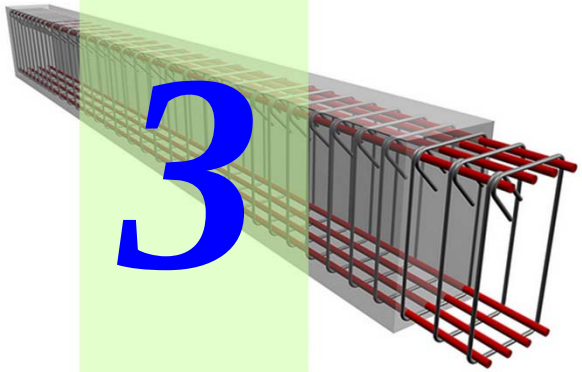
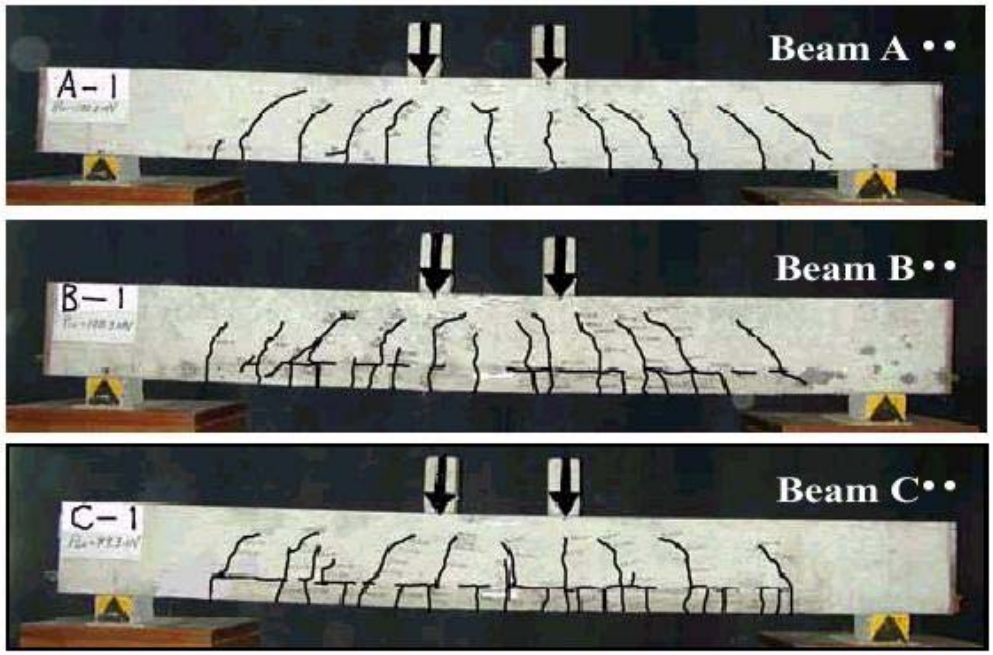


3

Reinforced Concrete Design II

Flexural Design of Beam Sections 1



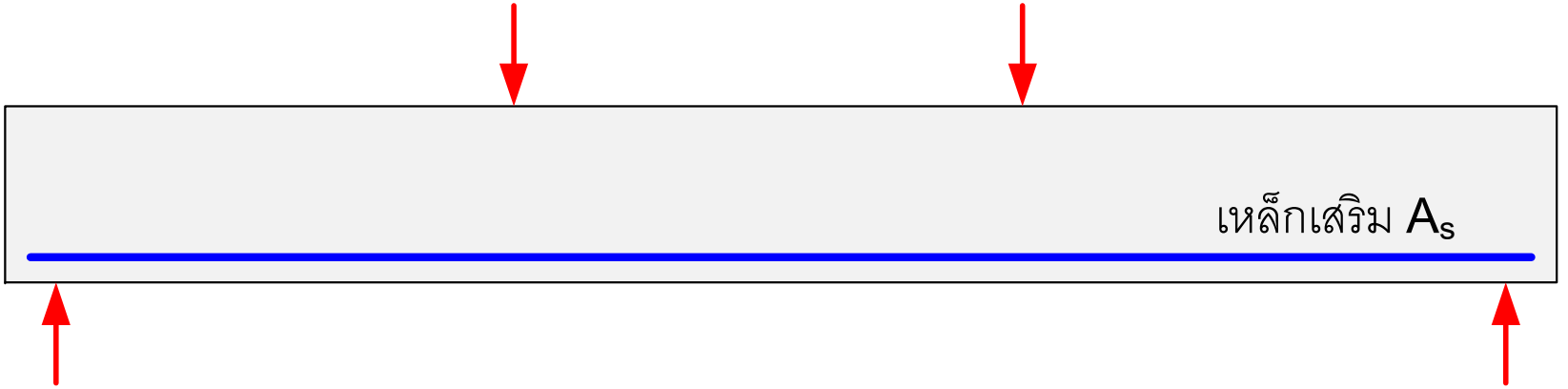
- Nominal Moment Strength
- Balance Steel Ratio
- Design Procedure
- Design Examples

