Specimen Design of Corner Beam-Column Connections

Advisor : Professor Mosalam
Student Researcher : SANGJOON PARK

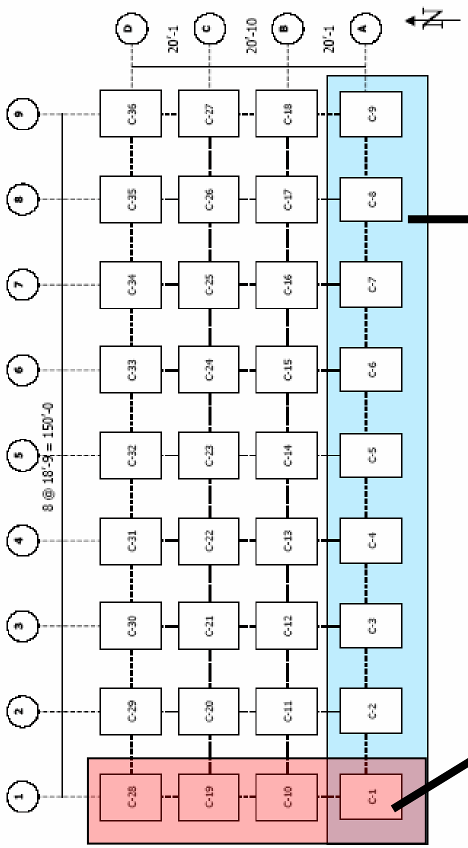
Prototype – Van Nuys Holiday Inn (7story)

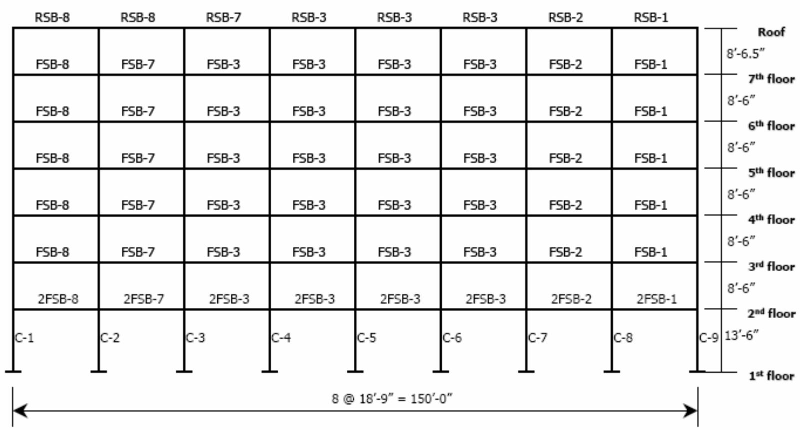
	Con'c(ksi)		Rebar
Column	1st	5.0	Grade 60
	2nd	4.0	
	3-7	3.0	
Beam Slab	2nd	4.0	Grade 40
	3-roof	3.0	

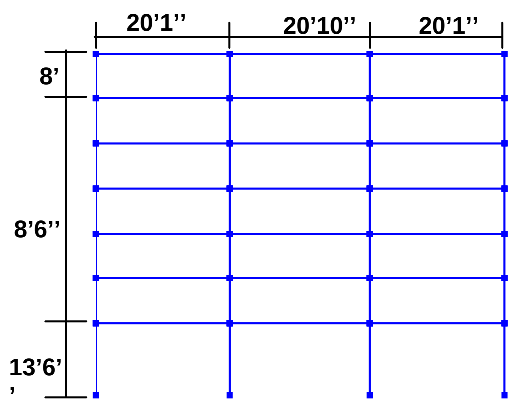
- Gravity Design Information
  - -. Beam : 16''x30'' Column : 14''x20'' Span : 20 ft
- Beam Shear and Column Axial Force Relation
  - -. Linear equation : $P_{average}=185 + 3.5(V_{b,x}-10) +3.5(V_{b,y}-10)$
- Range of Corner Column Axial Force Variation
  - -. $P_{overturning} \approx$ 60% of $P_{gravity}$ to each direction
  - -. $P_{total} =(0.15\, f_c\, A_g)*(1+0.6*2)=0.33 f_c A_g$ ≈ @ the balance point
- Joint Shear Strength and Demand
  - -. Small joint shear demand due to small amount of reinforcement in beam

Prototype – Van Nuys Holiday Inn

1. **Designed per L.A City Building Code 64**
2. **7 story Building**







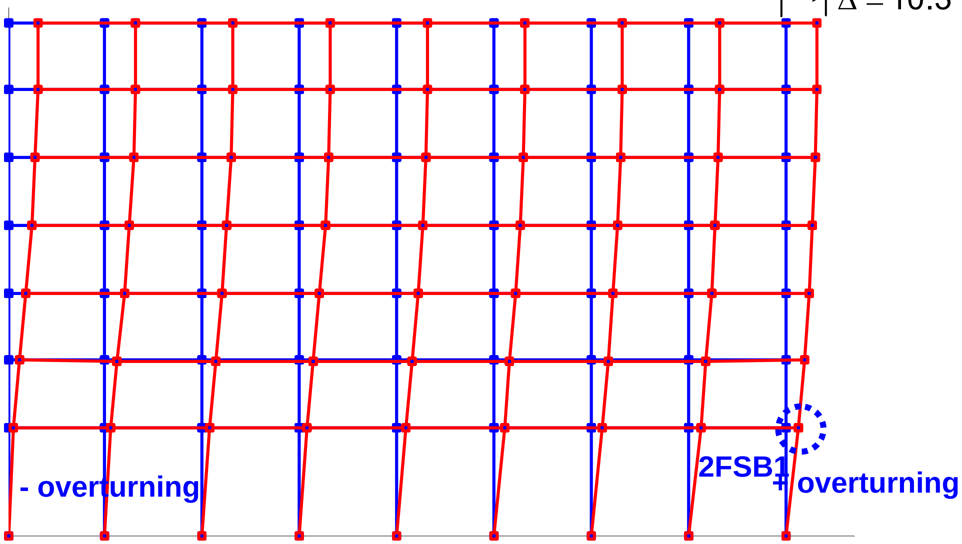
Material Properties

	Con'c(ksi)		Rebar
Column	1st	5.0	Grade 60
	2nd	4.0	
	3-7	3.0	
Beam Slab	2nd	4.0	Grade 40
	3-7	3.0	

Prototype – Van Nuys Holiday Inn

-. Longitudinal

When 2FSB1 reached M_{ult}=3015(kip-in)

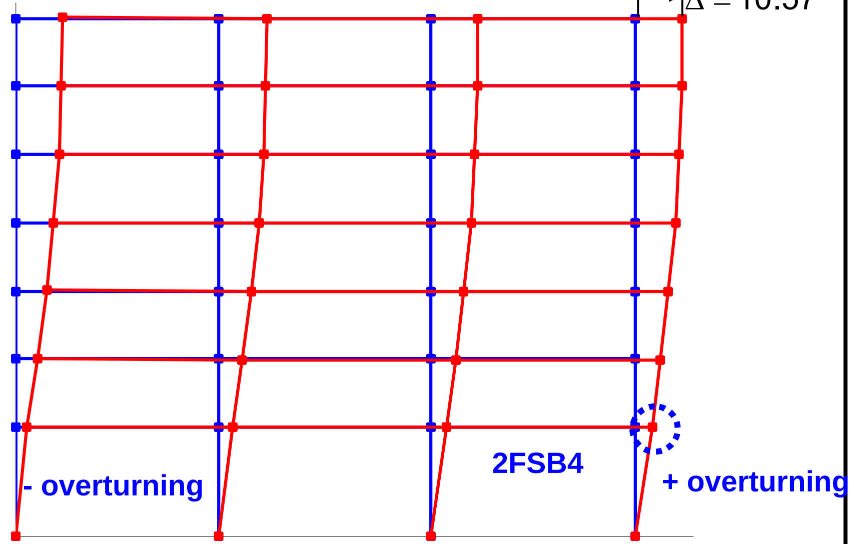


	+ overturning	- overturning
$P_{col,1st}$(kip)	157(gravity)+79	157(gravity)-90
V_{joint}(kip)[1]	60	43
$V_j / \sqrt{f'_c}$	3.8	2.7
$\phi\gamma\sqrt{f'_c}\, b_j h_c$ (kip)	162	162

1 : $V_{joint} = A_s f_y - \dfrac{V_{col,2} + V_{col,1}}{2}$

-. Transverse

When 2FSB4 reached M_{ult}=3867(kip-in)



	+ overturning	- overturning
$P_{col,1st}$(kip)	160(gravity)+102	160(gravity)-102
V_{joint}(kip)[1]	99	52
$V_j / \sqrt{f'_c}$	5.6	2.9
$\phi\gamma\sqrt{f'_c}\, b_j h_c$(kip)	181	181

