-naka

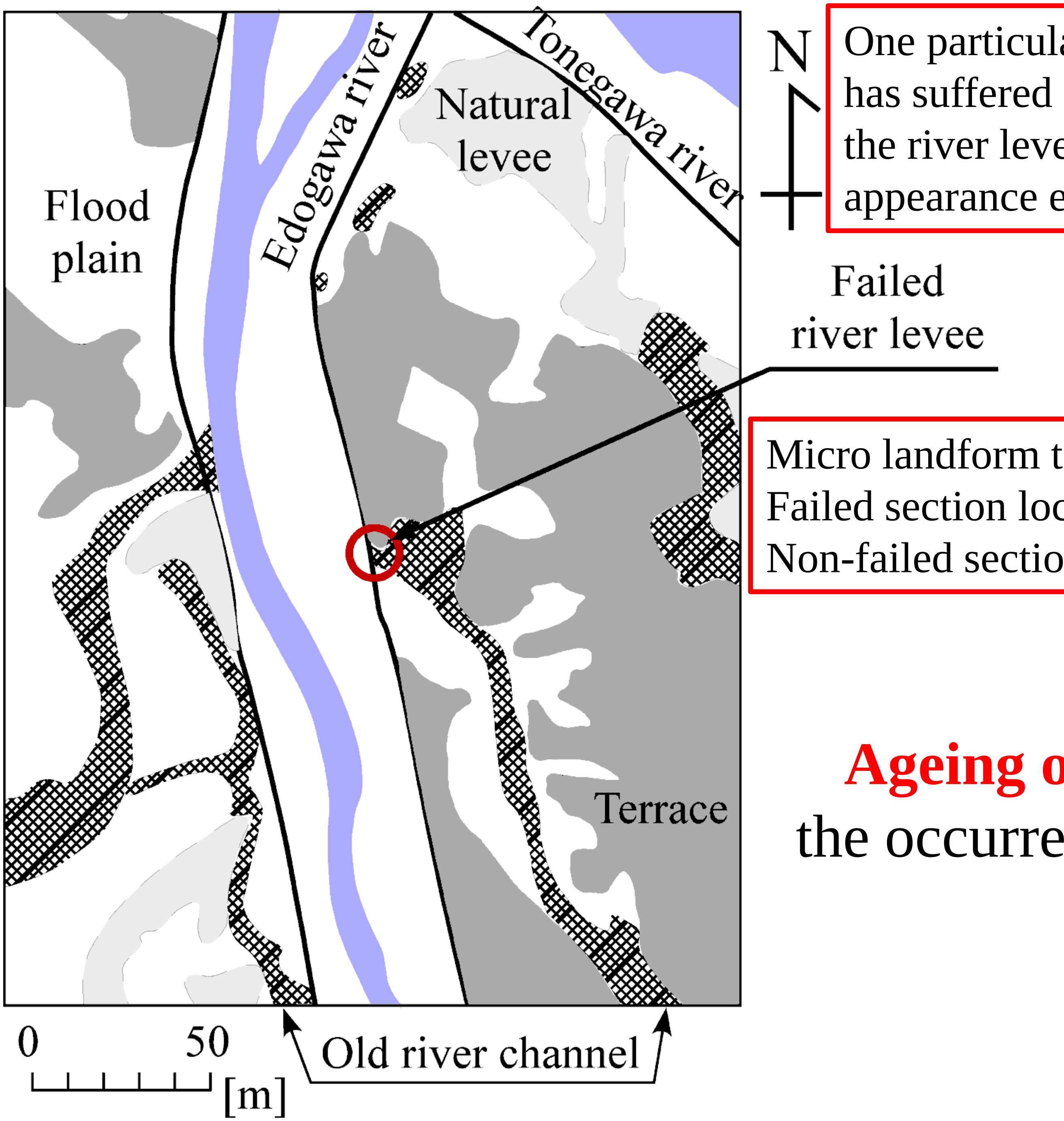
Swedish weight sounding (SWS) tests with soil sampling



Current objectives of the investigations

➡ Liquefaction-induced **river levee failures**

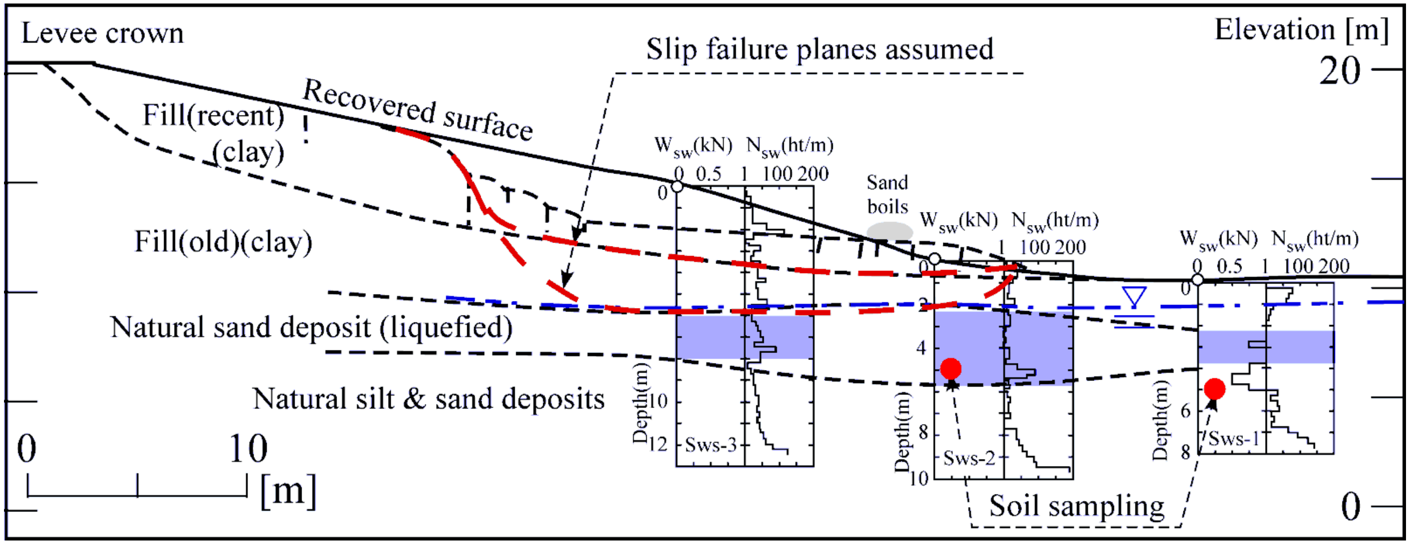
River levee failure observed at Sekiyado of Noda city, Chiba