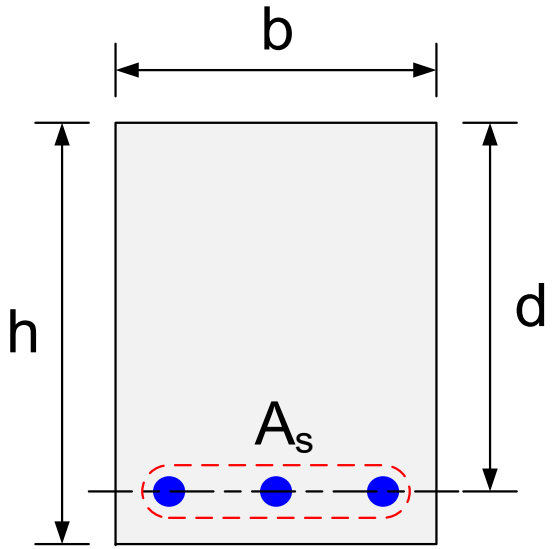
Mongkol JIRAVACHARADET

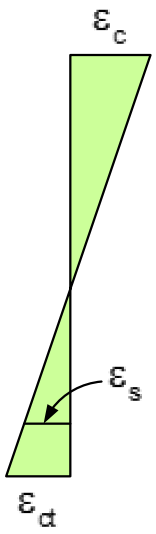
SURANAREE UNIVERSITY OF TECHNOLOGY

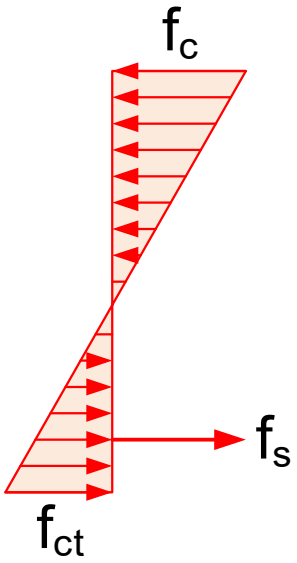
INSTITUTE OF ENGINEERING
SCHOOL OF CIVIL ENGINEERING

พฤติกรรมของคานคอนกรีตเสริมเหล็กก่อนเกิดการแตกร้าว

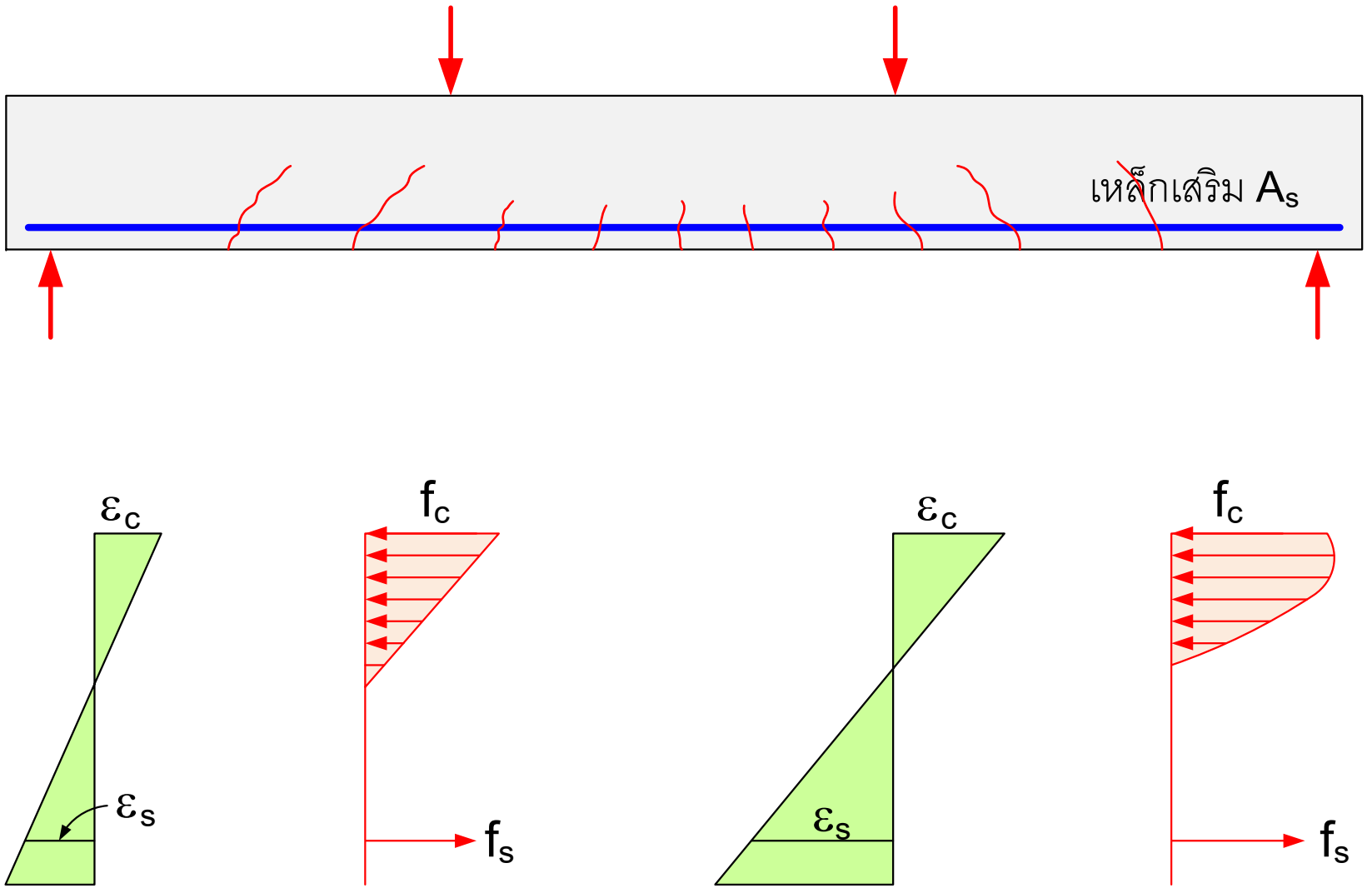




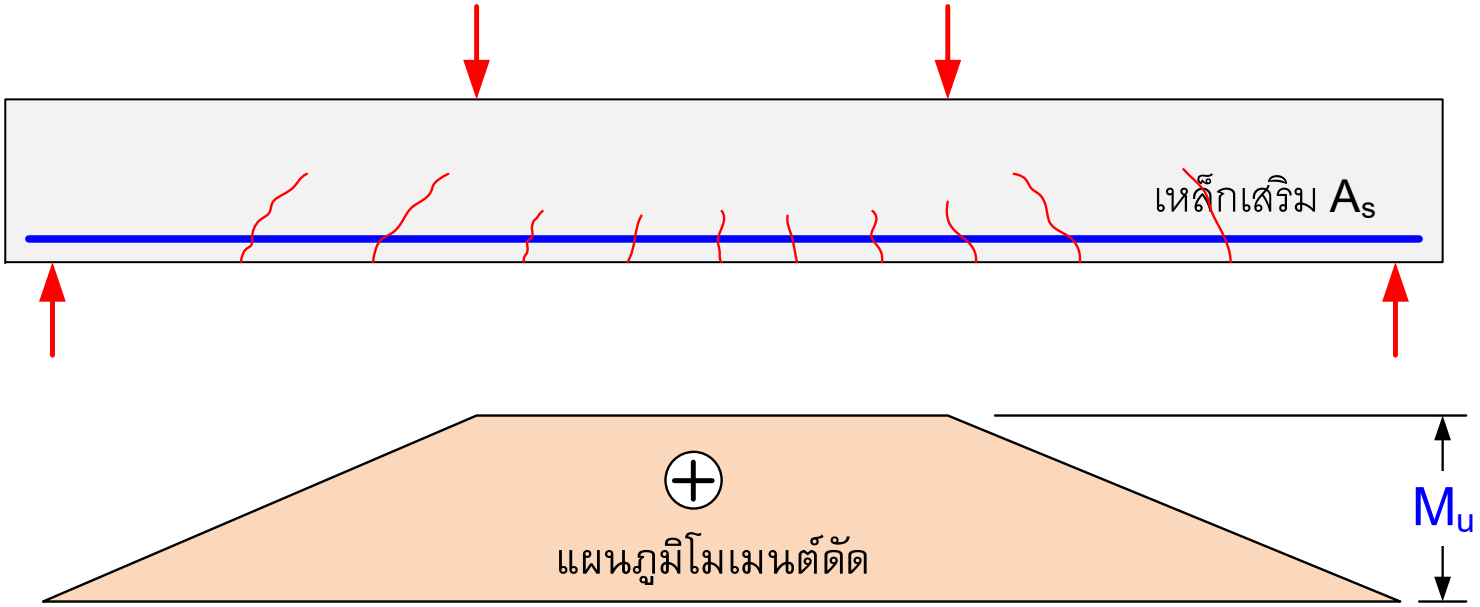


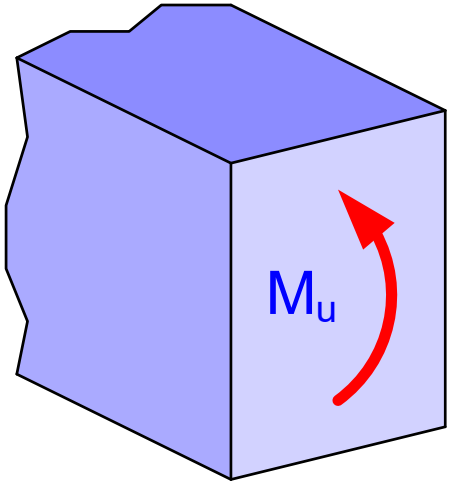


พฤติกรรมของคานคอนกรีตเสริมเหล็กหลังเกิดการแตกร้าว



Flexural Strength Design





กำลังดัดต้านทาน $\geq$ กำลังดัดที่ต้องการ

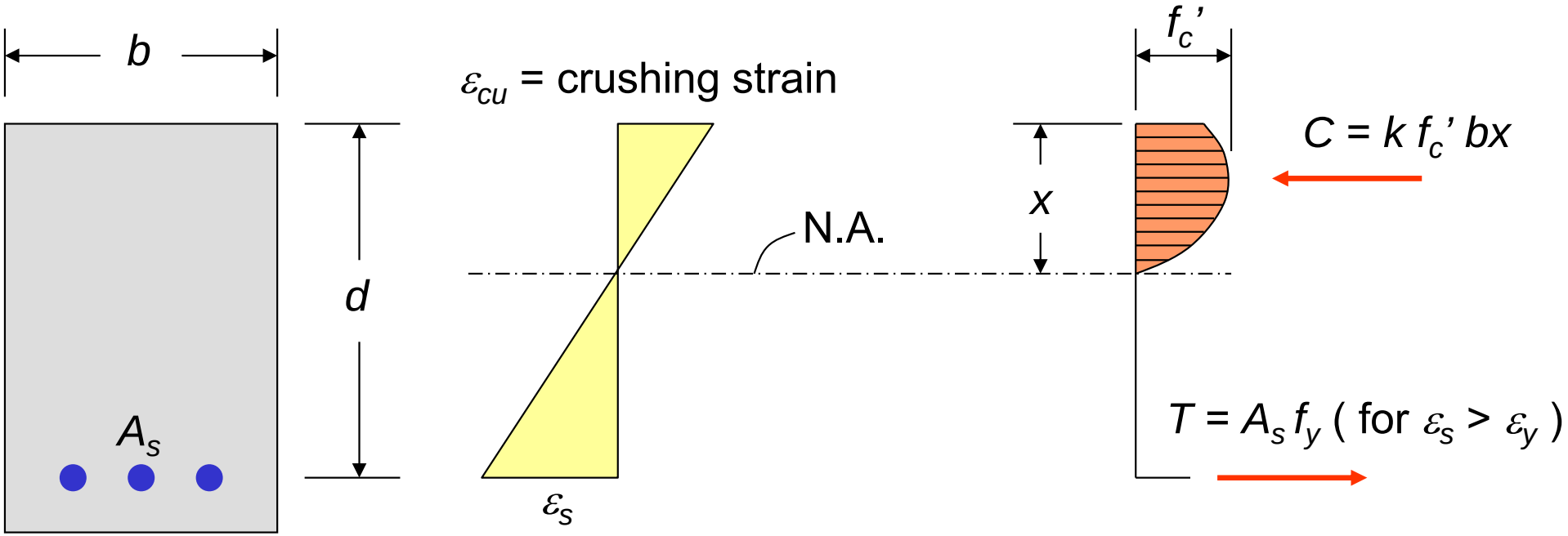
$$\phi M_n \geq M_u$$

M_u = Factored Moment

M_n = Nominal Moment

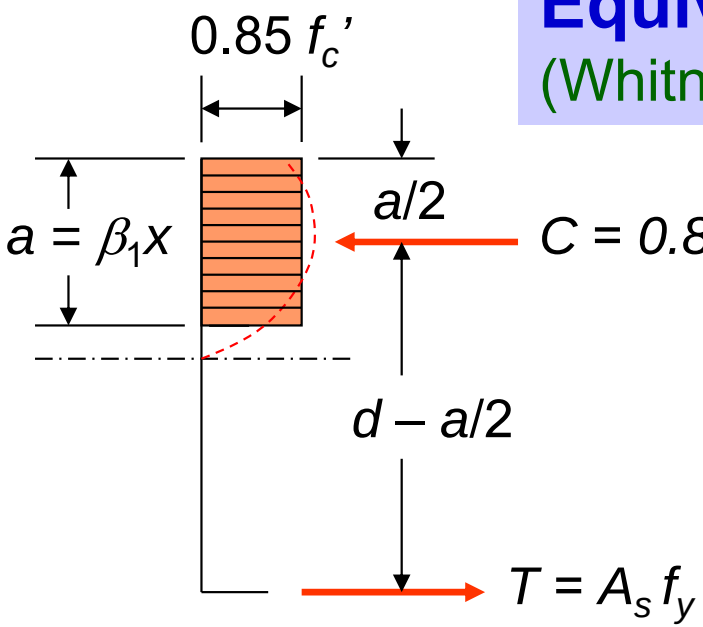
ϕ = 0.90 = Reduction Factor for tension in bending

Nominal Moment Strength (M_n)



Equivalent Stress Distribution

(Whitney stress block)

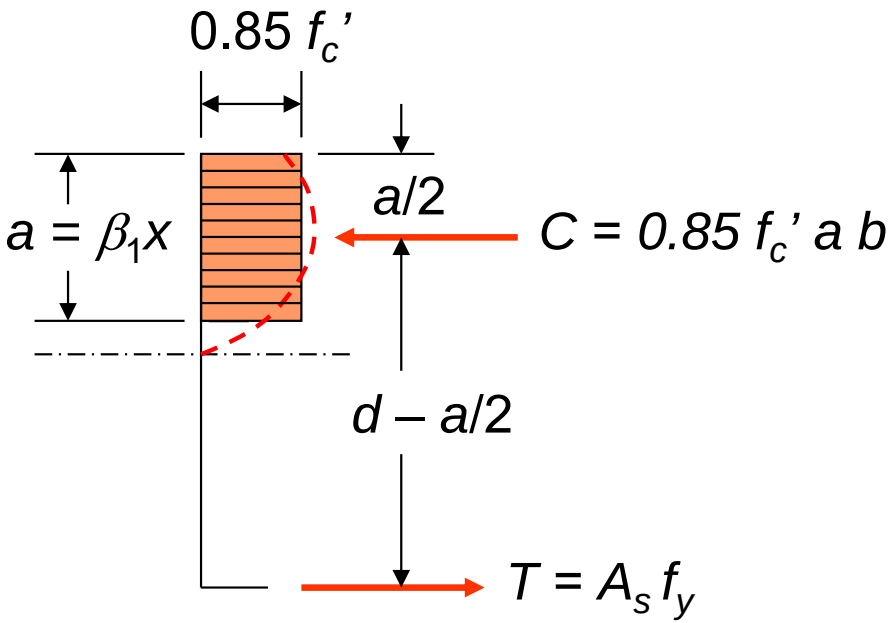


$[\Sigma F_x = 0]$ $\quad C = T$

$$0.85 f_c' a b = A_s f_y$$

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

Equivalent Stress Distribution
(Whitney stress block)



$$M_n = T(d - a/2) = A_s f_y \left(d - \frac{\rho f_y d}{2(0.85) f_c'} \right)$$

$$M_n = \rho f_y b d^2 \left(1 - \frac{\rho f_y}{1.7 f_c'} \right)$$

Flexural resistance factor $\boldsymbol{R_n}$:

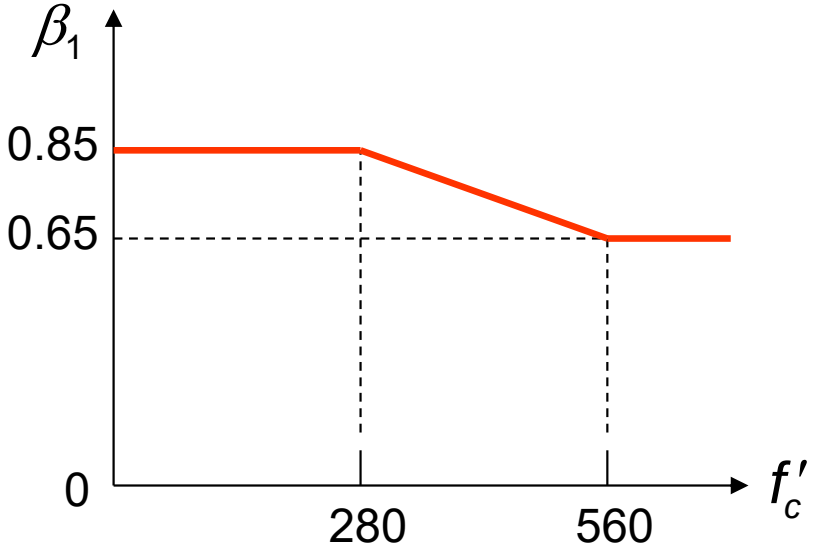
$$M_n = R_n b d^2$$

$$R_n = \rho f_y \left(1 - \frac{\rho f_y}{1.7 f_c'} \right)$$

Modular ratio: $m = \dfrac{f_y}{0.85 f_c'}$ $\longrightarrow$ $R_n = \rho f_y \left(1 - \dfrac{1}{2} \rho m \right)$

for $f_c' \leq$ 280 ksc, $\beta_1 = 0.85$

for $f_c' >$ 280 ksc, $\beta_1 = 0.85 - 0.05\left(\frac{f_c' - 280}{70}\right) \geq 0.65$



f_c'	β_1
210	0.85
240	0.85
280	0.85
320	0.82
350	0.80

Reinforcement Ratio ρ :

From $R_n = \rho f_y\left(1 - \frac{1}{2}\rho m\right)$ $\longrightarrow$ $m f_y \rho^2 - 2 f_y \rho + 2R_n = 0$

