Preloading & Vertical drains (VD)

Currently practiced to improve very compressible (soft) soils

1. Preloading
2. Vertical drains (VD): sand & prefabricated drains, installation, constitutive material
3. Design of vertical drains networks
4. Vertical drains project in Tunisia
5. Control and follow up of VD projects

Preloading

- Saturated compressible soil: low bearing capacity
- Embankment load: very simple
- Increase undrained shear strength ($C_u$), partial primary consolidation
- Prediction from UC triaxial test
- Reduction of settlement
- Time constraint (vertical consolidation too long)
Principle of preloading

\[ P_0 : \text{real projected foundation} \]
\[ P_1 : \text{allowable loading} \]

\[ C^1_u = C^0_u + U(C^f_u - C^0_u) \]

Preloading Limitation:
Staged construction: soft clays & (or) large height embankment, delayed consolidation

Real need: accelerate primary consolidation

The use of vertical drains: horizontal consolidation much more effective for reducing time consolidation

Too reduced drainage path & bigger permeability \((k_h > k_v)\) of drain material
**Vertical Drains**  
*associated with preloading*

- Sand Drains: may contribute in settlement reduction
- **better option for depth**
- Geodrains = Prefabricated Vertical Drains (PVD): rapid installation & higher drainage properties
- **Limited depth (Equipment)**

**Focus:** Drains installation, designing drains  
**Main criteria:** *Spacing between drains*  
networks, case histories: projects accomplished

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**Sand drains**  
**Drain efficiency**

- **Constitutive material**: drained coarse sand  
Obeying to *filter condition* which depends on the gradation curve of the initial soil to improve.  
Grain size distribution
- **Installation method**
Sand drains

- **Efficiency**: ensuring drainage
  
  *Good choice of grain size*

- **Installation**: it sometimes **needs** substitution of initial soil *(Several procedures)*

- **Filter condition** *(Drain)*
  
  *grain size distribution of soil to consolidate*

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Filter condition: experiments

- **Earth dams** *(Terzaghi)*:
- **Cohesive material** containing a minimum of 15% clay
  
  No clogging of a filter $D_{15} = 0.1$ mm.

- **Purely frictional medium**:
  
  $\frac{(D_{15})_{\text{filter}}}{(D_{85})_{\text{soil}}} = 9$

- **Kérisel** : complementary condition (form of grain size curve)

- **$D_{100}$** : Maximum diameter of grains filter

- **Particles of diameter $D$**:
- **Validity of filter conditions (Terzaghi)**:
  
  Laboratory experiment *(Bertram, 1940)*

  $\frac{D_{100}(\text{filter})}{D_{100}(\text{soil})} < 4^{0.5} - \frac{D_{d}(\text{filter})}{D_{d}(\text{soil})}$
As conclusion:

- **Sand drain** has a limited duration of life.
  - risk of clogging by surrounding soil:

- **Sand Drain « well installed »**:
  
  *Works during all primary consolidation of initial soil.*

Method of capped casing with recoverable tip, Magnan (1983).
Prefabricated Vertical Drains (PVD)

- **Origin**: geo-composites
- **Performances to attain**:
  - Power full drainage
  - Role of filter & prevents fines transportation of soil to improve.

- **Steps of installation**
  
  **Installation effect**: disturbance of initial soil

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PVD’s installation

![Diagram of PVD installation]

Installation of card board drains, Magnan (1983).
Shapes of shoe used for PVD embedment, Magnan (1983).

PVD Installation Effects

1) Smear and disturbance: soil displaced during installation of drain (penetration).
   * Disturbance of soil around the drain
   * Shear strains and displacement
   * Increase of total stresses and pore pressure
   
   Drain performance is affected.

2) Well resistance: relates the degree of horizontal consolidation with drain’s length.

   Horizontal consolidation decreases with depth
Case histories (experienced projects)

<table>
<thead>
<tr>
<th>Rate of settlement</th>
<th>Mandrel</th>
<th>Smeared zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>Small area</td>
<td>Reduced</td>
</tr>
<tr>
<td>Slow</td>
<td>Large area</td>
<td>Large</td>
</tr>
</tbody>
</table>

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Design of vertical drains: acceleration of consolidation

1) Barron’s Theory (1948): unit cell model:

Equivalent diameter: \( D_c \) (drains regular network or mesh)

**Assumptions:**
- Horizontal drainage (one dimensional consolidation): 
- Constant vertical stress (applied load)
- Equal vertical strain: non-uniform vertical stress.

\[
\frac{\partial u}{\partial t} = C_h \left[ \left( \frac{\partial^2 u}{\partial r^2} \right) + \frac{1}{r} \frac{\partial u}{\partial r} \right] \quad u: \text{excess pore pressure}
\]

Soil Improvement Techniques, MB 16
Horizontal consolidation

Coefficient of horizontal of consolidation:

\[ C_h = \frac{k_h E_{soil}}{\gamma_w} \quad \text{with} \quad 1 \leq \frac{C_h}{C_v} \leq 5 \]

Time factor:

\[ T_h = \frac{C_v t}{D_v} \]

Charts:

\[ U_h = f(T_h,n) \]

\[ n = \frac{D_v}{d} \]

\( d \) Drain’s diameter (equivalent for PVD)

Design: needed time to reach a given horizontal consolidation rate?

\( n \); \( C_r \) and \( D_v \): Data (Parameters)

Methodology applicable for all types of vertical drains

Carillo’s Theory (1942): same framework

3D consolidation \((C_h \text{ and } C_v)\)

Combined solutions of Terzaghi & Barron:

\[
1 - U = \left[1 - U_h\right]\left[1 - U_v\right]
\]

Charts (three)

\( U_h \) and \( U_v \):

Point A: draw vertical line

\( U \): global degree of consolidation

\( C_h \) and \( t \): data

Point B: Choice of \( U \)

Draw horizontal

Diameter of drain and Diameter of influence, Fix the type of mesh

Spacing between drains

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Horizontal consolidation chart, Barron (1947).

3D consolidation

Example:

With $U_a = 30\%$ and $U_b = 60\%$ one has a degree of consolidation $U = 80\%$.

Equation of Carillo:

$$(1 - U) = (1 - U_a)(1 - U_b)$$
Design of Prefabricated Vertical Drains

(Hansbo, 1979)

\[ U_h = 1 - \exp\left(\frac{-8T_h}{F}\right) \]

\[ F = F(n) + F_s + F_r \]

- Barron
- Smear
- Well resistance

\[ U = f(T_h, n) \quad : \quad U_h \text{ et } n \quad T_h \]

To calculate t
Designing PVD (1)

- **Equivalent diameter of drain**  
  \[ d_w = \frac{a + b}{2} \]

- (Hansbo, 1979):
  \[ F = F(n) + F_s + F_r \]
  \[ U_h = 1 - \exp\left(\frac{-8T_h}{F}\right) \]

\[ F(n) = \ln\left[\frac{D_s}{d_w}\right] - \frac{3}{4} \]

**Smear effect** (disturbance during installation):  
\[ F_r = \frac{k_s}{k_h} - 1 \cdot \ln\left(\frac{d}{d_w}\right) \]

- Diameter of disturbed zone around the drain  
  \[ d_s \]

- Horizontal permeability of soil in disturbed zone  
  \[ k_s \]

- Horizontal permeability in undisturbed soil  
  \[ k_h \]

Designing PVD (2)

**Well-resistance** effect: Limited discharge capacity of drain

\[ F_r = \pi (L - z) \frac{k_h}{q_w} \]

Drainage occurs at **one end drain**: \( L = \text{Twice length of drain} \)

Drainage occurs at **both ends**: \( L = \text{length of drain} \)

Discharge capacity of the drain at hydraulic gradient of 1: \( q_w \)

Distance from the drainage end of the drain: \( Z \)

**Time to obtain a given degree of consolidation**:  
\[ t = \left(\frac{D^2}{8C_h}\right) \left(F(n) + F_s + F_r\right) \ln\left(\frac{1}{1 - U_h}\right) \]

**Coefficient of horizontal consolidation**:  
\[ C_h = \frac{k_h}{k_s} C_v \]


**Ratio**  
\[ \frac{k_h}{k_s} \]

Use charts of Rixner et al (1986)