## Retaining Wall Design

### Conventional Retaining Walls

- **Gravity Retaining Structures**
  - Stability depends on the self weight of the wall
  - Not economical for design

- **Semi-gravity Retaining Structures**
  - Minimum amount of reinforcement may be used in the wall to reduce the size of wall

- **Cantilever Retaining Walls**
  - Reinforced concrete is used in wall design with thin stem and slab base
  - Relatively economical for design

### Counterfort/Buttressed Retaining Walls

- Similar to Cantilever retaining walls, but thin slab stems may be used at some interval to tie the base slab and stem in order to reduce the shear force and bending moment for more economical design
First, approximate dimensions are chosen for the retaining wall.

Then, stability of wall is checked for these dimensions.

Section is changed if its undesirable from the stability or economy point of view.

Earth pressure may be calculated at the vertical section going through the heel of wall. This is under the constraint that Heel is proportioned in such a way that line AC makes an angle less than or equal to \( \eta \) with vertical.

\[ \eta = 45 - \frac{\phi}{2} - \frac{\psi}{2} - \sin \left( \frac{\text{horizontal}}{\text{sin} \phi} \right) \]
Earth Pressure on Retaining Wall

Along line AB

\[ P_h = \frac{1}{2} K_h H^2 \]

\[ P_v = \frac{1}{2} K_v H^2 \]

The units of \( K_h \) and \( K_v \) are the same as \( (P_h/H^2) \).

Terzaghi and Peck have produced semi-empirical charts for \( K_h \) and \( K_v \) for different types of soils as listed in the table below

1. Coarse-grained soil without admixture of fine soil particles, very permeable (clean sand or gravel)
2. Coarse-grained soil of low permeability due to admixture of particles of silt size.
3. Residual soil with stones, fine silty sand, and granular materials with conspicuous clay content.
4. Very soft or soft clay, organic silts, or silty clays.
5. Medium or stiff clays, deposited in clays and protected in such a way that a negligible amount of water enters the spaces between the clays during floods or heavy rains. If this condition of protection cannot be satisfied, the clay should not be used as backfill material. With increasing stiffness of the clay, danger to the wall due to infiltration of water increases rapidly.

Retaining walls with backfill slope of finite distance

Earth Pressure on Retaining walls with backfill slope of finite distance

(Terzaghi, Peck, and Mesri, 1996)
Stability of retaining wall

OVERTURNING about its toe.

SLIDING along the base

BEARING CAPACITY failure of supporting base

Excessive SETTLEMENT may occur if weak soil layer is located below the foundation within 1.5 times foundation width.

Deep seated shear failure may occur if there is a weak soil layer below the foundation within a depth of about 1.5 times width of foundation. The failure surface may be assumed to have cylindrical shape and critical failure surface for sliding may be determined through analysis.

For back fill with its slope less than 10°, the critical sliding surface may be assumed to pass through heel of the retaining wall.

Check Against OVERTURNING
The wall must be safe against overturning about the toe

\[
FOS = \frac{\sum M_{e}}{\sum M_{o}} \quad \text{Resisting Moment}
\]

\[
FOS = \frac{P_{a}B + \sum W_{s}x_{s}}{P_{a}B - P_{a}y_{p}} \geq 2
\]

\[FOS = 1.5, \text{ if wind/seismic forces are considered}\]

Location of Resultant force from toe can determined as

\[
(P_{a} + \sum W_{s})x = \sum M_{e} - \sum M_{o}
\]

\[
FOS = \frac{\sum M_{e} - \sum M_{o}}{P_{a} + \sum W_{s}}
\]

In the design of cantilever retaining wall it is preferred that the stem center is right above the location of resultant force at the base (resultant of soil reaction).

