CE 123 – Fall 2011
Instructor: M. Panagiotou                                        Name:______________________________

Mid-Term Examination No. 2 – **Duration 1 hour and 45 minutes**

Instructions:

- Read these instructions. Do not turn the exam over until instructed to do so.
- Work all problems. Pace yourself so that you have time to work on each problem. Reasonable assumptions and approximations should be made where necessary.
- Show all relevant work. Credit will not be given for key elements of the solution that are not apparent.
- Partial credit will be given if procedures are outlined clearly.
- Work the solutions for each of the problems on separate sheets, working on one side of each sheet of paper. One problem solution may span more than one sheet. However, do not show the work for more than one problem on any given sheet. Staple the solution sheets to this cover sheet, problem 1 first, then problem 2, etc.
- If you have any questions, or need any paper or other materials, walk to the front of the classroom and ask the exam proctor. Do not raise your hand to get the proctor's attention, and do not call out questions from your seat.
- Neatness counts five percent of the grade. Therefore, write neatly and organize your solutions to make checking as easy as possible.
- Unless otherwise stated, all problems use the ACI 318-11 strength design method, and all concrete is normal weight.

| | Possible Points | Score |
|---|---|---|
| Problem 1 | 50 | _____ |
| Problem 2 | 50 | _____ |
| TOTAL | 100 | _____ |

## Problem 1 (50 points)

The 32 ft tall wall, see Figure 1, with the rectangular section shown in Figure 2 is subjected to a lateral force F at its top. $f_c'$ = 4 ksi, and $f_y$ = 60 ksi. Consider the loads F, and P already factored. For this case determine:

1.1) The nominal flexural strength $\boldsymbol{M_n}$ and the maximum probable flexural strength $\boldsymbol{M_{pr}}$. Idealize your section lumping the longitudinal steel in three locations. **Ignore the contribution of steel in compression.** (20 points)

1.2) If the wall is tension controlled. (3 points)

1.3) The maximum force ***F*** the wall can resist assuming that it has adequate shear strength. (4 points)

1.4) For the maximum force you determined above design the shear reinforcement of the wall. (15 points)

1.5) Determine the height of the wall over which boundary elements have to be used and determine the distance, s, between the transverse reinforcement of the boundary elements. (8 points)

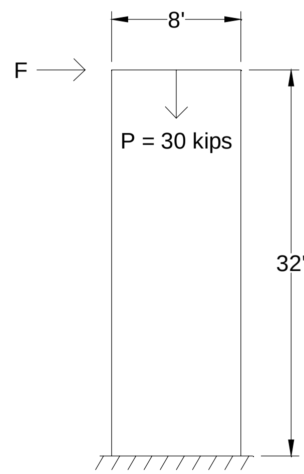



Figure 2. Section view of wall and location of external loads.

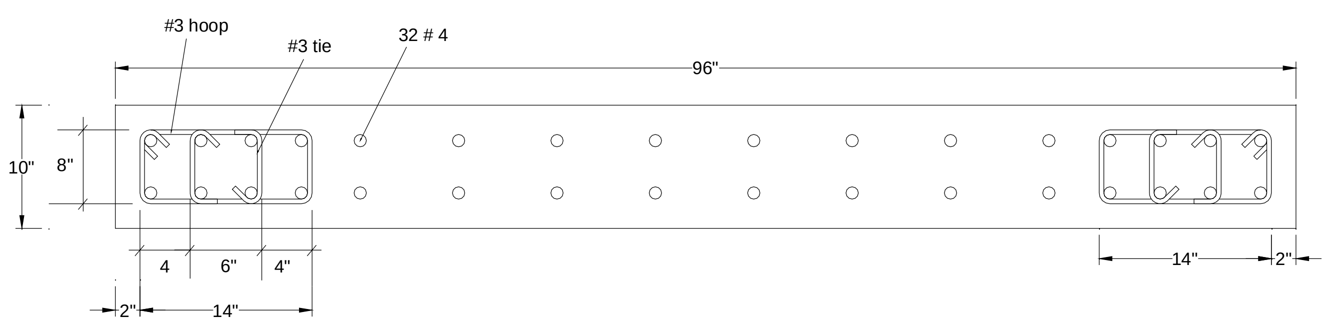



Figure 2. Section view of wall and reinforcing steel layout.

