



Concrete Strength and Ductility Improvement from Confinement

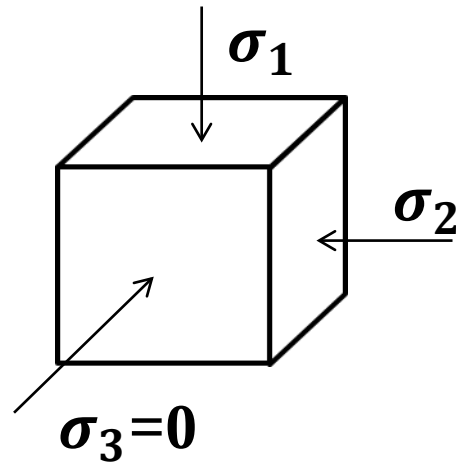
January, 2013

Jang-Ho Jay Kim

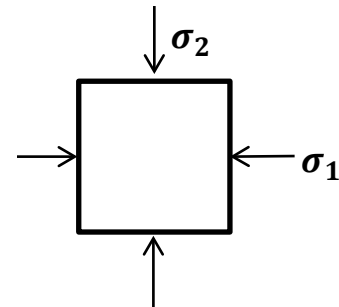
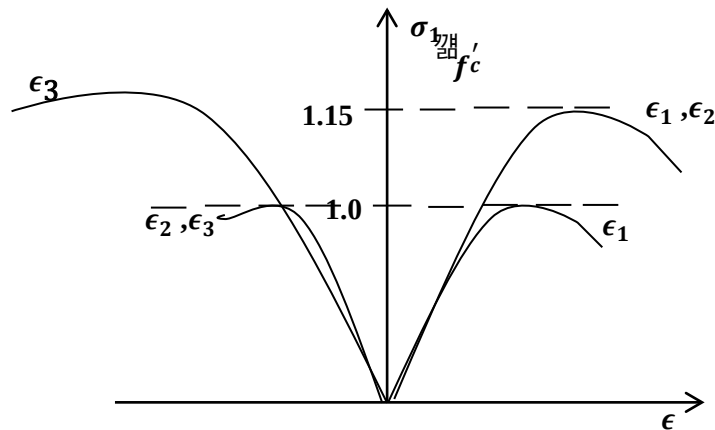
Yonsei University
Department of Civil and Environmental Engineering



◆ Biaxial Stress State



◆ Biaxial Behavior of Concrete

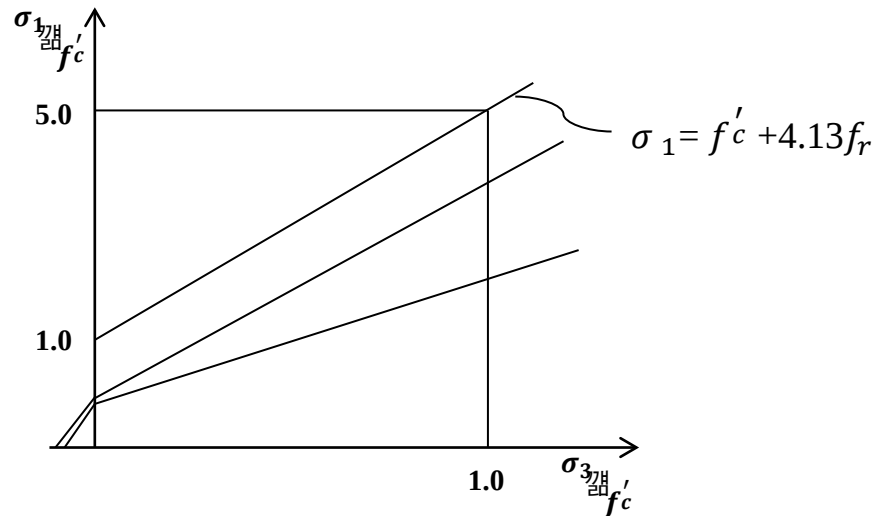


◆ Triaxial Stress State

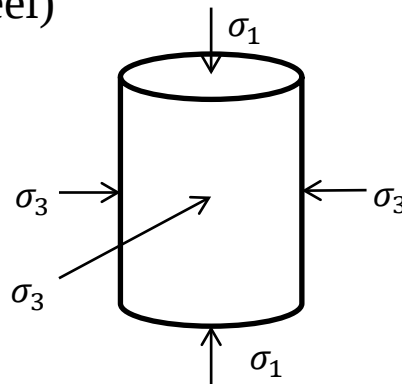
Hobb , J Structural
Engineering, ASCE

April 1977

Define : $\sigma_1 \geq \sigma_2 \geq \sigma_3$



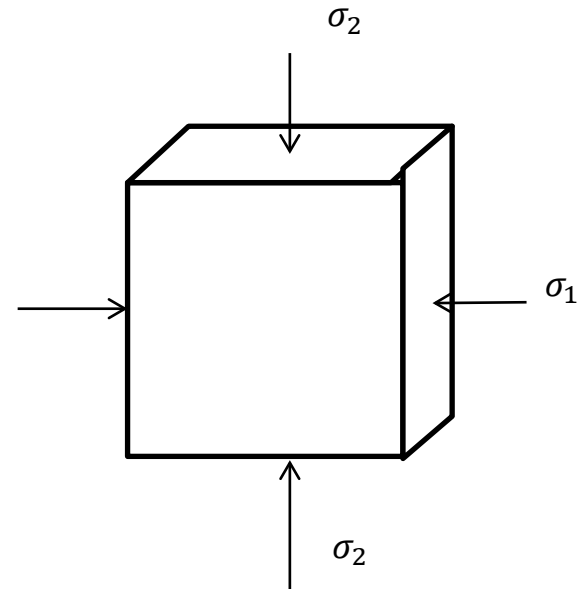
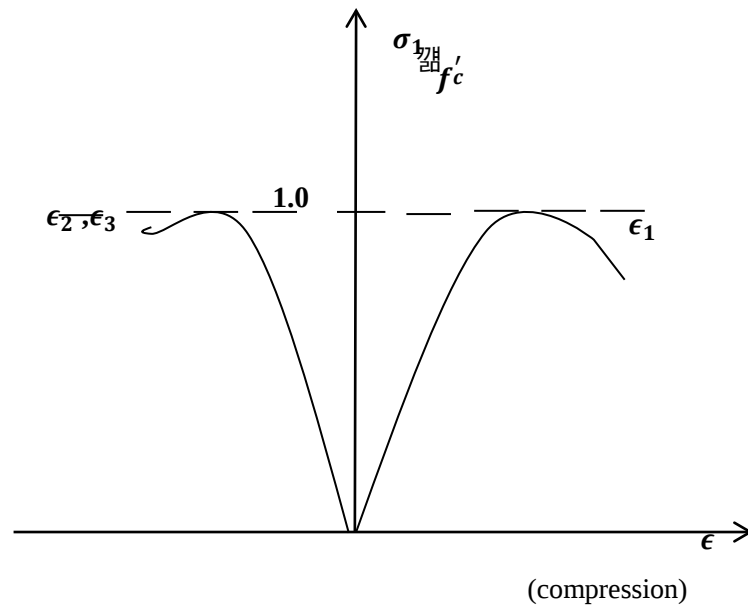
*By Confining the concrete ($\sigma_3 =$ very large), get very strong material is obtained
(Sometimes almost like steel)



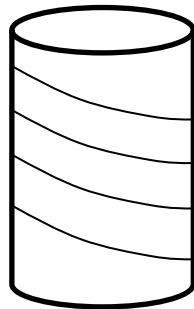
Quality Control	Good	Avg.	Poor
Conc. Variability	10%	15%	20%
Req'd mean f'_c	$f'_c + 500$	$f'_c + 700$	$f'_c + 1200$

- In ready mixed concrete, concrete with higher strength is usually delivered. Higher strength is not necessarily good, since it causes unexpected brittle failure.

