Retaining Wall Design

Given: The below retaining wall is 120 ft. long. Redesign it for WWR. This design includes the wall and foundation. $F_y$ for reinforcing steel is 60 ksi. $F_y$ for WWR is 80 ksi. Concrete $f'_{c} = 4000$ psi.

Wall Steel

1. Convert reinforcing steel to WWR

   Reinforcing Steel – Grade 60
WWR – Grade 80

Vertical Steel –
#5 @10" o/c,  \( A_s#5 = 0.31 \text{ in.}^2 \)
\[ A_{\text{provided/foot}} = 0.31 \times 12/10 = 0.372 \]
WWR \( A_s = 0.31 \times 60000/80000 = 0.2325 \text{ in.}^2 \) @ 10" spacing, need D23.3
Keep same spacing for overlapping with footer steel.

Horizontal steel –
#4 @ 8" o/c,  \( A_s#4 = 0.20 \text{ in.}^2 \)
\[ A_{\text{provided/foot}} = 0.20 \times 12/8 = 0.30 \]
WWR \( A_s = 0.20 \times 60000/80000 = 0.0.15 \text{ in.}^2 \) @ 8" spacing, need D15.

Minimum steel requirements, ACI 318 section 14.3

14.3.2 – Vertical reinforcement minimum ratio is 0.0012
14.3.3 – Horizontal reinforcement minimum ratio is 0.0020

Minimum vertical steel = \( 0.0012 \times 12 \times 12 = 0.173 \text{ in.}^2 < 0.372 \)
Minimum horizontal steel = \( 0.0020 \times 12 \times 12 = 0.289 < 0.30 \)

2. Splicing Requirements

Vertical steel is one sheet so no splicing is required. Overlap foundation steel.

Horizontal steel is spliced.
Calculate \( l_d \)
\[
\frac{l_d}{d_b} = \frac{3}{40} \cdot \frac{f_y}{\lambda \sqrt{f'_c}} \cdot \left[ \frac{\alpha \beta \gamma}{C+K_{tr}} \right]
\]
\[ K_{tr} = \frac{A_t f_{tr}}{1500 \text{ sn}} \]
\[ K_{tr} = \frac{(0.15 \times 80000)}{(1500 \times 10 \times 1)} \]
\[ = 0.80 \]
<table>
<thead>
<tr>
<th>Variables</th>
<th>Longitudinal Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D 15 @ 8”</td>
</tr>
<tr>
<td>$d_b$</td>
<td>0.437 in</td>
</tr>
<tr>
<td>$f_y$</td>
<td>80,000 psi</td>
</tr>
<tr>
<td>$f_c$</td>
<td>4,000 psi</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>1.3</td>
</tr>
<tr>
<td>$\beta$</td>
<td>1.0</td>
</tr>
<tr>
<td>$\alpha\beta$</td>
<td>1.3</td>
</tr>
<tr>
<td>$\gamma$</td>
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</tr>
<tr>
<td>$\lambda$</td>
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</tr>
<tr>
<td>$c$</td>
<td>2.0</td>
</tr>
<tr>
<td>$K_{tr}$</td>
<td>1.24</td>
</tr>
<tr>
<td>$A_{tr}$</td>
<td>.15 in$^2$</td>
</tr>
<tr>
<td>$F_{yt}$</td>
<td>80,000 psi</td>
</tr>
<tr>
<td>$s$</td>
<td>10 in</td>
</tr>
<tr>
<td>$n$</td>
<td>1</td>
</tr>
</tbody>
</table>

Solving for $l_d$,

$$\left\lfloor \frac{c + K_{tr}}{d_b} \right\rfloor = \frac{(2+0.8)}{0.437} = 6.41$$

$$l_d = 0.437\times(3/40)\times(80000/4000)\times(1.3\times0.8) / 6.41$$

$$= 6.72$$
Wire Factor (WF),

Greater of:

\[
\frac{f_y - 35,000}{f_y} \quad \text{or} \quad \frac{5db}{s}
\]

or (80000-35000)/80000 \quad \text{or} \quad (5*.437)/10

= 0.5625 or 0.2185

WF = 0.5625

Splice length = WF* 1.3 * l_d = 0.5625 * 1.3 * 6.72”

= 4.9”, minimum is 8”

3. Sheet design

Wall length = 120’ * 12 = 1440 in.
Less cover at ends(2*3”) = 6 in.

Maximum sheet length is 45’ = 540”, therefore try 3 sheets with a splice length of 8”.

With three sheets, 2 lap splices needed so the extra length = 2*8” = 16”

Total length = 1434 + 16 = 1450”

Sheet length = 1450/3 = 483.3” – use 484” = 40’-4” (sheet length)
Wire spacing = 10”, 40’-4” = 484”
48 spaces @10” = 480” w/ 2” overhangs at each end.

Total length in sheets is(484”*3) = 1452”, extra length = 1452 -1450 = 2” for 2 splices

So splice length = 8” + (2”/2) = 9”

Wall height = 10’*12 = 120”
WWR length = 120” – 3”(cover) = 117”
Wire spacing = 8" o/c
Spaces = 117/8 = 14.6, therefore 14 spaces @ 8" = 112"

117" – 112" = 5" (overhang), Use overhangs of 2" and 3"

Sheet designation

10x8 D23.3/D15 117" (+2", +3") 40'-4" (+2", +2")

Foundation Steel

The foundation is a continuous footer with two layers of reinforcement. The top mat consists of a #5 @ 12" o/c in the 7’ direction and #4 @ 8”o/c in the longitudinal direction or the length of the wall. The bottom mat is located in the toe area and extends into the wall and overlaps the wall steel.