## Problem 2 (50 points)

2.1) For the column shown in Figure 3: $f_c' = 6$ ksi, and $f_y = 60$ ksi. The effective depth of the column is d = 21 inches. Under combined factored axial load P = 600 kips and flexure determine the nominal flexural ($M_n$) resistance, for bending about the y axis, of the column. **Consider the contribution of steel in compression. (20 points)**

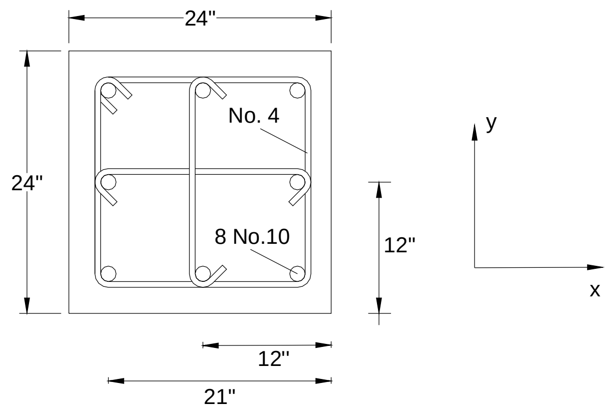



Figure 3. Section view of column and reinforcing steel layout.

2.2) The structural system shown in Figure 4 consists of a wall coupled with a gravity system and is designed for earthquake resistance. Due to deformation compatibility with the wall the gravity columns of the bottom story are required to be designed to be able to develop their probable flexural strength $M_{pr}$. If the gravity columns have the section shown in Figure 3 design the shear reinforcement of the columns of the bottom story. Show the design shear force diagram as well as an elevation of the transverse reinforcement layout. The vertical loads given are already factored. **(30 points)**

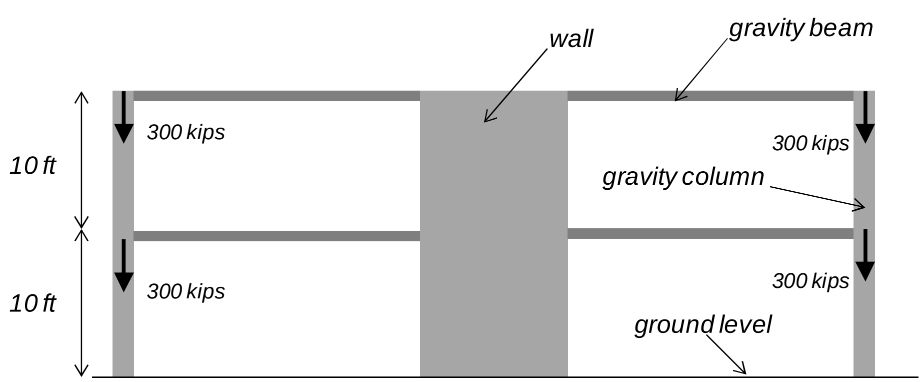
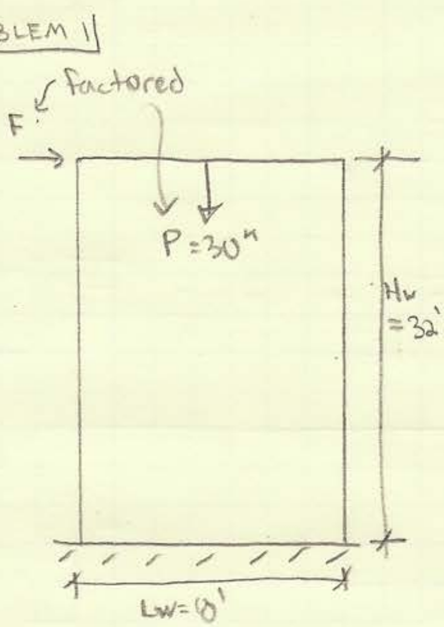
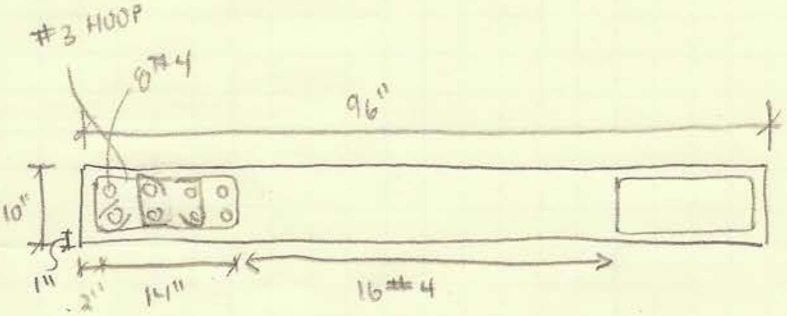