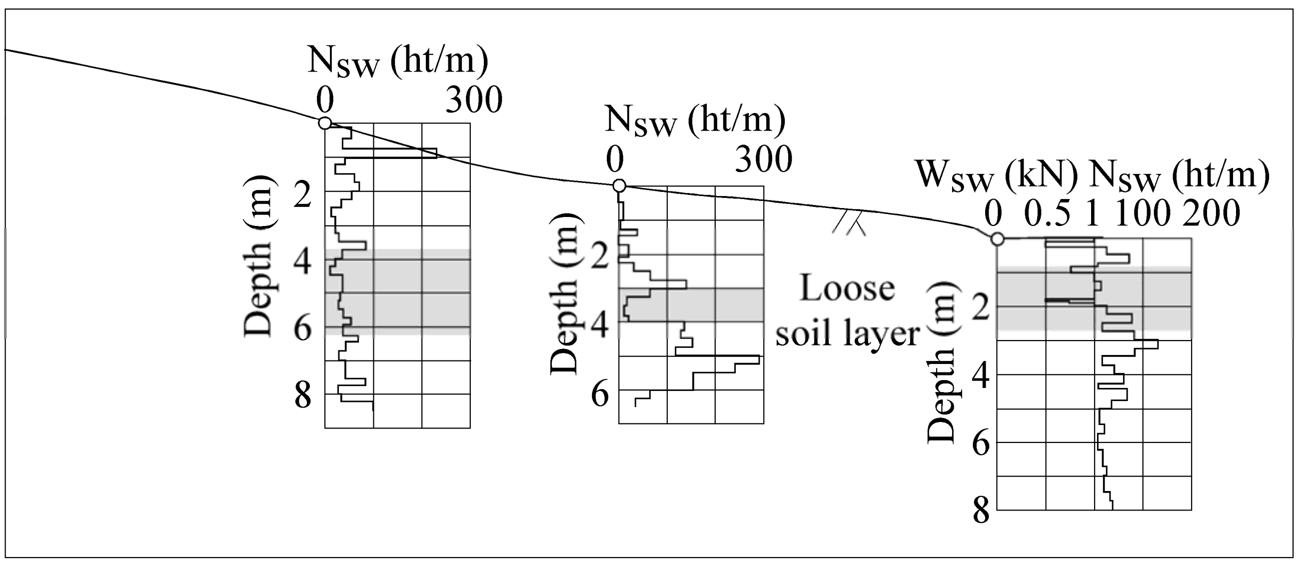
One particular section of the river levee has suffered from flow slides, though the river levee of similar outer appearance extended over a distance.

Micro landform tells that :
Failed section located on old river channel ;
Non-failed sections located on terrace.

Ageing of soils affecting the occurrence of flow slides



Failed section

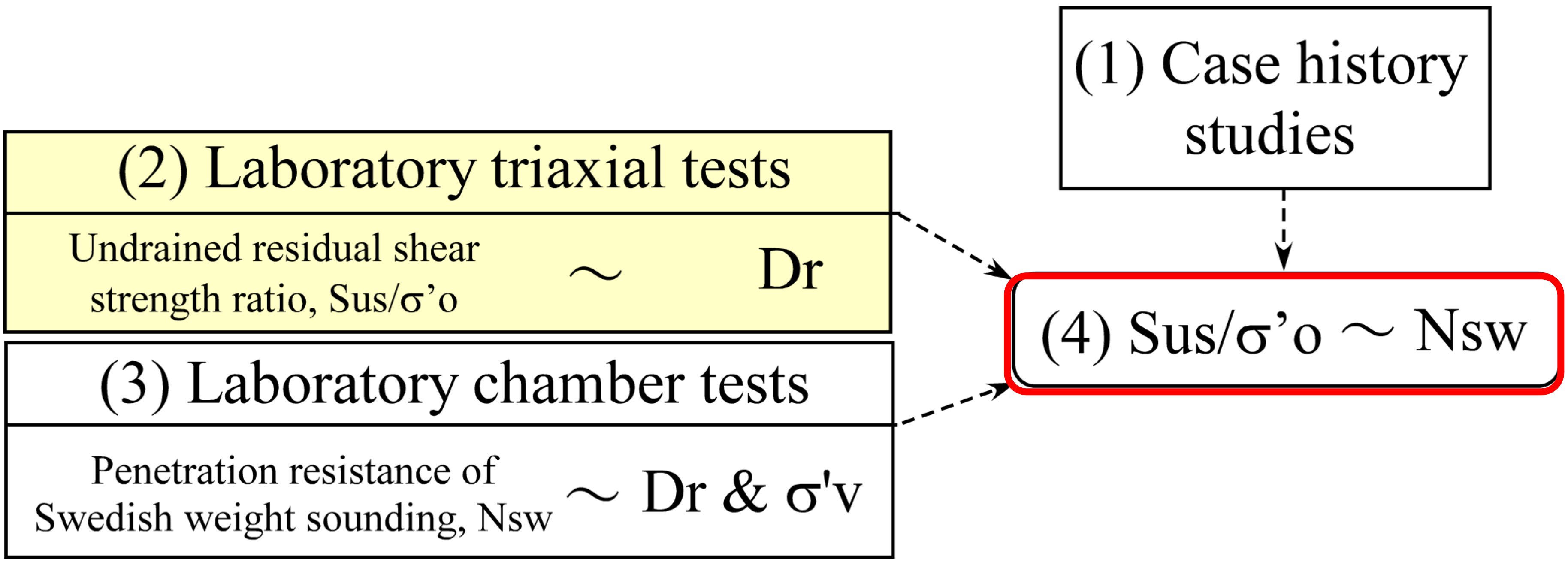


Non-failed section

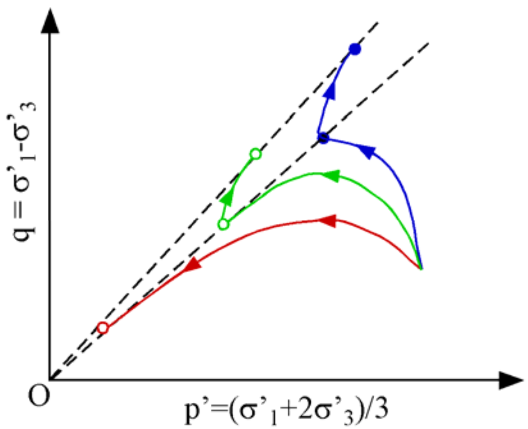
Large-strain Penetration resistances showing little difference found between failed and non-failed sections

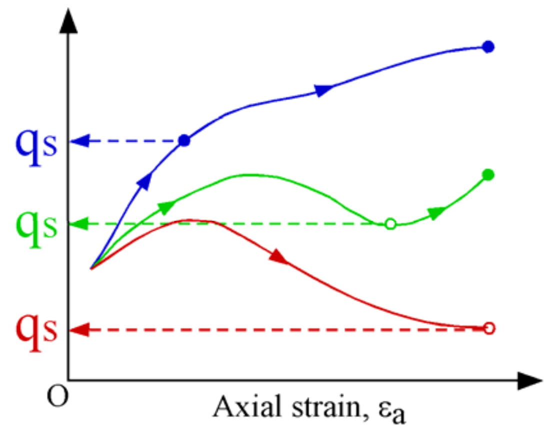
Current state of the art

Tsukamoto, Y., Ishihara, K. and Harada, K. (2009) "Evaluation of **undrained shear strength** of soils from **field penetration tests**", Soils and Foundations, Vol.49, No.1, 11 - 23.