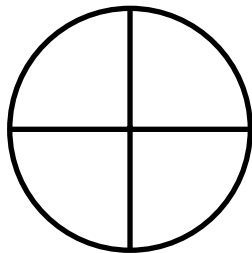
◆ Confined Concrete Behavior



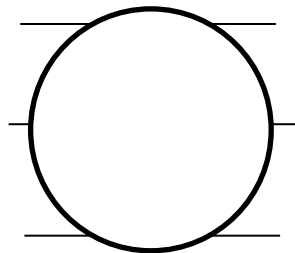
◆ Confining Methods



Wrapping (Spiral Reinforcement)



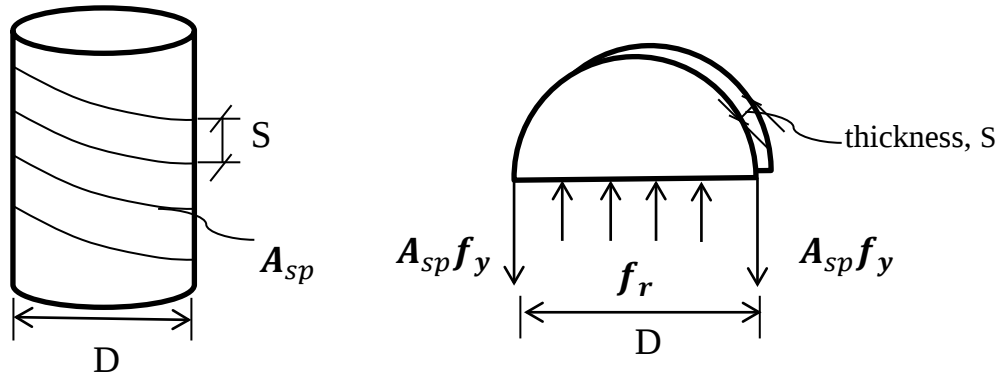
$$\epsilon_{developed} = 0.002$$



$$C = \pi D$$

$$\epsilon = 0.002 \text{ (still)}$$

Consider a slice of column of thickness, S



$$DSf_r = 2A_{sp}f_y$$

$$\therefore f_r = \frac{2A_{sp}f_y}{DS}$$

Define $\rho_s = \frac{\text{Volume of spiral wire}}{\text{Volume of confined core}}$

$$\rho_s = \frac{A_{sp}\pi D}{S\frac{\pi D^2}{4}} = \frac{4A_{sp}}{DS}$$

$$f_r = \frac{2\rho_s f_y}{DS}$$

$$f_{c \max} = f'_c + 4.1 f_r$$

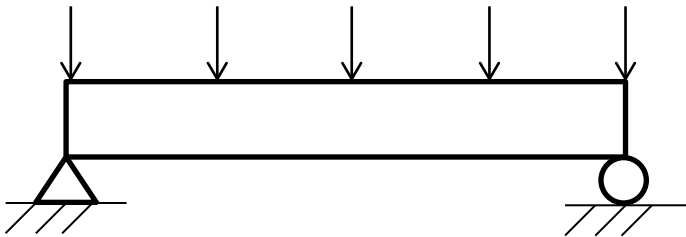
$$f_{c \max} = f'_c + 2.05\rho_s f_y \cong f'_c + 2\rho_s f_y$$

$$\therefore f_{c \max} = f'_c + 2\rho_s f_y$$

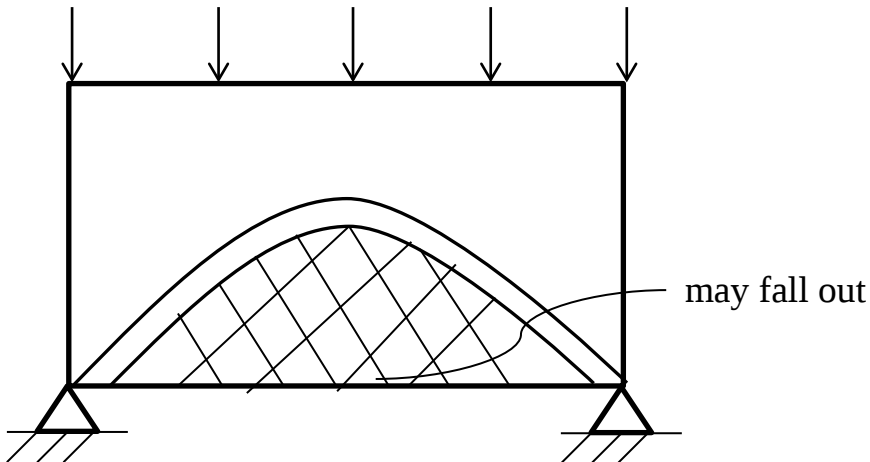
◆ Issues Regarding Confined Stress

Arching Action

Suppose we test plain concrete beams



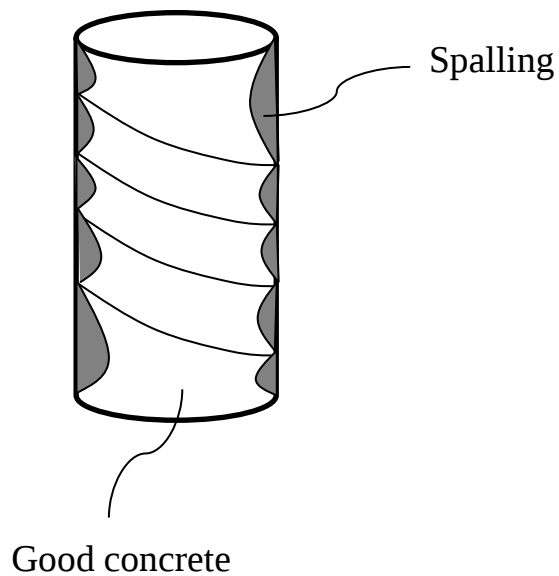
Cannot support much load



Zero tension strength

◆ Issues Regarding Confined Stress

Back to Spiral Reinforced

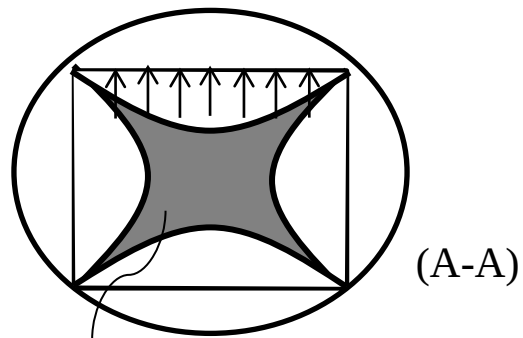


- Small the spacing (s), better strength due to better arching
- ACI Code : $S_{max} = 3" = 7.62\text{cm}$

