Design Loads

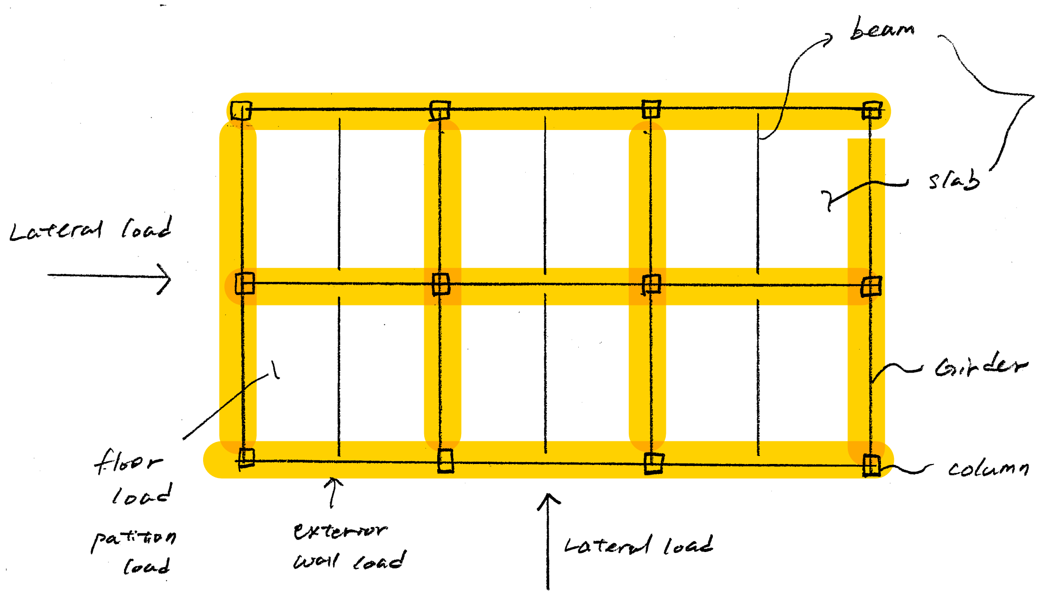
Gravity loads : Dead load, Live load, snow load

Lateral loads : Wind Load, Earthquake load

Soil and hydraulic pressure

Temperature change, creep & shrinkage of concrete

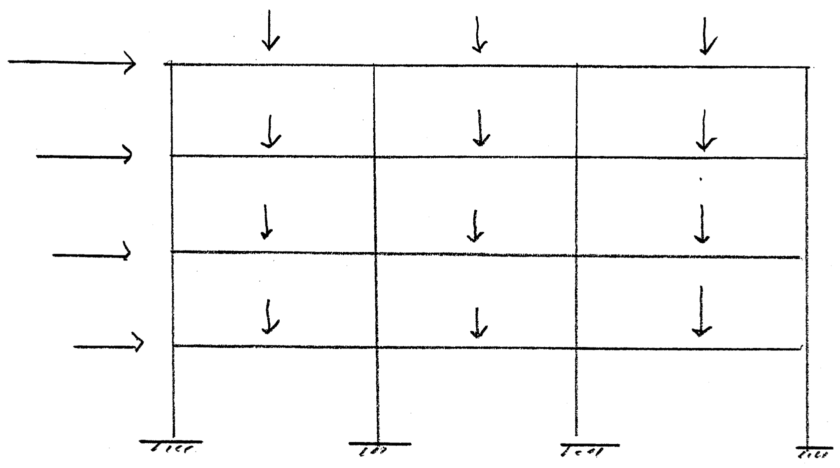
Moment resisting frame (beam - column frame)



pure gravity load system
(but diaphragm action for lateral load

resisting both gravity load and lateral load

⇒ structural analysis for two loads is required.



Design of Concrete members

Items to be checked

slabs — one way slabs – flexure, shear, deflection

two way slabs – flexure, shear (punching shear) deflection

beams – flexure, shear, deflection

columns – axial – flexure, shear

walls – axial – flexure (in-plane, out-of plane) shear

foundations – flexure, shear, punching shear, soil bearing

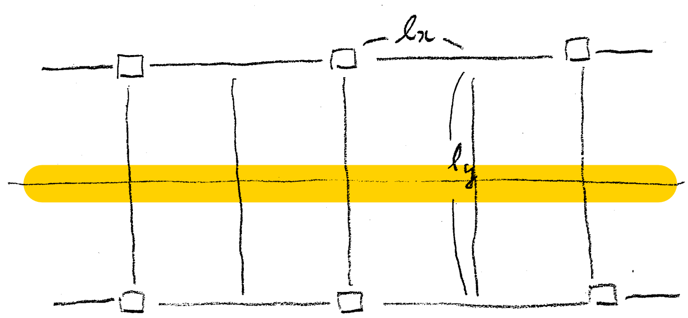
basement walls – flexure (out-of-plane), shear

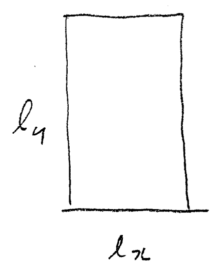
Miscelleneous – stair ways etc

One way slabs

only gravity load is considered

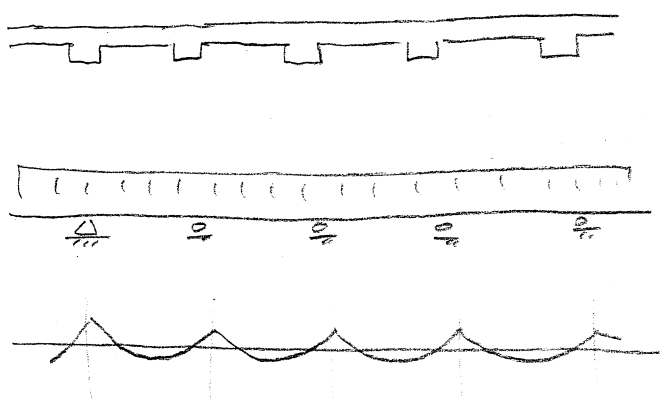
a strip of slab is supported by a series of beams and girders





If $l_y / l_x \geq 2$

$\Rightarrow$ one way slab



B.MD

Load combinations

$U = 1.4(D + F + H_v)$

$U = 1.2(D + F + T) + 1.6(L + \alpha_H H_v + H_h) + 0.5(L_r \text{ or } S \text{ or } R,$

$U = 1.2D + 1.3W + 1.0L + 0.5(L_r \text{ or } S \text{ or } R)$

$U = 1.2D + 1.0E + 1.0L + 0.2S$

$U = 0.9D + 1.3W + 1.6(\alpha_H H_v + H_h)$

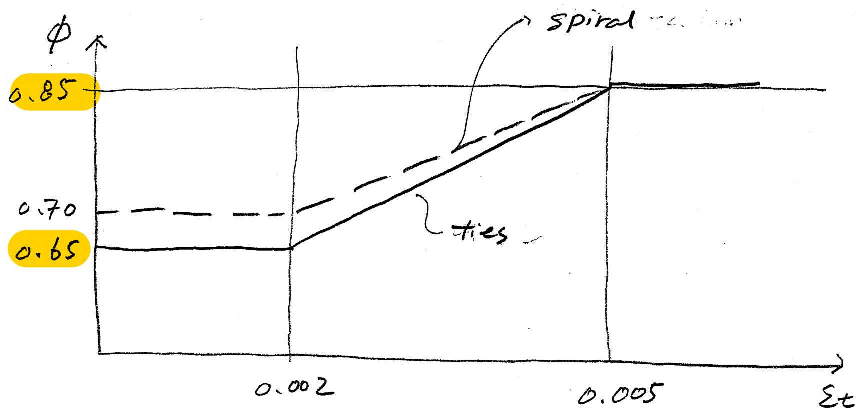
$U = 0.9D + 1.0E + 1.6(\alpha_H H_v + H_h)$

