FEMA P-2018: Example Application

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Evaluation Procedure

1. Building Description - - *General*
2. Loads and Component Strengths - - *Chapter 4*
3. Base Shear, Period and Early Outs - - *Chapter 5*
4. Global Seismic Drift Demand - - *Chapter 6*
5. Drift Demand on Critical Story - - *Chapter 6*
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8. Column Ratings - - *Chapter 6*
9. Story Rating - - *Chapter 6*
10. Building Rating - - *Chapter 10*

1. Building Description

- 5-Story Concrete Building
- Plan: 100’ N-S x 156’ E-W
- Typical story height 13’
  First: 17’
- Frames on three sides, and a solid concrete shearwall along the back (north) side
- N/S Direction classified as a **Frame** system, which will be presented herein

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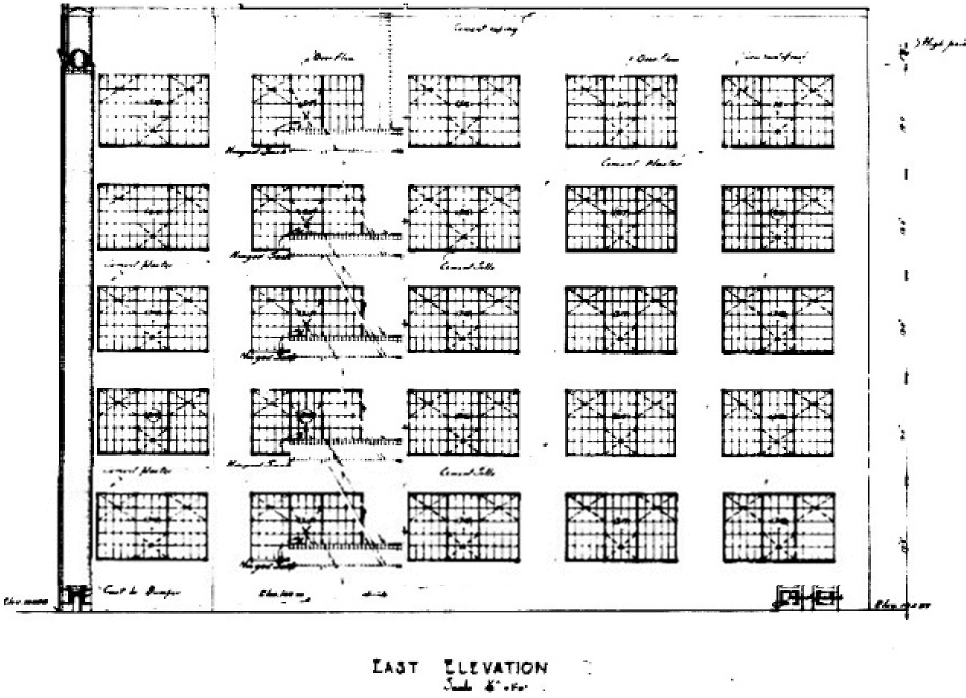
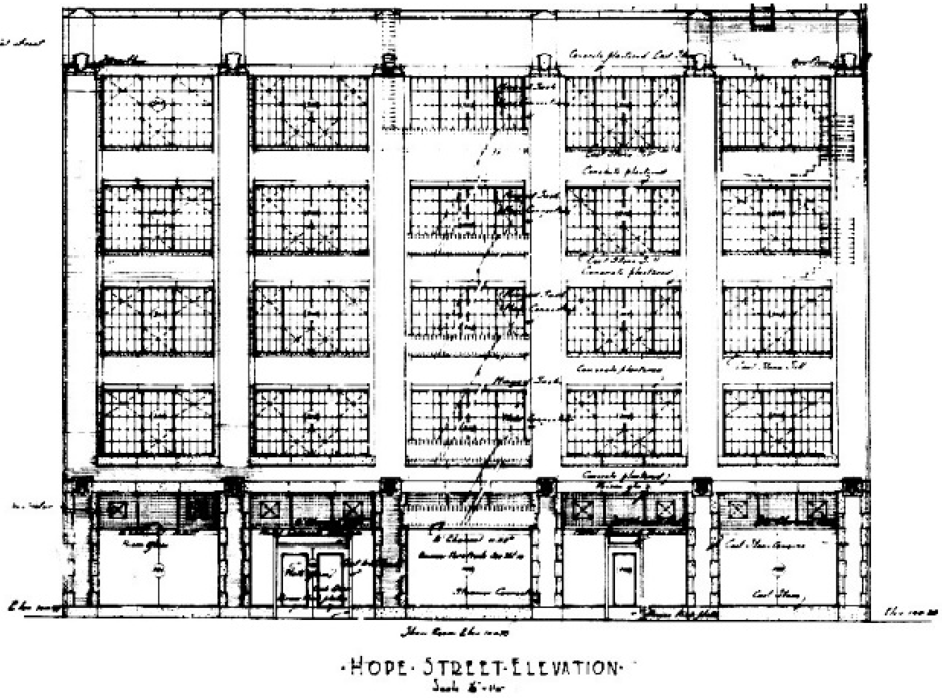
1. Building Description

