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Introduction

• There are two types of earth retaining structures
  – Embankments (slope stability analysis)
  – Retaining walls (rigid - gravity - and flexible walls)

Basic Concepts of Lateral Earth Pressures

• At Rest or \( K_o \) Condition
  – The horizontal strain is zero

\[
\sigma_{AV} = \gamma z_w + \gamma_{sat}(z_A - z_w) \\
\gamma_{sat} = \gamma_z (z_A - z_w) \\
\sigma'_{AV} = \sigma_{AV} - \gamma_{sat} \\
\sigma'_{AH} = K_o \sigma'_{AV} \\
K_o = 1 - \sin(\phi) \quad \text{(for NC soils)} \\
\sigma_{AH} = \sigma'_{AH} + \gamma_{sat}
\]
Basic Concepts of Lateral Earth Pressures

• Active $K_A$ and Passive $K_P$ Conditions
  – There is horizontal deformation

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Basic Concepts of Lateral Earth Pressures

• Active $K_A$ and Passive $K_P$ Conditions
  – Limit equilibrium analysis
  – Coulomb (1776): upper bound theorem
  – Rankine (1857): lower bound theorem
  – Assumptions:
    • The earth retaining wall is vertical
    • The wall earth interface is frictionless (no shear stresses)
    • The soil surface is horizontal (no shear stresses)
    • The wall is rigid and the soil is dry, homogeneous and isotropic
    • The soil is loose and initially at rest
Basic Concepts of Lateral Earth Pressures

• Active $K_A$ and Passive $K_P$ Conditions
  – Coulomb (1776): upper bound theorem

$$F_p = \phi / 2$$

$$W$$

Fp

45-\(\phi / 2\)

Rankine passive zone

Wall movement

Fp

45-\(\phi / 2\)

Rankine active zone

Fq

45+\(\phi / 2\)

Basic Concepts of Lateral Earth Pressures

• Active $K_A$ and Passive $K_P$ Conditions
  – Rankine (1857): lower bound theorem

$$\sigma'_{v}$$

Failure surface

$K_a\sigma'_{v}$

$K_p\sigma'_{v}$

$K_a\sigma'_{v}$

$K_p\sigma'_{v}$

$K_a = \frac{1 - \sin(\phi)}{1 + \sin(\phi)}$

$K_p = \frac{1 + \sin(\phi)}{1 - \sin(\phi)}$
Basic Concepts of Lateral Earth Pressures

- **Active** $K_A$ and **Passive** $K_P$ Conditions

\[
K = \begin{cases} 
\frac{1}{2} \gamma K_a H^2 & \text{Active zone} \\
\frac{1}{2} \gamma K_p H^2 & \text{Passive zone} 
\end{cases}
\]

\[
F_a = \frac{1}{2} \gamma K_a H^2 \\
F_p = \frac{1}{2} \gamma K_p H^2
\]

**Example Problem**

- **Active Case**

  - Determine the resultant earth force (magnitude and position) and the factors of safety against sliding and overturning

\[
\begin{align*}
\gamma &= 15 \text{ kN/m}^3 \\
\phi &= 30 \text{ deg} \\
\gamma_{sat} &= 20 \text{ kN/m}^3 \\
\gamma_w &= 10 \text{ kN/m}^3 \\
\phi &= 35 \text{ deg} \\
\gamma_{concrete} &= 25 \text{ kN/m}^3 \\
\phi_{rock-concrete} &= 45 \text{ deg}
\end{align*}
\]
The Effect of Pore Water

• Active Case – No Drains
  – Determine the resultant earth force (magnitude and position) and the factors of safety against sliding and overturning

\[ \gamma_{sat} = 20 \text{kN/m}^3 \]
\[ \gamma_w = 10 \text{kN/m}^3 \]
\[ \phi = 35 \text{ deg} \]
\[ \gamma_{concrete} = 25 \text{kN/m}^3 \]
\[ \phi_{rock-concrete} = 45 \text{ deg} \]

The Effect of Pore Water

• Active Case – Drains
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Cantilever Sheet Pile Walls

• Analysis

- Select a point O (arbitrary)
- Calculate the active and passive earth pressures (reduce the strength parameters: $\phi/F_\phi$, where $F_\phi = 1.2$ to 1.5)
- Calculate the net pore water pressure and the seepage force.
- Determine the depth $d_o$ by summing moments about O.
- Determine $d = 1.2$ to $1.3 \times d_o$.
- Calculate $R$ by summing forces horizontally over the depth $(H_o + d)$. 

$H_o$ = depth of excavation
$d =$ depth of embedment
$d_o =$ depth of rotation

Pressure distribution
Approximated pressure distribution
Cantilever Sheet Pile Walls

• Analysis (cont.)
  – Determine net passive resistance between \( d_o \) and \( d \).
  – Check that \( R \) is greater than net passive resistance. If not extent the depth of embedment and determine new \( R \).
  – Calculate the maximum bending moment \( M_{\text{max}} \) over \( H_o-d_o \).
  – Determine the section modulus: \( S = \frac{M_{\text{max}}}{\sigma_{\text{allow}}} \).

References and Bibliography