Design Example of Cantilever Retaining Wall without and with Relief Shelf

A design example is given here to understand the procedure used in the analysis of retaining wall in this study. Analysis and design has been carried out by considering the stated properties of cohesionless backfill and also height of backfill to be retained for cantilever retaining wall and cantilever retaining wall with relief shelf at center of height of retaining wall. The tentative dimensions for cantilever retaining wall and the values of properties of soil are adopted based on prevailing thumb-rules. The detail calculations for cantilever retaining wall and cantilever retaining wall with relief shelf at center of height of retaining wall are given and the calculated results have been presented.

1. Cantilever Retaining Wall without Relief Shelf

Following data is assumed.

- Height of backfill to be supported (H) = 6 m
- Unit weight of soil (γ) = 19000 N/m³
- Angle of internal friction (φ) = 30°
- Cohesion (c) = 0
- Allowable Bearing Capacity of soil (q₀) = 200 kN/m²
- Angle of wall friction with backfill (δₜₜₜ) = 22°
- Angle of wall friction with base soil (δₜₜₜ) = 25°
- Unit weight of reinforced cement concrete = 25000 N/m³
- M₂₀ grade concrete (safe stress in concrete) = 7 N/mm²
- Fe 415 steel (safe stress in steel) = 230 N/mm²
- Design Constants Modular ratio (m) = 13,
  J = 0.9,
$Q = 0.91$

Width of base slab $(B) = 3.60 \, m$ (0.4 $H$ to 0.7 $H$)

Thickness of stem at top of retaining wall $(T_0) = 0.40 \, m$

(200 mm minimum, preferably 300 mm)

Thickness of stem at intersection of stem and base slab $(T_s) = 0.8 \, m$ ($H/12$ to $H/8$)

Thickness of base slab $(T_b) = 0.8 \, m$ ($H/12$ to $H/10$)

Height of stem $(h) = H - t_b = 6.00 - 0.80 = 5.2 \, m$

Projection of base slab towards toe (0.20 $B$ to 0.40 $B$) = 0.60 $m$

$K_a = \text{Coefficient of Active Earth Pressure}$

$$K_a = \frac{1 - \sin \varphi}{1 + \sin \varphi} = \frac{1 - \sin 30}{1 + \sin 30} = 0.33$$

Centroid $z = \frac{\sum M_1 - \sum M_2}{\sum V} = \frac{(757916 - 225720)}{367360} = 1.448 \, m$

Eccentricity $e = \frac{B}{2} - z = \frac{3.60}{2} - 1.478 = 0.322 \, m < \frac{B}{6} (0.6 \, m)$

From the Table 3.3 Summation of vertical forces $\Sigma V = 367360$

Pressure intensity at Toe $P_{max} = \frac{\Sigma V}{B} \times \left( 1 + \left( \frac{6e}{B} \right) \right) = \left( \frac{367360}{3.60} \right) \times \left( 1 + \frac{6 \times 0.322}{3.60} \right)$

$$= 156808.3 \, N/m^2$$

Pressure intensity at Heel $P_{min} = \frac{\Sigma V}{B} \times \left( 1 - \left( \frac{6e}{B} \right) \right) = \left( \frac{367360}{3.60} \right) \times \left( 1 - \frac{6 \times 0.263}{3.60} \right)$

$$= 47280.6 \, N/m^2$$

Factor of Safety against sliding $= \mu \frac{\Sigma V}{\Sigma H} = \tan 25 \times \frac{367360}{112860} = 0.47 \times \frac{367360}{112860}$

$$= 1.53 > 1.5$$

Factor of Safety against Overturning $= \frac{\text{Resisting Moment}}{\text{Overturning Moment}}$
\[
\frac{\Sigma M_1}{\Sigma M_2} = \frac{757916}{225720} = 3.35 > 1.5
\]

**FIGURE A-1. PROPORTIONING AND PRESSURE INTENSITY BELOW THE BASE OF RETAINING WALL WITHOUT RELIEF SHELF**

\[P_a = 112860 \text{ N/m}^2\]

\[K_a\gamma H = 37620 \text{ N/m}^2\]

