6.11.5 Example 6.8: Design of Brackets and Corbels by the Strut-and-Tie Meth

Design the corbel in Example 6.6 by the strut-and-tie method.

Solution:

Column size: 12 × 18 in.

Corbel width = 18 in.

(1) Truss Model Selection

Assume the corbel is monolithically cast with the column. The total depth $h = 18$ in. and ef tive depth $d = 14$ in. are based on the requirement that the vertical dimension of the corbel c side the bearing area is at least *one half* the column face width of 14 in. (column size: 12 × 14 i Select a simple strut-and-tie model as shown in Fig. 6.35(a), assuming that the center of tie A is located at a distance of 4 in. below the top extreme corbel fibers, using one layer of reinfo ing bars. Also assume that horizontal tie DG lies on a horizontal line passing at the re-entr corner C of the corbel. The solid lines in Fig. 6.34 denote tension tie action (T), and the dash lines denote compression strut action (C). The nodal points A, B, C, D result from the select strut-and-tie model. Note that the entire corbel is a D-region structure because of the existi statical discontinuities in the geometry of the corbel and the vertical and horizontal loads.

(2) Strut-and-tie truss forces

From Example 6.6, $V_u = 80{,}000$lb

$$N_{ue} = 0.20\ V_u = 16{,}000 \text{ lb}$$

The following are the truss member forces calculated from statics in Fig. 6.34:

a) *Compression strut BC:*

$$\text{Length } BC = \sqrt{(7)^2 + (14)^2} = 15.652 \text{ in.}$$

$$F_{BC} = 80{,}000 \times \frac{15.652}{14} = 89{,}443 \text{ lb.}$$

b) *Tension tie BA:*

$$F_{BA} = 80{,}000 \times \frac{7}{14} + 16{,}000 = 56{,}000 \text{ lb.}$$

c) *Compression strut AC:*

$$F_{AC} = \frac{56{,}000\sqrt{(8)^2 + (14)^2}}{8} = 112{,}872 \text{ lb.}$$

d) *Tension tie AD:*

$$F_{AD} = \frac{112{,}872 \times 14}{\sqrt{(8)^2 + (14)^2}} = 98{,}000 \text{ lb.}$$

e) *Compression strut CC′:*

$$F_{CC'} = 80{,}000 + 98{,}000 = 178{,}000 \text{ lb.}$$

f) *Tension tie CD:*

$$F_{CD} = 56{,}000 - 80{,}000 \times \frac{7}{14} = 16{,}000 \text{ lb.}$$

(3) Steel Bearing Plate Design

$f_{ce} = \phi(0.85 f'c)$ where = 0.75 for bearing in strut-and-tie models.

$$\text{Area of plate is } A_1 = \frac{80{,}000}{0.75(0.85 f'_c)}$$

$$= \frac{80{,}000}{0.75 \times 0.85 \times 5000} = 25.10 \text{ in.}^2$$

Use 5½ × 5½ in. plate and select a thickness to produce a rigid plate.

(4) Tie Reinforcement Design

$$A_{ts,AB} = \frac{56{,}000}{\phi f_y} = \frac{56{,}000}{0.75 \times 60{,}000} = 1.25 \text{ in.}^2$$