Prototype – Van Nuys Holiday Inn

3.2 For Hypothetical Van Nuys : Square Plan with the same as Van Nuys transverse geometry (3Bays)

-. Modifications of Van Nuys

a. Identical to Van Nuys Geometry and Material Properties

b. All column section 18''x18''(8-#10) , all beam width is 16'' and increase reinforcement ratio slightly

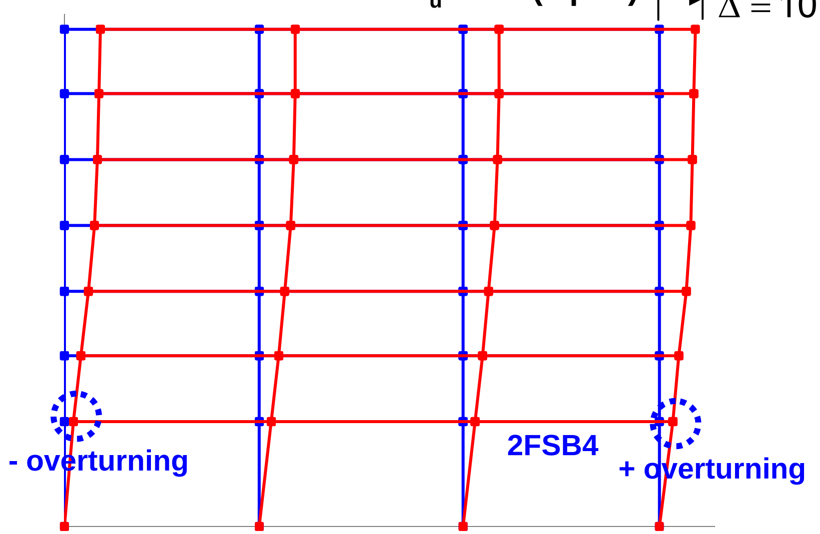
□ Increase Van Nuys dead load by **1.15**

c. Including slab section : b_{eff}=column width(b_{col})+transverse beam depth(h_{beam})

d. ***Concrete01*** with $\varepsilon_{psc0} = 0.003$, $\varepsilon_{psu} = 0.005$, $f_{pcu} = 0$(no residual strength)

Reinforcingsteel

When 2FSB4 reached M_u=4350(kip-in) $\Delta = 10.1''$



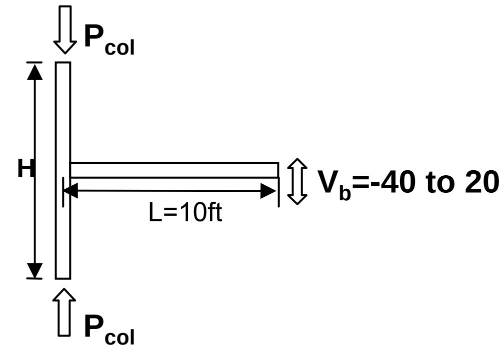
	+ overturning	- overturning
$P_{col,1st}$(kip)	183(gravity)+107	183(gravity)-106
V_{joint}(kip)	140	93
$V_j / \sqrt{f'_c}$	7.7	5.2
$\phi\gamma\sqrt{f'_c}\, b_j h_c$(kip)	185	185

Prototype – Van Nuys Holiday Inn

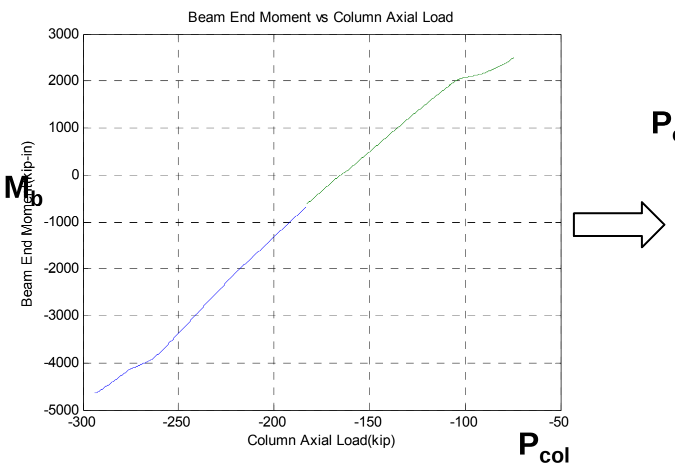
3. Axial Loading Equation

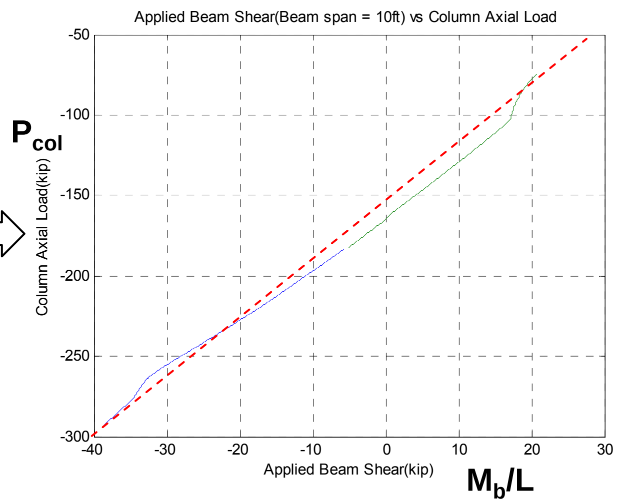
-. Take the maximum and minimum moment at the beam end, axial force on the ground floor column and column shear from modified Van Nuys,

	+ overturning	- overturning
$P_{col,1st}$(kip)	180 +110 =290	180-110 = 70
V_{col}(kip)	40	25
M_b(kip-in)	-4400□-4800	2300□2400
$V_b=M_b/L$	≈ -40	≈ 20



-. Derive the relationship between Beam End Moment and Column Axial Force for both direction





$$P = 3.5V_b + 150$$

$$= 185 + 3.5(V_b - 10)$$

cf) 2/3 scale Royal Palm(12story)

$$P_{2nd} = 178 \pm 4V_x \pm 5V_y$$

Specimen Design

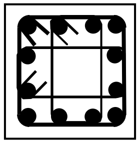
-. Specimen Matrix

Specimen	dimension	Beam Reinforcement				Aspect ratio (h_b/h_c)	Target Failure
		main rebars		stirrups	**Slab[1]**		
		Top	Bot				
SP1	16''X30''	**5-#8**	**5-#8**	#3@4''	**6-#3**	1.92 : 1	J
SP2	16''X18''	**5-#8**	**5-#8**	#3@4''	**4-#3**	1.00 : 1	J
SP3	16''X30''	**4-#7**	**4-#7**	#3@4''	**6-#3**	1.92 : 1	BJ
SP4	16''X18''	**4-#7**	**4-#7**	#3@4''	**4-#3**	1.00 : 1	BJ

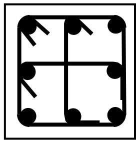
[1] : assuming effective slab width is summation of beam width(b_b) and transverse beam depth(h_{tb})

Specimen	Column			Slab	
	dimension	reinforcement	hoops[2]	thickness	reinforcement
SP1 & 3	18''X18''	**12-#10**	#3@4''	6''	#3@12''(top & bot)
SP2 & 4	18''X18''	**8-#10**	#3@4''	6''	#3@12''(top & bot)

