DESIGN AND DETAILING OF RETAINING WALLS

Learning Outcomes:

• After this present you will be able to do the complete design and detailing of different types of retaining walls.
Cantilever Retaining wall

- with shear key -
Classification of Retaining walls

- Cantilever retaining wall-RCC (Inverted T and L)
- Counterfort retaining wall-RCC
- Buttress wall-RCC
Classification of Retaining walls

Gravity RW

T-Shaped RW

Counterfort RW

L-Shaped RW

Counterfort

Tile drain

Buttress RW

Backfill

Weep hole
Earth Pressure (P)

- Earth pressure is the pressure exerted by the retaining material on the retaining wall. This pressure tends to deflect the wall outward.

- **Types of earth pressure**:
  - Active earth pressure or earth pressure ($P_a$) and
  - Passive earth pressure ($P_p$).

- Active earth pressure tends to deflect the wall away from the backfill.
Factors affecting earth pressure

- Earth pressure depends on type of backfill, the height of wall and the soil conditions

Soil conditions: The different soil conditions are

- Dry leveled back fill
- Moist leveled backfill
- Submerged leveled backfill
- Leveled backfill with uniform surcharge
- Backfill with sloping surface
Analysis for dry back fills

Maximum pressure at any height, \( p = k_a \gamma h \)

Total pressure at any height from top,
\[
p_a = \frac{1}{2} [k_a \gamma h] h = \frac{1}{2} [k_a \gamma h^2]
\]

Bending moment at any height
\[
M = p_a x h / 3 = \frac{1}{6} [k_a \gamma h^3]
\]

\[
\therefore \text{ Total pressure, } P_a = \frac{1}{2} [k_a \gamma H^2]
\]

\[
\therefore \text{ Total Bending moment at bottom, } M = \frac{1}{6} [k_a \gamma H^3]
\]

H=stem height
Where, $k_a$ = Coefficient of active earth pressure

- $k_a = (1 - \sin \phi)/(1 + \sin \phi) = \tan^2 \phi$
- $k_a = 1/k_p$, coefficient of passive earth pressure
- $\phi$ = Angle of internal friction
- $\gamma$ = Unit weight or density of backfill

If $\phi = 30^\circ$, $k_a = 1/3$ and $k_p = 3$. Thus $k_a$ is 9 times $k_p$
Backfill with sloping surface

- \( p_a = k_a \gamma H \) at the bottom and is parallel to inclined surface of backfill

- \( k_a = \cos \theta \left[ \frac{\cos \theta - \sqrt{\cos^2 \theta - \cos^2 \phi}}{\cos \theta + \sqrt{\cos^2 \theta - \cos^2 \phi}} \right] \)

- Where \( \theta = \) Angle of surcharge
  - Total pressure at bottom
  \( \therefore P_a = k_a \gamma H^2 / 2 \)
Stability requirements of RW

- Following conditions must be satisfied for stability of wall
  - It should not overturn
  - It should not slide
  - i.e. Max. pressure at the toe should not exceed the safe bearing capacity of the soil under working condition
Check against overturning

Factor of safety against overturning

\[ \frac{M_R}{M_O} \geq 1.55 \ (=1.4/0.9) \]

Where,

- \( M_R \) = Stabilising moment or restoring moment
- \( M_O \) = Overturning moment
Check against Sliding

- FOS against sliding
  \[ \mu \sum W / \text{Pa} \geq 1.55 \]  
  (=1.4/0.9)

- Friction \( \mu \sum W \)

SLIDING OF WALL

Friction \( \mu \sum W \)
Design of Shear key

- In case the wall is unsafe against sliding
  
  - \( p_p = p \tan^2 (45 + \phi/2) \)
  - \( = p \, k_p \)
  - where \( p_p \) = Unit passive pressure on soil above shearing plane AB
  
- \( p \) = Earth pressure at BC

- \( R \) = Total passive resistance = \( p_p \times a \)
Design of Shear key-Contd.,

• If $\sum W =$ Total vertical force acting at the key base

  $\phi =$ shearing angle of passive resistance

• $R =$ Total passive force $= p_p \times a$

• $P_A =$ Active horizontal pressure at key base for $H+a$

  $\mu \sum W =$ Total frictional force under flat base

• For equilibrium, $R + \mu \sum W = \text{FOS} \times P_A$

• $\text{FOS} = (R + \mu \sum W) / P_A \geq 1.55$
Maximum pressure at the toe

Pressure below the Retaining Wall
• Let the resultant R due to $\sum W$ and $P_a$
• lie at a distance $x$ from the toe.
• $X = \frac{\sum M}{\sum W}$,
  $\sum M = \text{sum of all moments about toe.}$

• Eccentricity of the load = $e = (b/2-x) < b/6$

• Minimum pressure at heel= $P_{\text{min}} = \frac{\sum W}{b} \left[ 1 - \frac{6e}{b} \right]$

• For zero pressure, $e=b/6$, resultant should cut the base within the middle third.