1. Convert to WWR

Top Steel

#5 @12" o/c, A,#5 = 0.31 in.²
WWR $A_s = 0.31 \times \frac{60000}{80000} = 0.2325 \text{ in.}^2$ @ 12” spacing, need D23.3

Longitudinal steel –
#4 @ 8” o/c, $A_s$#4 = 0.20 in.$^2$
$A_{s\text{provided/foot}} = .20 \times 12/8 = 0.30$

WWR $A_s = 0.20 \times \frac{60000}{80000} = 0.15 \text{ in.}^2$ @ 8” spacing, need D15.

Bottom Steel
#5 @10” o/c, $A_s$#5 = 0.31 in.$^2$
WWR $A_s = 0.31 \times \frac{60000}{80000} = 0.2325 \text{ in.}^2$ @ 10” spacing, need D23.3

Longitudinal steel – same as top steel, D15 @ 8” o/c

Minimum Steel Requirements

ACI 14.3.3 – Horizontal reinforcement ratio is 0.0020

Minimum steel in transverse direction = 0.0020 * 12 * 12 = 0.289 in$^2$

$A_{s\text{provided}} = 0.233(\text{top}) + 0.233(12/10) = 0.513 > 0.289$

Minimum steel in longitudinal direction = 0.0020 * 12 * (7 * 12) = 2.0 in$^2$

$A_{s\text{provided}} = 0.15(78/8) + 0.15 * ((36”-3’-2”)/8) = 1.46 + 0.58 = 2.04 > 2.0 – OK$

2. Splicing Requirements

There are two types of splices, one with the D15 wires running longitudinally and the D23.3 wires.

D15 Splice

See splice calculations in the wall section for overlap splice. Splice length is 8”

D23.3 Splice

Calculate $I_d$
\[
\frac{I_d}{d_b} = \frac{3}{40} \cdot \frac{f_y}{\lambda \sqrt{f'_c}} \cdot \left[ \frac{\alpha \beta \gamma}{C + \frac{K_{tr}}{d_b}} \right]
\]

\[
K_{tr} = \frac{A_{tr} f_{yt}}{1500 \cdot s}
\]

\[
K_{tr} = \frac{(0.233 \times 80000)}{(1500 \times 10 \times 1)}
\]

\[
= 1.24
\]

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</tr>
<tr>
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Solving for \( l_d \),

\[
\frac{c + K_t}{d_b} = \frac{2 + 1.24}{0.545} = 5.94
\]

\[ l_d = 0.545 \times \frac{3}{40} \times \frac{80000}{1 \times 4000} \times \frac{1.3 \times 0.8}{5.94} = 9.0" \]

Wire Factor (WF),

Greater of:

\[
\left( \frac{f_y - 35,000}{f_y} \right) \quad \text{or} \quad \left( \frac{5d_b}{s} \right)
\]

ACI 318 12.7.2

But not greater than 1.

Greater of \( \frac{80000 - 35000}{80000} \) or \( \frac{5 \times 0.545}{10} \)

= 0.5625 or 0.27

WF = 0.5625

Splice length = WF * 1.3 * \( l_d \) = 0.5625 * 1.3 * 9"

= 6.58", minimum is 8"

3. Sheet Design

Top Sheet - D 23.3 @ 12" o/c transverse direction and D15 @ 8" o/c in the longitudinal direction

Footer length = 120' * 12 = 1440"

Wire length = 1440 – cover (3" + 3") = 1434"

Sheet length (max.) = 45', 1434/12 = 119.5', use three sheets

Splice length of longitudinal wire (D 15) is 8", so with three sheets there will be two 8" splices.

Overall sheet length with splices = 1434 + 8 + 8 = 1450", divided into 3 sheets

Sheet length = 1450/3 = 483.33", use 484"

D23.3 spacing is 12", spaced over 484", 484"/12 = 40'-4" , this is 40 spaces with 2" overhang at each end. D23.3 length = 7' * 12 = 84" – cover(3"+3") = 78"
D 15 @ 8” o/c, sheet width = 78”, no splice in transverse direction.

No. of D15 wires, 78”/8 = 9.75 spaces, 9 spaces @ 8” = 72” with 6” left over, or 3” overhangs

Top Sheet designation - 12x8 D23.3/D15 78” (+3”, +3”) 40'-4” (+2”, +2”)

Bottom Sheet – L shaped sheet that reinforces toe of footer and overlaps wall sheet.

Consists of D23.3 @ 10” o/c with 8” overlap of wall sheet and D15 @ 8” o/c that runs longitudinally.
Splicing of D15 is the same as top sheet.

Since this is a bent sheet there are a couple fabrication rules that apply. One is the maximum sheet length for a bending machine is around 20 ft. The other is the minimum distance from a bend to a wire is 2”, particularly when the wires are on the inside of the bend as in this sheet. The reason is the mandrels need clearance space. Therefore with this requirement the sheet cross-section will look like the below.

With the sheet length limited to 20’, there will be 6 sheets and five splice locations. For the D15 wire the splice length is 8”. 
Overall Sheet length = 1434 + (5*8") = 1474"

Individual sheet length = 1474"/6 = 245.67", Use 246" = 20’-6"

D23.3 spacing is 10” o/c.  246/10 = 24.6 spaces.

24 * 10” = 240” with 6” for overhangs, or 3” overhangs on each end.

Bottom sheet designation - 10x8 D23.3/D15 48” (0,0) 24’-6” (+3", +3")