CHAPTER

3c

Prentice Hall

Prentice Hall Reinforced Concrete Design Fifth Edition

REINFORCED CONCRETE BEAMS: T-BEAMS AND DOUBLY REINFORCED BEAMS

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Part I – Concrete Design and Analysis

FALL 2002

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ENCE 355 - Introduction to Structural Design

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Procedure for Analysis of T-Beams For Moments

1. Establish the effective flange width, b based on ACI criteria.
2. Check $A_{s,\min}$. Use Table 1 (Table A-5, Textbook).
3. Check the ACI Code ductility requirements using the proper expression for $A_{s,\max}$ from Eq. 1 or Table 2 (Table 3-1, Textbook). $A_{s,\max}$ must be larger than actual A_s.

Procedure for Analysis of T-Beams For Moments

Table A-5 Textbook

Table 1
Design Constants

f'_c (psi)	$\left[\frac{3\sqrt{f'_c}}{f_y} \geq \frac{200}{f_y}\right]$	$\rho_{max} = 0.75\,\rho_b$	Recommended Design Values	
			ρ_b	$\bar{k}$ (ksi)
F_y = 40,000 psi				
3,000	0.0050	0.0278	0.0135	0.4828
4,000	0.0050	0.0372	0.0180	0.6438
5,000	0.0053	0.0436	0.0225	0.8047
6,000	0.0058	0.0490	0.0270	0.9657
F_y = 50,000 psi				
3,000	0.0040	0.0206	0.0108	0.4828
4,000	0.0040	0.0275	0.0144	0.6438
5,000	0.0042	0.0324	0.0180	0.8047
6,000	0.0046	0.0364	0.0216	0.9657
F_y = 60,000 psi				
3,000	0.0033	0.0161	0.0090	0.4828
4,000	0.0033	0.0214	0.0120	0.6438
5,000	0.0035	0.0252	0.0150	0.8047
6,000	0.0039	0.0283	0.0180	0.9657
F_y = 75,000 psi				
3,000	0.0027	0.0116	0.0072	0.4828
4,000	0.0027	0.0155	0.0096	0.6438
5,000	0.0028	0.0182	0.0120	0.8047
6,000	0.0031	0.0206	0.0144	0.9657

Procedure for Analysis of T-Beams For Moments

Table 2. Expressions for $A_{s,max}$ (T-Beams)

f'_c (psi)	f_y (psi)	$A_{s,max}$ (in^2)
3,000	40,000	$0.0478h_f\left\{b+b_w\left[\frac{0.582}{h_f}d-1\right]\right\}$
	60,000	$0.0319h_f\left\{b+b_w\left[\frac{0.503}{h_f}d-1\right]\right\}$
4,000	40,000	$0.0638h_f\left\{b+b_w\left[\frac{0.582}{h_f}d-1\right]\right\}$
	60,000	$0.0425h_f\left\{b+b_w\left[\frac{0.503}{h_f}d-1\right]\right\}$

Procedure for Analysis of T-Beams For Moments

- The check the ductility of a T-beam, the following equation can be used for various combinations of f_c' and f_y

$$A_{s,\max} = \frac{0.638}{f_y} f_c' h_f \left\{ b + b_w \left[\frac{\beta_b}{h_f} \left(\frac{87{,}000}{87{,}000 + f_y} d \right) - 1 \right] \right\} \qquad (1)$$

Procedure for Analysis of T-Beams For Moments

4. Compute the total tension in the steel:
$$N_T = A_s f_y$$
5. Compute the magnitude of the compression that the flange its is capable of furnishing:
$$N_{Cf} = 0.85 f_c' b h_f$$
6. If $N_T > N_{Cf}$, the beam will behave as a ***true T-beam***, and the remaining compression, which equals N_T - N_{Cf}

Procedure for Analysis of T-Beams For Moments

will be furnished by additional web area. If $N_T < N_{Cf}$, the beam will behave as a rectangular beam of width b.

Rectangular T-Beam

7. Compute the actual steel ratio in order to find $\bar{k}$:

$$\rho = \frac{A_s}{bd}$$

Procedure for Analysis of T-Beams For Moments

8. Consult the proper Table 3, (Tables A-7 to A-11, Text) and find the required $\bar{k}$ for the ρvalue from step 7.
9. Compute the practical moment capacity ϕM_n of the beam cross section:

$$\phi M_n = \phi b d^2 \bar{k}$$

Procedure for Analysis of T-Beams For Moments

Sample Values

Table 3.
Coefficient of Resistance

Table A-10 Textbook

ρ	$\bar{k}$
0.0010	0.0595
0.0011	0.0654
0.0012	0.0712
0.0013	0.0771
0.0014	0.0830
0.0015	0.0888
0.0016	0.0946
0.0017	0.1005
0.0018	0.1063
0.0019	0.1121
0.0020	0.1179
0.0021	0.1237

Procedure for Analysis of T-Beams For Moments

True T-Beam

7. Determine the depth of the compressive stress block:

$$a = \frac{N_T - N_{Cf}}{0.85 f'_c b_w} + h_f$$

8. (a) Locate the centroid of the total compressive area referenced to top of the flange using the relationship