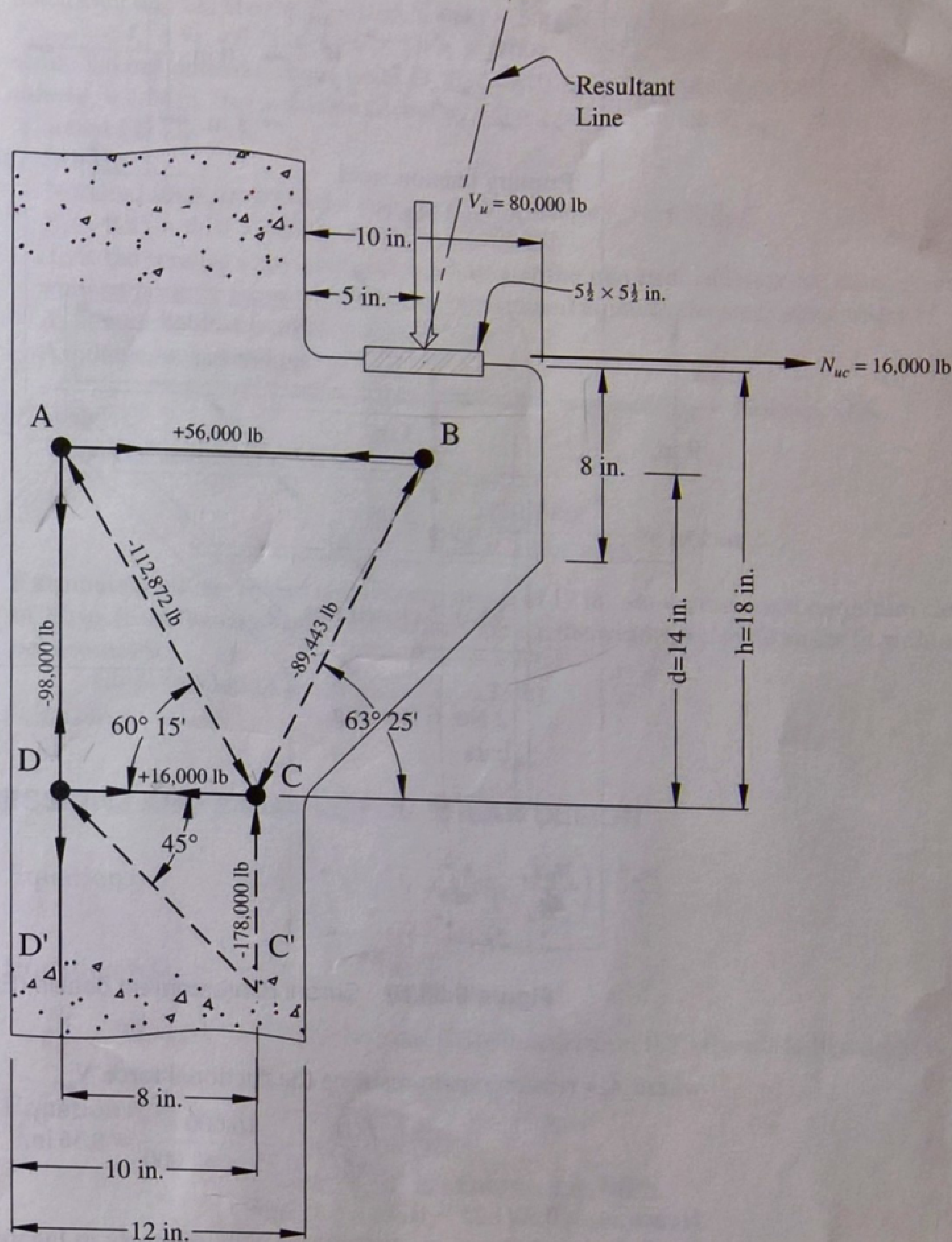

Figure 6.35(a) Strut-and-Tie Model in Example 6.8.

Use 3 # 6 bars = 1.32 in.^{2}, or, conservatively,

3 # 7 bars = 1.80 in.^{2} as in Example 6.6.

These top bars in one layer have to be fully developed along the longitudinal column reinforcement.

$$A_{ts,CD} = \frac{16{,}000}{0.75 \times 60{,}000} = 0.36 \text{ in.}^2$$

Use 2 # 6 tie bars = 0.88 in.^{2} to form part of the cage shown in Fig. 6.35(b).

