MAPLE
ENGINEERING SERVICES

The Team

Moied Haddadin
Geotechnical Engineering Lead

Adamo Bernola
Structural Design Lead

Philippe Allard
Project Manager

Loren Yan
Drafting Technologist

Elia Abu-Manneh
Bridge Designer

Presentation Agenda

1. *Project Overview*
2. *Physical Context*
3. *Load Combinations*
4. *Loads*
5. *Modelling + Analysis*
6. *Connection Design*
7. *Footing & Column Design*
8. *Construction Plan*
9. *Estimation*

Project Overview

Existing Loads

Modelling and Analysis

Detail Design

Implementation

Project Overview

As part of the *Cogswell Redevelopment Program* in Halifax, Nova Scotia

Source: Google Earth, 2020.

Our Scope

Design a new structural system that can hold the current pedestrian bridge spanning Cogswell Street which will enable the removal of the central support column

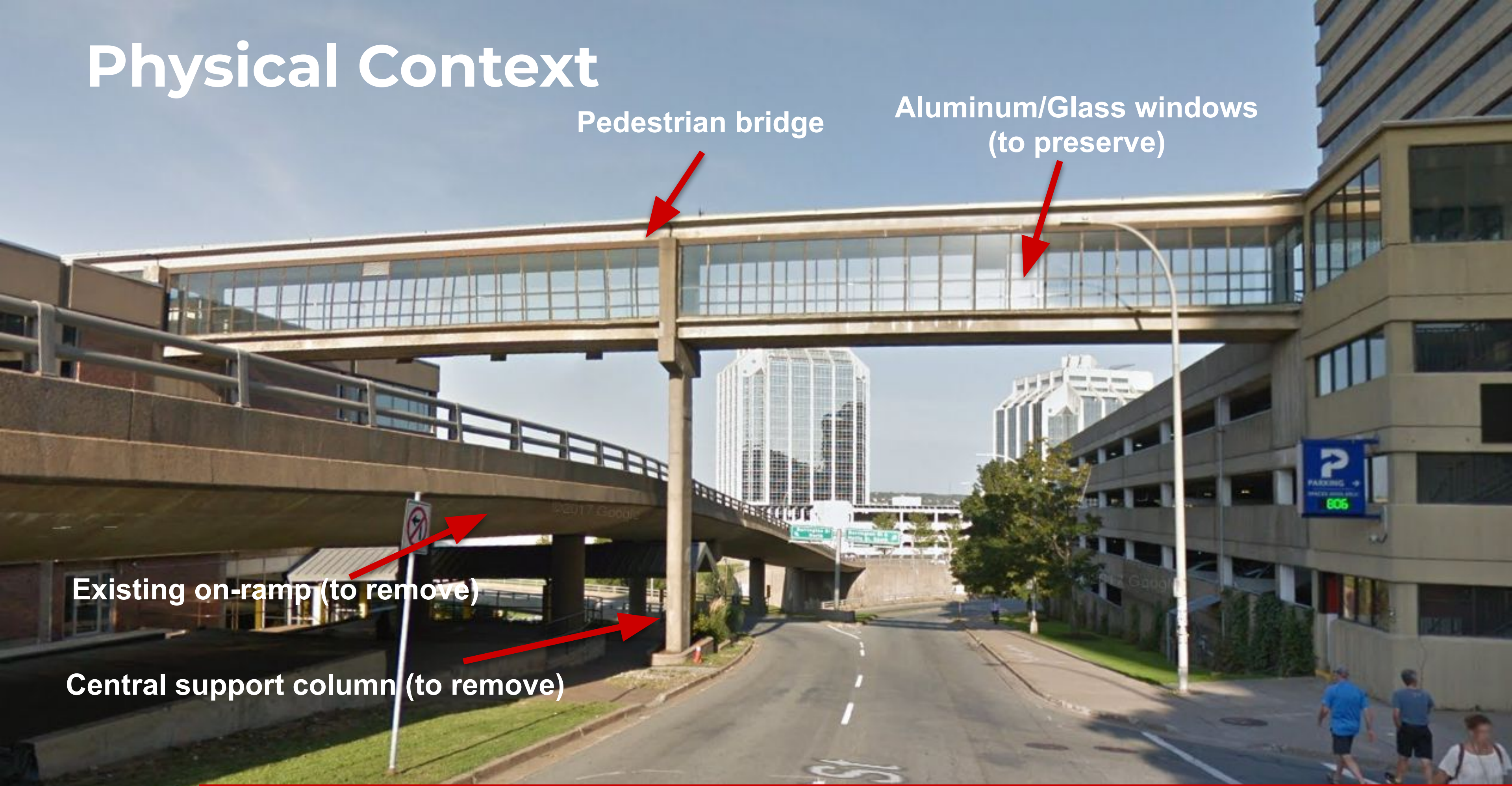
Key Design Considerations

- Minimize deflection of the glass exterior & water pipes located on the bridge roof
- Minimize interruption of pedestrian and road traffic on & under the bridge
- Maximize the public use space under the bridge and along Cogswell Street, including the deconstruction of the Cogswell Street on-ramp

