CHAPTER

5e

Prentice Hall

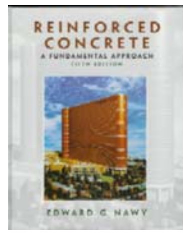
REINFORCED CONCRETE

A Fundamental Approach - Fifth Edition

FLEXURE IN BEAMS

A. J. Clark School of Engineering •Department of Civil and Environmental Engineering

SPRING 2004



By
Dr . Ibrahim. Assakkaf

ENCE 454 – Design of Concrete Structures

Department of Civil and Environmental Engineering

University of Maryland, College Park

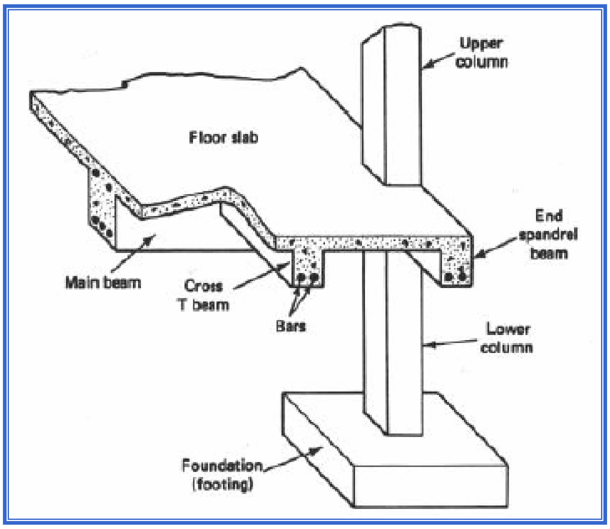
CONCRETE.com

Nonrectangular Sections

- T and L beams are the most commonly used flanged sections.
- Reinforced concrete structural systems such as floors, roofs, decks, etc., are almost monolithic, except for precast systems.
- Forms are built for beam sides the underside of slabs, and the entire construction is poured at once, from the bottom of the deepest beam to the top of the slab.

Nonrectangular Sections

- Floor-Column Systems



Nonrectangular Sections

- Beam and Girder System
  - This system is composed of slab on supporting reinforced concrete beams and girder..
  - The beam and girder framework is, in turn, supported by columns.
  - In such a system, the beams and girders are placed monolithically with the slab.
  - The typical monolithic structural system is shown in Figure 26.

Nonrectangular Sections

- Beam and Girder Floor System

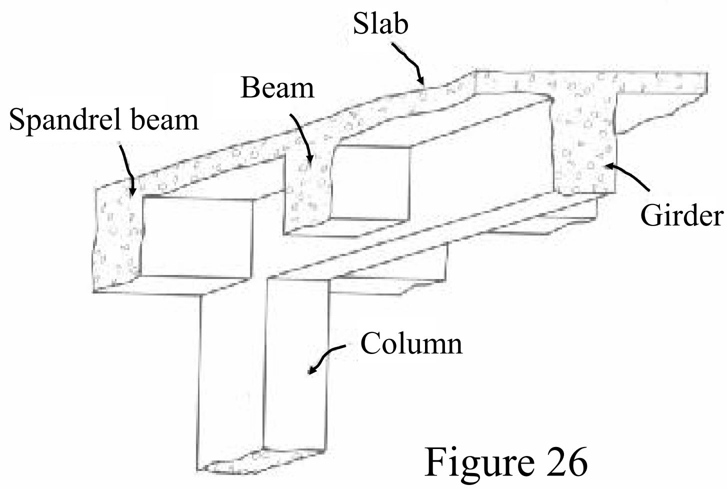


Figure 26

Nonrectangular Sections

- Common Beam and Girder Layout

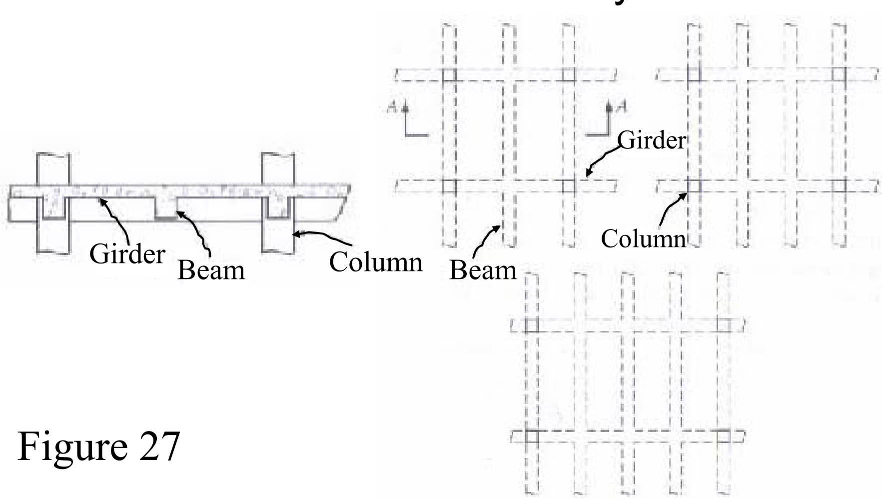


Figure 27

Nonrectangular Sections

- Positive Bending Moment
  - In the analysis and design of floor and roof systems, it is common practice to assume that the monolithically placed slab and supporting beam interact as a unit in resisting the positive bending moment.
  - As shown in Figure 28, the slab becomes the compression flange, while the supporting beam becomes the web or stem.

