Balanced, Tension-Controlled, and Compression-Controlled or Brittle Sections and Failure

Q. Define Balanced Sections, Tension-Controlled Sections, and Compression-Controlled or Brittle Sections_

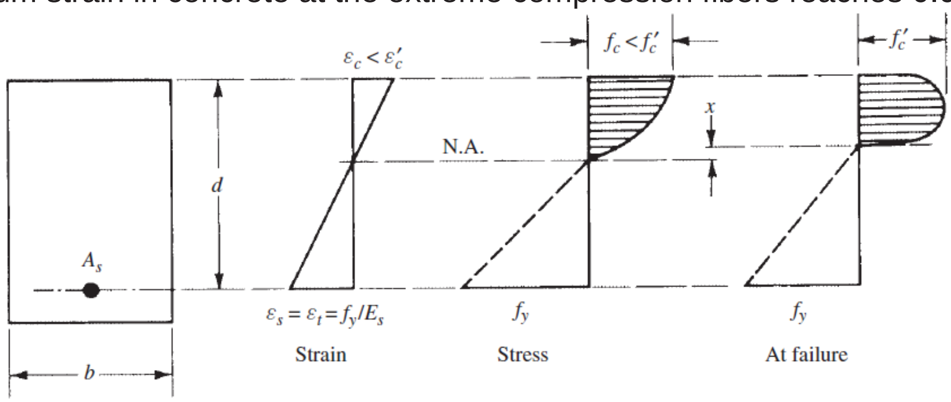
The design provisions for both reinforced and prestressed concrete members are based on the concept of tension or compression-controlled sections, ACI Code, Section 10.3.

1. Compression-controlled sections are those sections in which the net tensile strain, NTS, in the extreme tension steel at nominal strength is equal to or less than the compression controlled strain limit at the time when concrete in compression reaches its assumed strain limit of 0.003, (εc = 0.003). For grade 60 steel, (fy = 60 ksi), the compression-controlled strain limit may be taken as a net strain of 0.002. This case occurs mainly in columns subjected to axial forces and moments.

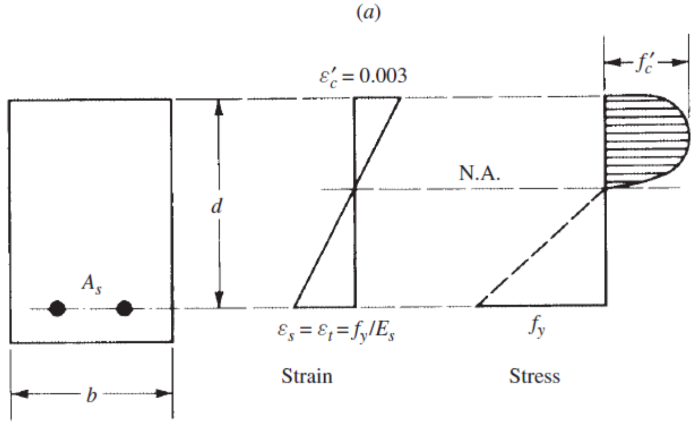
2. Tension-controlled sections are those sections in which the NTS, εt , is equal to or greater than 0.005 just as the concrete in the compression reaches its assumed strain limit of 0.003.

3. Sections in which the NTS in the extreme tension steel lies between the compression controlled strain limit (0.002 for fy = 60 ksi) and the tension-controlled strain limit of 0.005 constitute the transition region.

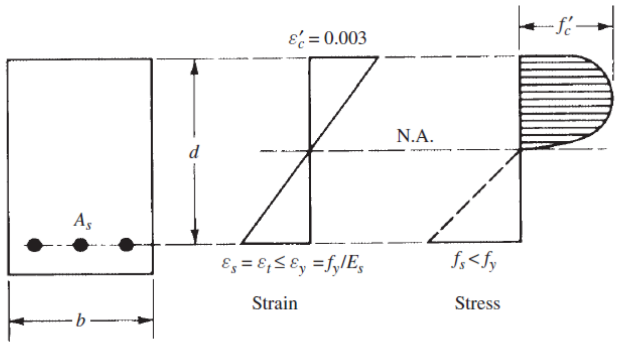
4. The **balanced strain condition** develops in the section when the tension steel, with the first yield, reaches a strain corresponding to its yield strength, fy or $\varepsilon s = fy/Es$, just as the maximum strain in concrete at the extreme compression fibers reaches 0.003.



(a)



(b)



(c)

Figure: Stress and strain diagrams for (a) tension-controlled, (b) balanced, and (c) compression-controlled sections.

Table: Strain Limits

Section Condition	Concrete Strain	Steel Strain	Notes (f_y = 60 ksi)
Compression controlled	0.003	$\varepsilon_t \le f_y/E_s$	$\varepsilon_t \le 0.002$
Tension controlled	0.003	$\varepsilon_t \ge 0.005$	$\varepsilon_t \ge 0.005$
Transition region	0.003	$f_y/E_s < \varepsilon_t < 0.005$	$0.002 < \varepsilon_t < 0.005$
Balanced strain	0.003	$\varepsilon_s = f_y/E_s$	$\varepsilon_s = 0.002$
Transition region (flexure)	0.003	$0.004 \le \varepsilon_t < 0.005$	$0.004 \le \varepsilon_t < 0.005$

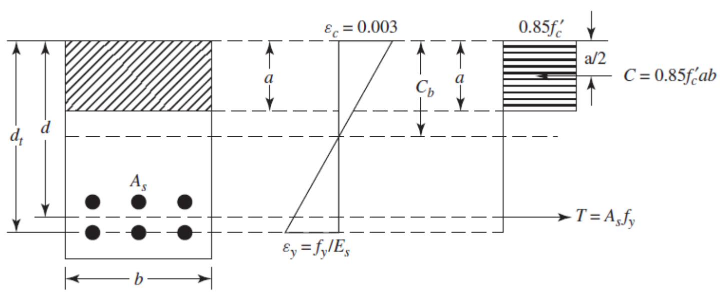


Figure: Rectangular balanced section.

$$\rho_b = \frac{A_s(\text{balanced})}{bd} = \frac{A_{sb}}{bd}$$

$$\rho_b = 0.85\beta_1 \frac{f_c'}{f_y}\left(\frac{87}{87 + f_y}\right)\left(\frac{d_t}{d}\right)$$

$$\overline{\rho_b} = \alpha \frac{f_c'}{f_y} \frac{\epsilon_u}{\epsilon_u + \epsilon_y}$$

substituting ε_u = 0.003 and E_s = 29,000 ksi

$$\overline{\rho_b} = 0.85\beta_1 \frac{f_c'}{f_y}\left(\frac{87{,}000}{87{,}000 + f_y}\right)$$

Here $\beta_1 = 0.85$ for $f_c' \le 4000$ psi (27.6 MPa) and decreases linearly by 0.05 per 1000 psi (6.9 MPa) for higher concrete strengths

The value of *dt* is equal to *d* when only one single layer of steel is provided.