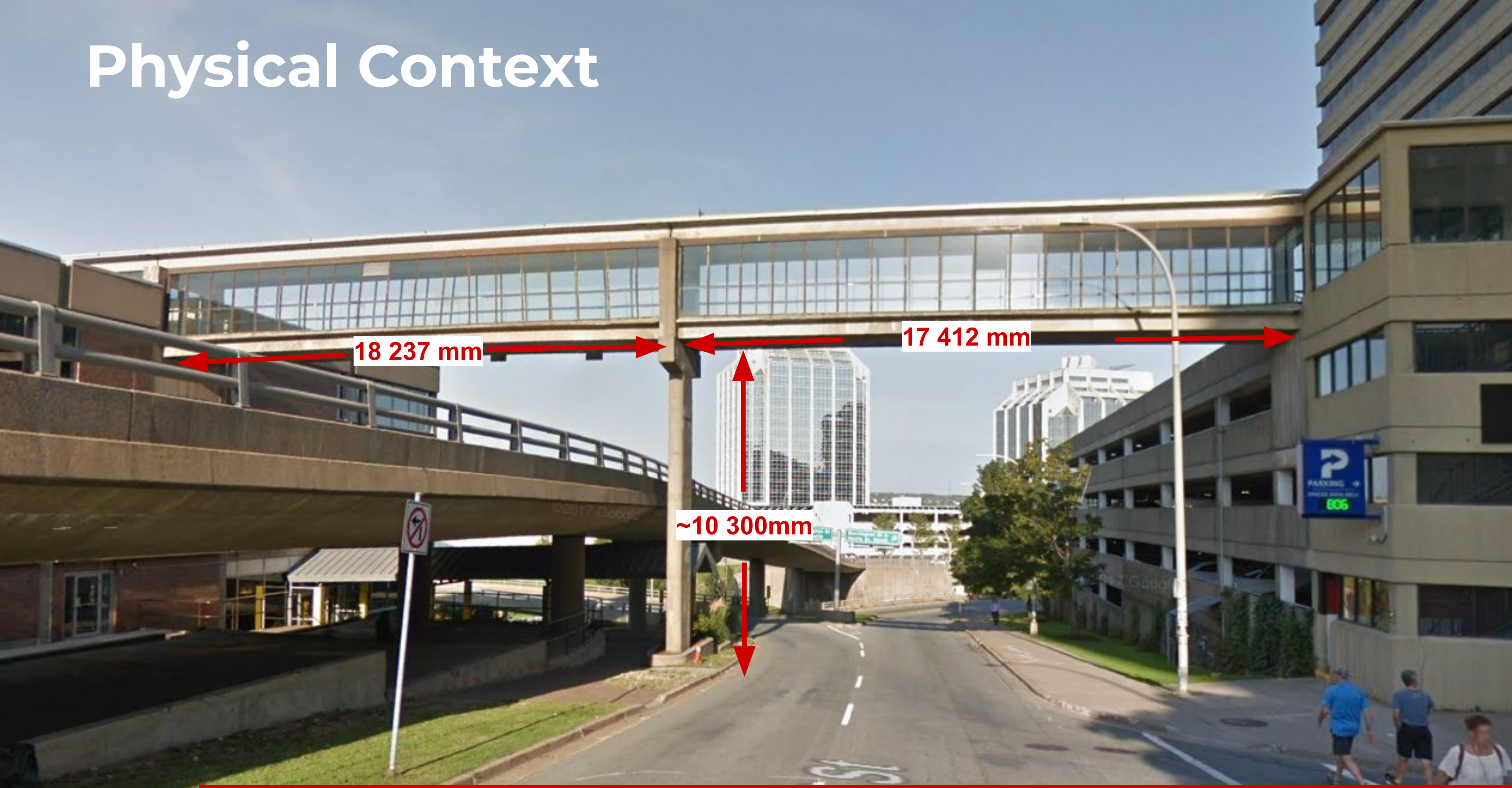
Physical Context

Physical Context

Physical Context

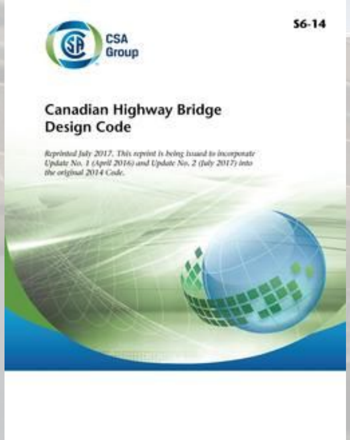


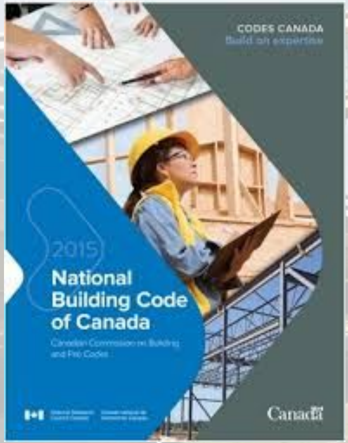
Physical Context

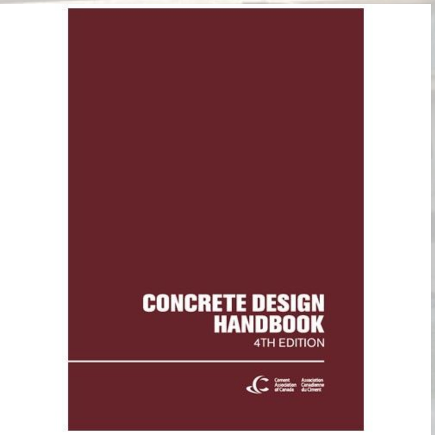


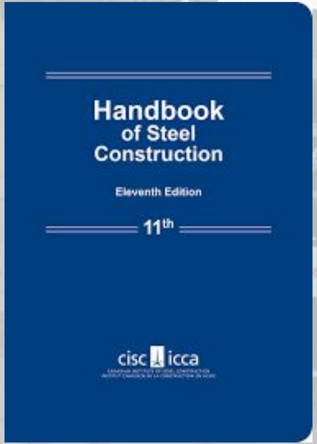
Physical Context

Applicable Codes and Standards





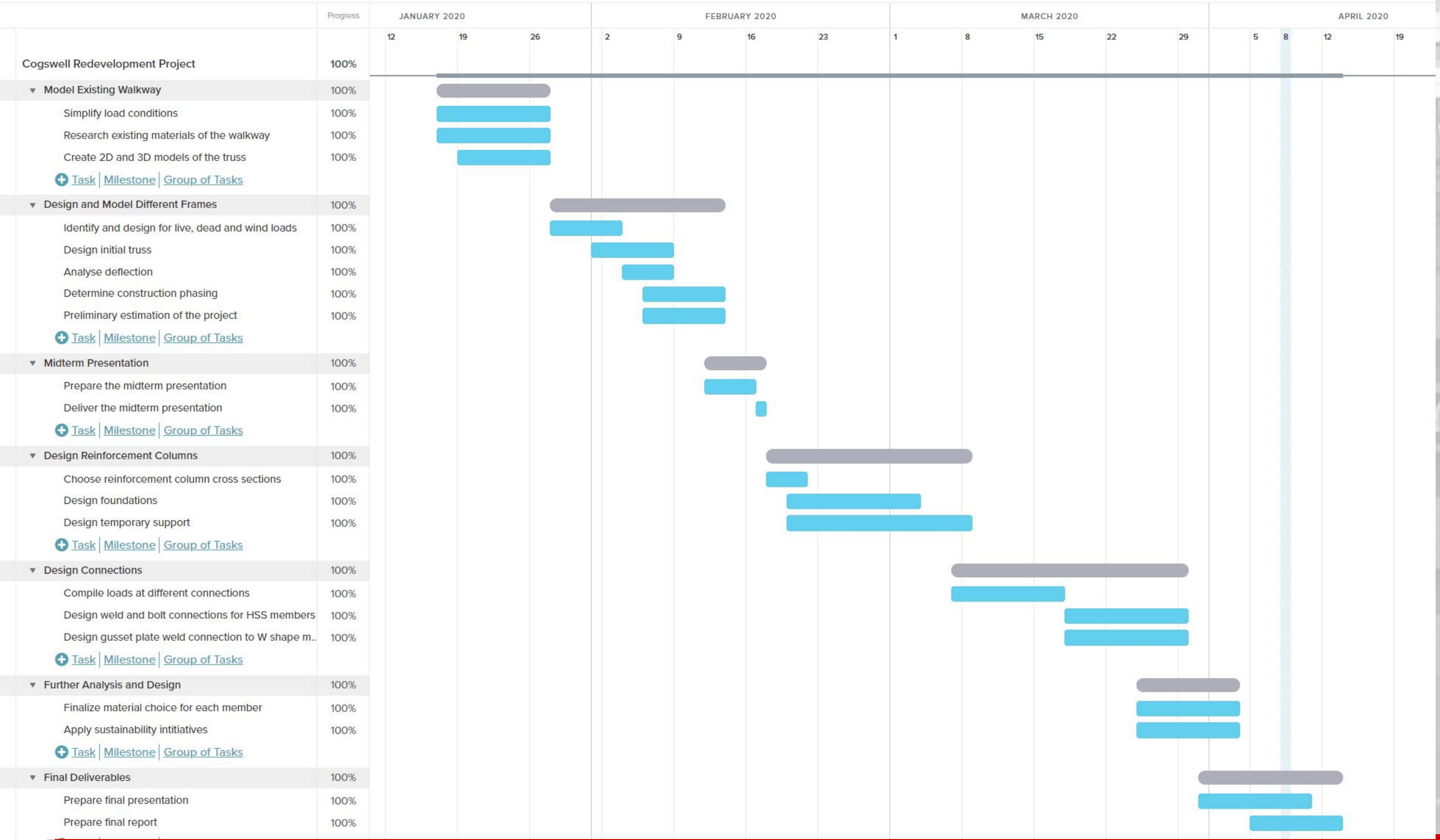




Softwares and References

- Softwares:
  - Microsoft Excel
  - SAP2000
  - AutoCAD 3D
  - SketchUp
- References:
  - “Elastomeric Bearings,” Goodco Z-Tech. 2010. https://bit.ly/34qH2te
  - “Hollow Structural Section, Connections and Trusses,” Packer, J.A. & Henderson, J.E. 1997. https://bit.ly/2JVLiHH
  - “Manuel de conception des structures,” Transports Québec. Jan. 2020.

