Retaining Wall
Retaining Walls

- What are retaining walls
  - Retaining walls are soil-structure systems intended to support earth backfills.

- Type of retaining walls
  - Gravity retaining wall
    - gravity walls rely on their own weight to provide static equilibrium.
    - typically made of plain (unreinforced) concrete or stone blocks.
  - Cantilever retaining walls
    - cantilever walls derive a portion of their stabilizing forces and moments from the backfill soil above the heel.
    - require the use of steel reinforcement to resist the large moments and shear stresses.
Retaining Walls

- MSE walls
  - Mechanically Stabilized Earth (MSE) walls derive their stability from the internal stresses developing at the interface between the soil and the reinforcement elements.
  - MSE walls are constructed by compacting the soil in layers separated by reinforcement strips or sheets. Reinforcement strips are attached to facing units, and extend far enough into the backfill to ensure adequate pullout resistance.

- Soil-Nailed walls
Retaining Walls

- Reinforced Earth Walls
- Geotextile-Reinforced Walls
- Cantilever Sheet Piles
Reinforced Earth Walls
Cantilever Sheet Piles
Cantilever Retaining Walls

- **Basic Principles**
  
  - Cantilever walls are made of reinforced concrete, & come in different geometries.
  
  - Rely on their self-weight to resist sliding & overturning, but derive part of their stability from the weight of the backfill above the heel of the wall.
Cantilever Retaining Walls

- Typical Dimensions of retaining walls

- **Gravity walls**
  - $D = (H/8 - H/6)$
  - $(0.5 - 0.7)H$

- **Cantilever Wall**
  - $B = (0.4 - 0.7)H$
  - $H/12 - H/10$

- **Counter form Walls**
  - $0.2 - 0.3$
  - $0.69$
  - $(0.3 - 0.6)H$
Different locations of shear key in retaining wall
(c) Cantilever wall
In addition to the external stability, cantilever walls must also satisfy internal structural.

The wall section should be able to withstand the shear stresses and bending moments resulting from the lateral earth pressure as well as the difference in pressure between the top and bottom faces of the base.
Cantilever Retaining Walls

- External stability

ampus In analyzing or designing for external stability, all the forces acting on the structure are considered. These forces include lateral earth pressures, the self-weight of the structure, & the reaction from the foundation soil.

ampus The stability of the wall is then evaluated by considering the relevant forces for each potential failure mechanism.

ampus The wall has to be stable against:

ampus Sliding

ampus Overturning

ampus Bearing capacity

$$FS_{sliding} = \frac{\sum \text{Resisting forces}}{\sum \text{Sliding forces}} > 1.5$$

$$FS_{overturning} = \frac{\sum \text{Righting moments}}{\sum \text{Overturning moments}} > 1.5$$

$$FS_{BC} = \frac{q_{all}}{q_{max}} > 1$$
Cantilever Retaining Walls

■ Design Example

✧ Given data

➢ As shown in the figure

➢ \( f_c' = 25 \text{MPa} \)

➢ \( f_y = 420 \text{MPa} \)

➢ \( q_{all} = 150 \text{kN/m}^2 \)

✧ Design the retaining wall
Design Example

Step 1: Check for overturning

Calculate the weight per unit width ($W_i$)

$W_1 = 23.5 \times 0.5 \times 0.7 = 8.23kN$  (per meter)

$W_2 = 23.5 \times 5 \times 0.5 = 58.75kN$

$W_3 = 23.5 \times 0.5 \times 1.4 = 16.45kN$

$W_4 = (17 \times 2.5 + 19 \times 0.2)1.4 = 112.7kN$

Moment arm ($x_i$)