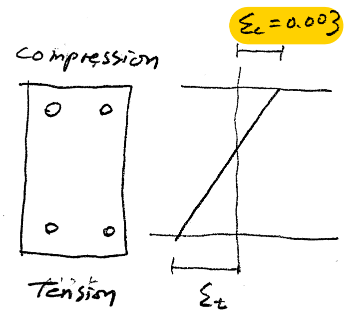
F = fluid $\quad H_v, H_h$ = (vertical, Horizontal) soil & hydraulic pressures

T = Temperature & Time (shrinkage, creep)

Strength Reduction factor

Flexural Design (flexure - axial design)





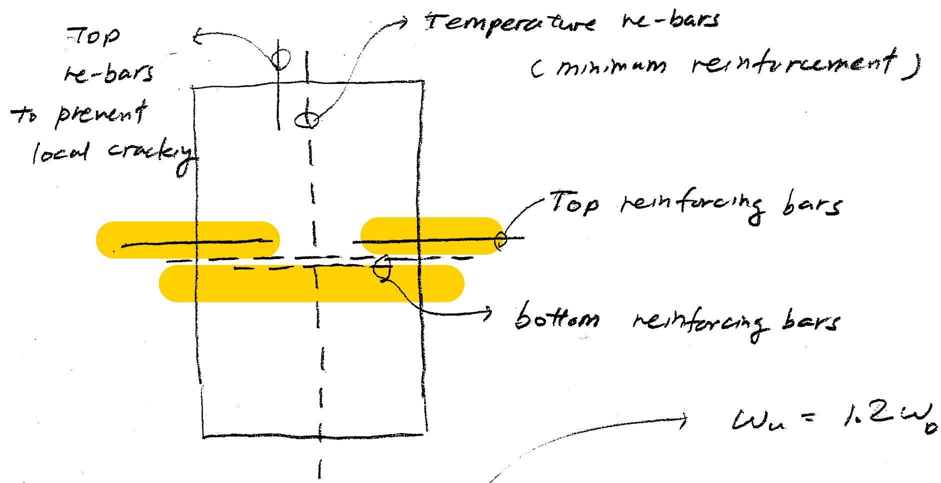
Shear & Torsion $\phi = 0.75$

Modulus of Elasticity $E_c = 8500 \sqrt[3]{f_{cu}}$ (MPa), $\quad$ concrete mix design strength $f_{cu} = f_{ck} + 8$ (MPa)

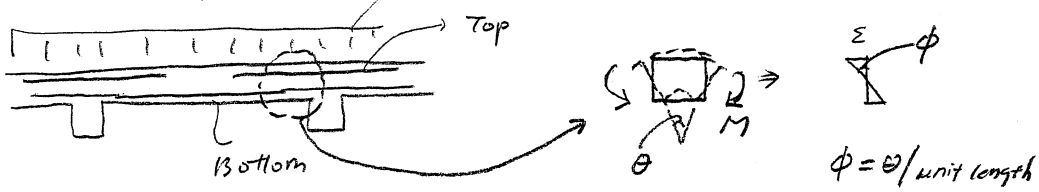
$E_s = 200{,}000$ (MPa)

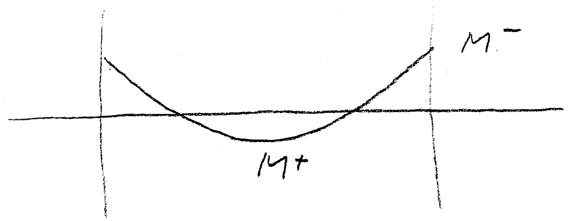
for continuous slabs

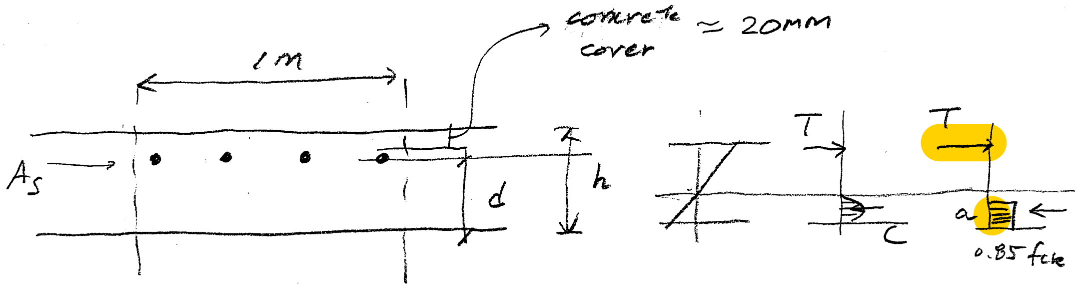
thickness $\geq \ell/28$ specified in KCI or KBC for controlling deflection



$w_u = 1.2 w_D + 1.6 w_L$







$C = 0.85 f_{ck} \cdot a\, b$ $\quad b = 1m$

$T = A_s f_y$ $\quad A_s$ = area of re-bars per 1m width of slab

By force - equilibrium

$C = T \quad A_s f_y = 0.85 f_{ck}\, a\, b \qquad a = \dfrac{A_s f_y}{0.85 f_{ck}\, b}$

$M_n = A_s f_y \left(d - \dfrac{a}{2} \right)$

$\phi M_n = M_u^-$ solve A_s (2nd order equation)

$\phi = 0.85$

In general, $(d - \frac{a}{2}) = jd \approx 7/8\, d \; (0.875d)$

$$\text{req'd } A_s \approx \frac{M_u}{\phi f_y \, 0.875 d}$$

for slabs, use D10, D13, D16, or D19
or in combination

minimum reinforcement $\rho = 0.0018$ or 0.0020

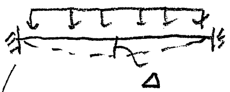
$$\min A_s = \rho \cdot b \cdot h$$

1m

Check deflection

In general, if $h \geq \ell/28$ (continuous slabs) is satisfied, deflection check can be omitted.

$$\Delta = \frac{w \ell^4}{384 EI}$$



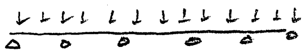
boundary condition for continuous slab

EI = effective stiffness

w = service load

$\leq \ell/240,\ \ell/480$ $\quad = w_D\ (w_L)$ or $w_D + w_L$

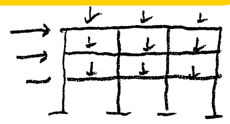
(conditional according to design criteria)

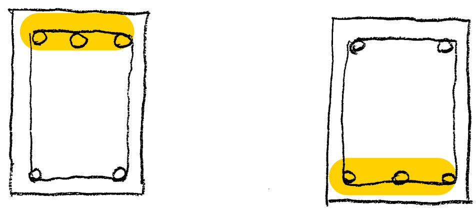


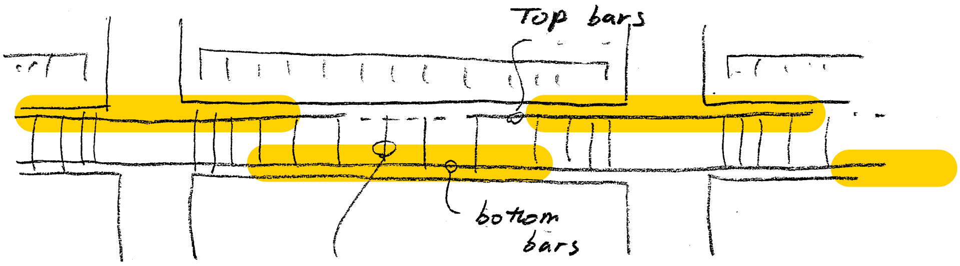
Design of beams

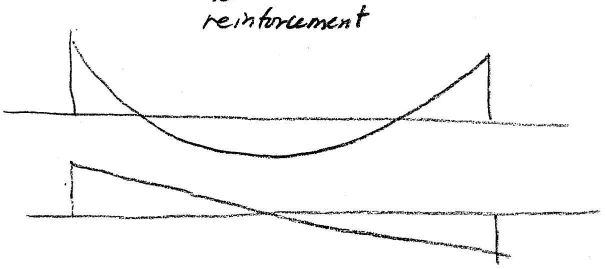
- beams resisting floor loads
- girders resisting floor loads and lateral load

frame analysis is required





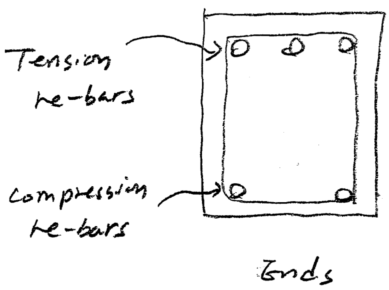




Flexural Design of beam — the same as slabs

$$\text{req'd } A_s = \frac{M_u}{\phi f_y \, \gamma d} \qquad \rho = \frac{A_s}{B d} \quad \text{tensile reinforcement ratio}$$

In general, compression re-bars are used but, the compression bars do not significantly affect the flexural strength. Thus, the effect can be neglected.