Project Timeline



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Project Overview

Existing Loads

Modelling and Analysis

Detail Design

Implementation

Load Combinations Acting on Structure

- Neglect
  - Secondary prestress effects
  - Loads due to earth pressure and hydrostatic pressure (including surcharges but excluding dead load)
  - Wind load on traffic
  - Differential settlement and/or movement of the foundation
  - Stream pressure and ice forces or debris torrents
  - Collision load arising from highway vehicles or vessels (E, P, H, V, F)
- Use: FLS-1, SLS-1, 2,
- ULS-1, 2, 3, 4, 5, 7, 9

	Permanent loads			Transitory loads					Exceptional loads			
Loads	*D*	*E*	*P*	*L**	*K*	*W*	*V*	*S*	*EQ*	*F*	*A*	*H*
Fatigue limit state												
FLS Combination 1	1.00	1.00	1.00	1.00	0	0	0	0	0	0	0	0
Serviceability limit states												
SLS Combination 1	1.00	1.00	1.00	0.90	0.80	0	0	1.00	0	0	0	0
SLS Combination 2†	0	0	0	0.90	0	0	0	0	0	0	0	0
Ultimate limit states‡												
ULS Combination 1	α_D	α_E	α_P	Table 3.2	0	0	0	0	0	0	0	0
ULS Combination 2	α_D	α_E	α_P	Table 3.2	1.15	0	0	0	0	0	0	0
ULS Combination 3	α_D	α_E	α_P	Table 3.2	1.00	0.45§	0.45	0	0	0	0	0
ULS Combination 4	α_D	α_E	α_P	0	1.25	1.40§	0	0	0	0	0	0
ULS Combination 5	α_D	α_E	α_P	0	0	0	0	0	1.00	0	0	0
ULS Combination 6**	α_D	α_E	α_P	0	0	0	0	0	0	1.30	0	0
ULS Combination 7	α_D	α_E	α_P	0	0	0.75§	0	0	0	0	1.30	0
ULS Combination 8	α_D	α_E	α_P	0	0	0	0	0	0	0	0	1.00
ULS Combination 9	1.35	α_E	α_P	0	0	0	0	0	0	0	0	0