• Maximum pressure at toe= $P_{\text{max}} = \frac{\sum W}{b} \left[ 1 + \frac{6e}{b} \right] < \text{SBC of soil.}$
Depth of foundation

- Rankine’s formula:
  \[ D_f = \frac{SBC}{\gamma} \left[ \frac{1 - \sin \phi}{1 + \sin \phi} \right]^2 \]
  \[ = \frac{\gamma}{k_a} SBC \]

- Diagram showing the depth of the foundation.
Preliminary Proportioning (T shaped wall)

- Stem: Top width 200 mm to 400 mm
- Base slab width $b = 0.4H$ to $0.6H$, $0.6H$ to $0.75H$ for surcharged wall
- Base slab thickness = $H/10$ to $H/14$
- Toe projection = $(1/3-1/4)b$ Base width
Behaviour or structural action

- Behaviour or structural action and design of stem, heel and toe slabs are same as that of any cantilever slab.

DEFORMATION UNDER LOADING
Dist. from top

Every alternate bar cut

Provided

Cross section

Curtailment curve
Design of Heel and Toe

1. Heel slab and toe slab should also be designed as cantilever and determine the maximum bending moments at the junction.

2. Determine the reinforcement.

3. Also check for shear at the junction.

4. Provide enough development length.
Design of stem

- $A_s(\text{min}) = 14/f_y \cdot b_d$
- $1.34A_s = \text{Development length (Stem steel)}$

\[ u = \frac{V}{\sum \sigma j d} \]

\[ l_d = \frac{d_b f_s}{4u_n} \]
• Check for shear
Forces acting on the wall and the pressure below the wall

Pressure below the Retaining Wall
Design of heel

![Diagram of heel design with force calculations](image)

- 120.6 T/m²
- 30.16 T/m²
Design of toe slab—Contd.,

- Check for shear: at $d$ from junction (at xx as wall is in compression)
Other details

- Construction joint
- Drainage
เหล็กเสริมป้องกันการแตกร้าว

- เพื่อป้องกันการแตกร้าวเนื่องจากการหดตัว (shrinkages) และการเปลี่ยนแปลงของอุณหภูมิ (Temperature) ที่ผิวของคอนกรีต ACI กำหนดให้เสริมเหล็ก ขึ้นต่ำดังนี้

- เหล็กข้ออ้อย $f_y = 3,000$ กก./ชม.$^2$ เท่ากับ 0.0020bt
- เหล็กข้ออ้อย $f_y = 4,000$ กก./ชม.$^2$ เท่ากับ 0.0018bt
- เหล็กข้ออ้อยที่มีกำลังมากกว่า $4,282.50$ กก./ชม.$^2$ ต้องไม่น้อยกว่า $7.71bt/f_y$ และ 0.0014bt
Design and Detailing of Counterfort Retaining wall
Counterfort Retaining wall

- When \( H \) exceeds about 6m,
- Stem and heel thickness is more
- More bending and more steel
- Cantilever-T type-Uneconomical
- Counterforts-Trapezoidal section
- 1.5m -3m c/c
Parts of CRW

- Same as that of Cantilever Retaining wall
  Plus Counterfort

![Diagram of CRW](attachment:crw_diagram.png)
Design of Stem

- The stem acts as a continuous slab.
- Soil pressure acts as the load on the slab.
- Earth pressure varies linearly over the height.
- The slab deflects away from the earth face between the counterforts.
- The bending moment in the stem is maximum at the base and reduces towards top.

\[ p = K_a \gamma h \]
Maximum Bending moments for stem

- Maximum + B.M = p\(l^2/16\)
- (occurring mid-way between counterforts)
- and
- Maximum - B.M = p\(l^2/12\)
- (occurring at inner face of counterforts)

Where ‘\(l\)’ is the clear distance between the counterforts
- and ‘\(p\)’ is the intensity of soil pressure
Design of Toe Slab

- The base width = \( b = 0.6 \text{ H} \) to \( 0.7 \text{ H} \)
- The projection = \( 1/3 \) to \( 1/4 \) of base width.
- The toe slab is subjected to an upward soil reaction and is designed as a cantilever slab fixed at the front face of the stem.
- Reinforcement is provided on earth face along the length of the toe slab.
- In case the toe slab projection is large i.e. \( > \frac{b}{3} \), front counterforts are provided above the toe slab and the slab is designed as a continuous horizontal slab spanning between the front counterforts.
Design of Heel Slab

- The heel slab is designed as a continuous slab spanning over the counterforts and is subjected to downward forces due to weight of soil plus self weight of slab and an upward force due to soil reaction.

- Maximum +ve B.M = $pl^2/16$
- (mid-way between counterforts)
- And
- Maximum -ve B.M = $pl^2/12$
- (occurring at counterforts)
Design of Counterforts

- The counterforts are subjected to outward reaction from the stem.
- This produces tension along the outer sloping face of the counterforts.
- The inner face supporting the stem is in compression. Thus counterforts are designed as a T-beam of varying depth.
- The main steel provided along the sloping face shall be anchored properly at both ends.
- The depth of the counterfort is measured perpendicular to the sloping side.
Important points

- Loads on Wall
- Deflected shape
- Nature of BMs
- Position of steel
- Counterfort details
a. Proportioning of Wall Components

- Coefficient of active pressure = $k_a = \frac{1}{3}$
- Coefficient of passive pressure = $k_p = 3$
- The height of the wall above the base
  
  $= H = 7 + 1.25 = 8.25$ m.
- Base width = 0.6 $H$ to 0.7 $H$
- (4.95 m to 5.78 m), Say $b = 5.5$ m
- Toe projection = $b/4 = 5.5/4 = \text{say 1.2}$ m
- Assume thickness of vertical wall = 250 mm
- Thickness of base slab = 450 mm
Spacing of counterforts

\[ l = 3.5 \left( \frac{H}{\gamma} \right)^{0.25} = 3.5 \left( \frac{8.25}{18} \right)^{0.25} = 2.88 \text{ m} \]

\[ \therefore \text{ c/c spacing} = 2.88 + 0.40 = 3.28 \text{ m} \]

\[ \therefore \text{ Provide counterforts at 3 m c/c.} \]

Assume width of counterfort = 400 mm

\[ \therefore \text{ clear spacing provided} = l = 3 - 0.4 = 2.6 \text{ m} \]
Details of wall

- CF: 3m c/c, 400 mm
- $h = 7.8$ m
- $h^1 = 7$ m
- $H = 8.25$ m
- $d$
- $\theta$
- $b = 5.5$ m
- $T$
- $1.25$ m
- $1.2$ m
- $4.05$ m
### b. Check Stability of Wall

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Description of loads</th>
<th>Loads in kN</th>
<th>Dist. of e.g. from T in m</th>
<th>Moment about T in kN-m</th>
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<tbody>
<tr>
<td>1</td>
<td>Weight of stem $W_1$</td>
<td>25x0.25x1x7.8 = 48.75</td>
<td>1.2 + 0.25/2 =1.325</td>
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<td>2</td>
<td>Weight of base slab $W_2$</td>
<td>25x5.5x1x0.45 = 61.88</td>
<td>5.5/2 =2.75</td>
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<td>3</td>
<td>Weight of earth over heel slab $W_3$</td>
<td>18x4.05x1x7.8 = 568.62</td>
<td>1.45 +4.05/2 = 3.475</td>
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<td></td>
<td>Total</td>
<td>$\Sigma W = 679.25$</td>
<td></td>
<td>$\Sigma W = 2210.71$</td>
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</table>
Pressure distribution

Cross section of wall - Stability analysis
Stability of walls

- Horizontal earth pressure on full height of wall
  \[ P_h = k_a \gamma H^2 / 2 \]
  \[ P_h = 18 \times 8.25^2 / (3 \times 2) = 204.19 \text{ kN} \]

- Overturning moment
  \[ M_0 = P_h \times H/3 \]
  \[ M_0 = 204.19 \times 8.25 / 3 = 561.52 \text{ kN.m.} \]

- Factor of safety against overturning
  \[ \sum M / M_0 = 2210.71 / 561.52 = 3.94 > 1.55 \]
  \[ \therefore \text{ safe.} \]
Check for sliding

Total horizontal force tending to slide the wall

\[ P_h = 204.19 \text{ kN} \]

Resisting force \( = \sum \mu.W = 0.58 \times 679.25 \)

\[ = 393.97 \text{ kN} \]

\[ \therefore \text{Factor of safety against sliding} \]

\[ = \frac{\sum \mu.W}{P_h} = \frac{393.97}{204.19} \]

\[ = 1.93 > 1.55 \quad \therefore \text{safe.} \]
Check for pressure distribution at base

Let $x$ be the distance of R from toe (T),

$\therefore x = \frac{\sum M}{\sum W}$

Eccentricity $e = \frac{b}{2} - x < \frac{b}{6}$

$\therefore$ Whole base is under compression.

Maximum pressure at toe

$= p_A = \frac{\sum W}{b \left(1 + \frac{6e}{b}\right)} = $

Minimum pressure at heel
Intensity of pressure at junction of stem with toe  
i.e. under B

Intensity of pressure at junction of stem with heel  
i.e. under C
b) Design of Toe slab

- Max. $BM_B = \text{psf} \times (\text{moment due to soil pressure} - \text{moment due to wt. of slab TB})$
Check for Shear

- Critical section for shear: At distance $d$ (= 390 mm) from the face of the toe
(c) Design of Heel Slab

Forces on heel slab

- 166.61 kN/m²
- 153.9 kN/m²
- 147.8 kN/m²
- 143.9 kN/m²
- 80.39 kN/m²
- 5500 mm

- 7.75 kN/m
- 71.26 kN/m
Shear analysis and Zone of shear steel
(d) Design of Stem (Vertical Slab).

- Continuous slab spanning between the counterforts and subjected to earth pressure.
- The intensity of earth pressure
  \[ p_h = k_a \gamma h \]
- Area of steel on earth side near counterforts:
- Maximum -ve ultimate moment,
  \[ M_u = p_h l^2/12 \]
- Required d
(e) Design of Counterfort

At any section at any depth \( h \) below the top, the total horizontal earth pressure acting on the counterfort

\[ = \frac{1}{2} k_a y h^2 \]

\( c/c \) distance between counterfort

Counterfort acts as a T-beam.

Even assuming rectangular section,
The effective depth is taken at right angle to the reinforcement.

\[ h = 7.8 \text{ m} \]
\[ d = 4.05 \text{ m} \]
Design of Horizontal Ties

- The direct pull by the wall on counterfort for 1 m height at base
  - \( = k_\gamma h \times \text{c/c distance} = \frac{1}{3} \times 18 \times 7.8 \times 3 = 140.4 \text{ kN} \)
- Area of steel required to resist the direct pull
  - \( = 140.4 \times 10^3/(0.5fy) = 583 \text{ mm}^2 \) per m height.
- Using 8 mm 2-legged stirrups, \( A_{st} = 100 \text{ mm}^2 \)
- spacing \( = 1000 \times 100/583 = 170 \text{ mm c/c}. \)
- Since the horizontal pressure decreases with \( h \), the spacing of stirrups can be increased
Design of Vertical Ties

- The maximum pull will be exerted at the end of heel slab where the net downward force = 71.26 kN/m.

- Total downward force at D
  - = 71.26 x c/c distance.
  - Required $A_{st} = 1.5 \times 213.78 \times 10^3/(0.87 \times 415) = 888 \text{ mm}^2$
  - Using 8 mm 2-legged stirrups, $A_{st} = 100 \text{ mm}^2$
  - spacing = $1000 \times 100/888 = 110 \text{ mm c/c}$.

- Increase the spacing of vertical stirrups towards the end C
Cross section between counterforts
Cross section through counterforts
Section through stem at the junction of Base slab.
Lateral pressure against retaining wall due to surcharge loads
x1 = 4.00 m
x2 = 12.00 m
Qstr = 20.00 kN/m²

\[ \sigma_R = 43.31 \text{ kN/m} \]

\[ Z_R = -8.05 \text{ m} \]
TRIANGULAR LOADS

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x = 3.00 m

c = 4.00 m

b = 10.00 m

Qtri = 20.00 kN/m²

σR = 74.15 kN/m

ZR = -8.48 m
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$Q_{unif} = 20.00$ kN/m²

$\sigma_R = 186.00$ kN/m

$z_R = 12.50$ m
**RAMP LOADS**

\[
\sigma_H = \frac{q}{k} e^{\beta + x + 2z \ln \frac{R_2}{R_1}}
\]

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**x =** 2.00 m  
**c =** 5.00 m  
**Q_{ramp} =** 20.00 kN/m²  

\[
\sigma_f = 246.37 \text{ kN/m}  
\]

\[
Z_R = -12.92 \text{ m}
\]
ข้อบคุณครับ