◆ Issues Regarding Confined Stress

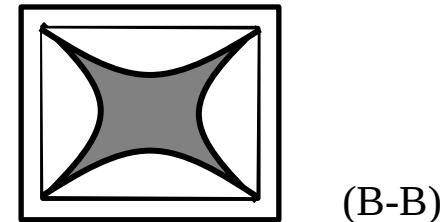
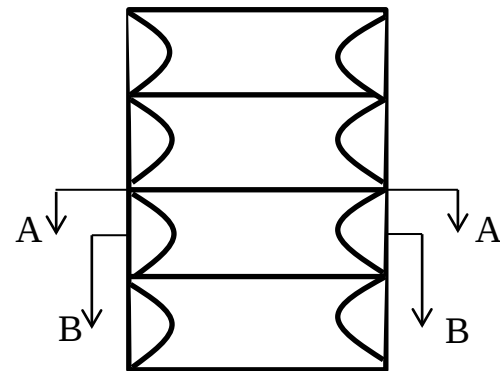
Rectangular Section

Plan View



Good concrete, but so small that it has little resistance to load

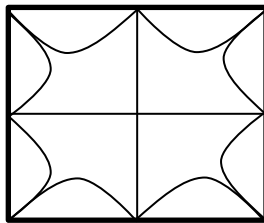
Elevation View



◆ Issues Regarding Confined Stress

Well detailed Section

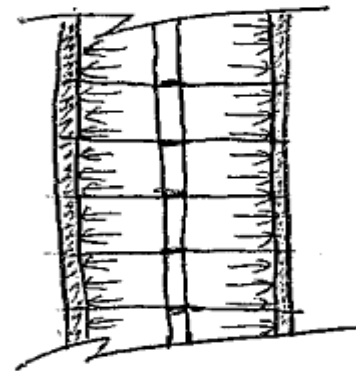
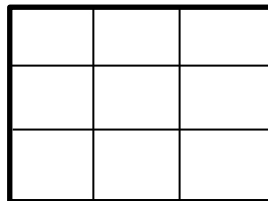
Cross Tie