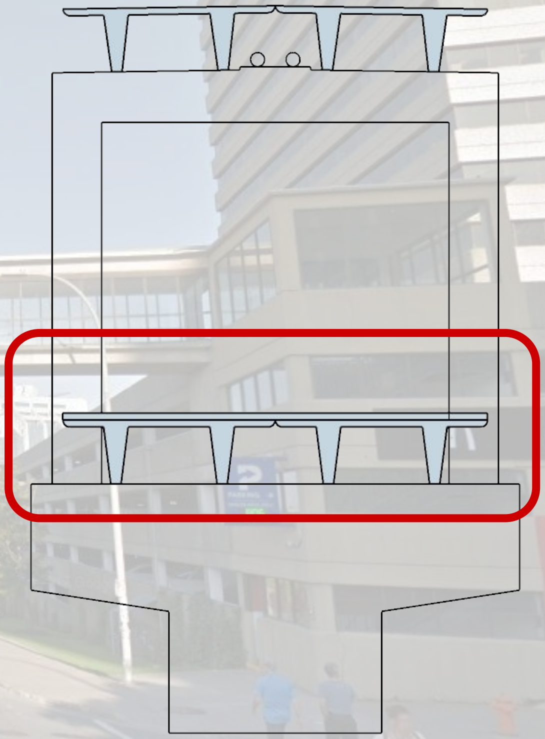
Dead Loads

Bottom Span:

Superimposed dead load (from plans): 3.65 kN/m

Self-weight dead load: 5.86 kN/m

Total unfactored dead load: **9.51 kN/m**



Dead Loads

Bottom Span:

Superimposed dead load (*from plans*): <u>3.65 kN/m</u>

Self-weight dead load: <u>5.86 kN/m</u>

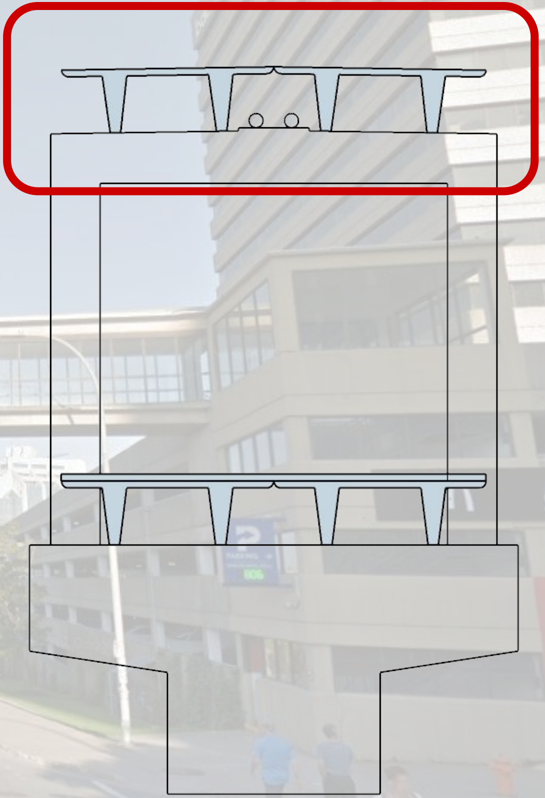
Total unfactored dead load: **<u>9.51 kN/m</u>**

Top Span:

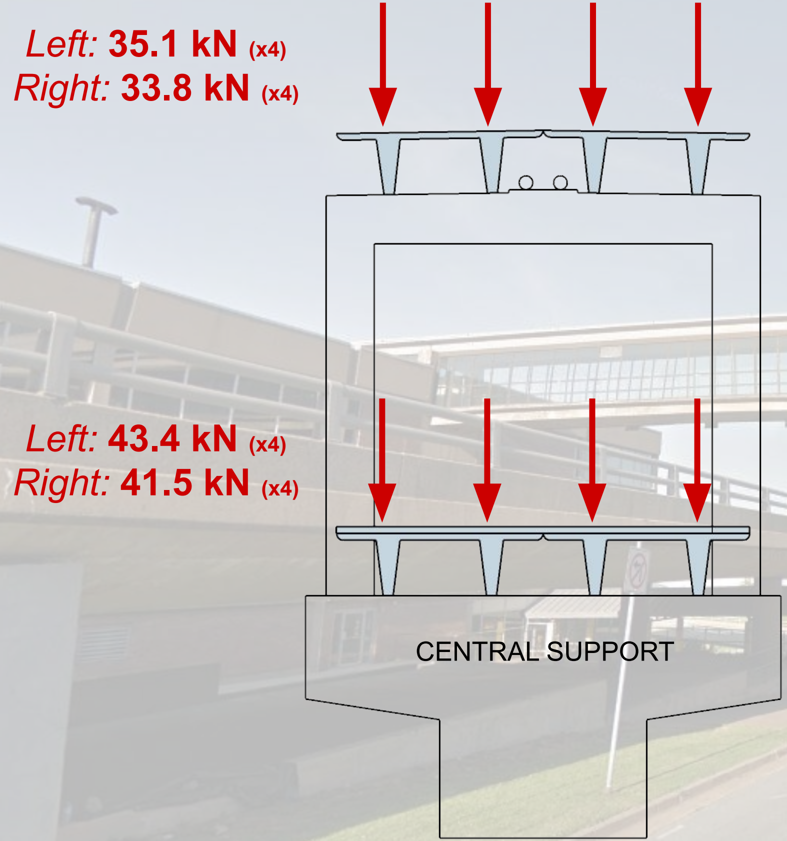
Superimposed dead load (*from plans*): <u>3.65 kN/m</u>