Nonrectangular Sections

- T-Beam as Part of a Floor System

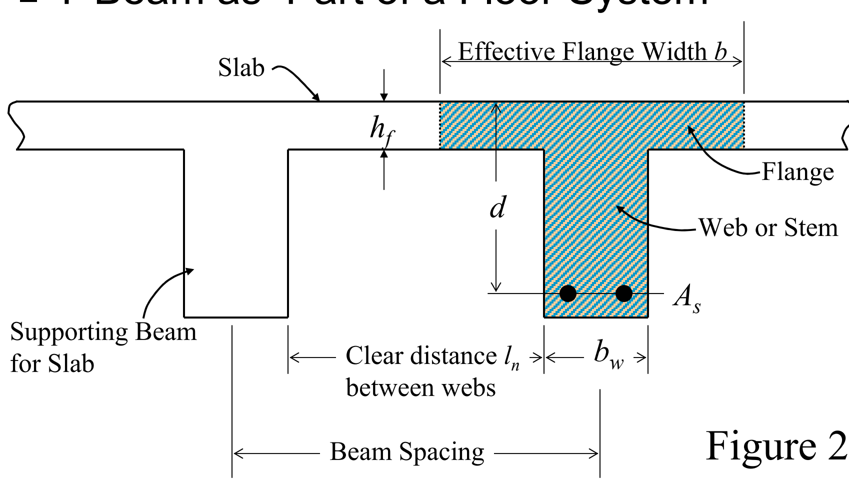


Figure 28a

Nonrectangular Sections

- **T-Beam**
  - The interacting flange and web produce the cross section having the typical T-shape, thus the T-Beam gets its name (see Figure 29b).
- **L-Beam**
  - The interacting flange and web produce the cross section having the typical L-shape, thus the L-Beam gets its name (see Figure 29b). Sometimes an L-beam is called Spandrel or Edge Beam (beam with a slab on one side only.

Nonrectangular Sections

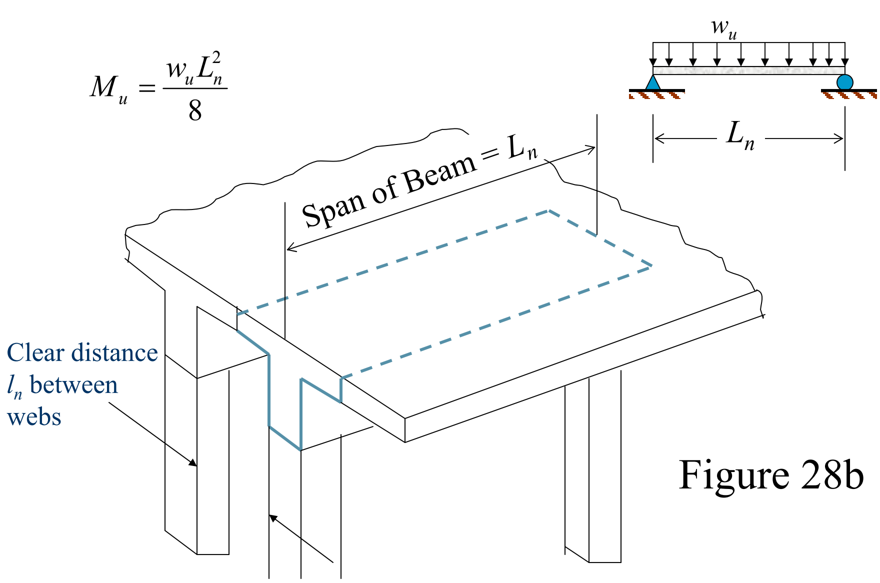
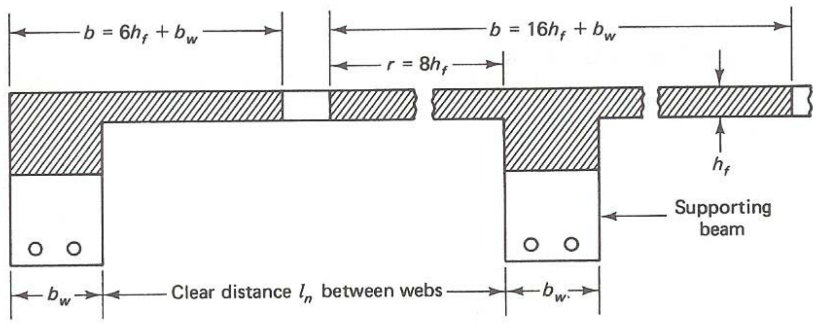


Figure 28b

Nonrectangular Sections



(a) L-Beam (Spandrel or Edge Beam)   (b) T-Beam

Figure 29. T- and L-beams as part of a slab beam floor system (cross-section at beam midspan)

Nonrectangular Sections

- Negative Bending Moment
  - It should be noted that when the T- or L-Beam is subjected to negative moment, the slab at the top of the stem (web) will be in *tension* while the bottom of the stem is in *compression*.
  - This usually occurs at interior support of continuous beam.
  - In these cases, the support sections would an inverted doubly reinforced sections having A'_s at the bottom fibers and A_s at the top fibers (see Figure 30)