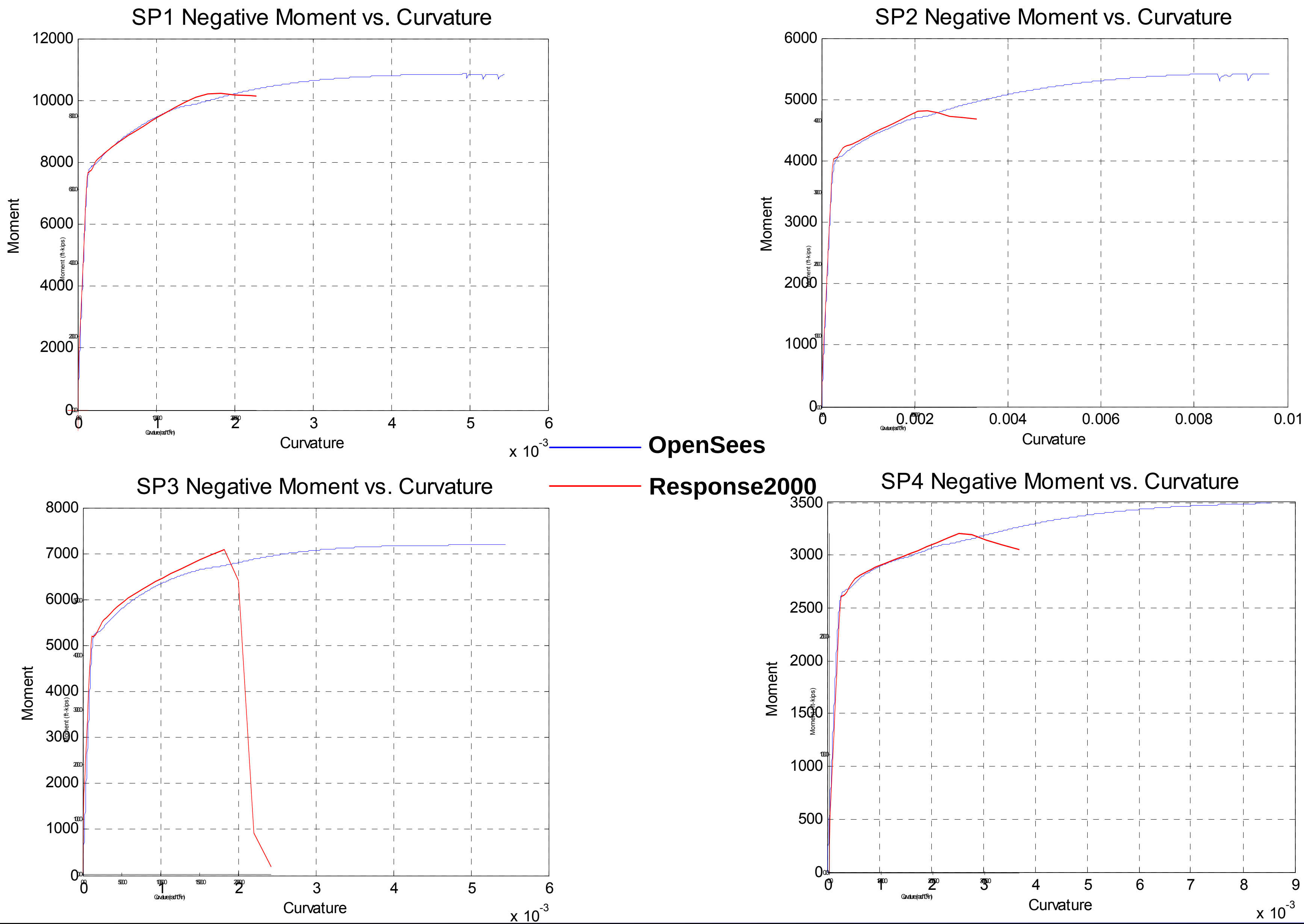
[2] : Two types of hoops



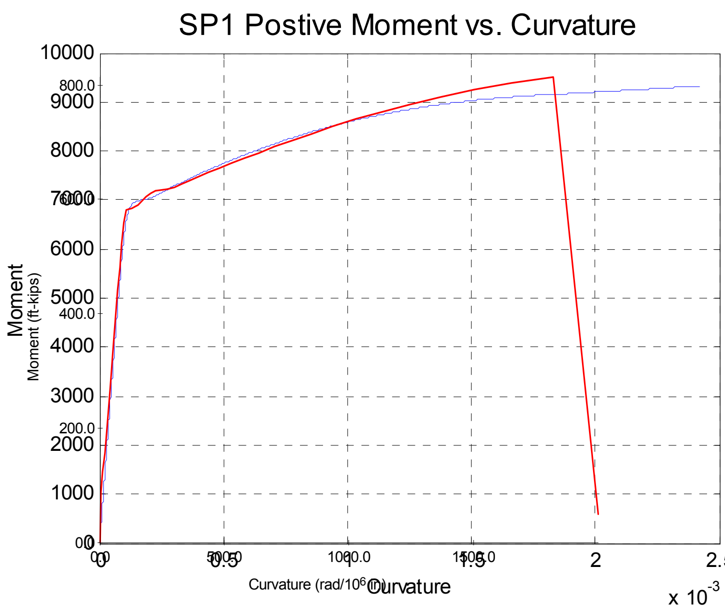
SP1&3

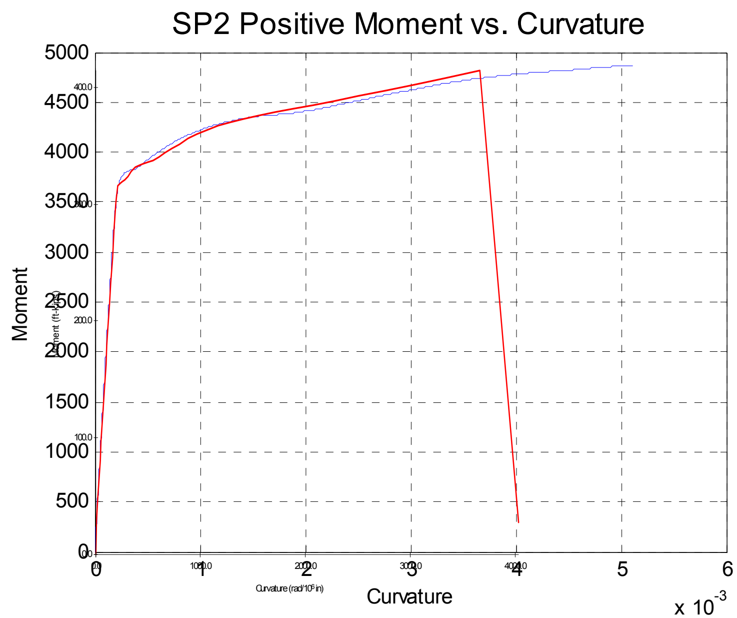


SP2&4



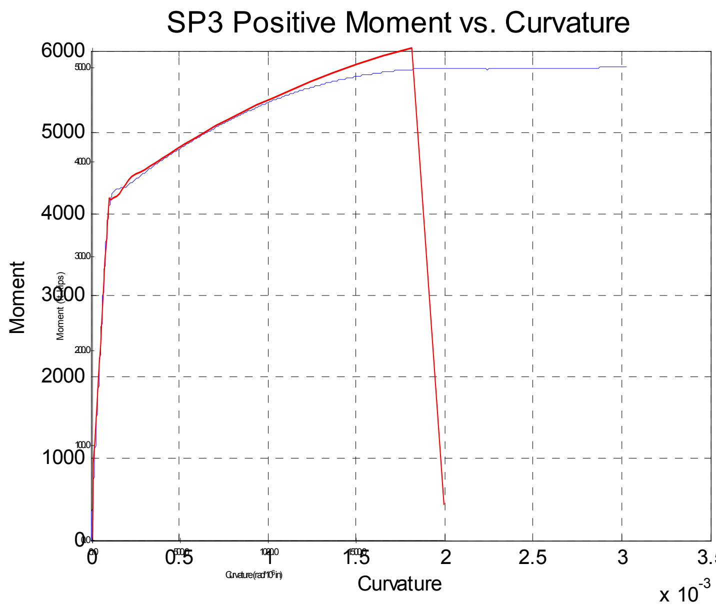
Advisor : Professor Mosalam **Student Researcher : SANGJOON PARK**