East Elevation



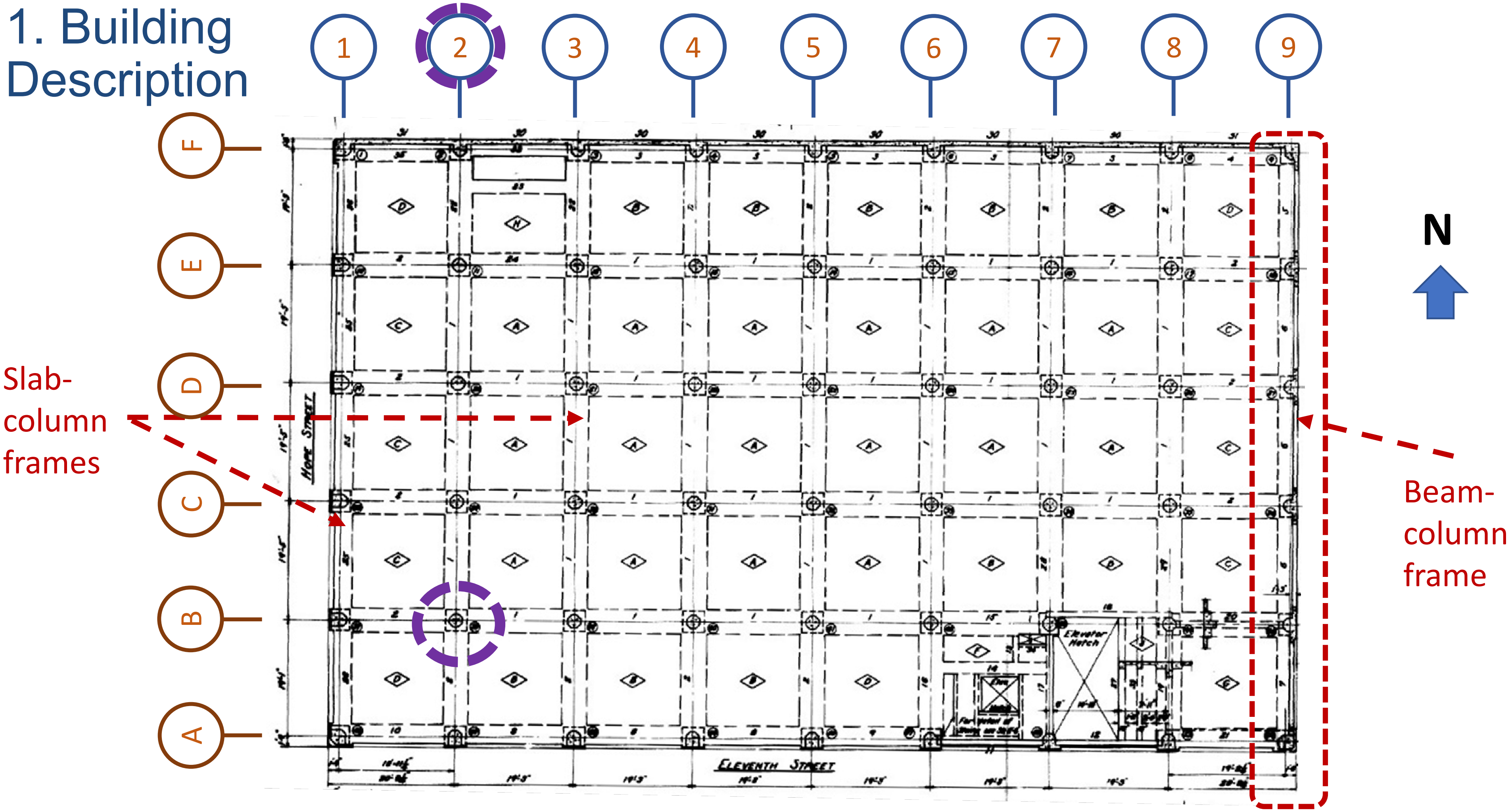
West Elevation



1. Building Description

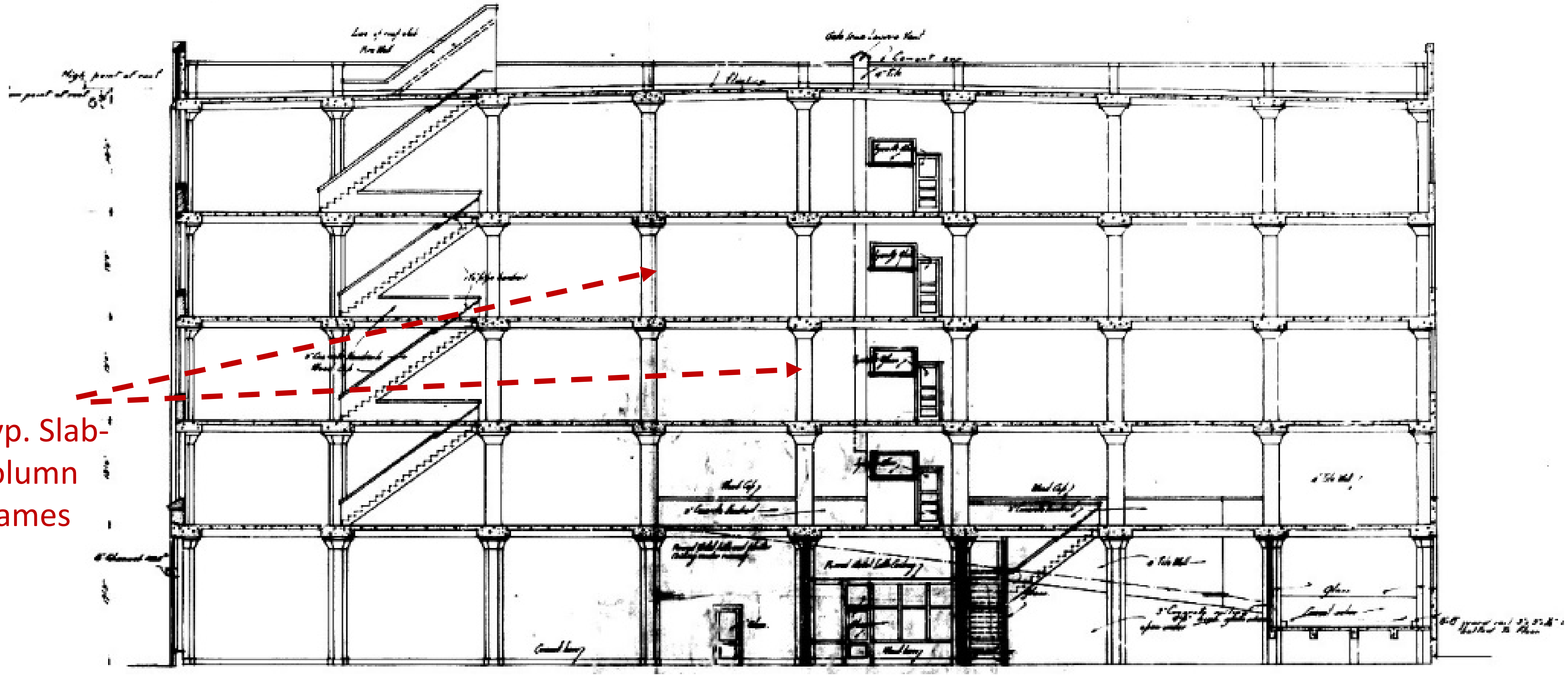
Typical Floor

1. Building Description



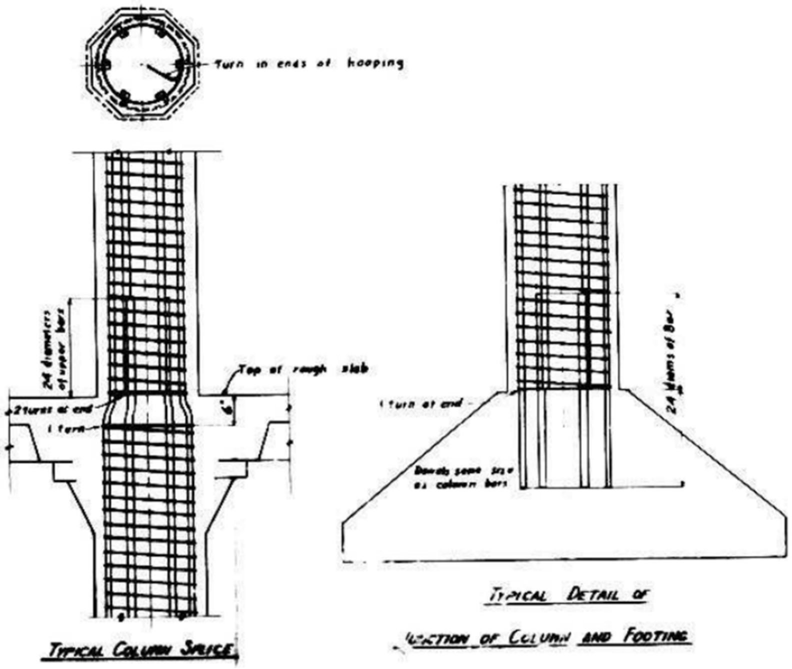
1. Building Description

Typical Building Section

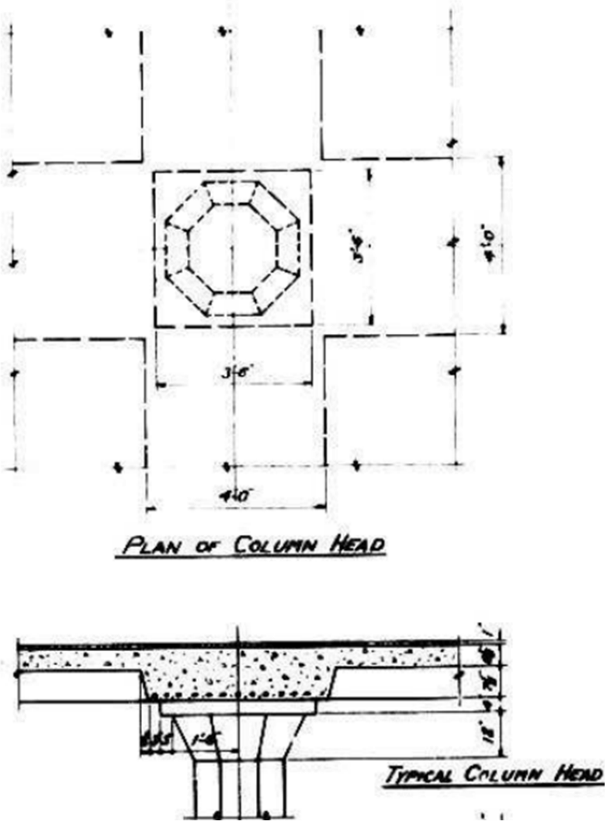


Typ. Slab-column frames

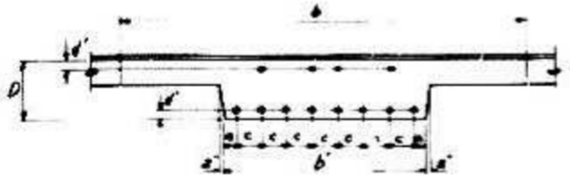
1. Building Description

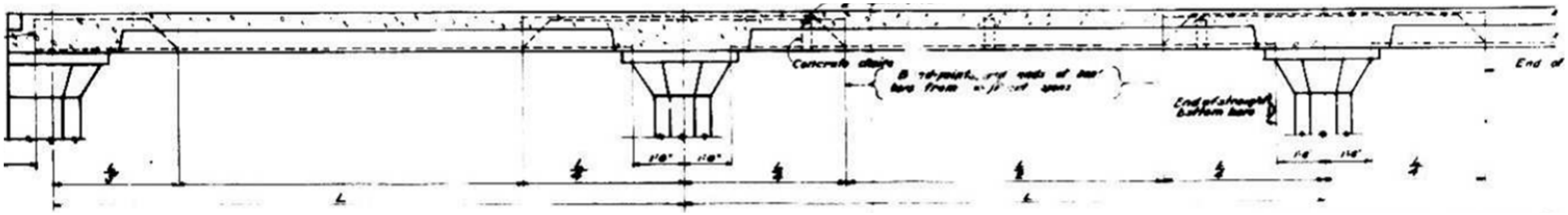


(Octagonal, Spirally reinf Col's)



1. Building Description





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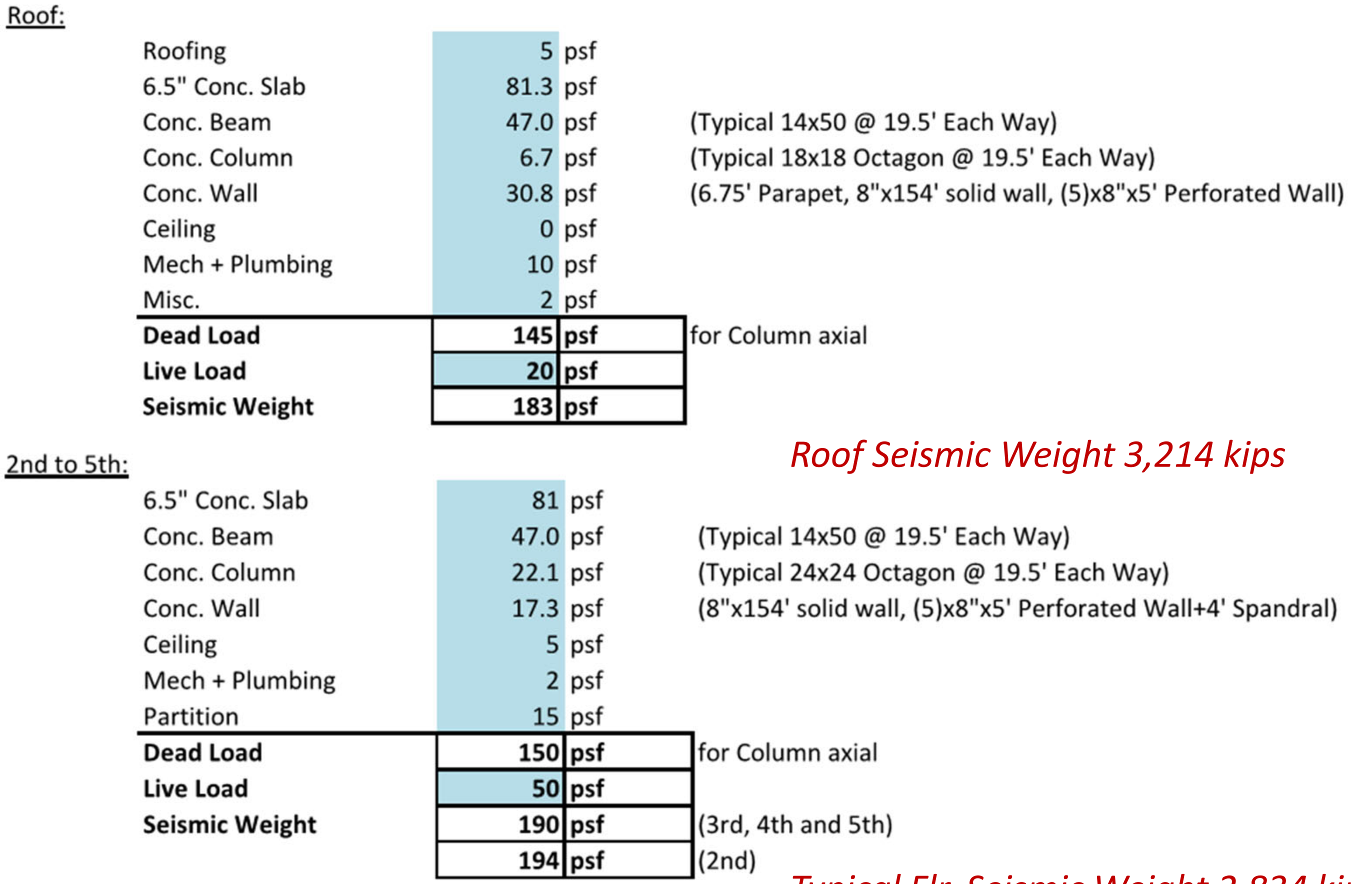
2. Loads and Component Strengths



Roof:

Roofing	5	psf	
6.5" Conc. Slab	81.3	psf	
Conc. Beam	47.0	psf	(Typical 14x50 @ 19.5' Each Way)
Conc. Column	6.7	psf	(Typical 18x18 Octagon @ 19.5' Each Way)
Conc. Wall	30.8	psf	(6.75' Parapet, 8"x154' solid wall, (5)x8"x5' Perforated Wall)
Ceiling	0	psf	
Mech + Plumbing	10	psf	
Misc.	2	psf	
Dead Load	**145**	**psf**	for Column axial
Live Load	**20**	**psf**	
Seismic Weight	**183**	**psf**	

Roof Seismic Weight 3,214 kips

2nd to 5th:

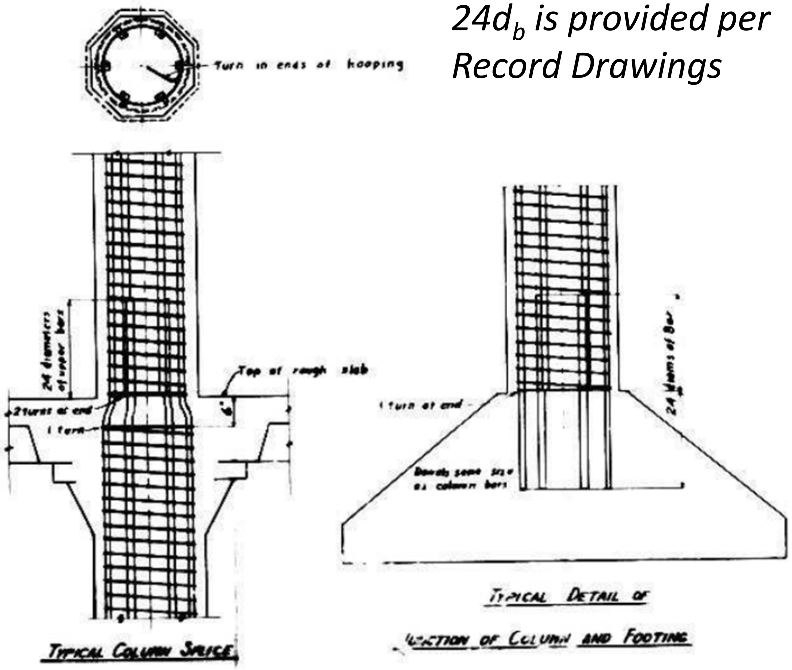
6.5" Conc. Slab	81	psf	
Conc. Beam	47.0	psf	(Typical 14x50 @ 19.5' Each Way)
Conc. Column	22.1	psf	(Typical 24x24 Octagon @ 19.5' Each Way)
Conc. Wall	17.3	psf	(8"x154' solid wall, (5)x8"x5' Perforated Wall+4' Spandral)
Ceiling	5	psf	
Mech + Plumbing	2	psf	
Partition	15	psf	
Dead Load	**150**	**psf**	for Column axial
Live Load	**50**	**psf**	
Seismic Weight	**190**	**psf**	(3rd, 4th and 5th)
	194	**psf**	(2nd)

Typical Flr. Seismic Weight 2,834 kips

2. Loads and Component Strengths

General Considerations when Calculating Component Strengths:

Take reduction for insufficient Lap splice: $24d_b$ is provided per Record Drawings



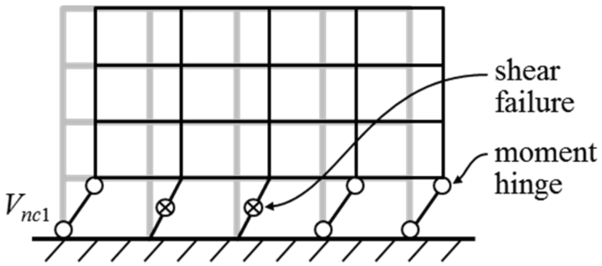
- Calculate component flexural/shear strengths based on expected material properties, Concrete: f'_{ce} = 3 ksi, and f_{ye} = 50 ksi
- Strength calculations are per ACI 318 with $\phi = 1$
- Consider the effect of expected gravity load: $P = P_D + 0.25\ P_L$
- Check for inadequate splices/ rebar development and adjust strengths for undeveloped rebars and lap splices (ASCE 41-17) *- - but not always (such as when calculating column's V_p)*

2. Loads and Component Strengths

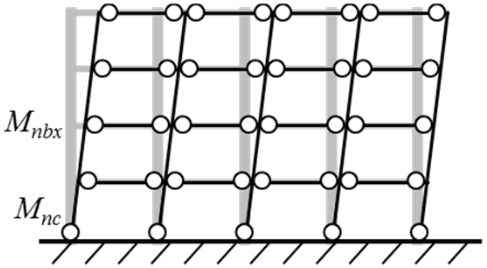
Component Strengths Needed:

>> For calculating *Plastic Mechanism Base-Shear Strength*, the strength of the following components are needed for Mechanisms 1 & 2 (Frame Building):

- First floor columns: flexure and shear strengths *(54 columns)*
- All beams: flexure and shear strengths *(470 beams)*



Mechanism 1



Mechanism 2

2. Loads and Component Strengths

a. Columns Flexural Strength (ACI 318):

- Obtain columns flexural strength, considering P-M interaction
- Consider insufficient rebar lap splice in moment calculations

(Sample spreadsheet)

ID	Col Info						Results
	b	h	As	A's	Aside	Pg	Mc
	(in)	(in)	(in^2)	(in^2)	(in^2)	(kips)	(k-in)
NS-2-a-2	21	21	1.6	1.6	0.8	142	2,559
NS-2-a-3	23	23	2.4	2.4	1.2	218	4,096
NS-2-b-1	23	23	2.4	2.4	1.2	218	4,096
NS-2-b-4	23	23	5.3	5.3	2.7	334	6,830

2. Loads and Component Strengths

b. Column Shear Strength (ASCE-41-17):

$$V_n = k\left(\frac{A_v f_{ye} d}{s} + \lambda\left(\frac{6\sqrt{f'_{ce}}}{l_{inf}/d}\sqrt{1+\frac{P_g}{6\sqrt{f'_{ce}}A_g}}\right)0.8A_g\right)$$

k = 1
s = Spacing of shear ties
Av = Area of shear ties
d = effective depth of column section,0.8hc
fye = 41.25 ksi
λ = 1 (normal weight 1, light weight concrete 0.75)
f'ce = 3 ksi
linf = half of column clear height at typical floor, 0.6h1 at first floor
Pg = expected gravity axial load calculated above in Section 1.6
Ag = gross area of column section

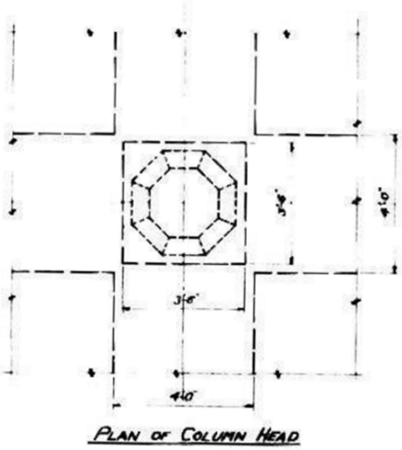
(Sample spreadsheet)

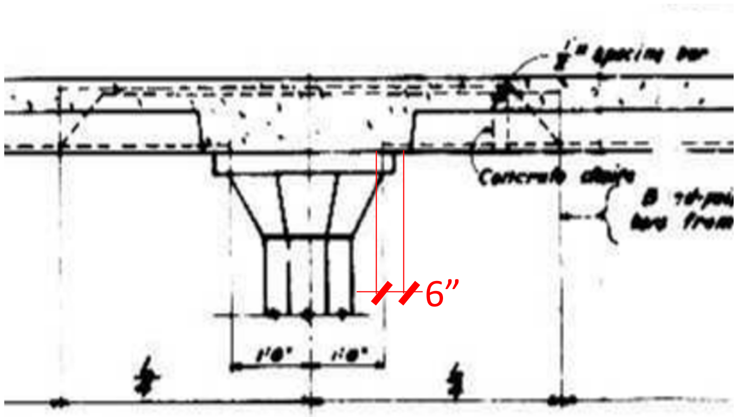
Story	Location	s	Av	d	linf	Pg	Ag	Vn
		(in)	(in^2)	(in)	(in)	(kips)	(in^2)	(kips)
1st	2/b	2.75	0.153	20.8	120.3	333.6	530.9	117.6
1st	3/a	2.75	0.153	20.8	120.3	218.5	530.9	110.4
1st	9/b	2.75	0.153	19.2	120.3	181.2	452.4	97.8
1st	1/a	2.75	0.153	19.2	120.3	142.3	452.4	95.1
1st	1/g	2.75	0.153	19.2	120.3	123.7	452.4	93.8
1st	9/g	2.75	0.153	19.2	120.3	105.1	452.4	92.4

2. Loads and Component Strengths

c. Beams Flexure and Shear Strength (ACI 318):

- Calculate beams flexure and shear strengths using ACI 318
- Take reduction for any discontinuous rebars or deficient lap splice. In this example, bottom reinforcement of interior beams extends only 6” into column-slab joints





2. Loads and Component Strengths

d. Columns Capacity-Limited Shear Strength:

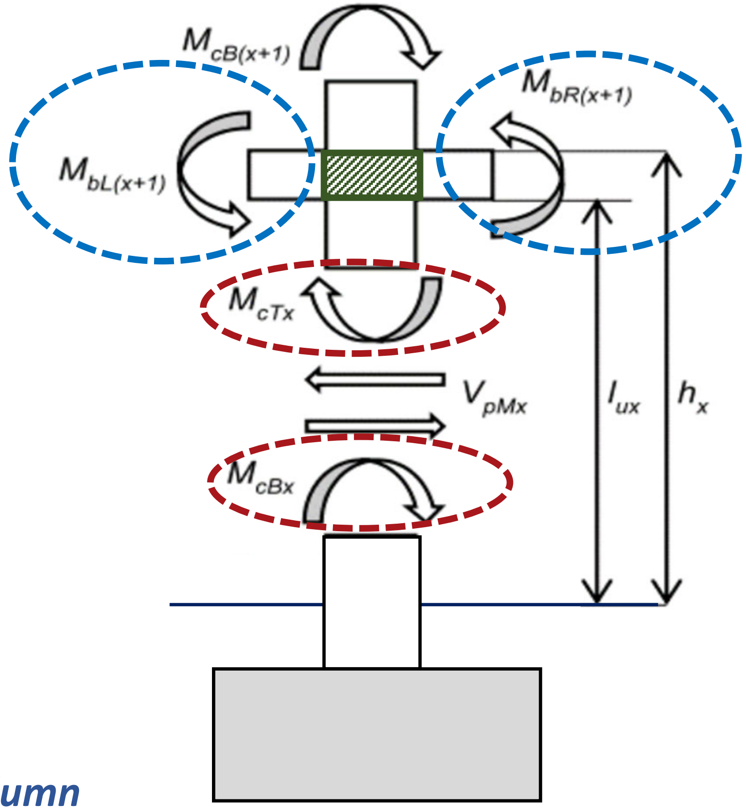
$$V_{pc} = min(V_{pM}, V_n) \qquad V_{pM} = \frac{M_{cT} + M_{cB}}{l_u}$$

M_{cT} and M_{cB} : Lesser of the

1. Flexural strength of the column section

2. Flexural strength controlled by the beams or slabs (including shear-limiting flexural capacity of beams)

3. Moment transfer strength of the slab-column connection based on punching shear



As an example, take Frame on Gridline 2 - interior column

2. Loads and Component Strengths

d. Columns Capacity-Limited Shear Strength:

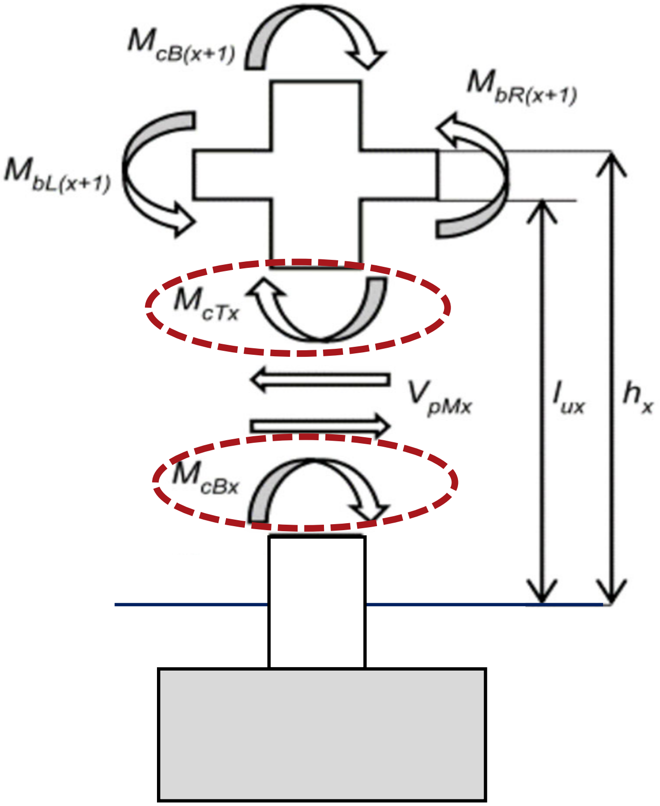
1. Calculate flexural strength of the column "section":