$x_1 = 0.35m$

$x_2 = 0.95m$

$x_3 = 1.9m$

$x_4 = 1.9m$
Design Example

Calculate the active earth pressure & the water pressure

\[ K_a = \frac{1 - \sin 35}{1 + \sin 35} = 0.27 \]

\[ \sigma'_{h1} = 17 \times 2.5 \times 0.271 = 11.52\, kPa \]
\[ \sigma'_{h2} = (17 \times 2.5 + (19 - 9.8) \times 2.5) \times 0.271 = 17.75\, kPa \]
\[ u = 9.8 \times 2.5 = 24.5\, kPa \]
\[ W_4 = (17 \times 2.5 + 19 \times 0.2)1.4 = 112.7\, kN \]

The active forces \(P_1\) to \(P_4\) per unit width

\[ P_1 = 0.5 \times 11.52 \times 2.5 = 14.4\, kN \]
\[ P_2 = 17.75 \times 2.5 = 44.38\, kN \]
\[ P_3 = 0.5 \times (17.75 - 11.52) \times 2.5 = 7.79\, kN \]
\[ P_4 = 0.5 \times 24.5 \times 2.5 = 30.63\, kN \]

Moment arm \((y_i)\)

\[ y_1 = 2.5 + \frac{2.5}{3} = 3.33m \]
\[ y_2 = \frac{2.5}{2} = 1.25m \]
\[ y_3 = \frac{2.5}{3} = 0.83m \]
\[ y_4 = 0.83m \]
Design Example

Calculate the active earth pressure & the water pressure

\[ FS_{	ext{overturning}} = \frac{M_R}{M_O} = \frac{\sum W_i x_i}{\sum P_i y_i} \]

\[ = \frac{8.23 \times 0.35 + 58.75 \times 0.95 + 16.45 \times 1.9 + 112.7 \times 1.9}{14.4 \times 3.33 + 44.38 \times 1.25 + 7.79 \times 0.83 + 30.63 \times 0.83} \]

\[ = \frac{304.1}{135.3} = 2.2 > 1.5 \quad OK \]

Step 2: Check for bearing capacity

The eccentricity on the wall base

\[ e = 0.5B - (M_R - M_O) / W \]

\[ = 0.5(2.6) - (304.1 - 135.3) / 196.1 \]

\[ e = 0.42m < B / 6 = 0.43 \quad OK \]

The maximum & minimum soil pressures at the toe & heel of the base are

\[ q_{\text{max}} = q_{\text{toe}} = \frac{F}{A} \pm \frac{M_x}{I_x} y = \frac{196.1}{2.6} + \frac{196.1 \times 0.42 \times 6}{2.6^2} = 148.5 \quad kN / m^2 \]

\[ q_{\text{min}} = q_{\text{heel}} = \frac{196.1}{2.6} - \frac{196.1 \times 0.42 \times 6}{2.6^2} = 2.3 \quad kN / m^2 \]
Design Example

\[ FS_{BC} = \frac{q_{all}}{q_{max}} = \frac{150}{148.5} = 1.01 > 1 \quad OK \]

Step 3: Check for shear strength at critical section

The ultimate shear on the base at a distance \( d \) from the face of the wall is

\[ d = 0.5 - 0.075 - 0.02 = 0.405 \text{m} \quad \text{Effective depth of base} \]

At the TOE

Pressure at distance \( d \) from the face of the wall

\[ q_{max} = 148.5 \text{ kN} / \text{m}^2 \]

\[ q_d = \frac{(148.5 - 2.3) \times 2.295}{2.6} + 2.3 = 131.3 \text{ kN} / \text{m}^2 \]

\[ V_u = 1.6qb(0.7 - d) \]

\[ = 1.6 \left( \frac{148.5 + 131.3}{2} \right) 1 \times (0.7 - 0.405) = 66 \text{ kN} \]

\[ \phi V_c = 0.17\phi\sqrt{f'c'b_d} \]

\[ = 0.17 \times 0.85\sqrt{30} \times 1 \times 0.405 = 293 \text{ kN} \quad > V_u \quad OK \]
Design Example