Active Pressure Diagram
Table A-3.1
(Stability Calculations for one meter Length of Cantilever Retaining Wall without Relief Shelf)

<table>
<thead>
<tr>
<th>Load due to</th>
<th>Load (N/m)</th>
<th>Distance from Toe (m)</th>
<th>Moment @ Toe (N-m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular part of stem of retaining wall 0.40 × 5.2 × 25000</td>
<td>52000</td>
<td>1.20</td>
<td>62400</td>
</tr>
<tr>
<td>Triangular part of stem of retaining wall 0.40/2 × 5.2 × 25000</td>
<td>26000</td>
<td>0.866</td>
<td>22516</td>
</tr>
<tr>
<td>Base slab of retaining wall 3.6 × 0.8 × 25000</td>
<td>72000</td>
<td>1.8</td>
<td>129600</td>
</tr>
<tr>
<td>Backfill above heel of base slab 2.2 × 5.2 × 19000</td>
<td>217360</td>
<td>2.5</td>
<td>543400</td>
</tr>
</tbody>
</table>
| Active Earth Pressure  \( P_a = \frac{1}{2} K_a \times \gamma \times h^2 \)  
\( = \frac{1}{2} \times 0.33 \times 19000 \times (6)^2 \) | 112860     | 2.0                   | 225720               |

**Design of stem**

Bending Moment = Moment of Resistance

\[ 22572000 \text{ N-cm} = 90 \times b \times d^2 \]

\[ d = \text{Effective depth} = \left( \frac{22572000}{90 \times 100} \right)^{1/2} = 50.00 \text{ cm} \]

Provide \( d = 50 \text{ cm} = 500 \text{ mm} \)

\[ M_{\text{u,lim}} = 0.36 \times f_{\text{ck}} \times x_{\text{umax}} / d \times (1 - 0.416 x_{\text{umax}} / d) \times b \times d^2 \]

\[ = 0.138 \times f_{\text{ck}} \times b \times d^2 \]

\[ = 0.138 \times 20 \times 1000 \times 500 \times 500 = 6.9 \times 10^8 \text{ N-mm} \]

Bending Moment < \( M_{\text{u,lim}} \)

\[ A_{\text{sl}} = 0.5 \times f_{\text{ck}} / f_y \left( 1 - \left( \frac{1}{(4.6 \times B.M.) / f_{\text{ck}} \times b \times d^2} \right)^{1/2} \right) \times b \times d \]
= \{(0.5 \times 20) / 415\} \times (1 - (1 - (4.6 \times 2.25 \times 10^8) / (20 \times 1000 \times 500 \times 500))^{1/2}) \times 1000 \times 500 = 1319.21 \text{ mm}^2

Spacing of Reinforcement = \(\frac{C/\text{sectional area of one bar} \times 1000}{\text{Area of steel} (A_{si})}\)

= \(\frac{201.1 \times 1000}{1319.21} = 152.44 \text{ mm}\)

Provide 16 mm diameter reinforcement @ 153 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

= \((0.12 / 1000) \times \{(400 + 800) / 2\} \times 1000 = 720 \text{ mm}^2\)

Spacing of Reinforcement = \(\frac{C/\text{sectional area of one bar} \times 1000}{\text{Area of steel} (A_{si})}\)

= \(\frac{78.5 \times 1000}{720.0} = 109.02 \text{ mm}\)

Provide 10 mm diameter reinforcement @ 109 mm center to center.

