

Structural Design Report for Beam-Column Joint Template

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1. Design Conditions

1) General Characteristics

(1) Project Name : Beam-Column Joint Template

(2) Design Code : ACI 318M-14

(3) Unit : Kips.in

(4) Strength Reduction Factors

Strut : 0.75

Tie : 0.75

Node : 0.75

(5) Scope of Report

The purpose of this report is to design structural concrete member using strut-tie model. The design is performed according to the ACI 318M-14 strut-tie model provisions.

This report provides results of calculation for:

- check capacity of bearing plates
- design tie reinforcement
- check capacity of struts
- check capacity of nodal zones

2) Materials

(1) Concrete

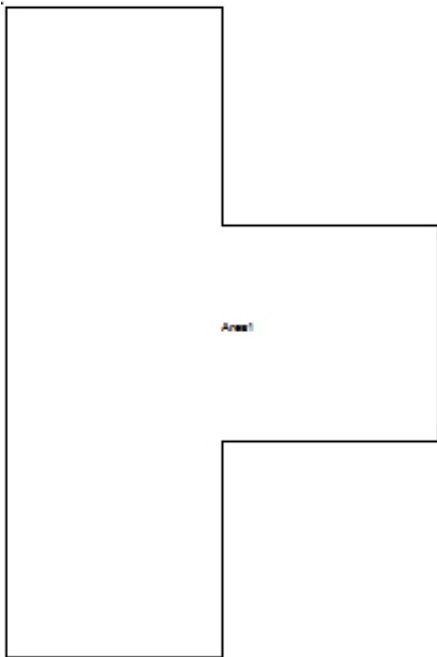
- Mass : 147 lb/ft³
- Weight : 149.6 lb/ft³
- Poisson's ratio : 0.15
- Compressive Strength of Concrete, f_{ck} : 3480.9 lb/in²
- Tensile Strength of Concrete, f_{ct} : 348.1 lb/in²
- Elastic modulus of concrete, E_c : 4,039,177 lb/in²

(2) Steel

- Mass : 490 lb/ft³
- Weight : 499.7 lb/ft³
- Poisson's ratio : 0.15
- Yield strength of steel, f_y : 58015.4 lb/in²
- Elastic modulus of steel, E_s : 29,007,699 lb/in²

1. Design Conditions

3) Geometrical Shape



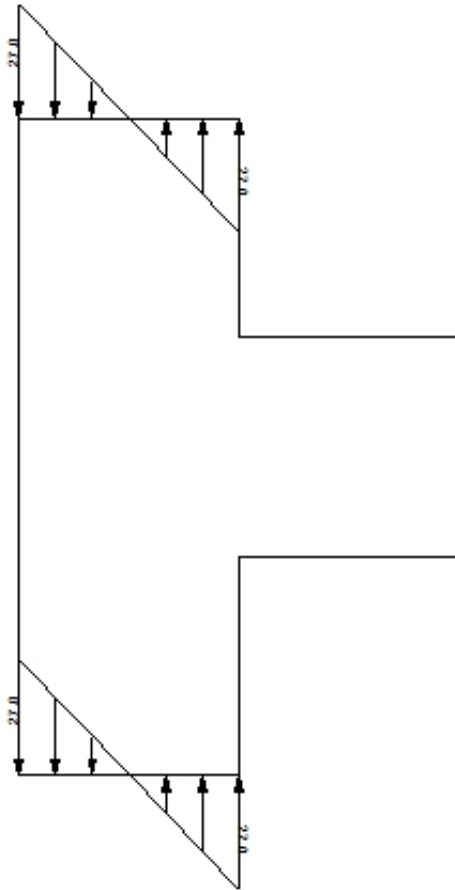
- Thickness : 39.37 in

1. Design Conditions

4) Loads and Load Combinations

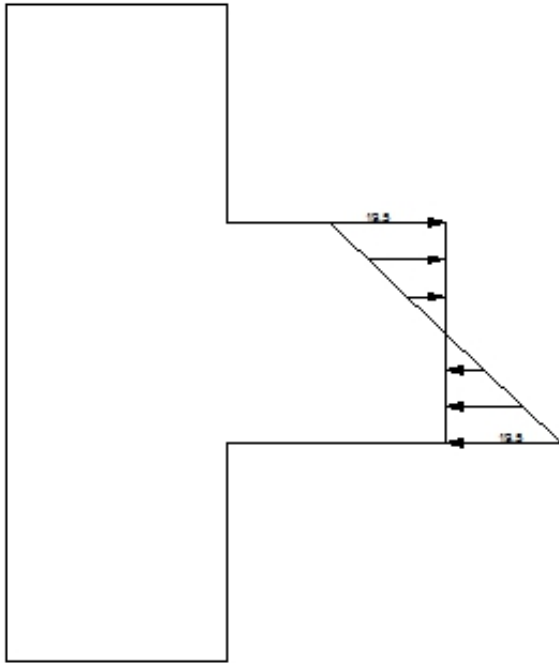
(1) Loads

M1 (Moment)