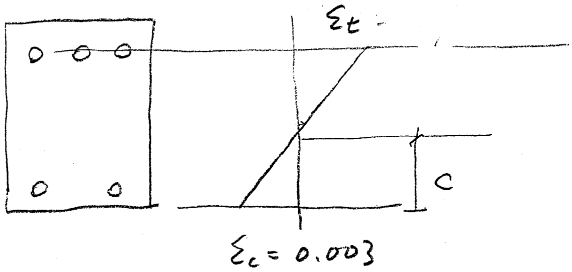


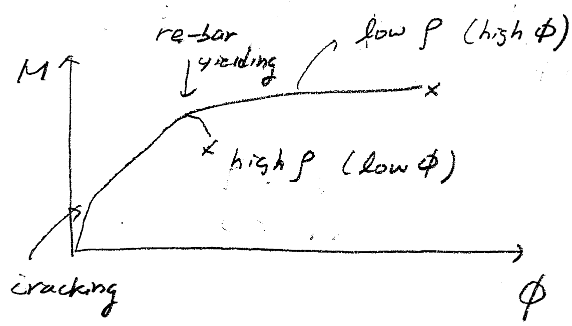
The role of compression bars

increase of ductility

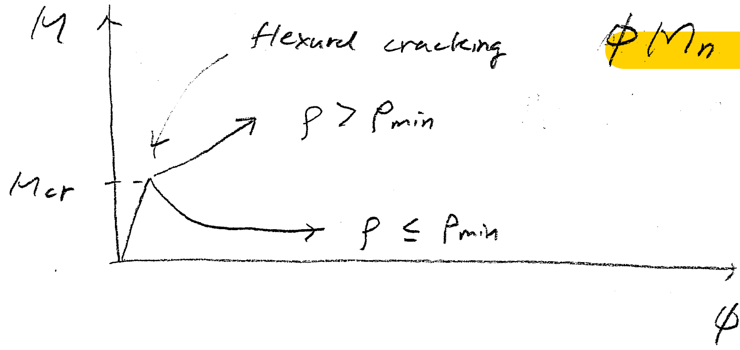
reduction of long term deflection (creep)

for beams, $\varepsilon_t \geq 0.005$ (or $2.5 \times \varepsilon_y$) to ensure re-bar yielding before crushing of concrete





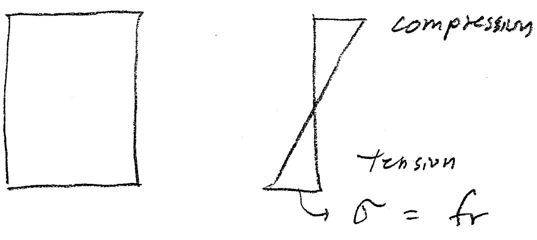
Minimum flexural reinforcement



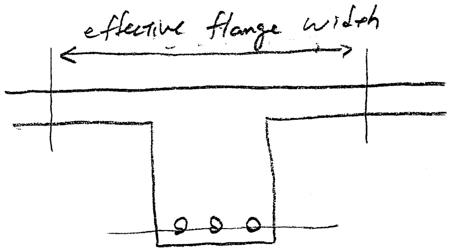
ρ_{min} to ensure

$$\phi M_n \geq M_{cr}$$

$$M_{cr} = S \cdot f_r$$



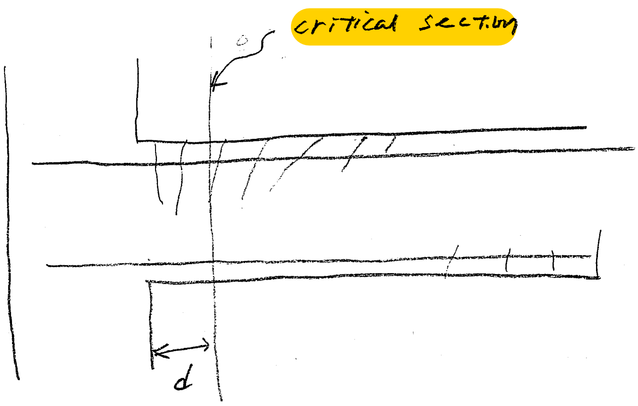
flexural Design at center ⇒ T beam section can be used



Advantage of T beam design

- decrease of A_s
- increase of ductility
- decrease of (short term / long term) deflections

Shear Design

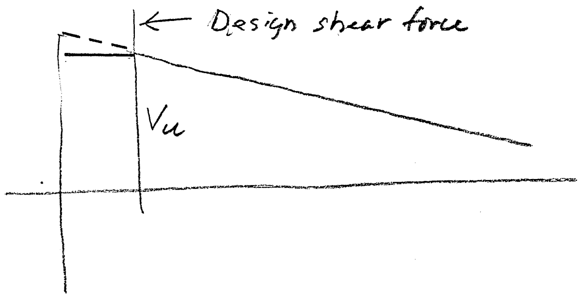


$V_n = V_c + V_s$

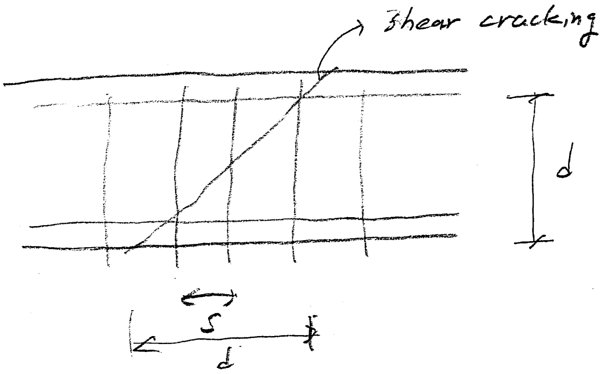
V_c = contribution of concrete

V_s = contribution of shear reinforcement

$V_c = \frac{1}{6}\sqrt{f_{ck}}\, b d$



$V_s = \frac{A_v f_y d}{s}$

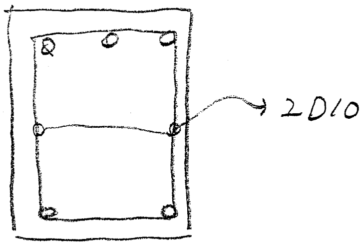


angle ≈ 45° is assumed

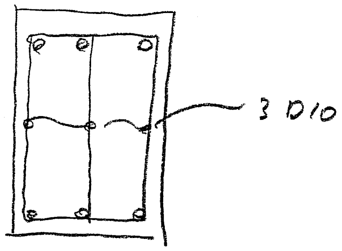
d/s ⇒ number of legs of shear reinforcement