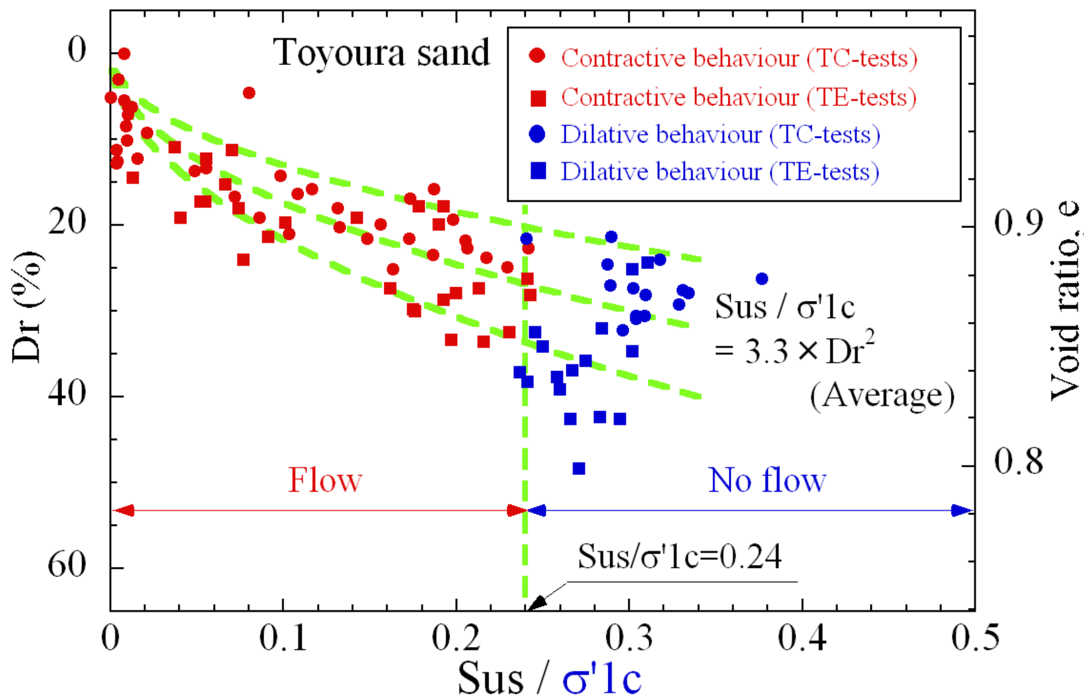
(2) $S_{us}/\sigma'_{1c} \sim D_r$





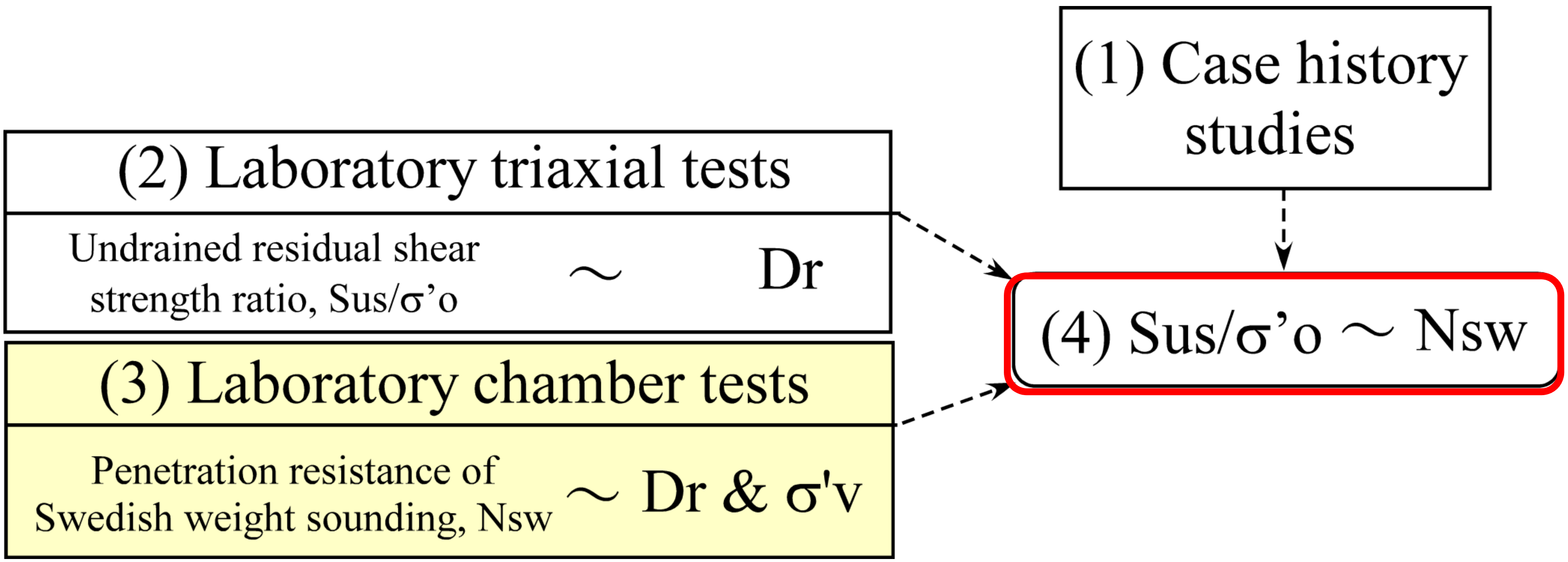
Undrained shear strength Sus

$$S_{us} = \frac{q_s \cos \phi_s}{2}$$

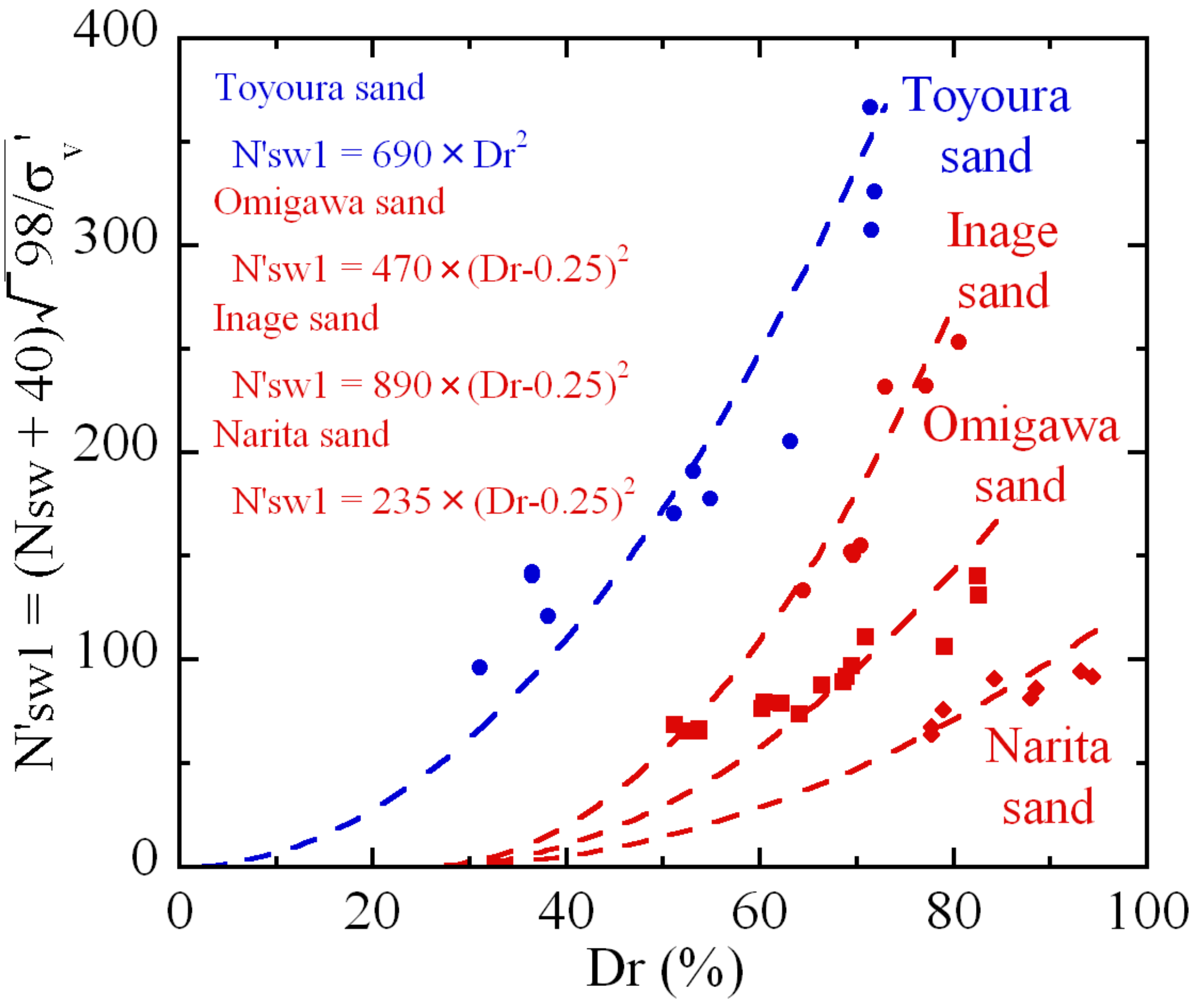


Data on reconstituted samples

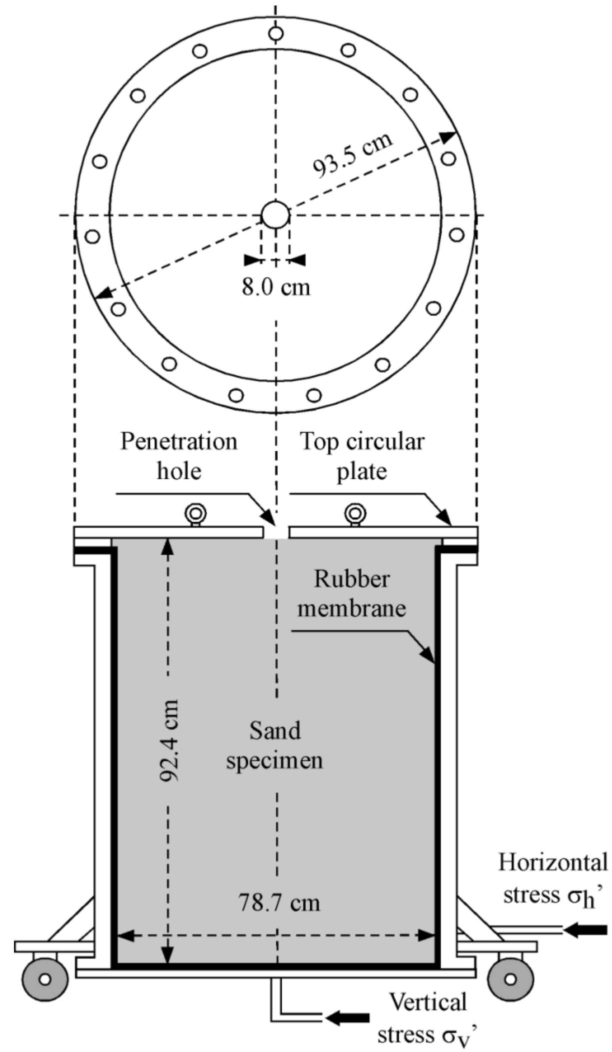
Tsukamoto, Y., Ishihara, K. and Harada, K. (2009) "Evaluation of **undrained shear strength** of soils from **field penetration tests**", Soils and Foundations, Vol.49, No.1, 11 - 23.



(3) $N_{sw} \sim D_r$

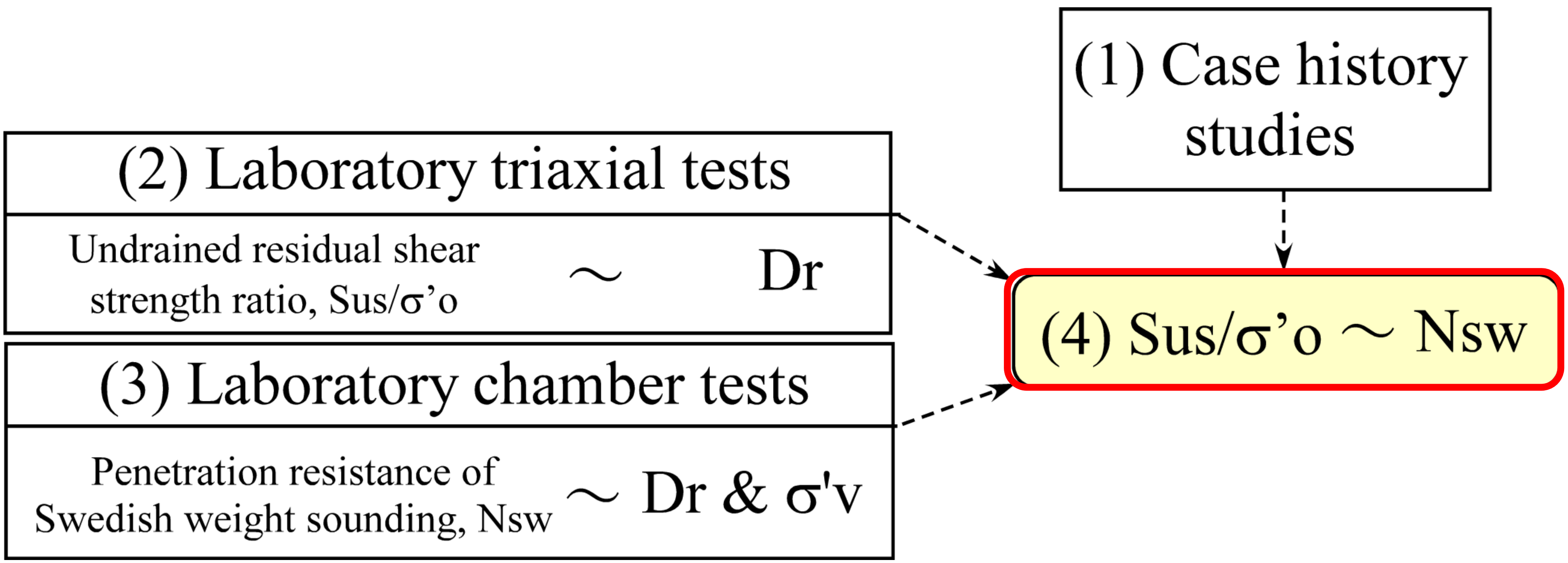


Toyoura sand
N'sw1 = 690 × Dr²
Omigawa sand
N'sw1 = 470 × (Dr-0.25)²
Inage sand
N'sw1 = 890 × (Dr-0.25)²
Narita sand
N'sw1 = 235 × (Dr-0.25)²
Toyoura sand
Inage sand
Omigawa sand
Narita sand
N'sw1 = (Nsw + 40)√(98/σ'v)
Dr (%)
0
100
200
300
400
0
20
40
60
80
100



93.5 cm
8.0 cm
Penetration hole
Top circular plate
Rubber membrane
92.4 cm
Sand specimen
78.7 cm
Horizontal stress σh'
Vertical stress σv'

Tsukamoto, Y., Ishihara, K. and Harada, K. (2009) “Evaluation of **undrained shear strength** of soils from **field penetration tests**”, Soils and Foundations, Vol.49, No.1, 11 - 23.