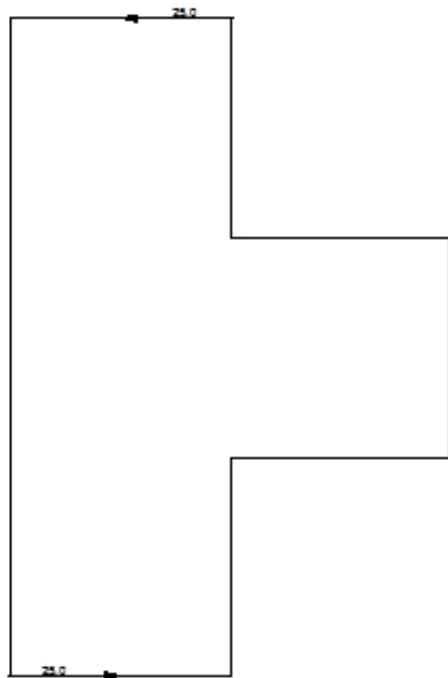


1. Design Conditions

M2 (Moment)

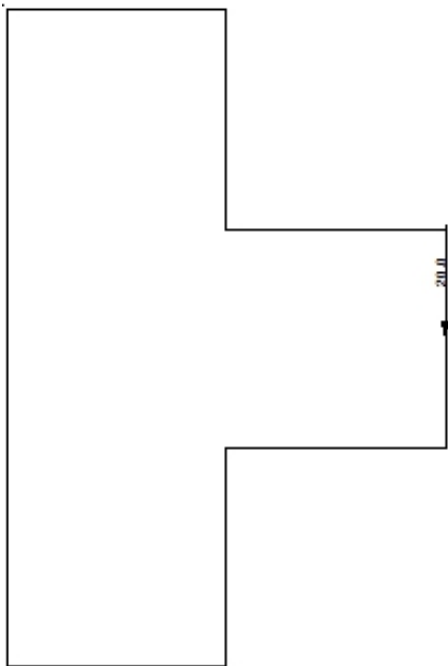


V1 ()



1. Design Conditions

V2 ()



(2) Load Combinations

$$1) LC01 : 1.00M1 + 1.00M2 + 1.00V1 + 1.00V2$$

5) Reference

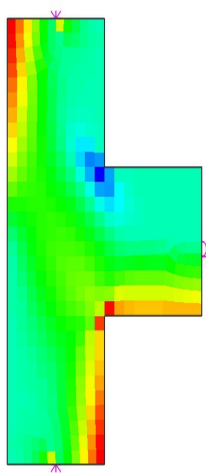
- | | |
|--------------|--|
| (1) Designer | : Hangil IT |
| (2) Date | : 2017-07-15 |
| (3) Note | : Design of Exterior Beam-Column Joint usnig Template (ACI 318-14) |

2. Strut-Tie Model Design (Load Combination-1)

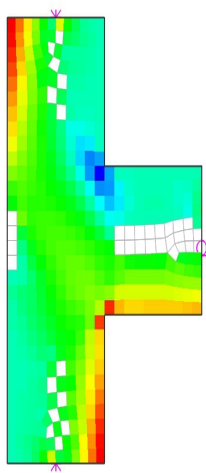
1) Construction of Strut-Tie Model

(1) ESO (Evolutionary Structural Optimization)

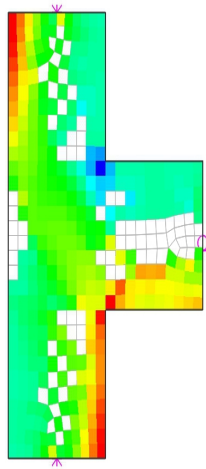
1. STAGE-01 (Initial shape)



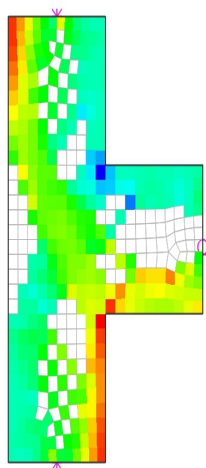
2. STAGE-02 (Elimination ratio = 9%)



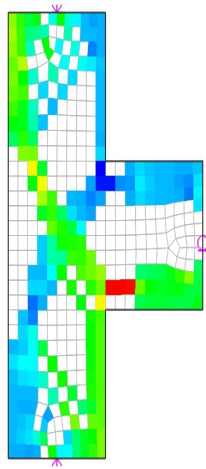
3. STAGE-03 (Elimination ratio = 17%)