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2mR_n}{f_y}}\right)$$

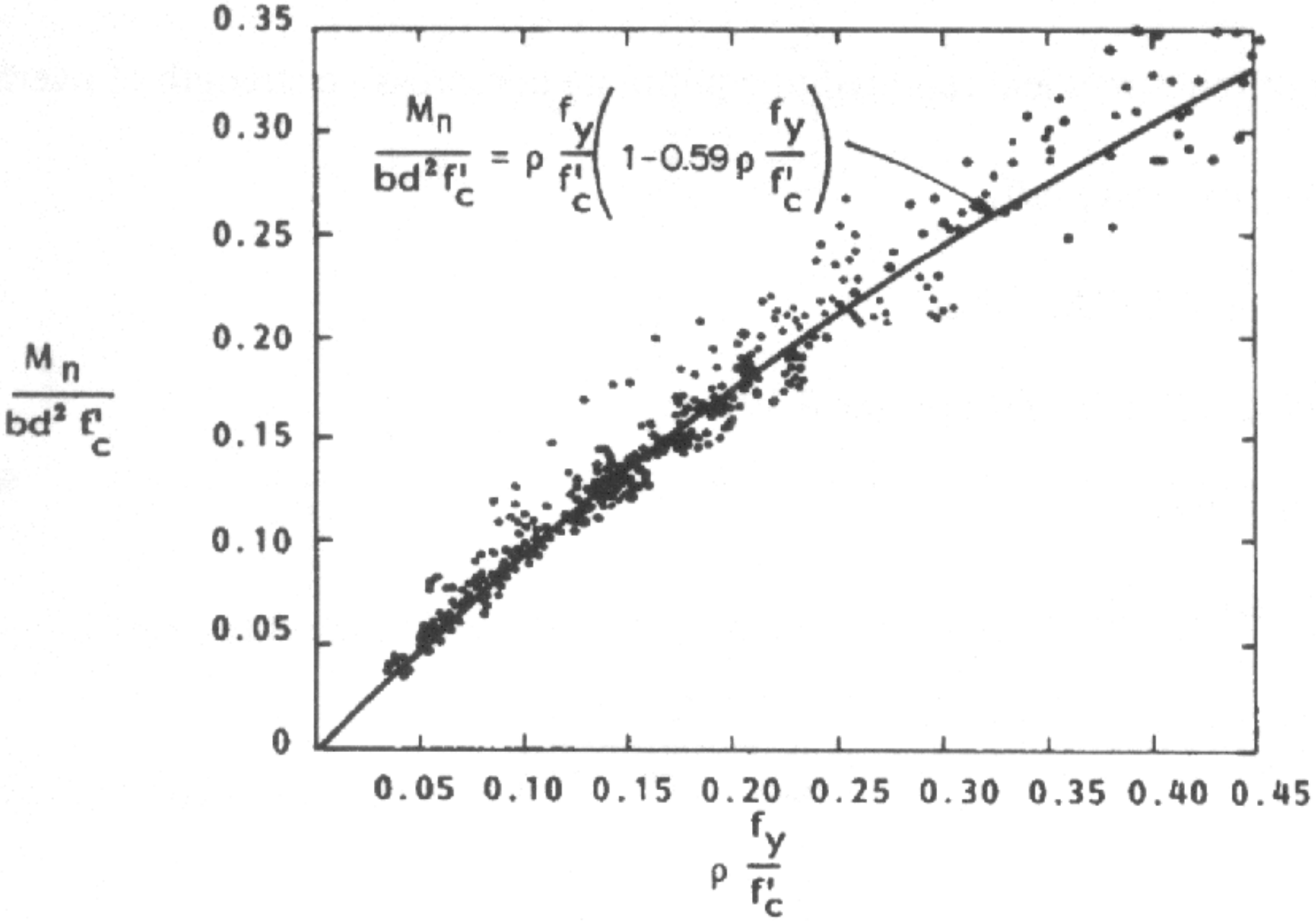
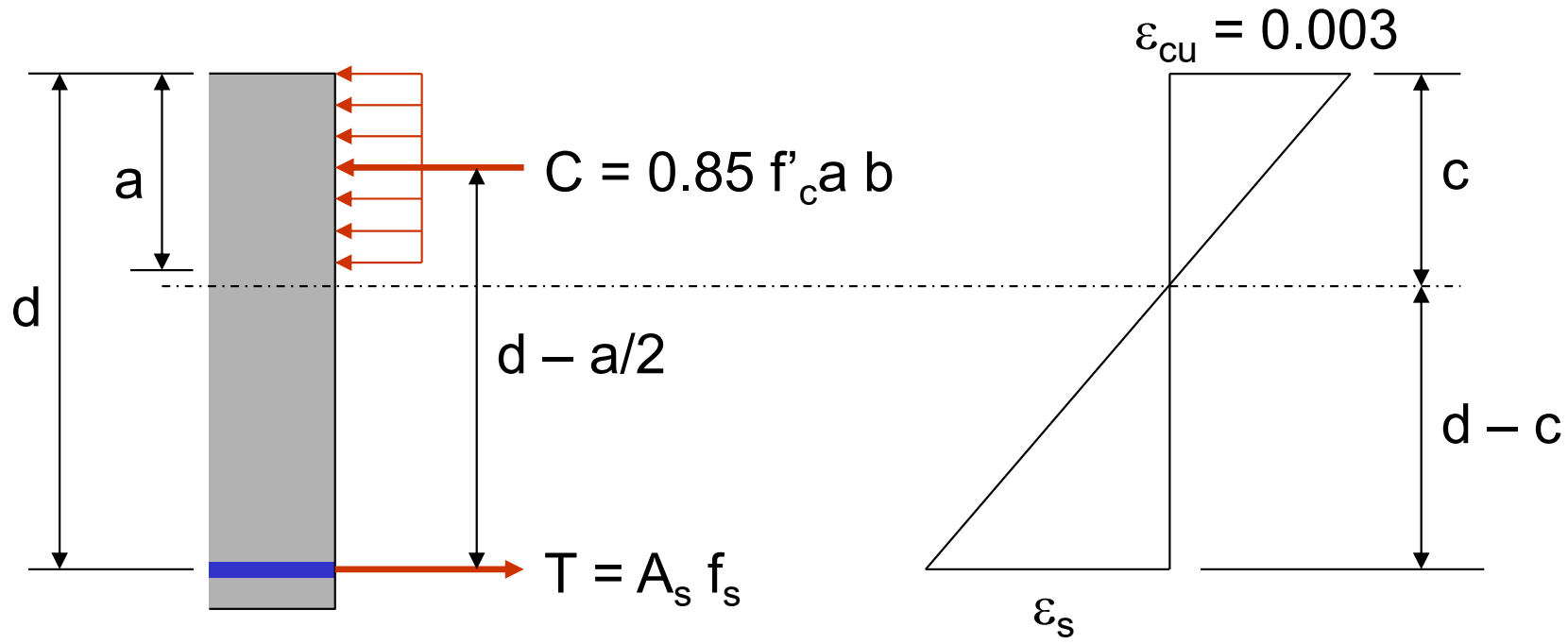


Figure 6-11 Tests of 364 Beams Controlled by Tension ($\varepsilon_s > \varepsilon_y$)

Analysis of Single RC Beam (Tension steel yield)



$[C = T] \quad 0.85\, f'_c\, a\, b = A_s\, f_y$

$$a = \frac{A_s f_y}{0.85 f'_c b} \rightarrow c = a/\beta_1$$

$$f_s = \varepsilon_s E_s = 6{,}120\left(\frac{d-c}{c}\right) \le f_y$$

$$\frac{c}{d-c} = \frac{\varepsilon_{cu}}{\varepsilon_s} \rightarrow \varepsilon_s = \left(\frac{d-c}{c}\right)\varepsilon_{cu}$$

If $\varepsilon_s > \left[\varepsilon_y = f_y / E_s\right] \rightarrow f_s = f_y$

Check by $\rho < \rho_b$

$$M_n = A_s f_y (d - a/2)$$

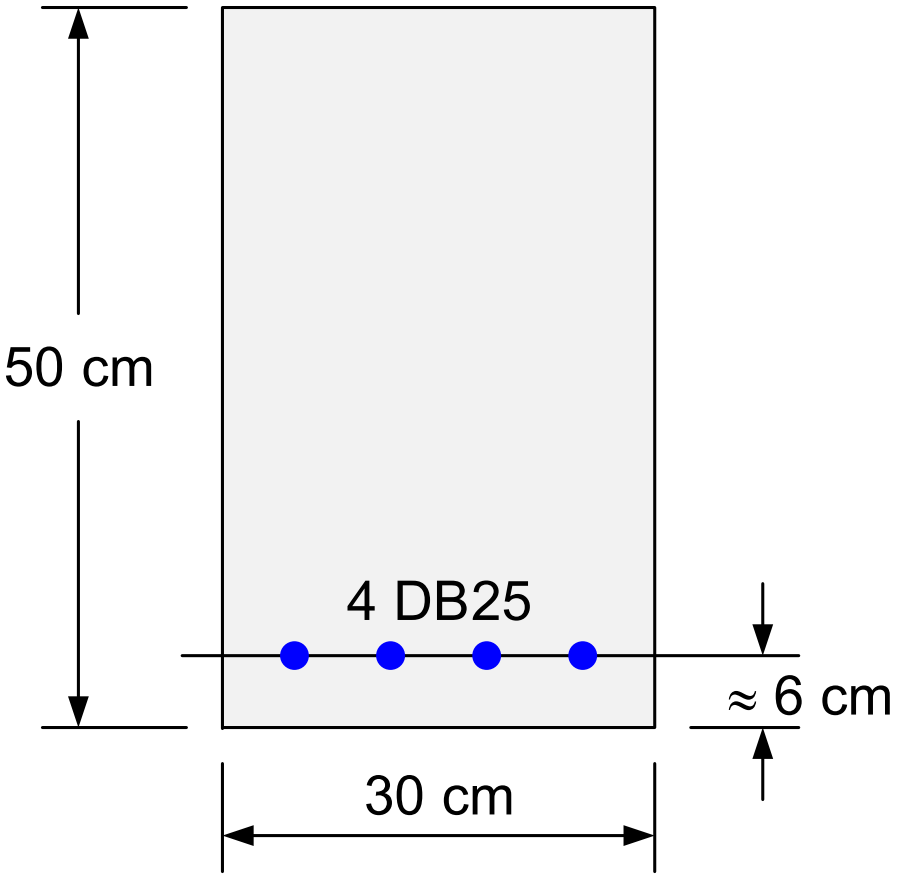
ตัวอย่างที่ 3.1 คำนวณกำลังโมเมนต์ดัด M_n ของหน้าตัดคานสี่เหลี่ยม

คำนวณ M_n ของหน้าตัดคาน กำลังอัดคอนกรีต $f'_c = 240$ กก./ซม.^{2} เสริมเหล็ก 4DB25 ซึ่งมีกำลังคราก $f_y = 4{,}000$ กก. /ซม.^{2}