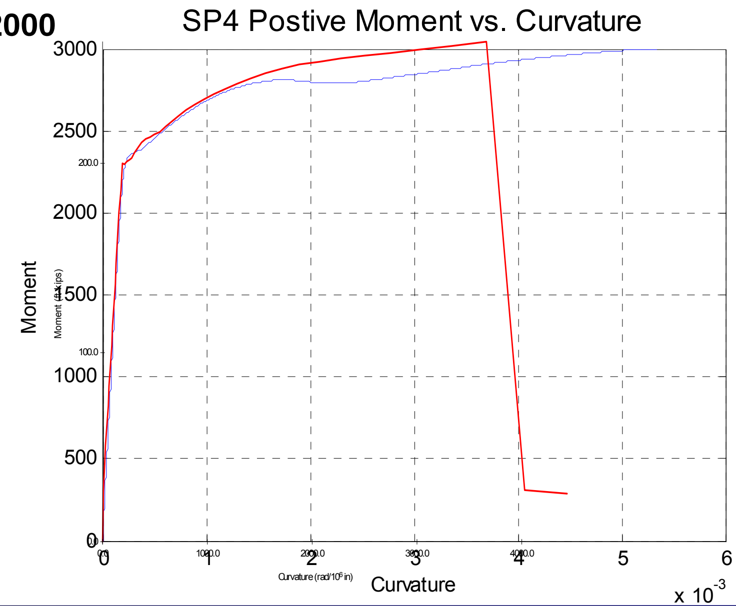




OpenSees

Response2000

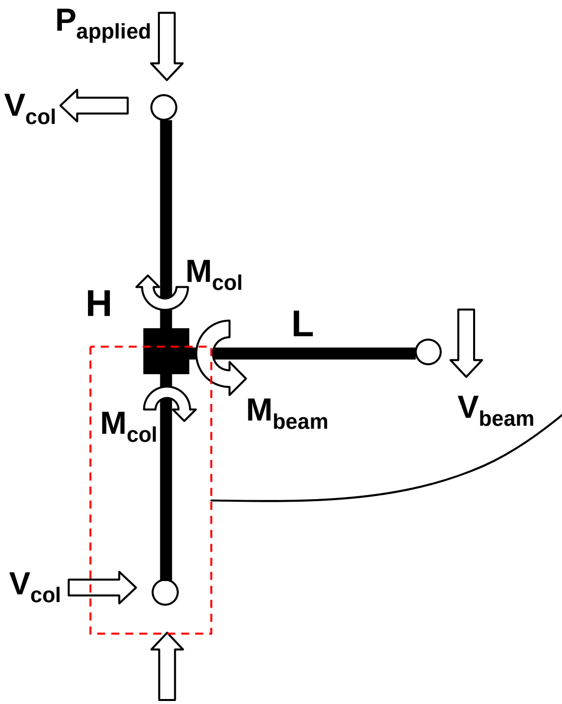


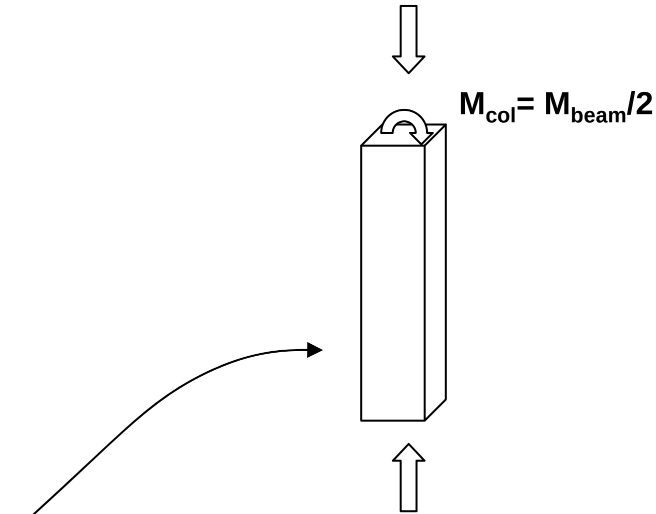


Advisor : Professor Mosalam

Student Researcher : SANGJOON PARK

-. Moment Capacity Ratio of Column to Beam





For biaxial loading,

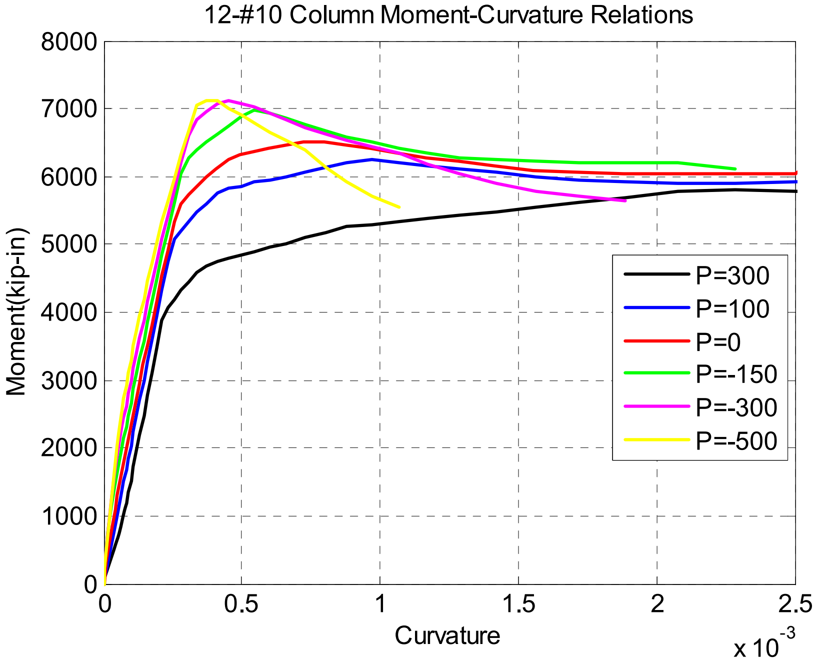
$$\left(\frac{M_{col,x}}{M_{nx,col}}\right)^{1.5} + \left(\frac{M_{col,y}}{M_{ny,col}}\right)^{1.5} = \left(\frac{M_{beam,x}}{2M_{nx,col}}\right)^{1.5} + \left(\frac{M_{beam,y}}{2M_{ny,col}}\right)^{1.5}$$

$$= \left(\frac{M_{beam,x}}{\sum M_{nx,col}}\right)^{1.5} + \left(\frac{M_{beam,y}}{\sum M_{ny,col}}\right)^{1.5}$$

$$\text{ex)}\ \frac{\sum M_{nx,col}}{M_{beam,x}} = 1.5 \Rightarrow \left(\frac{1}{1.5}\right)^{1.5} \times 2 = 1.09$$

$$\frac{\sum M_{nx,col}}{M_{beam,x}} = 1.8 \Rightarrow \left(\frac{1}{1.8}\right)^{1.5} \times 2 = 0.83$$

-. Moment Capacity Ratio of Column to Beam (SP1 & SP3)



For biaxial loading, if slab effect is included,

$$\frac{\sum M_{n,col}}{M_{n,beam}} > 1.5 \sim 1.8$$ to avoid column hinging

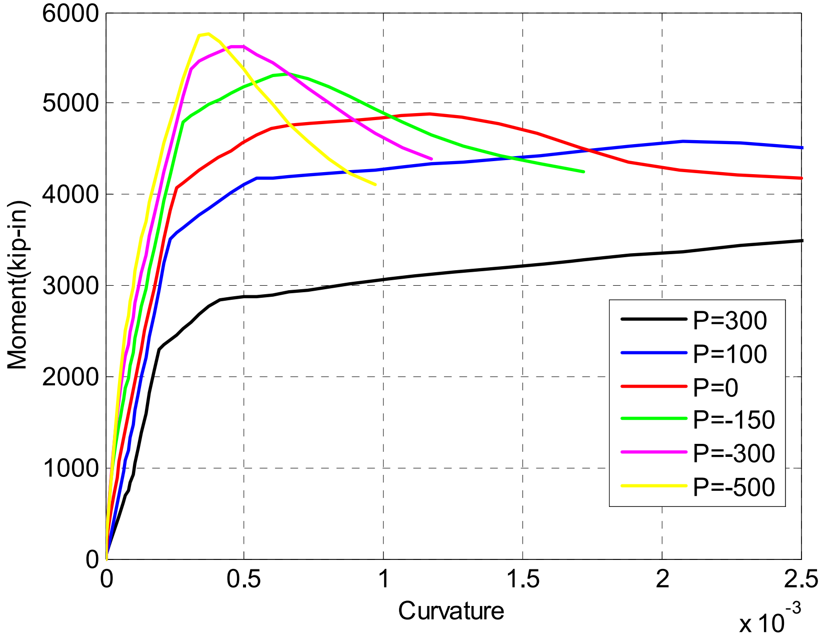
[from 'Towards New Bond and Anchorage Provisions for Interior Joints by R.T. Leon]

	$\sum M_{yield,col} / M_{beam}$											
	$M_{beam}=M_y$						$M_{beam}=M_{ult}$					
	Positive			Negative			Positive			Negative		
	$P\approx0$	$P\approx P_{uni}$	$P\approx P_{bi}$	$P\approx0$	$P\approx P_{uni}$	$P\approx P_{bi}$	$P\approx0$	$P\approx P_{uni}$	$P\approx P_{bi}$	$P\approx0$	P_{uni}	$P\approx P_{bi}$
SP1	**1.52**	**1.49**	**1.20**	**1.35**	**1.75**	**1.77**	1.15	1.07	0.78	0.99	1.33	1.22
SP3	**2.47**	**2.61**	**2.29**	**2.02**	**2.54**	**2.65**	**1.84**	**1.89**	**1.55**	**1.49**	**1.91**	**2.01**

Note : $M_{yield,col}$ is taken at reinforcing steel stress = 68ksi

-. Moment Capacity Ratio of Column to Beam (SP2 & SP4)

8-#10 Column Moment-Curvature Relations



	$\sum M_{yield,col} / M_{beam}$											
	$M_{beam}=M_y$						$M_{beam}=M_{ult}$					
	Positive			Negative			Positive			Negative		
	$P \approx 0$	$P \approx P_{uni}$	$P \approx P_{bi}$	$P \approx 0$	$P \approx P_{uni}$	$P \approx P_{bi}$	$P \approx 0$	$P \approx P_{uni}$	$P \approx P_{bi}$	$P \approx 0$	P_{uni}	$P \approx P_{bi}$
SP2	**2.12**	**2.02**	**1.42**	**2.00**	**2.73**	**2.86**	1.67	1.47	0.77	1.50	2.11	2.02
SP4	**3.41**	**3.53**	**2.58**	**3.04**	**3.95**	**4.18**	**2.71**	**2.77**	**2.04**	**2.33**	**3.13**	**3.34**