$\frac{V_u}{\phi} = V_n = V_c + V_s$ $\phi = 0.75$ (shear)

req'd $V_s = \frac{V_u}{\phi} - V_c$ req'd $s = \frac{A_v f_y d}{V_s}$



$A_s = 2 \times$ Area of D10



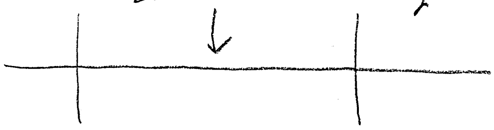
$A_s = 3 \times$ Area of D10

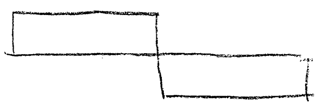
In case of $V_u > \phi V_c/2$, minimum shear reinforcement ($A_{v,min}$, $s \le d/2$)

$$A_{v,min} = 0.0625\sqrt{f_{ck}}\,\frac{b_w s}{f_{yt}}$$

f_{ck} (MPa)
b_w, s (mm)

concentrated loading

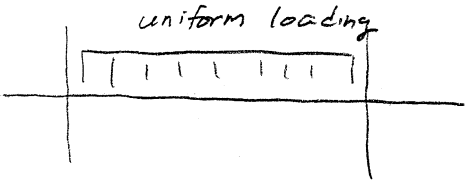


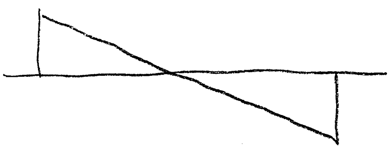


SFD

uniform arrangement of shear reinforcement

uniform loading





SFD

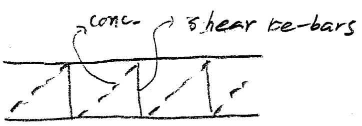
large shear reinforcement

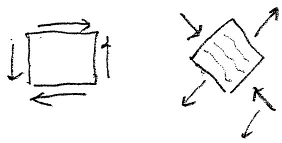
permissible maximum shear reinforcement $V_s = 4 \times V_c$

$= 2/3\sqrt{f_{ck}}\, b_w d$

f_{ck} (MPa)

Truss mech.





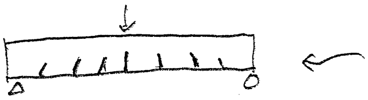
crushing can occur in the diagonal str

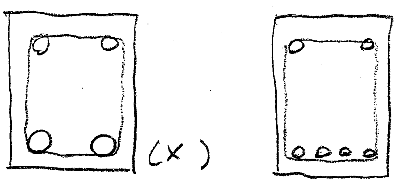
Deflection check — if $h \ge l/21$ (continuous beams) is satisfied, deflection check can be omitted.

otherwise,

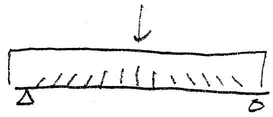
$$\Delta_L \le l/240 \text{ or } l/480 \text{ (conditional)}$$

check crack width



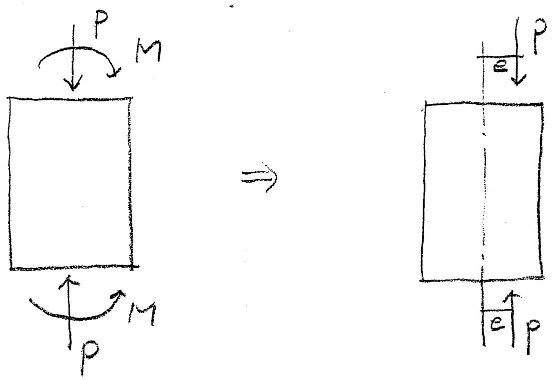


(x) (o)

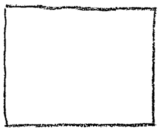


column design

11-3 Interaction Diagrams

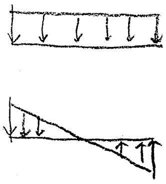


$M = P \cdot e$



$$\sigma_{total} = \frac{P}{A} + \frac{My}{I} = f_{cu}$$

$$\text{or} \quad \frac{P}{A} + \frac{My}{I} = f_{ct}$$



$$\sigma = \frac{P}{A}$$

$$\sigma = \frac{My}{I}$$

+ sign : compression

− sign : tension

case 1) $|f_{cu}| = |f_{ct}|$

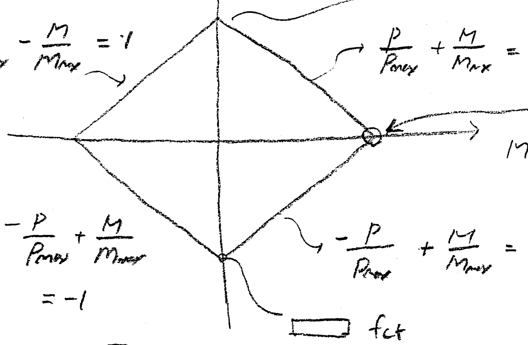
$$\frac{P}{A} + \frac{My}{I} = f_{cu} \qquad \frac{P}{f_{cu}A} + \frac{M}{f_{cu}\frac{I}{y}} = 1$$

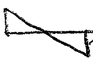
$$\frac{P}{P_{max}} + \frac{M}{M_{max}} = 1$$

compression P/P_{max} $\boxed{}$ f_{cu}

$$\frac{P}{A} + \frac{My}{I} = f_{cu}$$

$$\frac{P}{P_{max}} - \frac{M}{M_{max}} = 1 \qquad \frac{P}{P_{max}} + \frac{M}{M_{max}} = 1$$





$|f_{cu}| = |f_{ct}|$

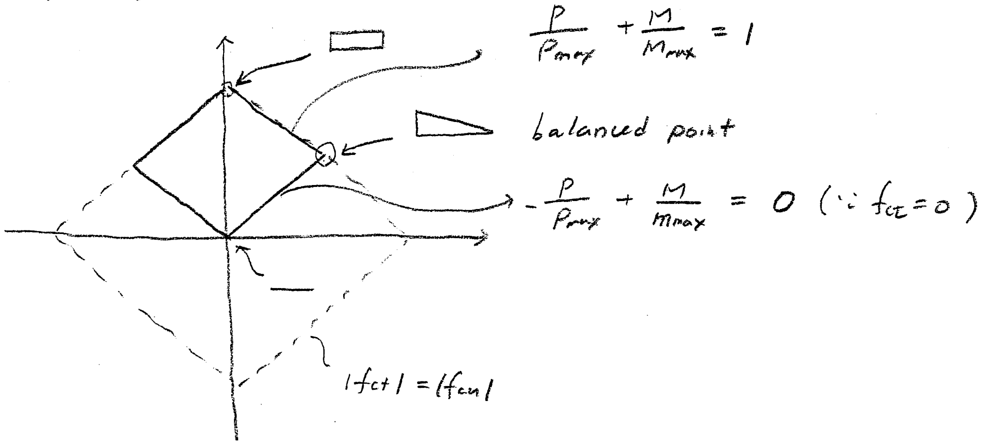
M/M_{max} balanced point

$$-\frac{P}{P_{max}} + \frac{M}{M_{max}} = -1 \qquad -\frac{P}{P_{max}} + \frac{M}{M_{max}} = 1$$