Cross Section



Better

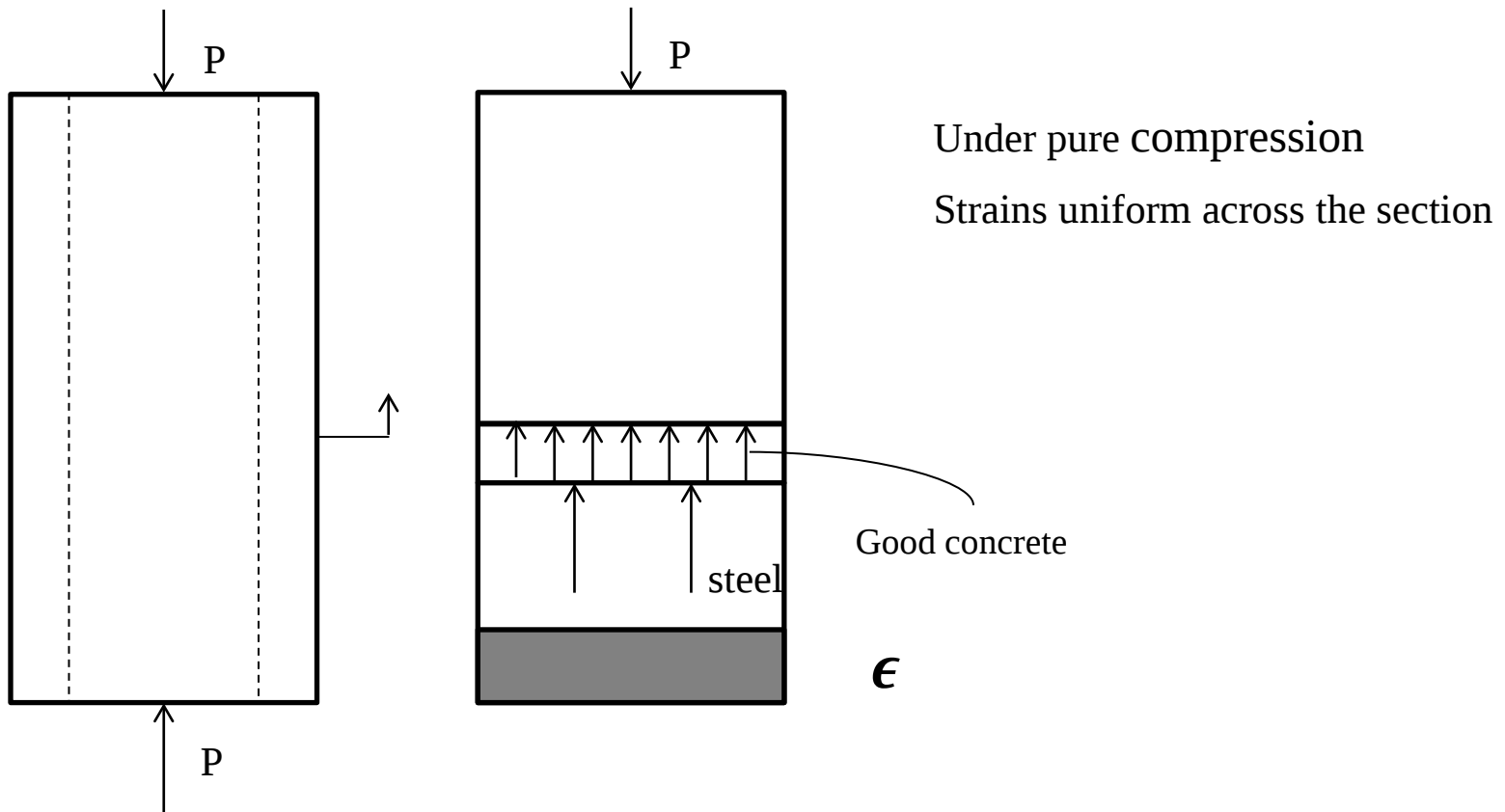


$$\text{Spiral : } f_{c \max} = f'_c + 2\rho_s f_y$$

$$\text{Rectangular : } f_{c \max} = f'_c + 2\rho_s f_y \lambda$$

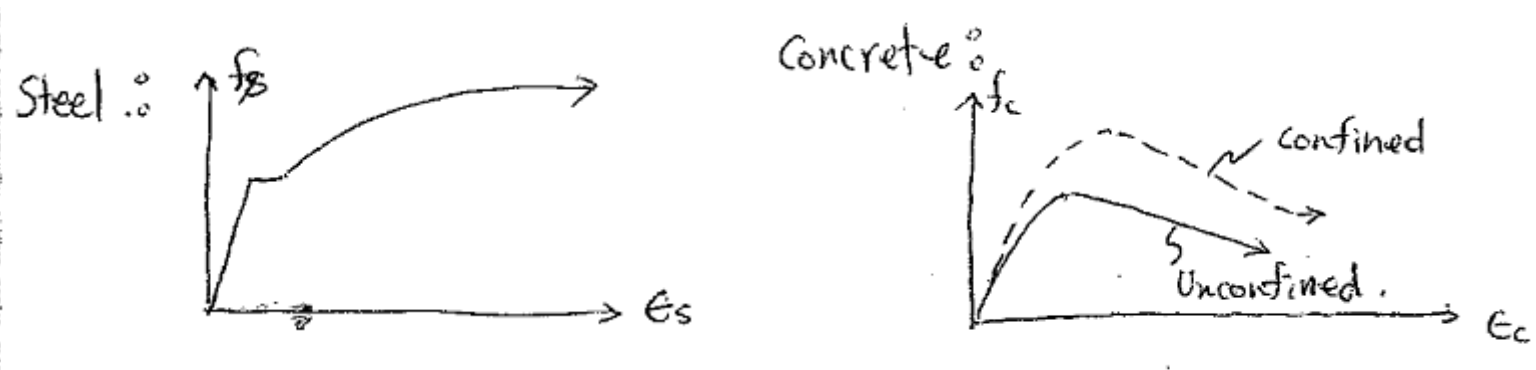
Efficiency
Factor

◆ Behavior of Concrete Confined Cross Section



◆ Behavior of Concrete Confined Cross Section

Assume that there is a unique relation between stress and strain



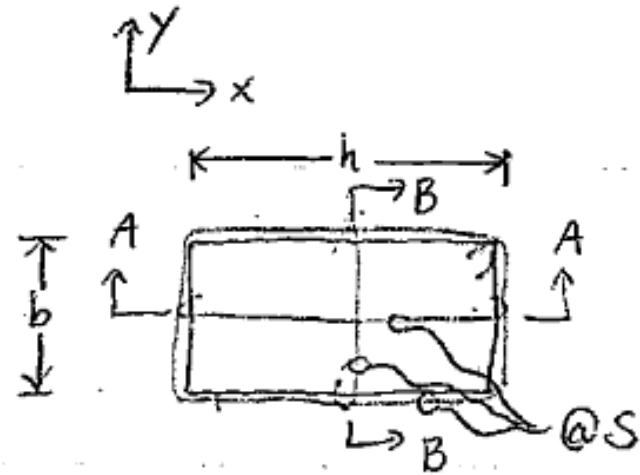
◆ Behavior of Concrete Confined Cross Section

Stress – Strain Relation

$$f_{c \max} = f'_c + 4.1 f_{\min}$$

$$= f'_c + 4.1 \frac{\sum A_s f_y}{hs} \lambda$$

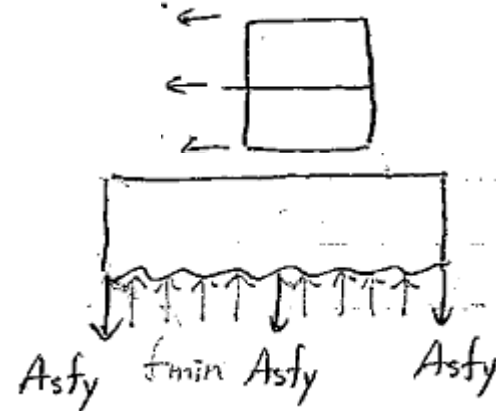
Confinement effectiveness
factor due to arching



Confining Reinforcement Index

$$\rho''_y = \frac{3A_s b}{bhs} = \frac{3A_s}{hs} = \frac{\sum A_s}{hs}$$

$$f_{c \max} = f'_c + 4.1 \rho''_{\min x \text{ or } y} f_y \lambda$$

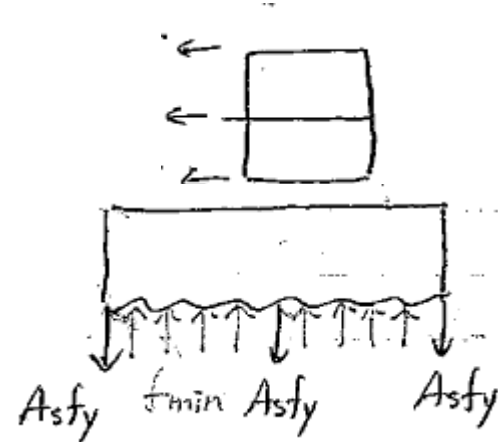


◆ Behavior of Concrete Confined Cross Section

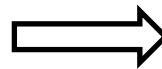
Confining Reinforce Index

$$\rho_y'' = \frac{3A_sb}{bhs} = \frac{3A_s}{hs} = \frac{\sum A_s}{hs}$$

$$f_{c\ max} = f'_c + 4.1\rho''_{\min\ x\ or\ y} f_y \lambda$$

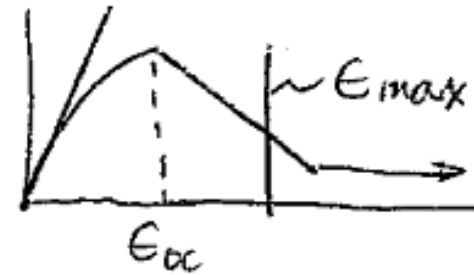


Suppose



λ will be very low

$$* \epsilon_{oc} = \epsilon_{ou} + \frac{f_c' \max}{f_c'}$$



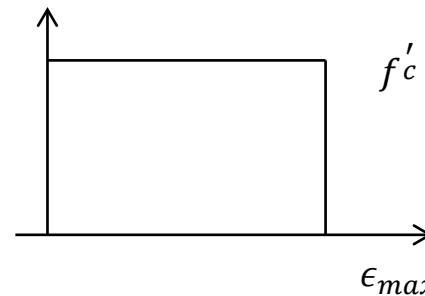
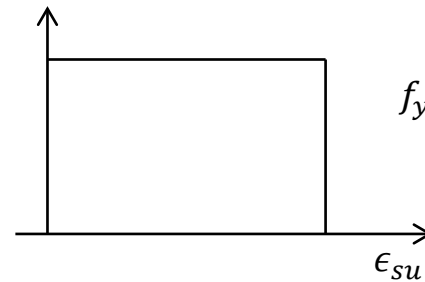
$$* \epsilon_{max}$$