**Design of Toe slab**

<table>
<thead>
<tr>
<th>Load due to</th>
<th>Load (N/m)</th>
<th>Dist. From B (m)</th>
<th>Moment about B (N\cdot m/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle (A'B'GH') 91273 x 0.6</td>
<td>84764</td>
<td>0.30</td>
<td>25429</td>
</tr>
<tr>
<td>Triangle (GHH') (15680.83 - 91273)x 0.6 / 2</td>
<td>19661</td>
<td>0.40</td>
<td>78653 / 33294</td>
</tr>
<tr>
<td>Deduct Self weight 0.6 x 0.8 x 25000</td>
<td>12000</td>
<td>0.30</td>
<td>3600 / 29694</td>
</tr>
</tbody>
</table>

**Table A-3.2**

(Stability Calculations of Toe Slab)

Bending Moment = Moment of Resistance

\[ 2969400 = 90 \times b \times d^2 \]

\[ d = \text{Effective depth} = \left( \frac{2969400}{(90 \times 100)} \right)^{1/2} = 18.17 \text{ cm} \]

Provide \(d = 19 \text{ cm} = 190 \text{ mm}\)

\[ M_{u \lim} = 0.36 \times f_{ck} \times x_{u max} / d (1 - 0.416 \times x_{u max} / d) \times b \times d^2 \]
Bending Moment < $M_{u,m}$

$$A_{st} = 0.5 \frac{f_{ck}}{f_y} (1 - \{(1 - (4.6 \times B.M.)/f_{ck} \times d^2)^{1/2} \times b \times d \}
= \{(0.5 \times 20) / 415 \} \times [1 - \{(1 - (4.6 \times 0.29 \times 10^8) / (20 \times 1000 \times 190 \times 190)}^{1/2} \]
1000 \times 190 = 455.76 \text{ mm}^2$$

Spacing of Reinforcement = (C/sectional area of one bar x 1000) / Area of steel ($A_{st}$)

$$= (78.5 \times 1000) / 455.76 = 172.16 \text{ mm}$$

Provide 10 mm diameter reinforcement @ 172 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

$$= (0.12 / 100) \times 800 \times 1000 = 960 \text{ mm}^2$$

Spacing of Reinforcement = (C/sectional area of one bar x 1000) / Area of steel ($A_{st}$)

$$= (78.5 \times 1000) / 960.0 = 81.78 \text{ mm}$$

Provide 10 mm diameter reinforcement @ 81 mm center to center.

**Design of Heel slab**

<table>
<thead>
<tr>
<th>Load due to'</th>
<th>Load (N)</th>
<th>Dist. From B (m)</th>
<th>Moment about B (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill</td>
<td>217360</td>
<td>1.1</td>
<td>239096</td>
</tr>
<tr>
<td>2.2 x 5.2 x 19000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self weight</td>
<td>44000</td>
<td>1.1</td>
<td>48400</td>
</tr>
<tr>
<td>0.8 x 2.2 x 25000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deduct for soil pressure Rectangle (C'D'EF')</td>
<td>104017</td>
<td>1.1</td>
<td>114419</td>
</tr>
<tr>
<td>47280.6 x 2.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Triangle (EFF')</td>
<td>21618</td>
<td>0.733</td>
<td>15846</td>
</tr>
<tr>
<td>(66933.6 - 47280.6) x 1.1</td>
<td></td>
<td></td>
<td>157231</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bending Moment = Moment of Resistance
\[15723100 = 90 \times b \times d^2\]

\[d = \text{Effective depth} = \sqrt{\frac{15723100}{90 \times 100}} = 41.79 \, \text{cm}\]

Provide \( d = 42 \, \text{cm} = 420 \, \text{mm} \)

\[M_{\text{ult}} = 0.36 \times f_{ck} \times u_{\text{max}}/d \left(1 - 0.416 \times u_{\text{max}}/d\right) b . d^2 = 0.138 \times f_{ck} \ b . \ d^2\]

\[= 0.138 \times 20 \times 1000 \times 420 \times 420 = 4.8686 \times 10^8 \, \text{N-mm}\]