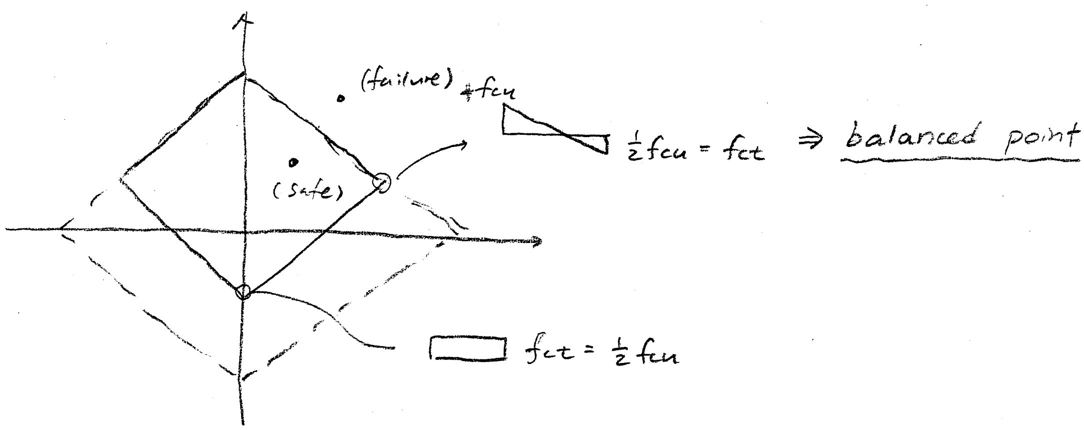
Tension $\boxed{}$ f_{ct}

$$-\frac{P}{A} + \frac{My}{I} = f_{ct}$$

case 2) $|f_{ct}| = 0$



case 3) $|f_{ct}| = \frac{1}{2}|f_{cu}|$

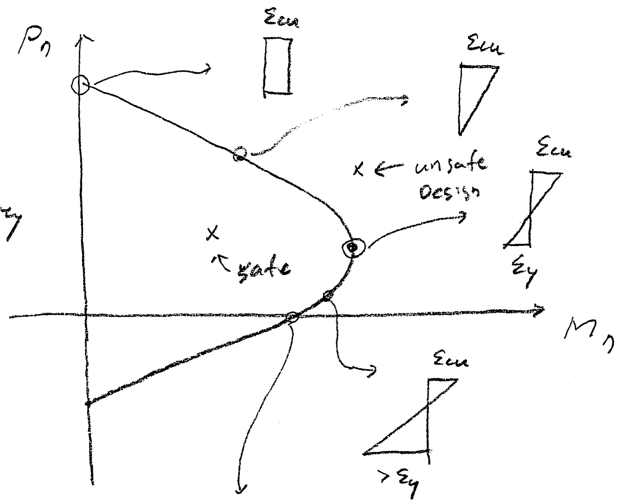


11-4 Interaction Diagrams for concrete columns

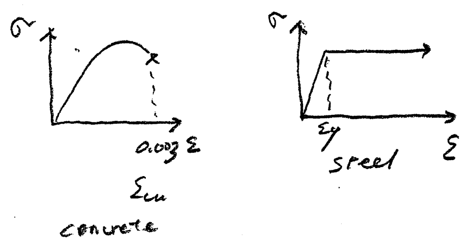
1. Strain Compatibility Solution

concrete 의 변형 : $\varepsilon_{cu} = 0.003$

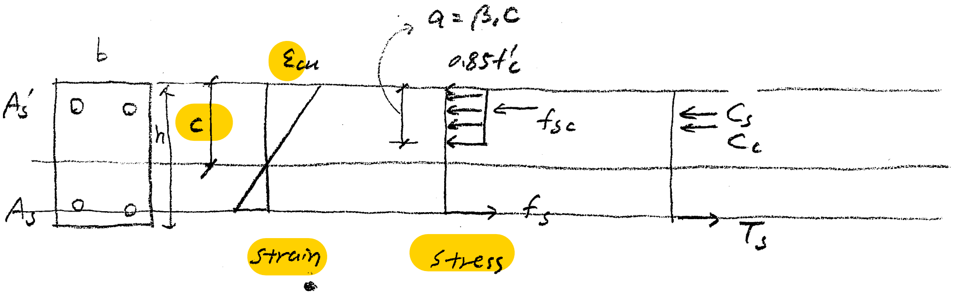
- ultimate strength Design
- strain compatibility
- failure caused by concrete crushing.



balanced point — ↑ compression failure (brittle) / ↓ Tension failure (ductile)



Solution by Equilibrium $P_n = 0$



$C_s = A_s' f_{sc} \le A_s' f_y$

$C_c = 0.85 f_c' b a$

$T_s = A_s f_s \le A_s f_y$

$$P = C_c + C_s - T_s$$

$$M = C_c \left(\frac{h}{2} - \frac{a}{2}\right) + C_s \left(\frac{h}{2} - d'\right) + T_s \left(d - \frac{h}{2}\right)$$

moment capacity w.r.t the center of the cross-section

2. Maximum Axial load

$$P_o = 0.85 f_c' (A_g - A_{st}) + f_y A_{st}$$ ⇒ pure axially load column

Accidental moments

- misalignments of columns
- uneven compaction of concrete
- misalignment of reinforcement

for spiral columns

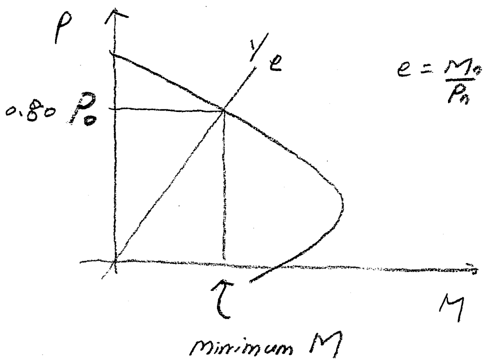
$$\phi P_n = 0.85\,\phi\,[0.85 f'_c (A_g - A_{st}) + f_y A_{st}]$$

$$\phi = 0.70$$

for tied columns

$$\phi P_n = 0.80\,\phi\,[0.85 f'_c (A_g - A_{st}) + f_y A_{st}]$$

$$\phi = 0.65$$



$e = \frac{M_n}{P_n}$ = accidental eccentricity

3. Strength Reduction factor for columns

$\phi P_n \geq P_u$ and $\phi M_n \geq M_u$

P_n : nominal strength

P_u : ultimate (applied) load

ϕ = 0.7~0.9 for spiral columns (ACI) ϕ = 0.7~0.85 (KCI)

0.65~0.9 for tied columns (ACI) ϕ = 0.65~0.85 (KCI)

0.90 for beams (ACI) ϕ = 0.85 (KCI)

The reasons are

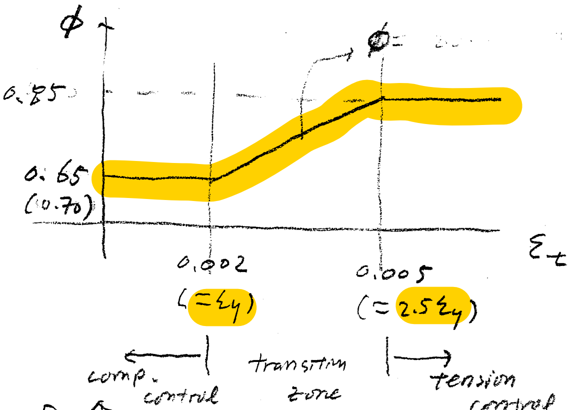
1) column strength more strongly depends on conc. strength. (which is not reliable)

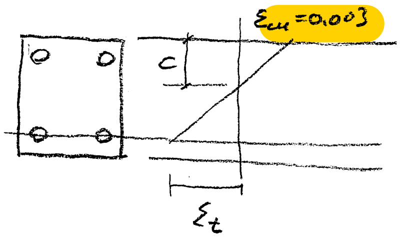
2) The failure of column is much more brittle. (warning to people and force-redistribution are difficult

ϕ accounts for variations in { material strength " reliability, analytical method, Construction skill, dimensions }

Variations of Strength reduction factor ϕ

KBC 2016, KCI 2012, ACI 318-14





if $f_y = 400MPa$ $E = 200{,}000 MPa$ (200GPa)

