

CHAPTER 2 - SECTION 6

REINFORCED CONCRETE (RC)

The BARS system allows the analyst a choice in how the section properties are computed for reinforced concrete members. This section will discuss the formulation of section properties using the Allowable Stress method, assuming a straight line relationship exists between stress and strain, as recommended by the current AASHTO Manual for Maintenance Inspection Specification and the current AASHTO Standard Specification. Other analysis choices include Load Factor method, which is discussed in Division III.

In its calculation of properties, BARS develops an effective section modulus for reinforced concrete sections. This is used to calculate a resisting capacity of the section for stress calculation. In addition, moments of inertia are calculated for continuous beam stiffness calculations.

The concrete dimensions and primary (i.e., longitudinal) reinforcing steel bars are defined on input by means of the Type 13 forms (see Manual 2). Reinforcing bars may be tensile reinforcing only, or, if the analyst so desires, he may indicate that certain bars may act for both tension and compression. If this special indication is not made, the system assumes that the steel is used for tension only and should not be used for compression. Reinforcing steel is determined to be in tension or compression by its position in relation to the section neutral axis. Stirrups and bent up bars are defined by the input of data, on Type 17 forms, when a Shear Rating analysis is desired.

For each reinforced concrete section, four section moduli are calculated on a cracked section basis, two for positive bending, two for negative bending. One section modulus of each pair is for moment resisting capacity based on concrete and the other for moment resisting capacity based on reinforcing steel. In addition, two moments of inertia are calculated on a partially cracked section basis, one for positive bending and the other for negative bending. The section moduli that are computed for resistance to live load are derived using an "n" the modular ratio value, computed in accordance with the current AASHTO Standard Specifications as follows:

$$n = \frac{E_s}{E_c} \text{ where } \begin{array}{l} E_{\text{steel}} = 29,000,000 \\ E_{\text{concrete}} = 57,000\sqrt{f_c} \end{array}$$

For a reinforced concrete section with flanges (i.e., Tee's, I's, and boxes), the system by default determines that the flanges are not considered acting in the calculation of moment of inertia when they are on the tension side of the neutral axis. For a Tee section with flange on top, the moment of inertia is calculated including the flange for moments yielding compression on the top, but it is calculated as an uncracked rectangular section without flanges for moments yielding tension side of the neutral axis not considered in the calculation. This default designation can be changed using input from the Type 08 form as described in Manual 2. As a result, the use of the "X" code in column 67 of the Type 08 form will cause the system to use the entire moment of inertia and gross area of the reinforced concrete member for stiffness calculations.

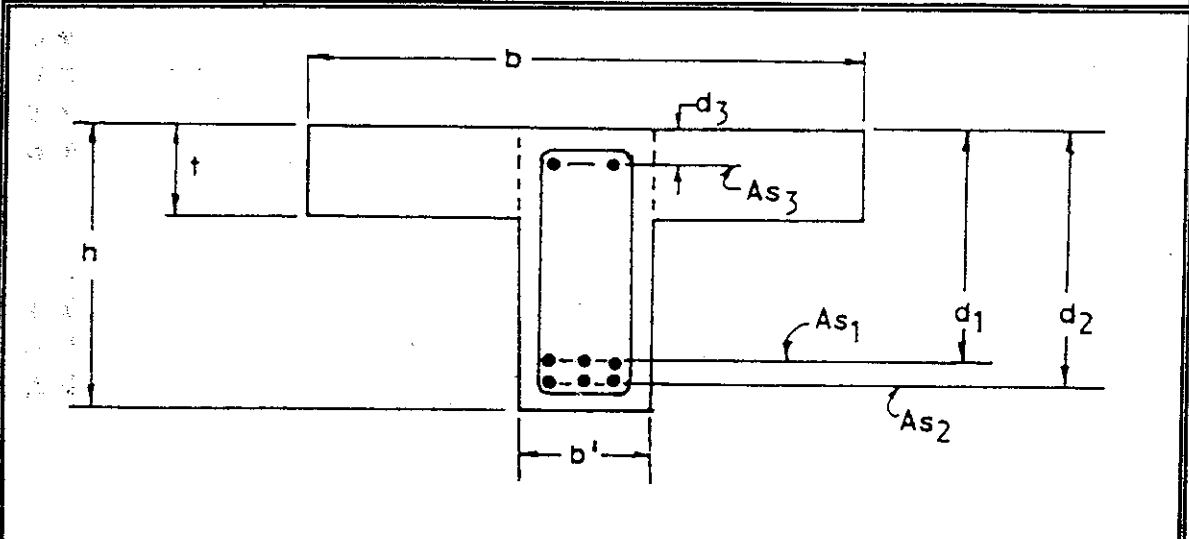
Figure 10 shows a sketch of a typical reinforced concrete T-beam with both tensile and compressive reinforcing steel. Under the sketch is the general formulation used in the calculation of section properties for reinforced concrete. Figure 11 shows the additional formulation used to calculate the constant j in the most general case (i.e., T-beam with compressive reinforcement).