Note : $M_{yield,col}$ is taken at reinforcing steel stress = 68ksi

-. Discussion of Moment Capacity Ratio

1. For Compression

All specimen : ‘Strong Column and Weak Beam’

2. For Tension

SP1 & SP2 (J failure) : column reinforcement may yield first during biaxial tension loading

3. Resolution

-. Too high tension may be unrealistic

-. Use different loading equation for tension to limit the maximum tension loading on column

-. $P_{max,tension} = 0.25 \times P_{max,compression}$

-. Prototype : $-30 < P_{axial} < 397$ $M_{negative} > M_{positive}$

-. 2/3 Royal Palm : $-118 < P_{axial} < 474$ $M_{negative} > M_{positive}$

Comparison of Axial Loads

SP1 vs SP2 : Joint Shear Failure before beam reinforcement yielding

J failure		$P_{joint,avg}$ @yield			$P_{joint,avg}$ @ult.		
		Beam Shear	Column Axial		Beam Shear	Column Axial	
			uniaxial	biaxial		uniaxial	biaxial
Neg.	SP1	-83	**-326**	**-510**	-113	-402	-660
	SP2	-42	**-331**	**-473**	-57	-394	-608
Pos.	SP1	73	**63**	**270**	97	123	390
	SP2	40	**40**	**265**	51	88	364

SP3 vs SP4 : Joint Shear Failure after beam reinforcement yielding

BJ failure		$P_{joint,avg}$ @yield			$P_{joint,avg}$ @ult.		
		Beam Shear	Column Axial		Beam Shear	Column Axial	
			uniaxial	biaxial		uniaxial	Biaxial
Neg.	SP3	-55	**-258**	**-370**	-75	**-307**	**-470**
	SP4	-28	**-266**	**-347**	-36	**-304**	**-419**
Pos.	SP3	45	**-7**	**130**	60	**31**	**205**
	SP4	25	**-28**	**157**	31	**1**	**184**

Advisor : Professor Mosalam **Student Researcher : SANGJOON PARK**

Axial Loading Sequence

SP1&3

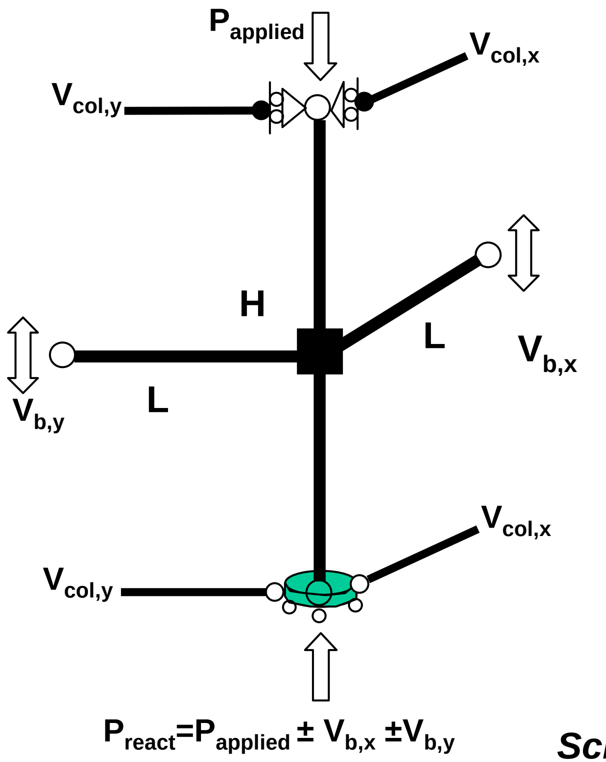
$$P_{applied} = -135 - 2(V_{b,x}+10) - 2(V_{b,y}+10)$$

