Structural Design Report for PSC Box Template

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1. Design Conditions

1) General Characteristics

(1) Project Name : PSC Box Template
(2) Design Code : EuroCode 2
(3) Unit : Kips.in
(4) Partial Safety Factors for Materials
Concrete : 1.50
Reinforcing and prestressing steel: 1.15
(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 EuroCode 2 strut-tie model provisions.

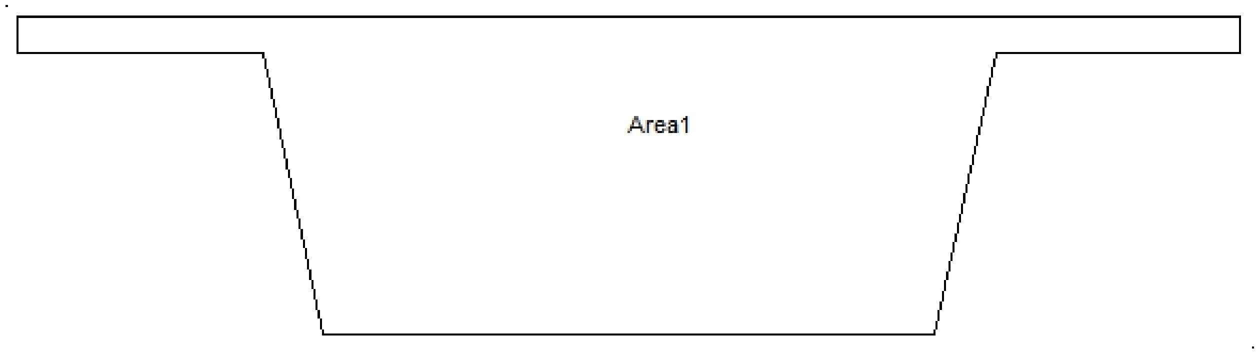
This report provides results of calculation for:
- check capacity of bearing plates
- design tie reinforcement
- check capacity of struts
- check capacity of nodal zones

2) Materials

(1) Concrete
- Mass : 147 lb/ft³
- Weight : 149.6 lb/ft³
- Poisson's ratio : 0.15
- Compressive Strength of Concrete, fck : 3480.9 lb/in²
- Tensile Strength of Concrete, fct : 348.1 lb/in²
- Elastic modulus of concrete, Ec : 4,039,177 lb/in²

(2) Steel1
- Mass : 490 lb/ft³
- Weight : 499.7 lb/ft³
- Poisson's ratio : 0.15
- Yield strength of steel, fy : 58015.4 lb/in²
- Elastic modulus of steel, Es : 29,007,699 lb/in²

3) Geometrical Shape

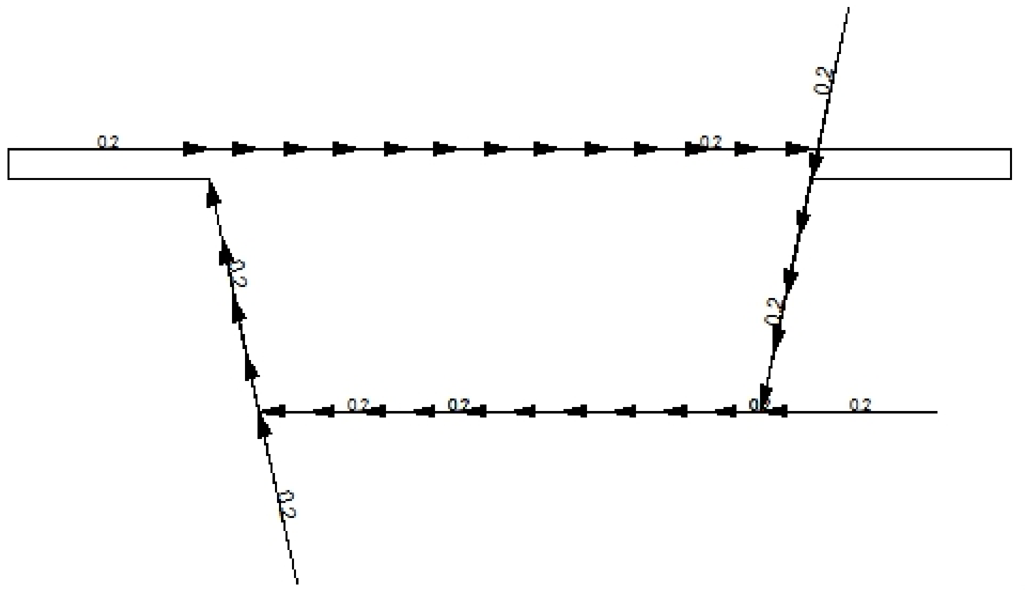


- Thickness : 12.00 in

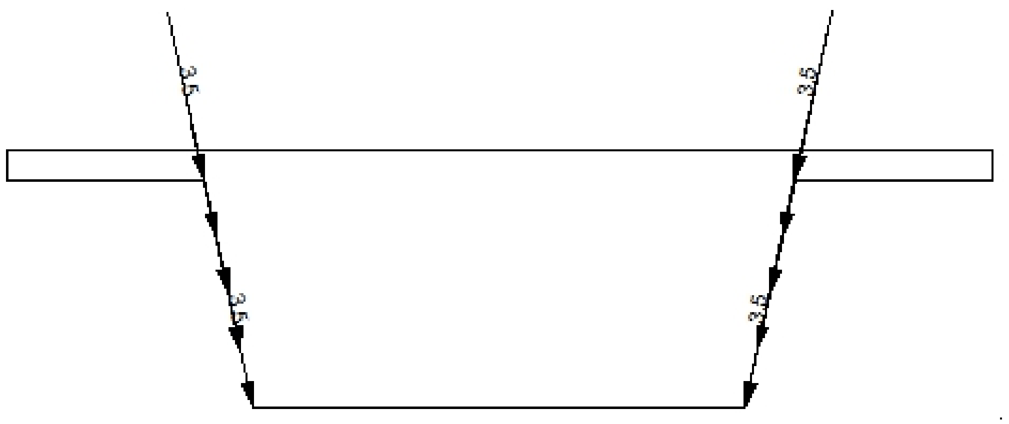
4) Loads and Load Combinations

(1) Loads

T (Moment)



V (Moment)



(2) Load Combinations

1) LC01 : 1.00T + 1.00V

5) Reference

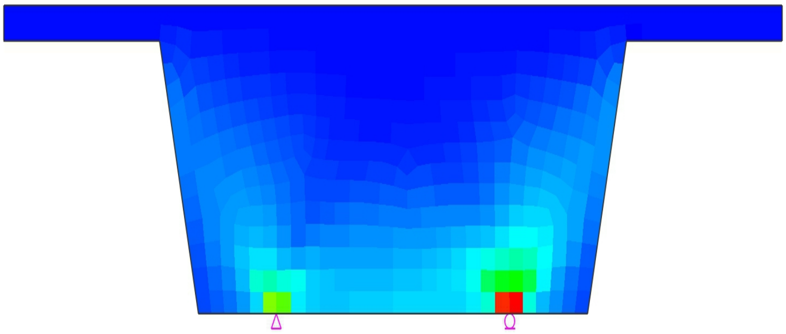
(1) Designer : Hangil IT
(2) Date : 2017-07-15
(3) Note : Design of Solid Type's PSC Box Uisng Template (Eurocode 2)

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

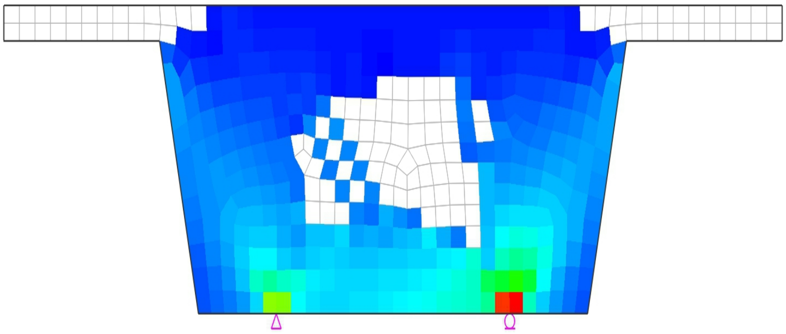
1) Construction of Strut-Tie Model

(1) ESO (Evolutionary Structural Optimization)

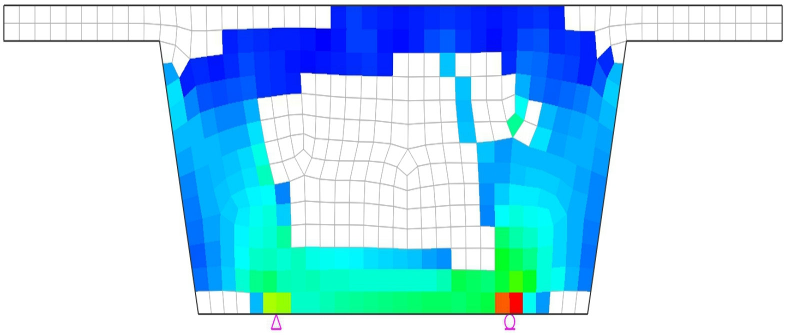
1. STAGE-01 (Initial shape)



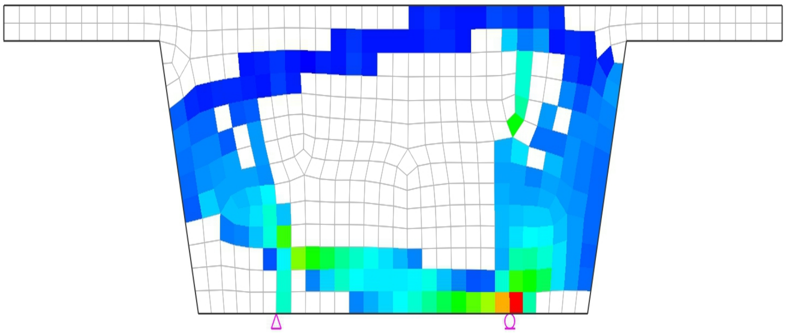
2. STAGE-04 (Elimination ratio = 24%)



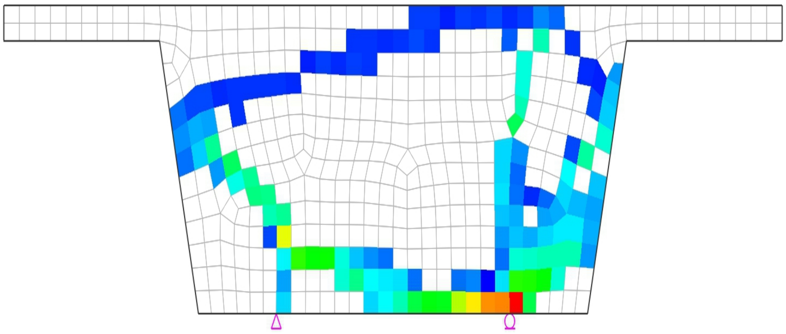
3. STAGE-07 (Elimination ratio = 44%)



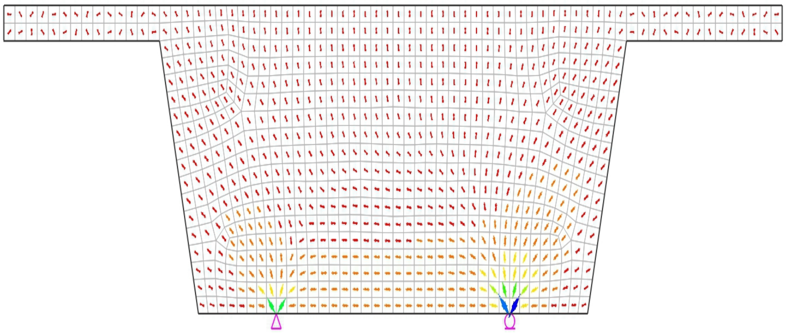
4. STAGE-10 (Elimination ratio = 58%)



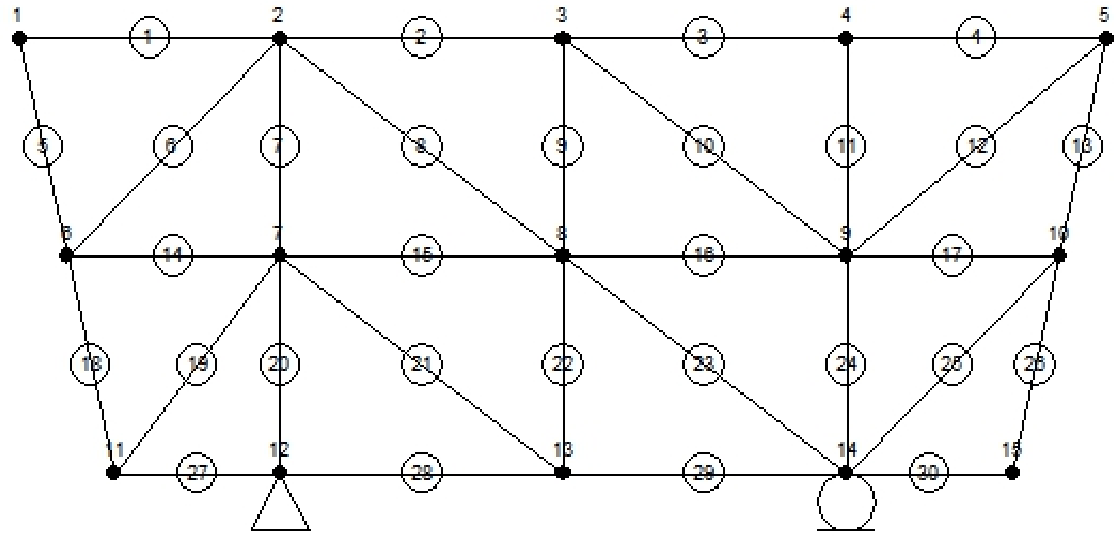
5. STAGE-13 (Elimination ratio = 70%)



(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	84.836	-6.000	2	140.000	-6.000
3	200.000	-6.000	4	260.000	-6.000
5	315.164	-6.000	6	94.836	-52.000
7	140.000	-52.000	8	200.000	-52.000
9	260.000	-52.000	10	305.164	-52.000
11	104.836	-98.000	12	140.000	-98.000
13	200.000	-98.000	14	260.000	-98.000
15	295.164	-98.000			

(B) Element Connectivity

Element No.	Start Node	End Node	Element No.	Start Node	End Node
1	1	2	2	2	3
3	3	4	4	4	5
5	1	6	6	2	6
7	2	7	8	2	8
9	3	8	10	3	9
11	4	9	12	5	9
13	5	10	14	6	7
15	7	8	16	8	9
17	9	10	18	6	11

19			20		
21			22		
23			24		
25			26		
27			28		
29			30		

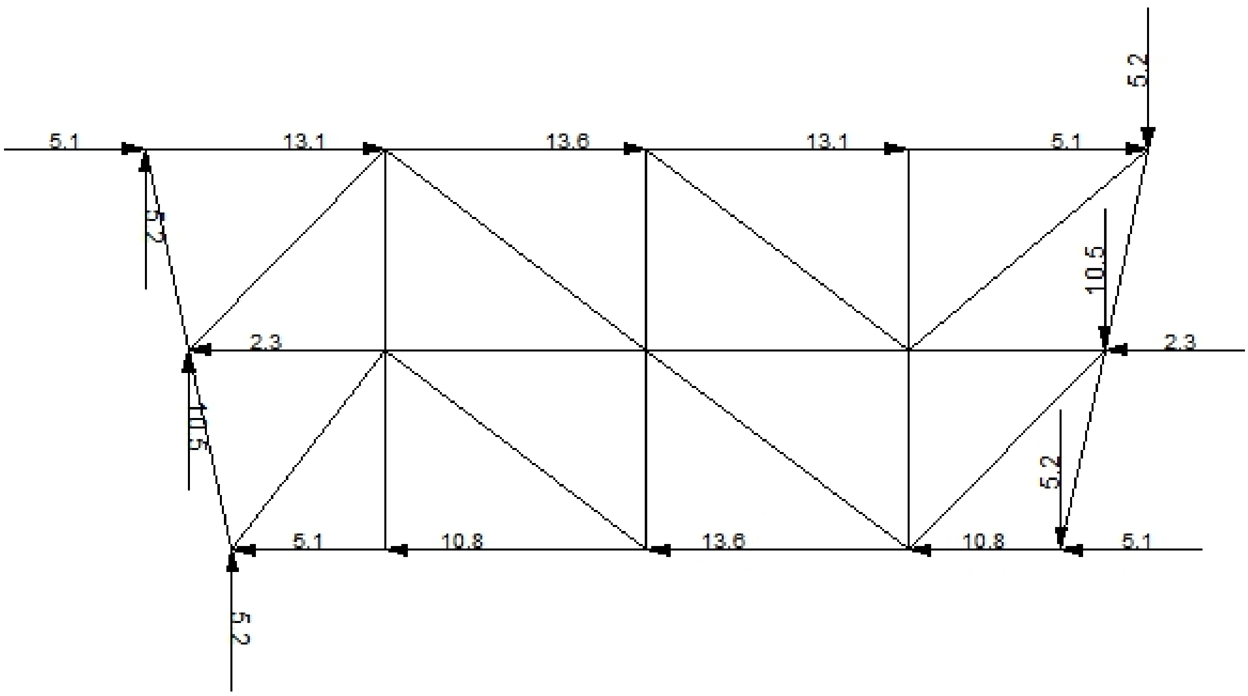
(C) Restraints

Node	Ux	Uy	Uz	Rx	Ry	Rz
12	0	0	0	0	-	0
14	-	-	0	-	-	-

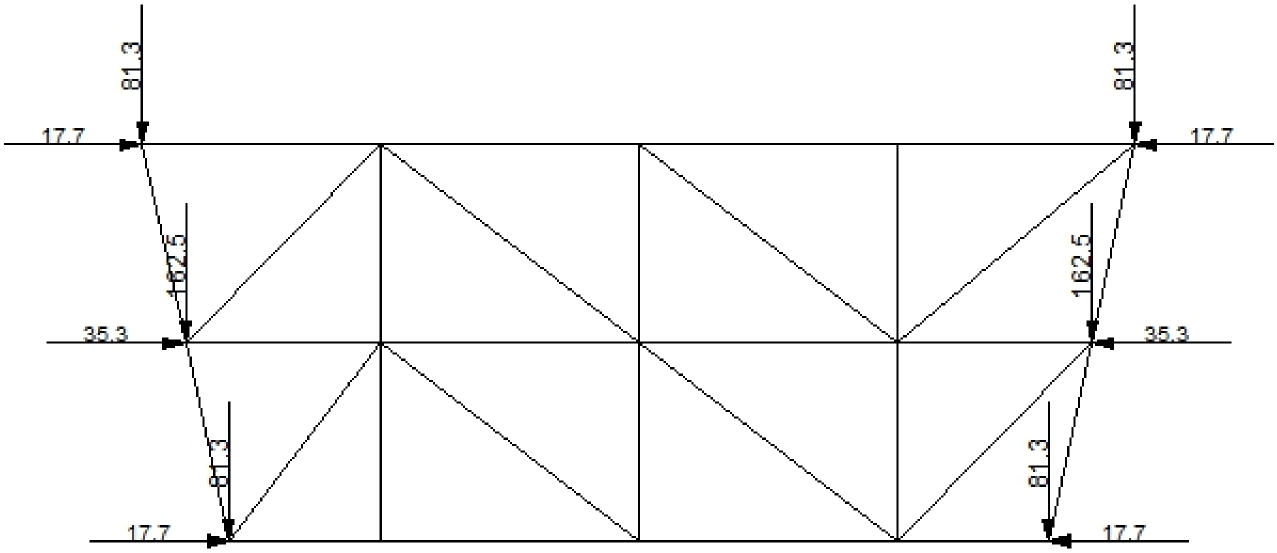
2) Analysis of Strut-Tie Model

(1) Loading Conditions

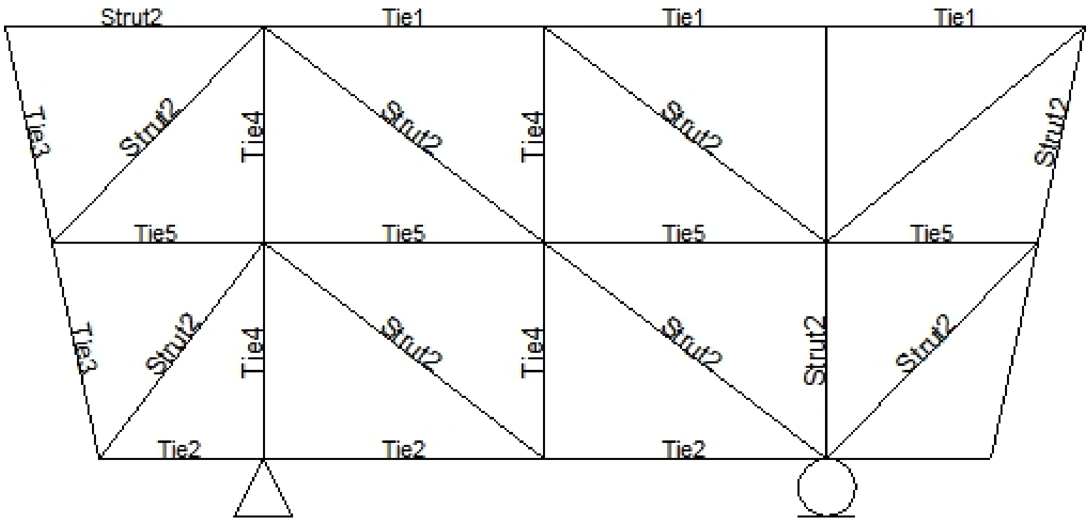
(1) Moment Load (T)



(2) Shear Load (V)

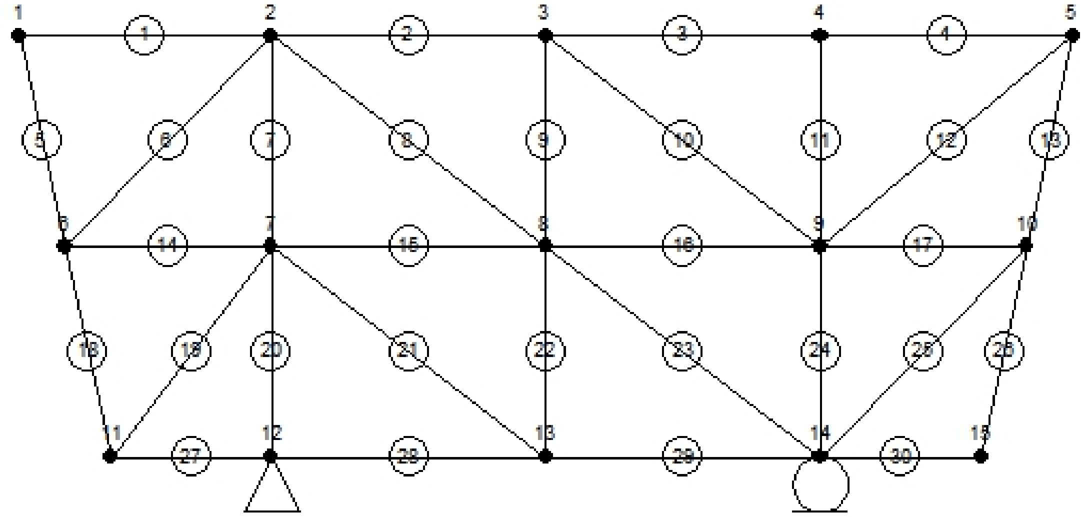


(2) Strut and Tie Types



- Strut2 : Strut with Transverse Tension
- Tie1 : Tie for top rebars
- Tie2 : Tie for bottom rebars
- Tie3 : Tie for inclined main rebars
- Tie4 : Tie for intermediate vertical rebars
- Tie5 : 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	-6.3	2	18.3	3	19.4	4	6.3
5	5.4	6	-5.5	7	35.7	8	-52.3
9	11.3	10	-18.5	11	0.0	12	0.0
13	-5.4	14	4.7	15	16.6	16	26.7
17	12.0	18	12.0	19	-21.4	20	71.8
21	-31.3	22	19.1	23	-65.1	24	-11.3
25	-22.0	26	-0.0	27	20.7	28	47.5
29	36.2	30	0.0				

3) Strength Verification and Required Rebars

(1) Required Area of Rebars

1) Main Rebars

(A) Horizontal Rebars

As.req = (Fu/cos theta) / (fy/gamma_s) < As.used
where,
Fu = member force of steel tie
gamma_s = partial safety factor for steel tie : 1.15
fy = yield strength of steel : 58015.4 lb/in²
theta = angle of steel tie measured from positive horizontal axis
(+: counterclockwise)

Tie No.	Types	Fu (kip)	theta (deg.)	Rebars	As.req (in²)	As.used (in²)	Note
2	Top	4.11	0.0	8-#8	0	6	O.K
3	Top	4.35	0.0	8-#8	0	6	O.K
4	Top	1.41	0.0	8-#8	0	6	O.K
27	Bottom	4.65	0.0	8-#8	0	6	O.K
28	Bottom	10.67	0.0	8-#8	1	6	O.K
29	Bottom	8.15	0.0	8-#8	1	6	O.K

(B) Inclined Rebars

As.req = (Fu/cos(theta1-theta2)) / (fy/gamma_s) < As.used
where,
Fu = member force of steel tie
gamma_s = partial safety factor for steel tie : 1.15
fy = yield strength of steel : 58015.4 lb/in²
theta1 = angle of inclined rebar measured from positive horizontal axis
(+: counterclockwise)
theta2 = angle of steel tie measured from positive horizontal axis
(+: counterclockwise)

Tie No.	Fu (kip)	theta1 (deg.)	theta2 (deg.)	Rebars	As.req (in²)	As.used (in²)	Note
5	1.20	77.7	77.7	10-#8	0	8	O.K
18	2.71	77.7	77.7	10-#8	0	8	O.K

2) Transverse Rebars

(A) Horizontal Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sh (in)	phi Fn (kip)	Note
14	1.06	0.0	4-#5	1.8	0.3	80.0	O.K

				1.8	0.3		
				1.8	0.3		
				1.5	0.3		

phi·Fn = Avh·(fy/gamma_s)·Weff,tie·cos theta / Sh > Fu
where,
Fu = member force of steel tie
gamma_s = partial safety factor for steel tie : 1.15
fy = yield strength of steel : 58015.4 lb/in²
theta = angle of steel tie measured from positive horizontal axis
(+: counterclockwise)
Sh = spacing of horizontal rebars
Weff,tie = effective width of tie

(C) Vertical Rebars

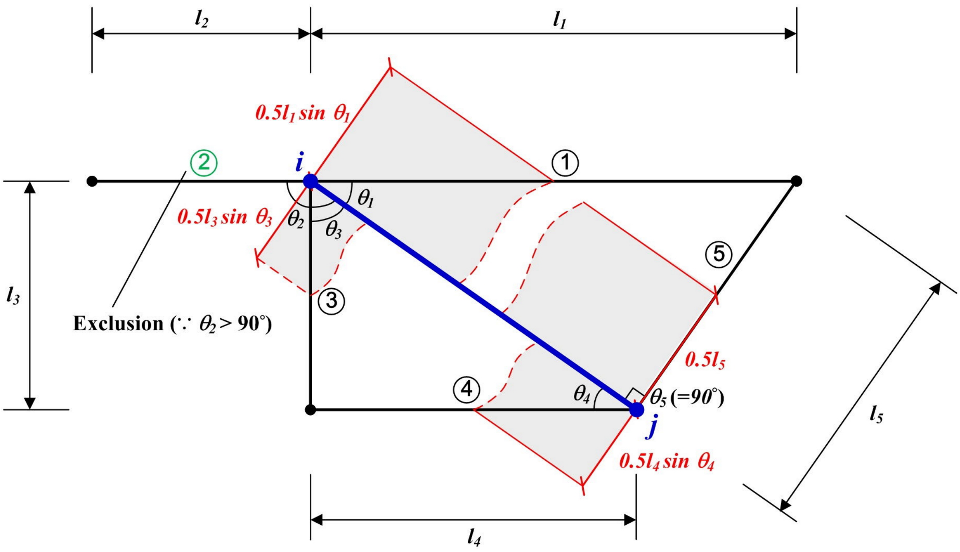
Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sv (in)	phi Fn (kip)	Note
7	8.03	90.0	2-#5	1.8	0.3	39.3	O.K
9	2.53	90.0	2-#5	2.4	0.3	52.2	O.K
20	16.14	90.0	2-#5	1.2	0.3	26.1	O.K
22	4.29	90.0	2-#5	2.4	0.3	52.2	O.K

phi·Fn = Avh·(fy/gamma_s)·Weff,tie·sin ? / Sv > Fu
where,
Fu = member force of steel tie
gamma_s = partial safety factor for steel tie : 1.15
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

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 three cases.

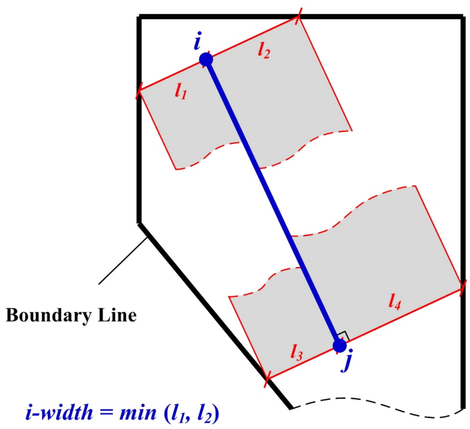
[CASE 1]



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

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

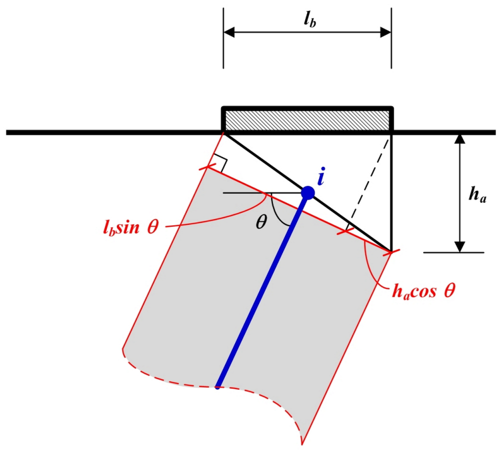
[CASE 2]



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

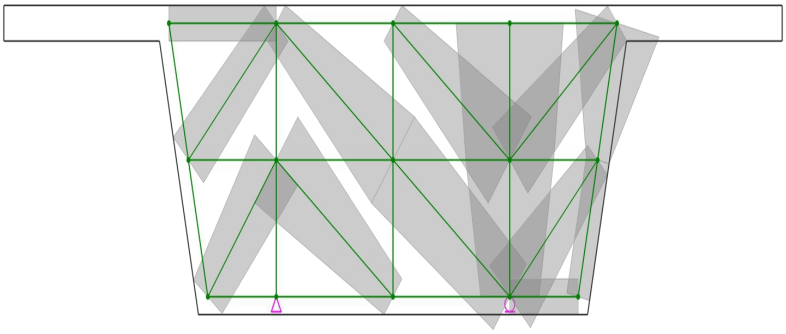
$j\text{-width} = \min(l_3,\ l_4)$

[CASE 3]



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

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
1	11.9	11.9	11.9	6	17.1	21.8	17.1
8	15.1	36.5	15.1	10	15.1	36.5	15.1
13	44.1	11.9	11.9	19	27.9	18.5	18.5
21	36.5	15.1	15.1	23	36.5	27.7	27.7
24	45.1	30.0	30.0	25	14.1	29.8	14.1

(3) Strength of Struts

- Design strength of concrete strut without transverse tension (Type 1)
  Wreq = Fu / ((alpha_cc·fck/gamma_c)·b) < Wprov (See Eurocode 2 Section 6.5.2(1))
- Design strength of concrete strut with transverse tension (Type 2)
  Wreq = Fu / (0.6·(1-fck/36,260)·(alpha_cc·fck/gamma_c)·b) < Wprov (See Eurocode 2 Section 6.5.2(2))
  gamma_c = partial safety factor for concrete = 1.50
  alpha_cc = coefficient of long term effects = 1.00

Strut No.	Type	theta	Fu (kip)	b (in)	Wreq (in)	Wprov (in)	Note
1	2	0.0	6.3	12.0	0.4	12.0	O.K
6	2	45.5	5.5	12.0	0.4	17.1	O.K
8	2	37.5	52.3	12.0	3.5	15.1	O.K
10	2	37.5	18.5	12.0	1.2	15.1	O.K
13	2	77.7	5.4	12.0	0.4	12.0	O.K

					1.4	18.	
					2.1	15.	
					4.3	27.	
					0.7	30.	
					1.5	14.	

(4) Strength of Nodal Zones

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, Wprov, with that required, Wreq

Wreq = Fu / (k·(1-fck/36,260)·(alpha_cc·fck/gamma_c)·b) < Wprov (See Eurocode 2 Section 6.5.4(4))

k = 1.00 (compression nodes where no ties are anchored at the node)
0.85 (compression-tension nodes with anchored ties provided in one direction)
0.75 (compression-tension nodes with anchored ties provided in more than one direction)

Under the conditions listed below, the design compressive stress values given in 6.5.4(4) may be increased by up to 10 percent where at least one of the following applies:

- triaxial compression is assured
- all angles between struts and ties are > 55
- the stresses applied at supports or at point loads are uniform, and the node is confined by stirrups
- the reinforcement is arranged in multiple layers
- the node is reliably confined by means of bearing arrangement or friction

Node No.	k	Type	Element	Fu (kip)	Wreq (in)	Wprov (in)	Note
1	0.85	CCT	C-1	6.3	0.3	12.0	O.K
			T-5	5.4	0.3	53.9	O.K
2	0.75	CTT	C-1	6.3	0.3	12.0	O.K
			T-2	18.3	1.0	12.0	O.K
			C-6	5.5	0.3	17.1	O.K
			T-7	35.7	1.9	45.2	O.K
			C-8	52.3	2.8	15.1	O.K
3	0.75	CTT	T-2	-	-	-	-
			T-3	1.1	0.1	12.0	O.K

3					0.6	60.	
					1.0	15.	
5					0.3	12.	
					0.3	44.	
6					-	-	
					0.3	21.	
6					0.2	46.	
					0.4	12.	
					-	-	
					-	-	
7					0.6	46.	
					1.1	27.	
					1.9	35.	
					1.7	36.	
					2.8	36.	
					-	-	
8					-	-	
					0.5	46.	
					0.4	60.	
					3.4	36.	
					1.0	36.	
					0.8	46.	
9					-	-	
					0.6	45.	
					0.3	12.	
					0.6	37.	
10					1.0	14.	
					0.6	12.	
					1.1	18.	
11					1.1	12.	
					1.7	15.	
					1.0	60.	
13					0.6	12.	
					-	-	
					3.1	30.	
					3.0	27.	
					0.5	30.	
14					1.0	29.	

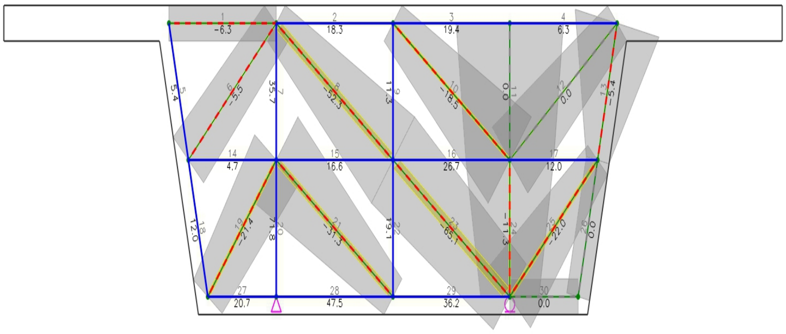
14					1.7	12.	

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

3. Summary

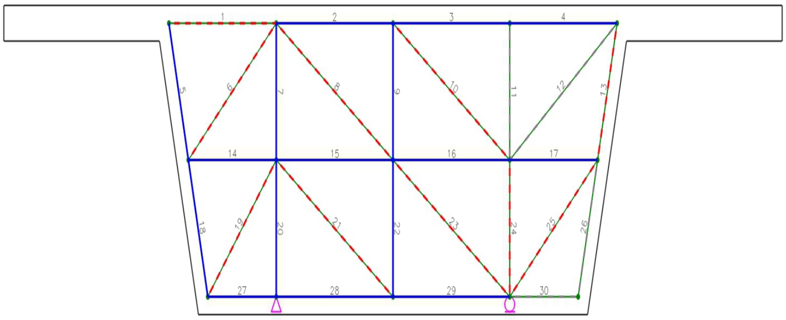
1) Dimensioned Shape

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
2	Top	4.11	0.0	8-#8	0	6	O.K

				8-	0	6	O.K
				8-	0	6	O.K
				8-	0	6	O.K
				8-	1	6	O.K
				8-	1	6	O.K

Tie No.	Fu (kip)	theta1 (deg.)	theta2 (deg.)	Rebars	As.req (in^2)	As.used (in^2)	Note
5	1.20	77.7	77.7	10-#8	0	8	O.K
18	2.71	77.7	77.7	10-#8	0	8	O.K

(B) Transverse Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sh (in)	phi Fn (kip)	Note
14	1.06	0.0	4-#5	1.8	0.3	80.0	O.K
15	3.73	0.0	4-#5	1.8	0.3	80.0	O.K
16	6.01	0.0	4-#5	1.8	0.3	80.0	O.K
17	2.70	0.0	4-#5	1.5	0.3	65.5	O.K

- Vertical Rebars

Tie No.	Fu (kip)	theta (deg.)	Rebars	Weff,tie (in)	Sv (in)	phi Fn (kip)	Note
7	8.03	90.0	2-#5	1.8	0.3	39.3	O.K
9	2.53	90.0	2-#5	2.4	0.3	52.2	O.K
20	16.14	90.0	2-#5	1.2	0.3	26.1	O.K
22	4.29	90.0	2-#5	2.4	0.3	52.2	O.K