At the HEEL
Pressure at distance $d$ from the face of the wall

$$q_d = \frac{(148.5 - 2.3) \times 0.995}{2.6} + 2.3 = 58.2 \text{ kN/m}^2$$

$$q_{\text{min}} = 2.3 \text{ kN/m}^2$$

$$V_u = 1.6qb(1.4 - d)$$

$$= 1.6 \left( \frac{58.2 + 2.3}{2} \right) \times (1.4 - 0.405) = 50 \text{ kN}$$

$$\phi V_c = 0.17 \phi \sqrt{f_c 'b_0d}$$

$$= 0.17 \times 0.85 \sqrt{30 \times 1 \times 0.405} = 293 \text{ kN} > V_u \text{ OK}$$

Step 3: Flexural reinforcement
At the HEEL
Case I

$$M_u = 1.6M_{\text{heel}} = 1.6 \left( 2.3 \times \frac{1.4^2}{2} + (81 - 2.3) \frac{1.4^2}{6} \right)$$

$$M_u = 44.8 \text{ kN.m}$$
Design Example

\[
\rho = \frac{0.85f_c'}{f_y} \left[ 1 - \sqrt{1 - \frac{2.61 \times 10^{-3} M_{u}}{b d^2 f_c'}} \right] = \frac{0.85 \times 25}{420} \left[ 1 - \sqrt{1 - \frac{2.61 \times 10^{-3} (44.8)}{1(0.405)^2 \times 25}} \right] = 0.0007 < \rho_{\text{min}} = 0.0018
\]

\[A_s = 0.0018(100)(40.5) = 7.3 \text{cm}^2\]

Use \(\phi 12\text{mm} \atop @ 15\text{cm}\)

Case II

\[M_u = 1.6 M_{\text{heel}} = 1.6(16.45 + 112.7)0.7 = 144.6 \text{ kN}\]

\[
\rho = \frac{0.85 \times 25}{420} \left[ 1 - \sqrt{1 - \frac{2.61 \times 10^{-3} (144.6)}{1(0.405)^2 \times 25}} \right] = 0.0024
\]

\[A_s = 0.0024(100)(40.5) = 9.7 \text{cm}^2\]

Use \(\phi 14\text{mm} \atop @ 15\text{cm}\)
Design Example

At the TOE

\[ M_u = 1.6M_{toe} = 1.6 \left( 109.1 \times \frac{0.7^2}{2} + (148.5 - 109.1) \frac{0.7^2}{3} \right) \]

\[ M_u = 53.1 \text{ kN} \cdot \text{m} \]

\[ \rho = \frac{0.85 \times 25}{420} \left[ 1 - \sqrt{1 - \frac{2.61 \times 10^{-3} (53.1)}{1(0.405)^2 \times 25}} \right] = 0.0009 < \rho_{\text{min}} = 0.0018 \]

\[ A_s = 0.0018(100)(40.5) = 7.3 \text{cm}^2 \]

Use φ 12mm @ 15cm

At the STEM

\[ M_{stem} = 14.4 \times 2.83 + 44.38 \times 0.75 + 7.79 \times 0.33 + 30.63 \times 0.33 \]

\[ M_{stem} = 86.7 \text{ kN} \cdot \text{m} \]

\[ M_u = 1.6M_{stem} = 1.6(86.7) = 138.7 \text{ kN} \cdot \text{m} \]

\[ \rho = \frac{0.85 \times 25}{420} \left[ 1 - \sqrt{1 - \frac{2.61 \times 10^{-3} (148.7)}{1(0.405)^2 \times 25}} \right] = 0.0023 \]
Design Example

\[ A_s = 0.0023(100)(40.5) = 9.3cm^2 \]

Use \( \phi \) 14mm @ 15cm

Step 4: Shrinkage reinforcement

\[ A_s = 0.0018(100)(40.5) = 7.3cm^2 \]

Use \( \phi \) 12mm @ 15cm
Design Example

- Flexural reinforcement
- Shrinkage reinforcement

φ 12mm @ 15cm

φ 14mm @ 15cm

φ 12mm @ 15cm