Bending Moment < \(M_{\text{ult}}\)

\[A_{st} = 0.5 \frac{f_{ck}}{f_y} \left(1 - \left(1 - (4.6 \times B.M.) / f_{ck} . b.d^2\right)^{1/2} \times b \times d\right)\]

\[= \{(0.5 \times 20) / 415\} \times \left[1 - \left(1 - (4.6 \times 1.57 \times 10^8) / (20 \times 1000 \times 420 \times 420)\right)^{1/2}\right] \times 1000 \times 420 = 1096.81 \, \text{mm}^2\]

\[= 0.5 \times 20 / 415 \left(1 - (1 - (4.6 \times 0.92564 \times 10^8) / 20 \times 1000 \times 330 \times 330)^{1/2}\right) \times 1000 \times 330 = 819.03 \, \text{mm}^2\]

Spacing of Reinforcement = \((C/\text{sectional area of one bar} \times 1000) / \text{Area of steel} (A_{st})\)

\[= (113.1 \times 1000) / 1096.81 = 103.11 \, \text{mm}\]

Provide 12 mm diameter reinforcement @ 103 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

\[= \left(0.12 / 100\right) \times 800 \times 1000 = 960 \, \text{mm}^2\]

Spacing of Reinforcement = \((C/\text{sectional area of one bar} \times 1000) / \text{Area of steel} (A_{st})\)

\[= (78.5 \times 1000) / 960.0 = 81.78 \, \text{mm}\]

Provide 10 mm diameter reinforcement @ 81 mm center to center.
2. Cantilever Retaining Wall with Relief Shelf at mid height of Retaining Wall

Height of backfill to be supported (H) = 6 m

Unit weight of soil (γ) = 19000 N / m³

Angle of internal friction (φ) = 30°

cohesion (c) = 0

Allowable Bearing Capacity of soil (q₁) = 200 kN / m²

Angle of wall friction with backfill (δₜ₉₉) = 22°

Angle of wall friction with base soil (δₜ₉₉) = 25°

Unit weight of reinforced cement concrete = 25000 N/m³

Width of base slab (B) = 2.50 m (0.4 H to 0.7 H)

Thickness of stem at top of retaining wall (t₀) = 0.30 m

(200 mm minimum, preferably 300 mm)

Thickness of stem at intersection of stem and base slab (tₛₙ) = 0.6 m (H/12 to H/8)

Thickness of base slab (Tₙ) = 0.5 m (H/12 to H/10)

Height of stem (h = H - Tₙ) = 6.00 - 0.50 = 5.5 m

Projection of base slab towards toe (Lₜ) = 0.50 m (0.20 B to 0.40 B)

Relief Shelf projection towards backfill (b) = 1.4 / 2 = 0.70 m

Thickness of relief shelf = Base slab thickness / 2 = 0.50 / 2 = 0.25 m

Centroid \( z = \frac{\sum M1 - \sum M2}{\sum V} = \frac{380361 - 137564}{253775} = 0.956 \text{ m} \)

Eccentricity \( e = \frac{B}{2} - z = \frac{2.5}{2} - 0.956 = 0.294 \text{ m} < \frac{B}{6} (0.6 \text{ m}) \)

From the Table 3.4 Summation of vertical forces \( \sum V = 253775 \)
Pressure intensity at Toe $P_{\text{max}} = \frac{\Sigma V}{B} \times \left( 1 + \left( \frac{6e}{B} \right) \right) = \left( \frac{253775}{2.5} \right) \times \left( 1 + \frac{6 \times 0.294}{2.5} \right) = 173135 \text{ N/m}^2$

Pressure intensity at Heel $P_{\text{min}} = \frac{\Sigma V}{B} \times \left( 1 - \left( \frac{6e}{B} \right) \right) = \left( \frac{253775}{2.5} \right) \times \left( 1 - \frac{6 \times 0.294}{2.5} \right) = 29884 \text{ N/m}^2$

Factor of Safety against sliding = $\mu \frac{\Sigma V}{\Sigma H} \tan 25 \times \frac{253775}{56228} = 0.47 \times \frac{253775}{56228} = 2.12 > 1.5$