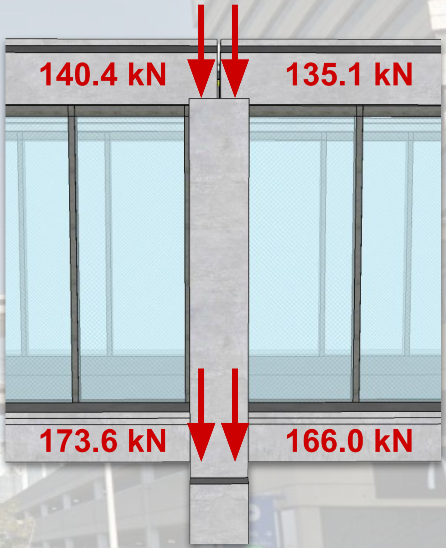
Self-weight dead load: <u>4.05 kN/m</u>

Total unfactored dead load: **<u>7.70 kN/m</u>**



Reactions on Central Support





Assumptions:

- Top span cross slope is insignificant to load results
- Glass cladding does not influence load distribution on outside web
- Cladding, pipes & accessory self-weight is included in plan-prescribed “superimposed dead load”
- Steel reinforcement and prestressing tendons not considered in weight calculations

Live Loads

3.8.9 Pedestrian load

For pedestrian bridges and sidewalks on highway bridges, the pedestrian load applied to the walkway area, *p*, shall be

$$p = 5.0 - \frac{S}{30}$$

but not less than 1.6 kPa and not greater than 4.0 kPa.

- S (span length) : 35.8 m
- p : 3.81 kPa
- Tributary area of span : 89.1 m^2
- Total load on structure : 339.1 kN

Wind Loads

3.10.2.2 Horizontal drag load

The following wind load per unit exposed frontal area of the superstructure shall be applied horizontally:

$$F_h = qC_eC_gC_h$$

where q, C_e, and C_g are as specified in Clauses 3.10.1.2, 3.10.1.4, and 3.10.1.3, respectively, and $C_h = 2.0$.

- *NBCC 2015 Appendix C, Table C-2*: q= 0.59 kPa
- *CSA S6-14*: Ce= 1.1, Cg=2.5
- Fh : 3.245 kPa
- Tributary Area : 121.6 m^2
- Total Load on Structure : 394.7 kN
- Load acts on existing bridge either on *leeward* or *windward* faces, but not simultaneously (East or West)

Wind Loads

3.10.2.3 Vertical load

The following wind load per unit exposed plan area of the superstructure shall be applied vertically:

$$F_V = qC_eC_gC_V$$

where q, C_e, and C_g are as specified in Clauses 3.10.1.2, 3.10.1.4, and 3.10.1.3, respectively, and $C_V = 1.0$.

- Fv : 1.623 kPa
- Tributary Area : 110.9 m^2
- Total Load on Structure 179.9 kN
- Load acts on existing bridge either on *bottom* or top *faces*, but not simultaneously

Ice Accretion Loads

3.12.6 Ice accretion

3.12.6.1 General

Ice accretion loads shall be taken to occur on all exposed surfaces of superstructure members, structural supports, traffic signals, luminaires, and railings. In the case of sign panels, bridge girders, and solid barriers, ice accretion shall be considered to occur on one side only.