Nonrectangular Sections

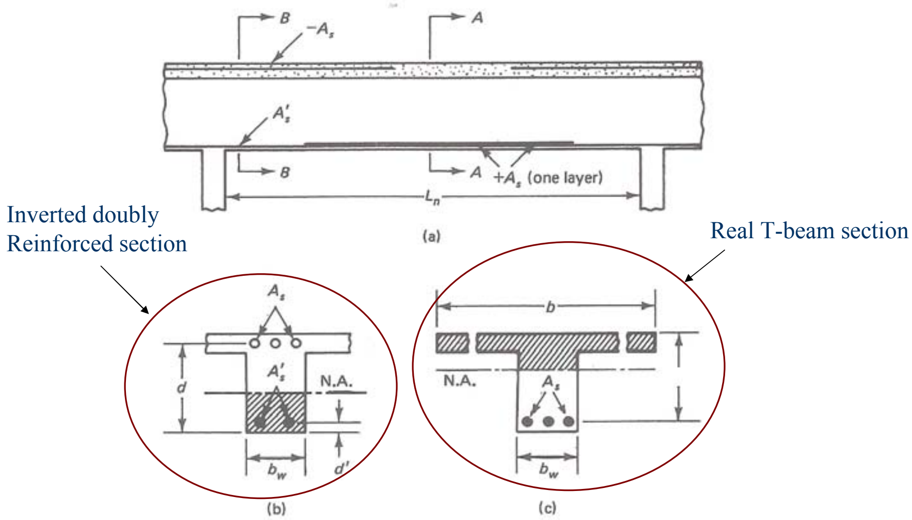


Figure 30. Elevation of monolithic beam: (a) beam elevation; (b) support section *B-B* (inverted doubly reinforced beam; (c) midspan *A-A* (real T-beam)

Nonrectangular Sections

- ACI Code Provisions for T- and L-Beams
  - T-Beam
    - **Section 8.10.2 of ACI318-02 Code stipulates:**
      - Width of slab effective as a T-beam flange shall not exceed one-quarter of the span length of the beam, and the effective overhanging flange width on each side of the web shall not exceed:
        - (a) eight times the slab thickness;
        - (b) one-half the clear distance to the next web.

Nonrectangular Sections

- ACI Code Provisions for T- and L-Beams
  - L-Beam (slab on one side only)
    - **Section 8.10.3 of ACI318-02 Code stiplulates:**
      - For beams with a slab on one side only, the effective overhanging flange width shall not exceed:
        - (a) one-twelfth the span length of the beam;
        - (b) six times the slab thickness;
        - (c) one-half the clear distance to the next web.
  - The following simplified interpretations for the preceding ACI provisions are listed.

Nonrectangular Sections

- ACI Code Provisions for T- and L-Beams
  1. The effective flange width must not exceed
     a. One-fourth the span length
     b. $b_w + 16h_f$
     c. Center-to-center spacing of the beam

     The smallest of the three values will control

  2. For beam having a flange on one side only (L-beam), the effective overhanging flange width must

Nonrectangular Sections

- ACI Code Provisions for T-Beams

  Not exceed ***one-twelfth*** of the span length of the beam, nor ***six times*** the slab thickness, nor ***one-half*** of the clear distance to the next beam.

  3. For isolated beam in which the T-shape is used only for the purpose of providing additional compressive area, the flange thickness must not be less than **one-half** of the width of the web, and the total flange width must not be more than **four times** the web width.

Analysis of T and L Beams

- The ductility requirements for T-beams are similar to those for rectangular beams:

  Find $\varepsilon_t = 0.003(d_t / c - 1)$ and compare it with Fig. 14
- The minimum tensile reinforcement for T-beam is the same as that for Rectangular beam section as specified by the ACI Code.
- However, if the beam is subjected to a negative bending moment there is also a requirement by the ACI Code.

Analysis of T and L Beams

- ACI-318-02 Code Strain Limits

ACI Code

Figure 14. Strain Limit Zones and variation of Strength Reduction Factor ϕ

ENCE 454 ©Assakkaf

Analysis of T and L Beams

- Minimum Steel Ratio for T-Beams
  - The T-beam is subjected to ***positive moment:***
    - The steel area shall not be less than that given by

$$A_{s,\min} = \frac{3\sqrt{f_c'}}{f_y} b_w d \geq \frac{200}{f_y} b_w d \qquad (60a)$$

$$\rho_{\min} = \frac{3\sqrt{f_c'}}{f_y} \geq \frac{200}{f_y} \qquad (60b)$$

Note that the first expression controls if f_c' > 4440 psi

ACI Code

Analysis of T and L Beams

- Minimum Steel Ratio for T-Beams
  - The T-beam is subjected to ***negative moment:***
    - The steel area A_s shall equal the smallest of the following expression:

$$A_{s,\min} = \text{smallest of } \frac{6\sqrt{f'_c}}{f_y} b_w d \quad \text{or} \quad \frac{3\sqrt{f'_c}}{f_y} b_w d \qquad (61a)$$

$$\rho_{\min} = \text{smallest of } \frac{6\sqrt{f'_c}}{f_y} \quad \text{or} \quad \frac{3\sqrt{f'_c}}{f_y} \qquad (61b)$$

ACI Code

Analysis of T and L Beams

- Notes on the Analysis of T-Beams
  - Because of the large compressive in the flange of the T-beam, the moment strength is usually limited by the yielding of the tensile steel.
  - Therefore, it safe to assume that the tensile steel will yield before the concrete reaches its ultimate strain.
  - The ultimate tensile force may be found from

$$T = A_s f_y \qquad (62)$$

Analysis of T and L Beams

- Notes on the Analysis of T-Beams
  - In analyzing a T-beam, there might exist two cases:
    1. The stress block may be completely within the flange, as shown in Figures 31 and 32.
    2. The stress block may cover the flange and extend into the web, as shown in Figures 33 and 34.
  - These two conditions will result in what are termed: ***a rectangular T-beam*** and a ***true T-beam***, respectively.