Top of Column Section Flexural Strength:

M_{cT1} **= 6,830** k-in

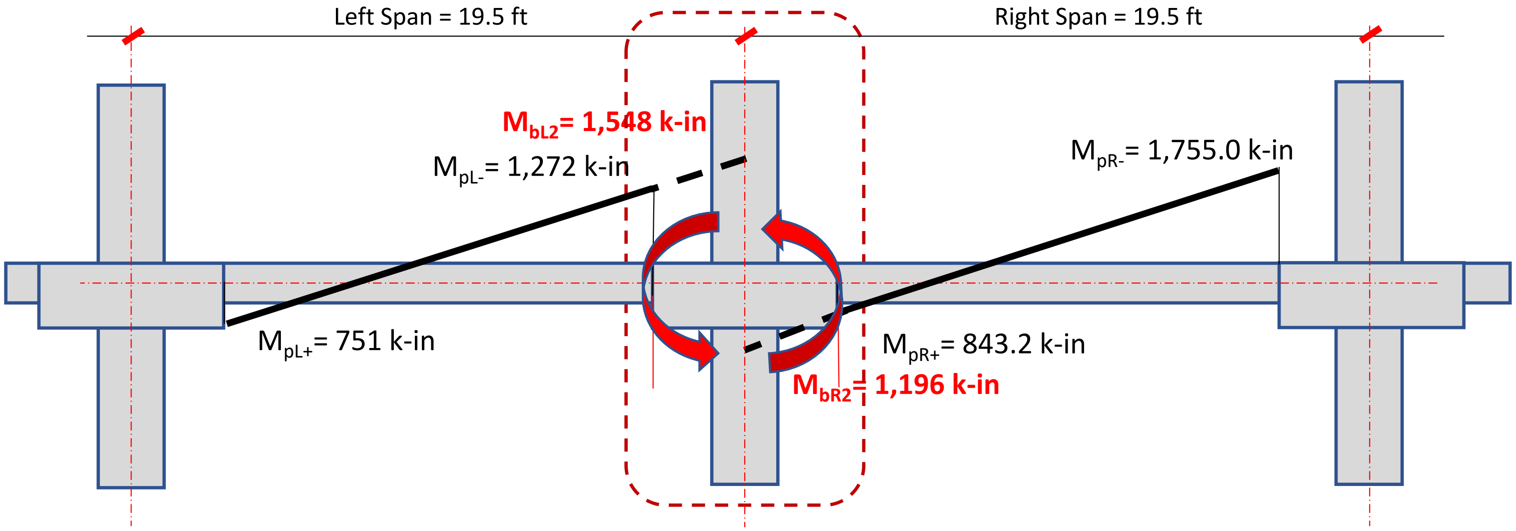
Bottom of Column Flexural Strength:

M_{cB1} **= 3,415** k-in *(assuming 50% strength at base)*



2. Loads and Component Strengths

2. Check if the flexural strength of the column top is controlled by the flexural strength of the slab-beams (including shear-limiting flexural capacity of beams);



a. Calculate plastic moments of slab-beams at col. CL:

M_{bL2} = 1,548 *k-in*
M_{bR2} = 1,196 *k-in*

b. Shear strength check (left beam):

V_{pML} = (1,272+751) / 184 = 11 kips --- Flexural
< V_{nL} = 65.7 kips --- Shear
Thus, Flexural Governs

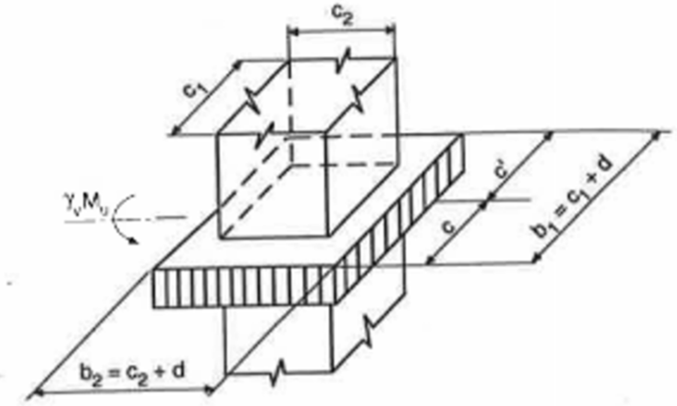
c. Obtain beam-controlled flexural strength at top of the column:

$M_{cT1} = [M_{bL2}+M_{bR2}] (h_1) / (h_1+h_2) =$ **1,565** *k-in* **<** $M_{cT1} =$ **6,830** *k-in*

2. Loads and Component Strengths

3. Check Slab-Column Connection Moment Transfer Capacity

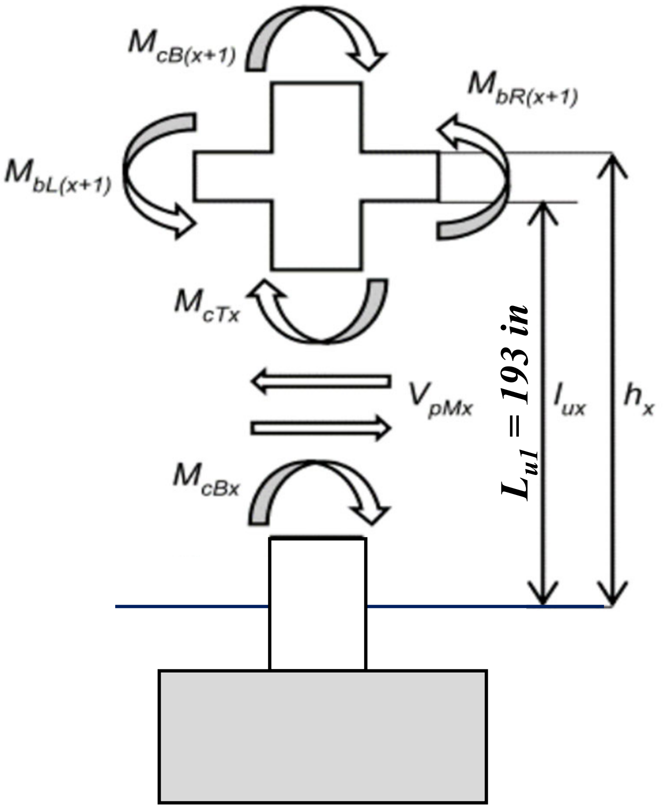
Critical Section Geometry: $d = 11$ in $c_1=c_2=50$ in, $b_1=b_2=61$ in $A = 2{,}675$ in^2



Slab-Column connection
moment transfer capacity
associated with punching shear: $(v_c - v_g)(J/c) / \gamma_v = 181 \times 54{,}812 / 0.4 =$ **24,850** k-in *(doesn't govern)*

2. Loads and Component Strengths

d. Columns Capacity-Limited Shear Strength:



Thus, Top of Column Flexural Strength:

M_{cT1} = *1,565* k-in

Bottom of Column Flexural Strength:

M_{cB1} = *3,415* k-in   *(assuming 50% strength at base)*

Column plastic shear strength based on flexural strength:

$V_{pM1} = (1{,}565 + 3{,}415) / 193 = 25.8$ *kips*

Column section shear strength:

$V_n = 118$ *kips*

$$V_{pc} = min(V_{pMx}, V_n)$$

V_{pc} = ***25.8*** kips --- *Flexural Controlled*

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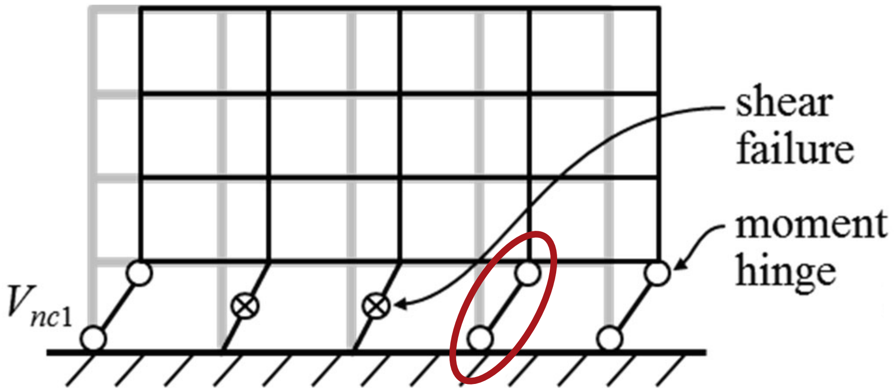
3. Base Shear Strength, Period and Early Outs

Mechanism #1 Assumes building strength controlled by the structural elements in the first story



For each column, calculate shear strength V_{nc1} and the shear associated with development of the column flexural strength, and take the minimum, that is:

$$V_{nc1} = \min\,[V_{nc}, \sum M_{nc}/l_u]$$

For a typical interior column:

Column flexural strength at top: M_{ncT} = *6,830 k-in*

Column flexural strength at bottom: M_{ncB} = *3,415 k-in*
(assuming 50% fixity at base)

Column Clear Height: l_u = *193 in*

Column Shear if *flexural controls*:

$\sum M_{nc}/l_u$ = *(6,830 + 3,415) / 193 =* ***53*** *kips*

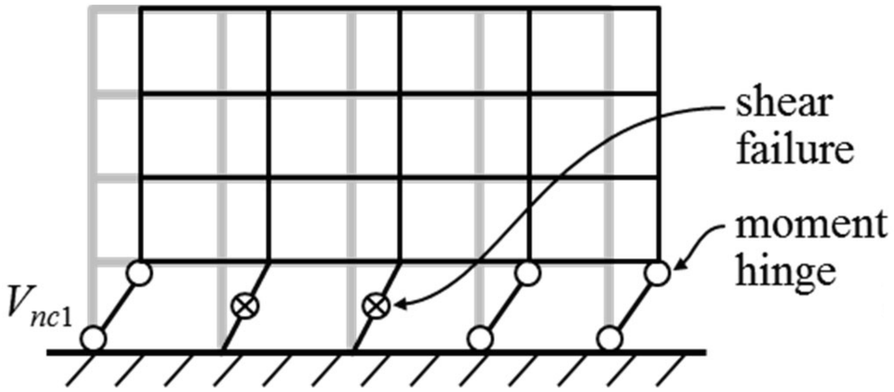
Column Shear Capacity: V_{nc} = ***118*** *kips* > $\sum M_{nc}/l_u$

V_{nc1} = ***53*** *kips - - >> Flexural Controls*

$\sum V_{nc1}$ = 276 kips -- Total for Frame on Gridline 2

3. Base Shear Strength, Period and Early Outs

Mechanism #1 Assumes building strength controlled by the structural elements in the first story



There are total of 9 Frames:

Frame on Gridline 1:

$\sum V_{nc1}$ = 167 kips

Frames on Gridlines 2 - 8:

(7) x $\sum V_{nc1}$ = (7) x 276 kips

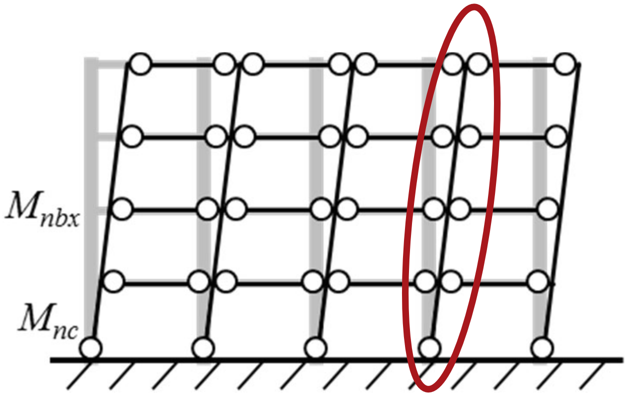
Frame on Gridline 9:

$\sum V_{nc1}$ = 370 kips

V_{P1} = 167 + 276 x7 + 370 = **2,470 kips**

3. Base Shear Strength, Period and Early Outs

Mechanism #2 Assumes that columns have sufficient strength to force yielding thru building height



For an interior column of the frame on Gridline 2:

2nd floor and above:

Summation of beams flexural strength, $\Sigma M_{nb} = 2{,}744$ k-in

Column base flexural strength, $M_{nc1} = 3{,}415$ k-in
(assuming 50% fixity)

$$V_{p1} = \frac{\sum M_{nc1} + \sum M_{nbx}}{h_{eff}}$$

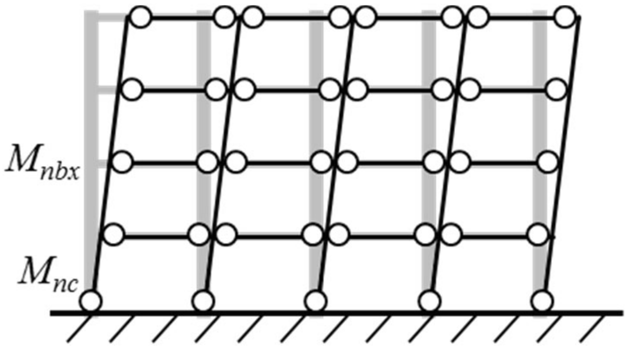
where $h_{eff} = 0.7h_n$

V_p = (3,415 + 2,744 x 5) / 590
= 29 kips @ the interior column

V_{p1} = 157 kips - Total for Frame on Gridline 2

3. Base Shear Strength, Period and Early Outs

Mechanism #2 Assumes that columns have sufficient strength to force yielding thru building height



There are total of 9 Frames:

Frame on Gridline 1:

$\sum V_{p1}$ = 124 kips

Frames on Gridlines 2 - 8:

(7) x $\sum V_{p1}$ = (7) x 157 kips

Frame on Gridline 9:

$\sum V_{p1}$ = 201 kips

V_{P1} = 1,424 kips < 2,470 kips from Mechanism 1

3. Base Shear Strength, Period and Early Outs

Thus, Plastic Mechanism 2 governs:

- Critical Story = 1st Story
- Effective Yield Strength V_y = **1,424** kips
- Building Total Seismic Weight W = 14,610 kips

$$V_y/W = \mathbf{9.7\%}$$

3. Base Shear Strength, Period and Early Outs

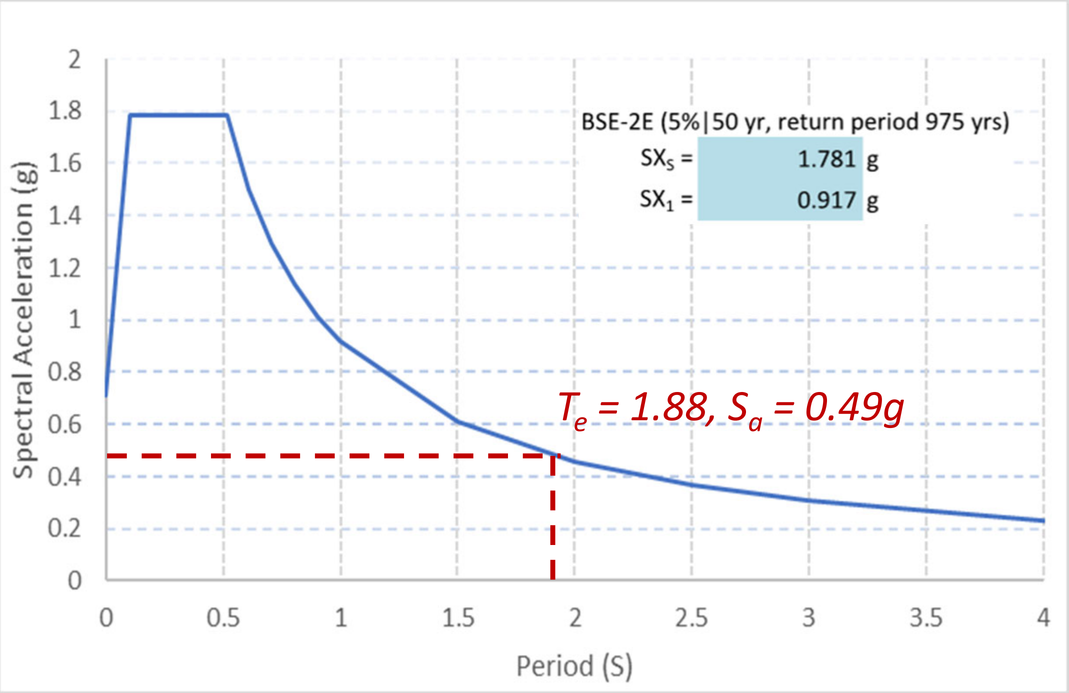
- Calculate the Effective Fundamental Period for the “frame” building:

$$T_e = 0.07(h_n)^{0.5}\left(\frac{V_y}{W}\right)^{-0.5}$$

$$= 0.07(70.25')^{0.5}(0.097)^{-0.5}$$

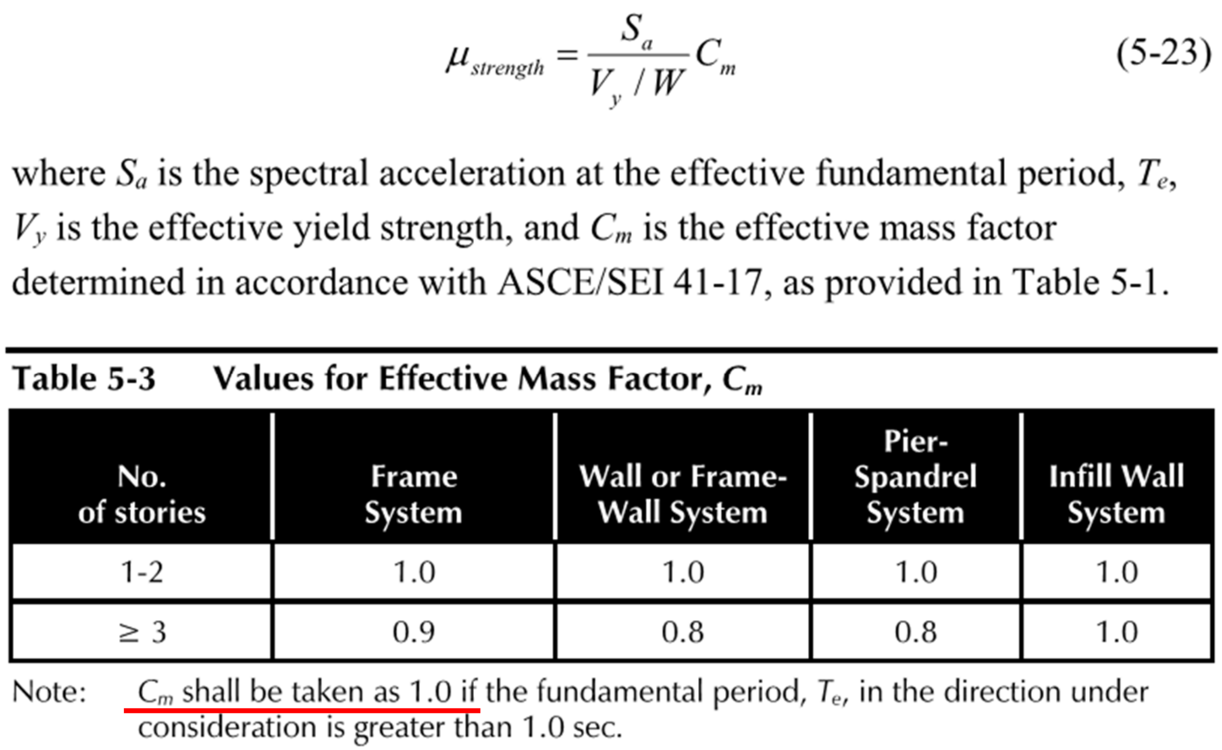
$= \mathbf{1.88}$ sec

- Develop the Acceleration Response Spectrum for the BSE-2E Earthquake



3. Base Shear Strength, Period and Early Outs

Check for Early-out - - Calculate Global Demand-to-Capacity Ratio, $\mu_{strength}$



$$\mu_{strength} = \frac{S_a}{V_y / W} C_m \qquad (5\text{-}23)$$

where S_a is the spectral acceleration at the effective fundamental period, T_e, V_y is the effective yield strength, and C_m is the effective mass factor determined in accordance with ASCE/SEI 41-17, as provided in Table 5-1.

Table 5-3 Values for Effective Mass Factor, C_m

No. of stories	Frame System	Wall or Frame-Wall System	Pier-Spandrel System	Infill Wall System
1-2	1.0	1.0	1.0	1.0
≥ 3	0.9	0.8	0.8	1.0

Note: C_m shall be taken as 1.0 if the fundamental period, T_e, in the direction under consideration is greater than 1.0 sec.

3. Base Shear Strength, Period and Early Outs

Check for Early-out - - Calculate Global Demand-to-Capacity Ratio, $\mu_{strength}$

$$\mu_{strength} = \frac{S_a}{V_y/W} C_m$$

$$= 0.49(1.0)/0.097$$

$$= 5.0$$

No early-out, but…!