$$P_{average} = -145 - 2.5(V_{b,x}+10) - 2.5(V_{b,y}+10)$$

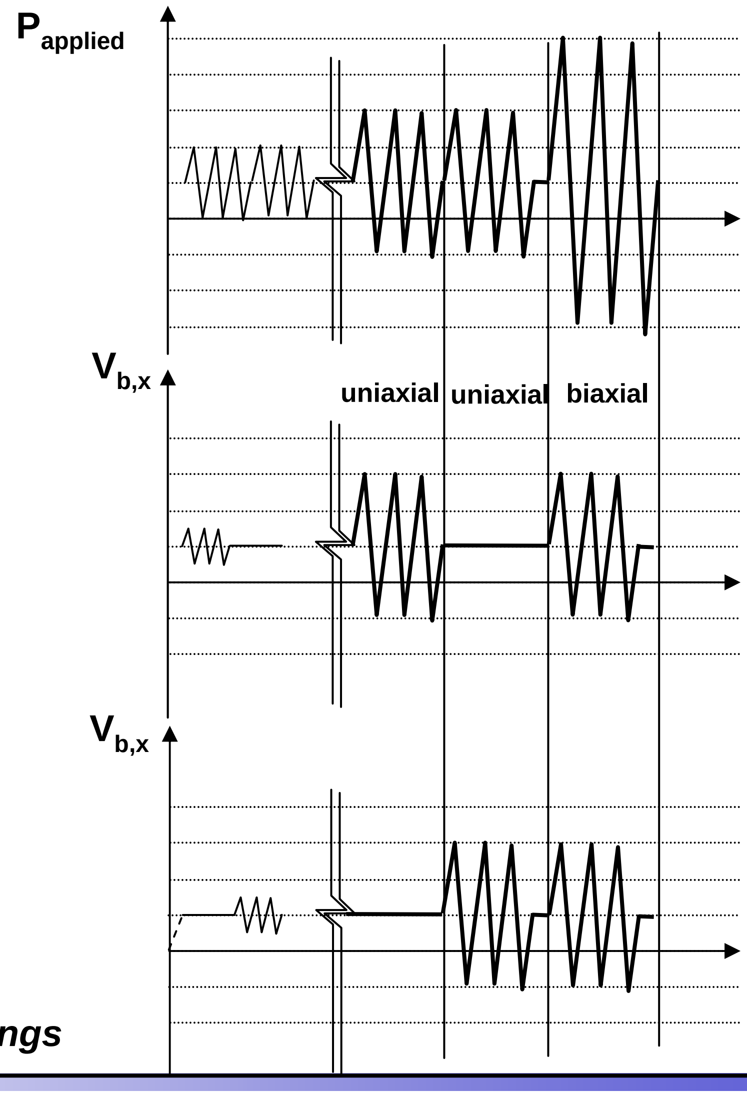
SP2&4

$$P_{applied} = -175 - 4(V_{b,x}+10) - 4(V_{b,y}+10)$$

$$P_{average} = -185 - 4.5(V_{b,x}+10) - 4.5(V_{b,y}+10)$$

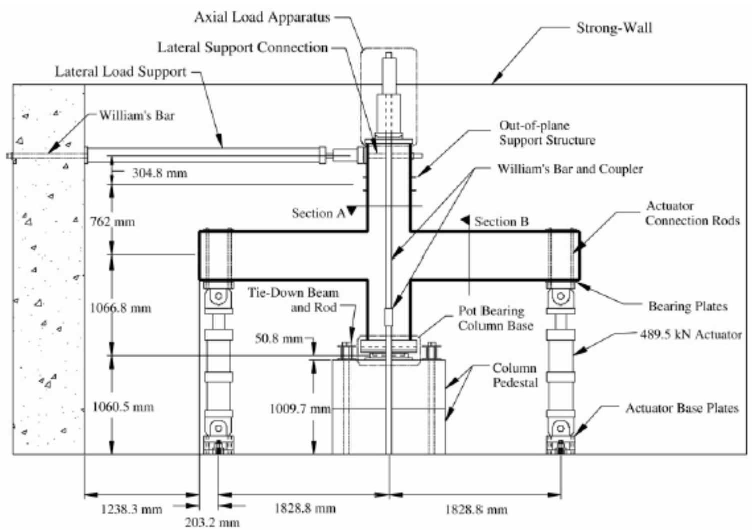


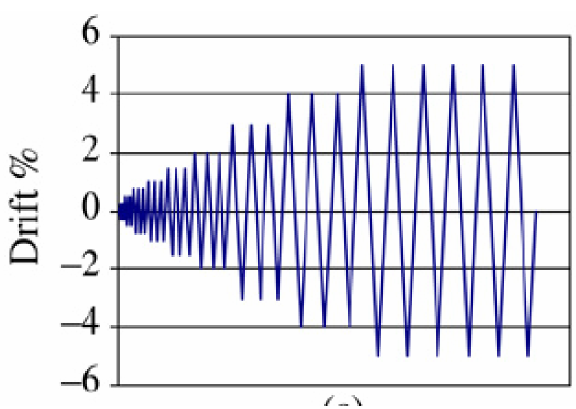
Schematic drawings



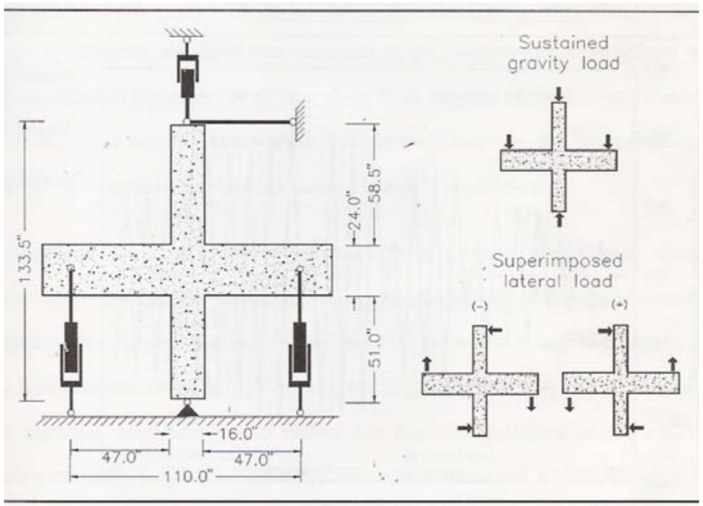
Examples of Uni-axial Loading Sequence

Walker

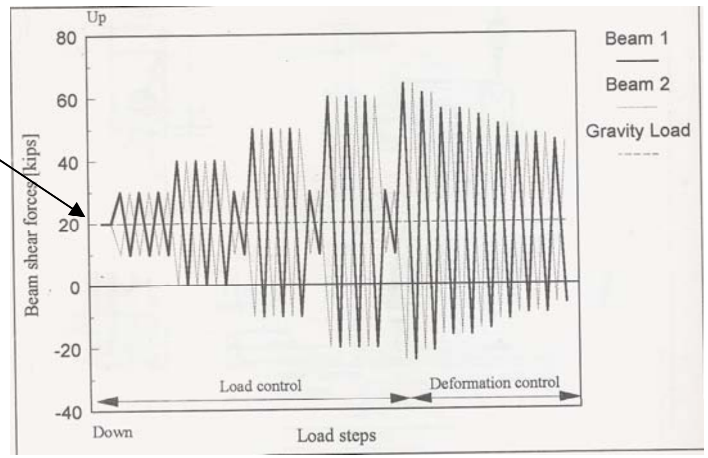




Beres et al



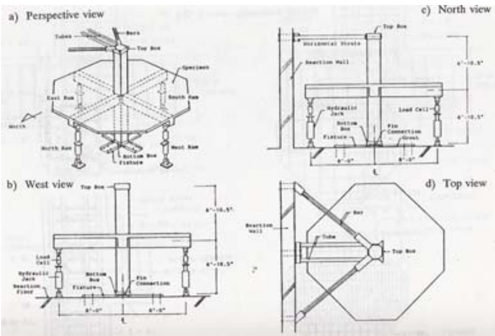
Due to gravity load

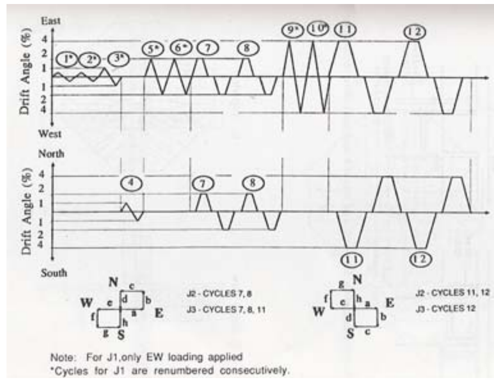


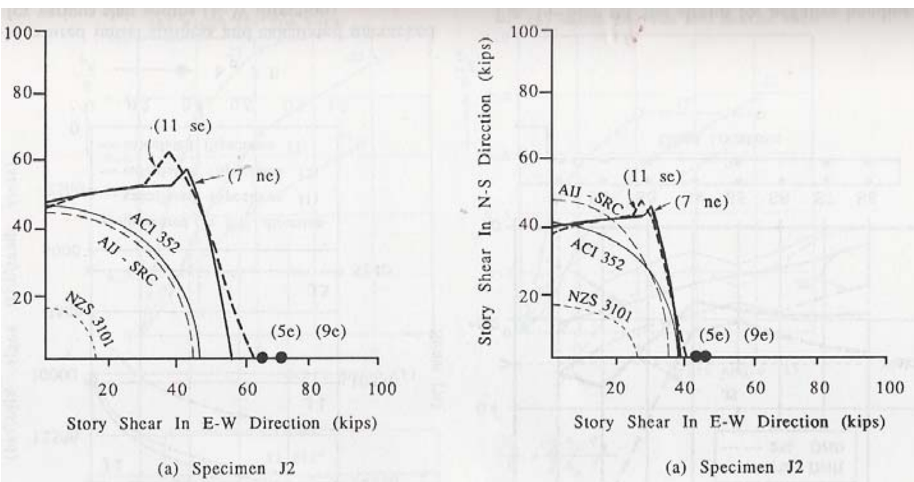
Examples of Bi-axial Loading Sequence

Case 1) Control column shear

Kurose et al





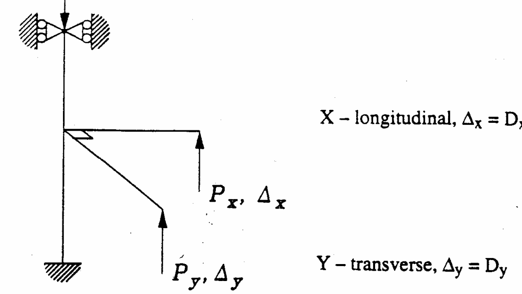


( ) cycle no. and direction, Fig.4

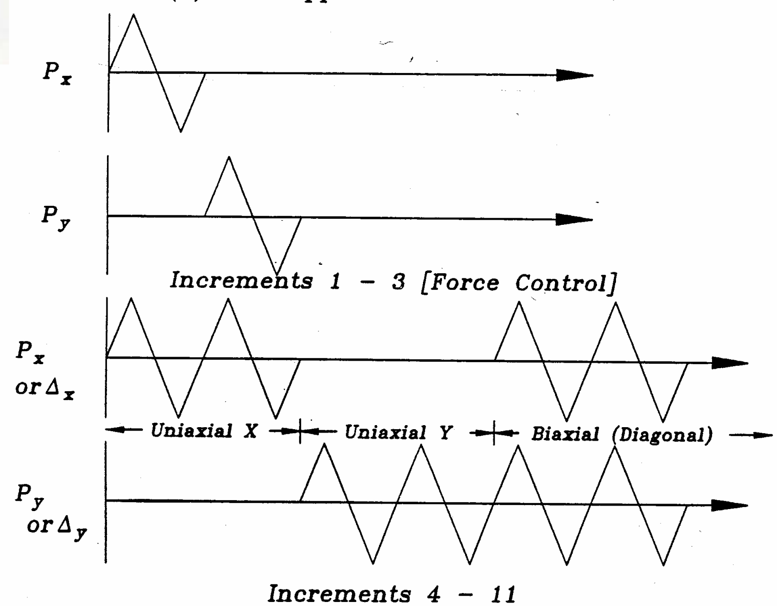
Case 2) Control beam shear

Priestley

$$P_V = P_o + k_1 P_x + k_2 P_y \quad (Eqn.\ 1)$$



(a) Load Application to Test Units

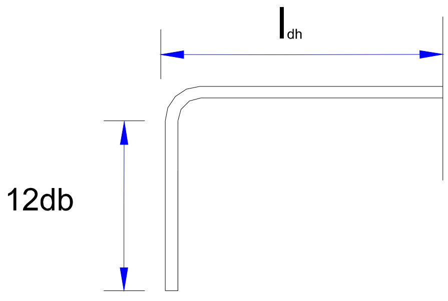


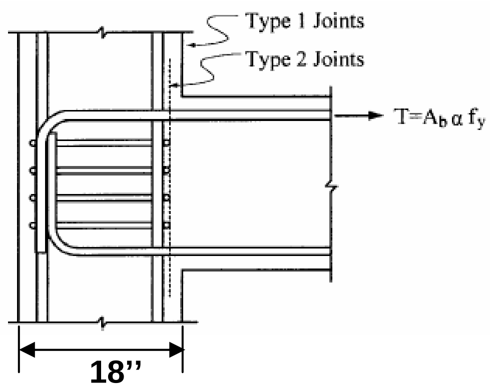
(b) Increment Pattern of Applied Force or Deformation