Tsukamoto, Y., Ishihara, K. and Harada, K. (2009) "Evaluation of **undrained shear strength** of soils from **field penetration tests**", Soils and Foundations, Vol.49, No.1, 11 - 23.

Laboratory triaxial tests

$$Sus/\sigma'v = \alpha \times (Dr - Dro)^2$$

Calibration chamber tests

$$N'sw1 = \beta \times (Dr - Dro)^2$$

$$N'sw1 = Csw \times Sus/\sigma'v$$

Csw is dependent upon grain composition of soils.

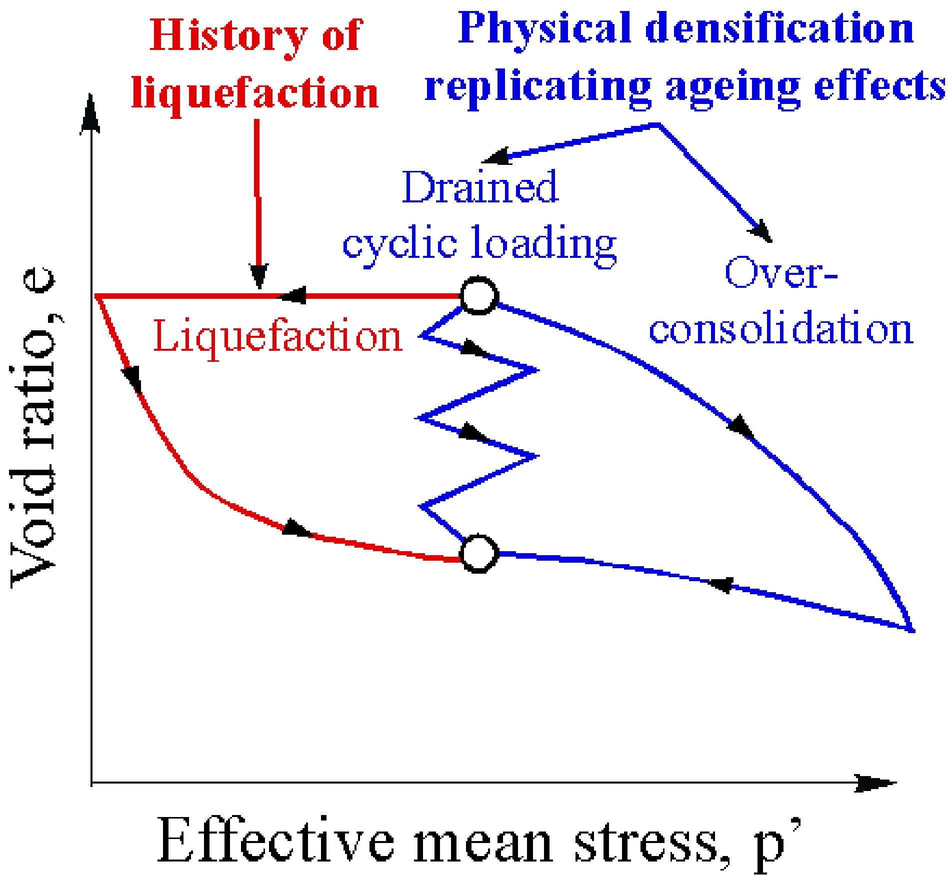
Geotechnical issues on discussion (1)

Ageing of soils ⇔ Recurrence of soil liquefaction

Ageing of soils : likely to increase liquefaction resistance R_l
Previous history of liquefaction : likely to reduce R_l

⬇

Contradicting effects



First-hand laboratory triaxial test results tell :

History of liquefaction

Undrained cyclic loading
& re-consolidation

$DA\varepsilon_a$

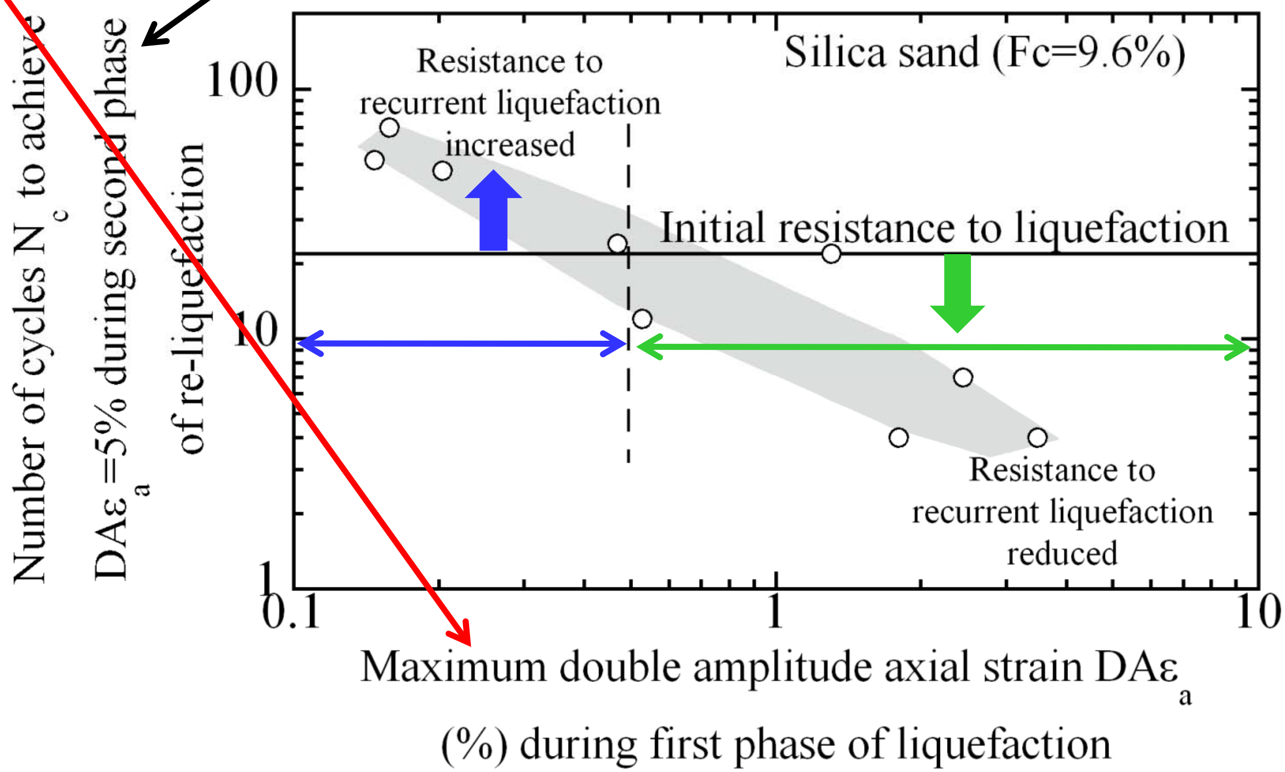
Recurrence of liquefaction

Undrained cyclic loading

Number of cycles N_c
to reach $DA\varepsilon_a$=5%

R_l increases after experiencing small shear strain.