Mander, J Structural Engineering, ASCE

Aug 1988

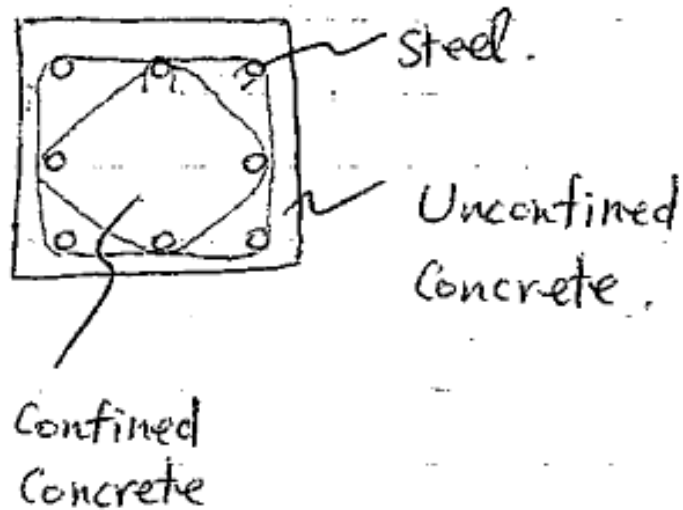
Energy Balance Approach

$$\int f_c' A d\epsilon_c = \int A_{tr} f_s d\epsilon_s$$

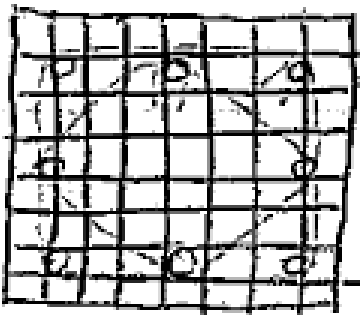


$$\epsilon_{max} = 0.004 + 0.14 \rho' \frac{f_y}{f_c'}$$

Volume ratio of transverse steel

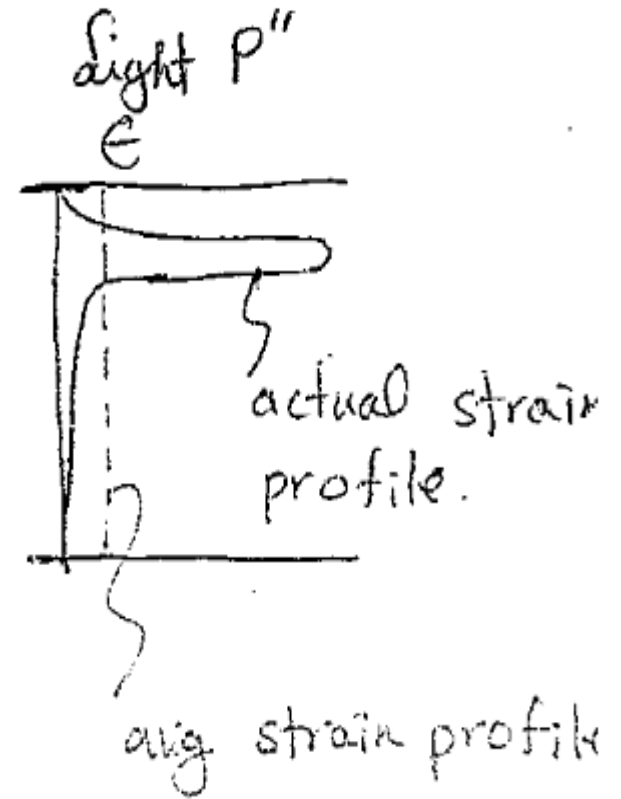
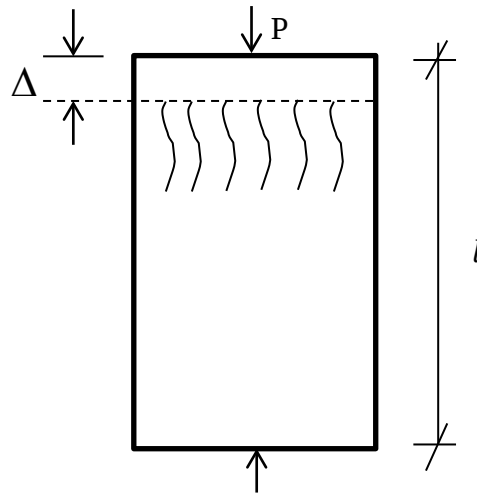
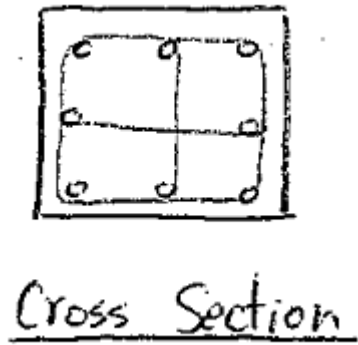


- 1) Impose strain
- 2) Calculate stress
- 3) $f * \text{Area} = \text{force}$
- 4) $\sum \text{Forces} = \text{Axial load}$

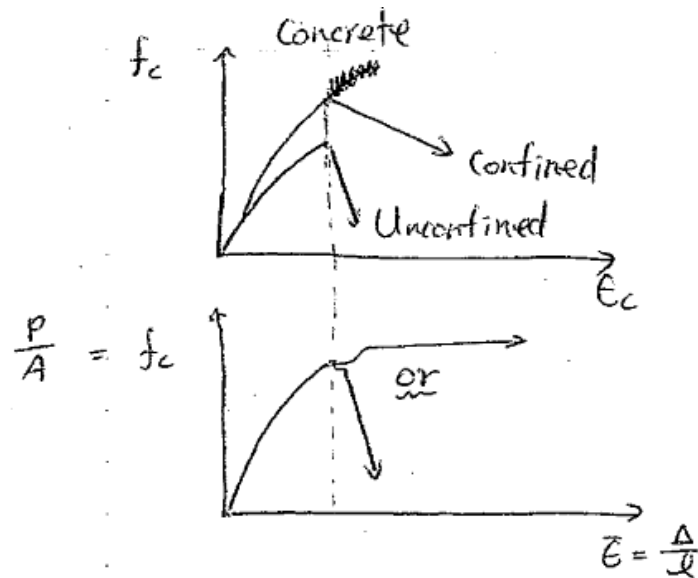


For computer use, define each block of the material property or go through the steps.

◆ Confined Columns in Compression



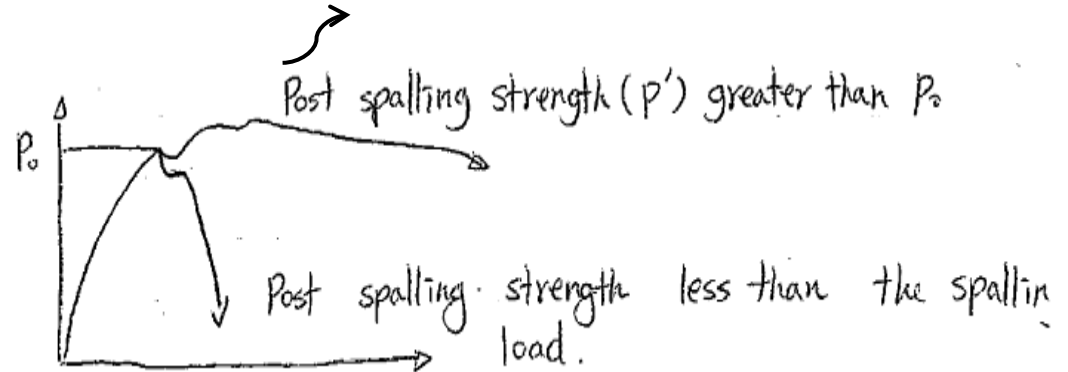
◆ Confined Columns in Compression



Make the whole column ductile by making the tailing section stronger than other sections