Analysis of T and L Beams

- Stress Block Completely within the Flange (Rectangular T-Beam)

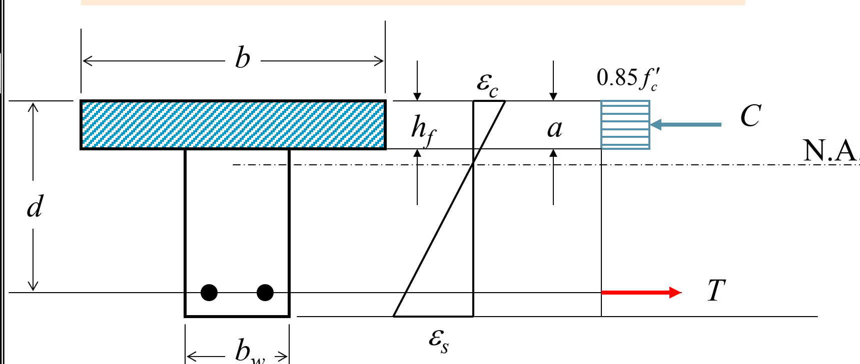


Figure 31

Analysis of T and L Beams

- A Rectangular T-beam

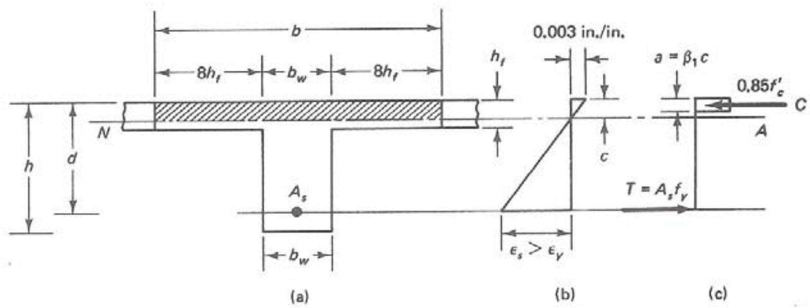


Figure 32. T-beam section with neutral axis within the flange ($c < h_f$): (a) Cross Section; (b) strains; (c) stresses and forces.

Analysis of T and L Beams

- Stress Block Cover Flange and Extends into Web (True T-Beam)

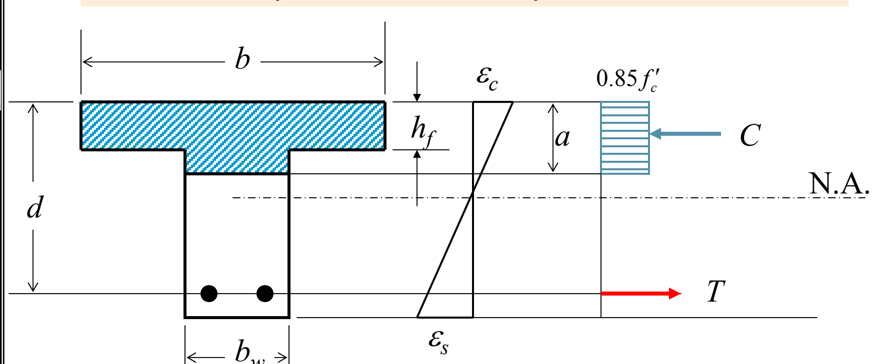


Figure 33

Analysis of T and L Beams

- A True T-beam

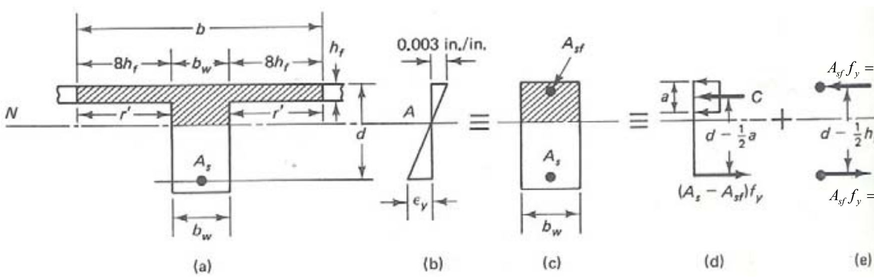


Figure 34. Stress and strain distribution in flanged sections design T-beam transfer): (a) Cross section; (b) strains; (c) transformed section; (d) part-1 forces; and (e) part-2 forces.

Analysis of T and L Beams

- **<u>Case I:</u>** A Rectangular T-beam
  - Stress Block Completely within the Flange

$$c < h_f \quad \text{and} \quad a < h_f$$

  - The nominal moment capacity in this case can be calculated from

$$M_n = A_s f_y \left(d - \frac{a}{2} \right) \qquad (63)$$

  - where

$$a = \frac{A_s f_y}{0.85 f_c' b}$$

Analysis of T and L Beams

- **Case II:** A True T-beam
  - Stress Block Cover Flange and Extends into Web

$$c > h_f$$

    - Two possible situations:

$$a < h_f \qquad \text{or} \qquad a > h_f$$

  - If a < h_f, then the nominal moment strength can be computed as in Case I. The beam section can be considered as rectangular section.

Analysis of T and L Beams

- **Case II (cont'd):** A True T-beam
  - If a > h_f, then the nominal moment strength can be computed from

$$M_n = \left(A_s - A_{sf}\right) f_y \left(d - \frac{a}{2}\right) + A_{sf} f_y \left(d - \frac{h_f}{2}\right) \quad (64)$$

  - where

$$A_{sf} = \frac{0.85 f_c' (b - b_w) h_f}{f_y} \quad (65)$$

$$a = \frac{\left(A_s - A_{sf}\right) f_y}{0.85 f_c' b_w} \quad (66)$$

Analysis of T and L Beams

- Checks for T and L Beams
  - To check whether a beam is considered a real T or L-beam, the tension force $A_s f_y$ generated by steel should be greater than the compression force capacity of the total flange area, that is