In most cases passive earth pressure is ignored while calculating FOS against sliding

\[
FOS = 1.5, \text{ if wind/seismic forces are considered}
\]

Base friction and adhesion may be taken by the following assumption

\[
s_{a} = (\frac{1}{2} \text{ to } \frac{2}{3})\delta_{p}^{'}
\]

\[
c_{s} = (\frac{1}{2} \text{ to } \frac{2}{3})\delta_{p}^{'}
\]
Check for BEARING CAPACITY failure

\[ R = \sqrt{\left( P_c + \sum W_i \right)^2 + \left( P_w - P_f \right)^2} \]

\[ CE = \frac{\sum M_x - \sum M_y}{P_{\text{av}} + \sum W_i} \]

Eccentricity:
\[ e = \frac{B}{2} \times \frac{C_E}{B} \]

For \( e > \frac{B}{6} \), \( q_{\text{min}} \) becomes negative, i.e., tensile force. This is not desirable and re-proportioning is required.

Bearing capacity of soil can be calculated using general bearing capacity equation.

\[ q_w = c.N_c.d.c_q + q.N_q.d.q_q + 0.5y.B.N_y.d.y_q + B' d_e \]

Following consideration have to made during the analysis:

- The eccentricity of load on the foundation can be incorporated using effective area method. The bearing capacity is calculated assuming the width of foundation as \( B' = B - 2e \).
- Inclination of resultant force has to taken into account
  \[ \tan \beta = \frac{P_{\text{av}} - P_f}{P_{\text{av}} + \sum W_i} \]

Factor of safety against bearing capacity:

\[ FOS = \frac{q_{\text{w}}}{q_{\text{av}}} \]

2 for granular soil
3 for cohesive soils

Wall Joints

- **Construction Joints**: Vertical or horizontal joints are placed between two successive pour of concrete. To increase shear resistance at the joints, keys may used as shown in the figure below.

- **Contraction Joint**: These are vertical joints placed in the wall (from top of base slab to the top of wall) that allow the concrete to shrink without noticeable harm. The groove may be 6-8 mm wide, 12-16 mm deep, and they are placed at 8-12 m spacing.
Wall Joints

- Expansion Joint: These vertical joints are provided in large retaining walls to allow for the expansion of concrete due to temperature changes and they are usually extended from top to bottom of the wall. These joints may be filled with flexible joint fillers. Horizontal reinforcing steel bars running across the stem are continuous through all joints. However, the current thinking is that the large resistance to expansion/contraction on the back face of wall from lateral pressure + the friction resistance of the base, these joints are practically useless.

Wall Drainage

- Accumulation of rain water in the back fill results in its saturation, and thus a considerable increase in the earth pressure acting on the wall. This may eventually lead to unstable conditions. Two of the options to take care of this problem are the following:
  - Provision of weep holes w/o geo-textile on the back-face of wall
  - Perforated pipe draining system with filter

- Weep Holes: They should have a minimum diameter of 10 cm and be adequately spaced depending on the backfill material. Geo-textile material or a thin layer of some other filter may be used on the back face of wall for the full height in order to avoid the backfill material entering the weep holes and eventually clogging them.
Wall Drainage

- **Perforated Pipes**: These are provided horizontally along the back face of the wall at the bottom of stem. The filter material around the perforated pipe should satisfy the following requirements.
  - The soil to be protected should not wash into the filter:
    \[
    \frac{D_{15}(\text{Filter})}{D_{15}(\text{Backfill})} < 5
    \]
  - Excessive hydraulic pressure head is not created in the soil due to low permeability:
    \[
    \frac{D_{15}(\text{Filter})}{D_{15}(\text{Backfill})} > 4
    \]

Wall Settlements

- **Settlement of soil below the wall**
  - Immediate settlement in granular soil.
  - Consolidation settlement in cohesive soil.

- **Differential settlement**
  - Heel settlement is larger when there is substantial increase in backfill.
  - Toe settlements are produced by lateral earth pressure. To minimize toe settlements, ground may be strengthened using sand piles, rock columns, grouting, or structural piles.
  - Differential settlements along the length of wall may produce cracks in the wall. This can be watched during construction itself and preemptive action may be taken such as ensuring proper compaction of the ground.

Design of Cantilever Retaining Wall