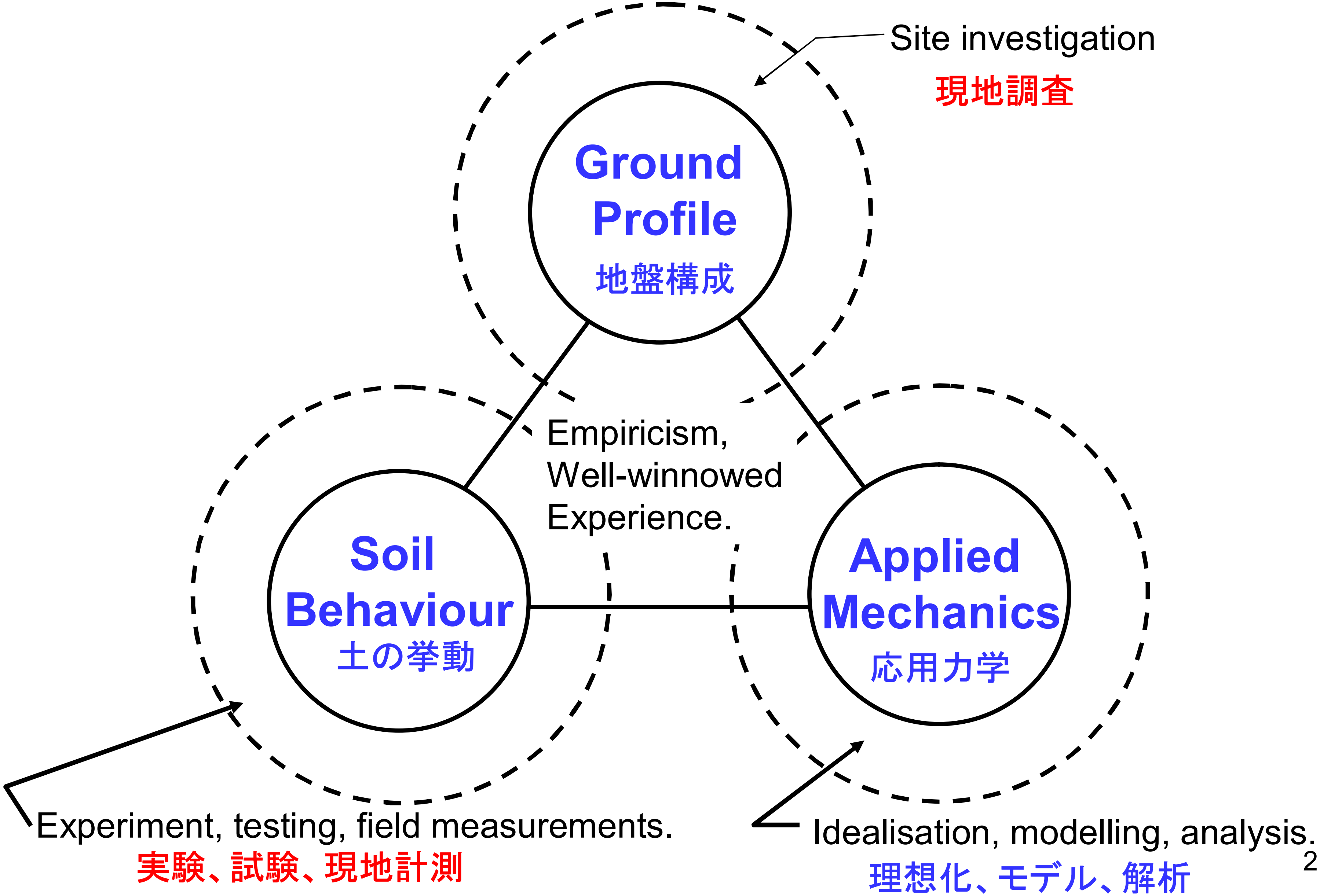
Mechanics of Geomaterials(土質材料学特論)

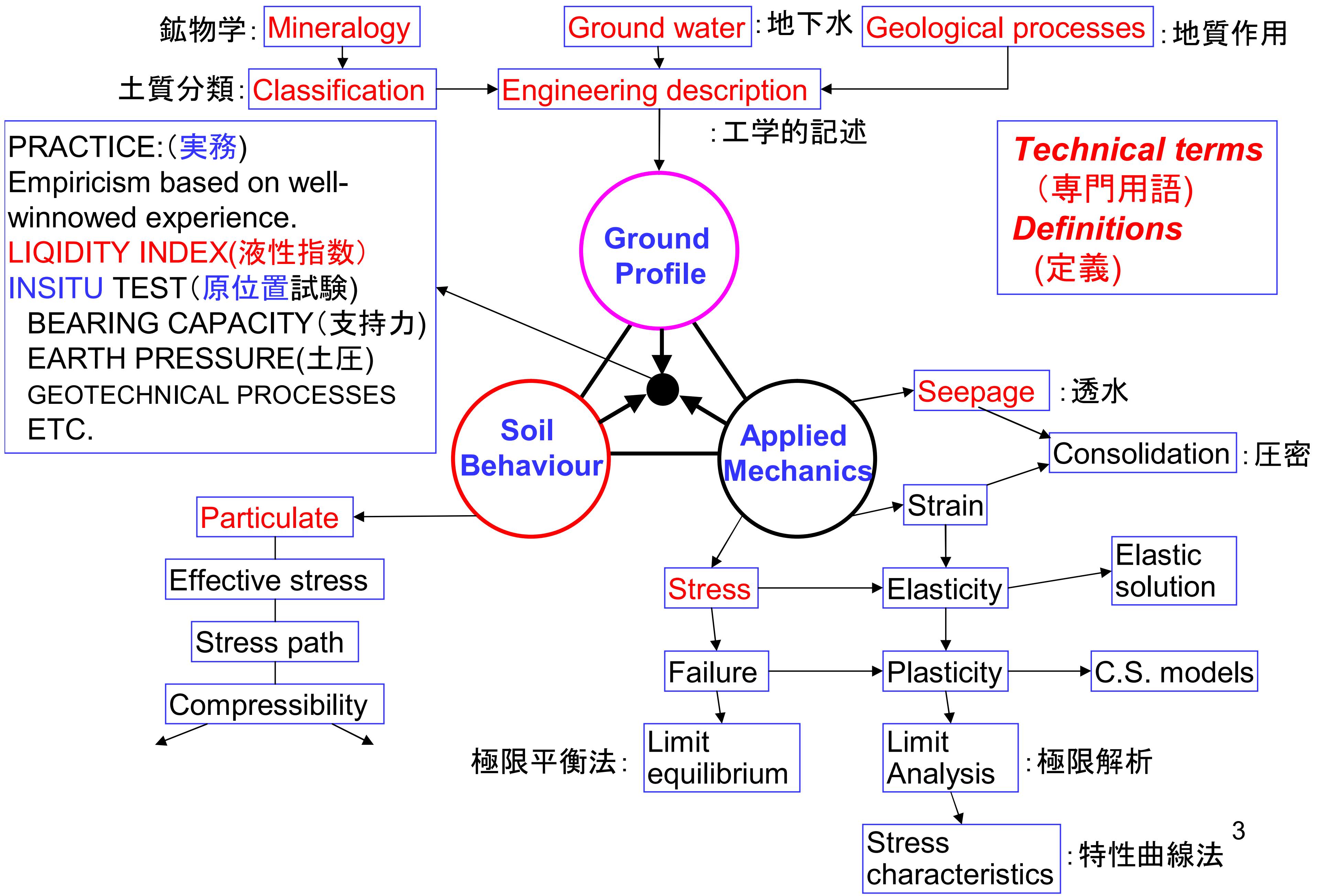
- Course syllabus -

(4/12) Stress path method	(O)
(4/19) Sampling and lab testing of cohesive geomaterials	(Ta)
(4/26) In-situ testing	(Ta)
(5/10) Liquefaction of soils I(Mechanism and evaluation)	(Ta)
(5/17) Liquefaction of soils II (Damage and Countermeasure)	(Ta)
(5/24) Stress orientation and earth pressure in soil mass	(Th)
(5/31) Mechanical characteristics of anisotropic soils	(Th)
(6/7) Failure criteria for geomaterials	(Th)
(6/14) In-situ mechanical behaviour of cohesive geomaterials	(O)
(6/21) Undrained behaviour of normally and over- consolidated cohesive soils	(O)
(6/28) Time dependent behaviour of cohesive geomaterials	(Th)
(7/12) In-situ mechanical behaviour of cohesionless geomaterials	(O)
(7/19) Laboratory and in-situ tests on compacted geomaterials	(O)
(8/2) Examination	

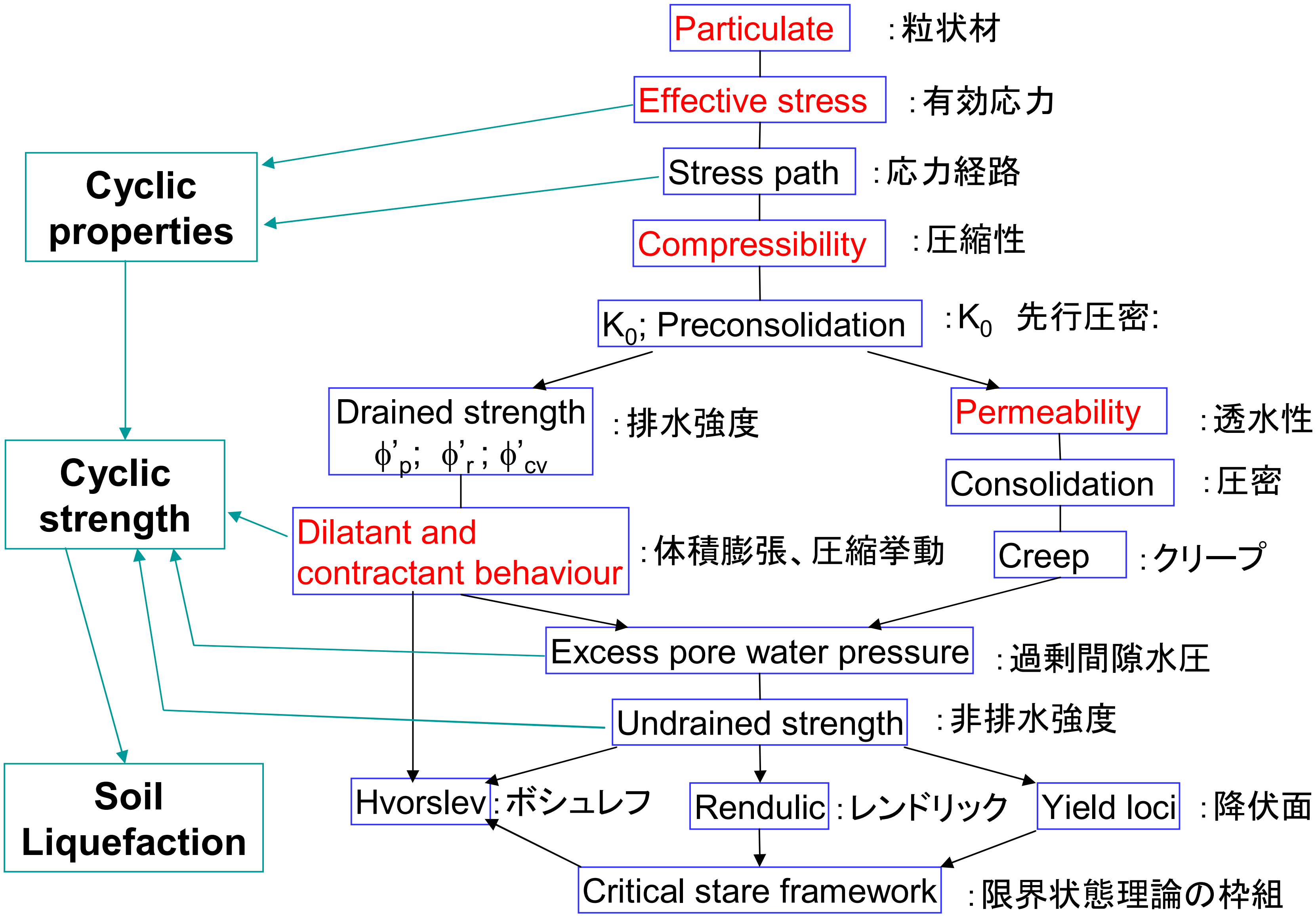
The soil mechanics triangle by Burland(1989)



Elements of a basic course of soil mechanics by Burland(1989)



Elements of course on soil behaviour



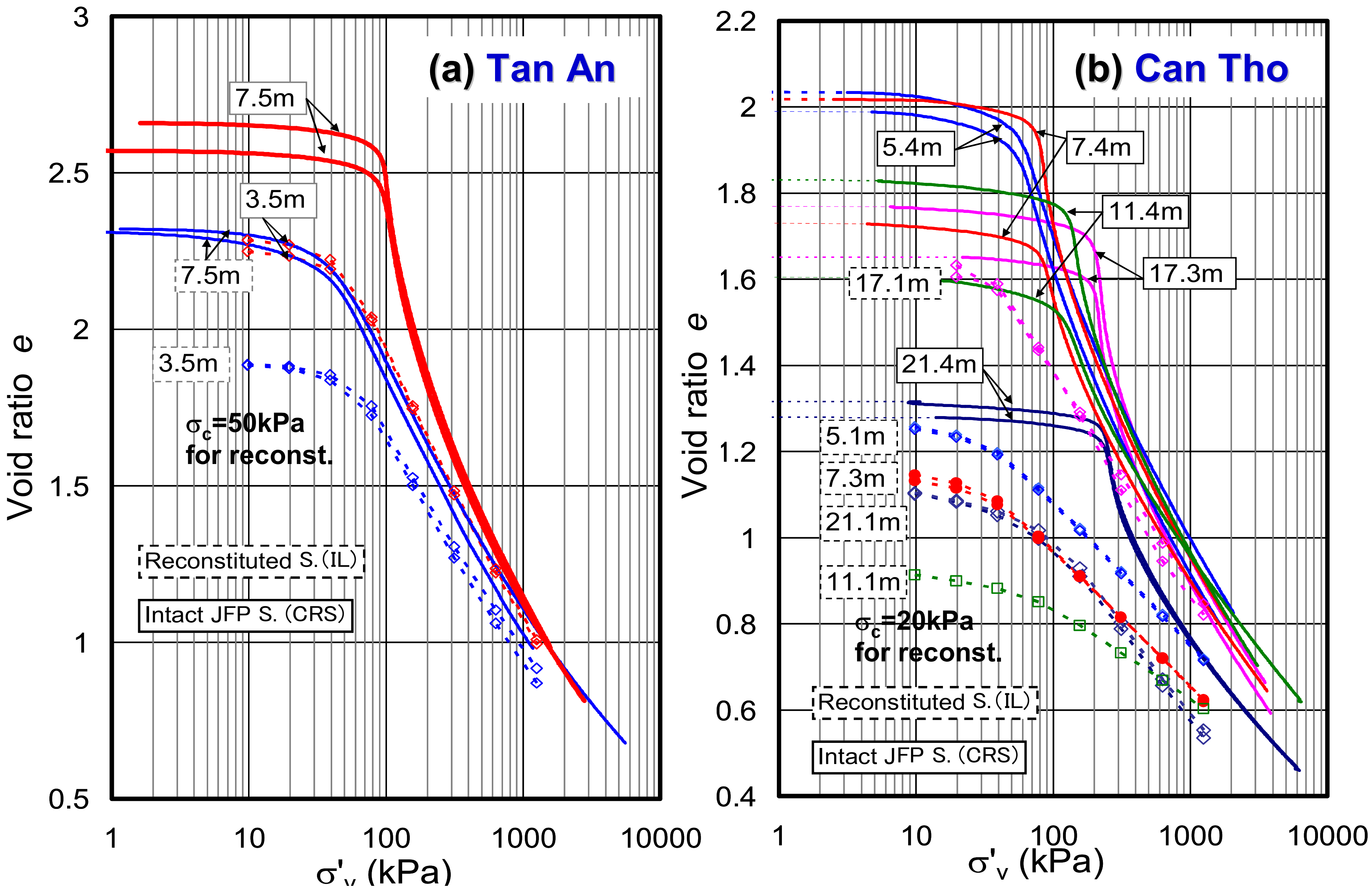
Types of soils and samples

Undisturbed soils ⇔ Remolded soils
Less disturbed soils (Reconstituted soils)