วิธีทำ

ประมาณความลึกประสิทธิผล d เท่ากับความลึกหน้าตัดลบ 6 ซม. (ระยะหุ้มคอนกรีต 4 ซม. + เหล็กปลอก (ปกติ RB9 หรือ DB10) + ครึ่งหนึ่งของขนาดเหล็กเสริม)

$$d = 50 - 6 = 44 \text{ ซม.}$$

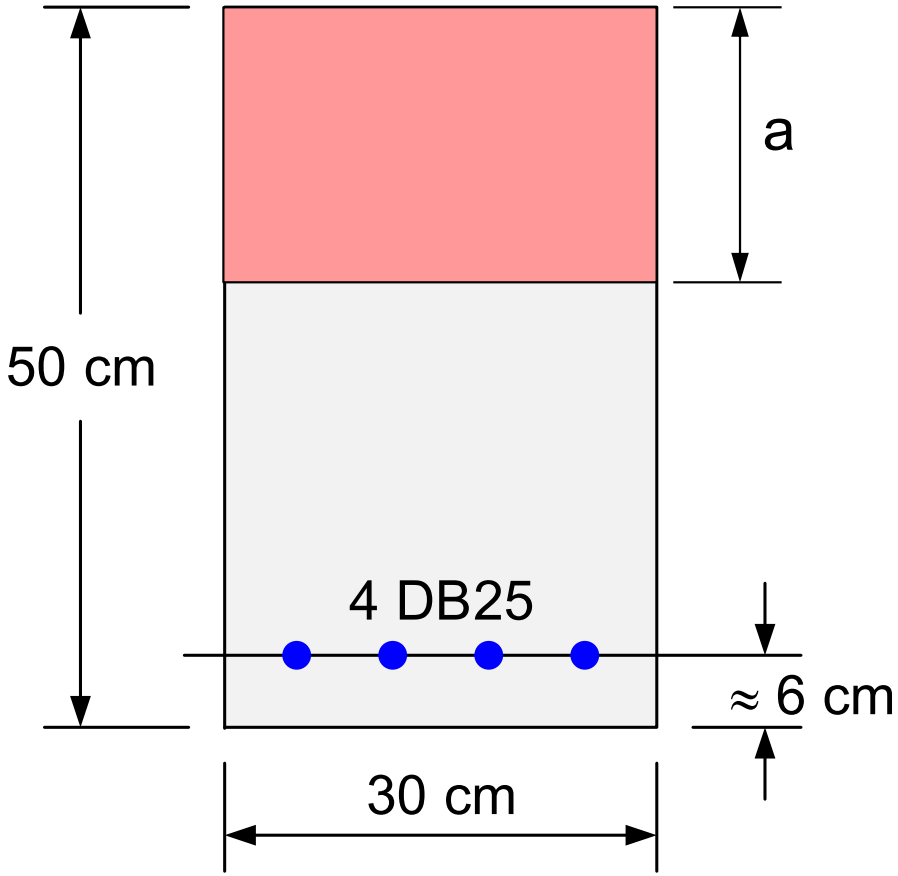


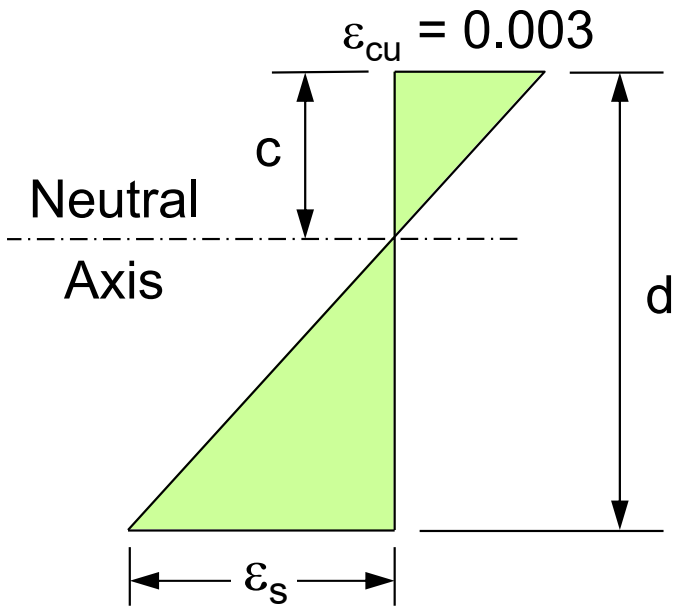
1. สมมุติให้เหล็กเสริมคราก $f_s = f_y$:

$$A_s = 4\,DB25 = 4 \times 4.91 = 19.64 \text{ cm}^2$$

$$T = A_s f_y = 19.64 \times 4.0 = 78.56 \text{ ton}$$

* $\varepsilon_s \geq \varepsilon_y$ จะถูกตรวจสอบในขั้นที่ 3 ซึ่งมักจะเป็นจริง เนื่องจากในการออกแบบจะใส่เหล็กเสริมน้อยเพื่อให้คราก่อนคอนกรีตรับแรงอัดจะวิบัติ





2. คำนวนพื้นที่รับแรงอัดซึ่งทำให้ **C = T** :

$$0.85 f'_c b a = A_s f_y$$

$$a = \beta_1 c = \frac{A_s f_y}{0.85 f'_c b}$$

$$= \frac{78.56}{0.85 \times 0.24 \times 30} = 12.84 \text{ cm}$$

3. ตรวจสอบว่าเหล็กเสริมครากหรือไม่

$$\varepsilon_y = \frac{f_y}{E_s} = \frac{4{,}000}{2.04 \times 10^6} = 0.00196$$

$$c = \frac{a}{\beta_1} = \frac{12.84}{0.85} = 15.11 \text{ cm}$$

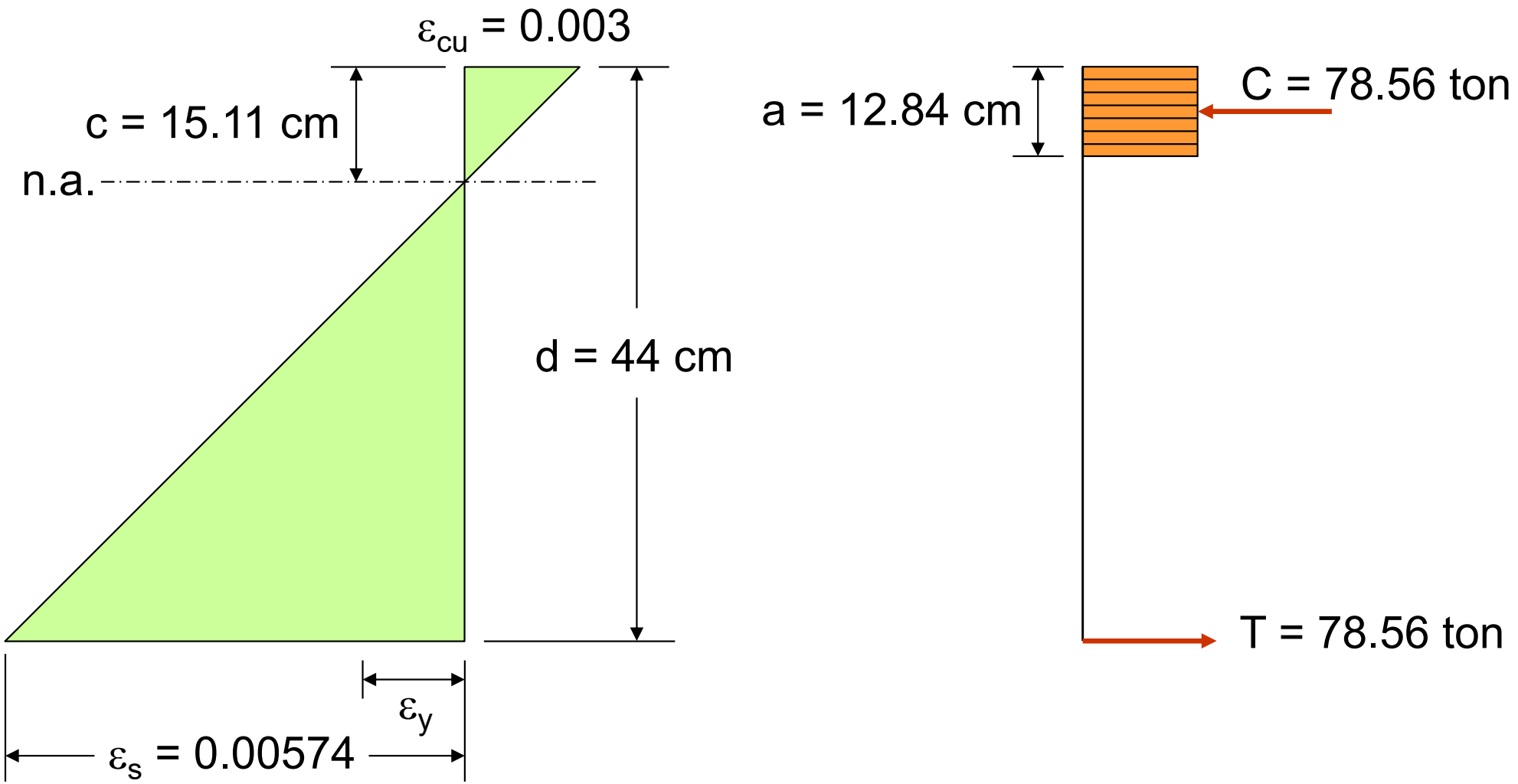
$$\varepsilon_s = \left(\frac{d-c}{c}\right)\varepsilon_{cu} = \left(\frac{44-15.11}{15.11}\right)0.003$$

$$= 0.00574 > \varepsilon_y$$ **OK** (as assumed)

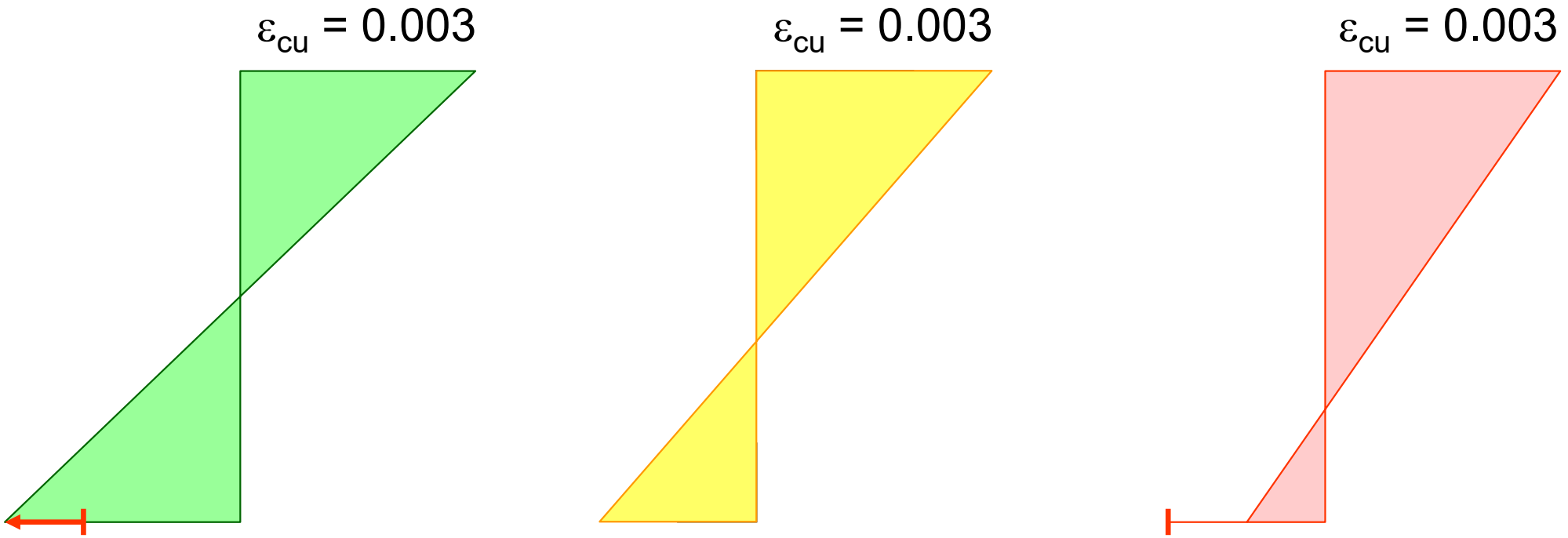
4. คำนวณกำลัง M_n :