Factor of Safety against Overturning = $\frac{\text{Resisting Moment}}{\text{Overturning Moment}} = \frac{\Sigma M_1}{\Sigma M_2} = \frac{380361}{137564} = 2.76 > 1.5$
FIGURE A-2. CANTILEVER RETAINING WALL WITH RELIEF SHELF
(PROPORTIONING AND PRESSURE INTENSITY BELOW THE BASE OF RETAINING WALL)
### Table A-3.4
(Stability Calculations for one meter Length of Cantilever Retaining Wall with Relief Shelf)

<table>
<thead>
<tr>
<th>Load due to</th>
<th>Load (N)</th>
<th>Distance from A (m)</th>
<th>Moment @ A (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular part of stem of retaining wall $0.30 \times 5.5 \times 25000$</td>
<td>41250</td>
<td>0.95</td>
<td>39188</td>
</tr>
<tr>
<td>Triangular part of stem of retaining wall $0.30 / 2 \times 5.5 \times 25000$</td>
<td>20625</td>
<td>0.70</td>
<td>14438</td>
</tr>
<tr>
<td>Base slab of retaining wall $2.5 \times 0.5 \times 25000$</td>
<td>31250</td>
<td>1.25</td>
<td>39063</td>
</tr>
<tr>
<td>Relief Shelf $0.70 \times 0.25 \times 25000$</td>
<td>4375</td>
<td>1.45</td>
<td>6344</td>
</tr>
<tr>
<td>Backfill above heel of base slab $((1.4 \times 6) - (0.70 \times 0.25)) \times 19000$</td>
<td>$156275$</td>
<td>1.8</td>
<td>$281295$</td>
</tr>
<tr>
<td>Active Earth Pressure above Relief Shelf $=P_{ai} = \frac{1}{2} K_a \times \gamma \times h_1^2$</td>
<td>25913</td>
<td>4.08</td>
<td>105725</td>
</tr>
<tr>
<td>Active Earth Pressure below Relief Shelf $=P_{ai2} = \frac{1}{2} K_a \times \gamma \times h_2^2$</td>
<td>$30615$</td>
<td>1.04</td>
<td>$31839$</td>
</tr>
</tbody>
</table>

**Design of stem -**

**Bending Moment = Moment of Resistance**

$13756400 \text{ N-cm} = 90 \times b \times d^2$

$d = \text{Effective depth} = \sqrt[1/2]{13756400 / (90 \times 100)} = 39.09 \text{ cm}$

Provide $d = 40 \text{ cm} = 400 \text{ mm}$

$M_{ullim} = 0.36 \times f_{ck} \times \gamma_{max} / d \times (1 - 0.416 \times \gamma_{max} / d) \times b \times d^2 = 0.138 \times f_{ck} \times b \times d^2$
Bending Moment < $M_{u\text{lim}}$

\[
A_{st} = 0.5 \frac{f_c}{f_y} (1 - \left( 1 - (4.6 \times B.M.) / f_c b.d^2 \right)^{1/2} \times b \times d \\
= \left( (0.5 \times 20) / 415 \right) \times \left[ 1 - \left( 1 - (4.6 \times 1.37 \times 10^8) / (20 \times 1000 \times 400 \times 400) \right)^{1/2} \right] \times 1000 \times 400 = 1005.44 \text{ mm}^2
\]

Spacing of Reinforcement = \( (C / \text{sectional area of one bar} \times 1000) / \text{Area of steel} (A_{st}) \)

\[= (113.1 \times 1000) / 1005.44 = 112.48 \text{ mm} \]

Provide 12 mm diameter reinforcement @ 112 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

\[= (0.12 / 100) \times (300 + 600) / 2 \times 1000 = 540 \text{ mm}^2 \]

Spacing of Reinforcement = \( (C / \text{sectional area of one bar} \times 1000) / \text{Area of steel} (A_{st}) \)

\[= (78.5 \times 1000) / 540.0 = 145.37 \text{ mm} \]

Provide 10 mm diameter reinforcement @ 145 mm center to center.