(不撹乱試料）（再構成試料）

Intact soil properties ⇔ Intrinsic soil properties

(地盤中の状態の性質）（本来の性質）



Intact and intrinsic compression curves: JFP samples

Relationship betw. In-situ void ratio (e_0) and log σ'_{v0}

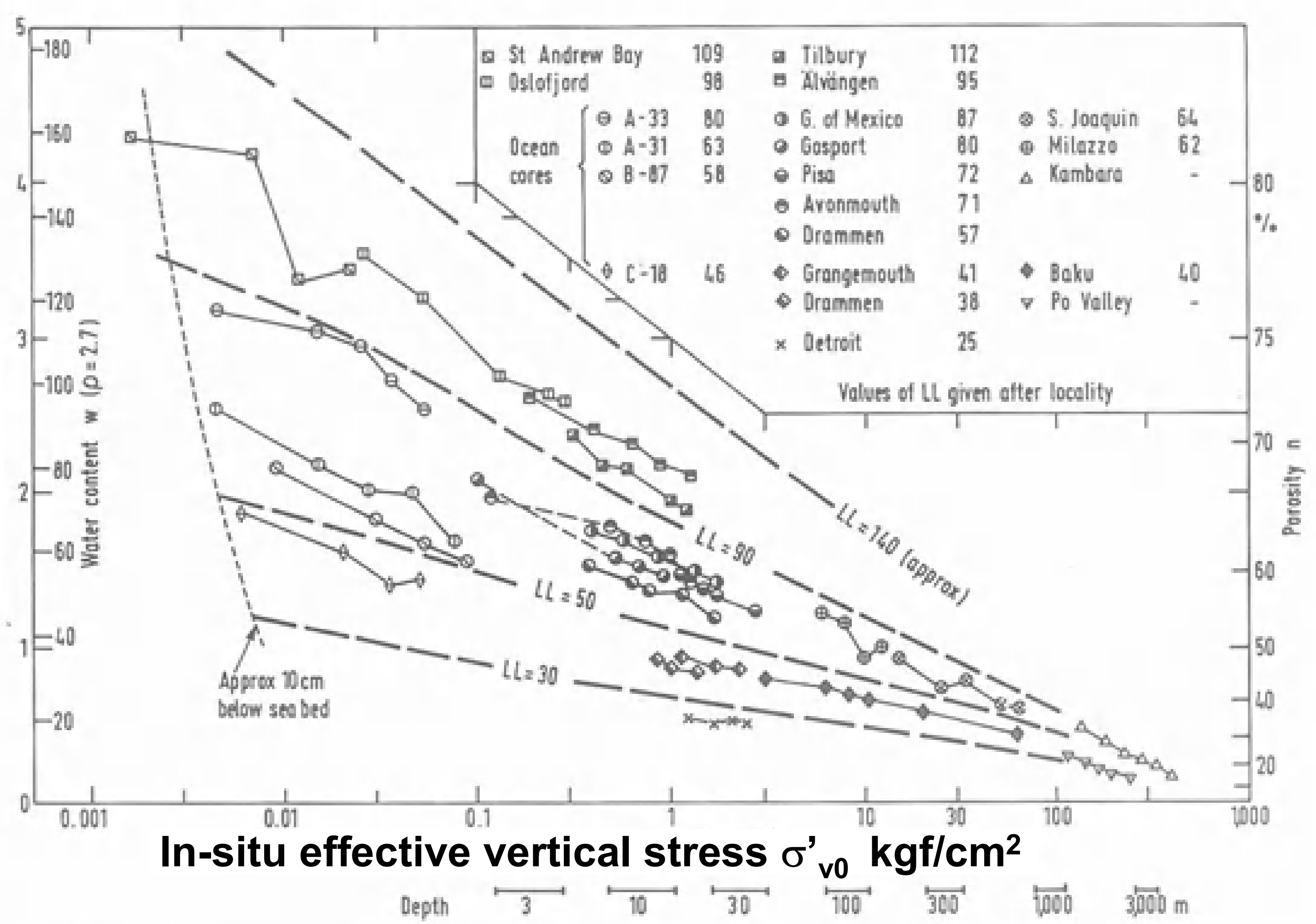
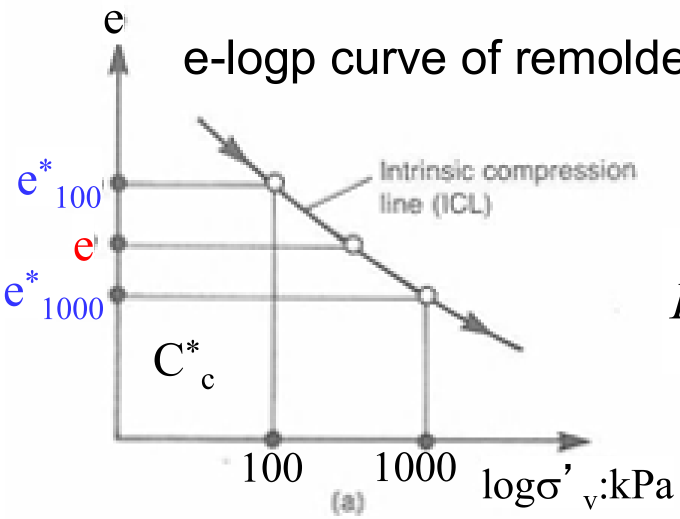


Fig. 1. Sedimentation compression curves for normally consolidated argillaceous sediments (Skempton 1970)

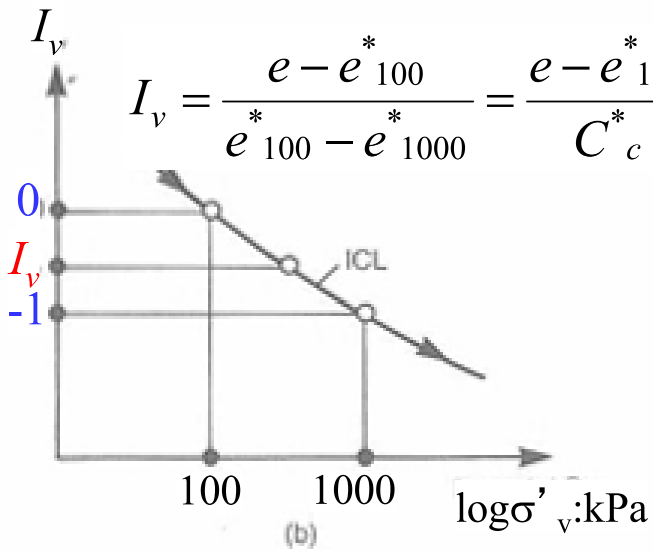
Burland (1990)

Void Index(I_v), Intrinsic Compression Line (ICL), Sedimentation compression line (SCL)

e-logp curve of remolded clay



$$I_v = \frac{e - e^*_{100}}{e^*_{100} - e^*_{1000}} = \frac{e - e^*_{100}}{C^*_c}$$



Normalized compression line

$$I_{v0} = \frac{e_0 - e^*_{100}}{C^*_c}$$

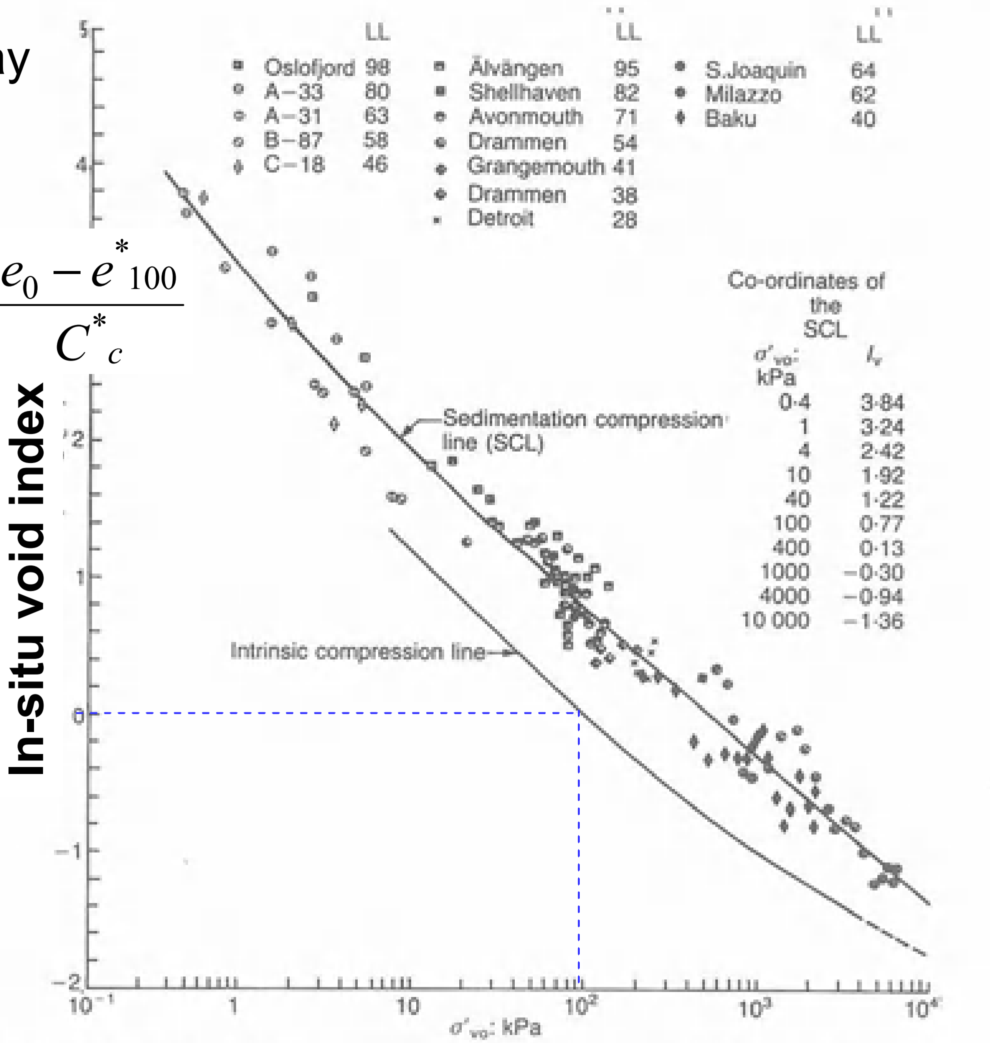
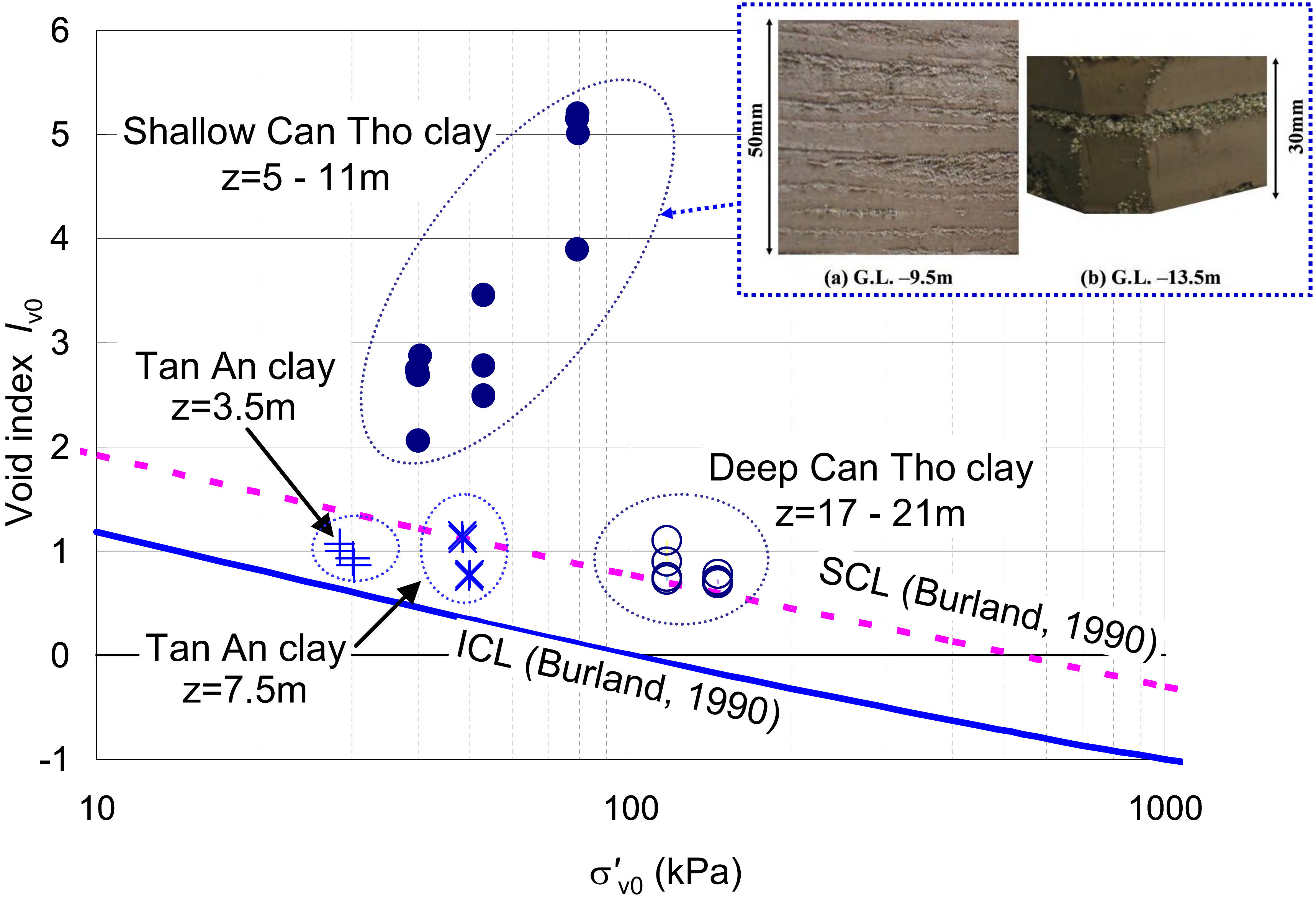


Fig. 13. Relationship between I_{v0} and log σ_{v0}' for many of the normally consolidated clays designated in Fig. 1: best-fit regression line through the data is termed sedimentation compression line (SCL)

Burland (1990)



SCL: Sedimentary compression line
ICL: Intrinsic compression line

Difference betw. Remold soils and In-situ soils

(Intrinsic soil properties) **(Intact soil properties)**

Index properties: G_s, e, w_n, w_L, w_P, I_P

Compressibility: C_c, m_v,

Stiffness: G, K,

Stress path , K_0

Strength: c_u, ϕ

Characterization of in-situ soils

Exploration of in-situ soil properties (原位置特性）

↳ **soils in actual ground**

•Geophysical investigation and logging(物理探査、検層）PS-logging, microtremor
常時微動

=> Stratification(層構成）,
=> Vs, Vp, => Gs, K,
=> resistivity => physical or chemical properties

•In-situ test or field test (原位置試験) (ex: SPT(標準貫入試験),　CPT(コーン貫入試験))
=> Mechanical properties

•**Sampling**(サンプリング)＋**Lab. Tests**(室内試験)
(e.g., consolidation test, shearing test ）
圧密、せん断試験

Process of soil sampling and testing

boring => sampling => transportation of sample

in sampling tube => retrieving sample from the sampler

=> soil testing

boring => sampling => retrieving sample from

the sampler at site => transportation of sample

=> soil testing

Boring (穿孔作業)

Basics of Soil Investigation:

Objectives and depths:

- **exploration of natural resources (hot spring, oil, gas, etc)** => **few hundred －few thousand m, Max: 13,000 m**
- **geological investigation**
- **well**
- **geotechnical investigation**

(well and geotechnical investigation => **few – few hundred m**)

Type: **Rotary boring with bit (common)**

(wireline boring for deep or marine exp.)

Augur boring

Percussion boring

Diamond core cutter

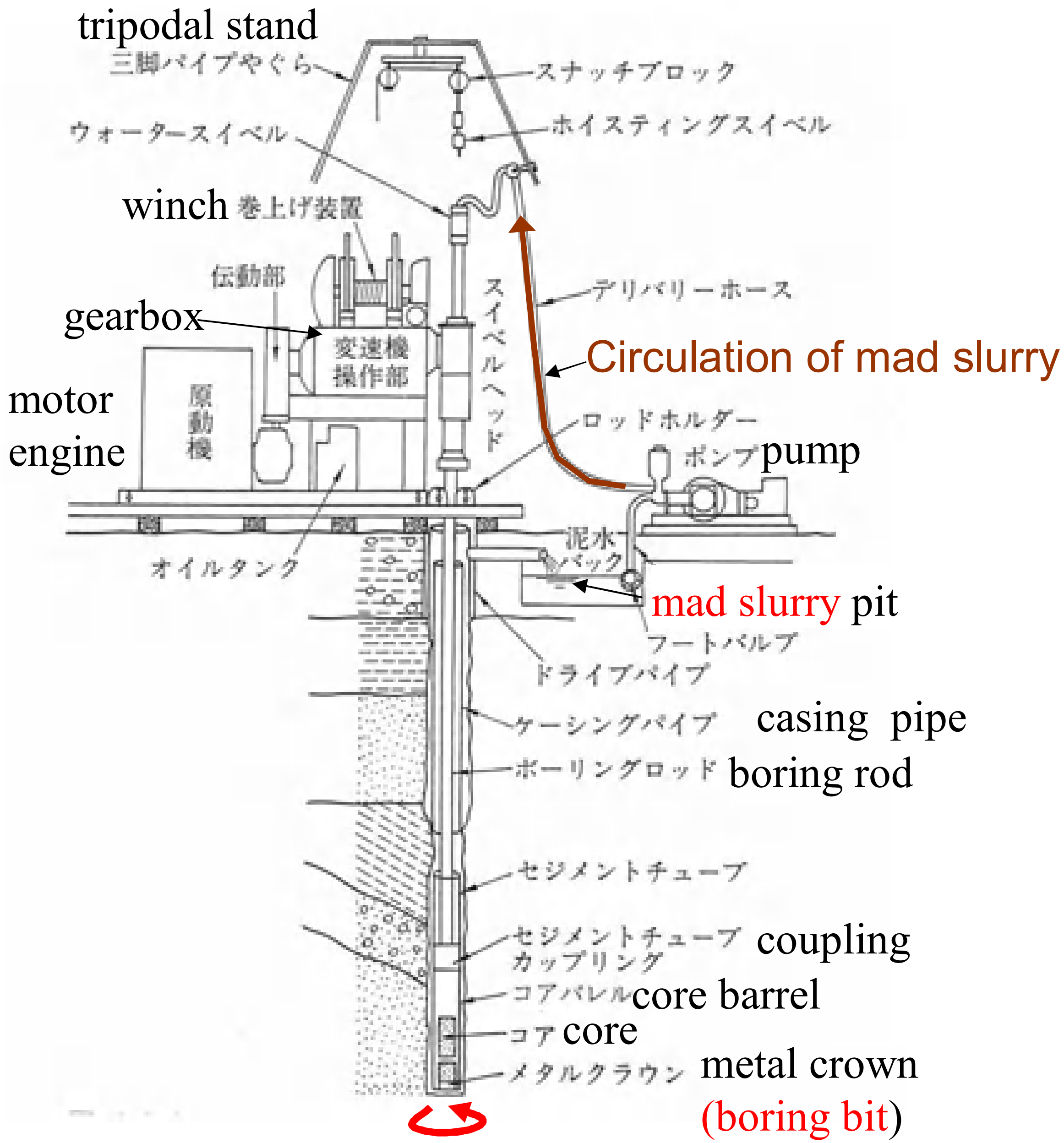
Test pit

Core boring <=> Non-core boring

⇐ **Purposes**
Ground conditions
Types of in-situ tests

Rotary type boring machine

(Hydraulic feed type)



Japanese Standards for Geotechnical and Geoenvironmental Investigation (JGS 2004)

Sampling (試料採取)

- **Collection of soil sample**：

  using bore hole in deep sampling

- **Sampling methods**

  types of geo-material, stiffness, purposes

  soft clay, hard clay, sand, rock

  stratification, classification,

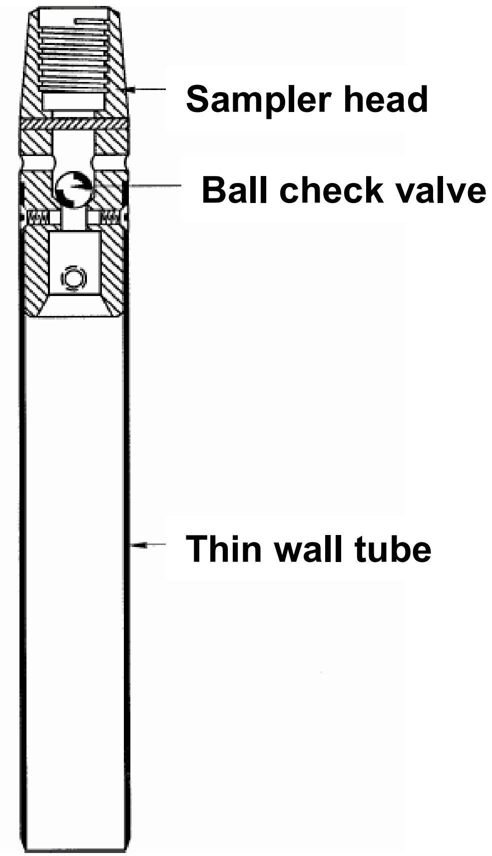
  physical properties（w, e, ρ)

  mechanical properties（strength, stiffness)

with various kinds of sampler

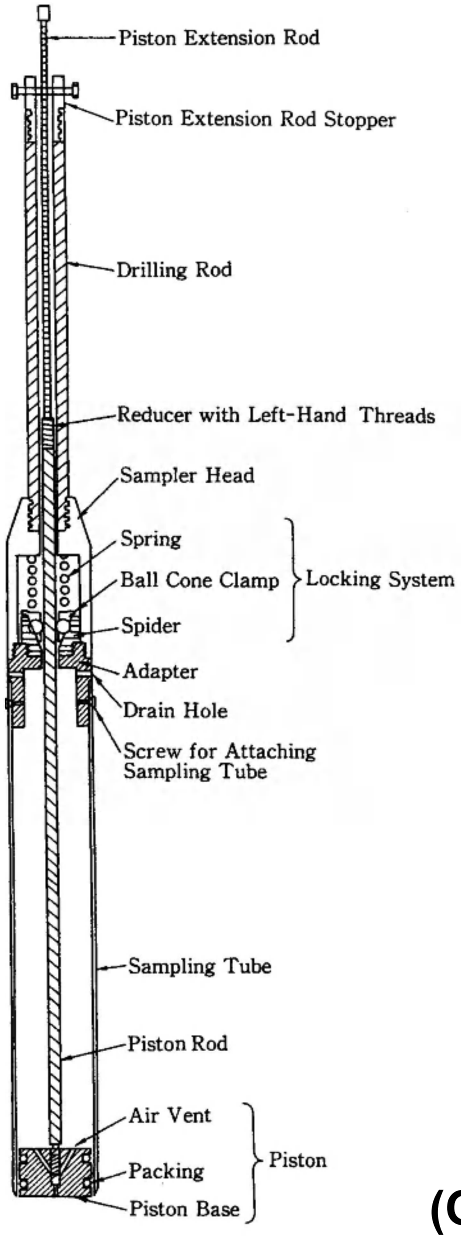
Open tube sampler,
Fixed piston thin-walled tube sampler,
Rotary double-tube sampler (Denison sampler)
others

Samplers for soft soils



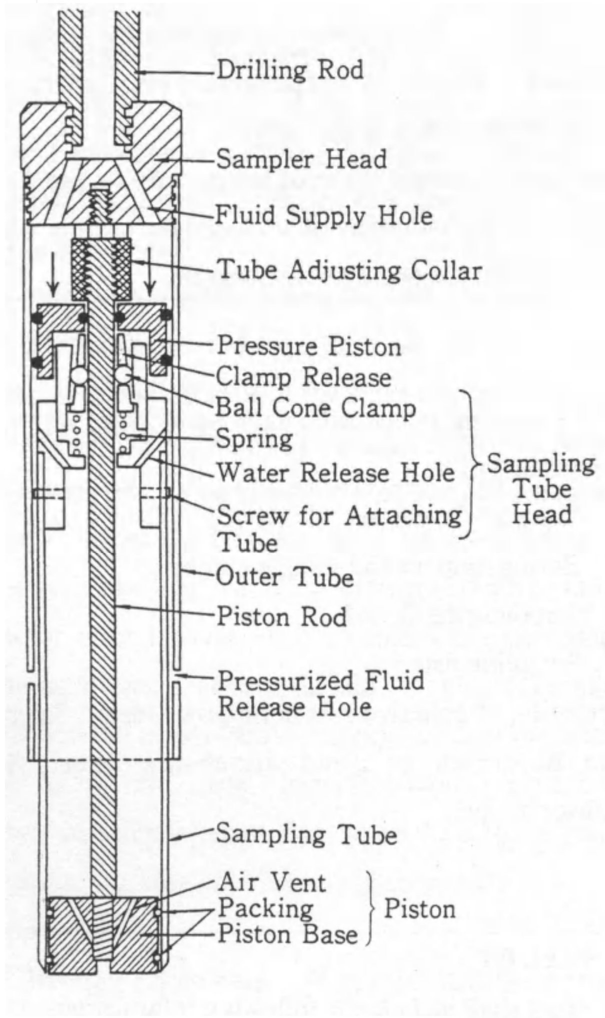
Ex. Open tube sampler (Shelby sampler)

Examples of fixed piston thin-wall sampler



Extension rod type

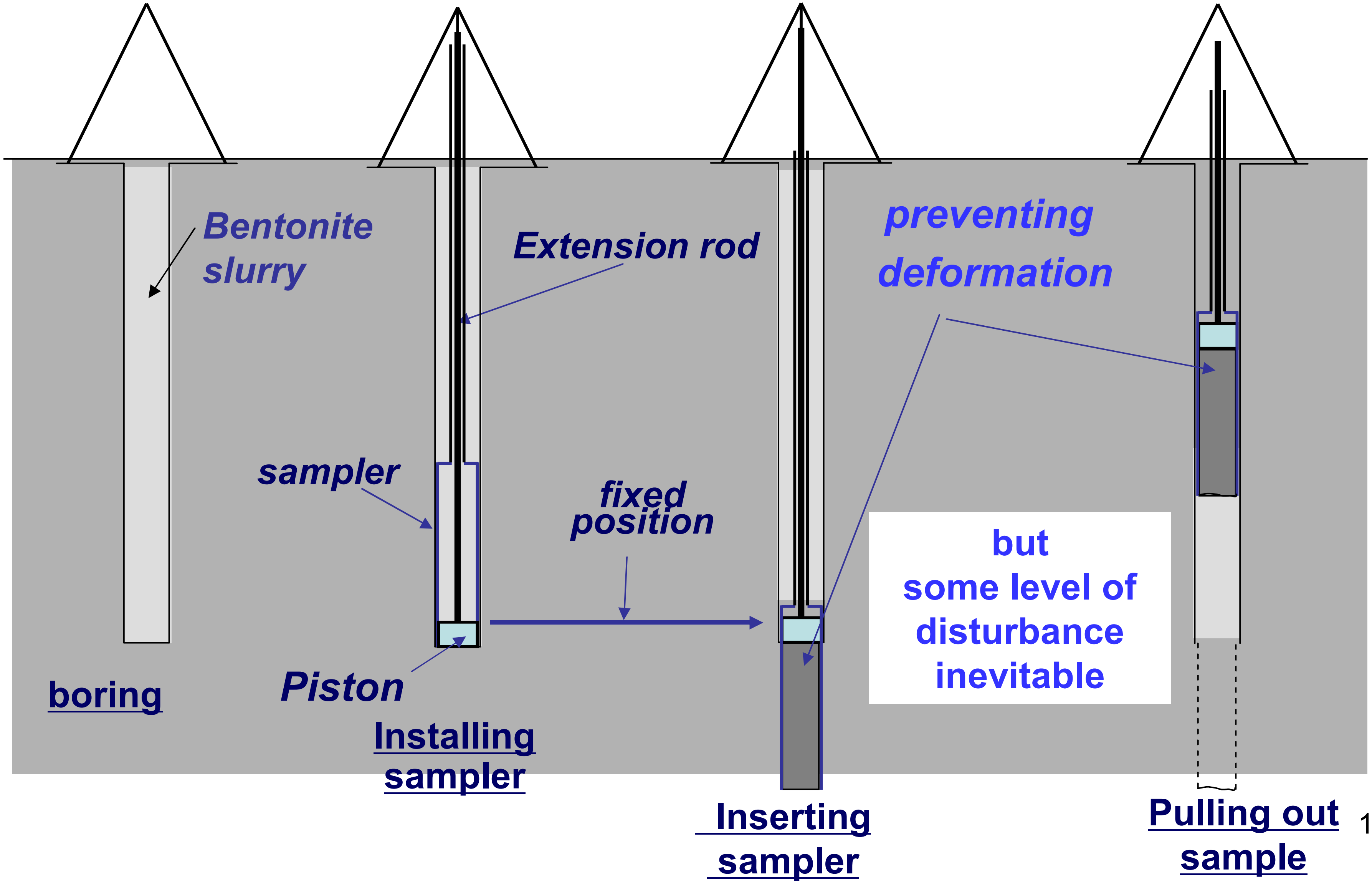
JGS standard



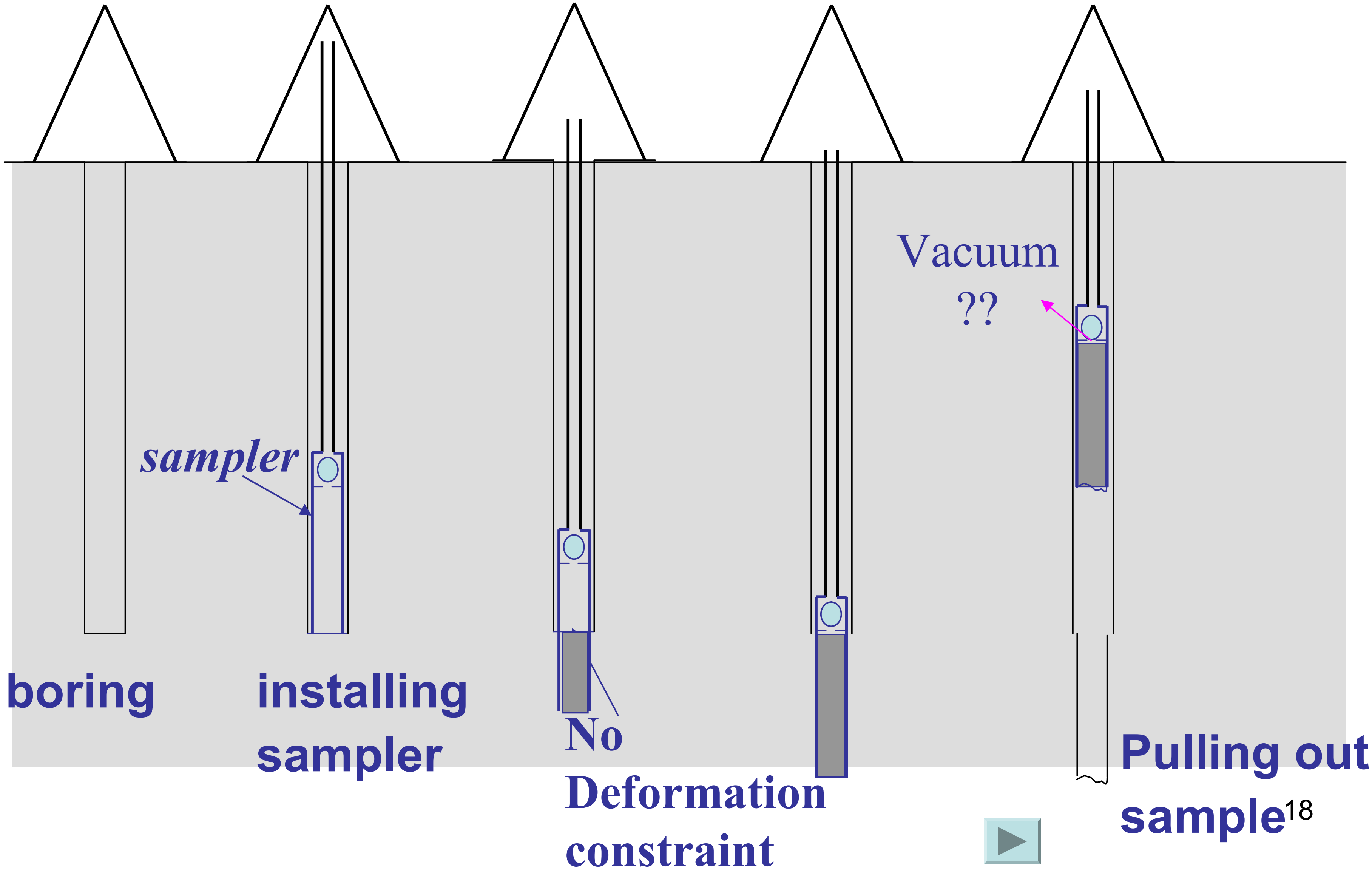
Hydraulic type (Osterberg sampler)

(JGS standards)

Thin-walled tube sampler with fixed piston
（固定ピストン式シンウォールサンプリング）
軟弱粘土：日本の基準

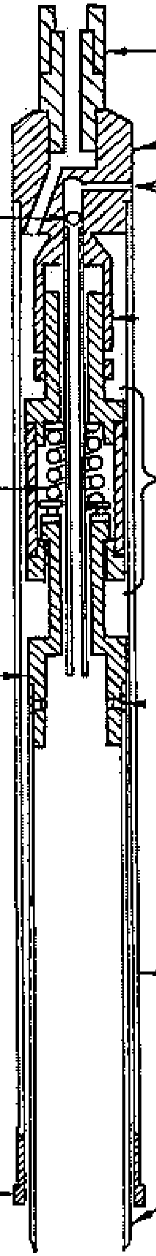


-Shelby tube sampler –
(シェルビー式サンプリング：オープン式）



Samplers for hard soils

Rotary double-tube sampler (Denison sampler)
デニソンサンプラー

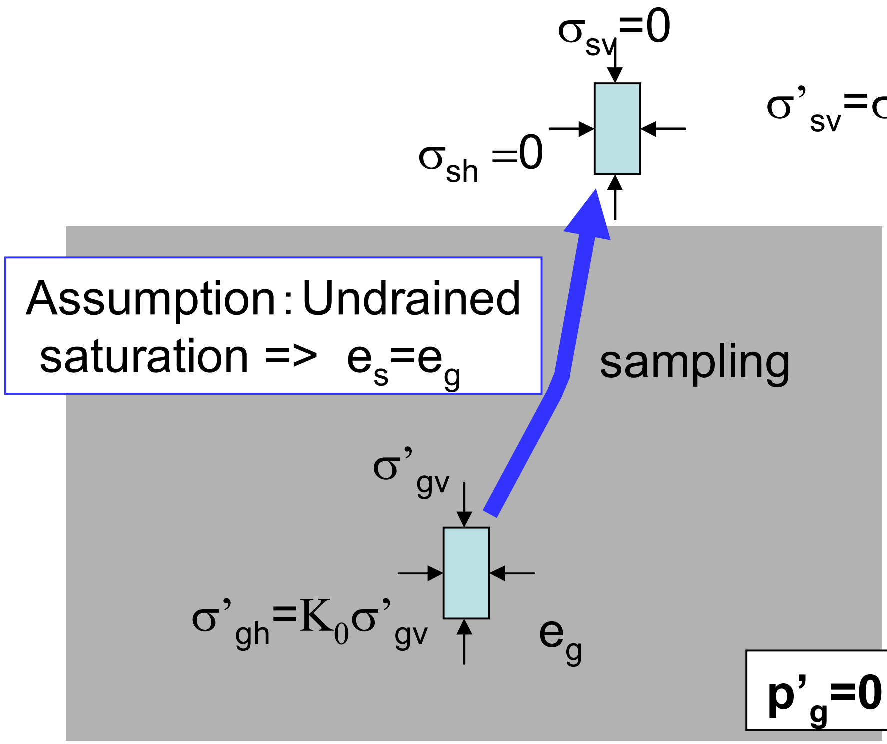


(JGS standards)

Sampling & Lab. Tests

Release of confined stresses in the ground (地中応力の解放)

Stress condition: isotropic(等方)、total stresses (σ)=0 but σ’ ??



$\sigma'_{sv}=\sigma'_{sh}$=-u(??)

Skempton’s eq.

$$\Delta u = B[\Delta\sigma_3 + A(\Delta\sigma_1 - \Delta\sigma_3)]$$

shear stress incre.

$$\Delta\sigma_3 = -K_0\sigma'_{gv}, \Delta\sigma_1 - \Delta\sigma_3 = -(1-K_0)\sigma'_{gv}$$

$$u = -\{K_0 + A(1-K_0)\}\sigma'_{gv}$$

$$\sigma'_{sv} = \sigma'_{sh} = \{K_0 + A(1-K_0)\}\sigma'_{gv}$$

e.g., K_0=0.5, A=-0.1～0.3 (for ex.)

=> $\sigma'_{sv} = p'_s$ = 0.45 ～0.65σ'_{gv}

p'_g=0.67σ'_{gv} ⇒ **Decrease of effective stress**

⇓

Decrease of strength and stiffness

Unavoidable effect of sampling ⇐

Furthermore,

disturbance (additional strains) in sampling, transportation, specimen preparation

⇓

Additional excess pore water pressure=>dec. p’＋deterioration of fabric structure (bonding、cementation）

Types of sample and Disturbance

Sample types

① **Ideal sample**：identical to in-situ soil　($\sigma'_{gh}=K_0\sigma'_{gv}$)
② **Perfect sample**：subjected to only the effect of stress release
③ **Undisturbed (Less disturbed)sample**：collected by sampling method
④ **Remolded (Reconstituted) sample**：

effective stress：①＞②＞③＞④
deterioration of structure：①＞②＞③＞④
stiffness：①＞②＞③＞④
strength：①＞②＞③＞④

Disturbance induced in whole process except stress release
Mechanical disturbance
(機械的乱れ)

Clear definition of ①、②、③, but level or effects of disturbance not clear

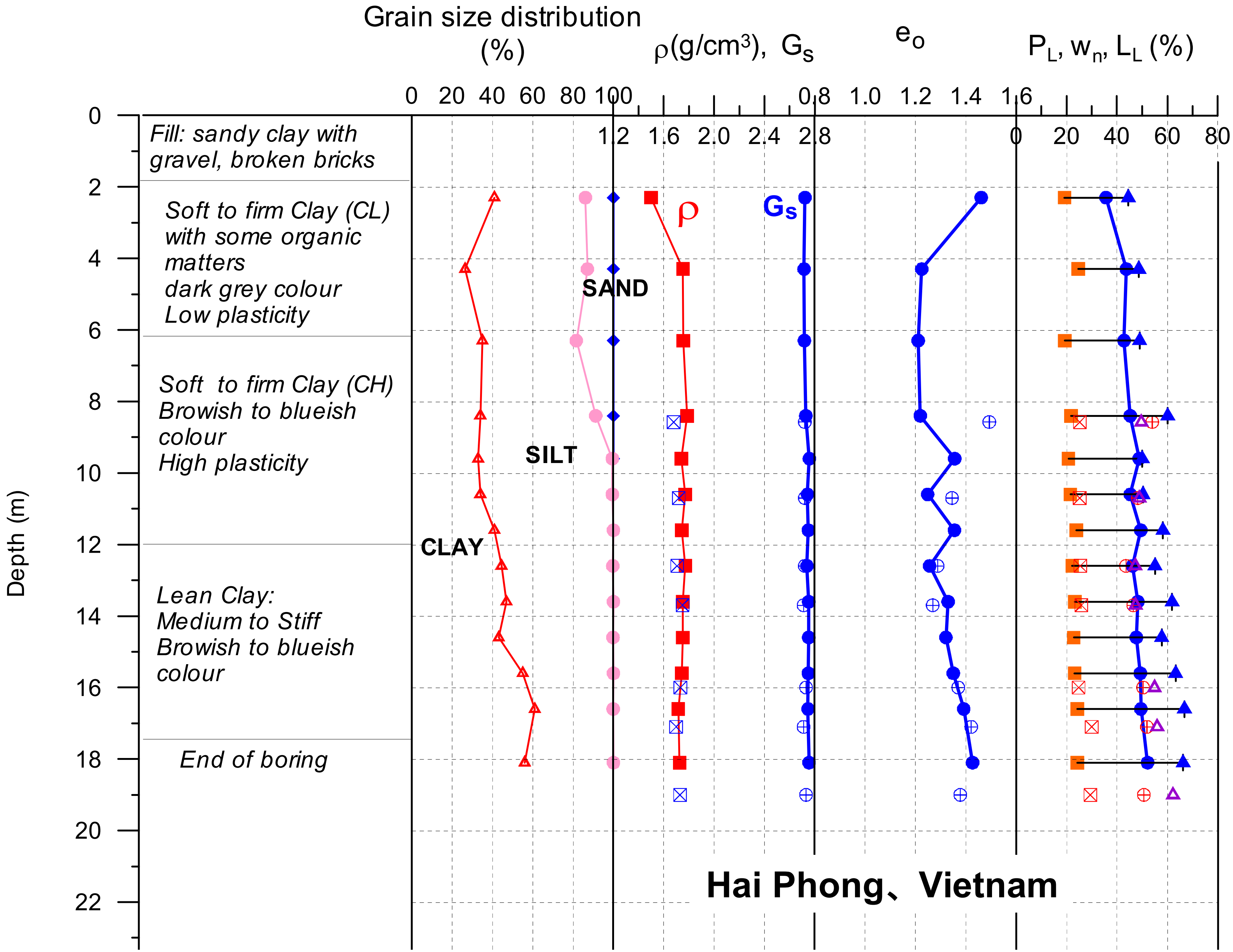
What is desirable sample？　Depending on purpose

（ex：index test（LL,PL,G_s) disturbance may not affect

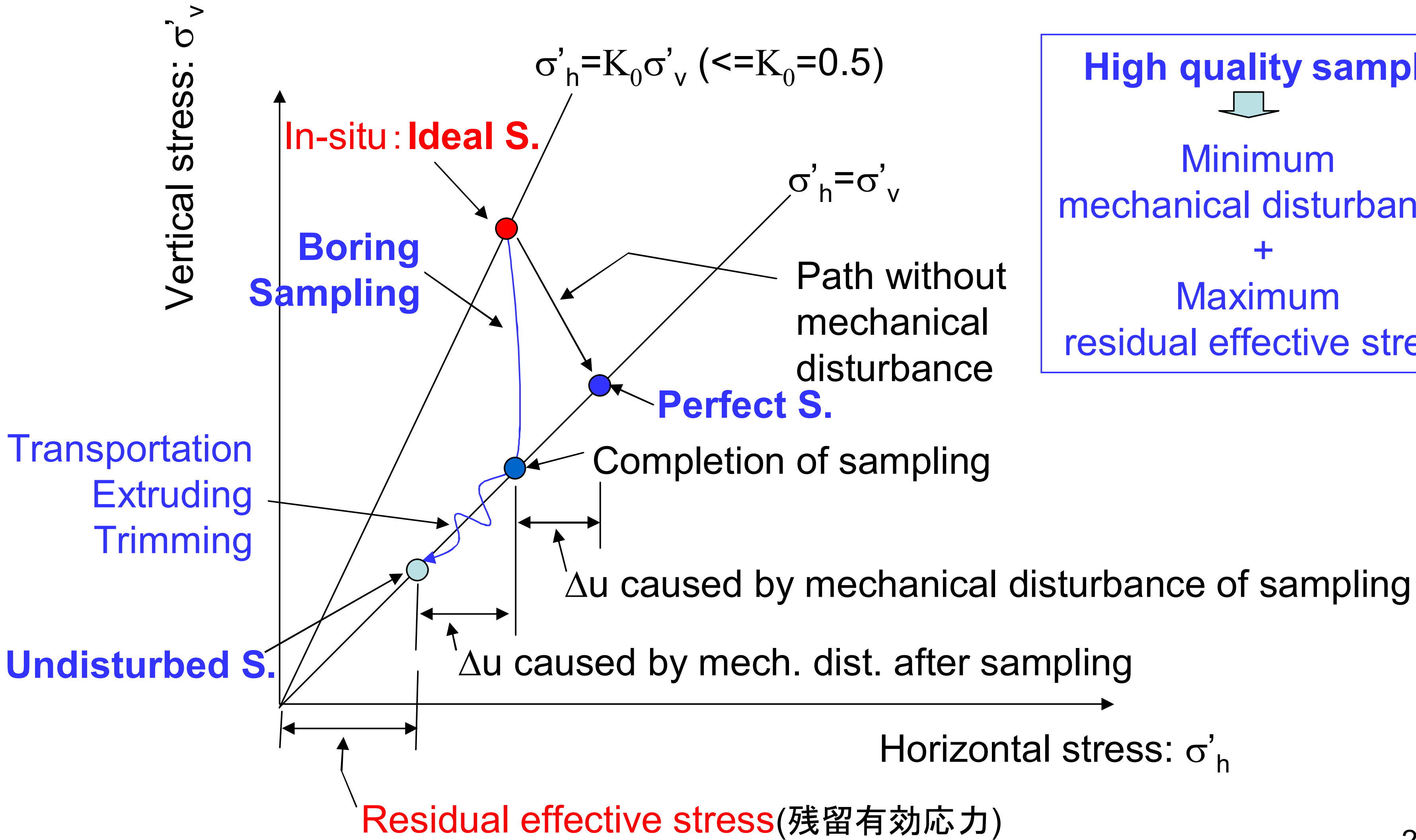
but **mechanical properties** highly affected .)

→ **less disturbed** and **as close to in-situ ones as possible,**

Soil profiles and physical properties
地層構成と物理特性



Effective stress history from sampling to specimen preparation



High quality sample

Minimum mechanical disturbance
\+
Maximum residual effective stress

Index about sensitivity to disturbance

$$Liquidity\ Index:\ I_L = \frac{w_n - w_p}{I_p}$$

液性指数

I_L>1 natural water cont.(w_n) > liquid limit (w_L)

⇓

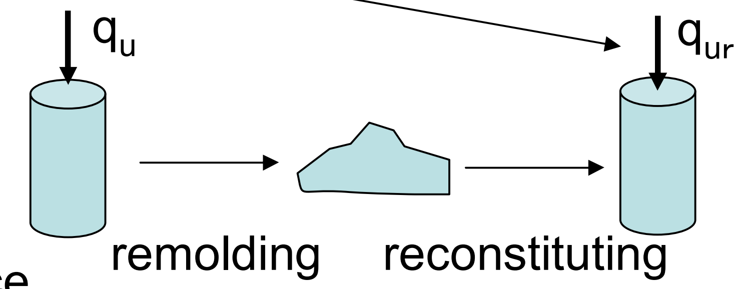
remolding => q_u < $q_{u\ at\ wL}$（～1.5kPa)

⇓

Very sensitive

$$Sensitivity:S_t = \frac{q_u\ \ of\ \ undisturbed\ \ sample}{q_{ur}\ \ of\ \ remolded\ \ sample}$$

鋭敏比



Quick clay ：S_t＞100
Marine clay in Japan：S_t=10～20

why：
Decrease of strength and stiffness by disturbance

？＋？

Young clay) => small S_t
Aged clay => large S_t

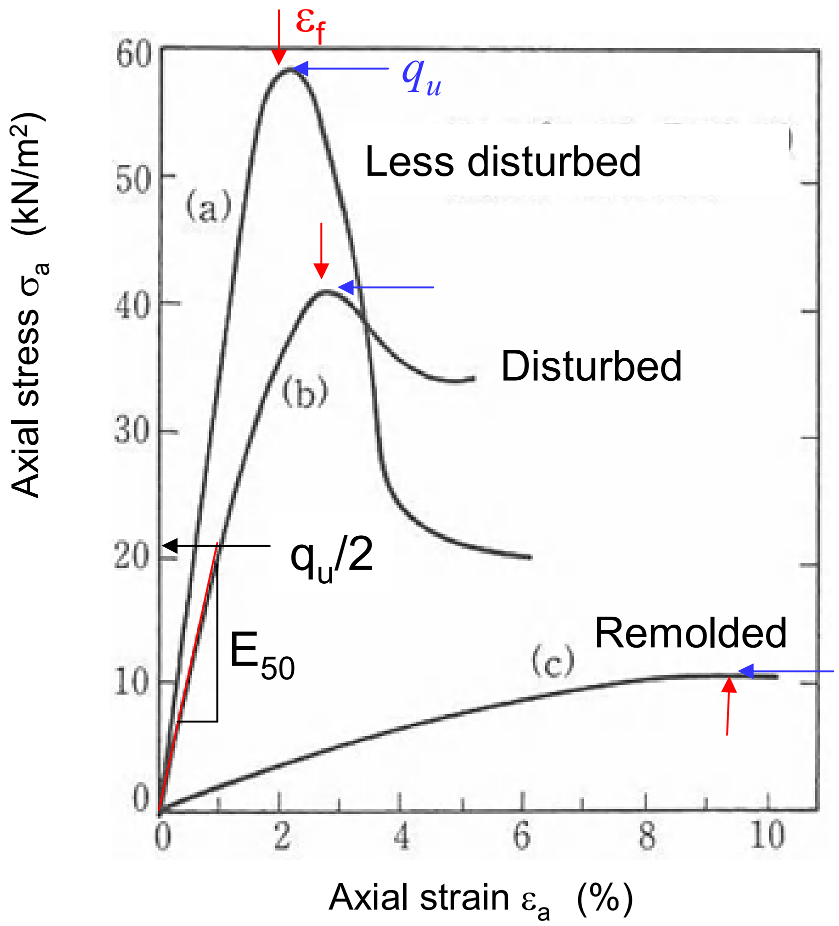
Why?

?

Quality of clay samples

difference of less disturbed and disturbed samples

Stress-strain of UU test



The more disturbed,

① larger failure strain (ε_f)

② smaller stiffness (E_{50})

③ smaller strength (q_u)

<u>Index of disturbance from UU tests</u>

① ε_f

② $\dfrac{E_{50}}{q_u/2}$ < 150-200 in Japanese clay

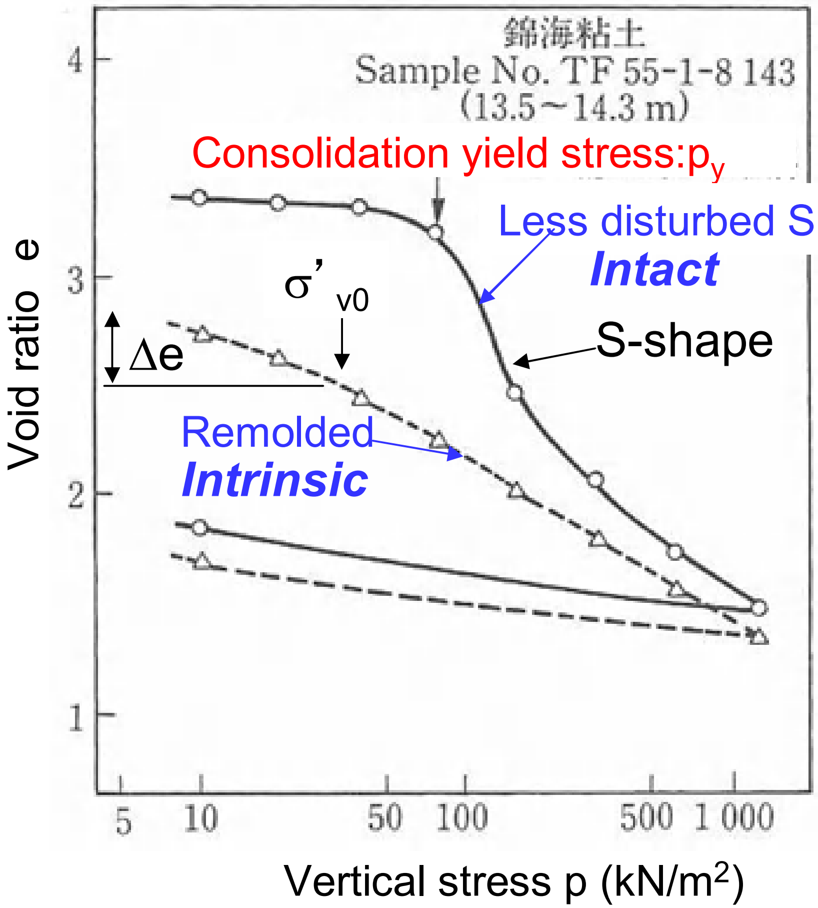
disturbed

↑

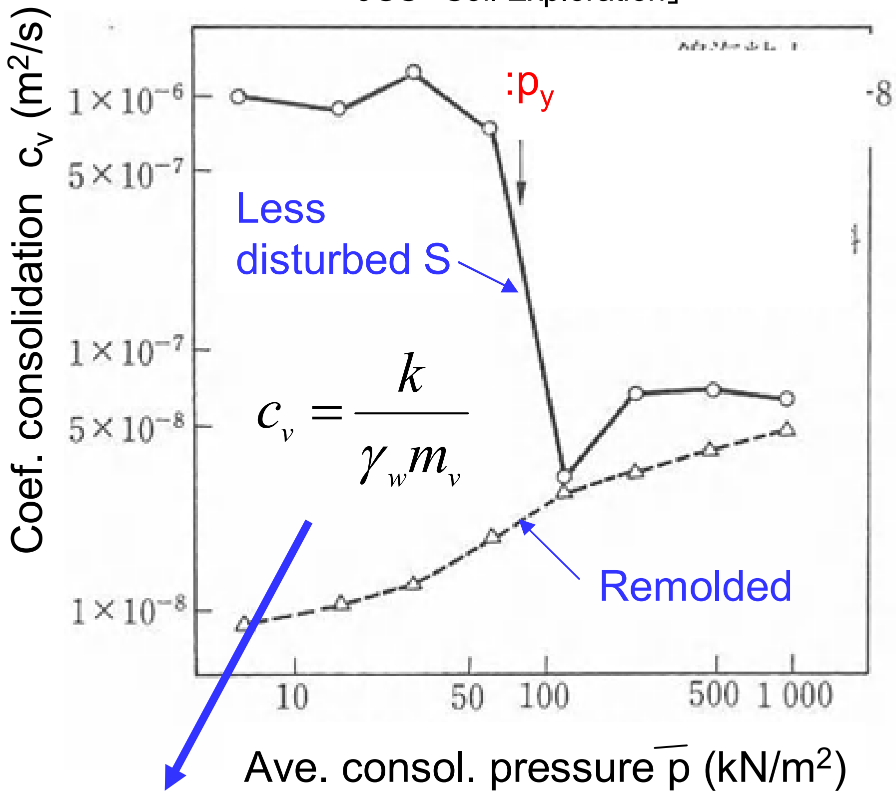
E_{50} more sensitive than q_u

Effect of disturbance observed in Oedometer tests

JGS「Soil Exploration」



JGS「Soil Exploration」



$$c_v = \frac{k}{\gamma_w m_v}$$

$$m_v = \frac{\Delta e}{(1+e)\Delta p}$$

Index of disturbance:

c_v at small pressure

Less dist.: larger c_v

Dist.: smaller c_v

Index of disturbance: **e－log*p* curve**

Less dist.: small void ratio change ($p < p_y$) + marked decrease of e

Dist.: no clear p_y、large compression at $p < \sigma'_{v0}$、less decrease at $p > p_y$

Δe: decrement of void ratio caused by recompression to σ'_{v0}

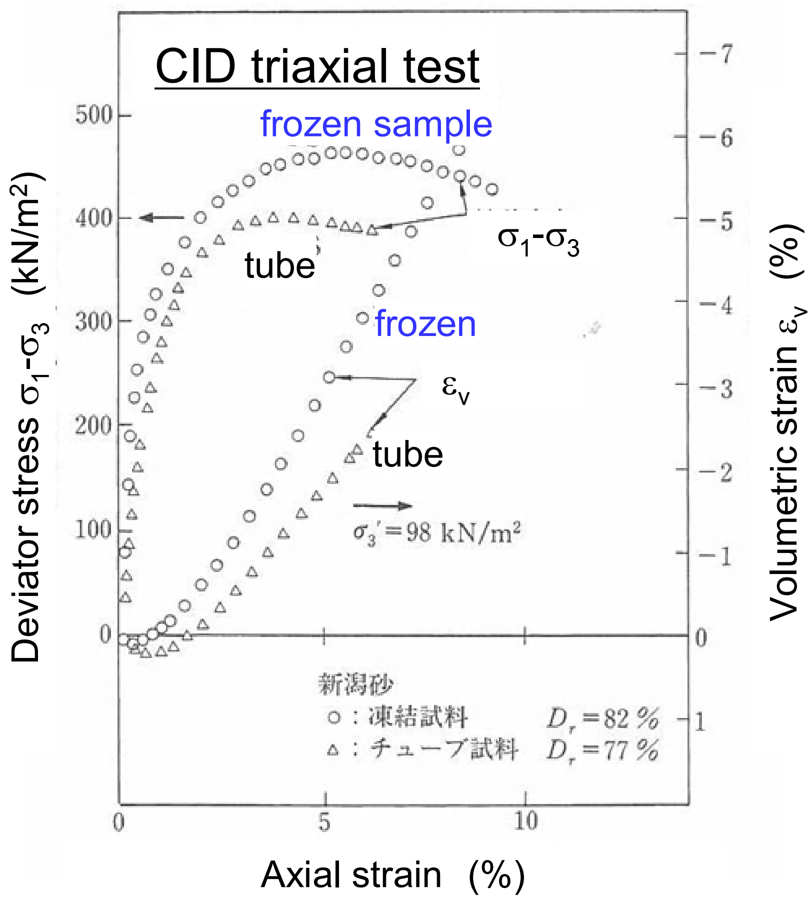
Sand sampling

Method of sampler penetration：
Loose sand=> pushing
Hard, dense sand =>rotary sampling

Mechanical properties of the sand sampled by these methods are different from those of ideal ones.

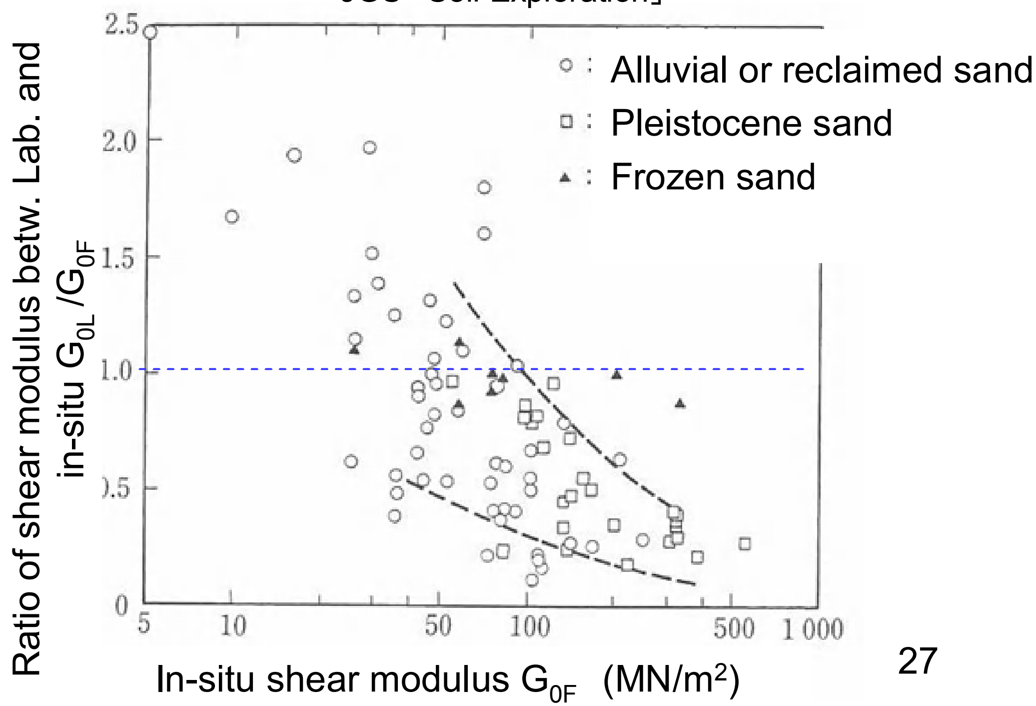
Properties of sand evaluated from sounding, field tests (e.g., SPT=>N-value)

JGS「Soil Exploration」

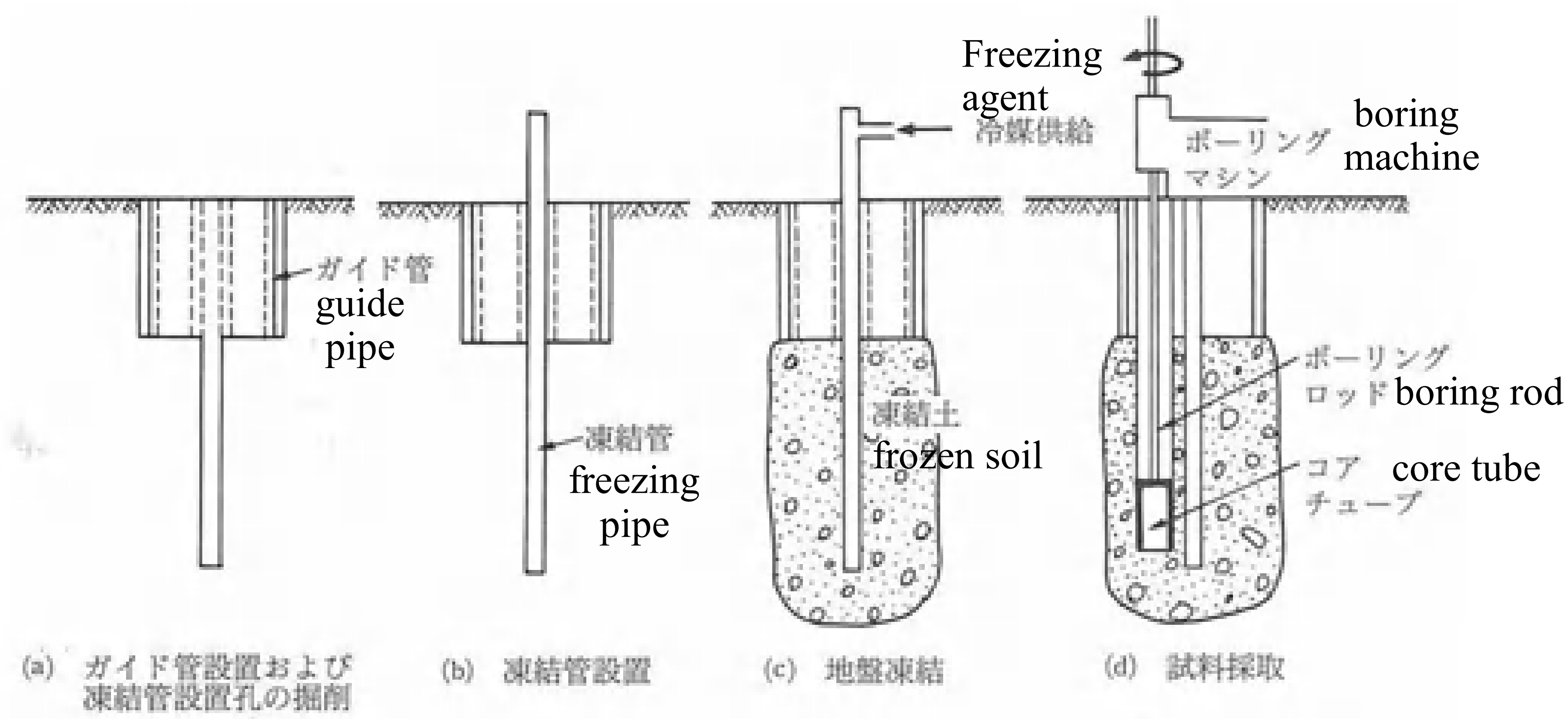


To obtain the reliable properties
Freezing sampling
(凍結サンプリング)

JGS「Soil Exploration」



Freezing sampling of sand



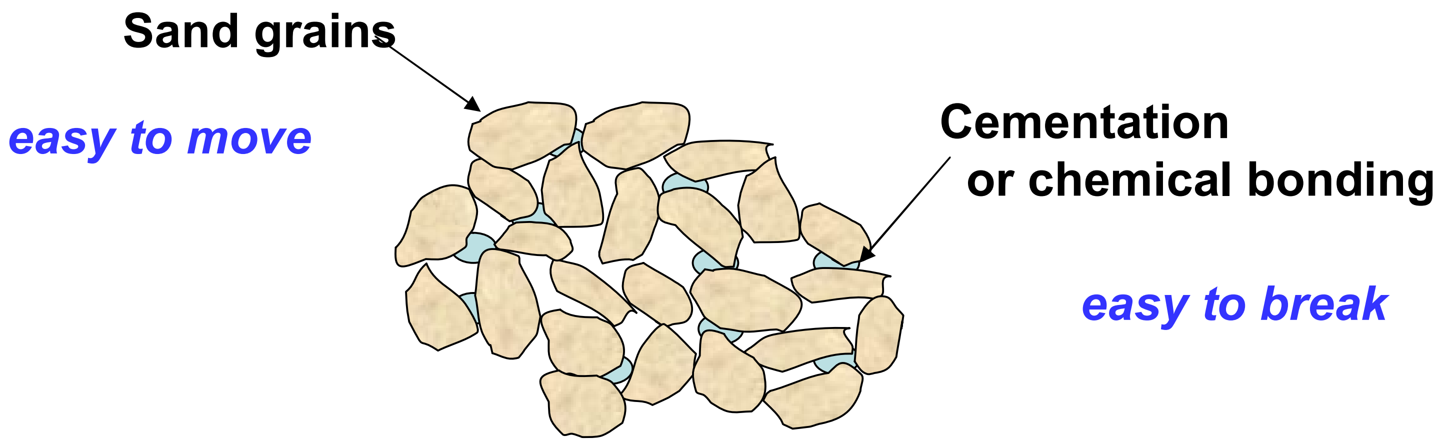
Installation of guide pipe and boring for freezing pipe

Installation of freezing pipe

Ground freezing

Sampling of frozen soil

Structure of natural sand



Structure of natural sand

Fragile

Sensitive to disturbance or shear deformation.

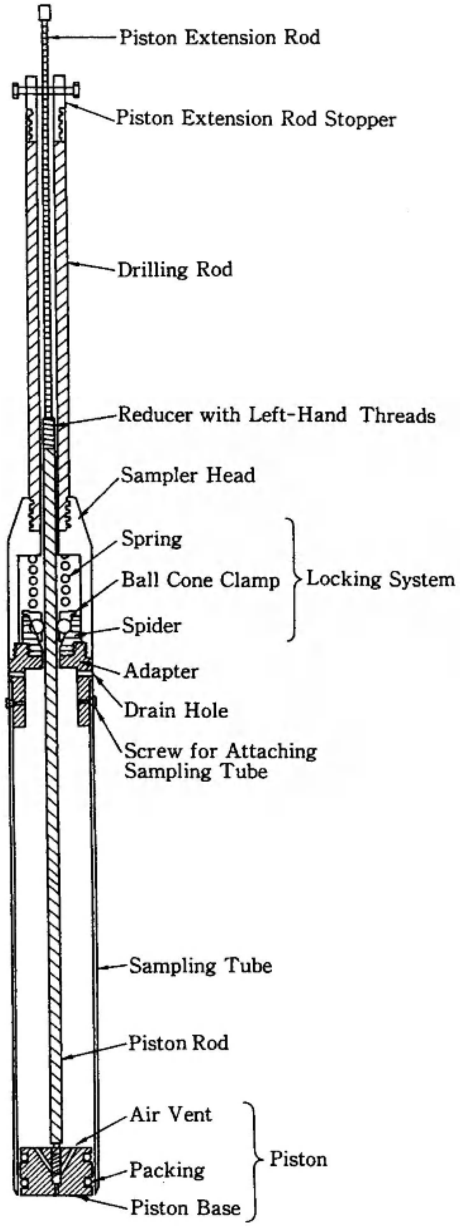
Difficult to have less disturbed sample with similar properties of ideal one.

サンプリン風景（ベトナム、ハイフォン）

Sampling at the site

Pre-boring

Undisturbed soil sampling- JPN Fixed Piston Sampler (Extension rod type)



Rotary Core Tube

t=1.50mm
D=75mm
L=1,000mm

Fixed Piston sampler

Undisturbed soil sampling- Shelby Sampler

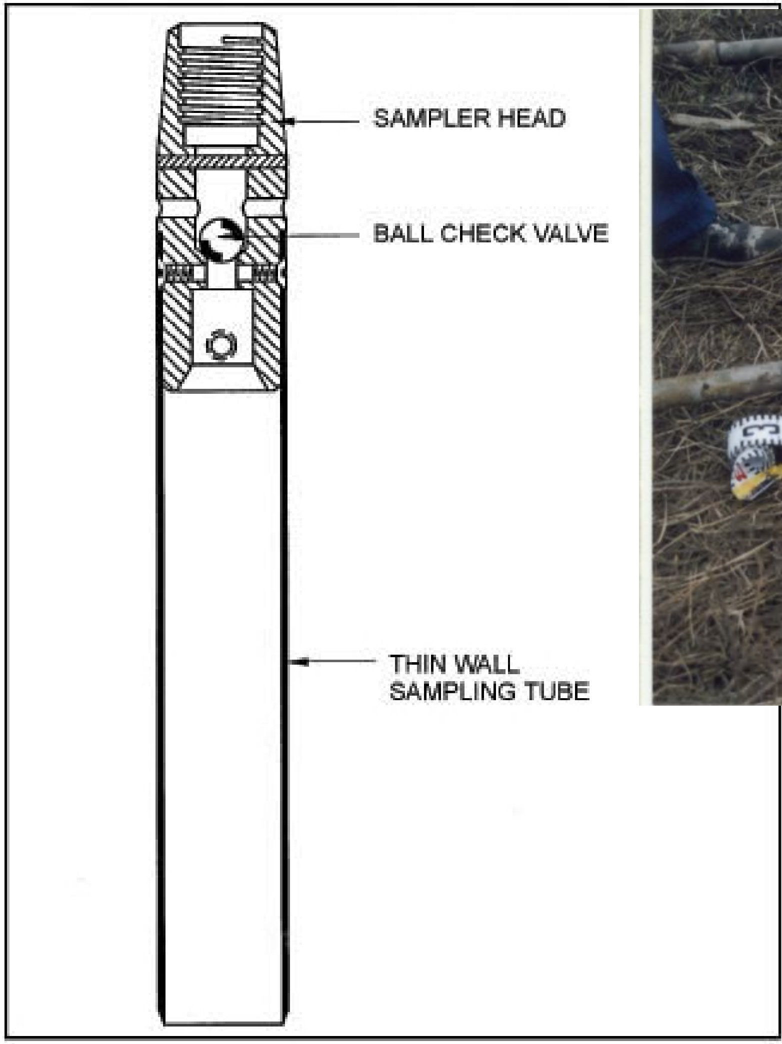


Figure 5-1. Schematic drawing of an open-tube sampler

t=1.65mm
D=72mm
L=800mm

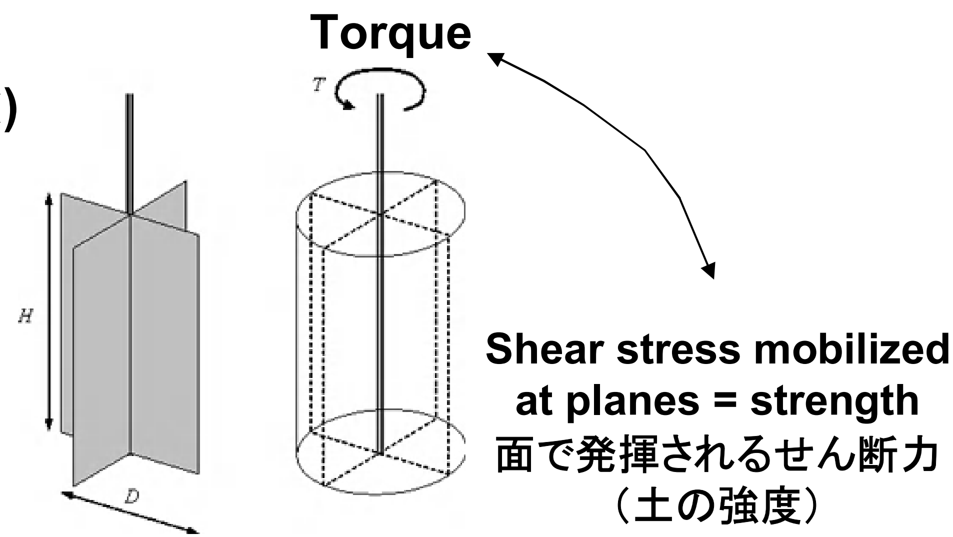
Sounding (サウンディング)

Sounding:

General expression of in-situ tests in which soil parameters are estimated from the response to the load applied to the ground by various method.

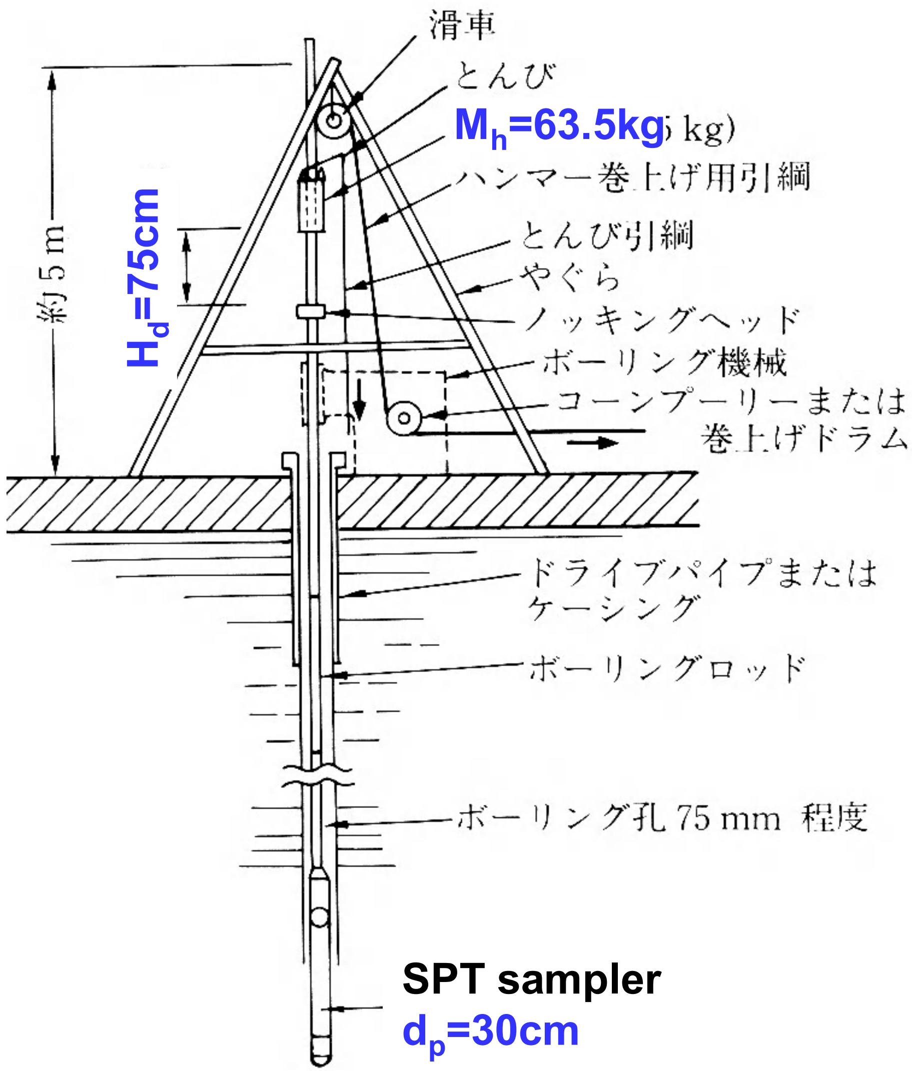
地盤中のサンプラー、コーン等を貫入し、貫入時の抵抗、水圧計測により、地盤の特性を調べる、原位置調査法の総称。

- **Standard Penetration Test(標準貫入試験)**
- **Cone Penetration Test(コーン貫入試験)**
- **Swedish weight sounding test (スウェーデン式サウンディング)**
- **Field vane test(原位置ベーン試験)**
- **Pressuremeter test(孔内水平載荷試験)**



vane test (ベーン試験)

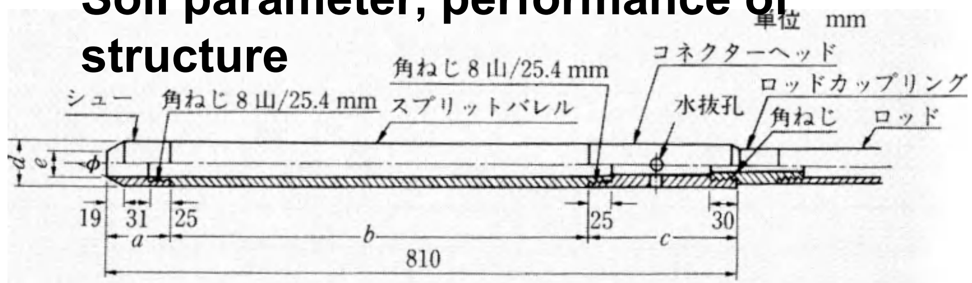
Standard penetration test: SPT
(標準貫入試験)



Terzaghi & Peck (1948)
"Soil Mechanics in Engineering Practice"

N値（N-value）:
- Mass of hammer (M_h): 63.5kg
- Dropping height (h_d): 75cm
- Penetration depth (d_p): 30cm

Huge data on the correlation betw.
N-value and field observation
Soil parameter, performance of structure

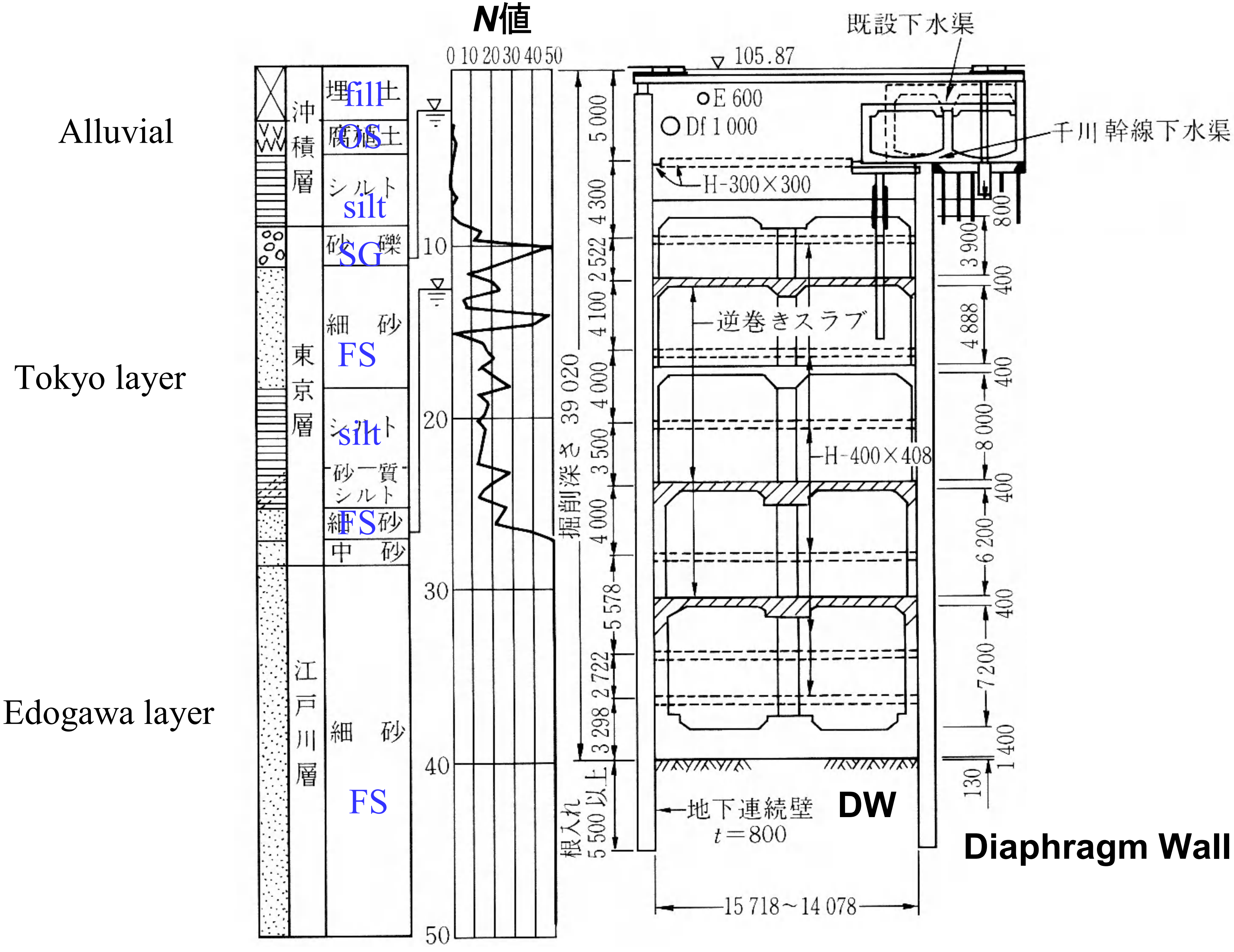


各部	全長	シュー長 a	バレル長 b	ヘッド長 c	外径 d	内径 e	シュー角度 ϕ
寸法	810	75	560	175	51	35	19°47′

Sampler of SPT

N-value：Subway station construction site

南北線後楽園駅工事現場



Practical Application of N-value

N-value ～ Relative Density of sand
Terzaghi & Peck(1948)

N-value	Dr
0-4	Very loose
4-10	Loose
10-30	Medium
30-50	Dense
>50	Very dense

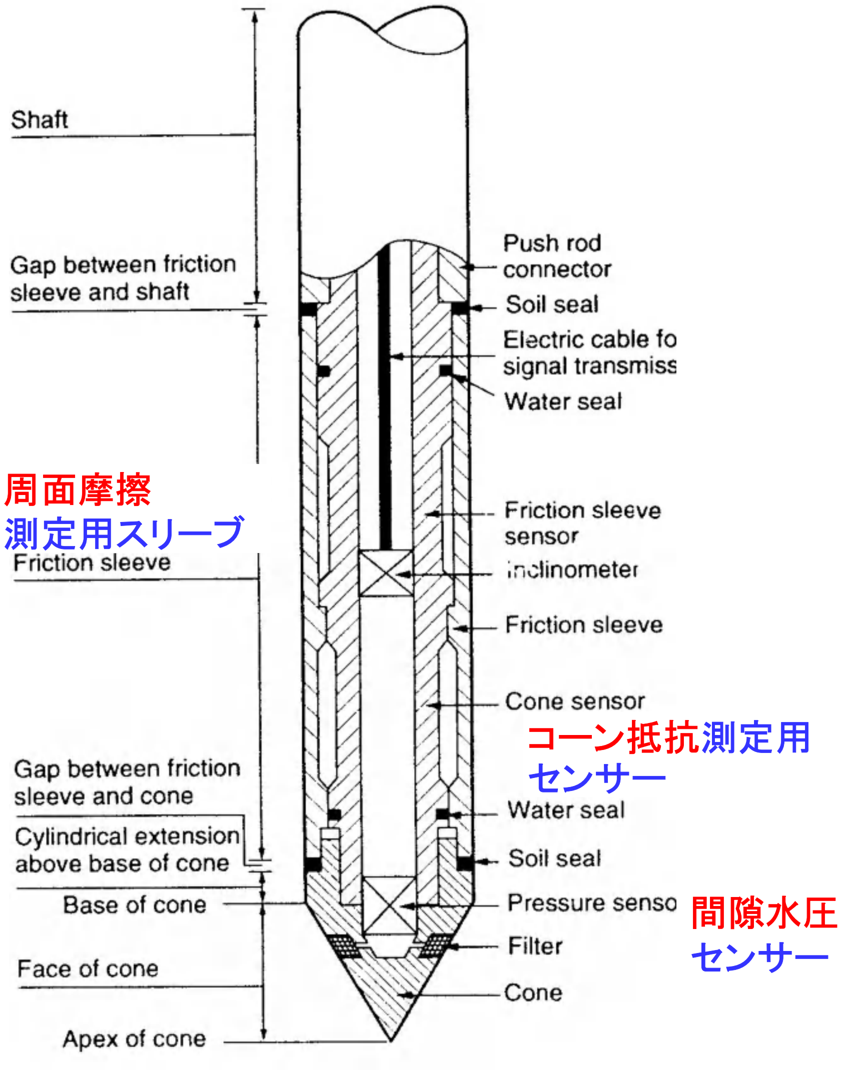
Consistency, N-value and q_u
Terzaghi & Peck(1948)

Consistency	N値	q_u(kPa)
Very soft	<2	＞25
Soft	2-4	25-50
Medium	4-8	50-100
Hard	8-15	100-200
Very hard	15-30	200-400
Extremely hard	>30	>400

Properties estimated by N-value

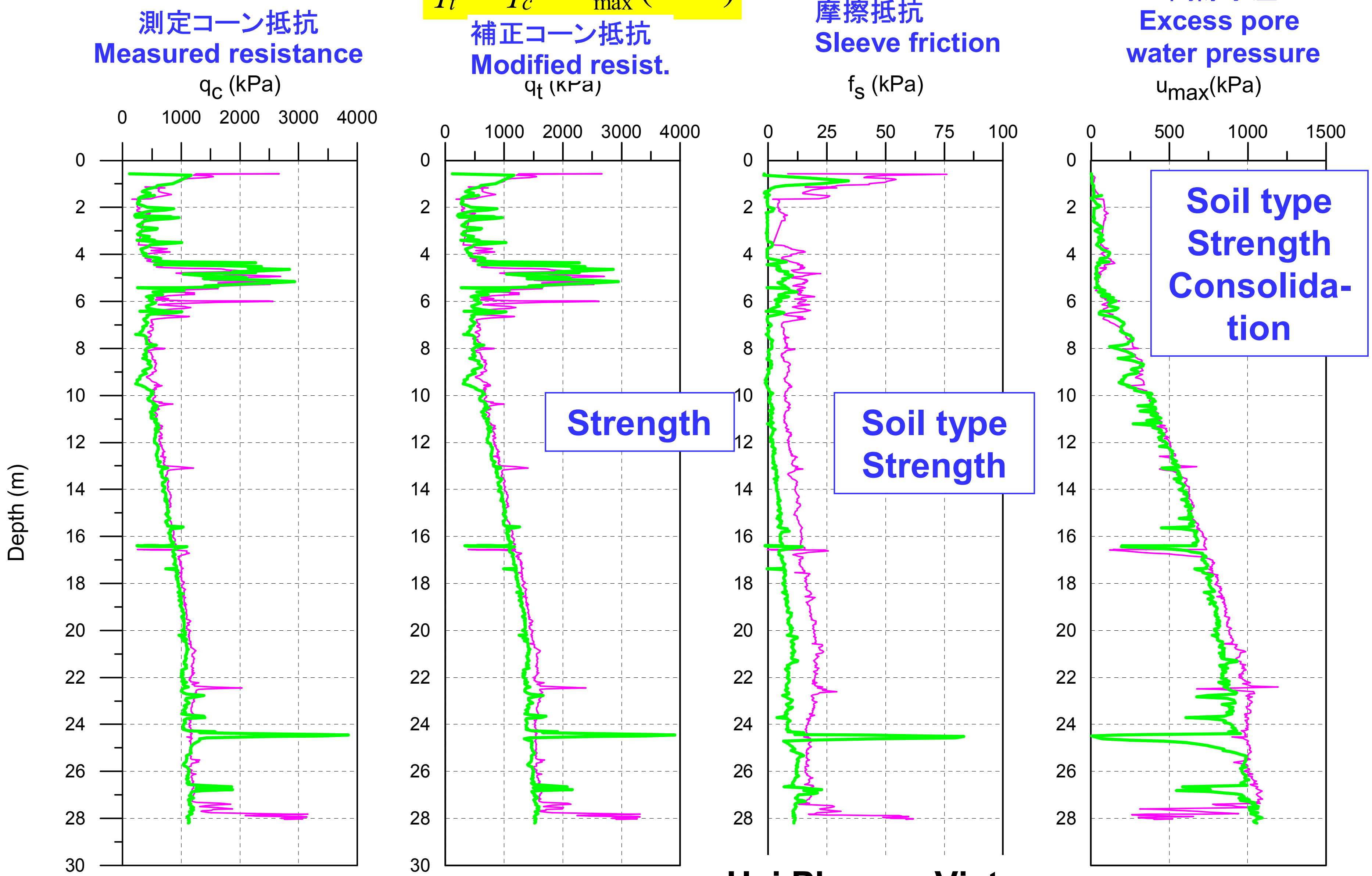
- **Sand**
  Relative density(相対密度)、friction angle(内部摩擦角)、Stiffness(変形係数) Subgrade reaction(地盤反力係数)、 Bearing capacity, K_0 pressure、 Liquefaction resistance 、void ratio
- **Clay**
  Consistency、Unconfined compression strength(一軸圧縮強さ) Bearing capacity
- **Evaluation of ground**
  Bearing layer, Soft layer
  Selection of foundation
  Penetrability of pile and sheet pile (杭、矢板の貫入性の判定)
  Potential slip plane(すべり破壊面の推定)
  Confirmation of ground improvement (地盤改良効果の判定)

Piezocone tests (CPTU)
三成分コーン



Piezocone tests results (CPTU)

$$q_t = q_c + u_{max}(1-a)$$



Hai Phong、Vietnam

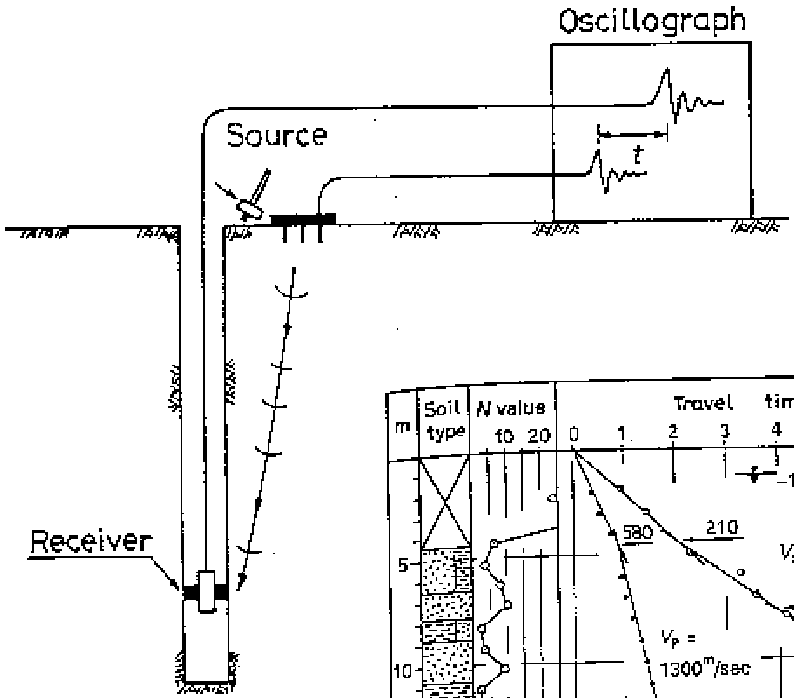
Geophysical investigation and logging

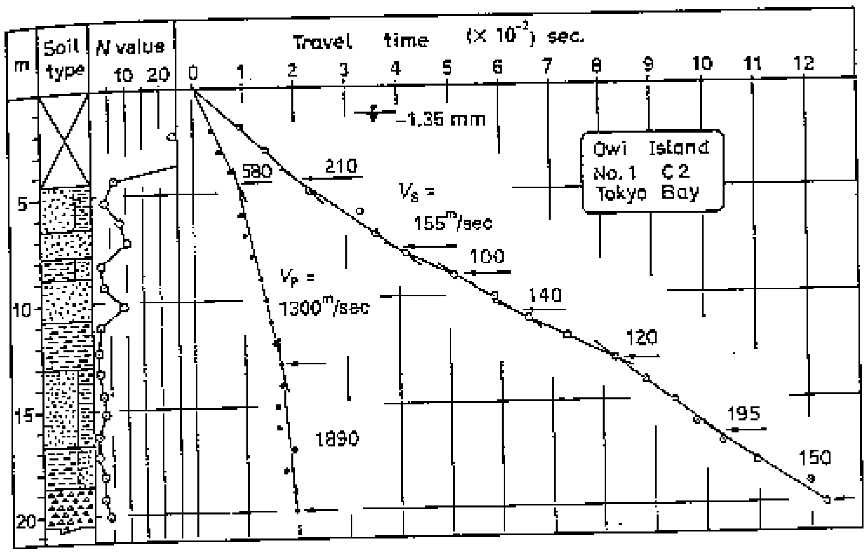
PS logging: measurement of velocities of P-wave and S-waves

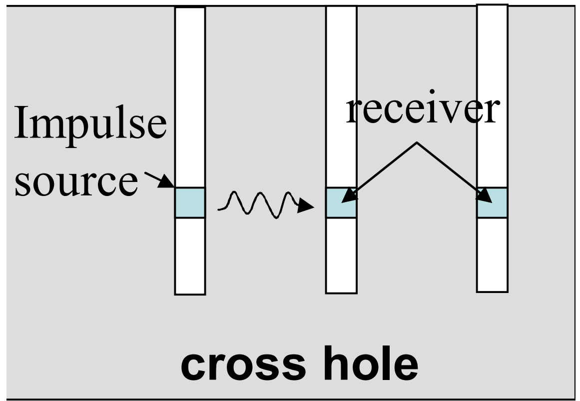
Poisson's ratio $$\nu = \frac{2-(V_p/V_s)^2}{2\{1-(V_p/V_s)^2\}}$$

Shear modulus $$G = \rho V_s^{\,2}$$

Young's modulus $$E = 2(1+\nu)G$$



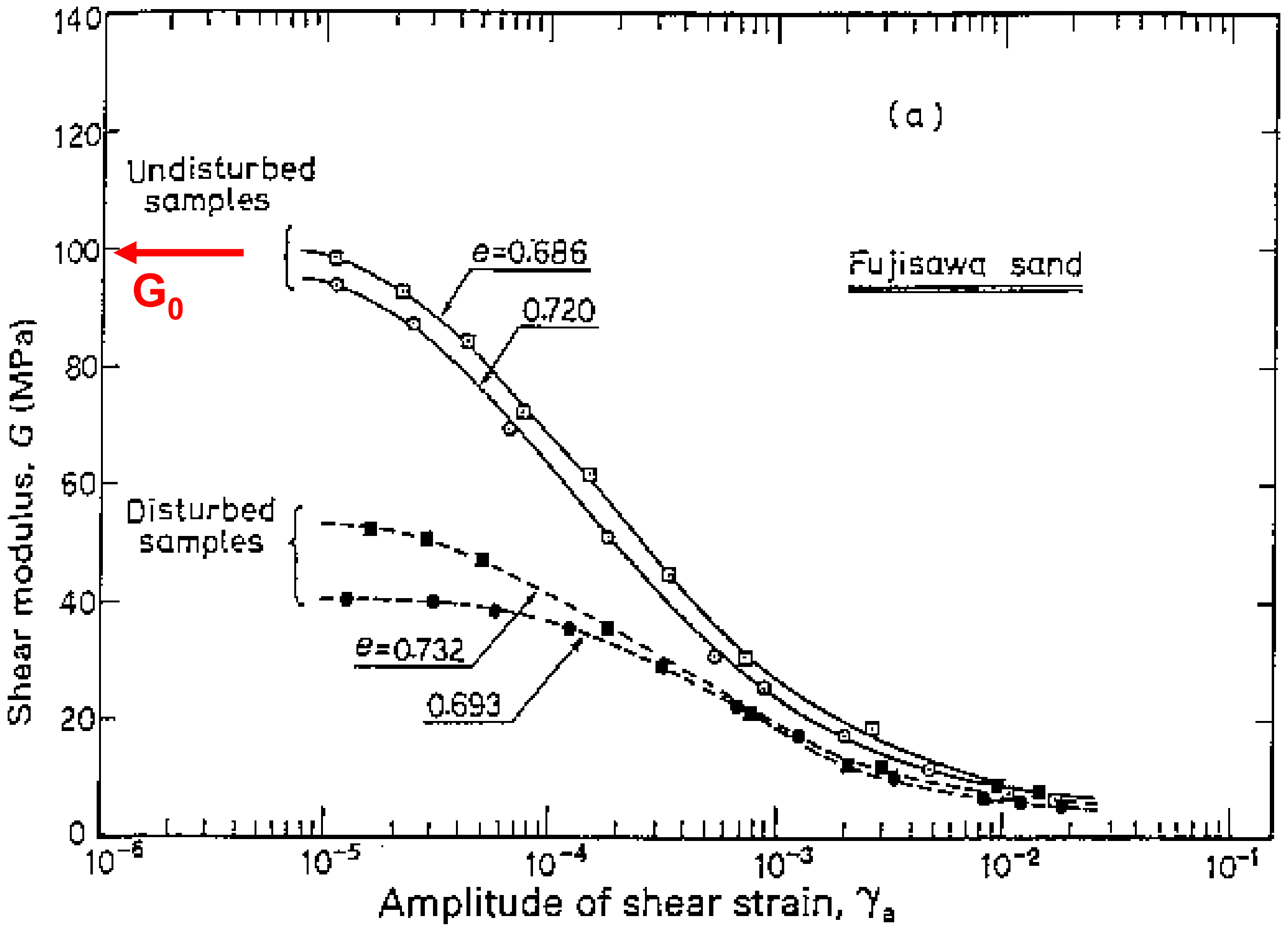




Velocity logging by down hole

"Soil behaviour in Earthquake Geotechnics " Ishihara

G-γ relation



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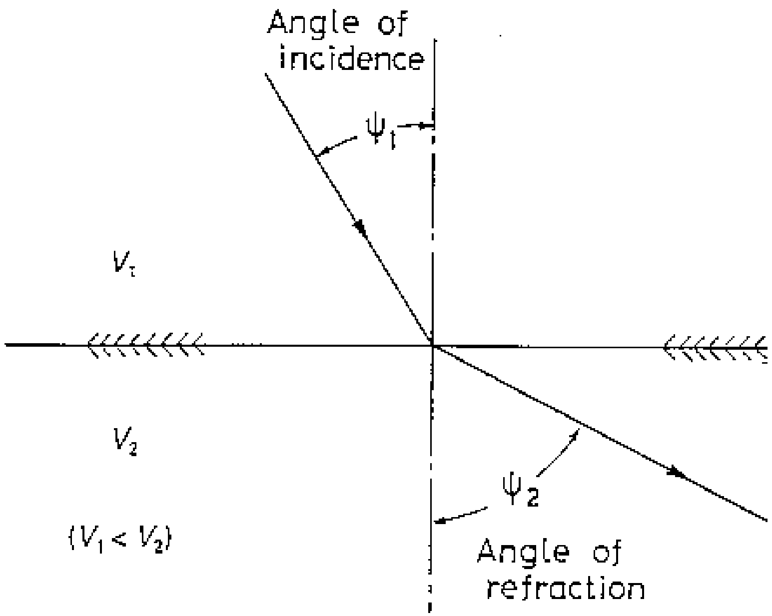
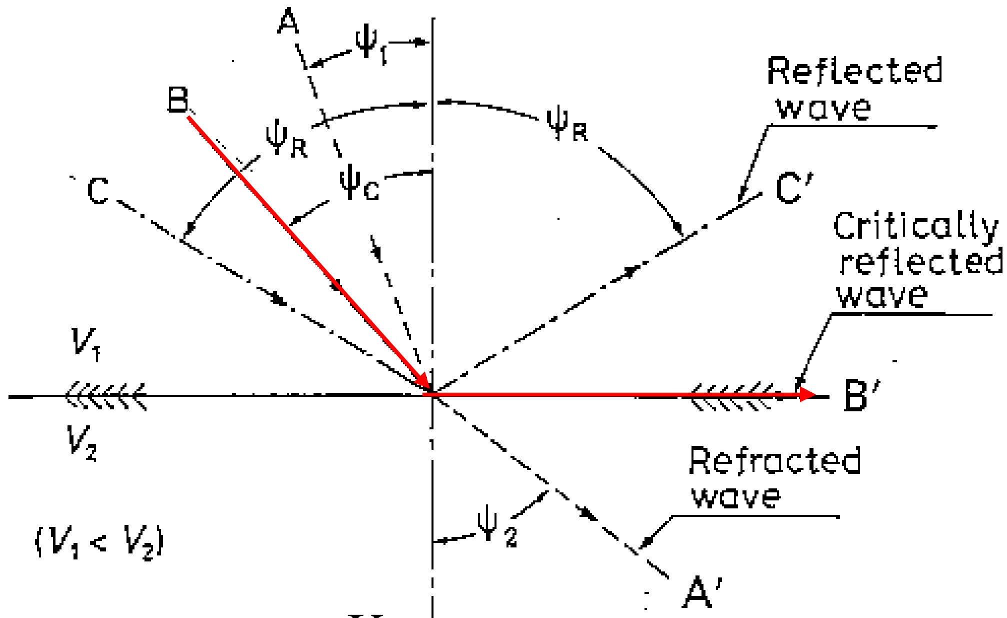
Refraction of wave



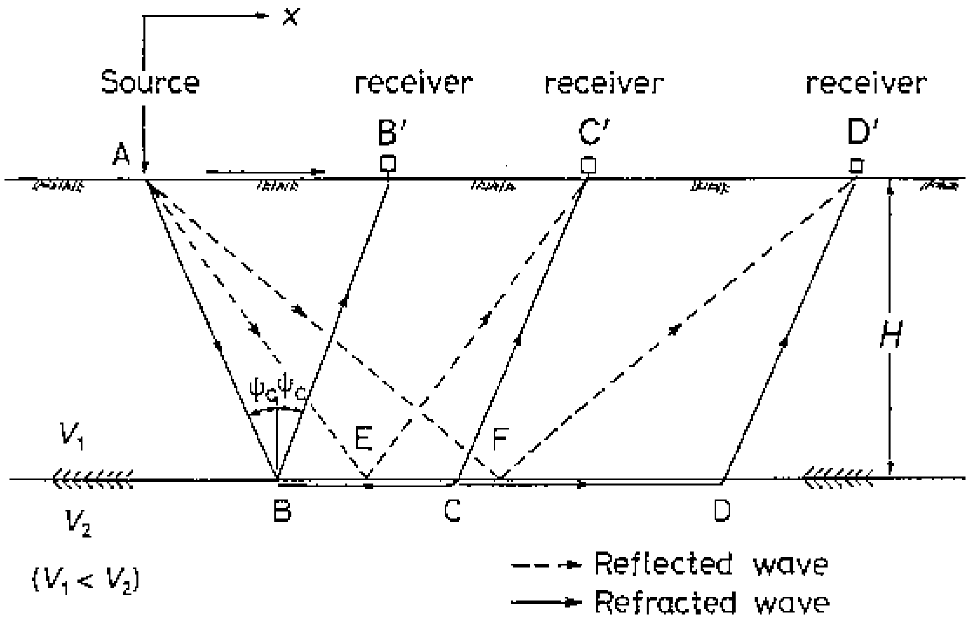


Snell's law $$\frac{\sin\psi_1}{\sin\psi_2} = \frac{V_1}{V_2}$$

$$\sin\psi_c = \frac{V_1}{V_2}$$

Critical angle of incidence ψ_c differencing refraction and reflection

Propagation of reflected and refracted



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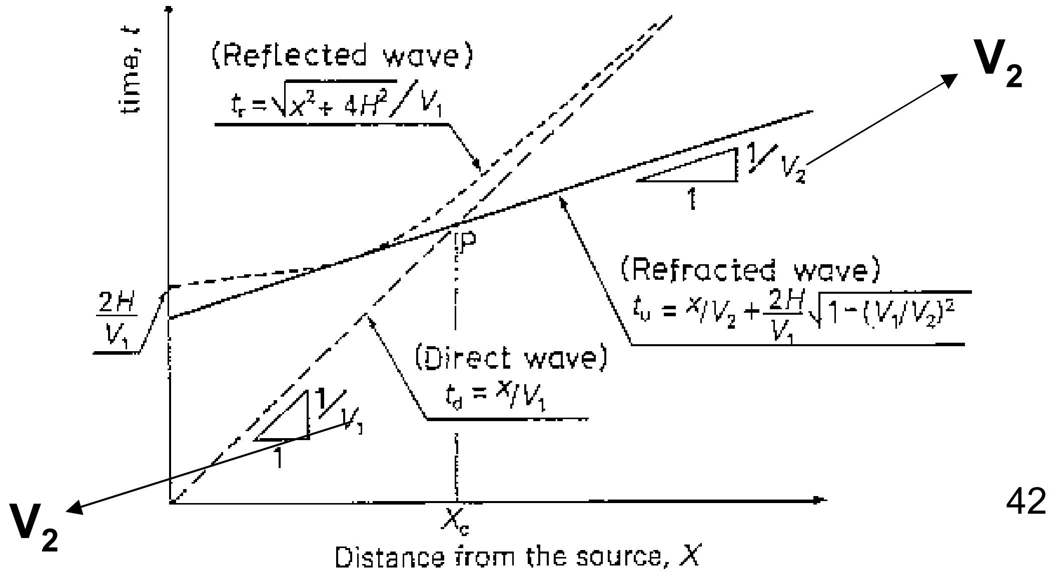
$$H = \frac{X_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}}$$

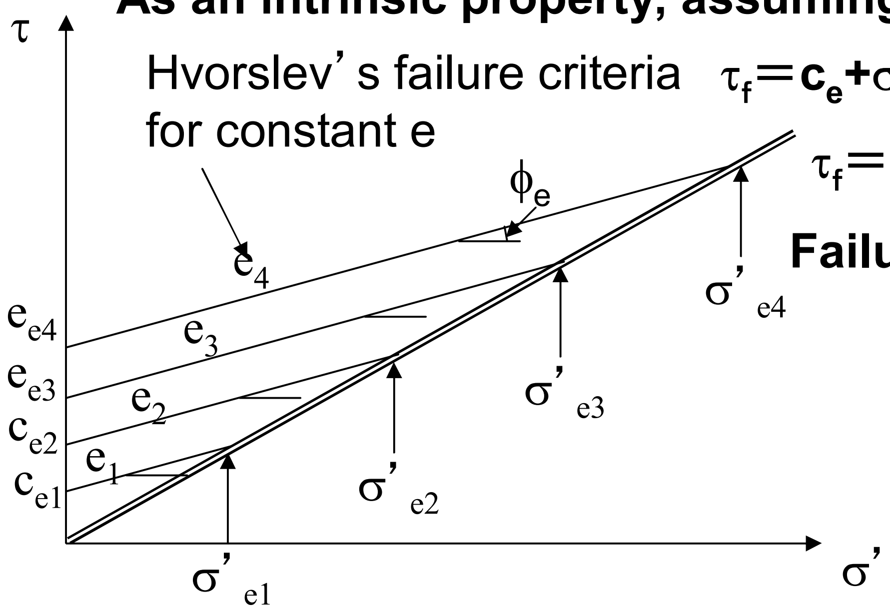


Short test and assignment 2: Effect of disturbance (due 5/10)

As an intrinsic property, assuming

Hvorslev's failure criteria $\tau_f = c_e + \sigma' \tan\phi_e$, $c_e = \kappa\sigma'_e$ for constant e

$\phi_e = 20^o$



Three unconfined compression test samples ($\sigma_1=\sigma_3=0$)
with different level of disturbance but the same void ratio (<u>c_e=10kPa</u>):

①Undisturbed sample with cementation closed to intact condition.
Residual effective stress of 20kPa, and q_u= 100kPa,
Assuming A_f=-0.1 => How is much mobilized cohesion (c_{mf}) at failure?

②Reconstituted sample without cementation but residual effective stress of 20kPa,
Assuming A_f=-0.1 => How much is the q_u?

③Remold sample without cementation and residual effective stress of 0kPa
Assuming A_f=-0.1 => How much is the q_u?