Note : Joints get damage by uniaxial loading befor biaxial loading

Some Details to be discussed

1. Hook Detail





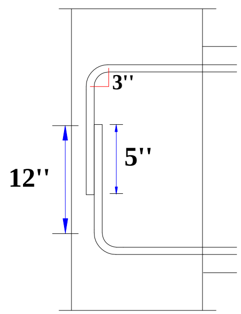
For #8 bar,

$$\text{type 1 } l_{dh} = \frac{f_y d_b (\text{psi})}{50\sqrt{f'_c}(\text{psi})} = 20''$$

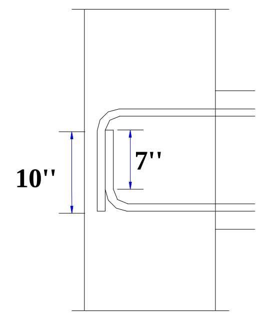
$$\text{type 2 } l_{dh} = \frac{\alpha f_y d_b (\text{psi})}{75\sqrt{f'_c}(\text{psi})} = 17''$$

$12d_b = 12''$

Specimen 1&3



Specimen 2 &

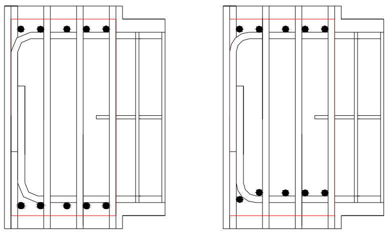


Some Details to be discussed

2. Crossed Beam Reinforcement Layers

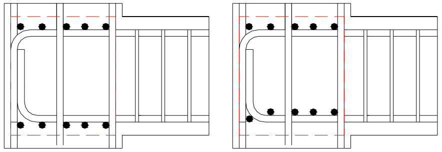
Specimen 1&3

option 1 option 2



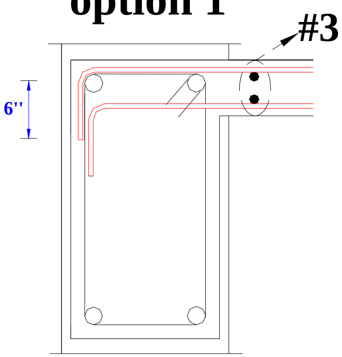
Specimen 2 & 4

option 1 option 2

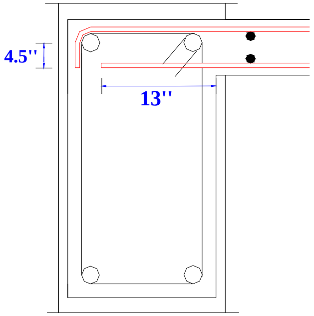


3. Slab Reinforcement Detail

option 1



option 2



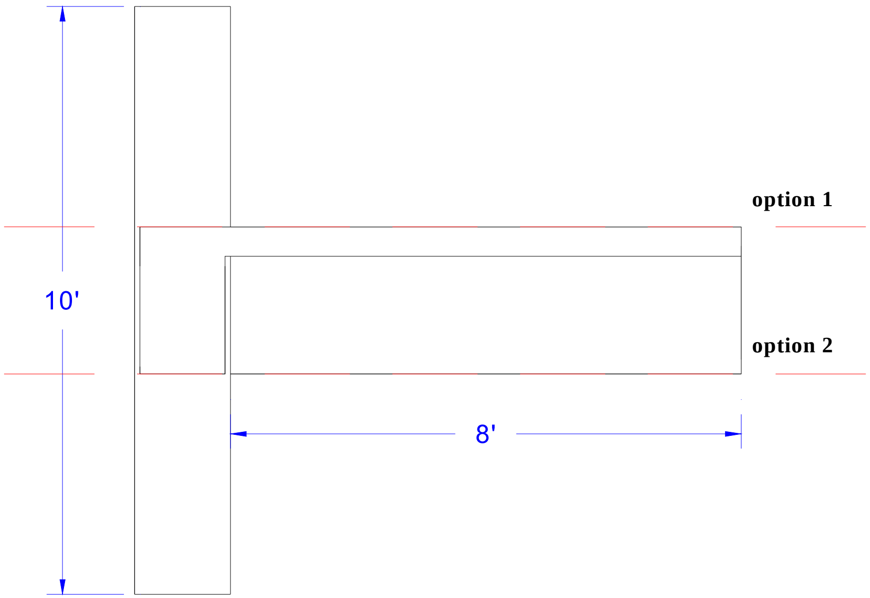
Advisor : Professor Mosalam
Student Researcher : SANGJOON PARK

Some Details to be discussed

4. Location of Construction Joints

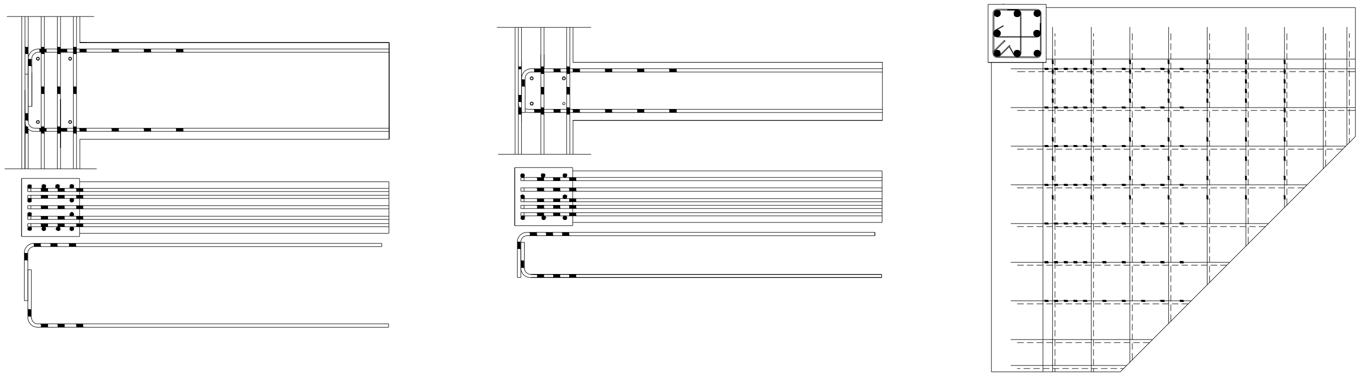
	Volume(ft^3)	Weight(kips)
SP 1&3	72.17	11.0
SP 2&4	61.5	9.5
Truck	270	