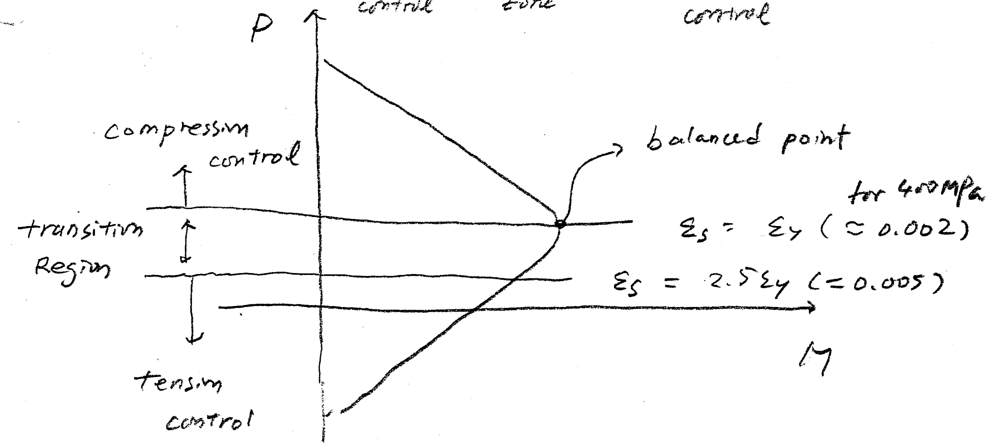
$\varepsilon_y \simeq 0.002$

tied column

$\phi = 0.65$ (Comp. control)

$\phi = 0.65 \sim 0.85$ (transition)

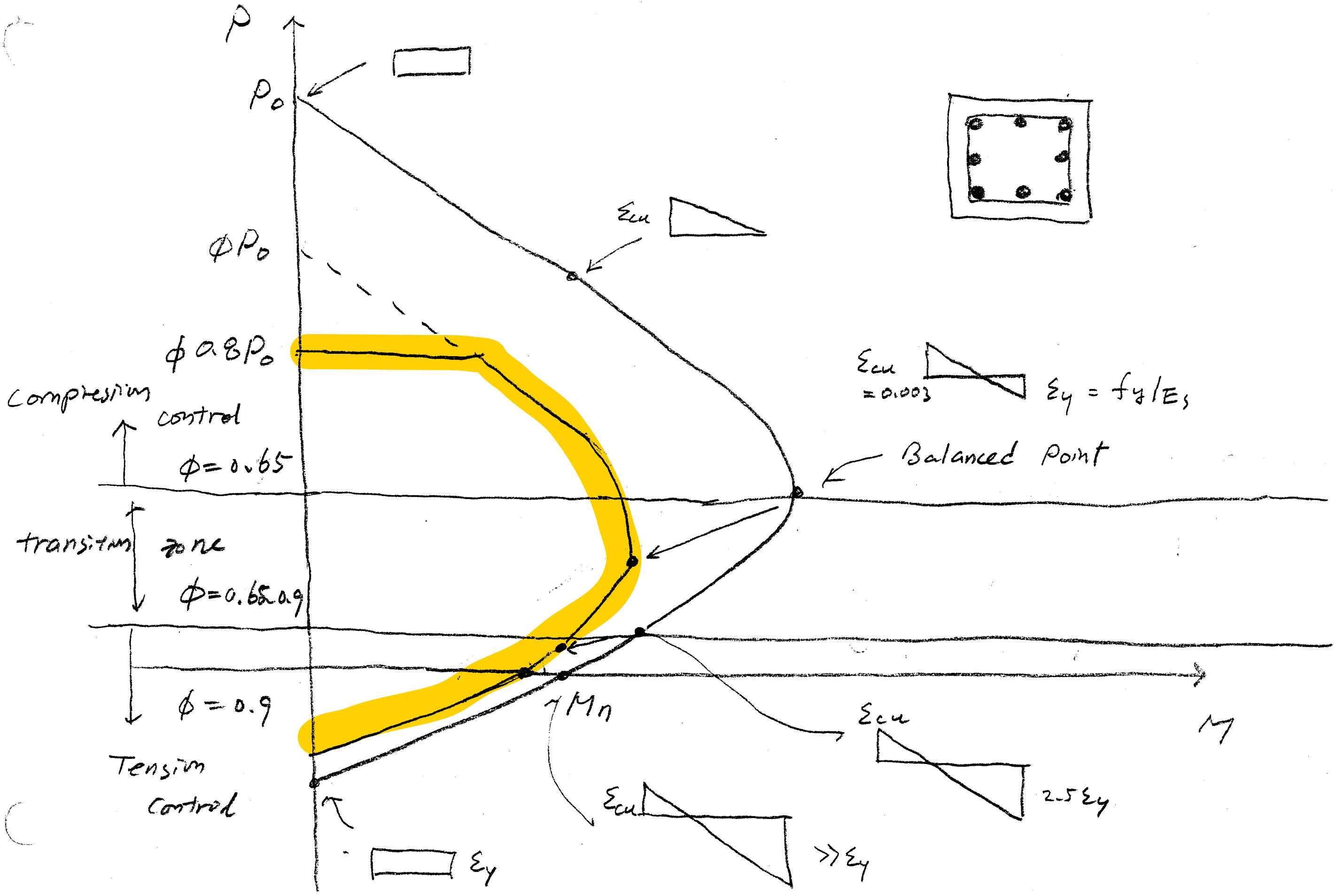
$\phi = 0.85$ (ten. control)