- Unit Weight : 9.81 kN/m^3
- Ice thickness : 66mm (from *Figure A3.1.4*)
- Tributary Area : 110.9 m^2
- Total Load on existing structure : 71.7 kN
- Load acts on *top side* of existing structure
- Once member sizes are chosen, ice accretion loads will also act on horizontal members

Snow Loads

- $S=I_s(S_s[C_bC_wC_sC_a]+S_r)$ from NBCC 2015 4.1.6.
- $S_s=1.9$ $S_r=0.6$ from Appendix C Table C-2
- $C_w=1.0$ from Sentences 3 & 4 Clause 4.1.6.2
- $C_b=0.8$ from Sentence 2 (Characteristic Length=5.93 m <70 m)
- $C_s=1.0$ from Sentences 5, 6 and 7
- $C_a=1.0$ from Sentence 8

- S : 2.12 kPa
- Tributary Area : 110.9 m2 (same as vertical wind load)
- Total Load on existing structure : 235.1 kN
- Snow Loads can also be applied on horizontal truss members

Seismic Loads

CSA S6-14- procedure

Site Class C

PGA (0.1)

- $k = \frac{PL}{Vsmax}$

- $Ta = 2\pi\sqrt{\frac{W}{gK}}$

Table 4.6
Values of $F(5.0)$ as a function of Site Class and PGA_{ref}
(See Clause 4.4.3.3 and Table 4.1.)

Site Class	Values of $F(5.0)$				
	$PGA_{ref} \le 0.1$	$PGA_{ref} = 0.2$	$PGA_{ref} = 0.3$	$PGA_{ref} = 0.4$	$PGA_{ref} \ge 0.5$
A	0.61	0.61	0.61	0.61	0.61
B	0.64	0.64	0.64	0.64	0.64
C	1.00	1.00	1.00	1.00	1.00
D	1.58	1.48	1.41	1.37	1.34
E	2.93	2.40	2.14	1.96	1.84
F	*	*	*	*	*

*Site-specific evaluation is required to determine F(T), F(PGA), and F(PGV) for Site Class F.

$$S(T) = F(0.2)S_a(0.2) \text{ or } F(0.5)S_a(0.5) \text{ whichever is larger for } T \le 0.2 \text{ s}$$
$$= F(0.5)S_a(0.5) \text{ for } T = 0.5 \text{ s}$$
$$= F(1.0)S_a(1.0) \text{ for } T = 1.0 \text{ s}$$
$$= F(2.0)S_a(2.0) \text{ for } T = 2.0 \text{ s}$$

- $V = S(T)IeW$

- $P = \frac{V}{L}$

Ta=3.8

Uniform Seismic load = 2.53kN/m

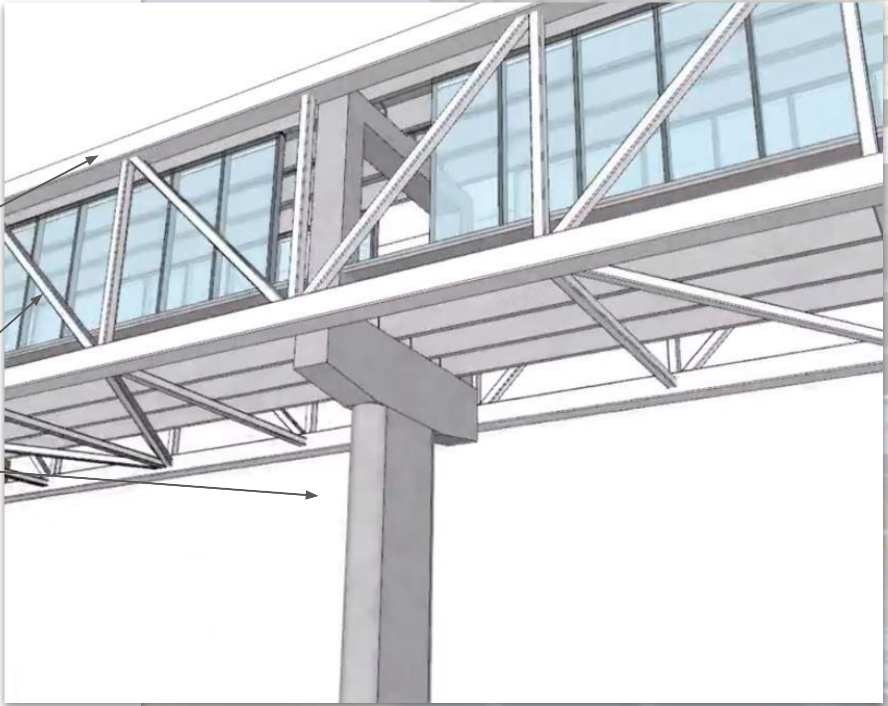
Seismic point load = 95.3kN

Seismic Loads

Table 4.17
Response modification factors, R, for substructure elements designed and detailed in accordance with Clauses 4.7 and 4.8
(See Clauses 4.4.7.2 and 4.4.10.4.2.)