Construction Joint Location

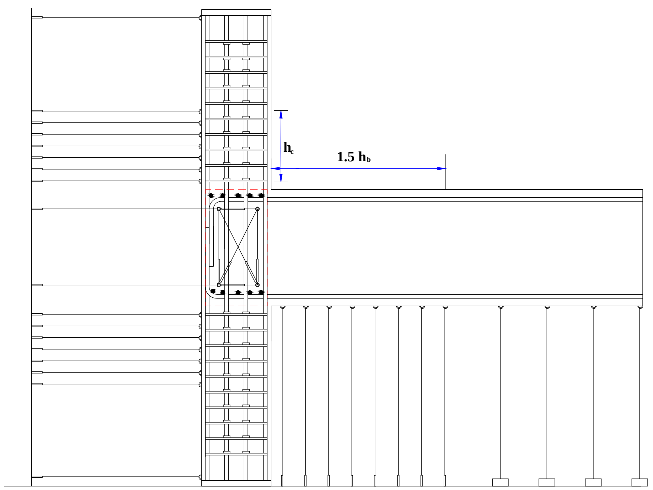


Instrumentation

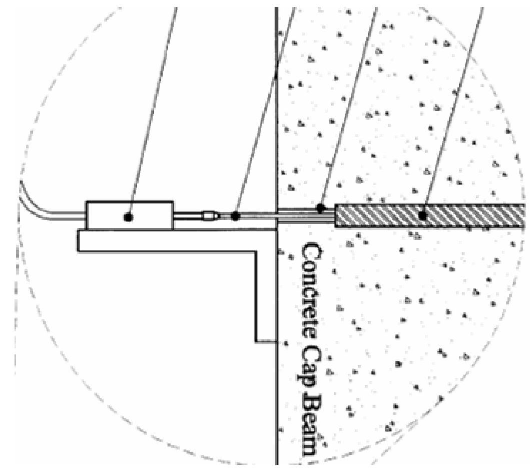
Strain gage location



Displacement Measurement

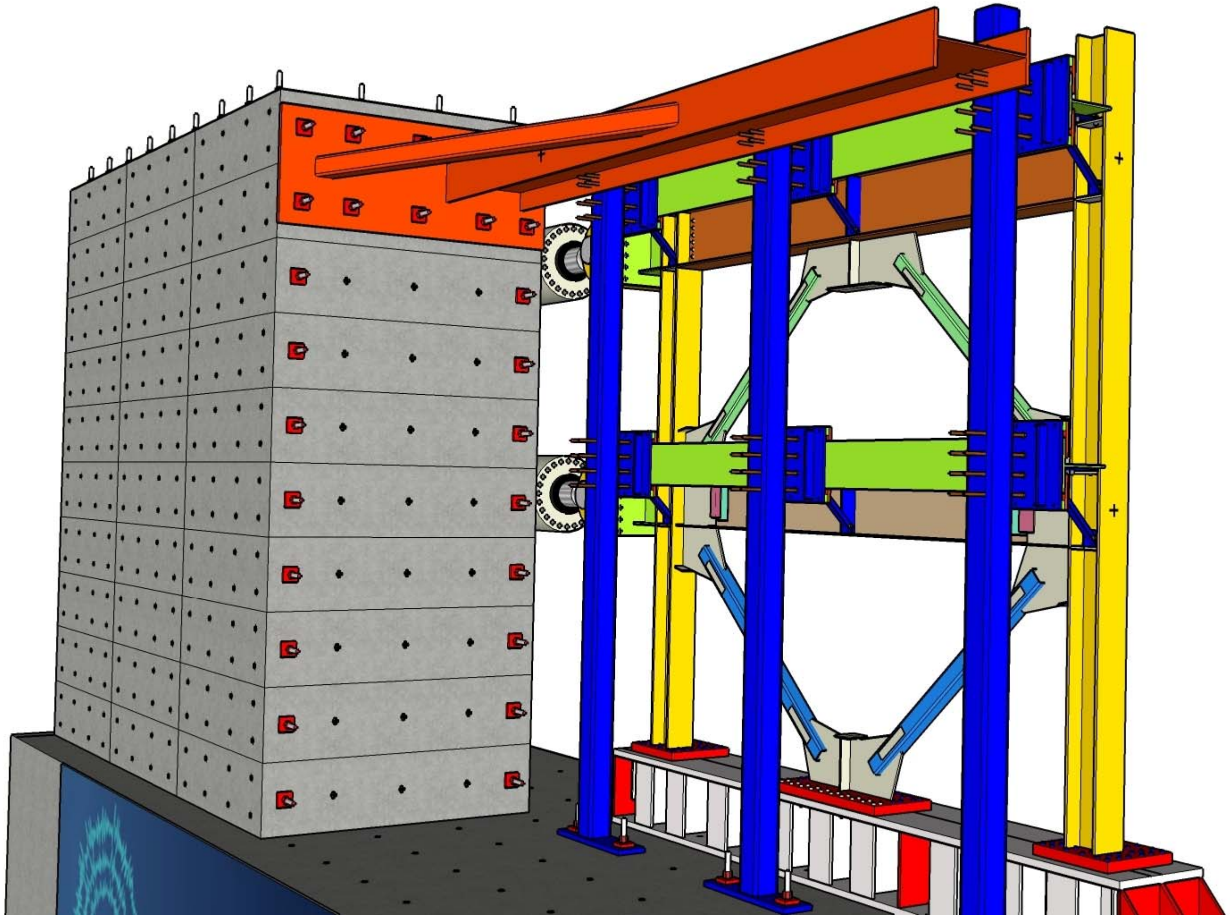


Slip measurement of slab reinforcement



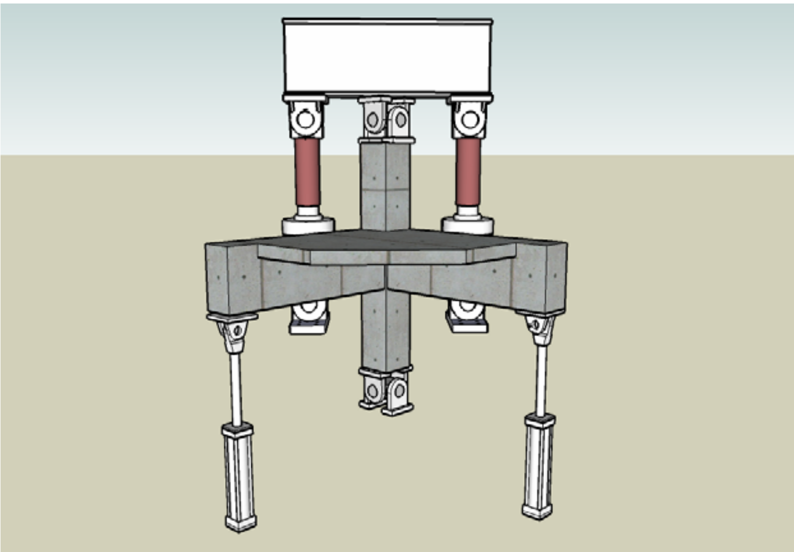
Test Setup

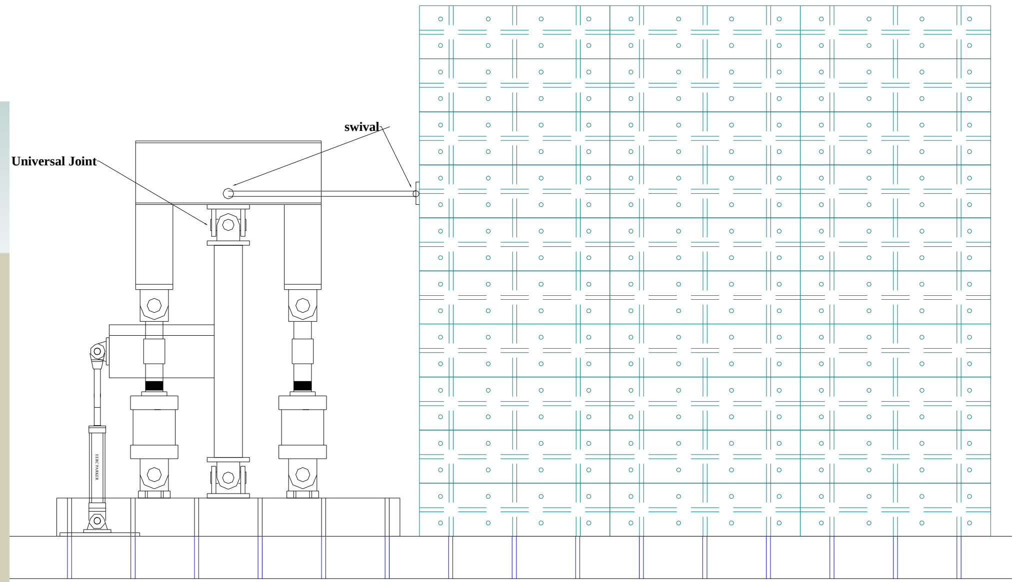
1. Lab Condition

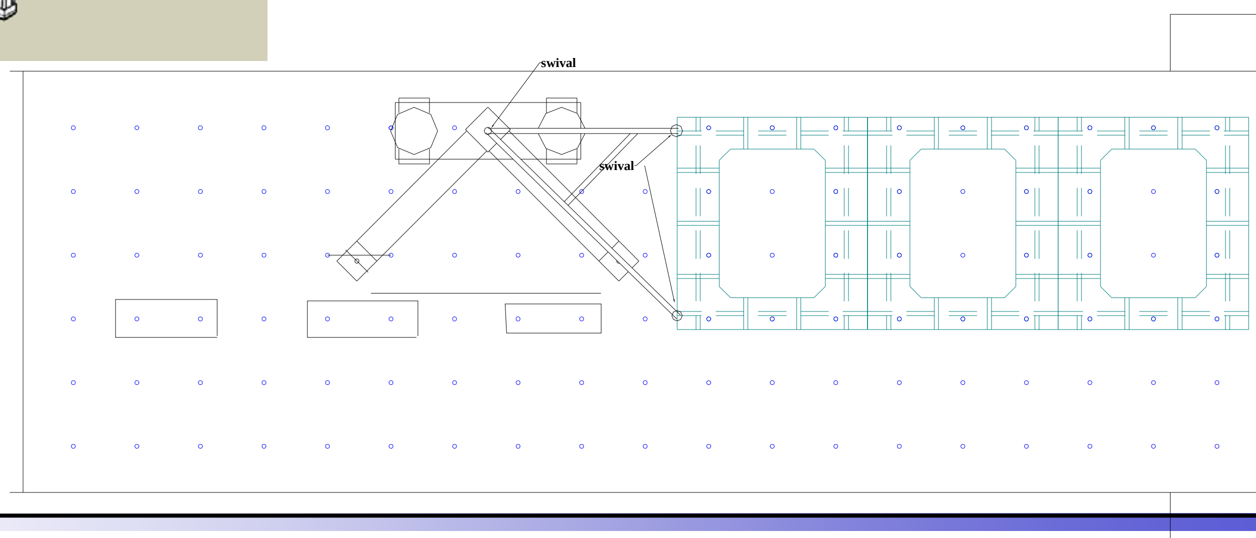


Test Setup

2. Setup







Test Setup

3. Setup