$$A_s f_y > 0.85 f_c' b h_f \qquad (67)$$

  - or

$$a = \frac{A_{sf} f_y}{0.85 f_c' b} > h_f \qquad (68)$$

Analysis of T and L Beams

- Checks for T and L Beams
  - Or

$$\left(a = 1.18 \overline{\omega} d\right) > h_f \qquad (69)$$

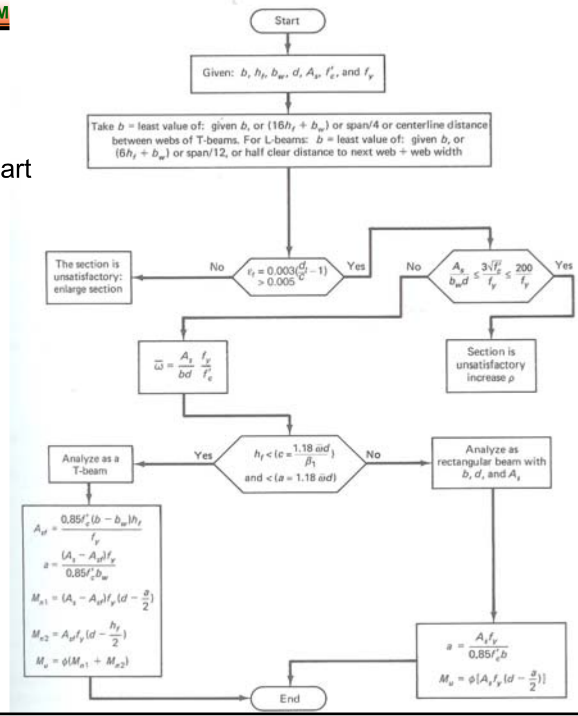
  - Or in terms of neutral axis c,

$$\left(c = \frac{1.18 \overline{\omega} d}{\beta_1}\right) > h_f \qquad (70)$$

  - where

$$\overline{\omega} = \frac{A_s f_y}{b d f_c'} \qquad (71)$$

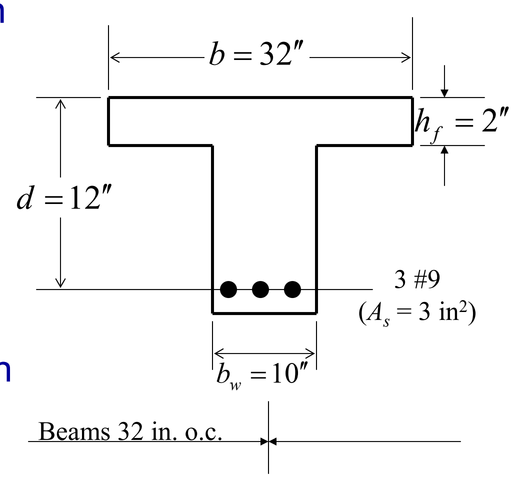
- **Figure 35.** Flow Chart For the Analysis of T- and L-beams



Analysis of T and L Beams

- Example 13

The T-beam shown in the figure is part of a floor system. Determine the practical moment strength ϕM_n if f_y = 60,000 psi (A615 grade 60) and f'_c = 3,000 psi. The span length is 16 ft.



Analysis of T and L Beams

- Example 13 (cont'd)

Determine the flange width in terms of the span length, flange thickness, and beam spacing:

$$\frac{1}{4}(\text{span length}) = \frac{1}{4}(16 \times 12) = 48 \text{ in.}$$

$$b_w + 16h_f = 10 + 16(2) = 42 \text{ in.}$$

$$\text{Beam spacing} = 32 \text{ in. o.c.}$$

Therefore,

Use $b = 32$ in. (smallest of the three values)

Analysis of T and L Beams

- Example 13 (cont'd)

$$A_s = 3\#9 = 3 \text{ in.}$$

$$\left(\rho_w = \frac{A_s}{b_w d} = \frac{30.025}{10(12)}\right) > \left(\rho_{\min} = 0.0033, \text{see Table 7}\right)$$

$$\overline{\omega} = \frac{A_s f_y}{bdf'_c} = \frac{3(60{,}000)}{10(12)(3000)} = 0.5$$

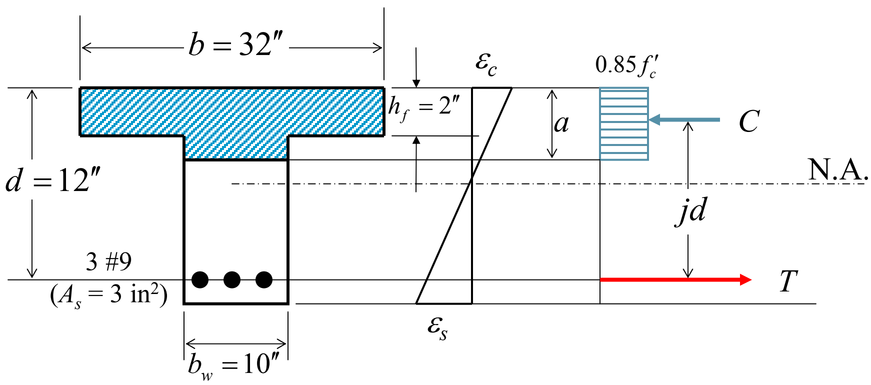
$$c = \frac{1.18\overline{\omega}d}{\beta_1} = \frac{1.18(0.5)12}{0.85} = 8.33 \text{ in.} > h_f = 2.00 \text{ in.}$$

$$a = 0.85c = 0.85(8.33) = 7.08 \text{ in.} > h_f = 2.00 \text{ in.}$$

Therefore, the beam should be treated as a true T-beam, and the stress block will extend into the web (see figure).