Figure 4. Elevation of structural system consisting of wall coupled with a gravity system.

PROBLEM 1

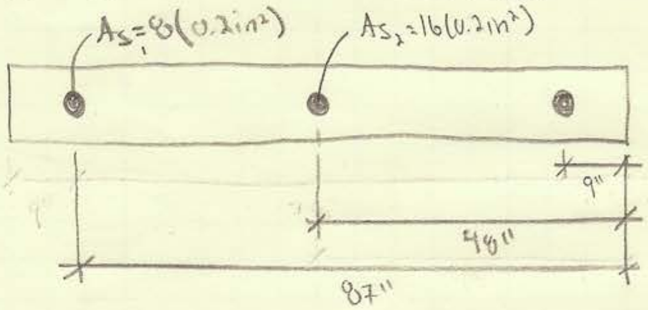


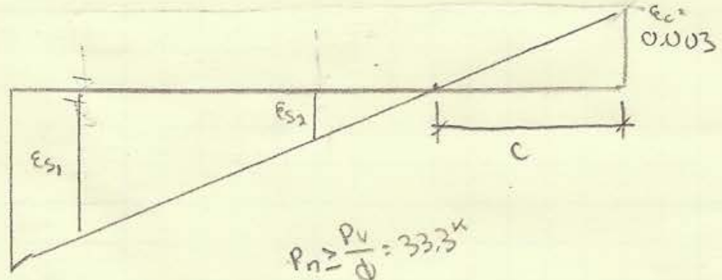

$f'_c = 4$ ksi
$f_y = 60$ ksi

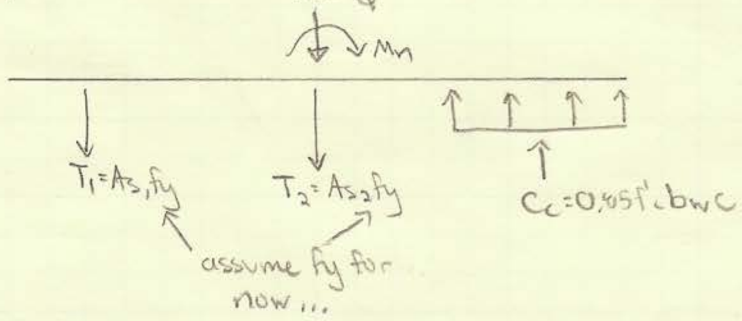



1.1) FIND $M_n$ & $M_{pr}$

USE "LUMPED STEEL" ASSUMPTION




* IGNORING STEEL IN COMPRESSION

$T_{s_1} = 8(0.2in^2)(60ksi) = 96^k$

$T_{s_2} = 16(0.2in^2)(60ksi) = 192^k$

$C_c = 0.85(4ksi)(10")c = 34c$

$\Sigma F = 0 \Rightarrow \frac{P_u}{\phi} + T_{s_1} + T_{s_2} - C_c = 0$

$\frac{30^k}{0.90} + 96 + 192 - 34c = 0$

$\Rightarrow c = 9.451"$

CHECK: $\varepsilon_{s_2} = \varepsilon_c \frac{(48" - c)}{c} = 0.0122 > \varepsilon_y$ ✓ OK