Procedure for Analysis of T-Beams For Moments

$$\bar{y} = \frac{\sum Ay}{\sum A}$$

From which

$$Z = d - \bar{y}$$

Compute the practical moment capacity ϕM_n of the beam:

$$\phi M_n = \phi N_C Z \quad \text{or} \quad \phi N_T Z$$

Procedure for Analysis of T-Beams For Moments

Or

(b) Calculate ϕM_n using a summation of internal couples contributed by the flange and the web:

$$\phi M_n = \phi\left\{N_{Cf}\left(d - \frac{h_f}{2}\right) + \left(N_T - N_{Cf}\right)\left[d - h_f\left(\frac{a - h_f}{2}\right)\right]\right\}$$

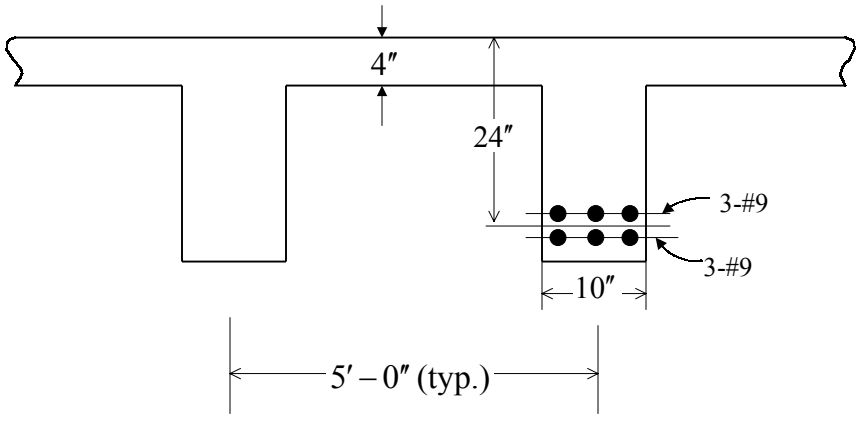
Procedure for Analysis of T-Beams For Moments

- Example 1: T-Beam Analysis

  Determine the practical moment capacity ϕM_n for the T-beam in the floor system shown. The beam span is 24 in. Use f_y = 60,000 psi and f'_c = 3,000 psi. Check the steel to ensure that it is within allowable limits according to the ACI Code.

Procedure for Analysis of T-Beams For Moments

- Example 1: T-Beam Analysis (cont'd)



Procedure for Design of T-Beams For Moments

1. Compute the design moment M_u.
2. Assume that the effective depth d is equal to $h - 3$ in.
3. Establish the effective flange width based on ACI criteria.
4. Compute the practical moment strength ϕM_{nf} assuming that the total effective flange is in compression:

$$\phi M_{nf} = \phi(0.85 f'_c) b h_f \left(d - \frac{h_f}{2} \right)$$

Procedure for Design of T-Beams For Moments

5. If $\phi M_{nf} > M_u$ the beam will behave as ***rectangular T-beam*** of width b. Otherwise, the beam will behave as a ***true T-beam***.

Rectangular T-Beam

6. Design as a rectangular beam with b and d as known values. Compute the required $\bar{k}$:

$$\text{required } \bar{k} = \frac{M_u}{\phi b d^2}$$

Procedure for Design of T-Beams For Moments

7. From the tables in Appendix A of textbook (see Table 3), determine the required ρ for the required $\bar{k}$ of step 6.
8. Compute the required A_s:

$$\text{required } A_s = \rho bd$$

9. Select bars and check the beam width. Check the actual d and compare it with the assumed d. If the actual d is slightly in excess of the assumed d,

Procedure for Design of T-Beams For Moments

the design will be slightly conservative. If the actual d is less than the assumed d, the design may be on the nonconservative side (depending on the steel provided) and should be more closely investigated for possible revision.

10. Check $A_{s,\min}$. Use Table 1 (Table A-5, Textbook).

Procedure for Design of T-Beams For Moments

11. Check the ACI ductility requirement using the proper expression for $A_{s,\max}$ from Table 2 (Table 3-1 Text) or Eq. 1. Note that $A_{s,\max}$ must be larger than actual A_s.
12. Sketch the design.

Procedure for Design of T-Beams For Moments

True T-Beam

6. Using an estimated $d_f = h - 3$ in. and $Z_f = d_f - h_f/2$, determine the steel area A_s required for the flange couple:

$$\text{required } A_{sf} = \frac{\phi M_{nf}}{\phi f_y Z_f}$$

7. Design the web couple as a rectangular reinforced concrete beam

Procedure for Design of T-Beams For Moments

having a total depth $h_w = h - h_f$ using an estimated $d_w = h_w - 3$ in. and a beam width of b_w. Design for an applied moment M_u - ϕM_{nf}. Determine required k, required ρ, and required $A_{sw.}$

8. Total required $A_{sw} = A_{sf} + A_{sw}$.
9. Select the bars. Bars must fit into beam width b_w. Check d as in step 9

Procedure for Design of T-Beams For Moments

of the rectangular T-beam design.

10. Check $A_{s,\min}$. Use Table 1 (Table A-5, Textbook).
11. Check $A_{s,\max}$. Use Table 2 (Table 3-1, Textbook) or Eq. 1.
12. Sketch the design.

Procedure for Design of T-Beams For Moments

- Example: T-Beam Design

  Design a T-beam having a cross section shown in the figure. Assume that the effective flange width given is acceptable. The T-beam will carry a total design moment M_u of 340 ft-kips. Use f'_c = 3,000 psi and f_y = 60,000 psi. Use 1.5-in. cover and No. 3 stirrups.

Procedure for Design of T-Beams For Moments

- Example: T-Beam Design (cont'd)