Analysis of T and L Beams

- Example 13 (cont'd)



Analysis of T and L Beams

- Table 7. Design Constants

f'_c (psi)	$\left[\frac{3\sqrt{f'_c}}{f_y} \geq \frac{200}{f_y}\right]$	ρ_b	Recommended Design Values	
			ρ	***R*** **(psi)**
		f_y = 40,000 psi		
3000	0.0050	0.03712	0.0135	482.82
4000	0.0050	0.04949	0.0180	643.76
5000	0.0053	0.05823	0.0225	804.71
6000	0.0058	0.06551	0.0270	965.65
		f_y = 50,000 psi		
3000	0.0040	0.02753	0.0108	482.80
4000	0.0040	0.03671	0.0144	643.80
5000	0.0042	0.04318	0.0180	804.70
6000	0.0046	0.04858	0.0216	965.70
		f_y = 60,000 psi		
3000	0.0033	0.0214	0.0090	482.82
4000	0.0033	0.0285	0.0120	643.76
5000	0.0035	0.0335	0.0150	804.71
6000	0.0039	0.0377	0.0180	965.65
		f_y = 75,000 psi		
3000	0.0027	0.0155	0.0072	482.80
4000	0.0027	0.0207	0.0096	643.80
5000	0.0028	0.0243	0.0120	804.70
6000	0.0031	0.0274	0.0144	965.70

Analysis of T and L Beams

- Example 13 (cont'd)
  - Using Eqs. 65 and 66:

$$A_{sf} = \frac{0.85 f_c'(b - b_w)h_f}{f_y} = \frac{0.85(3)(32-10)(2)}{60} = 1.87\ \text{in}^2$$

$$a = \frac{(A_s - A_{sf})f_y}{0.85 f_c' b_w} = \frac{(3.00-1.87)(60)}{0.85(3)(10)} = 2.66\ \text{in.}$$

$$c = \frac{a}{\beta_1} = \frac{2.66}{0.85} = 3.13\ \text{in.}$$

$$\varepsilon_t = 0.003\left(\frac{d_t}{c} - 1\right) = 0.003\left(\frac{12}{3.13} - 1\right) = 0.0085 >> 0.005 \quad \text{Strain OK}$$

Hence, tension-controlled ductile behavior and $\phi = 0.90$.

Analysis of T and L Beams

- Example 13 (cont'd)

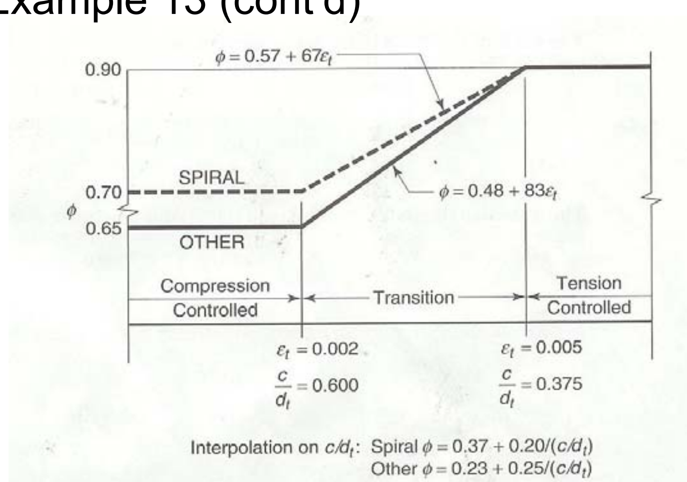


Figure 14. Strain Limit Zones and variation of Strength Reduction Factor ϕ

Analysis of T and L Beams

- Example 13 (cont'd)
  - Therefore, the practical moment strength is calculated as follows using Eq. 64:

$$M_n = (A_s - A_{sf}) f_y \left(d - \frac{a}{2} \right) + A_{sf} f_y \left(d - \frac{h_f}{2} \right)$$

$$= (3 - 1.87)(60{,}000)\left(12 - \frac{2.66}{2} \right) + 1.87(60{,}000)\left(12 - \frac{2}{2} \right)$$

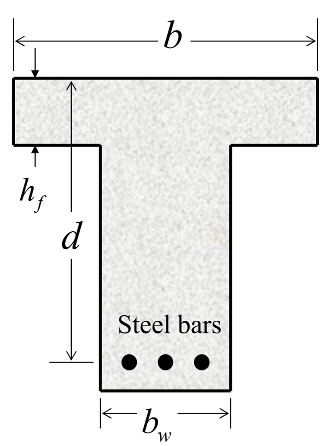
$$= 1{,}957{,}626 \text{ in.-lb} = 163.14 \quad \text{ft-kips}$$

  - The practical moment capacity is therefore

$$M_u = \phi M_n = 0.9(163.14) = 147 \ \text{ft-kips}$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Quantities that need to be determined in the design of a T-or L-beam are:
  - Flange Dimensions:
    - Effective Width, b
    - Thickness, h_f
  - Web Dimensions:
    - Width, b_w
    - Height
  - Area of Tension Steel, A_s



Trail-and-Adjustment Procedure for the Design of Flanged Sections

- In normal situations, the flange thickness is determined by the design of the slab, and the web size is determined by the shear and moment requirements at the end of the supports for continuous beam.
- Column size sometimes dictate web width.

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- ACI code dictates permissible effective flange width, b.
- The flange itself generally provides more than sufficient compression area; therefore the stress block usually lies completely in the flange.
- Thus, most T-and L-beams are only wide rectangular beams with respect to flexural behavior.

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Design Method
  - The recommended design method depends whether the beam behaves as a *rectangular T-beam* or a *true T-beam*.
  - For rectangular-T-Beam behavior, the design procedure is the same as for the tensile reinforced rectangular beam.
  - For true-T-beam behavior, the design proceeds by designing a flange component and a web components and combining the two.