$\varepsilon_{s_1} > \varepsilon_{s_2} \rightarrow$ ALL TENSION STEEL YIELDING

$\varepsilon_{s_1} = \varepsilon_c \frac{(87" - c)}{c} = 0.0246 > 0.005$

$\rightarrow \phi = 0.90$

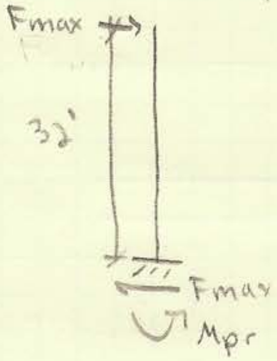
$\Sigma M_{center} = 0 \Rightarrow M_n = T_{s_1}(87" - 48") + C_c\left(48" - \frac{c}{2}\right) = 96^k(39") + 34(9.451")\left(48" - \frac{9.451"}{2}\right)$

$M_n = 17650$ kip-in $\Rightarrow$ **$M_n = 1471$ kip-ft**   **$M_{pr} \approx 1.25 M_n = 1839$ kip-ft**

1.2) IS WALL TENSION-CONTROLLED?

$\varepsilon_{s1} = 0.0246 > 0.005 \rightarrow$ **TENSION-CONTROLLED**

1.3) FIND MAX FORCE F THAT WALL CAN RESIST ASSUMING IT HAS ADEQUATE SHEAR STRENGTH



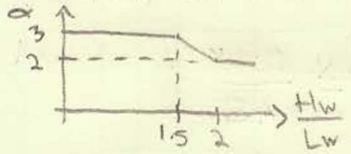

$$F_{max} = \frac{M_{pr}}{32'} = \frac{1930 \text{ kip-ft}}{32'}$$

$$\Rightarrow \boxed{F_{max} = 57.5^k}$$

1.4) DESIGN SHEAR REINFORCEMENT OF WALL FOR Fmax ABOVE

$$V_u = F_{max} = 57.5^k \le \phi V_n = \phi(V_c + V_s) = \phi\left(\alpha \sqrt{f'_c}\, A_c + \frac{A_v f_y L_w}{s}\right)$$

$A_c$ = $(L_w b_w)$ USE 2-#5 BARS




$$\frac{H_w}{L_w} = \frac{32'}{8'} = 4 \rightarrow \alpha = 2$$

$$V_u = 57.5^k \le 0.75\left[\frac{2\sqrt{4000\,psi}}{1000}(96'')(10'') + \frac{2(0.31 in^2)(60 ksi)(96'')}{s}\right]$$

$\Rightarrow s < 0$ NO HORIZONTAL REINF. REQ'D FOR STRENGTH

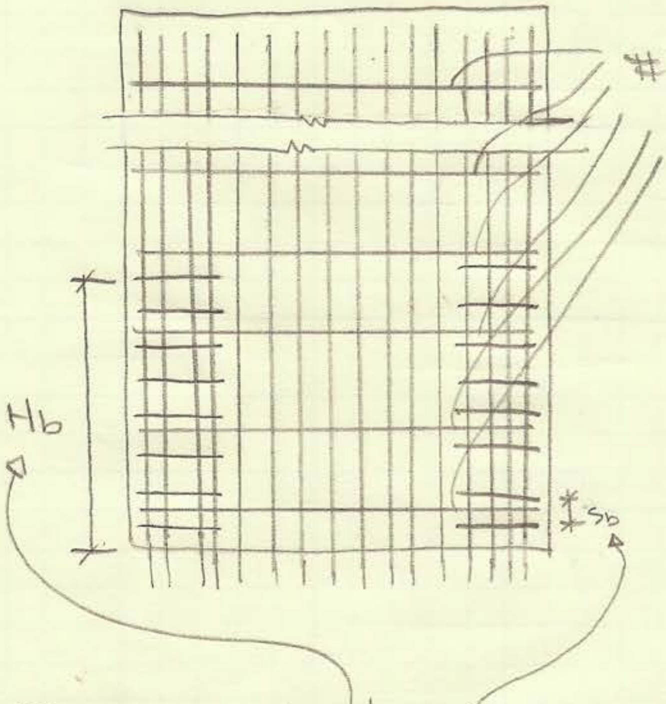
$$\rho_t = \frac{A_v}{b_w s} \ge 0.0025 \Rightarrow s_{max} = \frac{2(0.31 in^2)}{(10'')(0.0025)} = 24.8'' \rightarrow \text{set } s = 24.5''$$