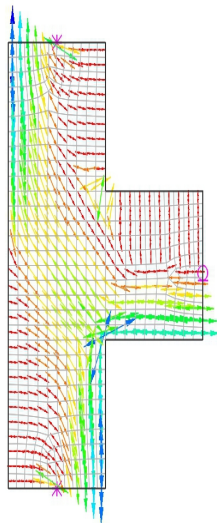
4. STAGE-04 (Elimination ratio = 24%)



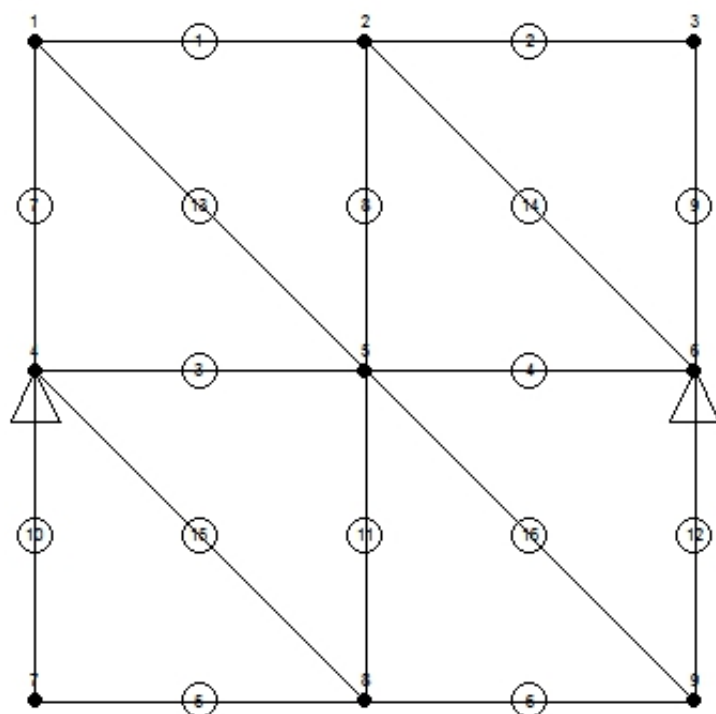
5. STAGE-07 (Elimination ratio = 43%)



(2) Compressive Principal Stress Flow



(3) Constructed Strut-Tie Model



(A) Nodal Coordinates

Node No.	X coordi.	Z coordi.	Node No.	X coordi.	Z coordi.
1	2.000	38.000	2	10.000	38.000
3	18.000	38.000	4	2.000	30.000
5	10.000	30.000	6	18.000	30.000
7	2.000	22.000	8	10.000	22.000
9	18.000	22.000			

(B) Element Connectivity

Element No.	Start Node	End Node	Element No.	Start Node	End Node
1	1	2	2	2	3
3	4	5	4	5	6
5	7	8	6	8	9
7	1	4	8	2	5
9	3	6	10	4	7
11	5	8	12	6	9
13	1	5	14	2	6
15	4	8	16	5	9

2. Strut-Tie Model Design (Load Combination-1)

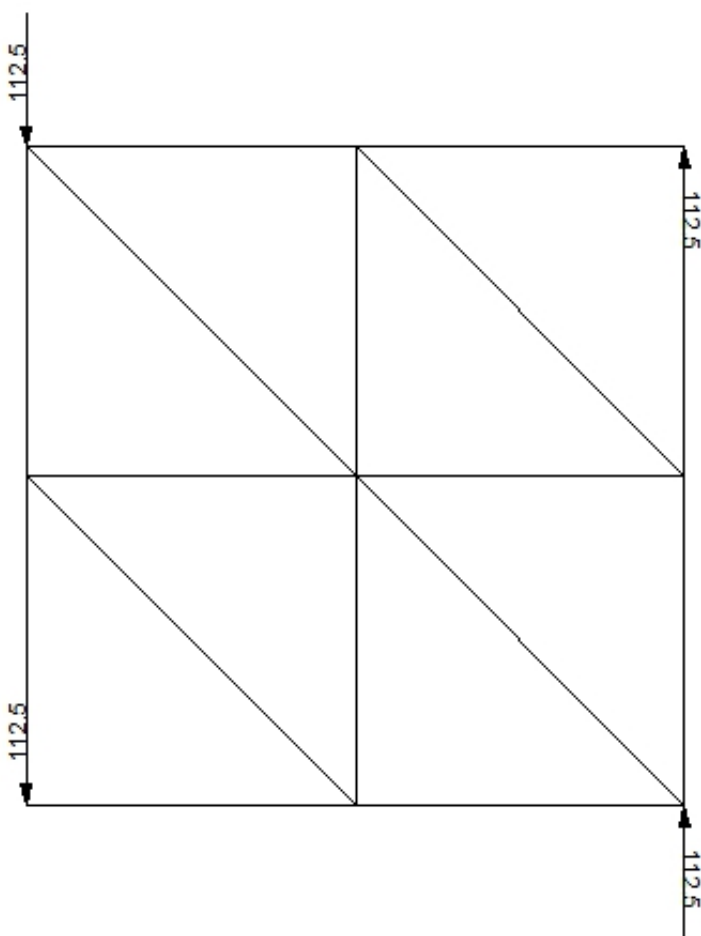
(C) Restraints

Node	Ux	Uy	Uz	Rx	Ry	Rz
4	0	0	0	0	-	0
6	-	0	0	0	-	0

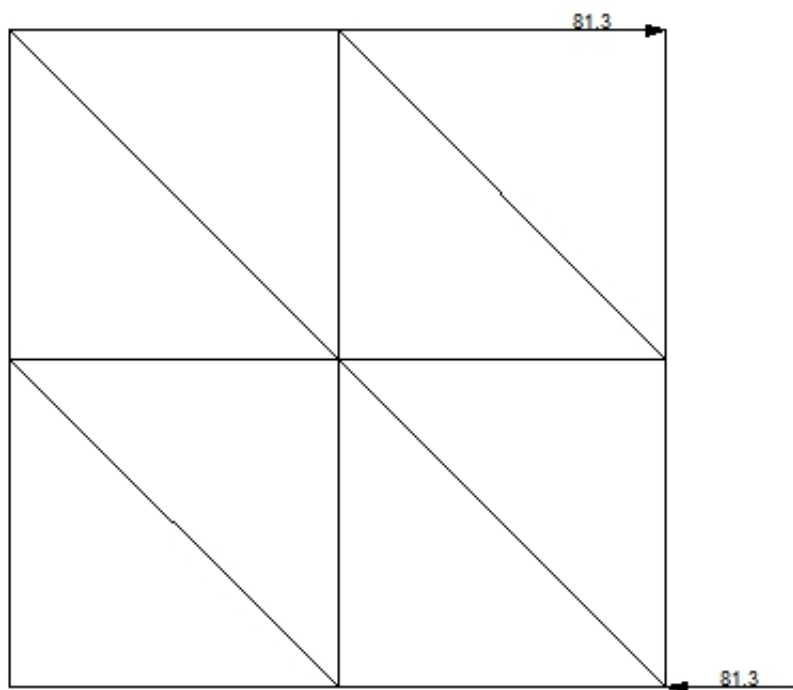
2) Analysis of Strut-Tie Model

(1) Loading Conditions

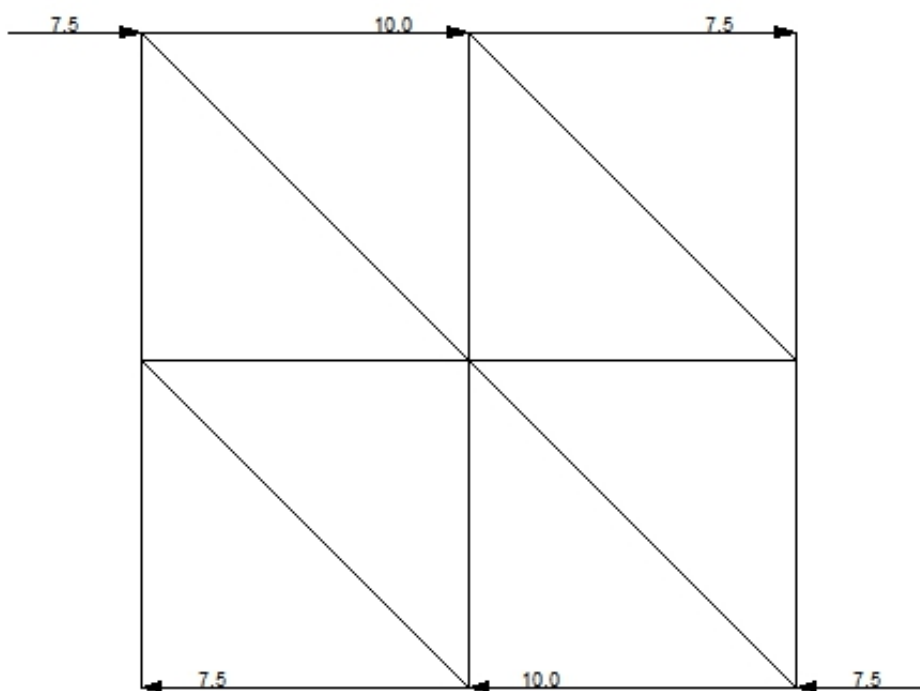
(1) Moment Load (M1)



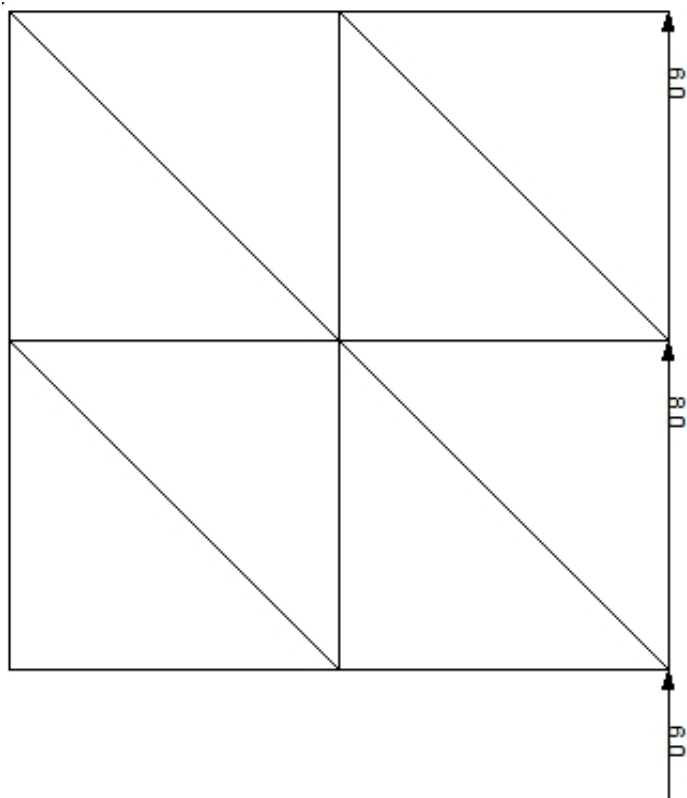
(2) Moment Load (M2)



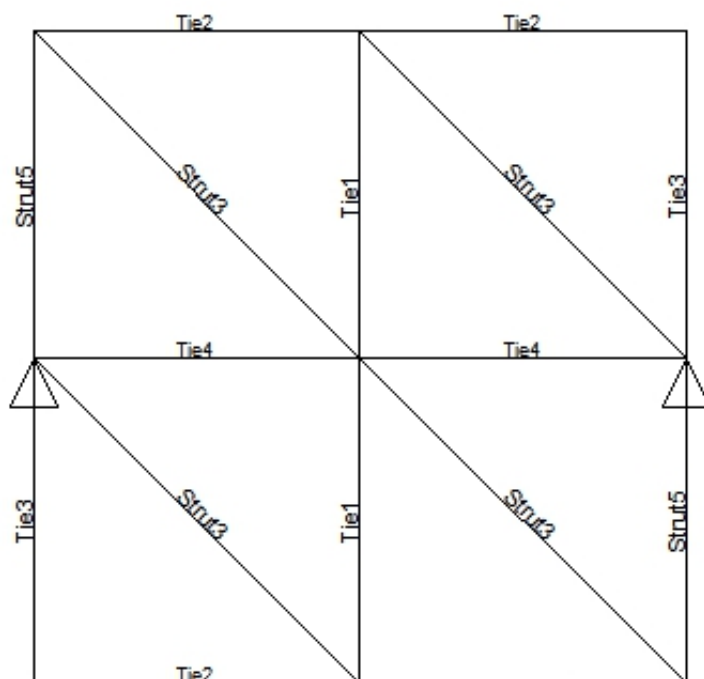
(3) Shear Load (V1)



(4) Shear Load (V2)

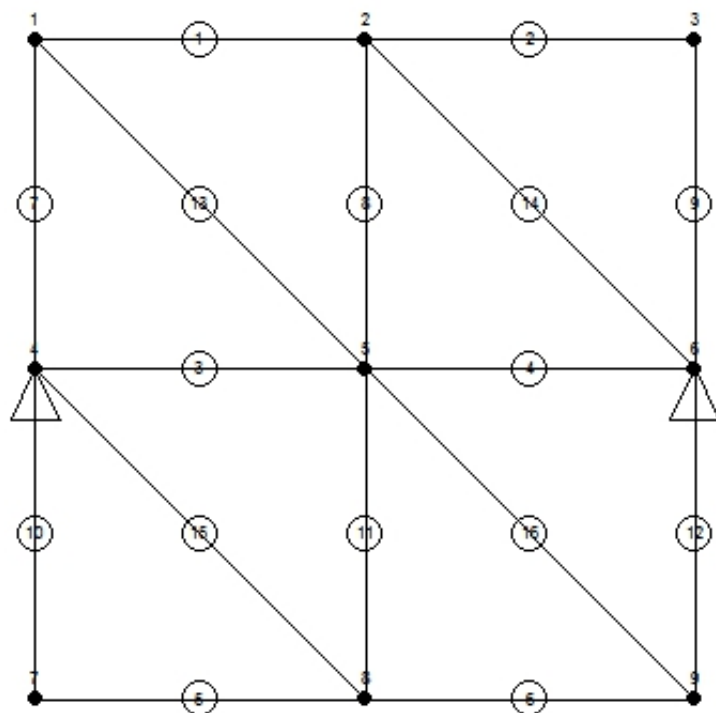


(2) Strut and Tie Types



- Strut3 : Bottle Shape Strut (Not Satisfying ACI 318M-14 23.5.3)
- Strut5 : All Other Cases
- Tie1 : Tie for column rebars
- Tie2 : Tie for top rebars
- Tie3 : Tie for intermediate vertical rebars
- Tie4 : Tie for intermediate horizontal rebars

(3) Strut and Tie Forces



Elem. No.	Force (kip)	Elem. No.	Force (kip)	Elem. No.	Force (kip)	Elem. No.	Force (kip)
1	81.3	2	88.8	3	17.5	4	17.5
5	7.5	6	0.0	7	-23.7	8	17.5
9	118.5	10	112.5	11	17.5	12	-29.7
13	-125.5	14	-24.7	15	-24.7	16	-125.5

3) Strength Verification and Required Rebars

(1) Required Area of Rebars

1) Main Rebars

(A) Horizontal Rebars

$$A_{s,req} = F_u / \phi \cdot f_y \cdot \cos \theta < A_{s,used}$$

where,

F_u = member force of steel tie

ϕ = strength reduction factor of steel tie : 0.75

f_y = yield strength of steel : 58015.4 lb/in²

θ = angle of steel tie measured from positive horizontal axis

(+: counterclockwise)

Tie No.	Types	Fu (kip)	theta (deg.)	Rebars	As.req (in ²)	As.used (in ²)	Note
1	Top	18.27	0.0	6-#8	2	5	O.K
2	Top	19.95	0.0	6-#8	2	5	O.K
5	Top	1.69	0.0	6-#8	0	5	O.K

(B) Vertical Rebars

$$A_{s,req} = F_u / \phi \cdot f_y \cdot \sin \theta < A_{s,used}$$

where,

F_u = member force of steel tie

ϕ = strength reduction factor of steel tie : 0.75

f_y = yield strength of steel : 58015.4 lb/in²

θ = angle of steel tie measured from positive horizontal axis

(+: counterclockwise)

Tie No.	Types	Fu (kip)	theta (deg.)	Rebars	As.req (in ²)	As.used (in ²)	Note
8	Column	3.93	90.0	8-#8	0	6	O.K

2) Transverse Rebars

(A) Horizontal Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	W _{eff,tie} (in)	Sh (in)	phi Fn (kip)	Note
3	3.93	0.0	4-#5	0.3	0.2	19.2	O.K

$$\phi \cdot F_n = \phi \cdot A_{vh} \cdot f_y \cdot W_{eff,tie} \cdot \cos \theta / S_h > F_u$$

where,

F_u = member force of steel tie

ϕ = strength reduction factor of steel tie : 0.75

f_y = yield strength of steel : 58015.4 lb/in²

θ = angle of steel tie measured from positive horizontal axis

2. Strut-Tie Model Design (Load Combination-1)



(+: counterclockwise)

Sh = spacing of horizontal rebars

Weff,tie = effective width of tie

(C) Vertical Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sv (in)	phi Fn (kip)	Note
9	26.64	90.0	4-#10	0.3	0.2	79.3	0.K
10	25.29	90.0	4-#10	0.2	0.2	39.7	0.K

$$\phi \cdot F_n = \phi \cdot A_v \cdot f_y \cdot W_{eff,tie} \cdot \sin \theta / S_v > F_u$$

where,

Fu = member force of steel tie

phi = strength reduction factor of steel tie : 0.75

fy = yield strength of steel : 58015.4 lb/in²

theta = angle of steel tie measured from positive horizontal axis

(+: counterclockwise)

Sv = spacing of vertical rebars

Weff,tie = effective width of tie

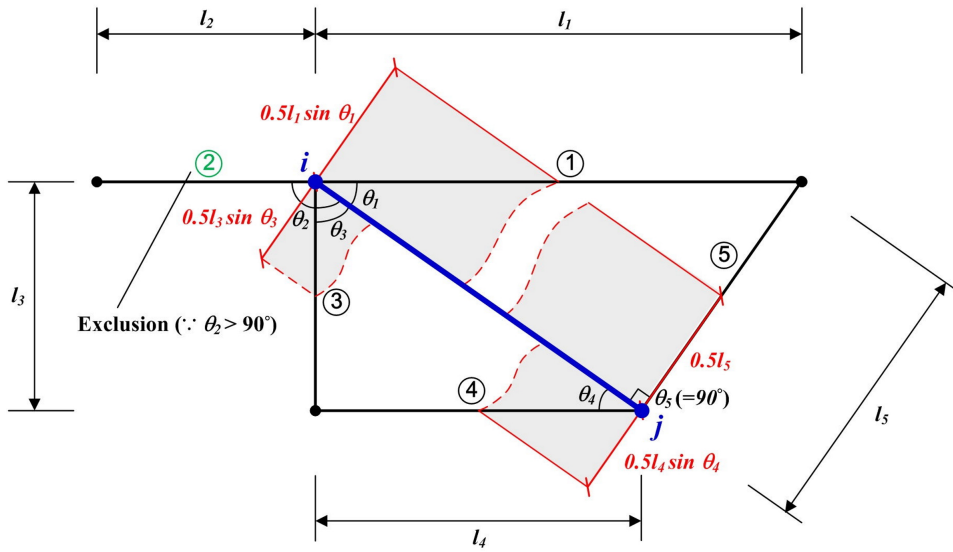
(2) Available Widths of Struts and Nodal Zones

1) Node without bearing plate

The available widths of a strut at both ends and nodal zone faces are determined by taking the minimum ones from the values calculated below for case 1 and case 2.

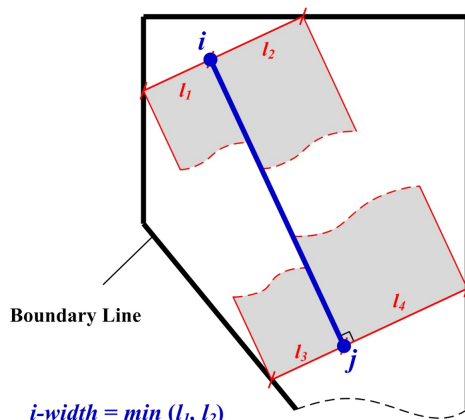
2) Node with bearing plate

The available widths of a strut at both ends and nodal zone faces are determined by taking the values calculated below for case 3.

[CASE 1]

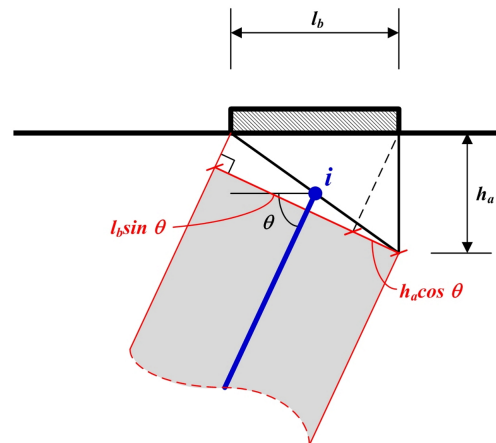
$$i\text{-width} = \min (l_1 \sin \theta_1, l_3 \sin \theta_3)$$

$$j\text{-width} = \min (l_4 \sin \theta_4, l_5)$$

[CASE 2]

$$i\text{-width} = \min (l_1, l_2)$$

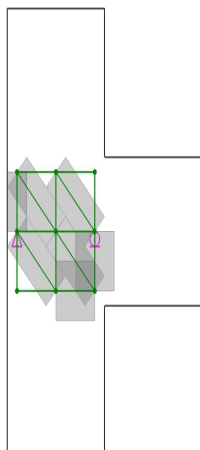
$$j\text{-width} = \min (l_3, l_4)$$

[CASE 3]

$$i\text{-width} = l_b \sin \theta + h_a \cos \theta$$

2. Strut-Tie Model Design (Load Combination-1)

The available widths of struts and ties determined by the methods introduced above are shown below



Elem. No.	i-width	j-width	Available Width	Elem. No.	i-width	j-width	Available Width
7	4.0	4.0	4.0	12	8.0	8.0	8.0
13	5.6	5.6	5.6	14	5.6	5.6	5.6
15	5.6	5.6	5.6	16	5.6	5.6	5.6

(3) Strength of Struts

$W_{req} = F_u / \phi \cdot 0.85 \cdot \beta_a \cdot f_{ck} \cdot b < W_{prov}$ (See ACI 318M-14 Section 23.4)

$\beta_a = 1.00$ (prismatic strut - uniform cross-sectional area along length)

0.75 (bottle-shaped strut satisfying ACI 318M-14 Section 23.5.3)

0.60 (bottle-shaped strut unsatisfying ACI 318M-14 Section 23.5.3)

0.40 (strut in tension zones)

0.60 (all other cases)

ϕ = strength reduction factor of concrete strut = 0.75

Strut No.	beta	theta	Fu (kip)	b (in)	Wreq (in)	Wprov (in)	Note
7	0.60	90.0	23.7	39.4	0.5	4.0	0.K
12	0.60	90.0	29.7	39.4	0.6	8.0	0.K
13	0.60	45.0	125.5	39.4	2.4	5.7	0.K
14	0.60	45.0	24.7	39.4	0.5	5.7	0.K
15	0.60	45.0	24.7	39.4	0.5	5.7	0.K
16	0.60	45.0	125.5	39.4	2.4	5.7	0.K

(4) Strength of Nodal Zones

2. Strut-Tie Model Design (Load Combination-1)



The verification of the nodal zone strength should be done through comparing the available nodal zone area with that required. In this report, if the thickness of the structural concrete is consistent, the verification will be done by comparing the

available nodal zone width, W_{prov} , with that required, W_{req}

$$W_{req} = F_u / \phi \cdot 0.85 \cdot \beta \cdot f_{ck} \cdot b < W_{prov} \text{ (See ACI 318M-14 Section 23.9)}$$

$\beta = 1.00$ (for the nodal zone bounded by struts, bearing areas, or both)

0.80 (for the nodal zone anchoring one tie)

0.60 (for the nodal zone anchoring two or more ties)

Node No.	beta	Type	Element	Fu (kip)	Wreq (in)	Wprov (in)	Note
1	0.80	CCT	T-1	81.3	1.2	8.0	O.K
			C-7	23.7	0.3	4.0	O.K
			C-13	125.5	1.8	5.7	O.K
2	0.60	CTT	T-1	-	-	-	-
			T-2	7.5	0.1	8.0	O.K
			T-8	17.5	0.3	8.0	O.K
			C-14	24.7	0.5	5.7	O.K
3	0.60	TTT	T-2	88.8	1.7	8.0	O.K
			T-9	118.5	2.3	8.0	O.K
4	0.60	CTT	T-3	17.5	0.3	8.0	O.K
			C-7	23.7	0.5	4.0	O.K
			T-10	112.5	2.1	4.0	O.K
			C-15	24.7	0.5	5.7	O.K
5	0.60	CTT	T-3	-	-	-	-
			T-4	-	-	-	-
			T-8	-	-	-	-
			T-11	-	-	-	-
			C-13	125.5	2.4	5.7	O.K
			C-16	125.5	2.4	5.7	O.K
6	0.60	CTT	T-4	17.5	0.3	8.0	O.K
			T-9	118.5	2.3	8.0	O.K
			C-12	29.7	0.6	8.0	O.K
			C-14	24.7	0.5	5.7	O.K
7	0.60	TTT	T-5	7.5	0.1	8.0	O.K
			T-10	112.5	2.1	4.0	O.K
8	0.60	CTT	T-5	7.5	0.1	8.0	O.K
			T-11	17.5	0.3	8.0	O.K

2. Strut-Tie Model Design (Load Combination-1)



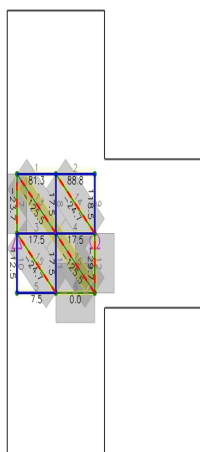
8					0.5	5.7	
9					0.3	8.0	
					1.4	5.7	

C: compression; T: tension; V: vertical force; H: horizontal force

3. Summary

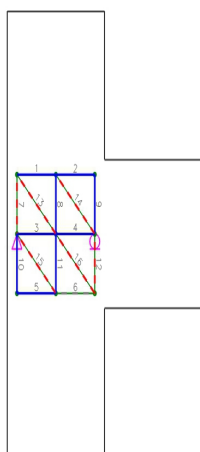
1) Dimensioned Shape

1) Load Combination - 1



2) Required and Used Areas of Rebars

1) Load Combination - 1



(A) Main Rebars

Tie No.	Types	Fu (kip)	theta (deg.)	Rebars	As.req (in ²)	As.used (in ²)	Note
1	Top	18.27	0.0	6-#8	2	5	0.K

3. Summary



				6-	2	5	0.K
				6-	0	5	0.K

Tie No.	Types	Fu (kip)	theta (deg.)	Rebars	As.req (in ²)	As.used (in ²)	Note
8	Column	3.93	90.0	8-#8	0	6	0.K

(B) Transverse Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sh (in)	phi Fn (kip)	Note
3	3.93	0.0	4-#5	0.3	0.2	19.2	0.K

- Vertical Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sv (in)	phi Fn (kip)	Note
9	26.64	90.0	4-#10	0.3	0.2	79.3	0.K
10	25.29	90.0	4-#10	0.2	0.2	39.7	0.K