Design of Toe slab

### Table A-3.5

(Stability Calculations of Toe Slab)

<table>
<thead>
<tr>
<th>Load due to</th>
<th>Load (N)</th>
<th>Dist. From B (m)</th>
<th>Moment about B (N·m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle A'B'GH'</td>
<td>144485 × 0.5</td>
<td>72243</td>
<td>0.25</td>
</tr>
<tr>
<td>Triangle (173135 - 144485) × 0.5 / 2</td>
<td>7163</td>
<td>0.333</td>
<td>2385</td>
</tr>
</tbody>
</table>
| Deduct self weight   | 0.5 × 0.5 × 25000 | 6250    | 0.25 | \[
\begin{array}{c}
\text{1563} \\
\text{18883}
\end{array}\
\]
Bending Moment = Moment of Resistance

\[ 1888300 \text{ N-cm} = 90 \times b \times d^2 \]

\[ d = \text{Effective depth} = \left( \frac{1888300}{(90 \times 100)} \right)^{1/2} = 14.48 \text{ cm} \]

Provide \( d = 15 \text{ cm} = 150 \text{ mm} \)

\[ M_{ulim} = 0.36 \times f_{ck} \times x_{umax}/d \left( 1 - 0.416 \times \frac{x_{umax}}{d} \right) b \cdot d^2 = 0.138 \times f_{ck} \times b \times d^2 \]

\[ = 0.138 \times 20 \times 1000 \times 150 \times 150 = 0.621 \times 10^8 \text{ N-mm} \]

Bending Moment < \( M_{ulim} \)

\[ A_{st} = 0.5 \frac{f_{ck}}{f_y} \left( 1 - \left( \frac{1 - (4.6 \times \text{B.M.})}{f_{ck} \times b \cdot d^2} \right)^{1/2} \times b \times d \right) \]

\[ = \left( \frac{0.5 \times 20}{415} \right) \left( 1 - \left( \frac{1 - (4.6 \times 0.189 \times 10^8)}{(20 \times 1000 \times 150 \times 150)} \right)^{1/2} \right) \times 1000 \times 150 = 367.52 \text{ mm}^2 \]

Spacing of Reinforcement = \( (C/\text{sectional area of one bar } \times 1000) / \text{Area of steel} (A_{st}) \)

\[ = \left( \frac{78.5 \times 1000}{367.52} \right) = 213.59 \text{ mm} \]

Provide 10 mm diameter reinforcement @ 213 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

\[ = \left( \frac{0.12}{100} \right) \times 500 \times 1000 = 600 \text{ mm}^2 \]

Spacing of Reinforcement = \( (C/\text{sectional area of one bar } \times 1000) / \text{Area of steel} (A_{st}) \)

\[ = \left( \frac{78.5 \times 1000}{600.0} \right) = 130.83 \text{ mm} \]

Provide 10 mm diameter reinforcement @ 130 mm center to center.
Design of Heel slab

<table>
<thead>
<tr>
<th>Load due to</th>
<th>Load (N)</th>
<th>Dist. From B (m)</th>
<th>Moment about B (N-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Backfill between Relief Shelf and Heel Slab 1.4 x 2.625 x 19000</td>
<td>69825</td>
<td>0.7</td>
<td>48878</td>
</tr>
<tr>
<td>Backfill above Relief Shelf 0.7 x 2.875 x 19000</td>
<td>38237</td>
<td>1.05</td>
<td>40149</td>
</tr>
<tr>
<td>Self weight 0.5 x 1.4 x 25000</td>
<td>17500</td>
<td>0.7</td>
<td>12250</td>
</tr>
<tr>
<td>Deduct for soil pressure Rectangle (C'D'EF') 29884 x 1.4</td>
<td>41838</td>
<td>0.7</td>
<td>29286</td>
</tr>
<tr>
<td>Triangle (110104 - 29884) x 1.4 / 2</td>
<td>56154</td>
<td>0.466</td>
<td>26167</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45824</td>
</tr>
</tbody>
</table>