$s_{max} = 18'' \not\ge 24.5'' \Rightarrow$ choose $s = 18''$

If 2-#4 BARS SELECTED INSTEAD, $s_{max} = \frac{2(0.20 in^2)}{(10'')(0.0025)} = 16'' < 18''$ ✓

choose $s = 16''$

DESIGN FOR SHEAR:

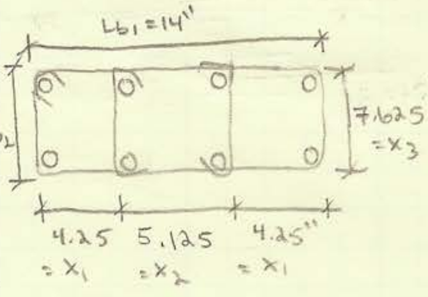



1.5) DETERMINE Hb & Sb

ACI 318 § 21.9.6.2(b):

$$H_{b,min} = \max \begin{cases} L_w = 96'' \\ \dfrac{M_u}{4V_u} = \dfrac{F(32')}{4(57.5^k)} \end{cases} \rightarrow F \text{ NOT GIVEN} \Rightarrow \boxed{H_b \geq 96''}$$

clear horiz. spacing between long. bars ≅ 3.75"




$h_x = \max\{x_1, x_2, x_3\} = 7.625''$

$$S_{b,max} = \min \begin{cases} 6d_b = 3'' \\ \dfrac{L_{b1}}{3} = 4.7'' \\ \dfrac{L_{b2}}{3} = 2'' \\ s_o = 4 + \left(\dfrac{14 - h_x}{3}\right) = 6.125'' \end{cases}$$

$4'' \leq s_o \leq 6'' \Rightarrow s_o = 6''$

$L_{b1} = 14''$

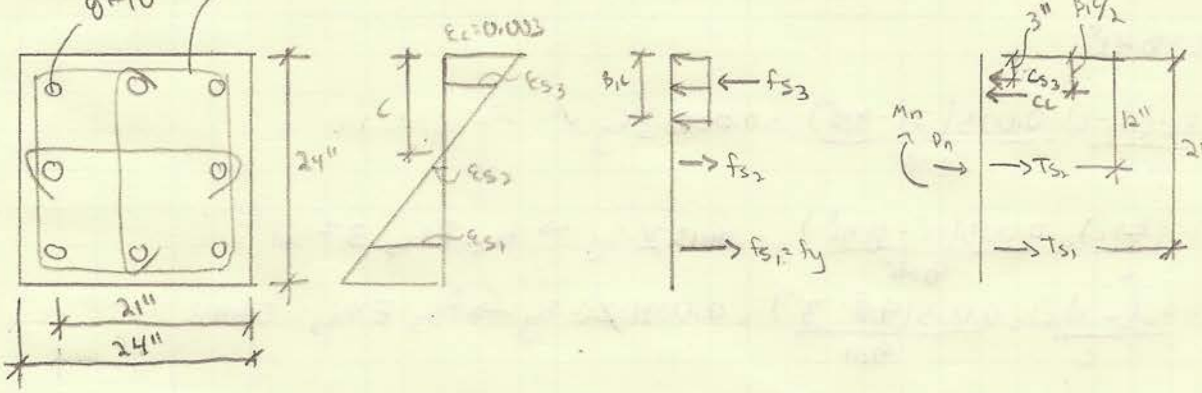
$L_{b2} = 10'' - 2(1'') = 8''$

$\rightarrow S_{b,max} = 2''$ $\rightarrow$ $\boxed{\text{choose } S_b = 2''}$

PROBLEM 2)

2.1) $P = 600^k$. FIND $M_n$

$f'_c = 6ksi \rightarrow \beta_1 = 0.75$
$f_y = 60ksi$




*CONSIDER STEEL IN COMPRESSION
ASSUME ALL STEEL IS YIELDING (INITIAL ASSUMPTION)

$\Sigma F_x = 0 \Rightarrow C_c + C_{s3} - T_{s1} - T_{s2} = P_n = P$

$0.85 f'_c \beta_1 c b + f_y (A_{s3} - A_{s1} - A_{s2}) = P$

$0.85(6ksi)(0.75)c(24") + 60ksi(-2(1.27in^2)) = 600 \Rightarrow c = 8.20"$

ONE ITERATION:

$\varepsilon_{s1} = \frac{\varepsilon_c(d_1 - c)}{c} = \frac{0.003(21" - 8.20")}{8.20"} = 0.0047 \geq 0.00207 = \varepsilon_y$ ✓

$\varepsilon_{s2} = \frac{\varepsilon_c(\frac{h}{2} - c)}{c} = \frac{0.003(12" - 8.20")}{8.20"} = 0.0014 \ngeq 0.00207 = \varepsilon_y \rightarrow f_{s2} = E\varepsilon_{s2} = 40ksi$

$\varepsilon_{s3} = \frac{\varepsilon_c(c - d_3)}{c} = \frac{0.003(8.20" - 3")}{8.20"} = 0.0019 \leq 0.00207 = \varepsilon_y \rightarrow f_{s3} = E\varepsilon_{s3} = 55ksi$

$\Sigma F_x = 0 \Rightarrow 0.85 f'_c \beta_1 c b + A_{s3} f_{s3} - A_{s1} f_y - A_{s2} f_{s2} = P$

$0.85(6ksi)(0.75)c(24") + 3(1.27in^2)[55ksi - 60ksi] - 2(1.27in^2)(40ksi) = 600^k$

$\Rightarrow c = 7.85"$
STOP ITERATION FOR TIME PURPOSES

$\Sigma M_{center} = 0 \Rightarrow M_n = C_{s3}(\frac{h}{2} - d_3) + C_c(\frac{h}{2} - \frac{\beta_1 c}{2}) + T_{s1}(d_1 - \frac{h}{2})$

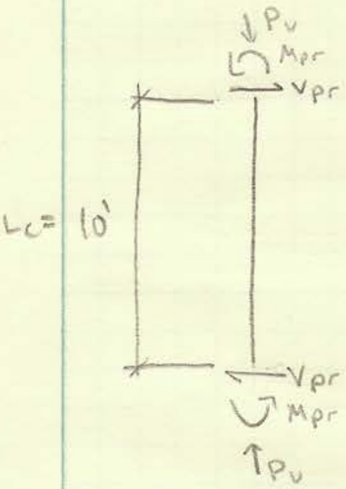
$M_n = 3(1.27in^2)(55ksi)(12" - 3") + 0.85(6ksi)(0.75)(7.85")(24")(12" - \frac{0.75(7.85")}{2})$

$+ 3(1.27in^2)(60ksi)(21" - 12")$

$\Rightarrow M_n = 10470$ kip·in $= 872$ kip-ft ← SOL'N CONTINUES USING THIS VALUE

*IF YOU INCLUDED: $f_s^* = f_s - 0.85 f'_c$, w/ ONE ITERATION ONLY, $M_n = 865$ kip-ft
(FOR STEEL IN COMPRESSION)

22) SEISMIC DESIGN OF GRAVITY COLUMN



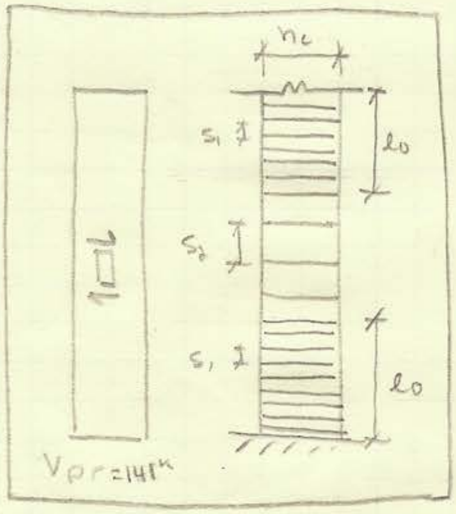

$M_{pr} \approx 1.25 M_n = 1.25(872 \text{ kip-ft}) = 1090 \text{ kip-ft}$

$V_{pr} = \frac{2M_{pr}}{L_c} = \frac{2(1090 \text{ kip-ft})}{10'} = 218^k = V_u$

ACI 318 § 21.6.4

$l_o \geq \max \begin{cases} h_c = 24'' \\ (l_{n-col})/6 \approx l_c/6 = \frac{10'(12''/')}{6} = 20'' \\ 18'' \end{cases}$

$\boxed{l_o = 24''}$



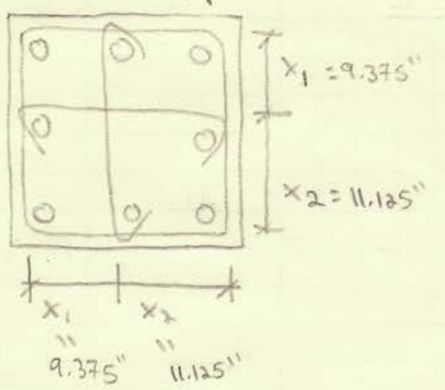

IN $l_o$ REGION

$V_c = 0$

$\frac{V_u}{\phi} = V_s = \frac{218}{0.75} = 291^k \leq 8\sqrt{f'_c}\, b_w d = 312^k$

$V_s = \frac{A_v f_y d}{s_1} \Rightarrow 291^k = \frac{3(0.2 in^2)(60 ksi)(21'')}{s_1} \Rightarrow s_1 \approx 2.5''$

$s_{1max} = \min \begin{cases} h_{col}/4 = 24''/4 = 6'' \\ 6d_b = 6(10/8'') = 7.5'' \\ s_o = 4 + \left(\frac{14 - h_x}{3}\right) \end{cases}$




clr spacing between long. bars ≈ 9.125''

$h_x = \max\{x_1, x_2\} = 11.125''$

$s_o = 4 + \left(\frac{14 - 11.125''}{3}\right) = 4.96''$

$4'' \leq s_o \leq 6''$ ✓ OK

$\Rightarrow s_{1max} = 4.96'' \geq 2.5'' = s_1$ ✓ OK

$\boxed{s_1 = 2.5''}$

## ▣ OUTSIDE $l_o$ REGION

$$V_c = 2\lambda\sqrt{f'_c}\,b_w d = 2\,\frac{\sqrt{6000\text{ psi}}}{1000}(24'')(21'') = 78.08^k$$

$$\frac{V_u}{\phi} - V_c = V_s = \frac{219^k}{0.75} - 78.08^k = 213^k = \frac{A_v f_y d}{s_2} = \frac{3(0.20\text{in}^2)(60\text{ksi})(21'')}{s_2}$$

$\Rightarrow s_2 \cong 3.5''$

$$s_{2max} = \min\begin{cases} 6d_b = 7.5'' \\ 6'' \end{cases} > 3.5'' = s_2 \checkmark \text{ OK}$$

$$\boxed{s_2 = 3.5''}$$