Design of Reinforced Concrete Beams per ACI 318-14

An Online Continuing Education Course for Engineers

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Reinforced concrete is made of two materials, concrete and reinforcing steel. Concrete is made of five parts:

- Air
- Water
- Cement, five main types per ASTM
- Sand, fine aggregate
- Gravel, course aggregate

The *compressive strength* (f_c') of concrete is the 28-day strength. This could be from 2,500 psi to 20,000 psi. Most concrete used is between 3,000 psi to 6,000 psi. Concrete is very good in compression but its *tensile strength* is only about 8 to 15% of the compressive strength. This is the reason why we need reinforcing steel. When we load a beam, the bottom is in tension.

Reinforcement could be fiber-reinforcement or reinforcing steel. In this course, we will only look at reinforcing steel. Reinforcing steel comes in the following sizes, areas, weights and diameters:

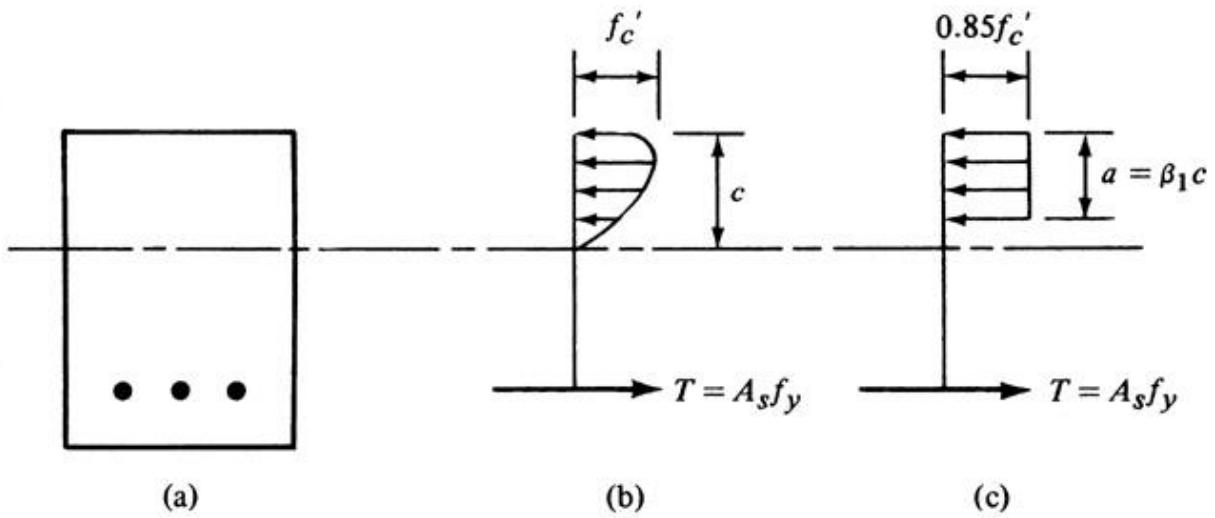
ASTM Standard Reinforcing Bars			
Bar Size	Area (in^2)	Weight (lbs/ft)	Diameter (in)
# 3	0.11	0.376	0.375
# 4	0.20	0.668	0.500
#5	0.31	1.043	0.625
# 6	0.44	1.502	0.750
# 7	0.60	2.044	0.875
# 8	0.79	2.670	1.000
# 9	1.00	3.400	1.128
# 10	1.27	4.303	1.270
# 11	1.56	5.313	1.410
# 14	2.25	7.650	1.693
# 18	4.00	13.600	2.257

Reinforcement steel comes in the following designations, types, grades, strengths.

ASTM Standard Reinforcing Steel Bars			
ASTM	Type	Grade	Strength (f_y)ksi
A615	Billet	40	40
		40	60
		75	75
		80	80
A616	Rail	50	50
		60	60
A617	Axle	40	40
		50	50
A706	Low-Alloy	60	60
		80	80
A996	Rail	50	50
		60	60
A996	Axle	40	40
		60	60

Not all sizes are available in every grade. For example, A615, Grade 40 only comes in sizes 3-6. A615, Grade 60 comes in sizes 3-18 and A615 grade 75 comes in sizes 6-18.

