Example 1

Consider the 2 meter deep beam described in Figure 1.1 below. Use the strut-and-tie model to determine the required amount of reinforcement.
Additional details:
fc' = 25 MPa, fy = 420 MPa, PDL = 800 kN dan PLL = 400 kN

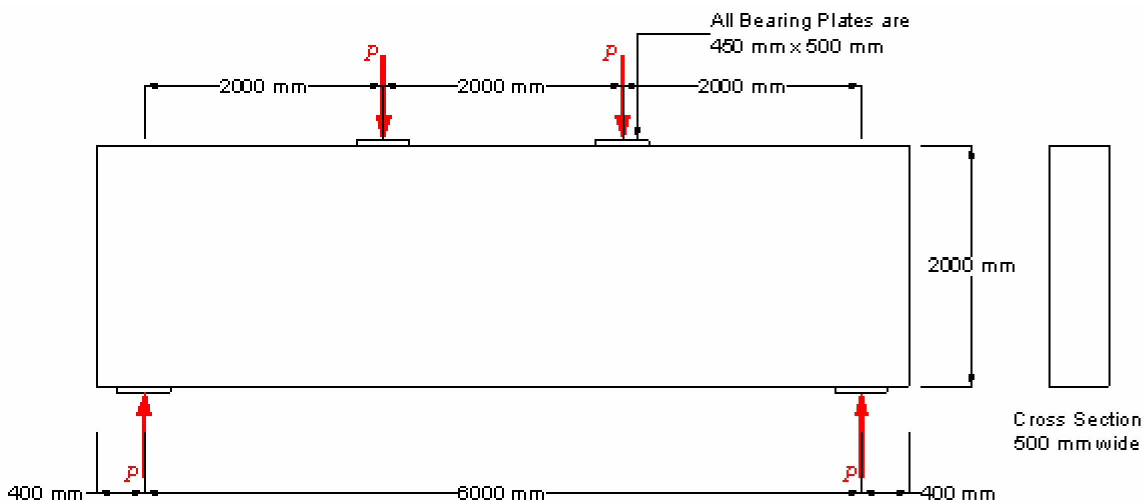


Figure 1.1

Step 1: Evaluate the Total Factored Load, P_u

$P_u = 1,2\ P_{DL} + 1,6\ P_{LL}$

$= 1,2\ (800) + 1,6(400) = 1600$ kN

Step 2: Check Bearing Capacity at Loading and Support Locations

Bearing strength at points of loading = $\phi 0,85 f_c' \beta_n A_c$

$= 0.75(0.85)(25)(1.0)(450)(500)$ N

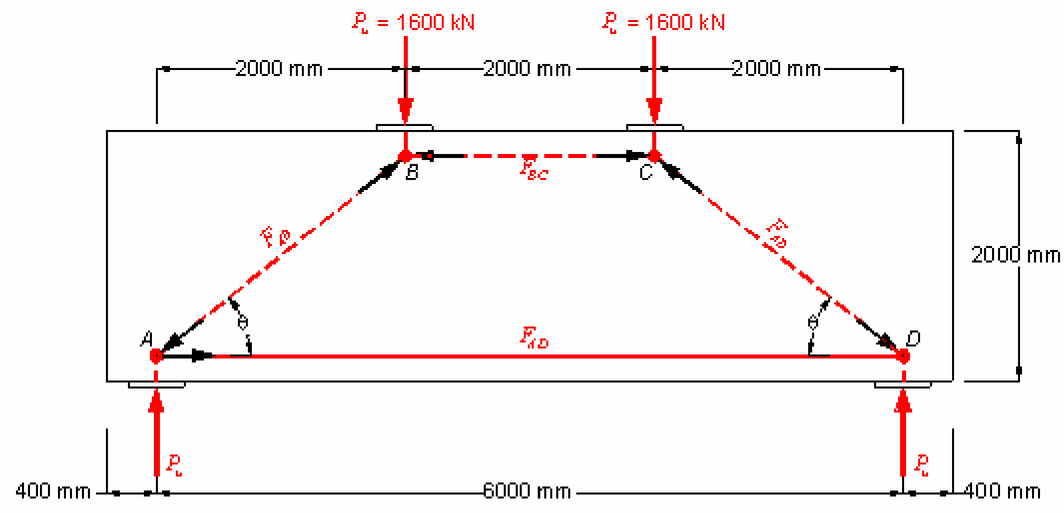
$= 3586$ kN > 1600 kN OK

Bearing strength at supports = $\phi 0,85 f_c' \beta_n A_c$

$=0.75(0.85)(25)(0.80)(450)(500)$ N

$= 2868$ kN > 1600 kN OK

Step 3: Select the Strut-and-Tie Model to Use in Design



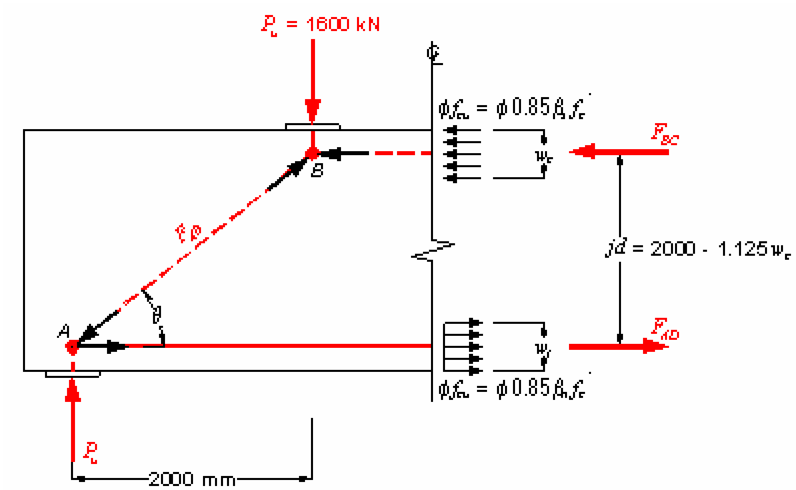
Step 4: Isolate Disturbed Region and Estimate Member Forces and Dimensions
The entire deep beam is a disturbed region, but it is only necessary to consider the left third of the structure to complete the design. The horizontal position of nodes *A* and *B* are easy to define, but the vertical position of these nodes must somehow be estimated or determined. What we do know is that the design strength of strut *BC* must be greater than or equal to the factored load in strut *BC*. That is:

Strut *BC*:
$\phi F_{nc} = \phi\, f_{cu}\, A_c = \phi\, (0{,}85\, \beta_s\, f_c')\, b\, w_c \geq F_{BC}$, where $\beta_s = 1.0$ (prismatic strut)

Similarly, the design strength of tie *AD* must be greater than the factored load in tie *AD*. In addition, this tie must be anchored over a large enough area ($w_t b$) such that the factored load is less than ϕF_{nn} .

Tie *AD*: $\phi F_{nt} = \phi\, A_y\, f_y \geq F_{AD}$ and
Tie *AD*: $\phi F_{nn} = \phi\, f_{cu}\, A_c = \phi\, (0{,}85\, \beta_n\, f_c')\, b\, w_t \geq F_{AD}$, where $\beta_n = 0.8$ (on tie anchored in Node *A*)

By setting the design strength equal to the required capacity, *jd* will be a maximum and $w_t = 1.25\, w_c$.
The flexural lever arm will be $jd = 2000 - w_c/2 - w_t/2 = 2000 - 1.125 w_c$.



By taking summation of moments about point *A*:

$\sum M_A = 1600\ (2000)\ (1000) = F_{BC}\ (2000 - 1.125 w_c)$

By substituting $\phi\ (0{,}85\ f_c')\ b\ w_c$ for F_{BC}, w_c = 231 mm, and therefore w_t = 288 mm.

If these values are used for the dimensions of the struts and ties, the stress in strut F_{BC} will be at its limit, and the force in tie F_{AD} will be anchored in just sufficient area. It is often wise to increase these values a little to leave some margin. w_c will be selected to be 240 mm, and w_t will be selected to be 300 mm.