(5) *Horizontal Reinforcement A_h for Crack Control of Shear Cracks*

$$A_h = 0.50(A_{sc} - A_n)$$

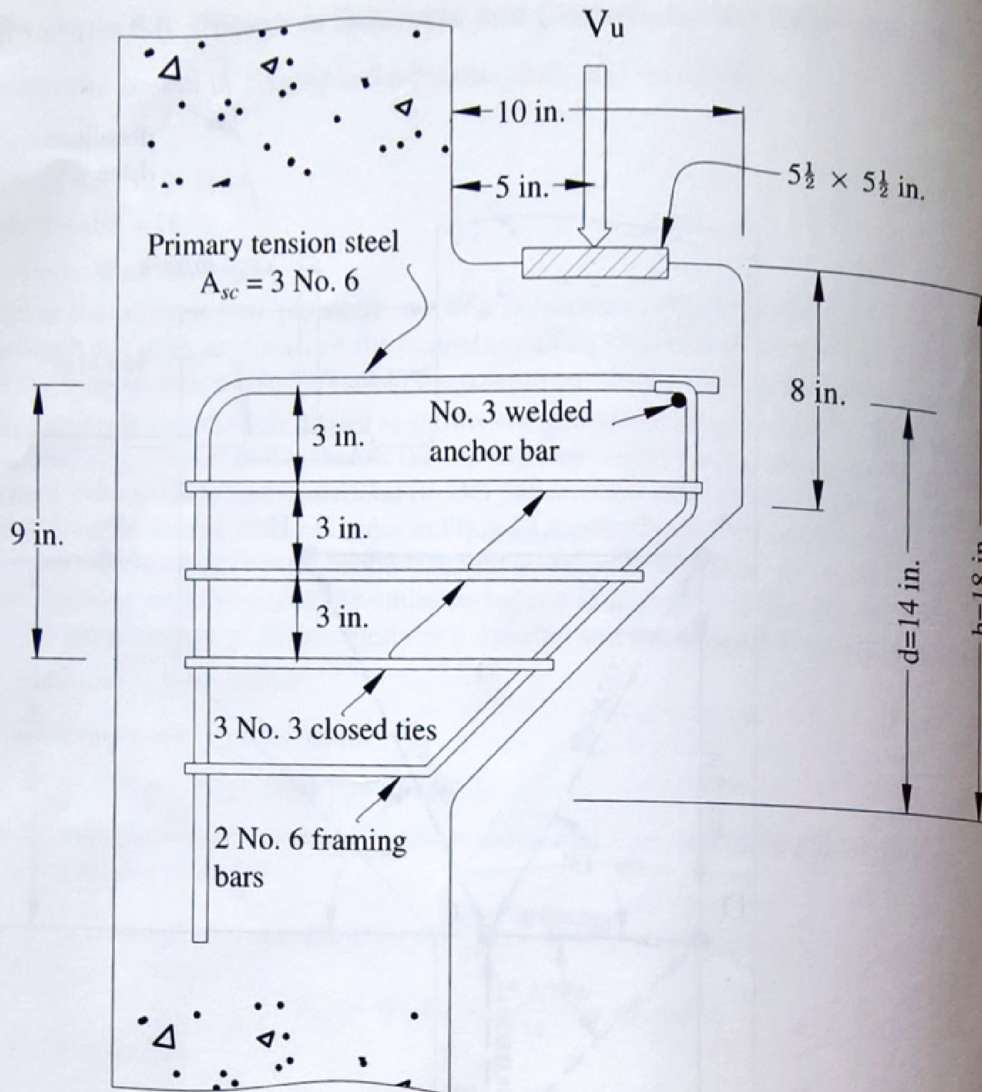

Figure 6.35(b) Corbel reinforcement details (Ex. 6.5).

where A_n= reinforcement resisting the frictional force N_{uc}.

$$A_n = \frac{N_{uc}}{\phi f_y} = \frac{16{,}000}{0.75 \times 60{,}000} = 0.36 \text{ in.}^2$$

Hence, $A_h = 0.50(1.25 - 0.36) = 0.45$ in.^{2}

Try 3 #3 closed ties evenly spaced vertically as shown in Fig. 6.35, giving $A_h = 3(2\,0.11) =$ 0.66 in.2 > 0.45 in.2, O.K.

Because $\beta_s = 0.75$ is used for calculating the effective concrete compressive strength in the struts in the following section, where f_{ce},= $0.85\beta_s f_c'$, the minimum reinforcement provided has also to satisfy:

$$\sum \frac{A_h / tie}{bs_t} \sin \gamma_t \geq 0.003$$

$$= \frac{2(0.11)}{14 \times 3.0} \sin 60°15' = 0.0045 > 0.003 \text{ O.K.}$$

Hence adopt 3#3 closed ties at 3.0 in. c. to c. spacing.