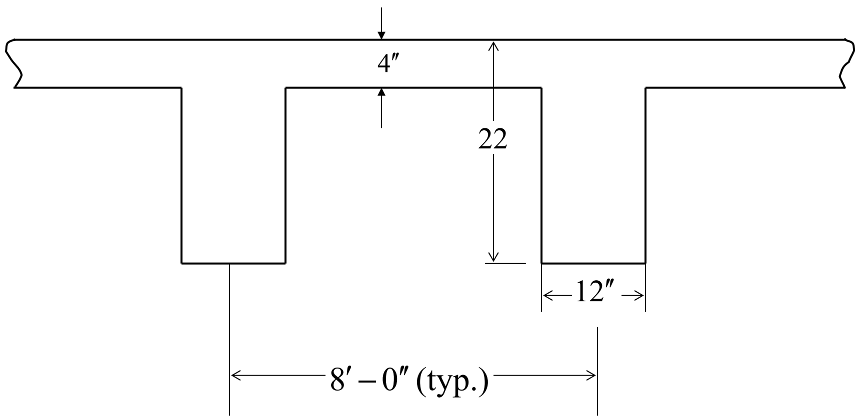
(For complete design procedure, see textbook, page 131.)

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14
  - Design the T-beam for the floor system shown in the figure. The floor has a 4-in. slab supported by 22-ft-span-length beams cast monolithically with the slab. Beams are 8 ft-0 in. on center and have a web width of 12 in. and a total depth = 22 in.; f_y = 60,000 psi (A615 grade 60) and f_c' =3000 psi. Service loads are 0.125 ksf live load and 0.256 ksf dead load. The given dead load does not include the weight of the floor system.

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)



Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)
  - Determine the Design Moment M_u:

$$\text{slab weight} = \frac{(8\times 12)(4)}{144}(0.150) = 0.4 \text{ k/ft}$$

$$\text{Stem (or web) weight} = \frac{(12)(22-4)}{144}(0.150) = 0.225 \text{ k/ft}$$

$$\text{Total} = 0.625 \text{ k/ft}$$

$$\text{service DL} = (8)(0.256) = 2.048 \text{ k/ft}$$

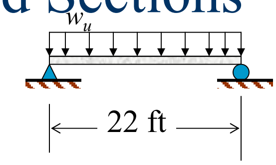
$$\text{service LL} = (8)(0.125) = 1.0 \text{ k/ft}$$

$$U = 1.2D + 1.6L \quad \text{ACI Code}$$

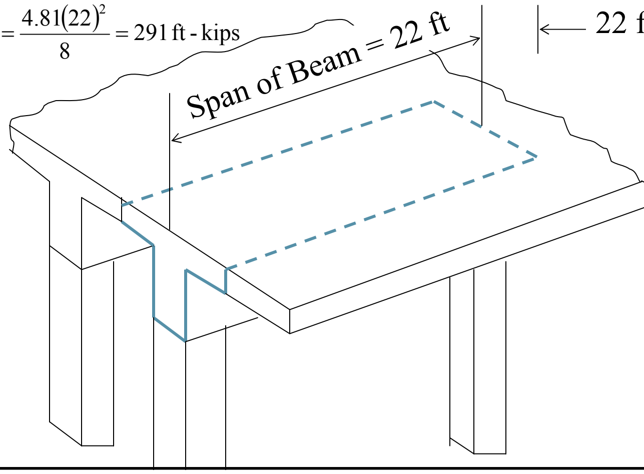
$$w_u = 1.2(0.625 + 2.048) + 1.6(1) = 4.81 \text{ k/ft}$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)



$$M_u = \frac{w_u L^2}{8} = \frac{4.81(22)^2}{8} = 291 \text{ ft-kips}$$



Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)
  - Assume an effective depth *d* = *h* – 3

$$d = 22 - 3 = 19 \text{ in.}$$

  - Find the effective flange width, *b*:

$$\frac{1}{4}\text{ span length} = \frac{1}{4}(22 \times 12) = 66 \text{ in.} \quad \longleftarrow \text{Controls}$$

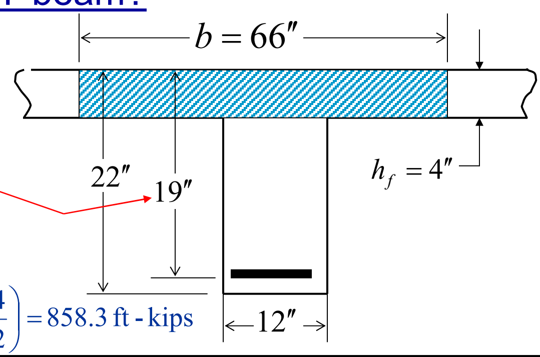
$$b_w + 16h_f = 12 + 16(4) = 76 \text{ in.}$$

$$\text{beam spacing} = 8 \times 12 = 96 \text{ in.}$$

Therefore, use $b = 66$ in. (smallest)

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)
  - Find out what type of beam to be used for design analysis, i.e., Is it a rectangular T-beam or a true T-beam?



$$\phi M_{nf} = \phi(0.85 f_c')bh_f\left(d - \frac{h_f}{2}\right)$$

$$= \frac{0.9(0.85)(3)(66)(4)}{12}\left(19 - \frac{4}{2}\right) = 858.3 \text{ ft-kips}$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Because (ϕM_{nf} = 858.3 ft-k) > (M_u = 291 ft-k), therefore $a < h_f$, and the total effective flange need not be completely used in compression.