Bending Moment = Moment of Resistance

4582400 N-cm = 90 × b × d²

d = Effective depth = \((4582400 / (90 \times 100))^{1/2}\) = 22.56 cm

Provide d = 23 cm = 230 mm

\[ M_{u_{lim}} = 0.36 \times f_{ck} \times x_{\text{umax}} / d \left( 1 - 0.416 \times \frac{x_{\text{umax}}}{d} \right) \times b \times d = 0.138 \times f_{ck} \times b \times b \times d \]

\[ = 0.138 \times 20 \times 1000 \times 230 \times 230 = 1.46 \times 10^8 \text{ N-mm} \]

Bending Moment < \(M_{u_{lim}}\)

\[ A_{at} = 0.5 \times f_{ck} / f_y \left( 1 - \left( 1 - (4.6 \times 10^8) / (20 \times 1000 \times 230 \times 230) \right)^{1/2} \right) \times b \times d \]

\[ = \left( 0.5 \times 20 \right) / 415 \times \left[ 1 - \left( 1 - (4.6 \times 0.459 \times 10^8) / (20 \times 1000 \times 230 \times 230) \right)^{1/2} \right] \times 1000 \times 230 = 582.73 \text{ mm}^2 \]
Spacing of Reinforcement = \( \frac{C}{\text{sectional area of one bar} \times 1000} / \text{Area of steel (} A_{st} \text{)} \)

\[ = \frac{78.5 \times 1000}{582.73} = 134.71 \text{ mm} \]

Provide 10 mm diameter reinforcement @ 134 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

\[ = \frac{0.12}{100} \times 500 \times 1000 = 600 \text{ mm}^2 \]

Spacing of Reinforcement = \( \frac{C}{\text{sectional area of one bar} \times 1000} / \text{Area of steel (} A_{st} \text{)} \)

\[ = \frac{78.5 \times 1000}{600.0} = 130.83 \text{ mm} \]

Provide 10 mm diameter reinforcement @ 130 mm center to center.

**Design of Relief Shelf**

<table>
<thead>
<tr>
<th>Load due to Backfill above Relief Shelf</th>
<th>Load (N)</th>
<th>Dist. From B (m)</th>
<th>Moment about B (N- m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7 x 2.65 x 19000</td>
<td>35245</td>
<td>0.35</td>
<td>12336</td>
</tr>
<tr>
<td>Self weight</td>
<td>3500</td>
<td>0.35</td>
<td>1225</td>
</tr>
</tbody>
</table>

Bending Moment = Moment of Resistance

\[ 1356100 \text{ N-cm} = 90 \times b \times d^2 \]

\[ d = \text{Effective depth} = (1356100/ 90\times100)^{1/2} = 12.27 \text{ cm} \]

Provide \( d = 13 \text{ cm} = 130 \text{ mm} \)

\[ M_{u hm} = 0.36 \times f_{ck} \times x_{umax}/d \times (1 - 0.416 \times x_{umax}/d) \times b \times d^2 = 0.138 \times f_{ck} \times b \times d^2 \]

\[ = 0.138 \times 20 \times 1000 \times 130 \times 130 = 0.467 \times 10^8 \text{ N-mm} \]

225
Bending Moment < $M_{ulm}$

$$A_{st} = 0.5 \frac{f_{ck}}{f_y} (1 - \{(1 - (4.6 \times B.M) / f_{ck} b.d^2\}^{1/2} \times b \times d$$

$$= \{(0.5 \times 20) / 415\}. \left[1 - \{(1 - (4.6 \times 0.135 \times 10^8) / (20 \times 1000 \times 130 \times 130)^{1/2}\} \times 1000 \times 130 = 302.91 \text{ mm}^2\right]$$

Spacing of Reinforcement = (C/sectional area of one bar × 1000) / Area of steel ($A_{st}$)

$$= (78.5 \times 1000) / 302.91 = 259.15 \text{ mm}\right]$$

Provide 10 mm diameter reinforcement @ 259 mm center to center.

Distribution Steel = 0.12 percent of gross area of cross section

$$= (0.12 /100) \times 200 \times 1000 = 240 \text{ mm}^2\right]$$

Spacing of Reinforcement = (C/sectional area of one bar × 1000) / Area of steel ($A_{st}$)

$$= (50.3 \times 1000) / 240 = 209.58 \text{ mm}\right]$$

Provide 08 mm diameter reinforcement @ 209 mm center to center.
Table A-3.8
(Comparison of Theoretical Analysis of Cantilever Retaining Wall of 6 m height without and with Relief Shelf (0.70 x 0.20 m) at mid height of retaining wall per meter Length)

<table>
<thead>
<tr>
<th>Sr. No</th>
<th>Description</th>
<th>Cantilever Retaining Wall without Relief Shelf</th>
<th>Cantilever Retaining Wall with Relief Shelf</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Eccentricity from toe</td>
<td>0.322 m</td>
<td>0.294 m</td>
</tr>
<tr>
<td>02</td>
<td>$P_{\text{max}}$ (Pressure intensity at Toe)</td>
<td>156808.3 N/m²</td>
<td>173135 N/m²</td>
</tr>
<tr>
<td>03</td>
<td>$P_{\text{mm}}$ (Pressure intensity at Heel)</td>
<td>47280.6 N/m²</td>
<td>29884 N/m²</td>
</tr>
<tr>
<td>04</td>
<td>Active Earth Pressure</td>
<td>112860 N/m</td>
<td>56528 N/m</td>
</tr>
<tr>
<td>05</td>
<td>Factor of safety against sliding</td>
<td>1.53</td>
<td>2.121</td>
</tr>
<tr>
<td>06</td>
<td>Factor of safety against overturning</td>
<td>3.35</td>
<td>2.76</td>
</tr>
<tr>
<td></td>
<td>Volume of concrete</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Base slab</td>
<td>2.88 m³</td>
<td>1.25 m³</td>
</tr>
<tr>
<td></td>
<td>ii) Stem</td>
<td>3.12 m³</td>
<td>2.47 m³</td>
</tr>
<tr>
<td></td>
<td>iii) Relief Shelf</td>
<td>----</td>
<td>0.14 m³</td>
</tr>
<tr>
<td>07</td>
<td>Total volume of concrete required</td>
<td>6.00 m³</td>
<td>3.86 m³</td>
</tr>
<tr>
<td>08</td>
<td>Area of reinforcement</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>a) Toe of base slab</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Longitudinal steel</td>
<td>455.76 m²</td>
<td>367.52 m²</td>
</tr>
<tr>
<td></td>
<td>ii) Distribution steel</td>
<td>960 m²</td>
<td>600.00 m²</td>
</tr>
<tr>
<td></td>
<td>b) Heel of base slab</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Longitudinal steel</td>
<td>1096.81 mm²</td>
<td>582.73 mm²</td>
</tr>
<tr>
<td></td>
<td>ii) Distribution steel</td>
<td>960 mm²</td>
<td>600 mm²</td>
</tr>
<tr>
<td></td>
<td>c) Stem</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Longitudinal steel</td>
<td>1319.21 m²</td>
<td>1005.44 m²</td>
</tr>
<tr>
<td></td>
<td>ii) Distribution steel</td>
<td>720 m²</td>
<td>540 m²</td>
</tr>
<tr>
<td></td>
<td>d) Relief Shelf</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) Longitudinal steel</td>
<td>----</td>
<td>302.91 m²</td>
</tr>
<tr>
<td></td>
<td>ii) Distribution steel</td>
<td>----</td>
<td>240 m²</td>
</tr>
<tr>
<td></td>
<td>Total area of reinforcement required</td>
<td>5511.78 m²</td>
<td>4238.6 m²</td>
</tr>
</tbody>
</table>
A typical sketch showing the reinforcement of a R. C. C. cantilever retaining wall with single relief shelf is shown in figure 3.