R_l reduces after experiencing large shear strain.



Replicating ageing by physical densification

Drained cyclic loading
or
Over-consolidation

→

History of liquefaction

Undrained cyclic loading
& re-consolidation

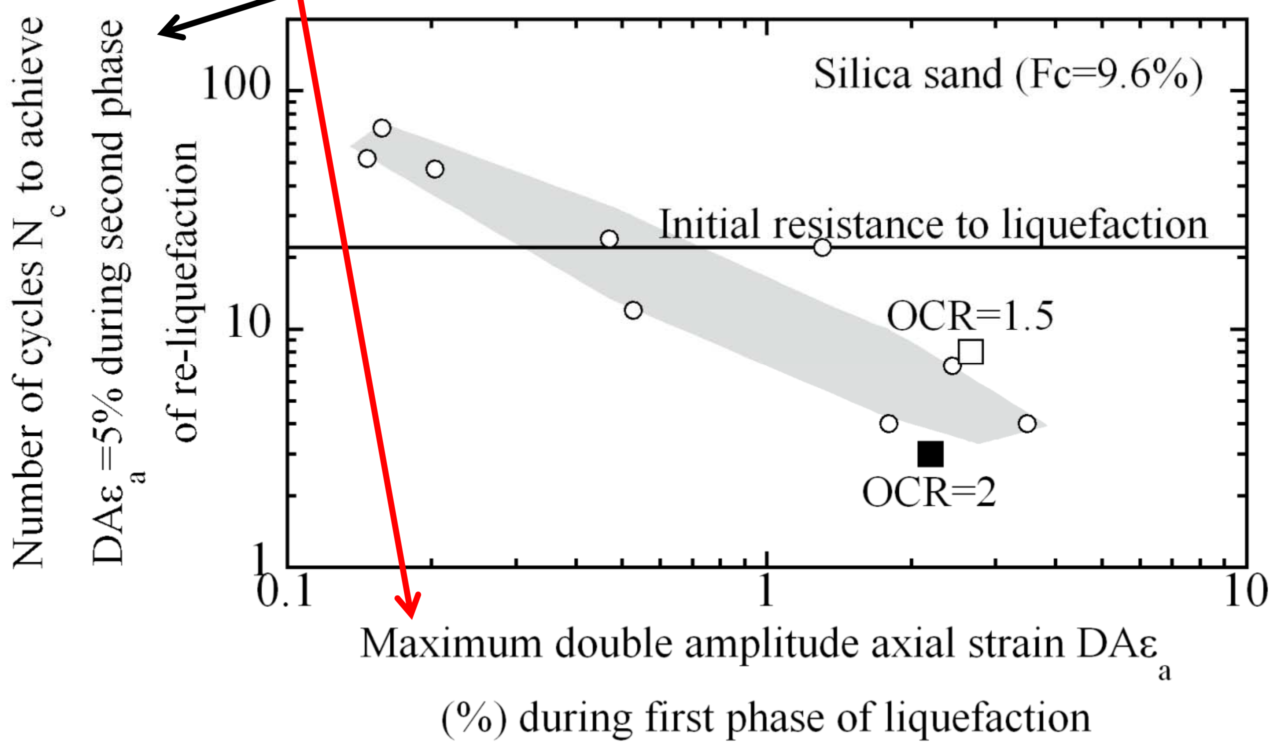
$DA\varepsilon_a$

→

Recurrence of liquefaction

Undrained cyclic loading

Number of cycles N_c
to reach $DA\varepsilon_a$=5%



Experiencing liquefaction wiped out any prior physical ageing effects on the recurrence of soil liquefaction.

History of liquefaction

Undrained cyclic loading
& re-consolidation

$DA\varepsilon_a$

→

Replicating ageing by physical densification

Drained cyclic loading
or
Over-consolidation

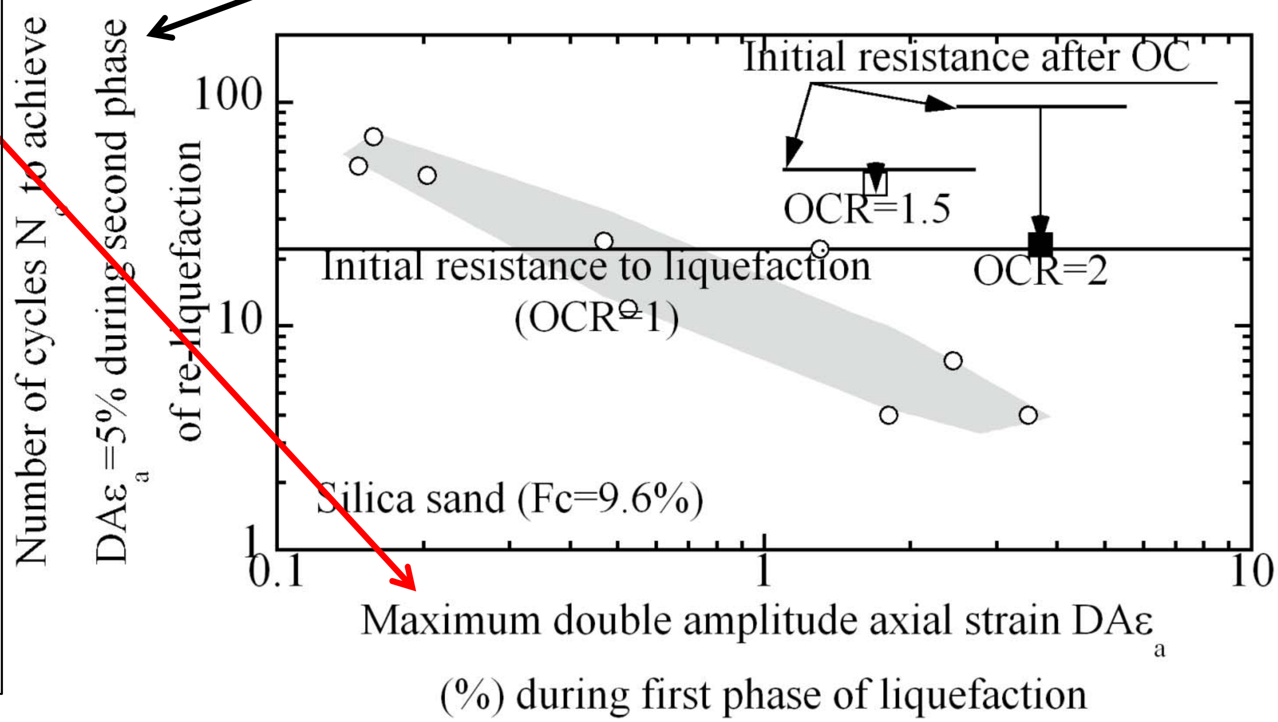
→

Recurrence of liquefaction

Undrained cyclic loading

Number of cycles N_c to reach $DA\varepsilon_a$=5%

Experiencing liquefaction would not prevent improvement of resistance to recurrent liquefaction due to physical ageing effects, though not fully.