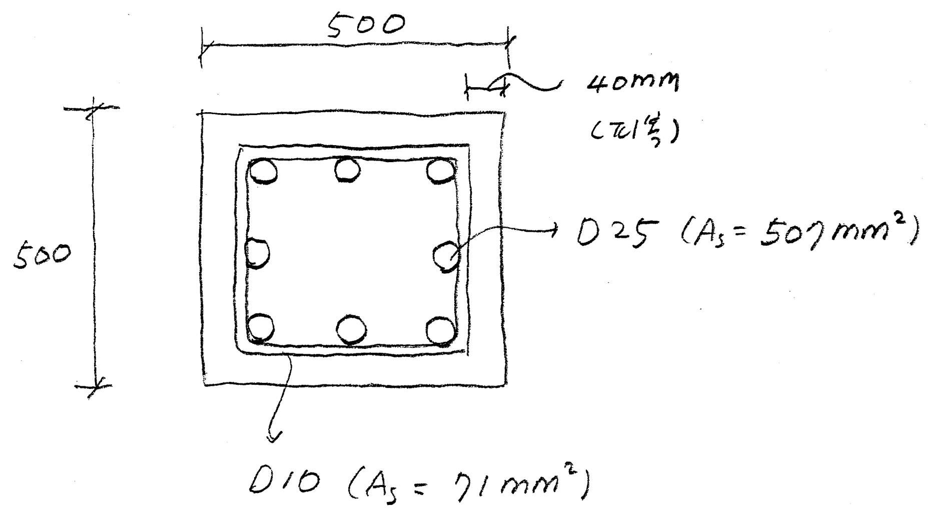
4. Derivation of computation Method

P493 ~ P498

Example 11-1



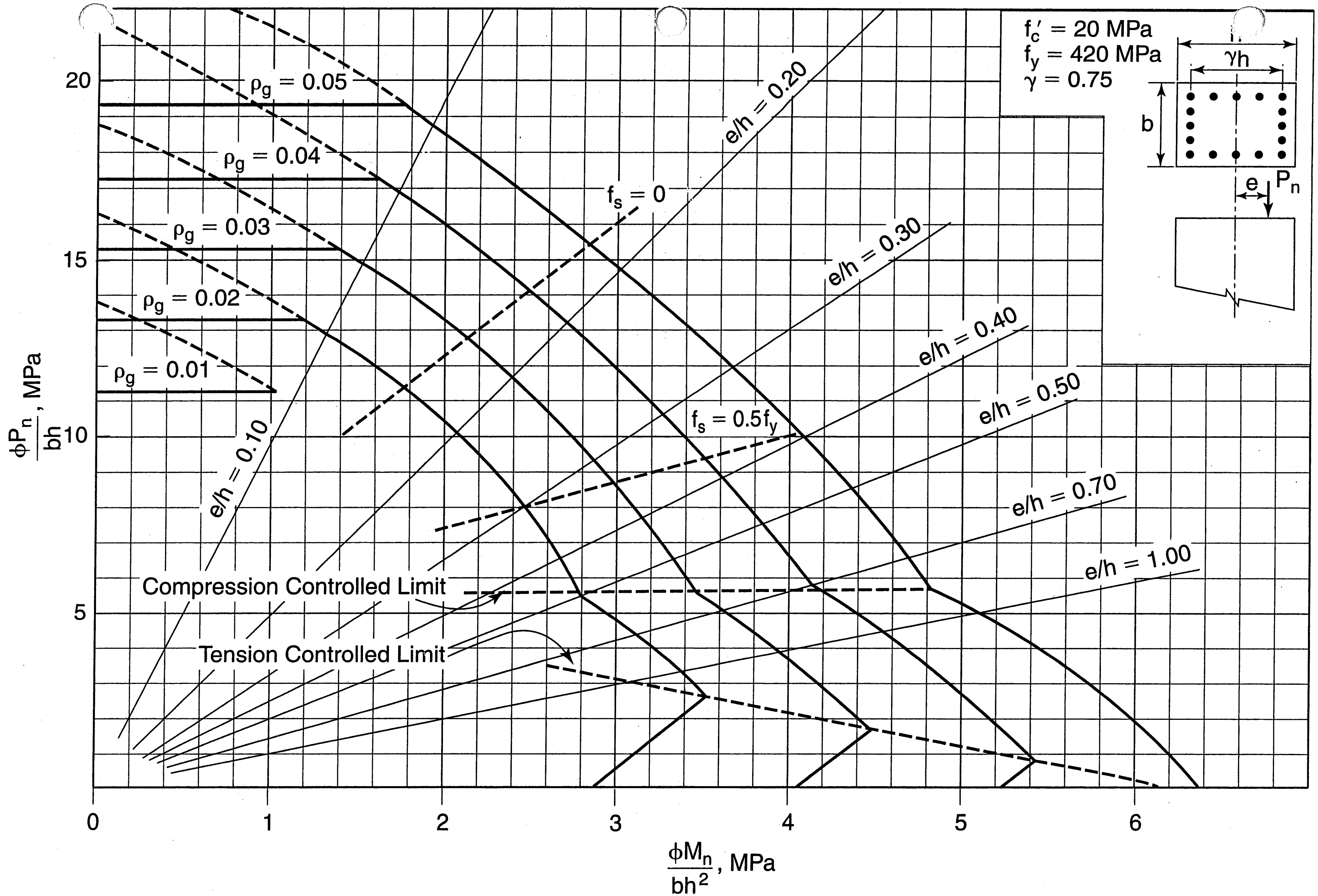
Example # 1   다음과 같은 기둥단면에 대한 Interaction diagram을 그려라 (tied column)



$f_y = 400\ MPa$

$E_s = 2 \times 10^5\ MPa$

$f_{ck} = 30\ MPa$



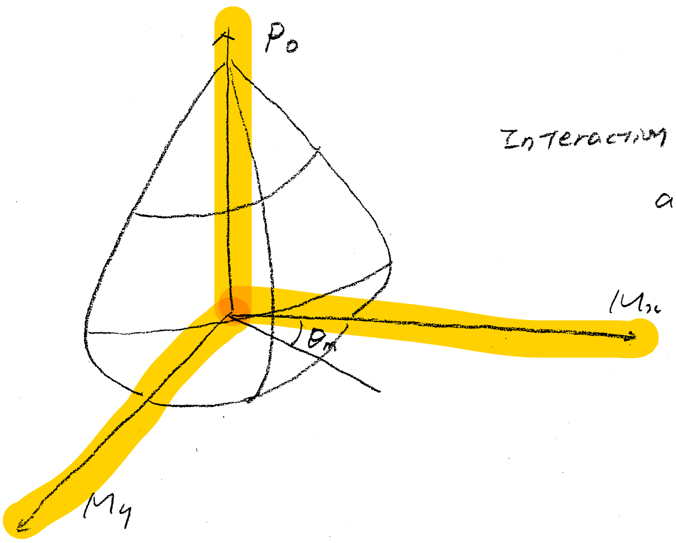
Note: The strength-reduction factors, ϕ, are from ACI 318-02 Section 9.3.2.
They must be used with load combinations from Section 9.2.