On the three succeeding pages, Figures 12, 13, and 14 show how the formulas for obtaining j become successively more simplified for:

- 12: T-beam without compressive reinforcement.
- 13: Rectangular beam with compressive reinforcement
- 14: Rectangular beam without compressive reinforcement.

Figure 15 shows the nomenclature and the formulation used to calculate the shear capacity. These formulas are in accordance with the current AASHTO Specifications. Figures 16A and 16B show the calculation of the section properties for additional types of Reinforced Concrete Box Girders that the BARS system can analyze.

FIGURE 10
 CALCULATION OF SECTION PROPERTIES
 FLEXURAL MEMBER
 REINFORCED CONCRETE



$$AREA = (b-b')t + b'h \quad (1-39)$$

$$I_x = \frac{1}{12}b'h^3 + \frac{1}{12}(b-b')t^3 + t\left(\frac{h-t}{2}\right)^2(b-b')\left[\frac{b'h}{(b-b')(t+b'h)}\right] \quad (1-40)$$

$$A_{RET} = b'h \quad (1-41)$$

$$I_{RET} = \frac{1}{12}b'h^3 \quad (1-42)$$

$$A_{BOT} = A_{s1} + A_{s2} \quad D_{BOT} = \frac{A_{s1}d_1 + A_{s2}d_2}{A_{BOT}}$$

$$A_{TOP} = A_{s3} \quad D_{TOP} = d_3$$

FOR POSITIVE BENDING:

$$A_s = A_{BOT} \quad d = D_{BOT}$$

$$A'_s = A_{TOP} \quad d' = D_{TOP} \quad I = I_x$$

FOR NEGATIVE BENDING:

$$A_s = A_{TOP} \quad d = h - D_{TOP}$$

$$A'_s = A_{BOT} \quad d' = h - D_{BOT} \quad I = I_{RET}$$

$$E_s = 29,000,000 \text{ psi}$$

For normal weight and light weight concrete:

$$E_c = 57,000\sqrt{f'_c}$$

FIGURE 11
 T-BEAM WITH COMPRESSIVE REINFORCEMENT

$n =$ Value determined from f_c' , in accordance with the current AASHTO Standard Specifications.

$$m = \frac{nA_s}{b'd} + \frac{(2n-1)A_s'}{b'd} + \frac{t(b-b')}{b'd} \quad (1-43)$$

$$q = \frac{nA_s}{b'd} + \left[\frac{(2n-1)A_s'}{b'd} \left[\frac{d'}{d} \right] + \left[\frac{t(b-b')}{b'd} \right] \left[\frac{t}{2} \right] \right] \quad (1-44)$$

$$k = \sqrt{m^2 + 2q} - m \quad (1-45)$$

$$y = \frac{1 - \frac{2t}{3kd}}{2 - \frac{t}{kd}} \quad (1-46)$$

$$j = 1 - \frac{\frac{k^2}{6} + \left[\frac{(2n-1)A_s'}{b'd} \right] \left[\frac{d'}{d} \right] \left[1 - \frac{d'}{kd} \right] + \left[\frac{t(b-b')}{b'd} \right] \left[\frac{yt}{d} \right] \left[1 - \frac{t}{kd} \right]}{\frac{k}{2} + \left[\frac{(2n-1)A_s'}{b'd} \right] \left[1 - \frac{d'}{kd} \right] + \left[\frac{t(b-b')}{b'd} \right] \left[1 - \frac{t}{kd} \right]} \quad (1-47)$$

