Workshop #1: Design methods for retaining walls

Design of gravity walls: 50 years of French practice

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Content

1. Main evolution stages for the design of gravity walls
2. The approach of the virtual back
3. Calculation of active earth pressures
4. Limit state consideration
5. Conclusions and Perspectives
Design of gravity walls: main stages during 50 years

1. Years 1960/1970: development of methods for the design of gravity walls in line with the construction of highway infrastructure (MUR 73)


4. Years 2000/2010: development of the national standard for the implementation of the Eurocode 7 in France (NF P 94-281)
1970s: Construction of highway infrastructure

1. Public policy for the rapid and huge development of highway infrastructure

2. The objective is to have a design method for an industrial policy: relevancy, reliability and robustness
   → Need of efficiency

1. Establishment of standard procedure for the design of structures (SETRA and LCPC)
   • Identification of typical structures or typical part of structures
   • Elaboration of a specific verification method for each specific structure:
     o Background report with prescriptions and explanations to assist the designer
     o First dedicated softwares
1970s: MUR73 for the design of gravity walls

Before: only theoretical soil mechanics books without practical calculation method or standard → Each wall is different

Content of MUR73:
• Overview of calculation methods (including active earth pressure assessment)
• Detailed method of the gravity walls linked to bridges (wing walls)
• Design charts
• Interaction with FOND72 (the first French standard for foundation design)
1970s: MUR73 for the design of gravity walls

Main influences for the choice of a method for the gravity walls:

• **First approaches for the calculation with limit state framework** (Directives Communes de la Construction : DCC 1971): active earth pressures are modified by considering +/-25% for compaction effects, +/- 20 % for shear properties, +/-15 % for density.

• **Earth pressure:**
  - Caquot-Kerisel or Coulomb
  - Introduction of the virtual back with adaptation of the stress inclination ($\alpha$)

• **Bearing capacity:**
  - From laboratory tests
  - From *in-situ* tests
  - Introduction of inclination reduction factor
1970s: MUR73 for the design of gravity walls

Prescriptive and execution rules:

- Drainage
- Criteria for engineered fill
- Earthwork execution
- Road safety barrier, highway noise barrier
1980s: Evolution of shallow foundation design

- Elaboration of national standards for the design of shallow foundations:
  - Fascicule 62 Titre V
  - DTU 13.12
- Limit state framework
- Semi-empirical method (pressuremeter test) from in situ tests (both full scale and centrifuge tests)
- Reduction factor accounting for load inclination
1990s: towards a standard for the implementation of Eurocode 7 (gravity walls)

• Need of harmonization for gravity wall design
  - Introduction of limit state and use of new standards (DTU and Fascicule 62 Titre V)
  - Use of partial factors for bearing capacity and sliding

• Scope of the Expert Group in the perspective of Eurocode 7 implementation:
  - Failure mechanisms
  - Uncertainties
  - Calculation method /Engineering judgement

• SETRA Guidelines:
  - Only SLS verifications (without ULS)
  - Use of partial factors: $2.0 + i_\delta^2$ close to 2.3 (value recommended by the Expert Group)
2000-2014: National standard NF P 94-281 (Eurocode 7)

- Elaboration of national standards (CNJOG)
  - NF P 94-261: shallow foundations (2013)
  - NF P 94-281: gravity walls (2014)

- Synthesis of the previous standards:
  - Earth pressure calculation: MUR73
  - Verification of the foundation: NF P 94261/Fascicule 62 Titre V/DTU 13.12
  - Partial factors: see the Expert Group conclusions
Method of the virtual back

- This method was introduced by MUR73
- The « true » mechanism is simplified by the use of a virtual back
- The stress inclination on the virtual back is defined in order to obtain actions and loads that are equivalent to those obtained by considering the « true » mechanisms
Method of the virtual back

\[ \theta = \frac{\pi}{4} + \frac{\varphi}{2} + \frac{(\gamma - \beta)}{2} \]

\[ \gamma = \arcsin \left( \frac{\sin \beta}{\sin \varphi} \right) \]
Method of the virtual back

\[
\delta_a = \beta \text{ if } B_t \tan(\theta) > h_v \\
\delta_a = \beta + (\delta_0 - \beta) \left(1 - \frac{B_t \tan(\theta)}{h_v}\right)^2 \text{ if } B_t \tan(\theta) < h_v \\
\text{with } \delta_0 = \max \left(\beta, \frac{2}{3} \varphi\right)
\]
Method of the virtual back

Parametric study:

\( e_v = e_s = H/15 \)

\( B_p = B/\alpha \) with \( 1.25 < \alpha < 20 \)

\( 27^\circ < \varphi < 39^\circ \)

\( B = 0.3H \)

### Resultant force

\[ \frac{(\Sigma F_v - \Sigma F_t)}{F_t} \text{ in } \% \]

### Load inclination

\[ \frac{(\delta_v - \delta_t)}{\delta_t} \text{ in } \% \]

### Eccentricity

\[ \frac{(e_v - e_t)}{B} \text{ in } \% \]

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<thead>
<tr>
<th>( \varphi - B_p = B/\alpha )</th>
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Method of the virtual back

Parametric study:
\[ e_v = e_s = H/15 \]
\[ B_p = B/\alpha \text{ with } 1.25 < \alpha < 20 \]
\[ 27^\circ \leq \varphi \leq 39^\circ \]
\[ B = 0.6H \]

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\( (\delta_v - \delta_t)/\delta_t \text{ in } \% \)

Resultant force

\( (\Sigma F_v - \Sigma F_t)/F_t \text{ in } \% \)

Eccentricity

\( (e_v - e_t)/B \text{ in } \% \)

Load inclination
Method of the virtual back

- The actions calculated with the theoretical approach and the virtual back approach are very close: the foundation is subjected to the same actions.

- The inclination of the active earth pressures on the virtual back may be significant and has a strong influence on the calculation results: considering a null inclination increases a lot the horizontal action and reduces to zero the vertical action, which is very conservative.
Active earth pressure calculation

- Caquot-Kerisel tables

- Coulomb calculation (complex geometry, external loads on the ground surface)

\[ K_a = \frac{\cos^2(\lambda - \varphi)}{\cos(\lambda + \delta) \left( 1 + \sqrt{\frac{\sin(\varphi + \delta)\sin(\varphi - \beta)}{\cos(\lambda + \delta)\cos(\beta - \lambda)}} \right)^2} \]
**Limit state calculations: comparisons of various methods**

<table>
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<tr>
<th>Partial factors on actions</th>
<th>Combination $G_{\text{min}}^{(1)}$</th>
<th>Combination $G_{\text{max}}^{(2)}$</th>
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<tbody>
<tr>
<td>Partial factors $\gamma_G$ on $G_x$ and $G_b$</td>
<td>1</td>
<td>1.35</td>
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<tr>
<td>Partial factors $\gamma_Q$ on $Q_v$ ($\Sigma q$ at the virtual back)</td>
<td>0</td>
<td>1.5</td>
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<tr>
<td>Partial factors $\gamma_G$ on $P_{ah,g}$ and $P_{av,g}^{(3)}$</td>
<td>1.35</td>
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<td>Partial factors $\gamma_Q$ on $P_{ah,q}$ and $P_{av,q}$</td>
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(1) $G_{\text{min}}^{(1)}$: the vertical actions are favourable

(2) $G_{\text{max}}^{(2)}$: the vertical actions are unfavourable

(3) the active earth pressures are always unfavourable
Limit state calculations: comparisons of various methods

• The implementation of the Eurocode 7 has required to calibrate the partial factors used until 2000.
• Several issues should be checked:
  o Partial factors for the bearing capacity and the sliding
  o Model factors
  o The virtual back approach is more conservative than the theoretical approach since the vertical actions are less increased whereas the horizontal actions are identical to the real case.

→ Need to compare the various methods
Limit state calculations: comparisons of various methods

**Methods:**

- **MUR min:** calculation with the software MUR (SETRA – ULS bearing capacity factor 1.5 + 0.5$i_{\delta^2}$)
- **Experts recommendations** (SLS coef 2.3)
- **EC7 $G_{\text{max}}$:** calculation with NF P 94-281 - $G_{\text{max}}$
- **EC7 $G_{\text{min}}$:** calculation with NF P 94-281 - $G_{\text{min}}$

**Ground properties:**
- $q_u$: ultimate bearing capacity
  - 0.8 – 1.2 et 2.4 MPa

**Engineered fill:**
- $\gamma$ (weight density): 20 KN/m$^3$
- $\phi$ (friction angle): 25 – 30 – 35 et 40°
- $c$ (cohesion): 0

- $\beta = 0 – 1/3 – 2/3$ et $0.8 \* \phi$
Limit state calculations: comparisons of various methods

The results are close. The most conservative method is EC7-\(G_{\text{min}}\), which is consistent with the previous comment about the role of the virtual back.
Conclusions and perspectives

- The evolution of the design methods was continuous during the last 50 years with the elaboration of an harmonized design method as a first step, the consideration of inclined loadings as a second step and the use of limite state framework as a third step.

- The virtual back method and the use of partial factors might be maybe improved by analysing the role of the ground mass above the heel.

- The calculation method includes some simplifications that are necessary for an efficient design and take into account the uncertainties about the ground properties and the execution.

- The knowledge of the previous calculation methods is fundamental for:
  - the maintenance and the reparation of the existing structures,
  - the possibility to propose future evolutions.
Thank you for your attention