Fig. A-10

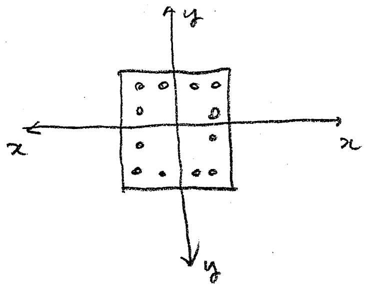
Design Examples

Example 11-2

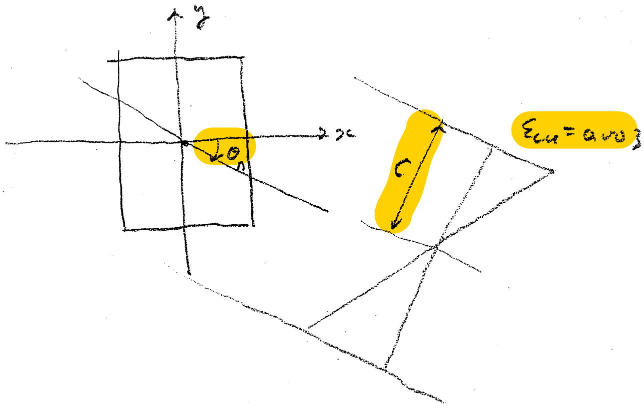
11-8 Biaxially loaded columns



Interaction surface for axial load and biaxial bending



Double iteration of calculation

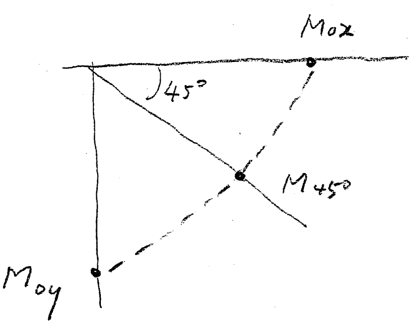


θ_n: angle of neutral axis

strain gradient across the section

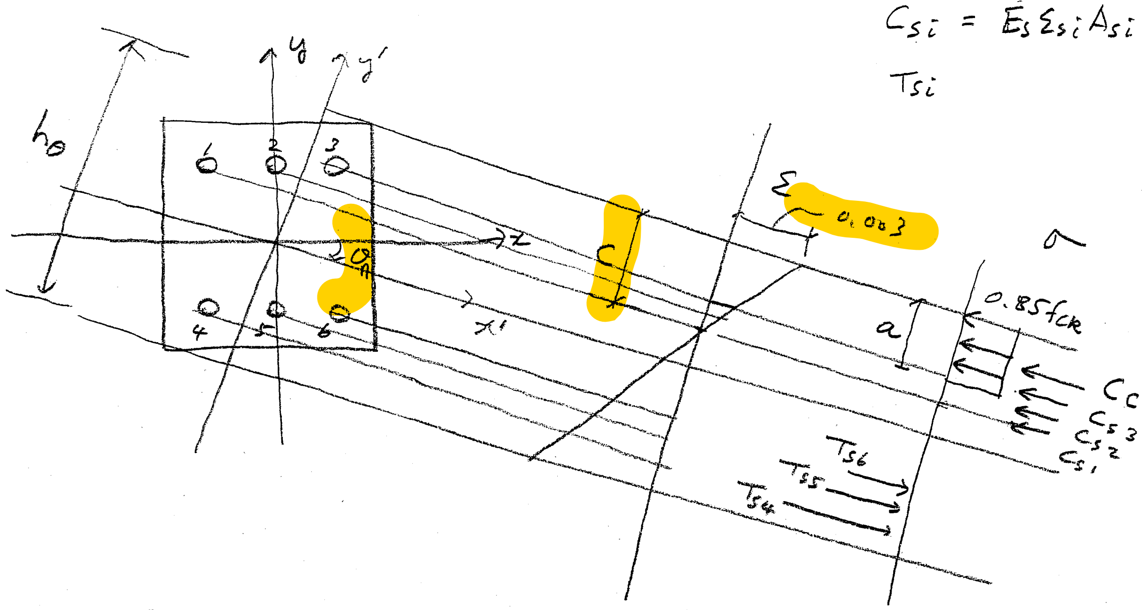
$\star\ \theta_n \neq \theta_m$

Approximate Diagram



$C_{si} = E_s \varepsilon_{si} A_{si} < f_y A_{si}$

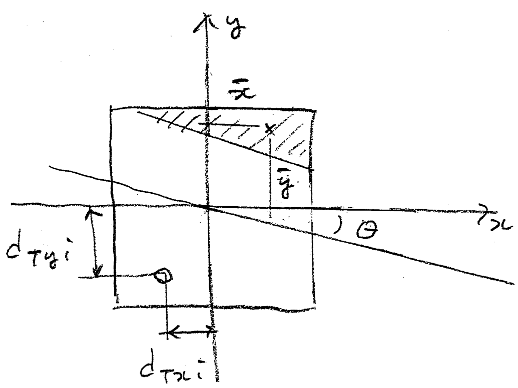
T_{si}

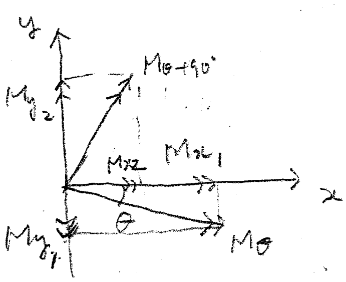


$P_n = C_c + C_{s3} + C_{s2} + C_{s1} - T_{s4} - T_{s5} - T_{s6}$

$M_{nx} = C_c \bar{y} + \Sigma C_{si} d_{cyi} + \Sigma T_{si} d_{Tyi}$

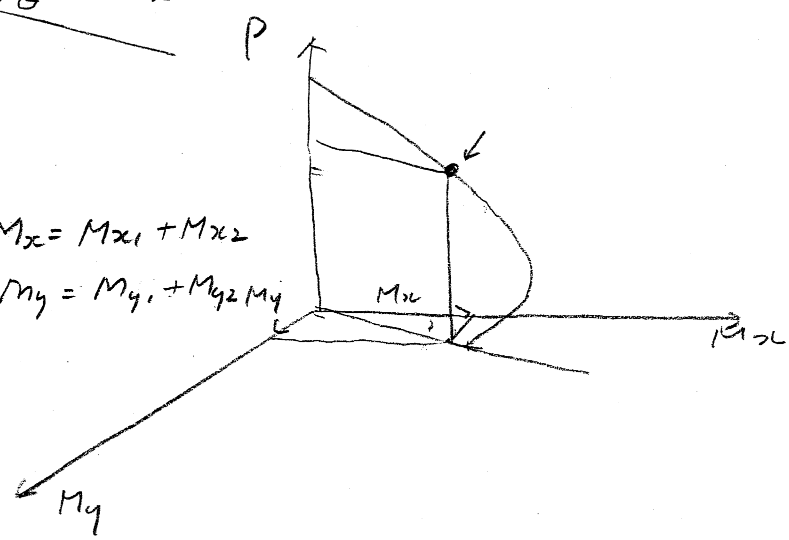
$M_{ny} = C_c \bar{x} + \Sigma C_{si} d_{cxi} + \Sigma T_{si} d_{Txi}$



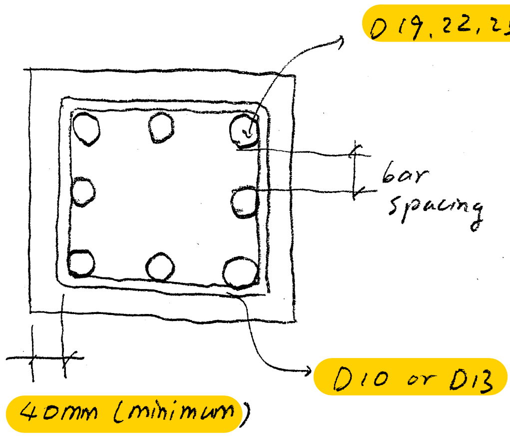


$M_x = M_{x1} + M_{x2}$

$M_y = M_{y1} + M_{y2}$



7) Details of Longitudinal Re-bars



- Required Area of re-bars
- Bar spacing
- length of lap splice

8) Details of tie bars

- shear Resistance

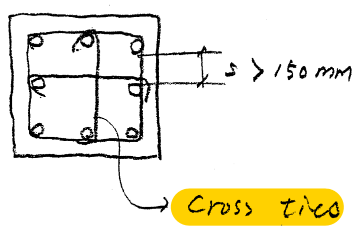
if $V_u > 0.5 \phi V_c$ → minimum ties

$V_c = \frac{1}{6}\sqrt{f_c'}\, bd$ (SI)

$V_c = 0.53\sqrt{f_c'}\, bd$ (kgf/cm²)

$V_u = \phi (V_c + V_s)$ $V_s = A_{st} f_y d / s$

- tie bar spacing



[vertical spacing
  horizontal spacing

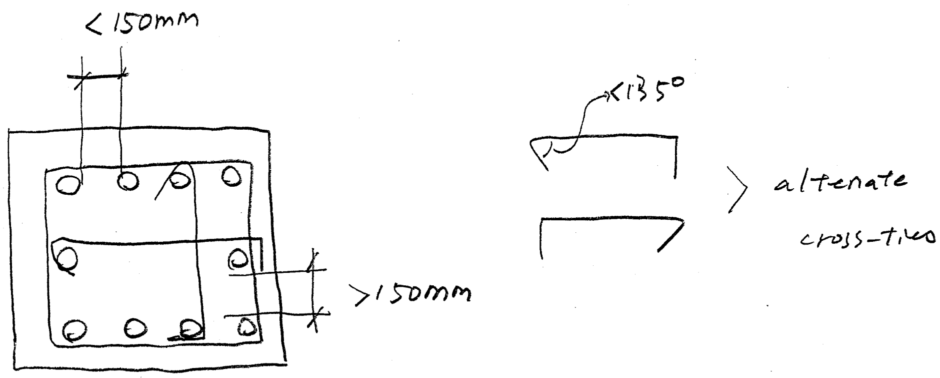
- concrete confinement for high seismic zone

Details of ties for columns

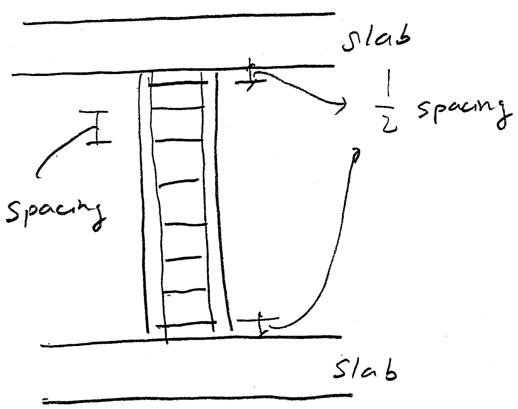
1. D10 for mainbars < D32, D13 for > D35

2. vertical spacing < 16 d_b
   48 d_t
   the least dimension

3.

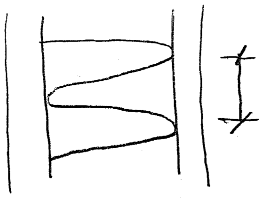


4.



Details of spirals

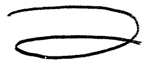
1. $> \phi\ 9mm$

2. 

spacing

$25mm \le$ spacing $\le 75mm$

$\ge$ 1.33 aggregate diameter

3. Anchorage = $1.5\ D_c \Rightarrow$ 

4. Splice : Cap splice $48\ d_{spiral} > 300mm$

welded splice

mechanical splice