(6)Strut Capacity Evaluation

(i) *Strut CC′*

The width w_s of nodal zone C has to satisfy the allowable stress limit on the nodal zones, namely, node B below the bearing plate and node C in the re-entrant corner to the column. Both nodes are CCT nodes and considered unconfined.

Because of the non-confinement of the nodes $f_{ce} = 0.85\ \beta_n f'_c$, where $\beta_n = 0.80$ for a nodal zone anchoring one tie. Hence, $f_{ce} = 0.85 \times 0.80 \times 5000 = 3400$ psi.
$F_{u,CC'} = \phi\, f_{ce}\, b\, w_s = 0.75 \times 3400 \times 18 \times w_s/1000 = 45.9\, w_s$ kips, where w_s = min. width of the strut. Taking moment about node D, $F_{u,CC'}\,(10 - w_s/2) = 80^k\,(5 + 10) - 16^k \times 18$ to give min. $w_s = 2.24$ in. But available corbel $w_s = 2 + 2 = 4$ in.; hence $F_{u,CC'} = 45.9 \times 4.0 = 183.6$ kip > actual 178 kip, O.K.

(ii) Strut BC

Nominal strength is limited to $F_{ns} = f_{ce} A_{cs}$, where $f_{ce}' = 0.85\beta_s f'_c$
$f_{ce}' = 0.85 \times 0.75 \times 5000 = 3188$ psi $= 3.188$ ksi
A_{cs} is the smaller strut cross-sectional area at the two ends of the strut, namely, at node C, while at node B, the node width can be assumed equal to the steel plate width of 5.50 in.
A_c at node $C = bw_s = 18 \times 2.24 = 40.32$ in.^{2}
Available factored $F_{us,C} = \phi\, F_{ns,C}$
$= 0.75 \times 3.188 \times 40.32 = 96.4$ kip > required $F_{BC} = 89.4$ kip, O.K.

(iii) Strut AC

Required min. width, w_s, of strut AC

$$= \frac{F_{u,AC}}{\phi\, f_{ce} b} = \frac{112.87\ kip}{0.75 \times 3.188 \times 18} = 2.62\ \text{in.}$$

Examination of the corbel and column depth of 12 in., shows there is a minimum clear cover of 2.0 in. from the outer concrete surface. Hence the widths, w_s, of all struts fit within the corbel geometry.

Adopt the design as shown in Fig. 6.35(b).

6.12 SI DESIGN EXPRESSIONS AND EXAMPLE FOR SHEAR DESIGN

Equation 6.8: $$V_c = \left[\left(\lambda\sqrt{f'_c} + 120\rho_w \frac{V_u d}{M_u}\right)\right]\frac{b_w d}{7}$$

Equation 6.9: $$V_c = \lambda\frac{\sqrt{f'_c}}{6} b_w d$$

where $\lambda = 1.0$ for normal weight concrete; 0.75 for all lightweight concrete.

Equation 6.10: $$V_c = \lambda\left(1 + \frac{N_u}{14A_g}\right)\frac{\sqrt{f'_c}}{6} b_w d$$

where N_u/A_g is expressed in MPa.

Equation 6.15a: $$V_s = \frac{A_v f_y d}{s}$$

Equation 6.15b: $$V_s = \frac{A_v f_y d}{(V_u/\phi) - V_c}$$

Min $A_v = \dfrac{b_w s}{3 f_y}$ where b_w and s are expressed in mm and f_y in MPa.

Limitations on Spacing Stirrups

0,018

8,40

1. $V_n - V_c > \dfrac{\sqrt{f'_c}}{3} b_w d$: $s_{\max} = \dfrac{d}{4} \le 610$ mm
2. $V_n - V_c \le \dfrac{\sqrt{f'_c}}{3} b_w d$: $s_{\max} = \dfrac{d}{2} \le 610$ mm
3. $V_n - V_c > \dfrac{2}{3}\sqrt{f'_c}\, b_w d$: enlarge section