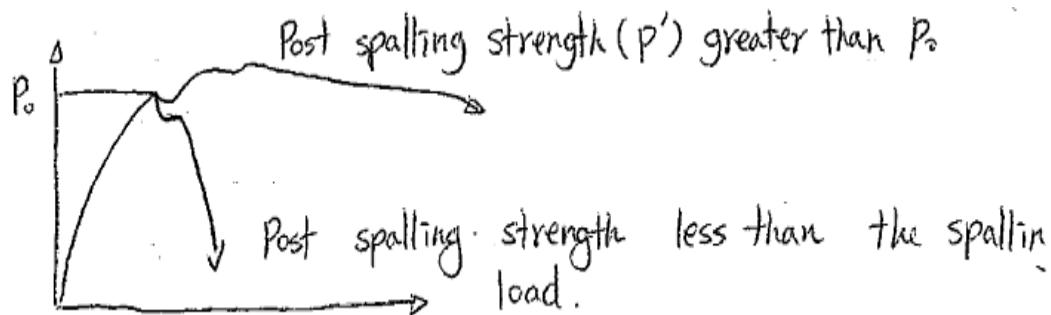


By providing a lots of confinement



Key : $P' < P_0$

◆ Confined Columns in Compression



Key : $P' > P_0$

$$P_0 = f'_c A_c + f_y A_s \quad \text{of RC column}$$

$$P_0 = 0.85 f'_c A_g - A_s \epsilon_{\text{shrinkage}} + f_y A_s \quad \epsilon_{\text{shrinkage}} \cong 0.0005$$

$$P' = f_{c \max} A_{\text{core}} + f_y A_s$$

$$P' > P_0$$

$$f_{c \max} \geq \left(\frac{A_g - A_s}{A_{\text{core}}} \right) (0.85 f'_c)$$

◆ Confined Columns in Compression

Spiral

$$f_{c \max} = f'_c + 2\rho'' f''_y$$

Yield Stress of Transverse Steel

$$f_{c \max} = 0.85f'_c + 2\rho'' f''_y$$

in Laboratory

in Situ

$$0.85f'_c + 2\rho'' f''_y \geq \left(\frac{A_g - A_s}{A_{core}}\right)(0.85f'_c)$$

$$\rho'' \geq \left[\left(\frac{A_g - A_s}{A_{core}}\right) - 1\right] 0.85f'_c \frac{1}{2f''_y}$$

$$\rho'' = \left[\left(\frac{A_g - A_s}{A_{core}}\right) - 1\right] \frac{f'_c}{f''_y} \times 0.425$$

◆ Confined Columns in Compression

Spiral

ACI Code

$$\rho'' = 0.45 \left(\frac{A_g}{A_{core}} - 1 \right) \frac{f'_c}{f''_y}$$

Suppose huge column

$$\left(\frac{A_g}{A_{core}} - 1 \right) \Rightarrow 0$$

In Seismic design : $\rho'' \geq 0.12 \frac{f'_c}{f''_y}$

◆ Confined Columns in Compression

Tied Column

$$f_{c \max} = 0.85f'_c + \frac{4\sum A_{tr}f''_y}{hs}\lambda$$

Solve $\sum A_{tr}$

$$\sum A_{tr} \geq 0.21 \left(\frac{A_g}{A_{core}} - \frac{A_s}{A_{core}} - 1 \right) \frac{f'_c}{f''_y} sh \frac{1}{\lambda}$$

$\nearrow^0$ $\nearrow^{\lambda=0.75}$
 $\searrow$ $\searrow$

ACI Code

$$\sum A_{tr} \geq 0.3 \left(\frac{A_g}{A_{core}} - \frac{A_s}{A_{core}} - 1 \right) \frac{f'_c}{f''_y} sh$$

Suppose huge column

$$\left(\frac{A_g}{A_{core}} - 1 \right) \Rightarrow 0$$

$$\text{Seismic design : } \sum A_{tr} \geq 0.09 \frac{f'_c}{f''_y} sh$$

Problem 1

A structure consists of a vertical reinforced concrete member supporting a rigid platform on which a concentrated load is placed. Assume “typical” normal-weight aggregate concrete having $f'_c = 4000 \text{ psi}$. Grade 60 steel.

Assume the load is placed at age of 1 year. Calculate the horizontal deflection at the load point at age of ten years. The reference point for zero deflection is the position at the time of casting. Do not use the ACI empirical equations for deflection calculations.

Hint: $\epsilon_c = 0.0005$

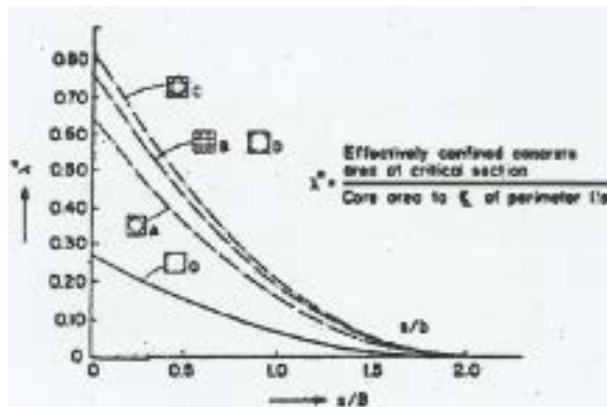
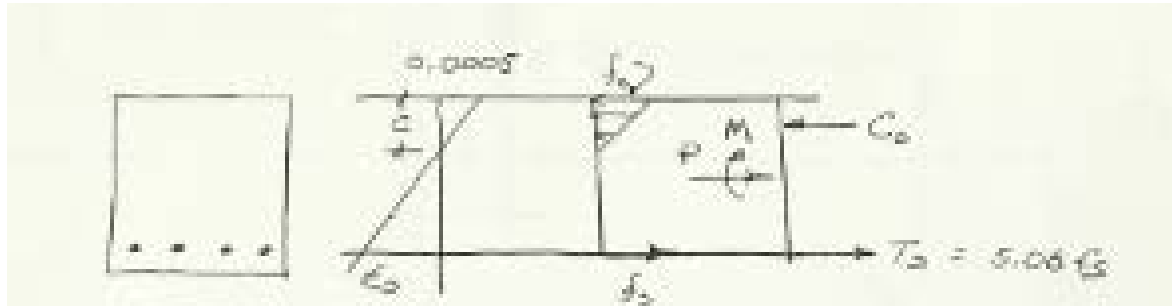


Fig. Effectively confined concrete area as a function of tie spacing and core size for various square steel configurations

bar #	d_b (in)	A_b (in^2)
3	3/8	0.11
4	4/8	0.20
5	5/8	0.31
6	6/8	0.44
7	7/8	0.60
8	1	0.79
9	1.12	1.00
11	1.44	1.56

Problem 1

Answer)



$$f_c = E_c \epsilon_c = 3600 \times 0.0005 = 1800 \text{ psi}$$

$$C_c = 1.800 \times 24 \times c \times 0.5 = 21.6 c$$

$$\epsilon_s = \frac{21 - c}{c} \times 0.0005$$

$$f_s = E_s \epsilon_s < f_y \Rightarrow f_s = 14.5 \frac{21 - c}{c} \leq 60 \text{ ksi}$$

C	f	T _s	C _c	P
12	10.9	55.4	259	204k
13	8.9	45.3	281	236k

$$\Phi_{sh} = 0.7 \frac{\epsilon_{sh}}{d} = 0.7 \frac{0.0005}{21} = 1.7 \times 10^{-5} \text{ in}^{-1}$$

$$\delta_{sh} = \Phi_{sh} \frac{l^2}{2} = 0.083 \text{ in}$$

$$\Phi_i = \frac{\epsilon_c}{c} = \frac{0.0005}{13} = 3.8 \times 10^{-5} \text{ in}^{-1}$$

$$\delta_i = \Phi_i \frac{l^2}{2} = 0.19 \text{ in}$$

$$\Phi_{cr} = k_r C_t \Phi_i = 0.85 \times 2 \times \Phi_i = 6.5 \times 10^{-5} \text{ in}^{-1}$$

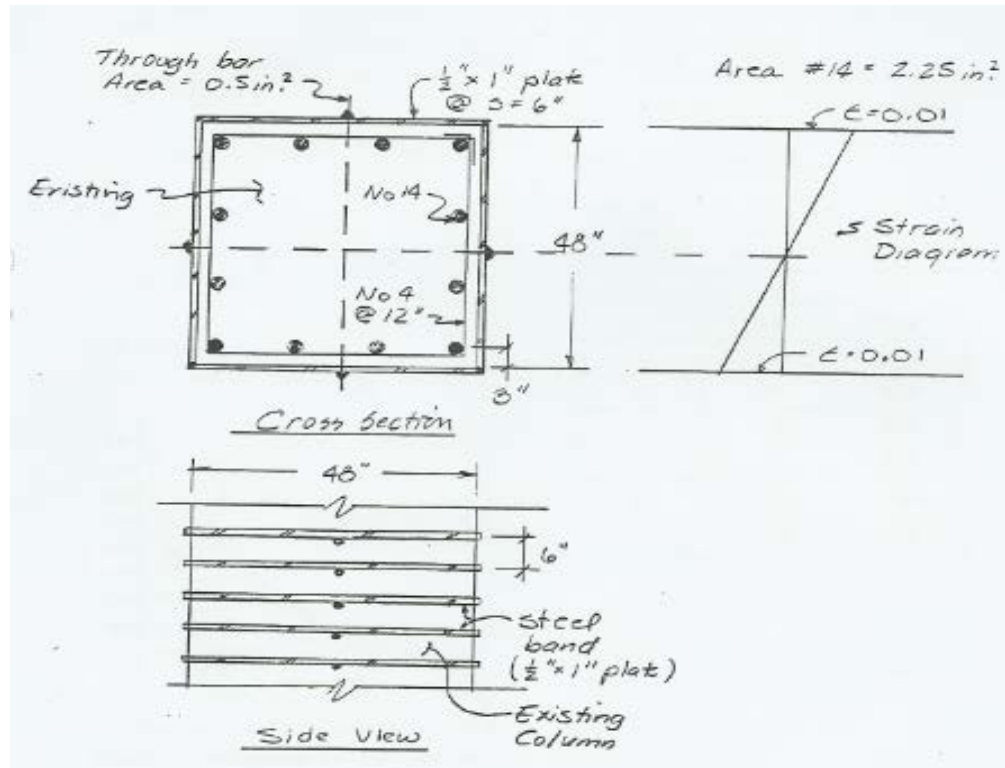
$$\delta_{cr} = \Phi_{cr} \frac{l^2}{2} = 0.32 \text{ in.}$$

$$\delta_{total} = \delta_{sh} + \delta_i + \delta_{cr} = 0.60 \text{ in}$$

Problem 2

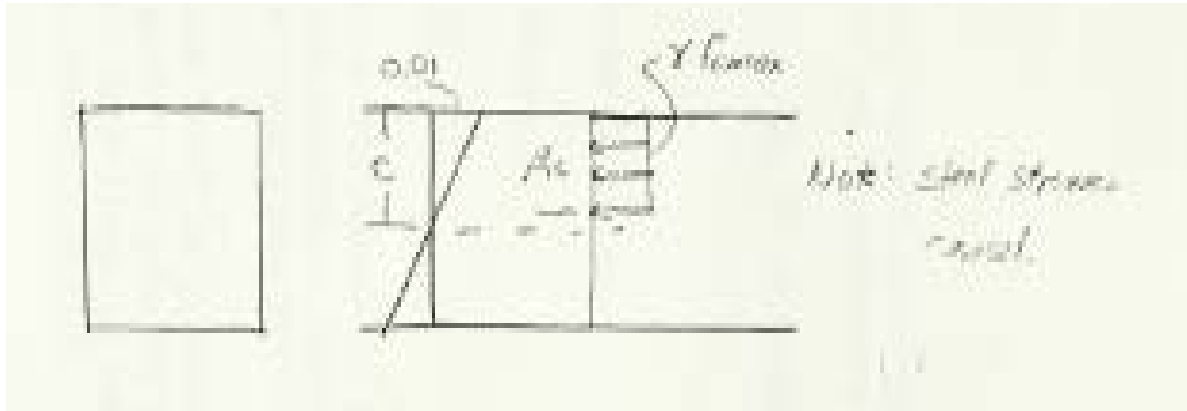
An existing bridge column has $f'_c = 4000 \text{ psi}$ and Grade 40 reinforcement (assume $f_y = 45,000 \text{ psi}$ and no strain hardening). Existing ties comprise No.4 perimeter hoops at 12-in. spacing as shown. A proposed retrofit consists of steel bands and through bars having $f_y = 50,000 \text{ ksi}$ and spacing of 6 inches.

As proof that you understand how to calculate behavior of this column, calculate the axial load corresponding to the strain condition shown below.



Problem 2

Answer)



$$f_r = 1.5 \times 50000 \div 48 \times 6 = 260$$

$$f_{c \max} = 0.85 \times 4000 + 4.1 \times 260 \times 0.6 = 4000 \text{ psi}$$

$$\sigma'' = \frac{0.5 \times 6 \times 48}{48^2 \times 6} = 0.0104$$

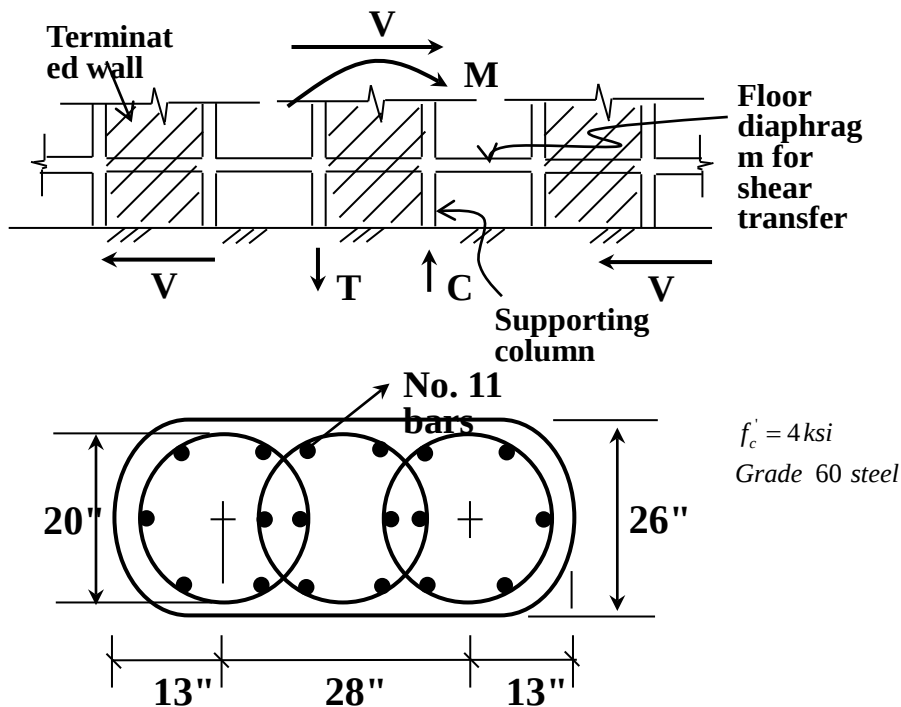
$$Z = \frac{0.5}{0.00366 + 0.022 - 0.002} = 21$$

$$\gamma = 0.85 ; \beta_1 = 0.95$$

$$\begin{aligned} \therefore P &= \gamma f_{c \max} \times \beta_1 c \times b \\ &= 0.85 \times 4000 \times 0.95 \times 24 \times 48 = 3700^k \end{aligned}$$

Problem 3

A multi-story building is to be constructed in downtown Berkeley. Owing to architectural considerations, it is necessary for one of the structural walls to be terminated, leaving an open bay in the first story with a structural wall above. In such a situation (which the engineer certainly should importune the architect to avoid), it is necessary (though not always sufficient) to ensure that both shears and overturning moments in the wall at the second floor level be transferred to the foundation level. As shown below, the structural engineer has selected to transfer shears through the floor diaphragm to a wall in another bay, and to transfer overturning moments through axial forces in columns supporting the wall. The column cross section is shown.



Discuss in a brief paragraph your objectives in design of the column, and your assumptions regarding behavior. Following the paragraph, determine a design (spacing and wire diameter) for the spiral reinforcing. Plot the relation between axial force and axial strain for the column, identifying points corresponding to first spalling, completion of spalling, yield of longitudinal steel, and onset of strain-hardening in longitudinal steel by the letters "a", "b", "c", and "d", respectively. Use the stress-strain relation shown in MacGregor for Grade 60 steel. Assume that standard cylinders at the time of the earthquake break at 4000 psi.



Problem 3

Answer)

Column Design

1. insure prespalling load (P_0) is less than post spalling load (P)
2. insure column with strain hardening and therefore fail in a ductile manner

Assume : concrete stress in situ = $0.85 f'_c$

steel in elastic – perfectly plastic – strain hardening

axial load in column only

uniform strain over cross-section

A. Determine design (spacing & arc diameter) for spiral reinforcing

$$A_g = (28" \times 26") + \pi \left(\frac{13}{4} \right)^2 = 860.7 in^2$$

$$A_s = 3(6 \times 1.56) = 28.08 in^2$$

$$A_{gc} = 3(\pi \times 10^2) - 6 \left[\frac{1}{2} \{ 9.9^2 \cdot 1.571 - 14.7^2 \} \right] = 774.6$$

Problem 3

1. yield of steel & spalling of concrete

$$\epsilon_c = \frac{60 \text{ ksi}}{E_{27,000}} = 2.07 \times 10^{-3}$$

$$\therefore f_c = 0.85 \times 4 \text{ ksi} = 3.4$$

$$P_1 = 3.4 \times 860.7 - 28.08 + 0.002 \times 27000 \times 28.08 = 4457.6^k$$

2. find strain for “completion of spalling” usually taken for

$$f_c = 0.5 f'_c \text{ to } 0 f'_c$$

$$= 0.25 \times 4 \text{ ksi} = 1 \text{ ksi}$$

$$f_{c \max} = 0.85 \times 4 \text{ ksi}$$

$$t_{oc} = 0.002$$

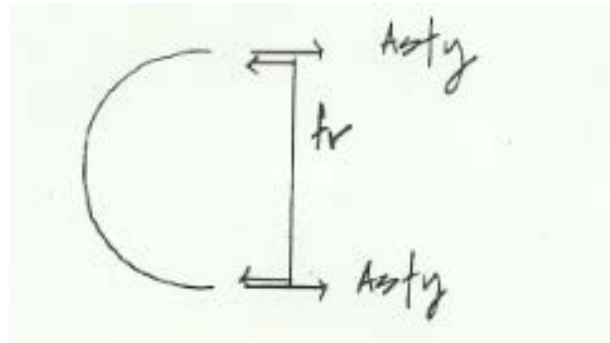
$$Z = \frac{0.577}{E_{27,000}} (0.0037 - 0.002) = 300$$

$$1 \text{ ksi} = 3.4 \text{ ksi} [1 - 300(t_c - 0.002)]$$

$$= 0.0044$$

Problem 3

* Calculation of f_r :



- Use 0.5 diameter bar, $A_s = 0.31 \text{ in}^2$

$$2(A_s) t_y = f_r D s$$

$$\therefore f_r = \frac{2(0.310)(60)}{(20)(s)} = 1.86 s$$

$$\therefore f'_c = 0.85(4.0 \text{ ksi}) + 4.1(1.86 s)$$

$$\text{try } 4" : f'_c = 5.31 \text{ ksi}$$

$$P' = 5.31(774.6 - 28.08) + 60(28.08) = 5648.8 \quad (OK)$$

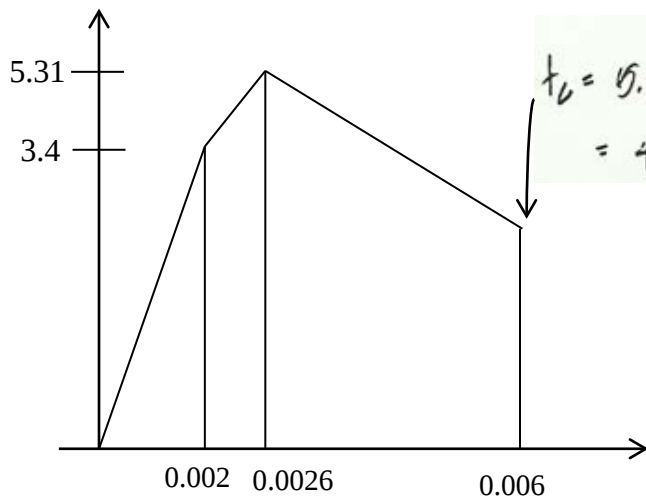
$\therefore$ use $\frac{5}{8}$ diameter @4" spacing

Problem 3

Find axial load carrying capacity at:

1. first spalling (0.002)
2. yield ($\epsilon_{27000} = 0.00207$)
3. completion of spalling occurs at $0.5f'_c$ for unconfined concrete : $\epsilon_{sp} = 0.0044$
4. onset of strain hardening = 0.006 (MacGregor)

Confined concrete relationship



$$f_c = 5.31 [1 - 23(0.0044 - 0.00207)] = 4.80 \text{ ksi}$$

$$Z = 0.5 \left[(0.00367 + 3.4(0.1)) - \frac{20}{4} - 0.006 \right] = 28.03$$

$$\rho'' = \frac{(0.31)(\pi \cdot 20^2)}{(4'' \cdot \pi \cdot \frac{20^2}{4})} = 0.0155$$

Problem 3

	ϵ	f_c	f_s	A_c	A_s	P	
1 st spell	0.002	3.4	58			4459.2	'a'
Yield	0.0024	5.09	60			5484.8	'c'
Completion of spall	0.0044	5.04	60			5447.3	'b'
Strain hardening	0.006	4.80	60	746.5	28.08	5268	'd'