Classification	Structural System	$\mu_{strength}$
Lower seismic risk	Frames with shear-critical columns ($V_p/V_n > 0.6$)	≤ 0.75
	All other cases	≤ 1.5
Exceptionally high seismic risk	Frames with shear-critical columns ($V_p/V_n > 1.5$)	> 2.0
	Frames without shear critical columns ($V_p/V_n \leq 0.6$)	> 5.5
	Some discontinuous wall-on-column conditions	Any
	Some discontinuous wall-on-girder conditions	Any
	Some pounding conditions	Any

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4. Global Seismic Drift Demand

Calculate Global Seismic Drift Demand

$$\delta_{eff} = C_1 C_2 S_a \frac{T_e^2}{4\pi^2} g$$

Equivalent SDOF displacement

SDOF spectral displacement

Coefficient to amplify short-period drift (from ASCE 41)

$$C_1 = 1 + \frac{\mu_{strength} - 1}{aT_e^2}$$

Coefficient to amplify drift due to degradation (from ASCE 41)

$$C_2 = 1 + \frac{1}{800}\left(\frac{\mu_{strength} - 1}{T_e}\right)^2$$

(All from ASCE 41)

$$C_1 = 1.0 \ \ (T_e > 1.0)$$

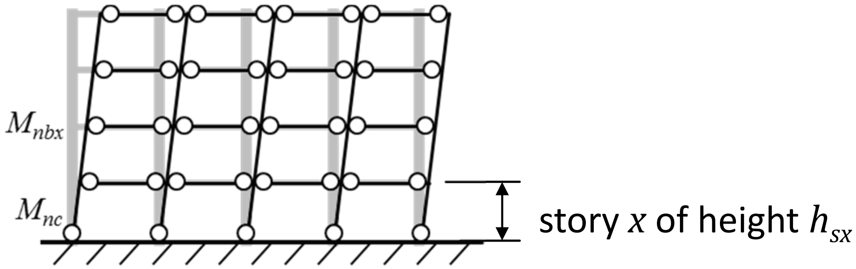
$$C_2 = 1.0 \ \ (T_e > 0.7)$$

$$\delta_{eff} = (1.0)(1.0)(0.49)\frac{1.9^2}{4\pi^2}(386)$$

$$\boxed{= \mathbf{16.9}\ in}$$

5. Drift Demand on Critical Story

a. Critical Story Drift Demand Adjustment – α



$$\delta_x = \alpha_x h_{sx}\left(\frac{\delta_{eff}}{h_{eff}}\right) \leq \delta_{eff}$$

α_x = 1.5, h_{sx} = 17.25’, h_{eff} = 0.7 x 70.25’ = 49.2’

Therefore, $\delta_1 = 0.53\delta_{eff}$ ***= 8.9** in*

In terms of drift ratio, $\frac{\delta_1}{h_{s1}} = 0.04$

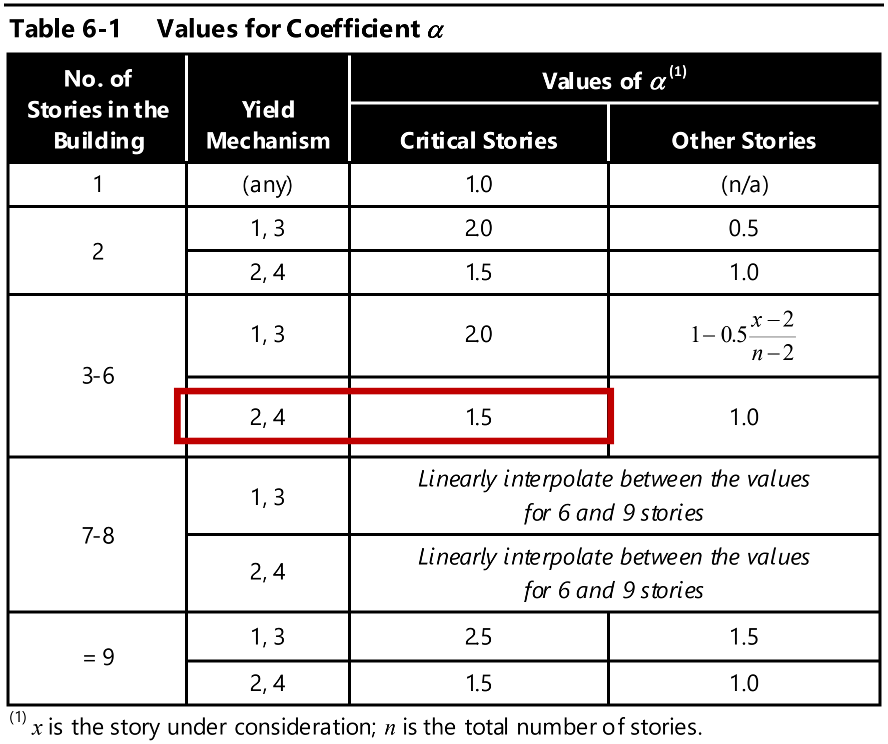


Table 6-1 Values for Coefficient α

No. of Stories in the Building	Yield Mechanism	Values of $\alpha^{(1)}$ Critical Stories	Values of $\alpha^{(1)}$ Other Stories
1	(any)	1.0	(n/a)
2	1, 3	2.0	0.5
	2, 4	1.5	1.0
3-6	1, 3	2.0	$1-0.5\frac{x-2}{n-2}$
	2, 4	1.5	1.0
7-8	1, 3	*Linearly interpolate between the values for 6 and 9 stories*	
	2, 4	*Linearly interpolate between the values for 6 and 9 stories*	
= 9	1, 3	2.5	1.5
	2, 4	1.5	1.0

(1) x is the story under consideration; n is the total number of stories.

5. Drift Demand on Critical Story

b. Critical Story Drift Demand Adjustment – P-Δ

$$\delta_{x1} = \delta_x \left[\frac{1}{1 - \frac{W_x \delta_x}{V_{px} h_x}} \right]$$

Gravity load above level 1

1st story height

Amplified story drift

Plastic mechanism shear strength at 1st story

For the critical 1st Story:

W_1 = 14,610 kips

δ_1 = 8.9 in (already amplified by α)

V_{p1} = 1,424 kips

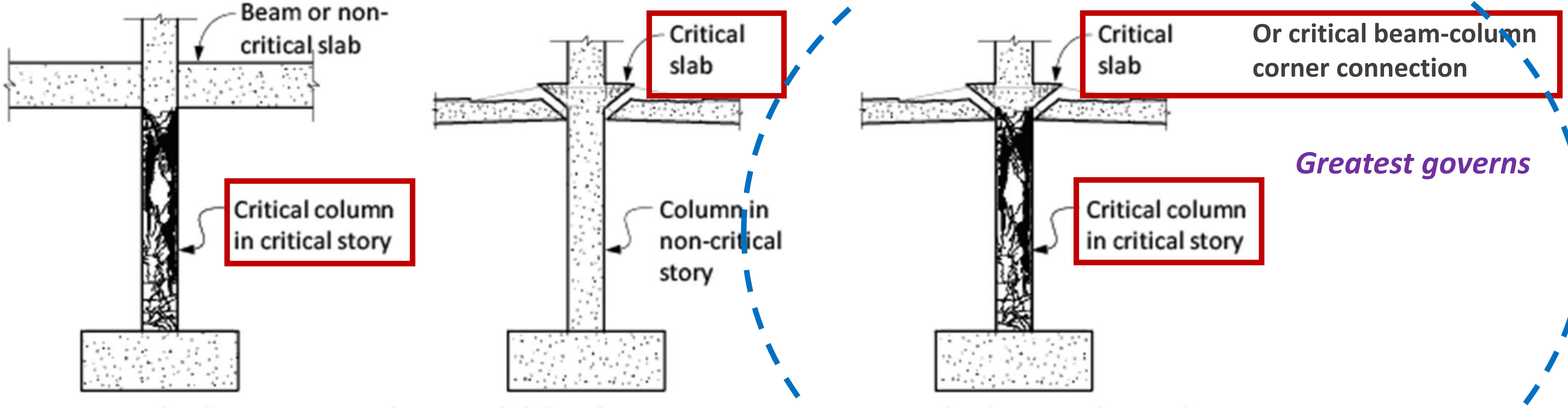
h_1 = 17.25 feet

$\delta_{x1} = 8.9 \text{ in x } (1.79) \boxed{= \textbf{\textit{15.9}}\ \textit{in}}$

In terms of drift ratio, now $\frac{\delta_1}{h_{s1}} = 0.08$

6. Drift Demand on Critical Components

Components for which Ratings are Required:



(a) Critical column

(b) Critical slab-column connection

(c) critical column and critical slab-column at same column

(d) Discontinuous Columns

6. Drift Demand on Critical Components

Calculate Component Drift Factors. *The Drift Factor, γ, defines the portion of the story drift demand attributable to component deformations:*

\>> Component Drift Demand = γ x Story Drift Demand

For Critical Columns: $$\frac{\sum M_c}{\sum M_b} = 3.72$$ Thus, γ = 0.30 per the table below

Ratio of Column Strengths to Beam Strengths(2) $\sum M_c/\sum M_b$	Column Drift Factor γ
≤ 0.6	0.85
1	0.70
≥ 2.4	0.30

For Critical Slab-Column and critical Beam-Column Corner Connections: γ = 1.0

6. Drift Demand on Critical Components

Calculate Component Drift Factors. *The Drift Factor, γ, defines the portion of the story drift demand attributable to component deformations:*

>> Component Drift Demand = γ x Story Drift Demand

				Demand				
				Critical Story Drift	γ–"Col"	γ–"Conn"	Δ_D-"Col"	Δ_D-"Conn"
Story	Frame Gridline	Gridline	Type	δ_{col}	γ	γ	Δ_D	Δ_D
				(in)			(in)	(in)
1st Story	2	A	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85
1st Story	2	B	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85
1st Story	2	C	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85
1st Story	2	D	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85
1st Story	2	F	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85
1st Story	2	G	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85

Evaluation Procedure

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6. Drift Demand on Critical Components - - *Chapter 6*
7. Drift Capacity of Critical Components - - *Chapter 6*
8. Column Ratings - - *Chapter 6*
9. Story Rating - - *Chapter 6*
10. Building Rating - - *Chapter 10*

7. Drift Capacity of Critical Components

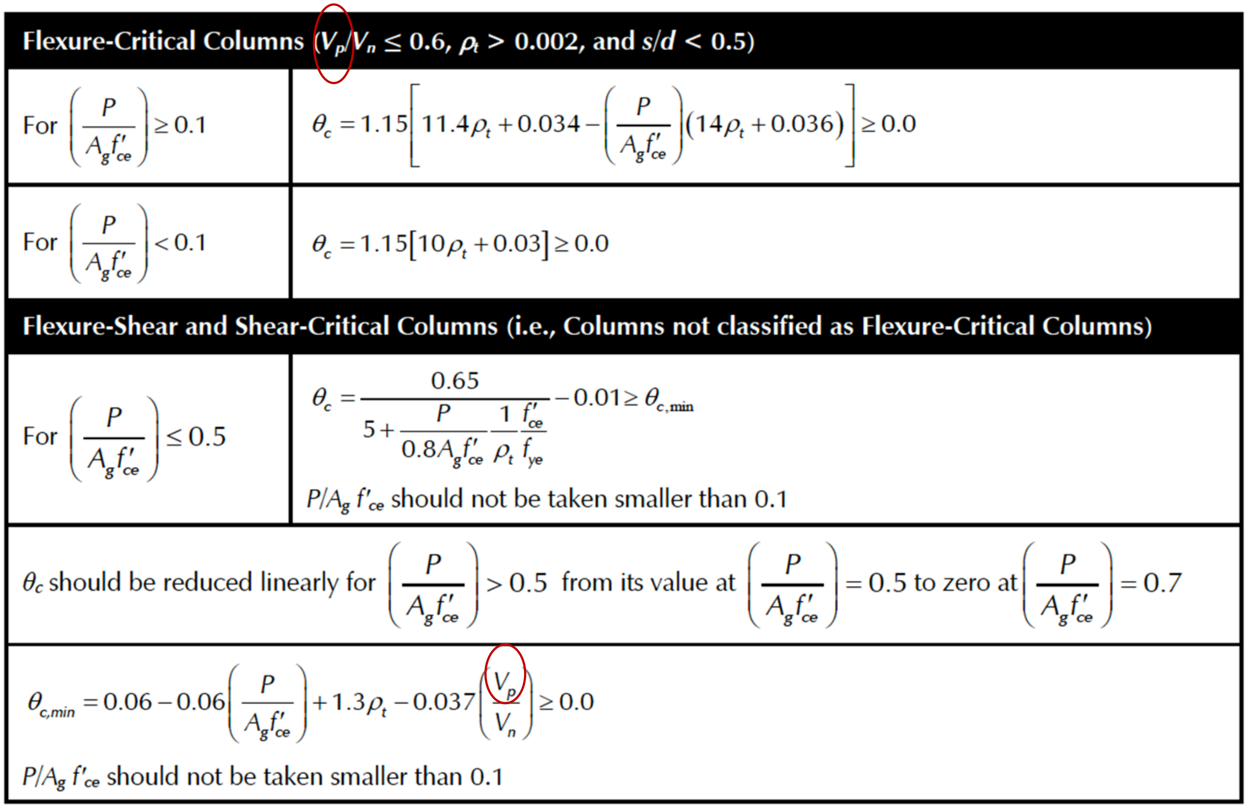
a. Drift Capacity of Critical Columns

$$\Delta_c = l_u(\theta_c + 0.01)$$

where:

l_u = clear height of the column

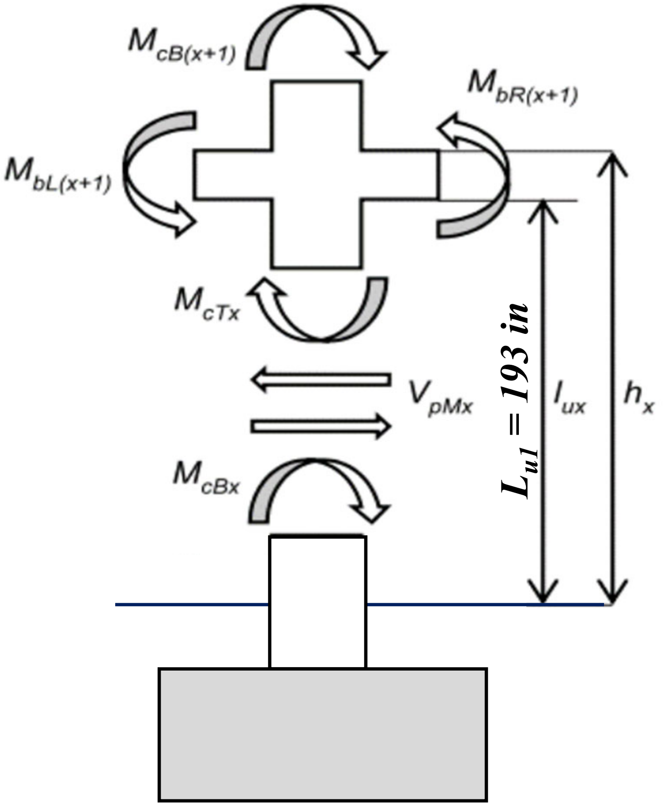
θ_c = column plastic rotation capacity



Flexure-Critical Columns ($V_p/V_n \le 0.6$, $\rho_t > 0.002$, and $s/d < 0.5$)	
For $\left(\frac{P}{A_g f'_{ce}}\right) \ge 0.1$	$\theta_c = 1.15\left[11.4\rho_t + 0.034 - \left(\frac{P}{A_g f'_{ce}}\right)(14\rho_t + 0.036)\right] \ge 0.0$
For $\left(\frac{P}{A_g f'_{ce}}\right) < 0.1$	$\theta_c = 1.15[10\rho_t + 0.03] \ge 0.0$
Flexure-Shear and Shear-Critical Columns (i.e., Columns not classified as Flexure-Critical Columns)	
For $\left(\frac{P}{A_g f'_{ce}}\right) \le 0.5$	$\theta_c = \frac{0.65}{5 + \frac{P}{0.8A_g f'_{ce}} \frac{1}{\rho_t} \frac{f'_{ce}}{f_{ye}}} - 0.01 \ge \theta_{c,\min}$ $P/A_g\, f'_{ce}$ should not be taken smaller than 0.1
θ_c should be reduced linearly for $\left(\frac{P}{A_g f'_{ce}}\right) > 0.5$ from its value at $\left(\frac{P}{A_g f'_{ce}}\right) = 0.5$ to zero at $\left(\frac{P}{A_g f'_{ce}}\right) = 0.7$	
$\theta_{c,min} = 0.06 - 0.06\left(\frac{P}{A_g f'_{ce}}\right) + 1.3\rho_t - 0.037\left(\frac{V_p}{V_n}\right) \ge 0.0$ $P/A_g\, f'_{ce}$ should not be taken smaller than 0.1	

7. Drift Capacity of Critical Components

a. Drift Capacity of Critical Columns



Calculate Shear Ratio: V_p/V_n

Column capacity-limited shear strength: $V_p = 25.8$ *kips*

Column section shear strength: $V_n = 118$ *kips*

Shear Ratio: $V_p/V_n = 0.22$

7. Drift Capacity of Critical Components

a. Drift Capacity of Critical Columns

Shear Ratio: $V_p/V_n = 0.22 < 0.6$

Axial Load Ratio:

$P_g/(A_g f'_{ce}) = 0.209 > 0.1$

Transverse Reinf. Ratio:

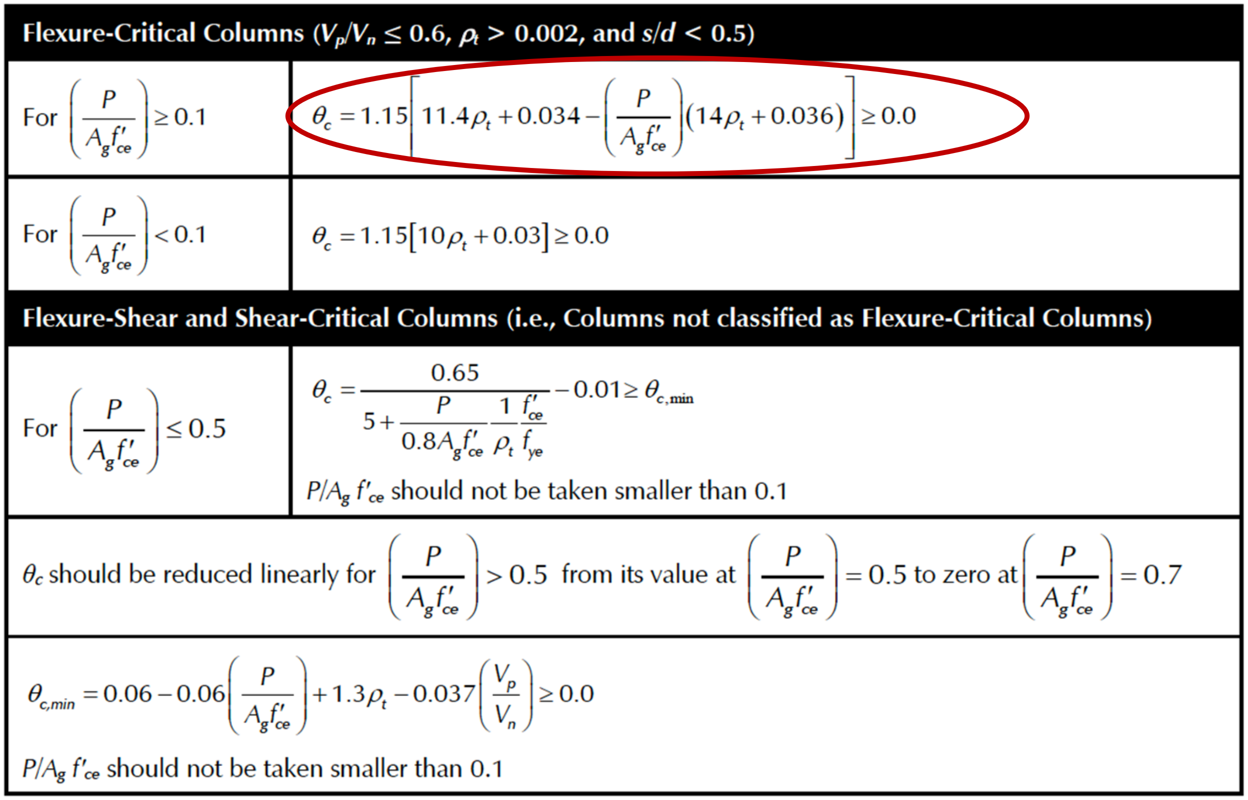
$\rho_t = A_v/(b_w s) = 0.0025 > 0.002$

Transverse Reinf. Spacing: $s/d < 0.5$

>> $\boldsymbol{\theta_c = 0.061}$

$$\Delta_c = l_u(\theta_c + 0.01)$$

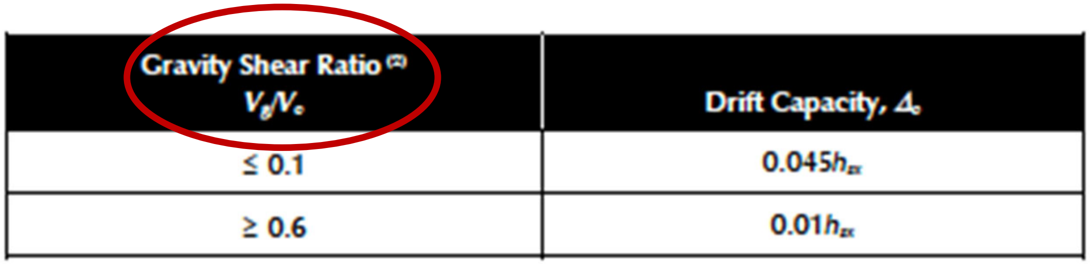
$\Delta_c = 193\ (0.061 + 0.01) =$ ***12.6*** *in*



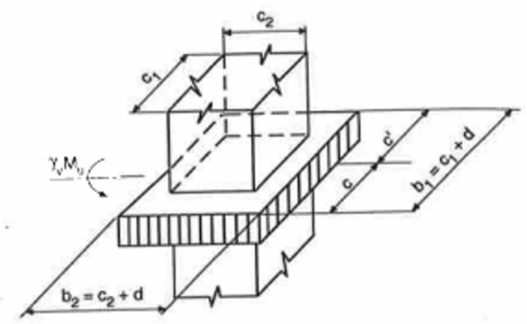
Flexure-Critical Columns ($V_p/V_n \le 0.6$, $\rho_t > 0.002$, and $s/d < 0.5$)	
For $\left(\frac{P}{A_g f'_{ce}}\right) \ge 0.1$	$\theta_c = 1.15\left[11.4\rho_t + 0.034 - \left(\frac{P}{A_g f'_{ce}}\right)(14\rho_t + 0.036)\right] \ge 0.0$
For $\left(\frac{P}{A_g f'_{ce}}\right) < 0.1$	$\theta_c = 1.15[10\rho_t + 0.03] \ge 0.0$
Flexure-Shear and Shear-Critical Columns (i.e., Columns not classified as Flexure-Critical Columns)	
For $\left(\frac{P}{A_g f'_{ce}}\right) \le 0.5$	$\theta_c = \dfrac{0.65}{5 + \dfrac{P}{0.8 A_g f'_{ce}} \dfrac{1}{\rho_t} \dfrac{f'_{ce}}{f_{ye}}} - 0.01 \ge \theta_{c,\min}$ $P/A_g f'_{ce}$ should not be taken smaller than 0.1
θ_c should be reduced linearly for $\left(\frac{P}{A_g f'_{ce}}\right) > 0.5$ from its value at $\left(\frac{P}{A_g f'_{ce}}\right) = 0.5$ to zero at $\left(\frac{P}{A_g f'_{ce}}\right) = 0.7$	
$\theta_{c,min} = 0.06 - 0.06\left(\frac{P}{A_g f'_{ce}}\right) + 1.3\rho_t - 0.037\left(\frac{V_p}{V_n}\right) \ge 0.0$ $P/A_g f'_{ce}$ should not be taken smaller than 0.1	