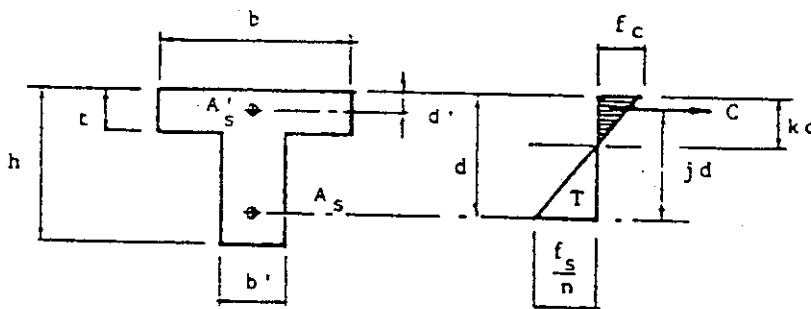


FIGURE 12
 T-BEAM WITHOUT COMPRESSIVE REINFORCEMENT

n = Value determined from f_c' , in accordance with
 the current AASHTO Standard Specifications

$$A_s' = 0$$

$$m = \frac{nA_s}{b'd} + \frac{t(b-b')}{b'd} \quad (1-48)$$

$$k = \sqrt{m^2 + 2q} - m \quad (1-45)$$

$$q = \left[\frac{nA_s}{b'd} \right] + \left[\frac{t(b-b')}{b'd} \right] \left[\frac{t}{d} \right] \quad (1-49)$$

$$y = \frac{1 - \frac{2t}{3kd}}{2 - \frac{t}{kd}} \quad (1-46)$$

$$j = 1 - (k) \left[\frac{\frac{1}{6} + \left[\frac{t(b-b')}{kb'd} \right] \left[\frac{y^2}{kd} \right] \left[1 - \frac{t}{2kd} \right]}{\frac{1}{2} + \left[\frac{t(b-b')}{kb'd} \right] \left[1 - \frac{t}{2kd} \right]} \right] \quad (1-50)$$

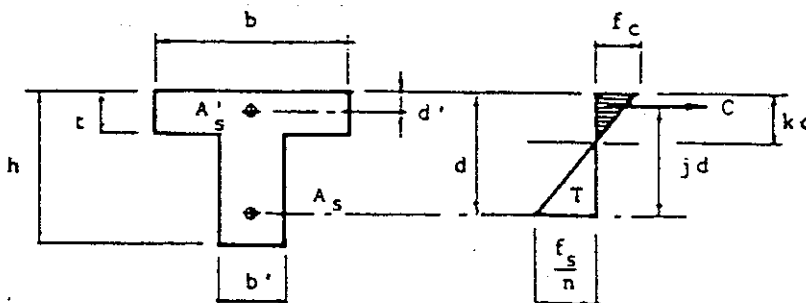


FIGURE 13
 RECTANGULAR BEAM WITH COMPRESSIVE REINFORCEMENT

n = Value determined from f'_c , in accordance with
 the current AASHTO Standard Specifications

$$b = b' \quad b - b' = 0$$

$$m = \frac{nA_s}{b'd} + \frac{(2n-1)A'_s}{b'd} \quad (1-51)$$

$$q = \frac{nA_s}{b'd} + \frac{(2n-1)A'_s}{b'd} \left[\frac{d'}{d} \right] \quad (1-52)$$

$$k = \sqrt{m^2 + 2q} - m \quad (1-45)$$

$$j = 1 - (k) \left[\frac{\frac{1}{6} + \left[\frac{(2n-1)A'_s}{b'd} \right] \left[\frac{d'}{kd} \right] \left[1 - \frac{d'}{kd} \right]}{\frac{1}{2} + \left[\frac{(2n-1)A'_s}{kb'd} \right] \left[1 - \frac{d'}{kd} \right]} \right] \quad (1-53)$$

