Lecture No.7

Compaction of soils

（土の締固め）
Construction of embankments, river dykes, earth fill dams, etc
（盛土・堤防・アースダム）

Compaction:
To densify (密実化) and stabilize (安定化) soil by applying static or dynamic load
Changes in state by compaction (締固めによる状態の変化)

• Air
• Water
• Soil particles

Void ratio (間隙比) $\rho_d$

Dry density (乾燥密度) $e$
Proctor (1933)
When a given soil is compacted at a given energy with varying water content, the dry density – water content relationship shows;

- $w = 10\%$
- $w = 30\%$

Dry density, $\rho_d$ (kg/m$^3$)

Zero air void curve (Saturation curve) (ゼロ空気間隙曲線)
How to obtain compaction curves – Compaction test

1. Prepare soil at a given $w$.
2. Add soil to mould.
3. Compact with rammer.
4. Complete each layer.
5. Trim the surface and weigh.
6. Measure $w$.

- Add water and repeat for a different $w$.
- Use a collar for the top layer.
- Drop from 30cm or 45cm.
- 2.5 kg or 4.5 kg.
- 30cm or 45cm.
- Repeat 2~4.
- Fill with 3 or 5 layers.
- Typically, 25 blows per layer.

- Calculate $\rho_d$ from $w$ and $\rho_t$.
- Total density, $\rho_t$. 
- Complete each layer.
Reference curves in compaction diagram

Dry density, $\rho_d$ (kg/m$^3$)

Water content, $w$ (%)
Equations for reference curves

### Constant degree of saturation curve

- **Air**
  - $V_v$
- **Water**
  - $V_w$
- **Soil**
  - $V_s$

### Saturation curve

- **Degree of saturation**
  - $S_r = \frac{V_w}{V_v}$
- **Water content**
  - $w = \frac{W_w}{W_s} \times 100\%$

### Constant air content curve

- **Air content**
  - $\nu_a = \frac{V_a}{V} \times 100\%$
- **Specific gravity**
  - $G_s = \frac{\rho_w}{\rho_s}$
$w_{\text{opt}}$: Important parameter in controlling soil compaction

Dry density, $\rho_d$ (kg/m$^3$)

Increasing $w$:
- $\rho_d$ bound by zero air void curve

Decreasing $w$:
- Increase of suction
- Increase of stiffness
- Harder to deform
  (harder to be compacted)

$w_{\text{opt}}$: Important parameter in controlling soil compaction
Effect of compaction energy

Compaction energy (締固めエネルギー) = Work done to soil (土に対する仕事量)

\[ W_R : \text{Rammer weight [kN]} \]
\[ H : \text{Fall height [m]} \]
\[ N_B : \text{Blow number per layer} \]
\[ N_C : \text{Number of layers} \]
\[ V : \text{Mould volume [m}^3\text{]} \]

Expected field compaction energy

Compaction energy in laboratory test
Effect of compaction energy

**Greater energy:** (i.e. Larger rammer weight or more blows)

- $w_{opt}$
- $\rho_{d,max}$

However... **Over-compaction** (過転圧、オーバーコンパクション)

Decrease of strength due to too much compaction energy in some soils
Effect of soil type

Location & shape of compaction curves depends on soil types
Strength

Maximum when compacted at slightly dry states

(Unconfined compression test)
Permeability

Saturated permeability
And unsaturated permeability:
To be distinguished
Compaction in field

Control variables

- Compaction machine (weight, mechanism)
- Layer thickness (“lift”)
- Number of load application

For given soil, the thinner each layer is, the denser it gets compacted.

1-unit energy for 15-cm lift
2-unit energy for 30-cm lift
3-unit energy for 30-cm lift

Which is best?

Roller

Depth

Energy

Vibration roller

Tamping roller

Vibrating plate compactor

Compaction of earth fill dam
Degree of compaction, $D_c$ (締固め度) and air content, $v_a$ (空気間隙率), as common indices

Generally ...

- Embankment: $D_c \geq 85\sim95\%
- Subgrade (路床): $D_c \geq 90\sim95\%$
Example: River dyke building with wet sand – clay mixed soil

![Image of river dyke construction]

- **Dry density,** $\rho_d$ (g/cm³)
- **Water content,** $w$ (%)

Sr100% $\rho_s = 2.611$ g/cm³
Sr90%
Sr80%

1次盛土 (H27施工)

最大乾燥密度の90% = 1.27 g/cm³

2015年築堤
2016年築堤