7. Drift Capacity of Critical Components

b. Drift Capacity of Critical Slab-Column Connections (Based on Punching Shear)



Gravity Shear Ratio (2) V_g/V_c	Drift Capacity, Δ_c
≤ 0.1	$0.045h_{sx}$
≥ 0.6	$0.01h_{sx}$



$d = 11$ in; $c_1 = 50$ in, $c_2 = 50$ in
$b_1 = 61$ in, $b_2 = 61$ in
$A = 2{,}675$ in^2

$v_g = V_g / A = 71.6$ kip / $2{,}675$ in^2 = 27 psi

$$v_c = \left(2+\frac{\alpha_s d}{b_0}\right)\sqrt{f'_c}\,b_0 d = 208 \text{ psi (ACI 318)}$$

$v_g / v_c = 0.129$

At first story, $h_{sx} = 194$ in >>> $\Delta_c = 0.043\, h_{s1} =$ ***8.3*** *in*

7. Drift Capacity of Critical Components

c. Drift Capacity of Critical Beam-Column Corner Connections

$$\Delta_c = \left(0.1 - 0.33\frac{P}{A_g f'_{ce}}\right)h_{sx}$$

Largest corner column axial load ratio is:

P = 158 kips

$A_g\ f_{ce}'$ = 1,357 kips

$P/(A_g\ f_{ce}')$ = 0.116

Δ_c = (0.1 - 0.33 x 0.116) h_{sx} = 0.062 h_{sx}

At first story, h_{sx} = 194 in

Δ_c = ***12.0*** in

Evaluation Procedure

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10. Building Rating - - *Chapter 10*

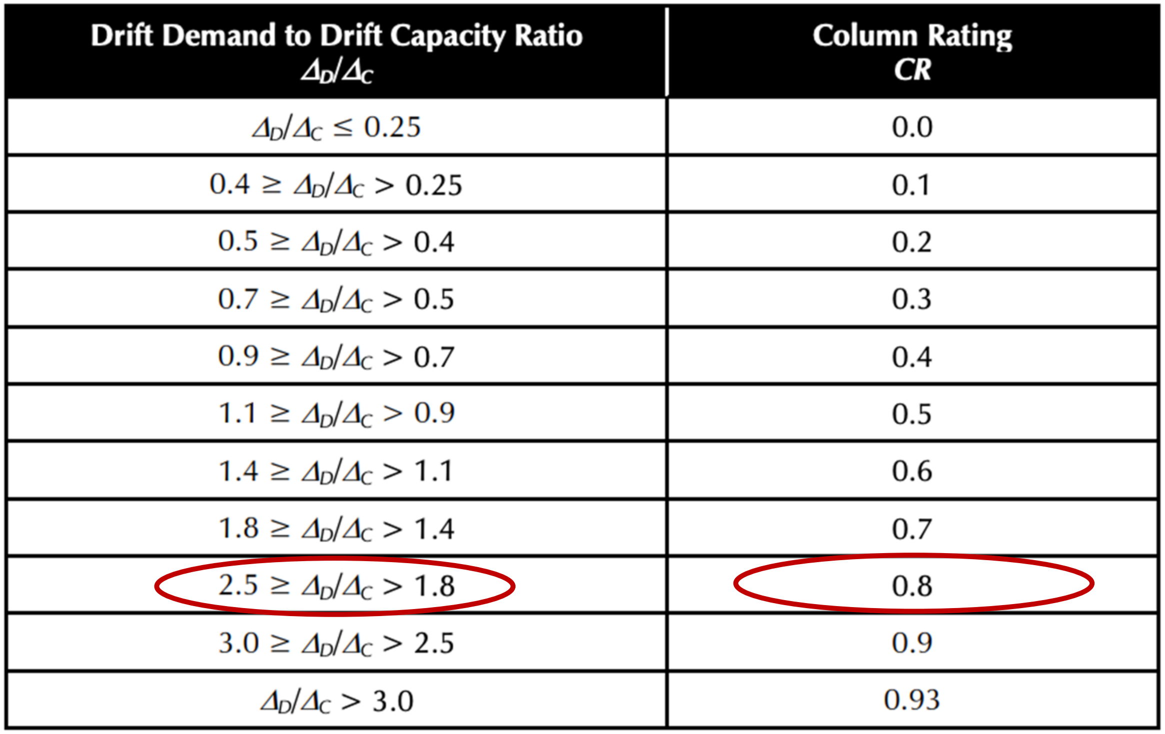
8. Column Ratings

Drift Demand/Capacity Ratios for Critical Columns and Slab-Column Connections –
(Showing Gridline 2 only)

				Demand					Capacity		D/C Ratio
				Story Drift	γ–"Col"	γ–"Conn"	Δ_D-"Col"	Δ_D-"Conn"	Δ_c -"Col"	Δ_c -"Conn"	Δ_D / Δ_c
Story	Frame Gridline	Gridline	Type	δ_{col}	γ	γ	Δ_D	Δ_D	Δ_c	Δ_c	DCR
				(in)			(in)	(in)	(in)	(in)	
1st Story	2	A	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	13.72	8.52	1.86
1st Story	2	B	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91
1st Story	2	C	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91
1st Story	2	D	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91
1st Story	2	F	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91
1st Story	2	G	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	13.72	8.52	1.86

8. Column Ratings

Every column (location) at the critical story is assigned a Column Rating, CR_i, based on the highest Δ_D/Δ_C rating for any critical component at that location



Drift Demand to Drift Capacity Ratio Δ_D/Δ_C	**Column Rating** CR
$\Delta_D/\Delta_C \leq 0.25$	0.0
$0.4 \geq \Delta_D/\Delta_C > 0.25$	0.1
$0.5 \geq \Delta_D/\Delta_C > 0.4$	0.2
$0.7 \geq \Delta_D/\Delta_C > 0.5$	0.3
$0.9 \geq \Delta_D/\Delta_C > 0.7$	0.4
$1.1 \geq \Delta_D/\Delta_C > 0.9$	0.5
$1.4 \geq \Delta_D/\Delta_C > 1.1$	0.6
$1.8 \geq \Delta_D/\Delta_C > 1.4$	0.7
$2.5 \geq \Delta_D/\Delta_C > 1.8$	0.8
$3.0 \geq \Delta_D/\Delta_C > 2.5$	0.9
$\Delta_D/\Delta_C > 3.0$	0.93

8. Column Rating

Columns Rating –
(Showing Gridline 2 only)

				Demand					Capacity		D/C Ratio	
				Story Drift	γ–"Col"	γ–"Conn"	Δ_D-"Col"	Δ_D-"Conn"	Δ_c -"Col"	Δ_c -"Conn"	Δ_D / Δ_c	Col Rating
Story	Frame Gridline	Gridline	Type	δ_{col}	γ	γ	Δ_D	Δ_D	Δ_c	Δ_c	DCR	CR_i
				(in)			(in)	(in)	(in)	(in)		
1st Story	2	A	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	13.72	8.52	1.86	**0.8**
1st Story	2	B	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91	**0.8**
1st Story	2	C	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91	**0.8**
1st Story	2	D	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91	**0.8**
1st Story	2	F	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	12.57	8.30	1.91	**0.8**
1st Story	2	G	Slab-Col Frame	15.85	0.30	1.00	4.76	15.85	13.72	8.52	1.86	**0.8**

9. Story Rating

Calculate “Weighted Average” Story Rating:

$$R_{avg} = \sum_{i=1}^{ncol} f_{col,i} CR_i$$

R_{avg} = Average of column ratings, weighted by the gravity load taken by each column

$f_{col,i}$ = Fraction of gravity loads supported by column *i* in a story. $\sum_{i=1}^{ncol} f_{col,i} = 1$ in each story

R_{avg} = 0.805

			Δ_D / Δ_c	Col Rating	Gravity Load	Trib. Ratio	
Story	Frame Gridline	Gridline	DCR	CR_i	P_g (kips)	f_{col}	CRi x f_{col}
1st Story	2	A	1.86	**0.8**	218	0.014	0.011
1st Story	2	B	1.91	**0.8**	334	0.021	0.017
1st Story	2	C	1.91	**0.8**	334	0.021	0.017
1st Story	2	D	1.91	**0.8**	334	0.021	0.017
1st Story	2	F	1.91	**0.8**	334	0.021	0.017
1st Story	2	G	1.86	**0.8**	218	0.014	0.011
1st Story	3	A	1.86	**0.8**	218	0.014	0.011
1st Story	3	B	1.91	**0.8**	334	0.021	0.017
1st Story	3	C	1.91	**0.8**	334	0.021	0.017
1st Story	3	D	1.91	**0.8**	334	0.021	0.017
1st Story	3	F	1.91	**0.8**	334	0.021	0.017
1st Story	3	G	1.86	**0.8**	218	0.014	0.011
1st Story	9	A	3.96	**0.93**	290	0.018	0.017
1st Story	9	B	1.91	**0.8**	448	0.028	0.022
1st Story	9	C	1.91	**0.8**	448	0.028	0.022
1st Story	9	D	1.91	**0.8**	448	0.028	0.022
1st Story	9	F	1.91	**0.8**	448	0.028	0.022
1st Story	9	G	3.96	**0.93**	290	0.018	0.017
					15,929	1.00	0.805

9. Story Rating

Adjustment based on coefficient of variation:

$$R_{adj} = R_{avg} + 0.625R_{avg}(COV - 0.4)$$

COV = the standard deviation of all the *column ratings* at a story divided by the weighted mean column rating at that story

$R_{avg} < R_{adj} < 1.25\, R_{avg}$

$>> R_{adj} = 0.8$

Story Rating:

$$SR = 1.5R_{adj} - 0.1$$

$SR = 1.5\ (0.80) - 0.1 = 1.10 \quad (0.1 < SR < 0.9)$

>> SR = 0.9

			Δ_D / Δ_c	Col Rating	Gravity Load	Trib. Ratio	
Story	Frame Gridline	Gridline	DCR	CR_i	P_g (kips)	f_{col}	CRi x f_{col}
1st Story	2	A	1.86	0.8	218	0.014	0.011
1st Story	2	B	1.91	0.8	334	0.021	0.017
1st Story	2	C	1.91	0.8	334	0.021	0.017
1st Story	2	D	1.91	0.8	334	0.021	0.017
1st Story	2	F	1.91	0.8	334	0.021	0.017
1st Story	2	G	1.86	0.8	218	0.014	0.011
1st Story	3	A	1.86	0.8	218	0.014	0.011
1st Story	3	B	1.91	0.8	334	0.021	0.017
1st Story	3	C	1.91	0.8	334	0.021	0.017
1st Story	3	D	1.91	0.8	334	0.021	0.017
1st Story	3	F	1.91	0.8	334	0.021	0.017
1st Story	3	G	1.86	0.8	218	0.014	0.011
1st Story	9	A	3.96	0.93	290	0.018	0.017
1st Story	9	B	1.91	0.8	448	0.028	0.022
1st Story	9	C	1.91	0.8	448	0.028	0.022
1st Story	9	D	1.91	0.8	448	0.028	0.022
1st Story	9	F	1.91	0.8	448	0.028	0.022
1st Story	9	G	3.96	0.93	290	0.018	0.017
			Mean	0.80	15,929	1.00	0.805
			Std Dev	0.02			
			R_{avg}	0.80			
			R_{adj}	0.80			

10. Building Rating

The building rating, *BR*, is taken as the maximum story rating, *SR*, determined in either direction, for critical stories over the height of a building.

BR = 0.9