Geotechnical issues on discussion (2)

Can the effects of ageing be incorporated into liquefaction triggering evaluation based on large-strain penetration testing ?

You might agree that

(a) It is known and the fact that laboratory reconstituted specimens of silty sands and silts tend to exhibit lower resistance to liquefaction that those of clean sands, though density should matter herein.

(b) The liquefaction resistances of silty sands and silts are estimated to be greater than clean sands, when they are evaluated based on SPT blow counts.

You might also agree that

(c) It is reasonable and agreeable that the SPT penetration resistances of silty sands and silts tend to be lower than clean sands, due most probably to more contractive dilatancy of silty sands and silts than clean sands.

(d) One might criticize that large-strain SPT N-values would not suit to examining ageing effects of soils that would form fragile inter-granular structures, hence comes in the shear wave velocity measurement, (ex. Andrus and Stokoe 2000).

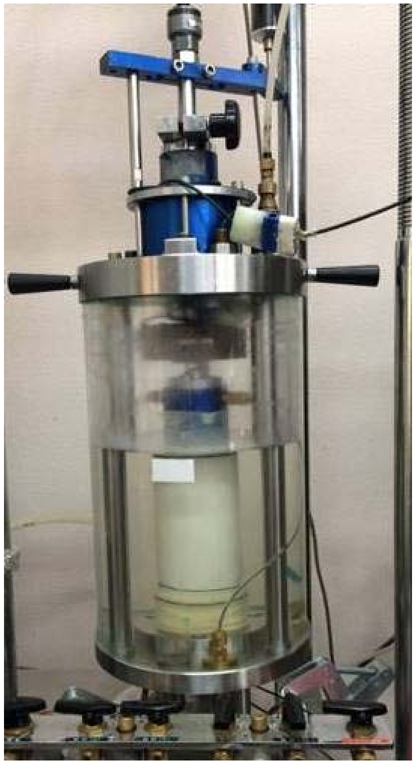
(e) One might assume that ageing inter-granular structures tend to be more easily developed or developable within silty sands and silts than clean sands, though their mineralogical origins should matter herein.

I am not aware of what could be the most probable scenario on what degree the effects of ageing are important in estimating the liquefaction resistance and undrained shear strength of silty sands and silts, from field penetration tests, …

though I am still interested in evaluating them from field penetration tests.

Bender element

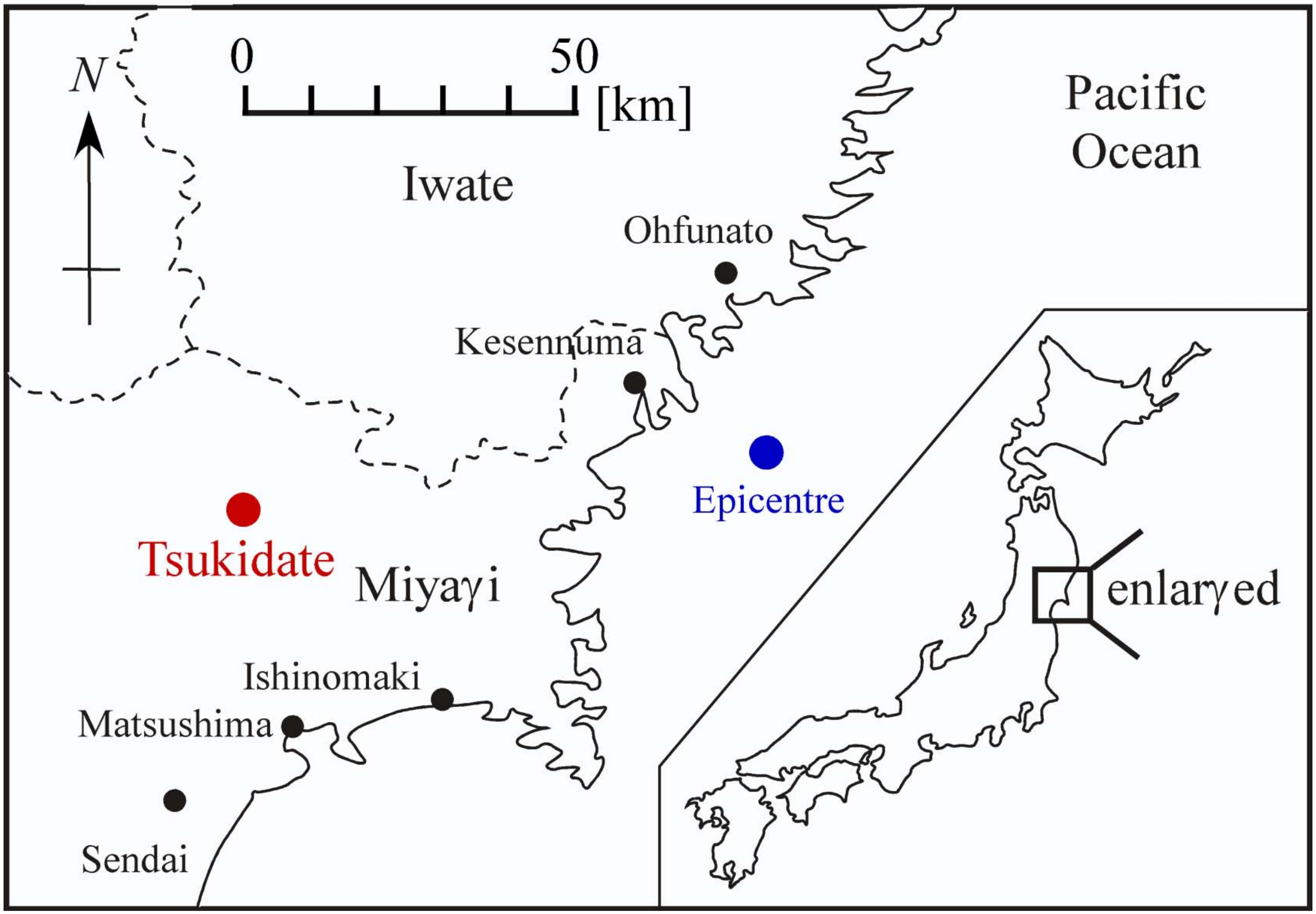
The current research topics are …



Professor Ishihara requested me to present you on the case history of Tsukidate (long-distance & rapid) landslide.