$$M_n = T\left(d - \frac{a}{2}\right) = 78.56\left(44 - \frac{12.84}{2}\right)$$

$$M_n = 2{,}952 \text{ ตัน-ซม.} = 29.5 \text{ ตัน-เมตร}$$



Tension, Compression and Balance Failures



$\varepsilon_s > \varepsilon_y$

$\varepsilon_y = f_y/E_s \approx 0.002$

$\varepsilon_s < \varepsilon_y$

Tension Failure

$\varepsilon_{cu} = 0.003$

$\varepsilon_s > \varepsilon_y \rightarrow f_s = f_y$

$\rho < \rho_b$

Balanced Failure

$\varepsilon_{cu} = 0.003$

$\varepsilon_s = \varepsilon_y \rightarrow f_s = f_y$

$\rho = \rho_b$

Compression Failure

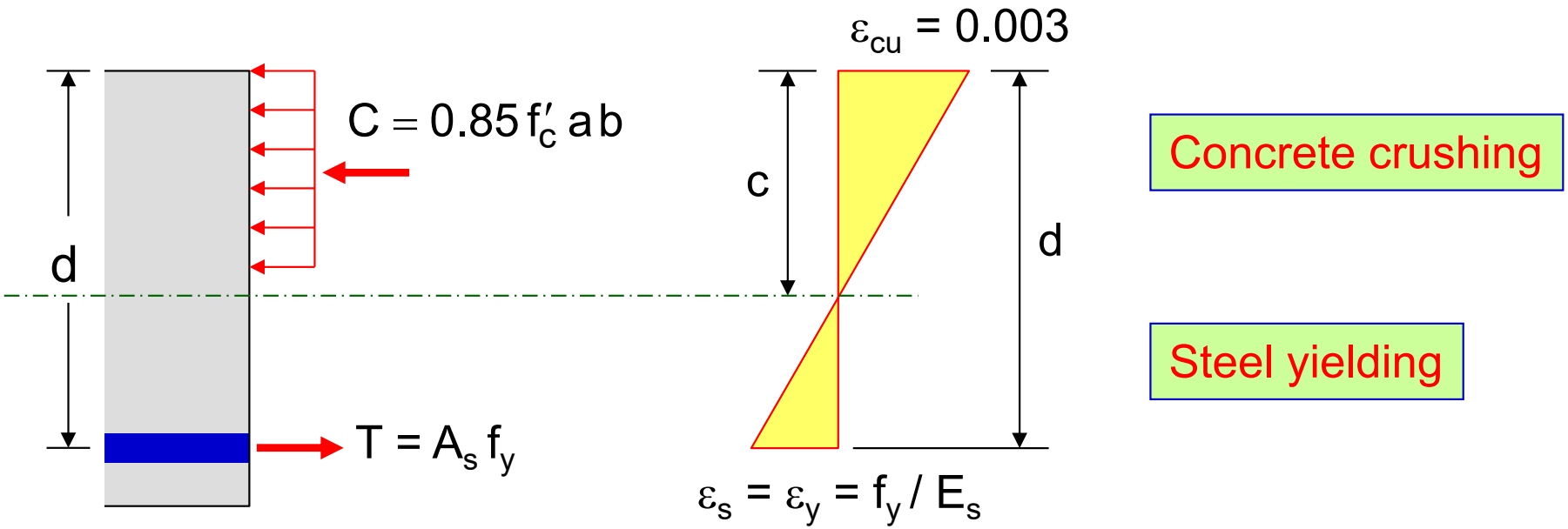
$\varepsilon_{cu} = 0.003$

$\varepsilon_s < \varepsilon_y \rightarrow \mathbf{f_s < f_y}$

$\rho > \rho_b$

Balance Steel Ratio (ρ_b)

ปริมาณเหล็กสมดุลซึ่งทำให้คอนกรีตและเหล็กถึงกำลังสูงสุดพร้อมกัน



From strain condition, $\dfrac{c}{d} = \dfrac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y} \rightarrow c = \left(\dfrac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y} \right) d$

From force equilibrium, $[\Sigma F_x = 0] \rightarrow C = T$

$$0.85 f'_c ab = A_s f_y \rightarrow 0.85 f'_c \beta_1 cb = \rho f_y bd$$

Balance Steel Ratio:

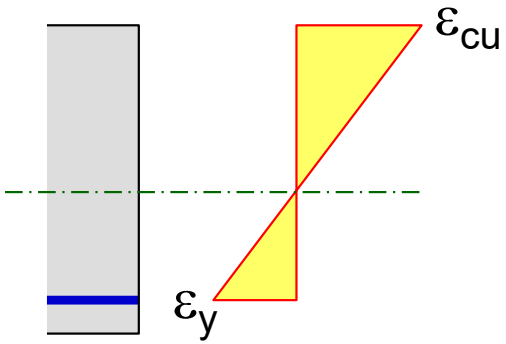
$$\rho_b = \frac{0.85 f'_c}{f_y} \beta_1 \left(\frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_y} \right)$$

แทนค่า $\varepsilon_{cu} = 0.003$ **และ** $\varepsilon_y = f_y / 2.04 \times 10^6$

$$\rho_b = \frac{0.85 f'_c}{f_y} \beta_1 \left(\frac{6{,}120}{6{,}120 + f_y} \right)$$

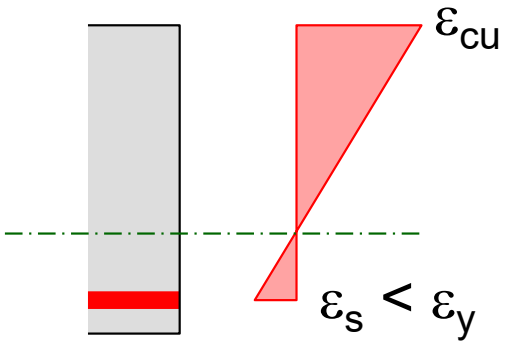
ปริมาณเหล็กสมดุลใช้ตรวจสอบปริมาณเหล็กเสริม $\rho = A_s/bd$

$\rho = \rho_b$



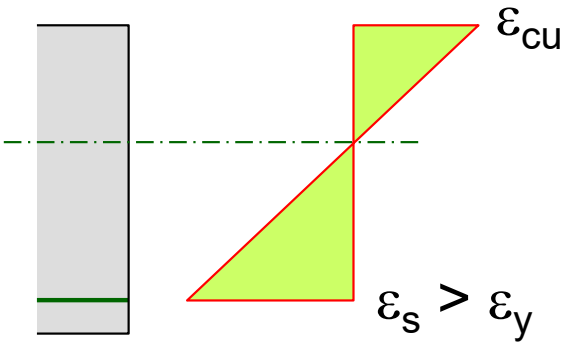
ปริมาณสมดุล
balance condition

$\rho > \rho_b$



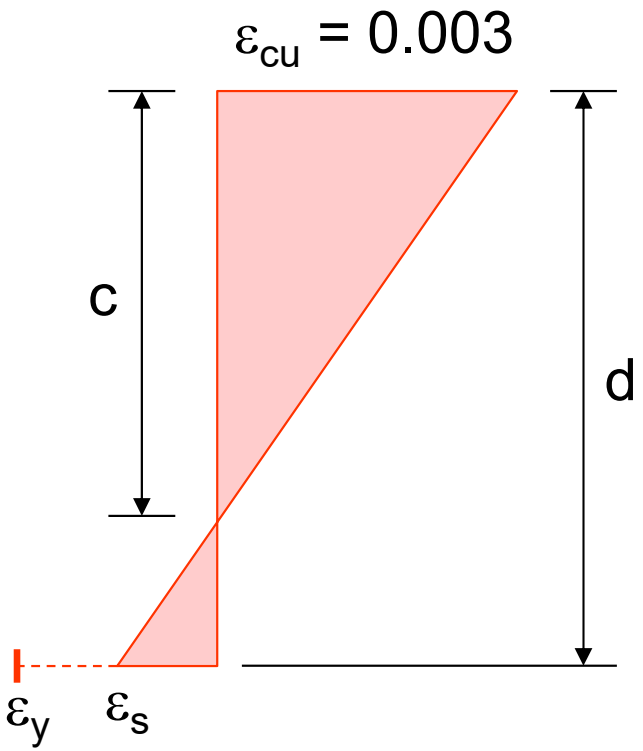
เสริมเหล็กมาก
Over RC

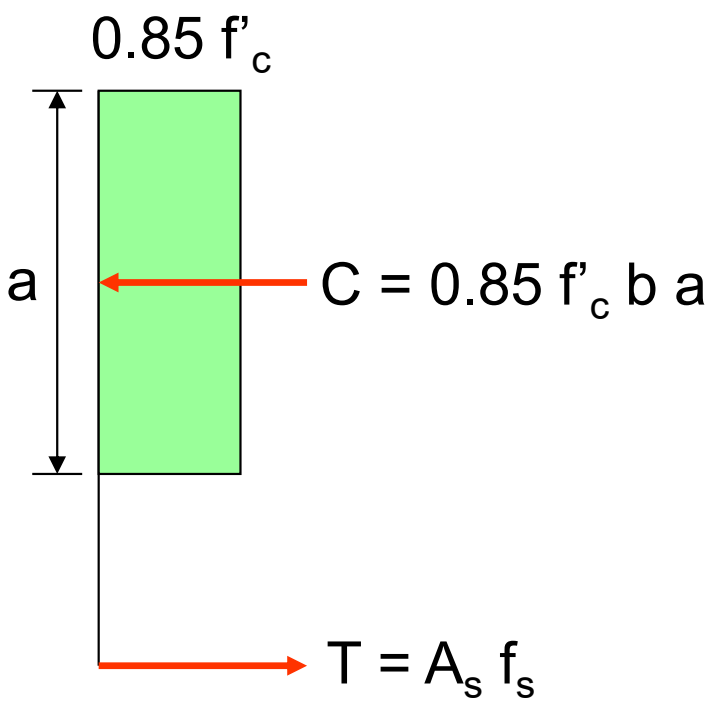
$\rho < \rho_b$



เสริมเหล็กน้อย
Under RC

Compression Failures





$$\frac{\varepsilon_s}{\varepsilon_{cu}} = \frac{d-c}{c}$$

$$f_s = \left(\frac{d-c}{c}\right)\varepsilon_{cu} E_s$$

$$f_s = 6{,}120\left(\frac{d-c}{c}\right) < f_y$$

$$C = T$$

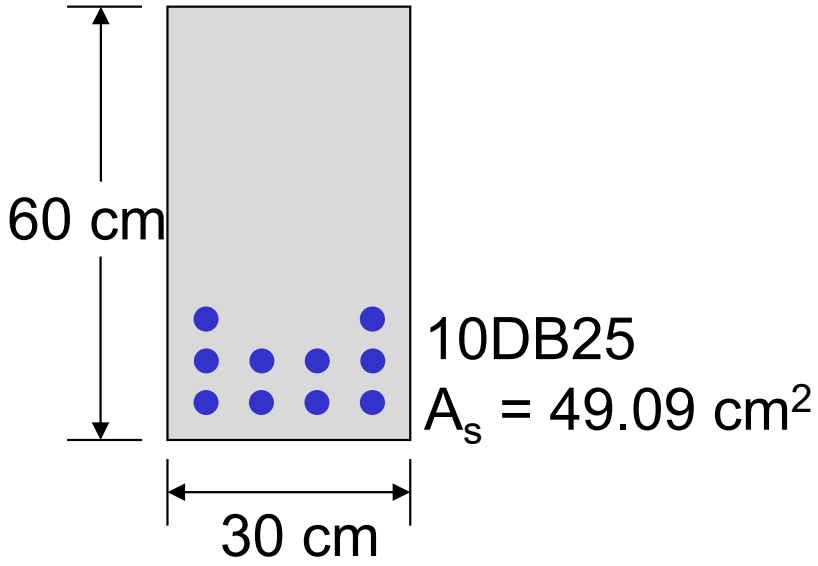
$$0.85\, f'_c\, b\, \beta_1\, c = A_s\, f_s$$