The beam can be analyzed as rectangular T-beam

Design a rectangular beam:

$$\text{required } R = \frac{M_u}{\phi bd^2} = \frac{291 \times 12}{0.9(66)(19)^2} \times 1000 = 162.84 \text{ psi}$$

$$\text{required } \rho = 0.0028 \text{ From Table 9}$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Table A-5 (Handout)

Table 9.
Coefficient of Resistance

ρ	$\bar{k}$
0.0020	117.1800
0.0021	122.8883
0.0022	128.5849
0.0023	134.2674
0.0024	139.9357
0.0025	145.5900
0.0026	151.2301
0.0027	156.8562
0.0028	162.4681
0.0029	168.0659
0.0030	173.6496
0.0031	179.2192

Value used in the example. (0.0028)

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)
  - Calculate the required steel area:

$$\text{required } A_s = \rho b d = 0.0028(66)(19) = 3.51 \text{ in}^2$$

  - Select the steel bars:

Use 3 #10 bars ($A_s = 3.81 \text{ in}^2$) From Table 6

Table 7 → Minimum $b_w = 10.5 \text{ in.} < 12 \text{ in.}$ OK

  - Check the effective depth, *d*:

Diameter of #3 Stirrup See Table 8

Diameter of #10 bar See Table 8

$$d = 22 - 1.5 - 0.375 - \frac{1.27}{2} = 19.49 \text{ in.}$$

19.49 in. > 19 in. OK

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Table 6. Areas of Multiple of Reinforcing Bars (in^2)

Number of bars	Bar number #3	#4	$5	#6	#7	#8	#9	#10	#11
1	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56
2	0.22	0.40	0.62	0.88	1.20	1.58	2.00	2.54	3.12
3	0.33	0.60	0.93	1.32	1.80	2.37	3.00	3.81	4.68
4	0.44	0.80	1.24	1.76	2.40	3.16	4.00	5.08	6.24
5	0.55	1.00	1.55	2.20	3.00	3.95	5.00	6.35	7.80
6	0.66	1.20	1.86	2.64	3.60	4.74	6.00	7.62	9.36
7	0.77	1.40	2.17	3.08	4.20	5.53	7.00	8.89	10.92
8	0.88	1.60	2.48	3.52	4.80	6.32	8.00	10.16	12.48
9	0.99	1.80	2.79	3.96	5.40	7.11	9.00	11.43	14.04
10	1.10	2.00	3.10	4.40	6.00	7.90	10.00	12.70	15.60

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

OK

Table 7. Minimum Required Beam Width, b (in.)

Number of bars	Bar number # 3 and #4	$5	#6	#7	#8	#9	#10	#11
2	6.0	6.0	6.5	6.5	7.0	7.5	8.0	8.0
3	7.5	8.0	8.0	8.5	9.0	9.5	10.5	11.0
4	9.0	9.5	10.0	10.5	11.0	12.0	13.0	14.0
5	10.5	11.0	11.5	12.5	13.0	14.0	15.5	16.5
6	12.0	12.5	13.5	14.0	15.0	16.5	18.0	19.5
7	13.5	14.5	15.0	16.0	17.0	18.5	20.5	22.5
8	15.0	16.0	17.0	18.0	19.0	21.0	23.0	25.0
9	16.5	17.5	18.5	20.0	21.0	23.0	25.5	28.0
10	18.0	19.0	20.5	21.5	23.0	25.5	28.0	31.0

Note that beam width b_w = 12 in.

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Table 8. Reinforced Steel Properties

Bar number	3	4	5	6	7	8	9	10	11	14	18
Unit weight per foot (lb)	0.376	0.668	1.043	1.502	2.044	2.670	3.400	4.303	5.313	7.650	13.60
Diameter (in.)	0.375	0.500	0.625	0.750	0.875	1.000	1.128	1.270	1.410	1.693	2.257
Area (in^2)	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27	1.56	2.25	4.00

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Alternative Method for finding required A_s:

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{A_s(60)}{0.85(3)(66)} = 0.3565 A_s$$

$$Z = d - \frac{a}{2} = 19 - \frac{0.3565 A_s}{2}$$

$$\phi M_n = M_u = 291 \times 12 = \phi A_s f_y Z = 0.9 A_s (60)\left(19 - \frac{0.3565 A_s}{2}\right)$$

or,

$$9.6255 A_s^2 - 1026 A_s + 3492 = 0 \qquad \text{(Quadratic Eq.)}$$

From which,

$$A_s = 3.52 \text{ in}^2$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)
  - Check A_s,min from Table 3:

$$A_{s,\min} = 0.0033 b_w d$$
$$= 0.0033(12)(19) = 0.75 \text{ in}^2$$
$$\left(A_s = 3.81 \text{ in}^2\right) > \left(A_{s,\min} = 0.75 \text{ in}^2\right) \qquad \text{OK}$$

  - Check strain limits for tension-controlled:

$$a = \frac{A_s f_y}{0.85 f'_c b} = \frac{(3.81)(60)}{0.85(3)(66)} = 1.38 \text{ in.} < h_f = 4.0 \text{ in.}$$

$$\varepsilon_t = 0.003\left(\frac{d_t}{c} - 1\right) = 0.003\left(\frac{19.49}{1.38/0.85} - 1\right) = 0.033 >> 0.005 \text{ Strain OK}$$

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

Table 3
Design Constants

Values used in the example.

f'_c (psi)	$\max\left(\frac{3\sqrt{f'_c}}{f_y}, \frac{200}{f_y}\right)$	ρ_b
$f_y = 40{,}000$ psi		
3000	0.0050	0.03712
4000	0.0050	0.04949
5000	0.0053	0.05823
6000	0.0058	0.06551
$f_y = 50{,}000$ psi		
3000	0.0040	0.02753
4000	0.0040	0.03671
5000	0.0042	0.04318
6000	0.0046	0.04858
$f_y = 60{,}000$ psi		
3000	0.0033	0.02138
4000	0.0033	0.02851
5000	0.0035	0.03354
6000	0.0039	0.03773
$f_y = 75{,}000$ psi		
3000	0.0027	0.01552
4000	0.0027	0.02069
5000	0.0028	0.02435
6000	0.0031	0.02739

Trail-and-Adjustment Procedure for the Design of Flanged Sections

- Example 14 (cont'd)

  Final Detailed Sketch of the Design: