

Structural Design Report for PSC Beam Template

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1. Design Conditions

1) General Characteristics

- (1) Project Name : PSC Beam Template
- (2) Design Code : EuroCode 2
- (3) Unit : KN.m
- (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

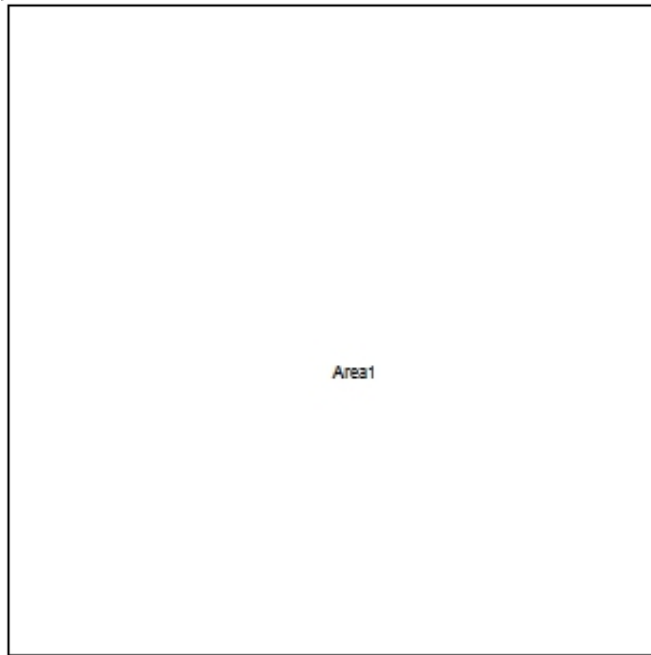
2) Materials

(1) Concrete

- Mass : 2,350 kg/m³
- Weight : 23.5 kN/m³
- Poisson's ratio : 0.15
- Compressive Strength of Concrete, f_{ck} : 24.0 MPa
- Tensile Strength of Concrete, f_{ct} : 2.4 MPa
- Elastic modulus of concrete, E_c : 27,849 MPa

(2) Steel

- Mass : 7,850 kg/m³
- Weight : 78.5 kN/m³
- Poisson's ratio : 0.15
- Yield strength of steel, f_y : 400.0 MPa
- Elastic modulus of steel, E_s : 200,000 MPa

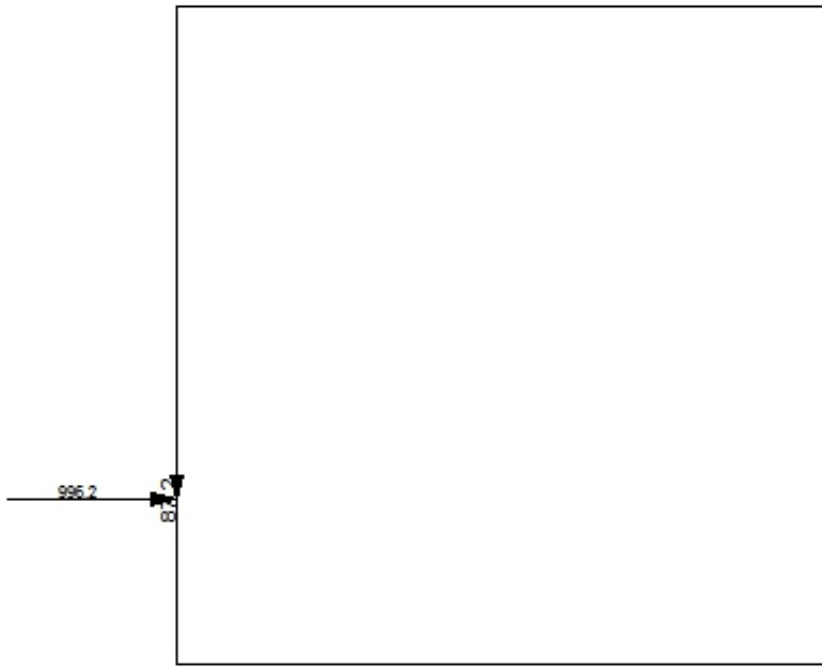
3) Geometrical Shape

- Thickness : 1.00 m

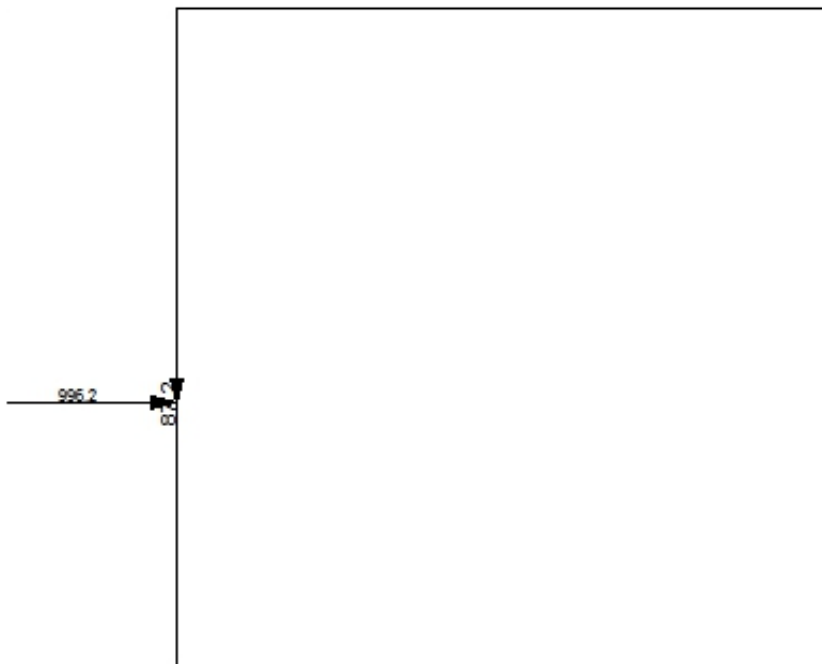
4) Loads and Load Combinations

(1) Loads

PS1 (PS1)

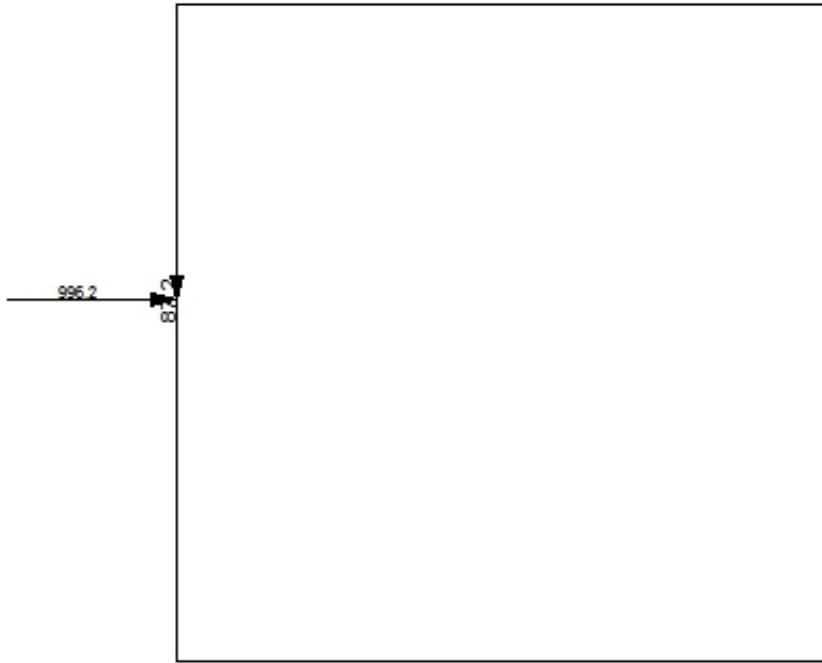


PS2 (PS2)

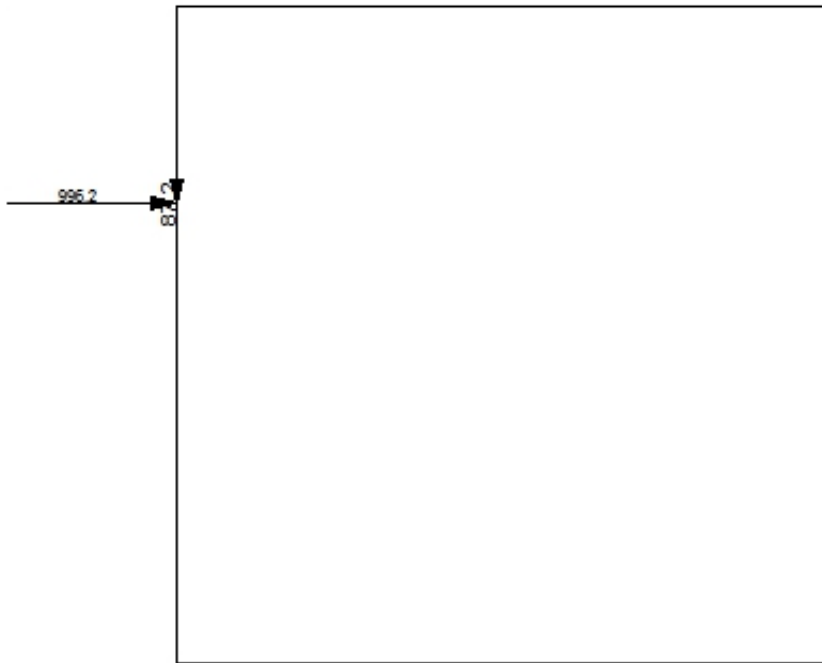


1. Design Conditions

PS3 (PS3)



PS4 (PS4)



1. Design Conditions



(2) Load Combinations

1) LC01 : $1.00PS1 + 1.00PS2 + 1.00PS3 + 1.00PS4$ **5) Reference**

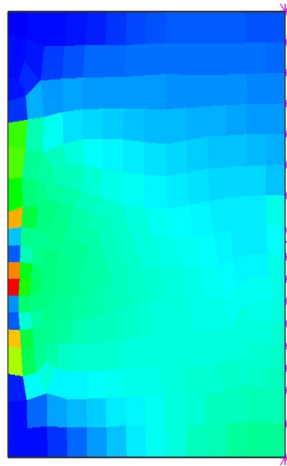
- (1) Designer : Hangil IT
(2) Date : 2017-07-15
(3) Note : Design of Anchorage in PSC Beam using Template (Eurocode 2)

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

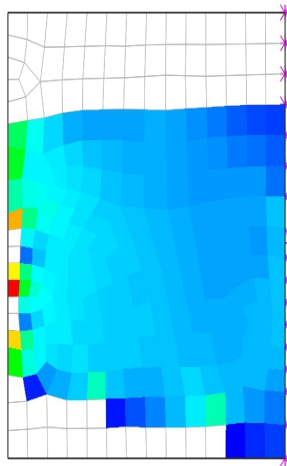
1) Construction of Strut-Tie Model

(1) ESO (Evolutionary Structural Optimization)

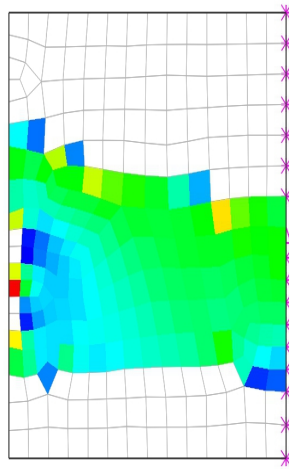
1. STAGE-01 (Initial shape)



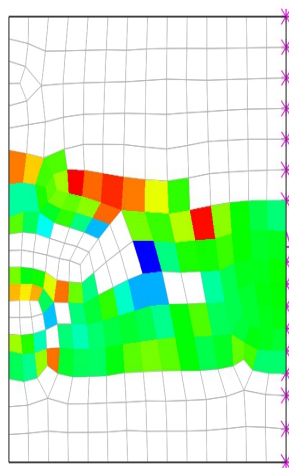
2. STAGE-04 (Elimination ratio = 25%)



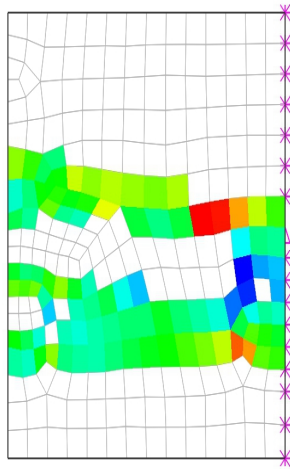
3. STAGE-07 (Elimination ratio = 44%)



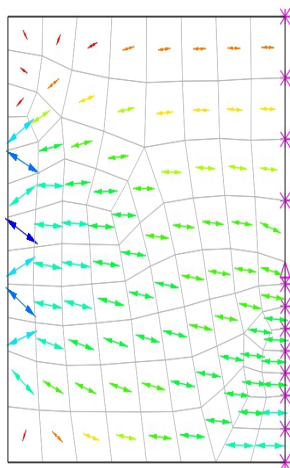
4. STAGE-10 (Elimination ratio = 58%)



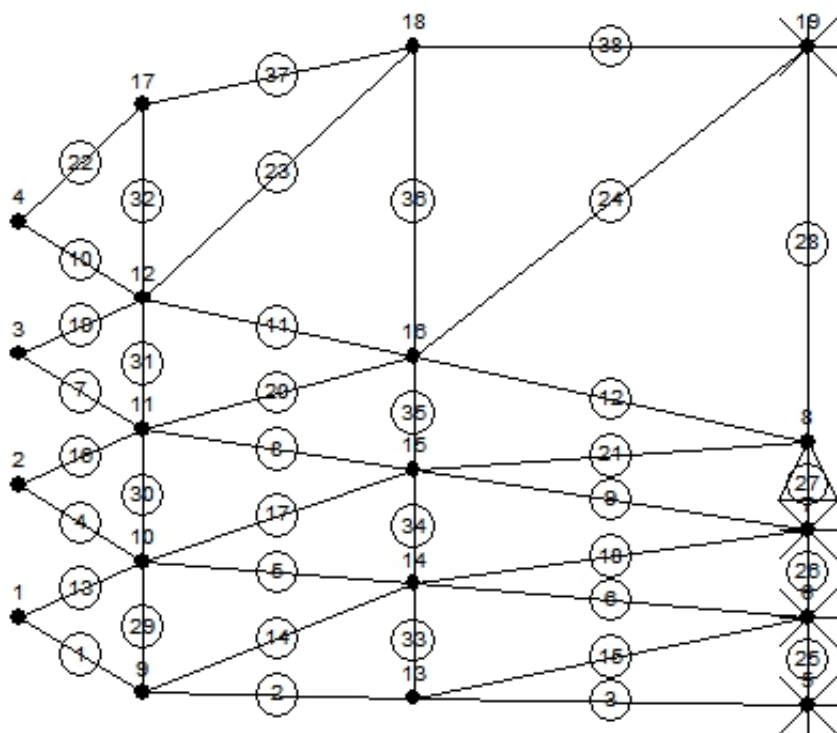
5. STAGE-11 (Elimination ratio = 62%)



(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	0.100	0.500	2	0.100	0.800
3	0.100	1.100	4	0.100	1.400
5	1.900	0.300	6	1.900	0.500
7	1.900	0.700	8	1.900	0.900
9	0.382	0.327	10	0.382	0.627
11	0.382	0.927	12	0.382	1.227
13	1.000	0.316	14	1.000	0.575
15	1.000	0.834	16	1.000	1.094
17	0.382	1.667	18	1.000	1.800
19	1.900	1.800			

(B) Element Connectivity

Element No.	Start Node	End Node	Element No.	Start Node	End Node
1	1	9	2	9	13
3	13	5	4	2	10
5	10	14	6	14	6

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



7	3	11	8	11	15
9	15	7	10	4	12
11	12	16	12	16	8
13	1	10	14	9	14
15	13	6	16	2	11
17	10	15	18	14	7
19	3	12	20	11	16
21	15	8	22	4	17
23	12	18	24	16	19
25	5	6	26	6	7
27	7	8	28	8	19
29	9	10	30	10	11
31	11	12	32	12	17
33	13	14	34	14	15
35	15	16	36	16	18
37	17	18	38	18	19

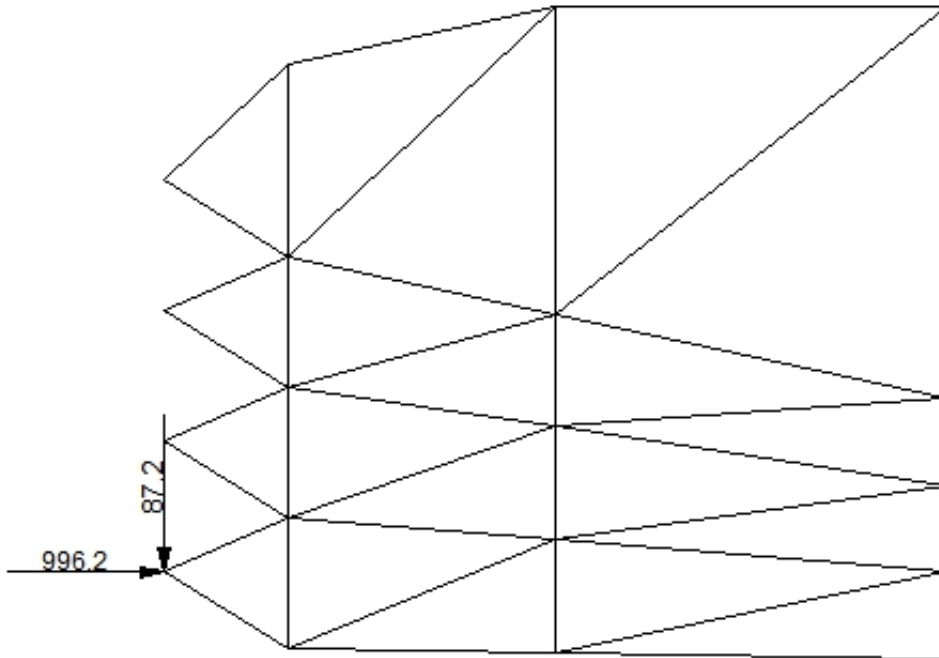
(C) Restraints

Node	Ux	Uy	Uz	Rx	Ry	Rz
5	0	-	-	-	-	-
6	0	-	-	-	-	-
7	0	-	-	-	-	-
8	0	0	0	0	-	0
19	0	-	-	-	-	-

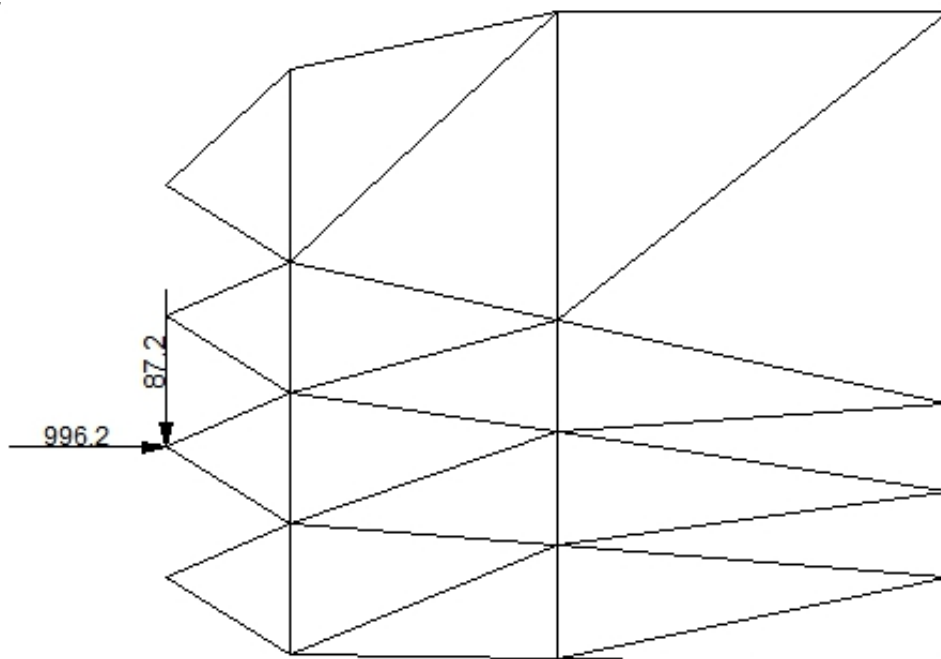
2) Analysis of Strut-Tie Model

(1) Loading Conditions

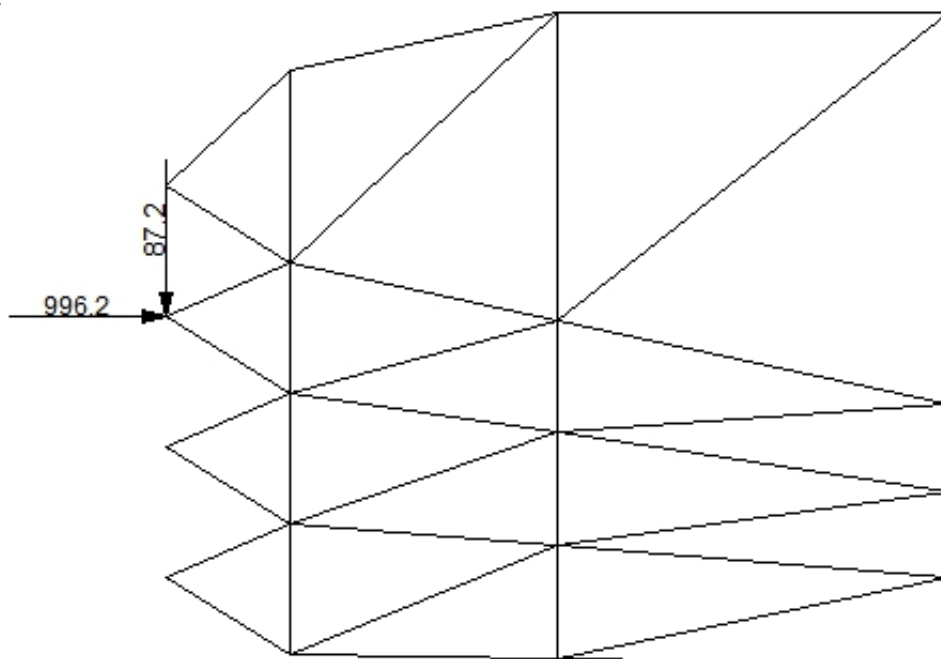
(1) (PS1)



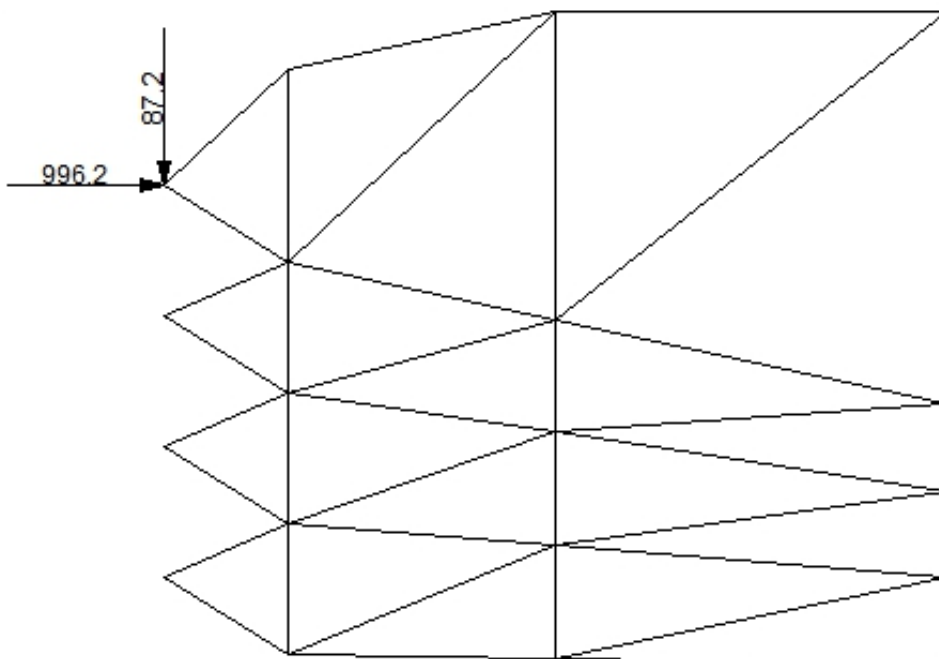
(2) (PS2)



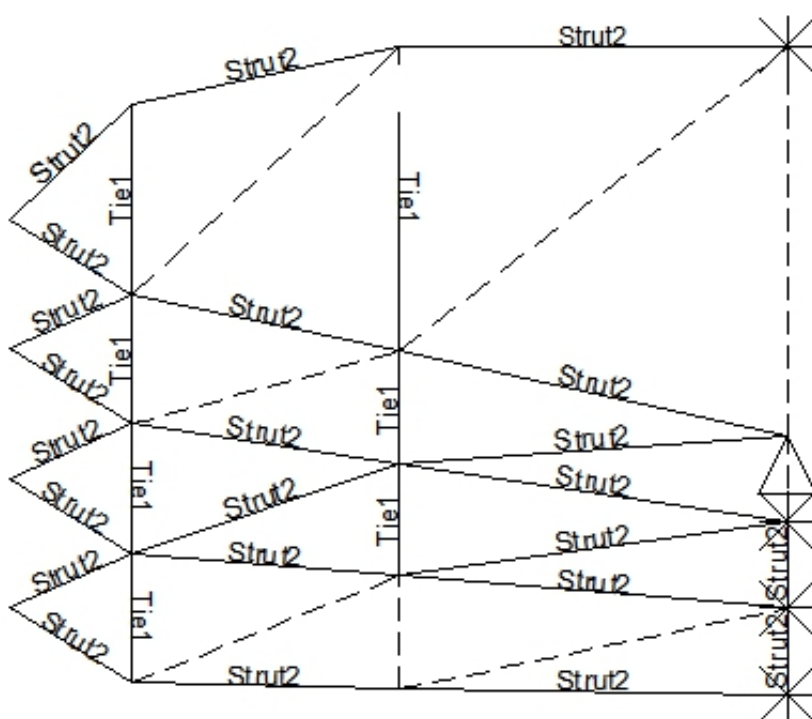
(3) (PS3)



(4) (PS4)

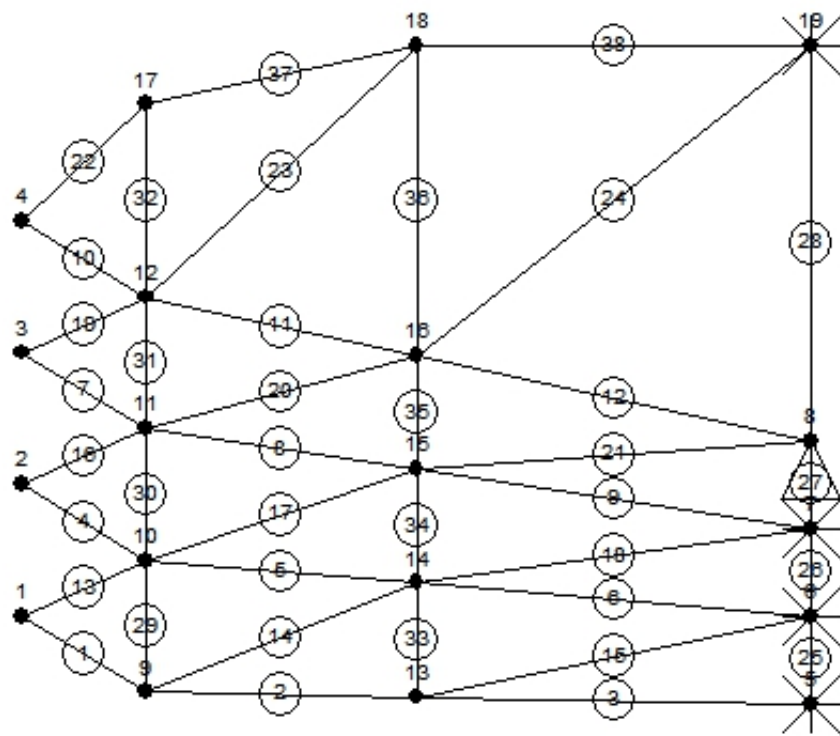


(2) Strut and Tie Types



- Strut2 : Strut with Transverse Tension
- Tie1 : Tie for intermediate vertical rebars

(3) Strut and Tie Forces



Elem. No.	Force (kN)	Elem. No.	Force (kN)	Elem. No.	Force (kN)	Elem. No.	Force (kN)
1	-590.0	2	-502.7	3	-502.2	4	-590.0
5	-837.4	6	-743.0	7	-590.0	8	-1007.2
9	-579.5	10	-774.2	11	-1179.6	12	-1179.6
13	-541.0	14	-0.1	15	-0.5	16	-541.0
17	-170.6	18	-95.0	19	-541.0	20	-0.0
21	-586.3	22	-463.1	23	0.0	24	-0.0
25	-55.0	26	-72.5	27	0.0	28	0.0
29	300.0	30	371.8	31	310.1	32	245.5
33	0.1	34	21.1	35	72.6	36	72.6
37	-344.2	38	-336.5				

3) Strength Verification and Required Rebars

(1) Required Area of Rebars

1) Transverse Rebars

(A) Vertical Rebars

Tie No.	Fu (kN)	theta (deg.)	Rebars	Weff,tie (mm)	Sv (mm)	phi Fn (kN)	Note
29	299.97	90.0	1-#10	282.1	200.0	401.0	O.K
30	371.78	90.0	1-#10	282.1	200.0	401.0	O.K
31	310.13	90.0	1-#10	282.1	200.0	401.0	O.K
32	245.53	90.0	1-#10	282.1	200.0	401.0	O.K
34	21.08	90.0	1-#10	617.9	200.0	878.2	O.K
35	72.56	90.0	1-#10	617.9	200.0	878.2	O.K

$$\phi \cdot F_n = A_{vh} \cdot (f_y / \gamma_s) \cdot W_{eff,tie} \cdot \sin \theta / S_v > F_u$$

where,

F_u = member force of steel tie

γ_s = partial safety factor for steel tie : 1.15

f_y = yield strength of steel : 400.0 MPa

θ = angle of steel tie measured from positive horizontal axis
(+: counterclockwise)

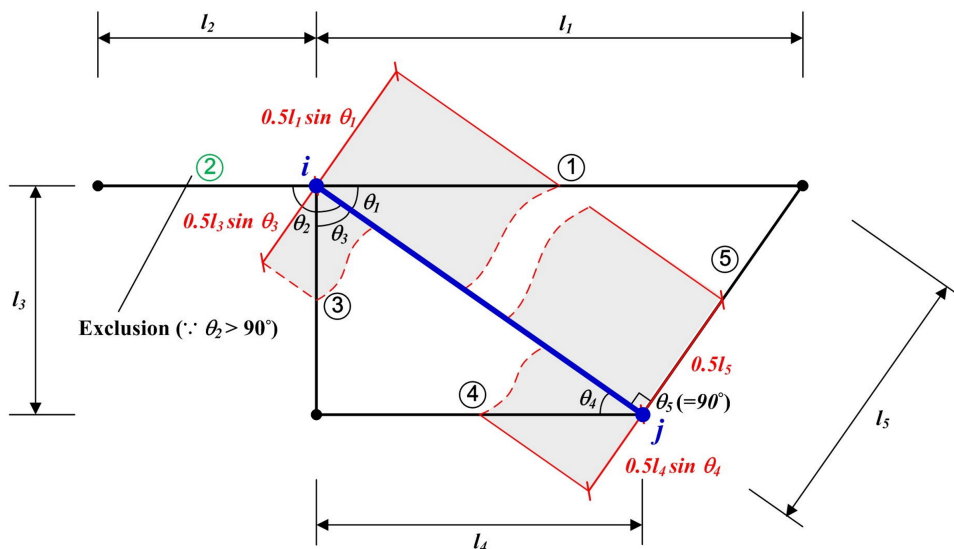
S_v = spacing of vertical rebars

$W_{eff,tie}$ = 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.

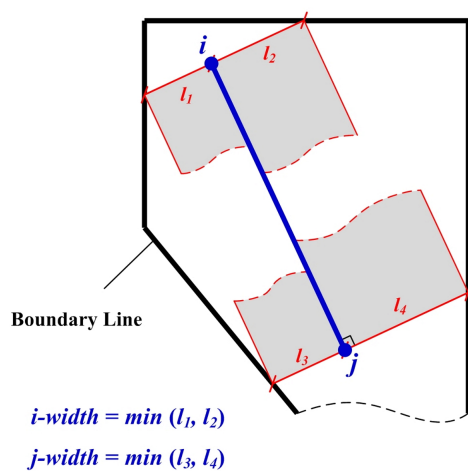
[CASE 1]



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

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

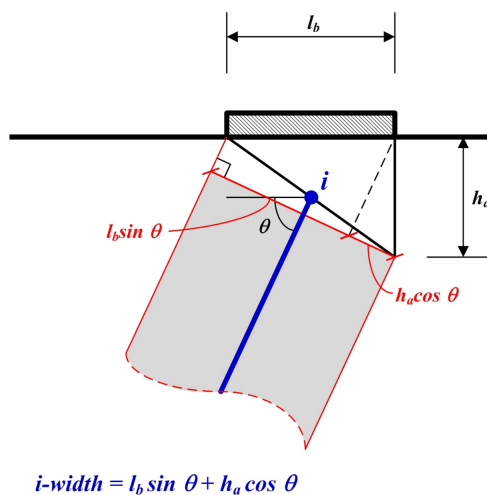
[CASE 2]



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

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

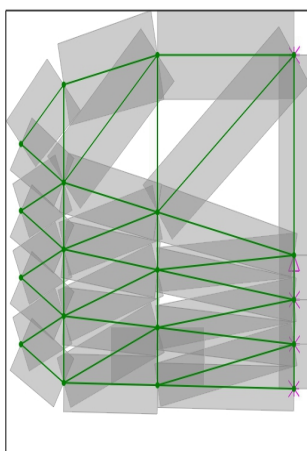
[CASE 3]



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

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
1	275.1	255.6	255.6	2	259.2	259.0	259.0
3	200.0	199.7	199.7	4	275.1	255.6	255.6
5	258.4	257.0	257.0	6	199.3	199.3	199.3
7	275.1	255.6	255.6	8	256.5	254.0	254.0
9	197.8	197.8	197.8	10	275.1	255.6	255.6
11	271.0	257.0	257.0	12	253.5	198.2	198.2
13	264.4	273.7	264.4	16	264.4	273.7	264.4
17	245.8	245.8	245.8	18	198.1	198.1	198.1
19	264.4	273.7	264.4	21	199.5	199.5	199.5
22	282.7	319.7	282.7	25	200.0	200.0	200.0
26	200.0	200.0	200.0	37	375.0	409.2	375.0
38	400.0	400.0	400.0				

(3) Strength of Struts

- Design strength of concrete strut without transverse tension (Type 1)

$$W_{req} = F_u / ((\alpha_{cc} \cdot f_{ck} / \gamma_c) \cdot b) < W_{prov}$$
 (See Eurocode 2 Section 6.5.2(1))

- Design strength of concrete strut with transverse tension (Type 2)

$$W_{req} = F_u / (0.6 \cdot (1 - f_{ck} / 250) \cdot (\alpha_{cc} \cdot f_{ck} / \gamma_c) \cdot b) < W_{prov}$$
 (See Eurocode 2

Section 6.5.2(2))

γ_c = partial safety factor for concrete = 1.50

α_{cc} = coefficient of long term effects = 1.00

Strut No.	Type	theta	F_u (kN)	b (mm)	W_{req} (mm)	W_{prov} (mm)	Note
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2. Strut-Tie Model Design (Load Combination-1)



1	2	31.6	590.0	1000.0	68.0	255.6	0.K
2	2	1.0	502.7	1000.0	57.9	259.0	0.K
3	2	1.0	502.2	1000.0	57.9	199.7	0.K
4	2	31.6	590.0	1000.0	68.0	255.6	0.K
5	2	4.8	837.4	1000.0	96.5	257.0	0.K
6	2	4.8	743.0	1000.0	85.6	199.3	0.K
7	2	31.6	590.0	1000.0	68.0	255.6	0.K
8	2	8.5	1007.2	1000.0	116.1	254.0	0.K
9	2	8.5	579.5	1000.0	66.8	197.8	0.K
10	2	31.6	774.2	1000.0	89.2	255.6	0.K
11	2	12.1	1179.6	1000.0	135.9	257.0	0.K
12	2	12.1	1179.6	1000.0	135.9	198.2	0.K
13	2	24.2	541.0	1000.0	62.3	264.4	0.K
16	2	24.2	541.0	1000.0	62.3	264.4	0.K
17	2	18.6	170.6	1000.0	19.7	245.8	0.K
18	2	7.9	95.0	1000.0	11.0	198.1	0.K
19	2	24.2	541.0	1000.0	62.3	264.4	0.K
21	2	4.2	586.3	1000.0	67.6	199.5	0.K
22	2	43.4	463.1	1000.0	53.4	282.7	0.K
37	2	12.2	344.2	1000.0	39.7	375.1	0.K
38	2	0.0	336.5	1000.0	38.8	400.0	0.K

(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, w_{prov} , with that required, w_{req}

$w_{req} = F_u / (k \cdot (1 - f_{ck}/250) \cdot (\alpha_{cc} \cdot f_{ck} / \gamma_c) \cdot b) < w_{prov}$ (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 $> 55^\circ$
- the stresses applied at supports or at point loads are uniform, and the node is confined by stirrups

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



- 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 (kN)	Wreq (mm)	Wprov (mm)	Note
1	1.00	CCC	H	996.2	68.9	200.0	0.K
			V	87.2	6.0	200.0	0.K
			C-1	590.0	40.8	275.1	0.K
			C-13	541.0	37.4	264.4	0.K
2	1.00	CCC	H	996.2	68.9	200.0	0.K
			V	87.2	6.0	200.0	0.K
			C-4	590.0	40.8	275.1	0.K
			C-16	541.0	37.4	264.4	0.K
3	1.00	CCC	H	996.2	68.9	200.0	0.K
			V	87.2	6.0	200.0	0.K
			C-7	590.0	40.8	275.1	0.K
			C-19	541.0	37.4	264.4	0.K
4	1.00	CCC	H	996.2	68.9	200.0	0.K
			V	87.2	6.0	200.0	0.K
			C-10	774.2	53.5	275.1	0.K
			C-22	463.1	32.0	282.7	0.K
5	1.00	CCC	C-3	502.2	34.7	199.7	0.K
6	1.00	CCC	C-6	743.0	51.4	199.3	0.K
7	1.00	CCC	C-9	579.5	40.1	197.8	0.K
			C-18	95.0	6.6	198.1	0.K
8	1.00	CCC	C-12	1179.6	81.6	198.2	0.K
			C-21	586.3	40.5	199.5	0.K
9	0.85	CCT	C-1	590.0	48.0	255.6	0.K
			C-2	502.7	40.9	259.3	0.K
			T-29	300.0	24.4	282.1	0.K
10	0.75	CTT	C-4	590.0	54.4	255.6	0.K
			C-5	837.4	77.2	258.4	0.K
			C-13	541.0	49.9	273.7	0.K
			C-17	170.6	15.7	245.8	0.K
			T-29	-	-	-	-
			T-30	71.8	6.6	282.1	0.K
11	0.75	CTT	C-7	590.0	54.4	255.6	0.K

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



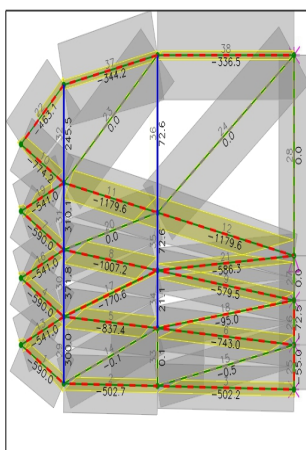
11	0.75	CTT	C-8	1007.2	92.9	256.5	0.K
			C-16	541.0	49.9	273.7	0.K
			T-30	61.7	5.7	282.1	0.K
			T-31	-	-	-	-
12	0.75	CTT	C-10	774.2	71.4	255.6	0.K
			C-11	1179.6	108.7	271.0	0.K
			C-19	541.0	49.9	273.7	0.K
			T-31	64.6	6.0	282.1	0.K
			T-32	-	-	-	-
13	1.00	CCC	C-2	502.7	34.8	259.0	0.K
			C-3	502.2	34.7	200.0	0.K
14	0.85	CCT	C-5	837.4	68.1	257.0	0.K
			C-6	743.0	60.4	199.3	0.K
			C-18	95.0	7.7	198.1	0.K
			T-34	21.1	1.7	617.9	0.K
15	0.75	CTT	C-8	1007.2	92.9	254.0	0.K
			C-9	579.5	53.4	197.8	0.K
			C-17	170.6	15.7	245.8	0.K
			C-21	586.3	54.0	199.5	0.K
			T-34	-	-	-	-
			T-35	51.5	4.7	617.9	0.K
16	0.75	CTT	C-11	1179.6	108.7	257.0	0.K
			C-12	1179.6	108.7	253.5	0.K
			T-35	-	-	-	-
			T-36	0.0	0.0	617.9	0.K
17	0.85	CCT	C-22	463.1	37.7	319.7	0.K
			T-32	245.5	20.0	282.1	0.K
			C-37	344.2	28.0	375.1	0.K
18	0.85	CCT	T-36	72.6	5.9	617.9	0.K
			C-37	344.2	28.0	409.2	0.K
			C-38	336.5	27.4	400.0	0.K
19	1.00	CCC	C-38	336.5	23.3	400.0	0.K

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

3. Summary

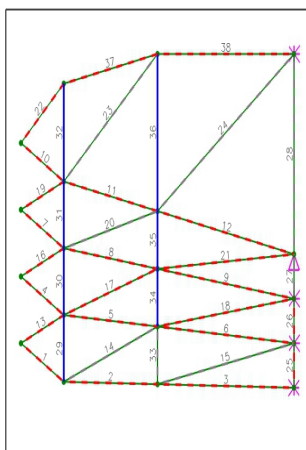
1) Dimensioned Shape

1) Load Combination - 1



2) Required and Used Areas of Rebars

1) Load Combination - 1



(A) Transverse Rebars

- Vertical Rebars

Tie No.	Fu (kN)	theta (deg.)	Rebars	Weff,tie (mm)	Sv (mm)	phi Fn (kN)	Note
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3. Summary



29	299.97	90.0	1-#10	282.1	200.0	401.0	0.K
30	371.78	90.0	1-#10	282.1	200.0	401.0	0.K
31	310.13	90.0	1-#10	282.1	200.0	401.0	0.K
32	245.53	90.0	1-#10	282.1	200.0	401.0	0.K
34	21.08	90.0	1-#10	617.9	200.0	878.2	0.K
35	72.56	90.0	1-#10	617.9	200.0	878.2	0.K