$$0.85 f'_c b \beta_1 c = 6{,}120 A_s (d-c)/c$$

Solve for c

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

Example 6.2 – Moment Strength of Single RC Beam #2



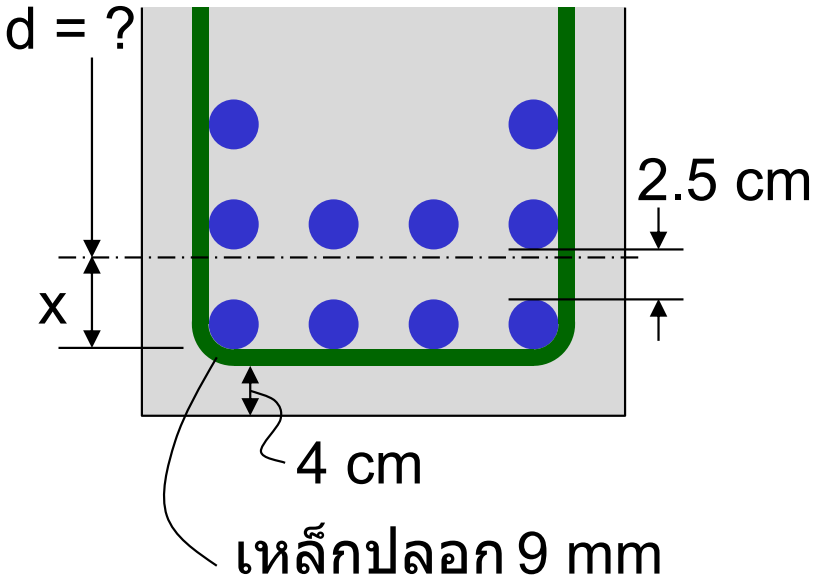
f'_c = 240 ksc, f_y = 4,000 ksc

x = (4x1.25+4x6.25+2x11.25)/10 = 5.25 cm

d = 60 – 4 – 0.9 – 5.25 = 49.9 cm

ρ = 49.09/(30x49.9) = 0.0328

จากตารางที่ ก.5 $\rho > [\ \rho_b = 0.0262\ ]$



$\therefore$ Tension steel not yield : $f_s < f_y$

$$0.85 f'_c b \beta_1 c = 6{,}120 A_s (d - c)/c$$

$$0.85\times240\times30\times0.85\times c = 6{,}120\times49.09(49.9-c)/c$$

$$c^2 + 57.8c - 2{,}882 = 0 \rightarrow c = 32.1 \text{ cm}$$

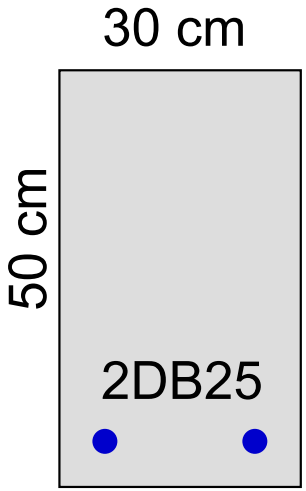
$$f_s = 6{,}120\left(\frac{d-c}{c}\right) = 6{,}120\left(\frac{49.9-32.1}{32.1}\right) = 3{,}394 \text{ ksc}$$

$$a = \beta_1 c = 0.85 \times 32.1 = 27.3 \text{ cm}$$

$$M_n = A_s f_s \left(d - \frac{a}{2}\right) = 49.09 \times 3.394 \left(49.9 - \frac{27.3}{2}\right)/100$$

$$= 60.4 \text{ ton-m}$$ **Ans.**

ตัวอย่าง การตรวจสอบปริมาณเหล็กเสริม (Under RC)



$f'_c = 240$ ksc

$\beta_1 = 0.85$

$f_y = 4{,}000$ ksc

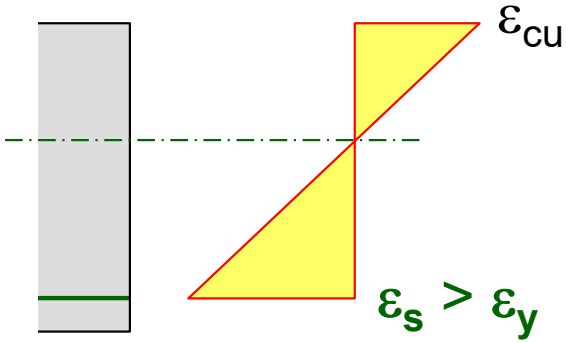
$$\rho_b = \frac{0.85 \times 240}{4{,}000} \times 0.85 \times \left(\frac{6{,}120}{6{,}120 + 4{,}000} \right)$$

$$= \mathbf{0.0262}$$

$A_s = 2 \times 4.91 = 9.82 \text{ cm}^2$

$$\rho = \frac{A_s}{bd} = \frac{9.82}{30 \times 45} = 0.0073 \rightarrow \rho < \rho_b \rightarrow \textbf{Under RC}$$

$\rho < \rho_b$



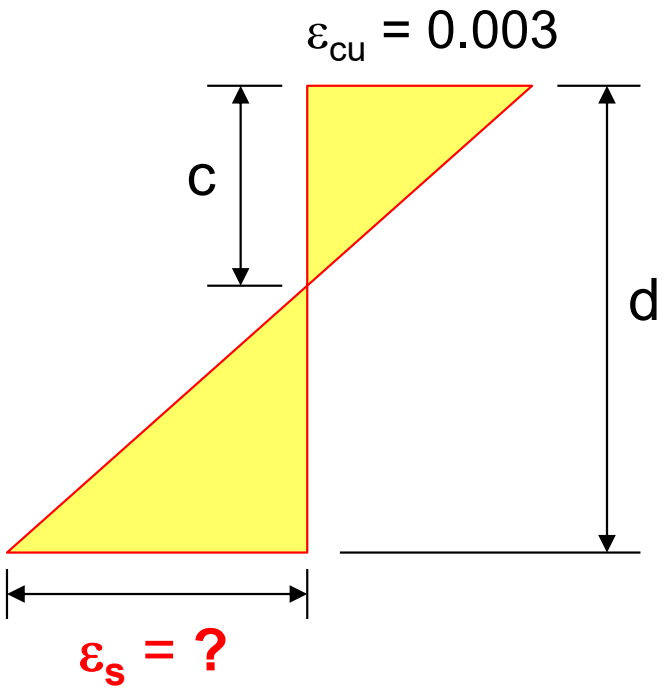
Steel Yield : $f_s = f_y$

$$C = T \rightarrow 0.85 f'_c \beta_1 c b = A_s f_y$$

$$0.85 \times 240 \times 0.85 \times \mathbf{c} \times 30 = 9.82 \times 4{,}000$$

$\mathbf{c} = 7.55$ cm

เสริมเหล็กน้อย
Under RC



Strain Condition: $\frac{\varepsilon_s}{\varepsilon_{cu}} = \frac{d-c}{c}$

$\varepsilon_s = (45 - 7.55) / 7.55 \times 0.003 = 0.0149$

$\varepsilon_y = f_y / E_s = 4{,}000 / 2.04e6 = 0.00196$

$\varepsilon_s > \varepsilon_y$ Steel Yield : $f_s = f_y$ **Under RC**

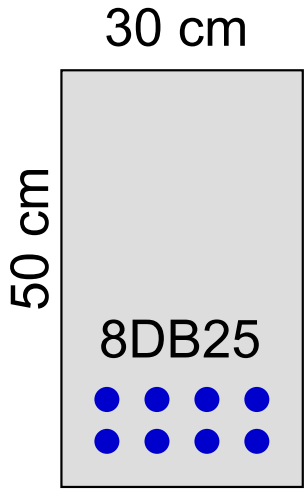
ACI 318-08 Section 10.5 : Minimum reinforcement of flexural members

10.5.1 – At every section of a flexural member where tensile reinforcement is required, A_s provided shall not be less than that given by

$$A_{s,\,min} = \frac{0.8\sqrt{f'_c}}{f_y} b\, d$$

and not less than **$14\ b\ d / f_y$** **To prevent concrete first crack**

ตัวอย่าง การตรวจสอบปริมาณเหล็กเสริม (Over RC)



$f'_c = 240$ ksc

$\beta_1 = 0.85$

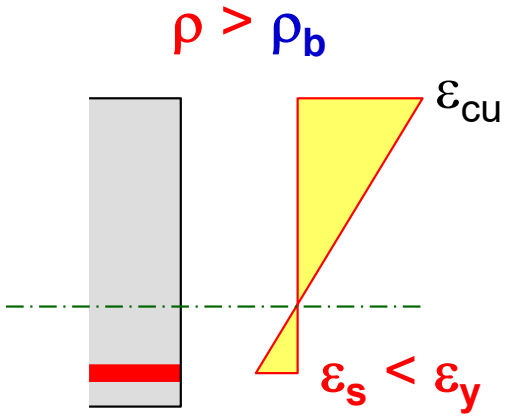
$f_y = 4{,}000$ ksc

$$\rho_b = \frac{0.85 \times 240}{4{,}000} \times 0.85 \times \left(\frac{6{,}120}{6{,}120 + 4{,}000} \right)$$

$$= \mathbf{0.0262}$$

$A_s = 8 \times 4.91 = 39.28$ cm^2

$$\rho = \frac{39.28}{30 \times 42} = 0.0312 \rightarrow \rho > \rho_b \rightarrow \textbf{Over RC}$$



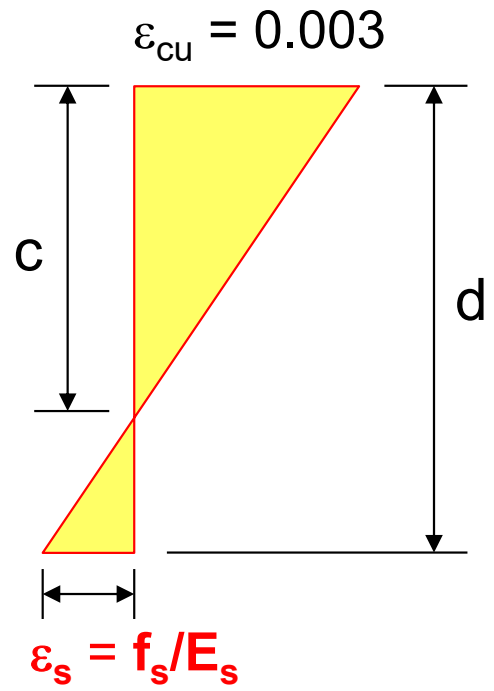
เสริมเหล็กมาก
Over RC

Steel NOT Yield : $f_s < f_y$

$$C = T \rightarrow 0.85 f'_c \beta_1 c b = A_s f_s$$

$$0.85 \times 240 \times 0.85 \times \mathbf{c} \times 30 = 39.28\ \mathbf{f_s} \quad (1)$$

2 unknowns: **c** and $\mathbf{f_s}$?



Strain Condition:

$$\frac{\varepsilon_s}{\varepsilon_{cu}} = \frac{d-c}{c}$$

$$\varepsilon_s = \frac{f_s}{E_s} = \left(\frac{d-c}{c}\right)\varepsilon_{cu}$$

$$f_s = 6{,}120\left(\frac{42-c}{c}\right) \rightarrow (1)$$

$$5{,}202\,c = 39.28 \times 6{,}120\left(\frac{42-c}{c}\right)$$

$$5{,}202\,c^2 + 240{,}393.6\,c - 10{,}096{,}531.2 = 0$$

MATLAB:

```
>> roots([5202 240393.6 -10096531.2])

ans =
  -72.8530
   26.6412
```

c = 26.6 cm

f_s = 3,543 ksc

$f_s < f_y$

Steel NOT Yield

Over RC

ACI 318-08: Section 10.3 – General principles and requirements

10.3.5 – For flexural members, a net tensile strain ε_t in extreme tension steel shall not be less than 0.004.