FIGURE 14
 RECTANGULAR BEAM WITHOUT COMPRESSIVE REINFORCEMENT

n = Value determined from f'_c , in accordance with
 the current AASHTO Standard Specifications

$$A'_s = 0 \qquad b - b' = 0 \qquad (1-54)$$

$$m = q = \frac{nA_s}{b'd}$$

$$k = \sqrt{m^2 + 2q} - m \qquad (1-45)$$

$$j = 1 - \frac{k}{3} \qquad (1-55)$$

FIGURE 15
 CALCULATION OF SECTION PROPERTIES
 FLEXURAL MEMBER - SHEAR ANALYSIS
 REINFORCED CONCRETE

$$V_{CAP} = V_c + V_s$$

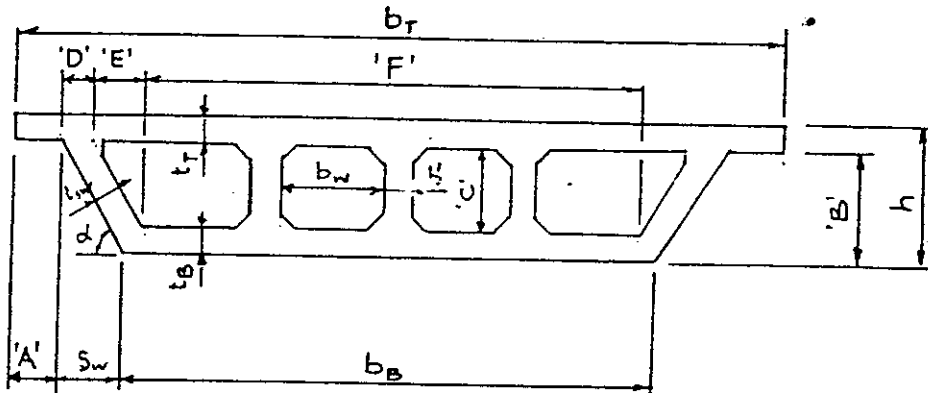
where :

V_{CAP} = Shear Capacity for Concrete

V_c = Nominal Shear Strength provided by the concrete portion of the beam and is determined based on the current AASHTO Specifications.

V_s = Nominal Shear Strength provided by the shear reinforcement and is determined based on the current AASHTO Specifications.

FIGURE 16
 CALCULATION OF SECTION PROPERTIES
 REINFORCED CONCRETE BOX GIRDER SECTION



$$\text{Dimension 'A'} = \frac{(b_T - b_B - 2 * S_w)}{2}$$

$$\text{Dimension 'B'} = h - t_T$$

$$\text{Dimension 'C'} = (\text{DIM 'B'}) - t_B$$

If $S_w = 0$, DIM 'E' = 0, $t_{sw} = b'$, DIM 'D' = b' , go to DIM 'F'

$$\tan(\alpha) = (\text{DIM 'B'} / S_w)$$

$$* \text{Dimension 'D'} = t_{sw} / \sin(\alpha)$$

$$* \text{Dimension 'E'} = \text{DIM 'C'} / \tan(\alpha)$$

$$\text{Dimension 'F'} = b_T - 2 [\text{DIM 'A'} + \text{DIM 'D'} + \text{DIM 'E'}]$$

Input N = number of voids

$$bw1 = \frac{[\text{DIM 'F'} - (n-1) (b') - (n-2) (bw)]}{2}$$

NOTE: gross void interior = $bw * \text{DIM 'C'}$
 void exterior = $(bw + (\text{DIM 'E'}/2) * \text{DIM 'C'})$