The stress distribution may be rectangular, parabolic, trapezoidal, etc. Here are two stress distributions, parabolic (b) and rectangular (c):



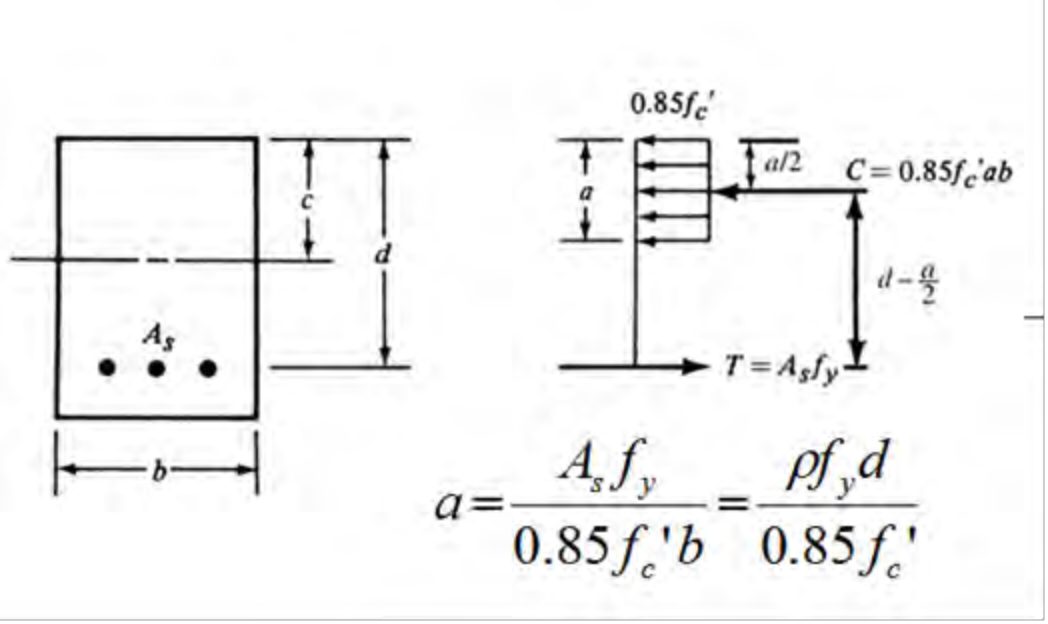
We use figure c, for rectangular beams.

We use table 22.2.2.4.3 to determine β_1

f_c', psi	β_1	
$2500 \leq f_c' \leq 4000$	0.85	(a)
$4000 < f_c' < 8000$	$0.85 - \frac{0.05\,(f_c' - 4000)}{1000}$	(b)
$f_c' \geq 8000$	0.65	(c)

The ACI code says design value must be greater than or equal to the required value.

$$\phi M_n \geq M_u$$
$$\varphi V_n \geq V_u$$
$$\varphi P_n \geq P_u$$



In the formula, ρ is the steel ratio, A_s / bd.

Beams are considered to be under three types of control:

Net tensile stain ε_t	**Classification**
$\varepsilon_t \leq \varepsilon_{ty}$	Compression-controlled
$\varepsilon_{ty} < \varepsilon_t < 0.005$	Transition[1]
$\varepsilon_t \geq 0.005$	Tension-controlled

From Table 21.2.2

We use a *strength reduction factor* to account for many uncertainties in the design. For tension-controlled beams, we use a *strength reduction factor* (φ) of 0.90.

ACI (9.6.1.2) specifies the minimum about of reinforcement by the following two formulas:

$$A_{s,\min} = \frac{3\sqrt{f_c'}}{f_y} b_w d$$

$$nor\ less\ than \frac{200\, b_w d}{f_y}$$

Note: When th…nulas, we use the formula that yi… and the other formula gives 1…lth of the beam.

ACI (22.2.2.1) st…ompression fiber shall be assumed…

40…					
50…					ρ max
600…				0.0377	ρ balanced
		0.0033	0.0035	0.0039	ρ min
	0.0135	0.0181	0.0213	0.0239	ρ max
75000	0.0155	0.0207	0.0243	0.0274	ρ balanced
	0.0027	0.0027	0.0028	0.0031	ρ min
	0.0108	0.0145	0.0170	0.0191	ρ max
f_y in psi					

It is desirable, under ordinary conditions, to design beams with a *steel ration* (ρ) between ρ min and ρ max.