ACI Code before 2002, $\rho_{max} = 0.75\,\rho_b$

For conservative design, we may use

$$\rho = 0.5\,\rho_{max} = 0.375\,\rho_b$$

From

$$M_n = R_n\,b\,d^2$$

$$R_n = \rho f_y\left(1-\frac{\rho f_y}{1.7 f_c'}\right)$$

If we use $\rho_{max} \rightarrow R_{n,max} \rightarrow M_{n,max}$

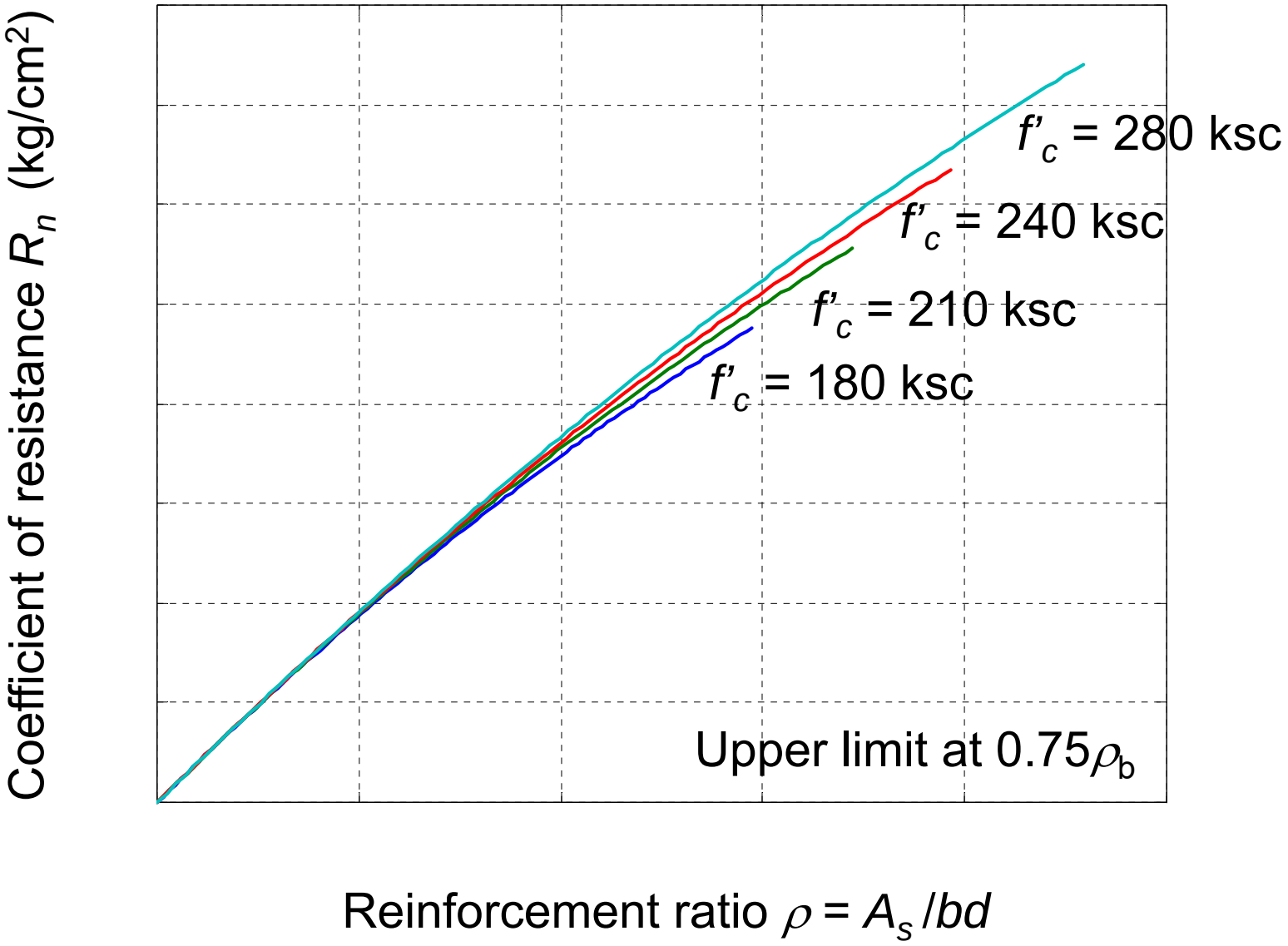
where $M_{n,max}$ is the maximum moment capacity of the section

ตารางที่ ก.5 ปริมาณเหล็กเสริมและค่าสัมประสิทธิ์ต้านแรงดัด

สำหรับ f_y = **4,000** ก.ก./ซม.^{2}

f'_c (ksc)	ρ_{min}	ρ_b	ρ_{max}	m	$R_{n,max}$ (ksc)
180	0.0035	0.0197	0.0147	26.1	47.62
210	0.0035	0.0229	0.0172	22.4	55.55
240	0.0035	0.0262	0.0197	19.6	63.49
280	0.0035	0.0306	0.0229	16.8	74.07
320	0.0035	0.0338	0.0253	14.7	82.46
350	0.0035	0.0360	0.0270	13.4	88.36

Strength Curve (R_n vs. ρ) for SD40 Reinforcement



ปริมาณเหล็กเสริมที่ต้องการ

Required moment from load = M_u

Design Moment Strength = $M_n = \frac{M_u}{\phi} = R_n b d^2 \rightarrow R_n = \frac{M_u}{\phi b d^2}$

From $R_n = \rho f_y \left(1 - \frac{1}{2}\rho m\right)$ where $m = \frac{f_y}{0.85 f'_c}$

จะได้ $m f_y \rho^2 - 2 f_y \rho + 2 R_n = 0$ แก้สมการกำลังสอง

$$\rho = \frac{2 f_y \pm \sqrt{4 f_y^2 - 8 m R_n f_y}}{2 m f_y} = \frac{1}{m}\left(1 \pm \sqrt{1 - \frac{2 m R_n}{f_y}}\right)$$

เนื่องจาก ρ_b มีค่าน้อยกว่า **1/m** เสมอ(ดูจากสูตร) ดังนั้น

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2 m R_n}{f_y}}\right)$$

ขั้นตอนการออกแบบหน้าตัดคานคอนกรีตเสริมเหล็ก

STEP 1 เลือกปริมาณเหล็กเสริมที่เหมาะสมภายในช่วง $\rho_{\min} \le \rho \le \rho_{\max}$

$$\rho_{\min} = 14 / f_y \qquad \rho_{\max} = 0.75\,\rho_b$$

$$\rho_b = \frac{0.85 f_c'}{f_y}\beta_1\left(\frac{6{,}120}{6{,}120 + f_y}\right)$$

$$\beta_1 = \begin{cases} 0.85 & ; f_c' \le 280 \text{ ksc} \\ 0.85 - 0.05\left(\dfrac{f_c' - 280}{70}\right) & ; 280 < f_c' \le 560 \text{ ksc} \\ 0.65 & ; f_c' > 560 \text{ ksc} \end{cases}$$

Conservative design select $\rho = 0.5\rho_{max} = 0.375\rho_b$

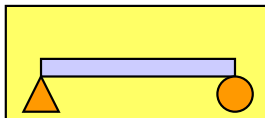
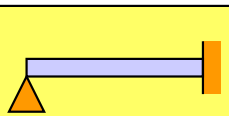
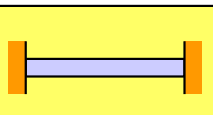
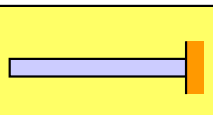
STEP 2 เลือกขนาดคานที่ต้องการ **$b\,d^2$**

จาก $M_n = R_n b d^2 \rightarrow b d^2 = \frac{M_n}{R_n} = \frac{M_u}{\phi R_n}$

$R_n = \rho f_y \left(1 - \frac{1}{2}\rho m\right)$ เมื่อ $m = \frac{f_y}{0.85 f'_c}$

STEP 3 เลือก **d** จากความลึก **h** ที่แนะนำเพื่อหลีกเลี่ยงปัญหาการแอ่นตัว

เลือก **$b \approx d/2$**

				
oneway slab	**L/20**	**L/24**	**L/28**	**L/10**
BEAM	**L/16**	**L/18.5**	**L/21**	**L/8**

การเลือกขนาดหน้าตัดคานจะใช้เลขเต็มสิบซม. เช่น **30x50** ซม.

STEP 4 ปรับปรุงค่า ρ ตามขนาดหน้าตัดที่เลือก (b, d)

จาก $M_n = R_n b d^2 \rightarrow R_n = \frac{M_n}{bd^2} = \frac{M_u}{\phi b d^2}$

$$\rho = \frac{1}{m}\left(1-\sqrt{1-\frac{2mR_n}{f_y}}\right) \quad \text{เมื่อ} \quad m = \frac{f_y}{0.85f'_c}$$

STEP 5 ตรวจสอบปริมาณเหล็กว่าอยู่ในช่วง $\rho_{min} < \rho < \rho_{max}$ หรือไม่ ?

ถ้า $\rho < \rho_{min}$ ให้ใช้ $\rho = \rho_{min}$

ถ้า $\rho > \rho_{max}$ ให้เพิ่มขนาดหน้าตัด แล้วคำนวณใหม่

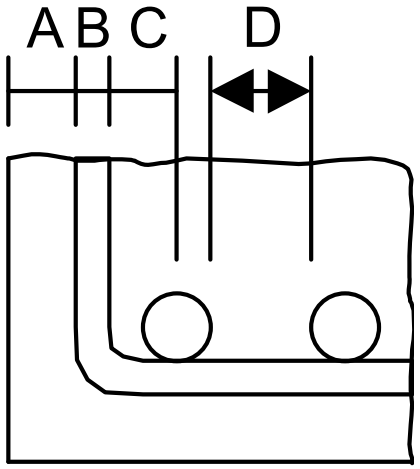
STEP 6 คำนวณพื้นที่เหล็ก $\mathbf{A_s = \rho bd}$ แล้วเลือกขนาดและจำนวนเหล็กเสริม

STEP 7 ตรวจสอบกำลังหน้าตัด $M_n = \rho f_y b d^2\left(1-\frac{\rho f_y}{1.7f'_c}\right) \geq \frac{M_u}{\phi}$

หรือ $a = \frac{A_s f_y}{0.85f'_c b} \rightarrow M_n = A_s f_y\left(d-\frac{a}{2}\right) \geq \frac{M_u}{\phi}$

ตารางที่ ก.4 ความกว้างคานน้อยที่สุด (ซม.)

เหล็กเสริม	จำนวนเหล็กในหนึ่งชั้น							เพิ่มสำหรับแต่ละเส้น
	2	3	4	5	6	7	8	
DB12	16.9	20.6	24.3	28.0	31.7	35.4	39.1	3.7
DB16	17.3	21.4	25.5	29.6	33.7	37.8	41.9	4.1
DB20	17.7	22.2	26.7	31.2	35.7	40.2	44.7	4.5
DB25	18.2	23.2	28.2	33.2	38.2	43.2	48.2	5.0
DB28	18.8	24.4	30.0	35.6	41.2	46.8	52.4	5.6



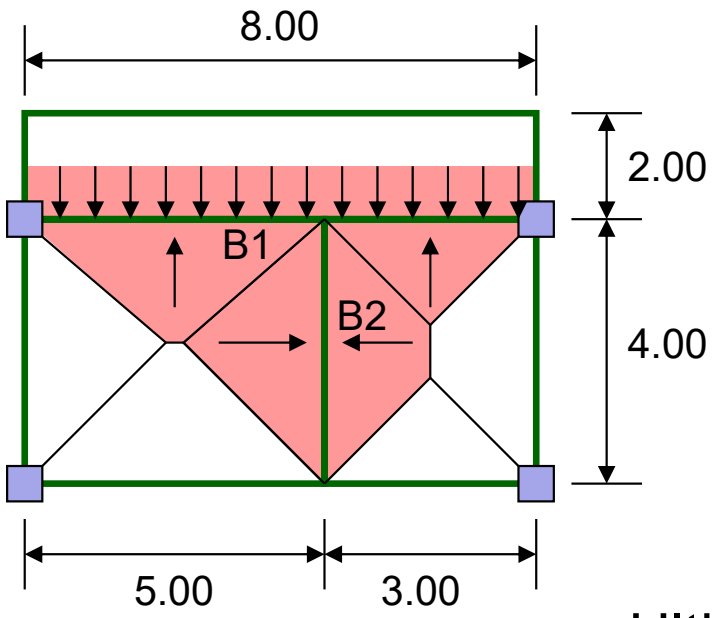
A = 4 ซม. จะหุ้มจากผิวคอนกรีตถึงเหล็กปลอก

B = 9 มม. เหล็กปลอก

C = 1.9 ซม.

D = ช่องว่างระหว่างเหล็ก = d_b หรือ 2.5 ซม.

Example: Design B1 in the floor plan shown below.