2003 Miyagiken-oki Earthquake

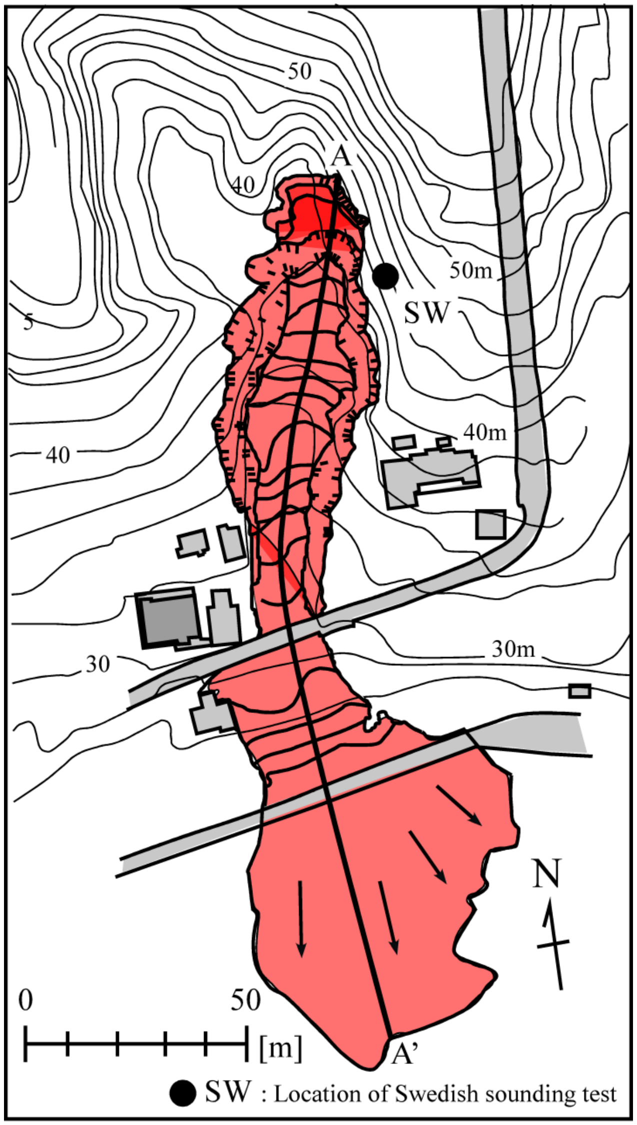
18:24, May 26 Mjma=7.0 Depth=70km Intra-plate



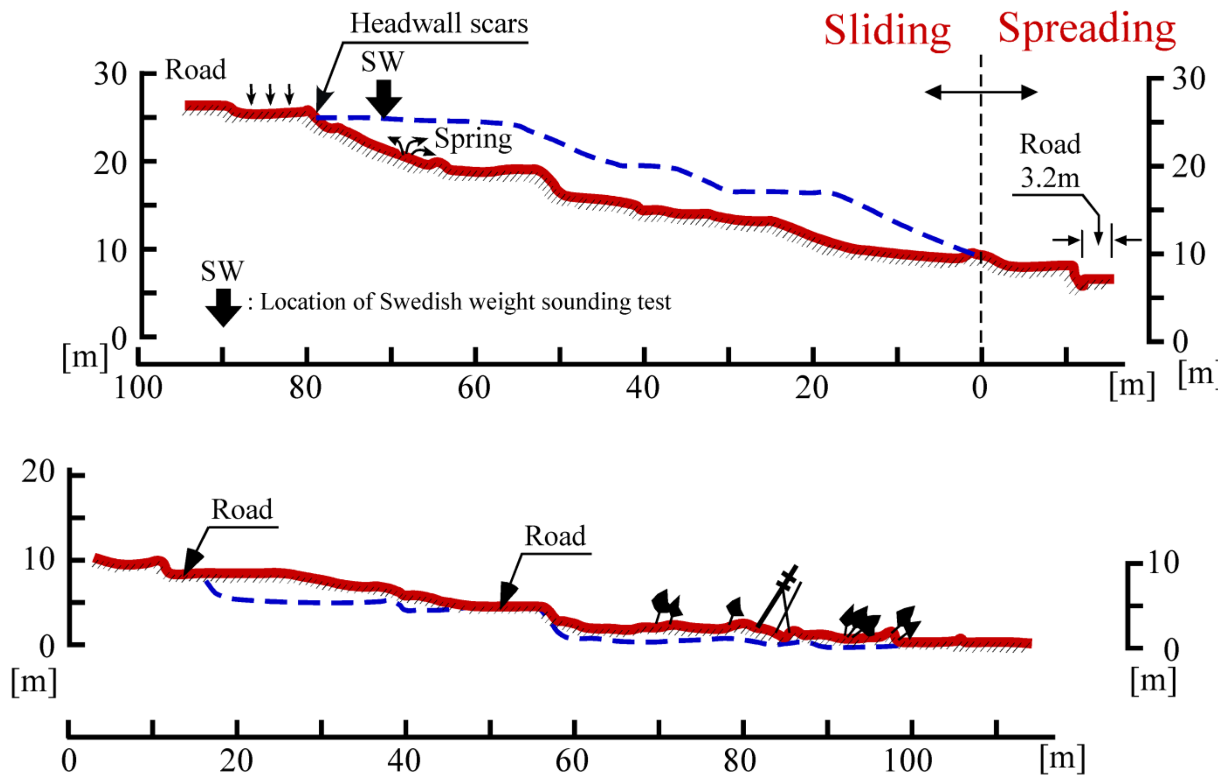
- Tsukidate landslide -

The rapid landslide occurred at Tsukidate.

The loose reclaimed soil deposits with 40 metres wide, 80 metres long and 5 metres deep were collapsed and flowed downstream on a gentle slope with 7 degrees inclination.



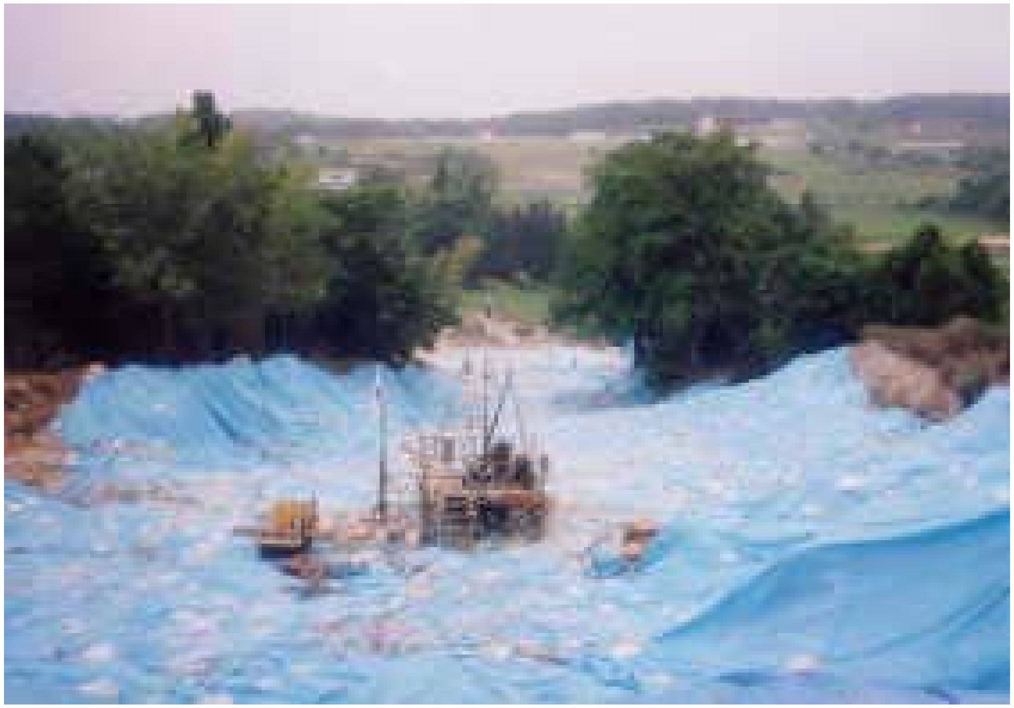
(a) Plan view



(b) Cross section A-A’

- Tsukidate landslide -

- Tsukidate landslide -



End. Thank you.