$\therefore jd = 2000 - 240/2 - 300/2 = 1730$ mm and

$F_{BC} = F_{AD} = 1600(2000)/1730 = 1850$ kN

Check capacity of strut *BC*:

$\phi F_{nc} = \phi\ (0{,}85\ \beta_s\ f_c')\ b\ w_t$

$= 0.75(0.85)(1.0)(25)(500)(240)$ N

$= 1912$ kN $\therefore$ OK

Step 5: Select Reinforcement

Tie *AD*: $\phi F_{nt} = \phi A_s\, fy \geq F_{AD} = 1850$ KN

As $\geq 1850\ (1000)/0.75(420) = 5873\ mm^2$

Consider 1 layer of 6 #36(11) bars = 6036 mm^2 @ 150 mm from bottom
Consider 2 layers of 5 #29(9) bars = 6450 mm^2 @ 80 mm and 220 mm from bottom

Consider 3 layers of 6 #22(7) bars = 6966 mm^2 @ 60, 150, and 240 mm from bottom

Check capacity of tie *AD*: $\phi F_{nt} = \phi A_s f_y = 0.75(6450)(420)$ N
= 2032 kN > 1850 kN OK

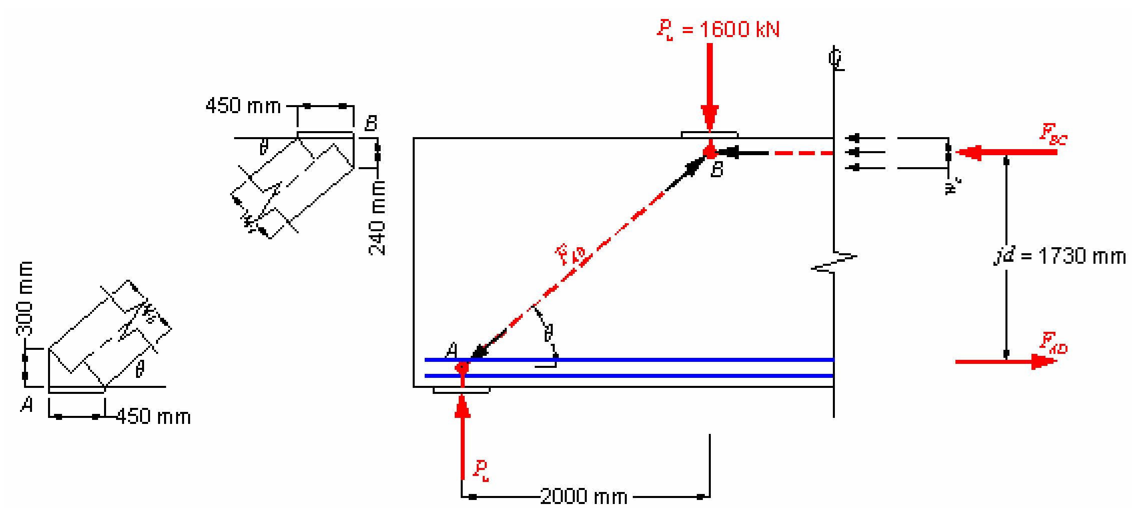
Step 6: Calculate Force in Diagonal Compressive Strut F_{AB} and Check Capacity

Tanθ = 1730/2000 and θ = 40.9°
Therefore, the force in the diagonal compressive strut,
FAB = 1600 / sin40.9° = 2444 kN.

Width at top of strut = $w_{ct} = l_b \sin\theta + h_a \cos\theta$
= 450 sin40.9° + 240 cos40.9° = 476 mm

Width at bottom of strut = $w_{cb} = l_b \sin\theta + h_a \cos\theta$
= 450 sin40.9° + 300 cos40.9° = 521 mm

Assuming that sufficient crack control reinforcement is used, then βs = 0.75
Check Capacity of strut *AB*:
$\phi F_{nc} = \phi\,(0{,}85\,\beta_s\,f_c')\,b\,w_t = 0.75(0.85)(0.75)(25)(500)(476)$ N
= 2885 kN > 2444 kN OK



Step 7: Minimum Distributed Reinforcement and Reinforcement for Bottle-Shaped Struts

Horizontal Web Reinforcement:

Use one #13(4) on each face at s_h = 300 mm over entire length,

$A_h/(b\ s_h)$ = 2(129)/500/300 = 0.0017 > 0.0015 OK

Vertical Web Reinforcement:

Use one #16(5) on each face at s_v = 300 mm over entire length,

$A_v/(b\ s_v)$ = 2(199)/500/300 = 0.00265 > 0.0025 OK

Check of Reinforcement to Resist Bursting Forces in Bottle-Shaped Struts: $\sum \rho_{vi} \sin \gamma_i$ = 0.0017 sin40.9° + 0.00265 sin 40.9° = 0.00312 > 0.003 OK