Slab thickness = 12 cm

LL = 300 kg/m^2

f'_c = 280 kg/cm^2

Steel: SD40

Slab DL = 0.12(2,400) = 288 kg/m^2

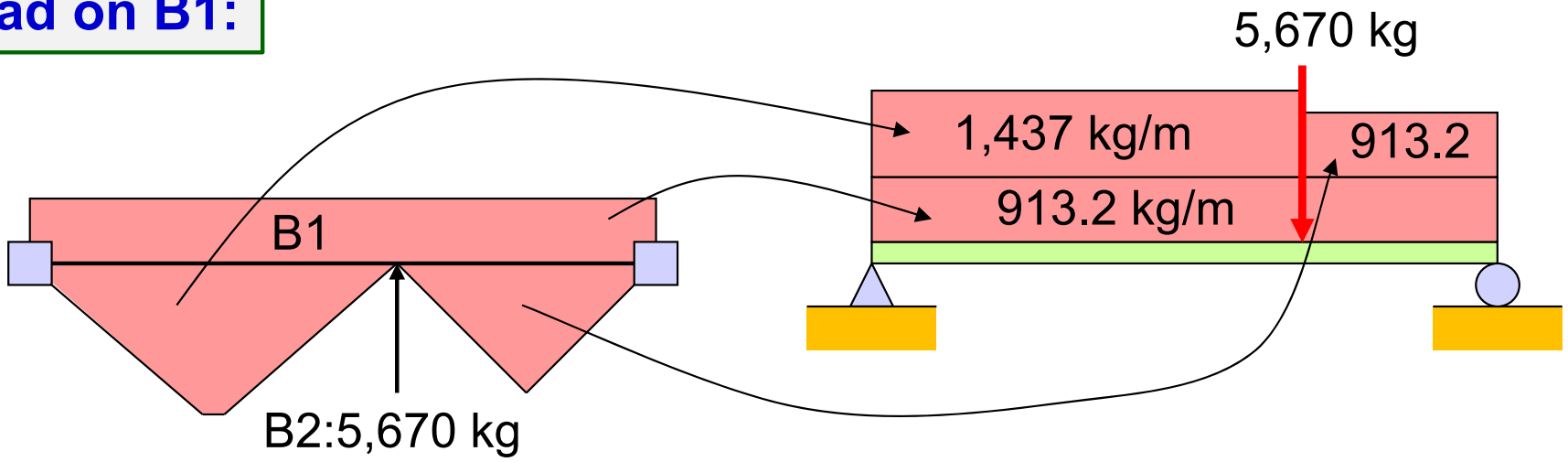
Ultimate load = 1.4(288) + 1.7(300) = 913.2 kg/m^2

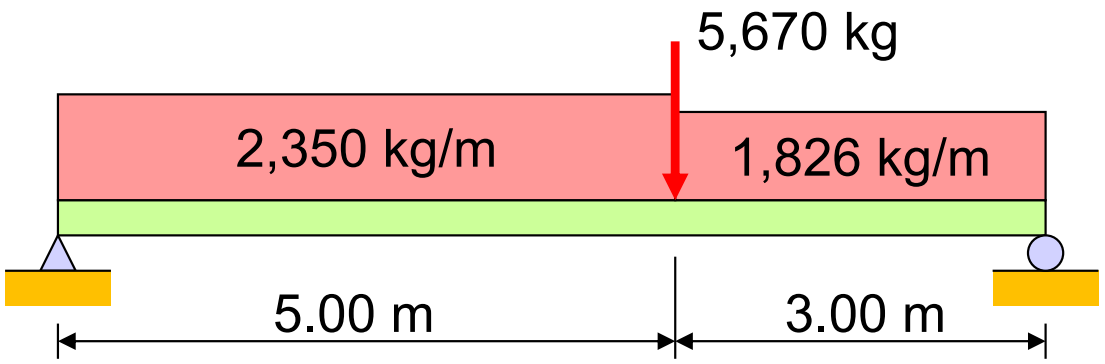
$$\text{Load on B2} = \frac{913.2(4)}{3} + \frac{913.2(3)}{3}\left(\frac{3-0.75^2}{2}\right) = 2{,}331 \text{ kg/m}$$

B2 weight (assume section 30 × 50 cm) = 1.4(0.3)(0.5)(2,400) = 504 kg/m

Reaction at B2's ends = $wL/2$ = (2,331+504)(4)/2 = 5,670 kg

Load on B1:

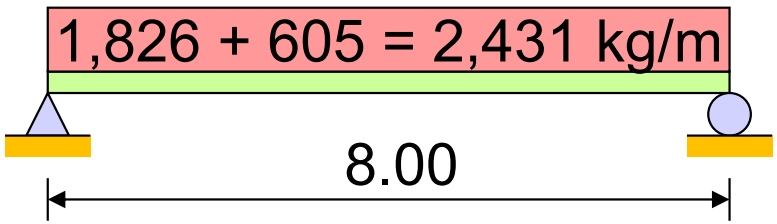




B1 weight: simply support min. depth = 800/16 = 50 cm

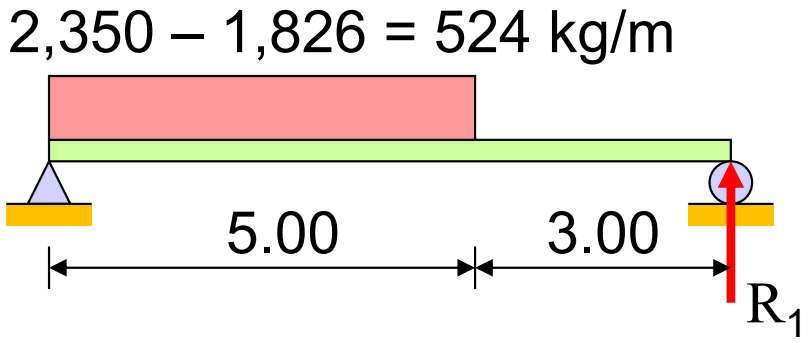
Try section 30 $\times$ 60 cm, w_u = 1.4(0.3)(0.6)(2400) = 605 kg/m

Max. moment on B1:



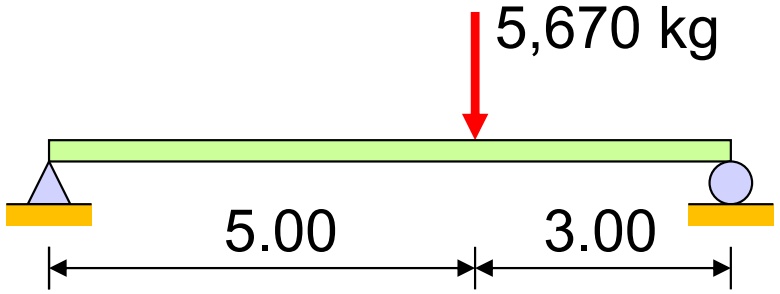
$M_{max} = 2{,}431(8.0)^2/8$

$= 19{,}448$ kg-m



$$R_1 = \frac{524(5)(5/2)}{8} = 819 \text{ kg}$$

$M_{max} = 819(3) = 2{,}456$ kg-m



$$M_{max} = \frac{5{,}670(5.0)(3.0)}{8}$$

$= 10{,}631$ kg-m

$M_u = 19{,}448 + 2{,}456 + 10{,}631 = 32{,}535$ kg-m

USE DB20: d = 60 - 4 - 2.0/2 - 0.9 = 54 cm

$$\rho_{min} = 14/f_y = 14/4{,}000 = 0.0035$$

$$\rho_b = \frac{0.85(280)}{4{,}000}(0.85)\left(\frac{6120}{6120+4000}\right) = 0.0306$$

$$\rho_{max} = 0.75\rho_b = 0.75(0.0306) = 0.0230$$

$$m = \frac{f_y}{0.85f'_c} = \frac{4{,}000}{0.85(280)} = 16.81$$

$$R_n = \frac{M_u}{\phi bd^2} = \frac{32{,}535(100)}{0.9(30)(54)^2} = 41.32$$

$$\text{Required } \rho = \frac{1}{m}\left(1-\sqrt{1-\frac{2mR_n}{f_y}}\right)$$

$$= \frac{1}{16.81}\left(1-\sqrt{1-\frac{2(16.81)(41.32)}{(4{,}000)}}\right)$$

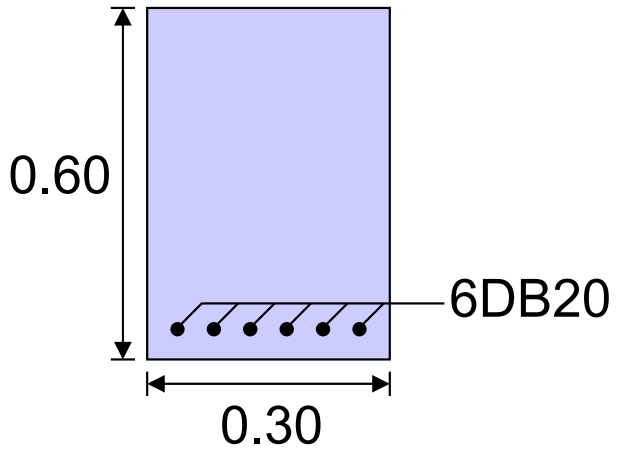
$$= 0.0114$$

$\rho_{min} = 0.0035 < \rho = 0.0114 < \rho_{max} = 0.0230$ **OK**

$A_s = \rho bd = 0.0114(30)(54) = 18.51\ cm^2$

USE 6DB20 ($A_s = 18.85\ cm^2$)

BUT 6DB20 need $b_{min} = 35.7$ cm **NG**



Home work: redesign section

ข้อสอบภย

ข้อที่ : 46

คานหน้าตัด 0.25x0.45 ม. เสริมเหล็กรับแรงดึงอย่างเดียว d = 0.40 ม. As = 6.75 ซม.^{2}, fc′ = 250 ksc, fy = 4000 ksc จงใช้วิธี USD ตรวจสอบว่าคานนี้มีการเสริมเหล็กแบบใด?

$$\rho = A_s / bd = 6.75 / (25 \times 40) = 0.00675$$

$$\rho_{min} = 14 / f_y = 14 / 4{,}000 = 0.0035$$

$$\rho_b = \frac{0.85 \times 250}{4{,}000}(0.85)\left(\frac{6{,}120}{6{,}120 + 4{,}000}\right) = 0.0273$$

$$\rho_{max} = 0.75\,\rho_b = 0.75 \times 0.0273 = 0.0205$$

$$\rho_{min} \le \rho \le \rho_{max}$$

Under Reinforced

ข้อสอบภย

ข้อที่ : 100

โดยวิธี Strength design: คานหน้าตัด 0.20x0.50 ม. (d = 0.45 ม.) เสริมเหล็กรับแรงดึง 3-DB20 จงหาโมเมนต์ที่คำนวณได้จริง(Nominal flexural moment หรือ ideal strength) ของหน้าตัดนี้ fc′ = 180 ksc และใช้เหล็กเสริม SD30

$$\rho = A_s / bd = (3 \times 3.14) / (20 \times 45) = 0.0105$$

$$\rho_{min} = 14 / f_y = 14 / 4{,}000 = 0.0035$$

$$\rho_b = \frac{0.85 \times 180}{3{,}000}(0.85)\left(\frac{6{,}120}{6{,}120 + 3{,}000}\right) = 0.0291$$

$$\rho_{max} = 0.75\,\rho_b = 0.75 \times 0.0291 = 0.0218$$

$$\rho_{min} \le \rho \le \rho_{max}$$

$$M_n = \rho f_y b d^2 \left(1 - \frac{\rho f_y}{1.7 f'_c}\right) = \mathbf{11{,}444\ kg\text{-}m}$$

ข้อสอบภย

ข้อที่ : 180

คานหน้าตัด 0.20x0.35 ม. (d = 0.30 ม.) เสริมเหล็กรับแรงดึงเพียงอย่างเดียว ถ้าใช้ fc′ = 200 ksc และ fy = 4,000 ksc เพื่อรับโมเมนต์ดัดประลัย Mu = 6,000 kg-m จงใช้วิธี USD ประมาณปริมาณเหล็กเสริม As ที่ต้องการ

$$R_n = \frac{M_u}{\phi b d^2} = \frac{6{,}000 \times 100}{0.9 \times 20 \times 30^2} = 37.04 \text{ ksc}$$

$$m = \frac{f_y}{0.85 f'_c} = \frac{4{,}000}{0.85 \times 200} = 23.53$$

$$\rho = \frac{1}{m}\left(1 - \sqrt{1 - \frac{2mR_n}{f_y}}\right) = 0.0106$$

$$A_s = \rho\, b\, d = 0.0106 \times 20 \times 30 = \mathbf{6.35\ cm^2}$$

Check $\rho_{min} \le \rho \le \rho_{max}$