Ductile substructure elements	Response modification factor, R
Wall-type piers*	
In direction of larger dimension	2.0
Reinforced concrete pile bents or drilled shafts	
Vertical piles or drilled shafts	3.0
With batter piles	2.0
Single columns	
Ductile reinforced concrete	4.0
Ductile steel	4.0
Steel or composite steel and concrete pile bents	
Vertical piles only	5.0
With batter piles	3.0
Multiple-column bents	
Ductile reinforced concrete	5.0
Ductile steel columns or frames	5.0
Steel braced frames	
Ductile steel braces	4.0
Eccentrically braced frames	4.0
Buckling restrained braced frames	4.0
Steel ductile diaphragms	See Clause 4.8.5

**A wall-type concrete pier may be treated as a single ductile reinforced concrete column in the weak direction of the pier if all of the requirements for columns specified in Clause 4.7.5.2 are satisfied.*



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Temperature Effects

- 73 degree effective temperature range
- Thermal compressive/expansive forces will be considered on truss members only
- Roller support with guided elastomeric bearing holes to provide area for truss movement

3.9.4.1 Temperature range

The temperature range shall be the difference between the maximum and minimum effective temperatures as specified in Table 3.8 for the type of superstructure. The temperature range shall be modified in accordance with the depth of the superstructure as indicated in Figure 3.5. The maximum and minimum mean daily temperature shall be taken from Figures A3.1.1 and A3.1.2.

Project Overview

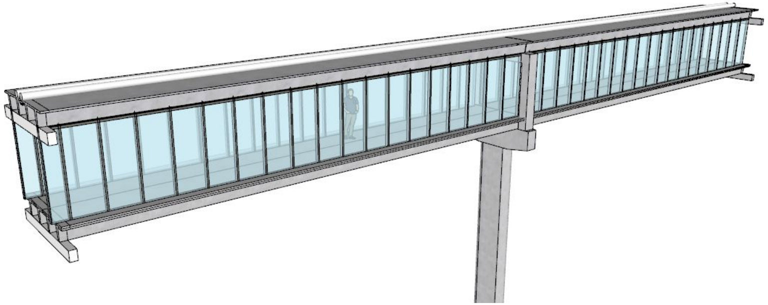
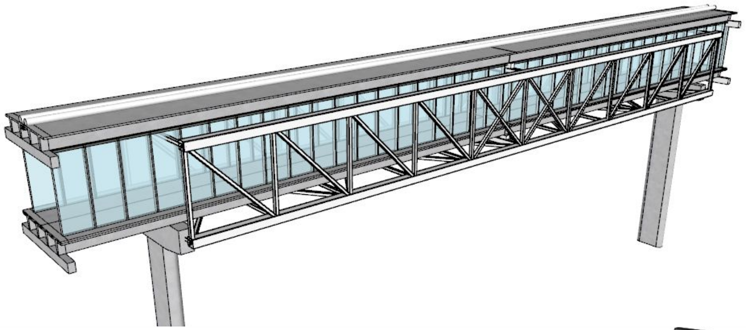
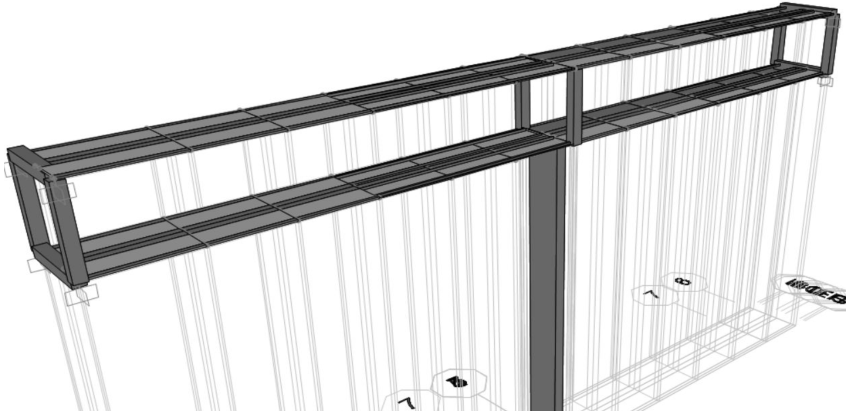
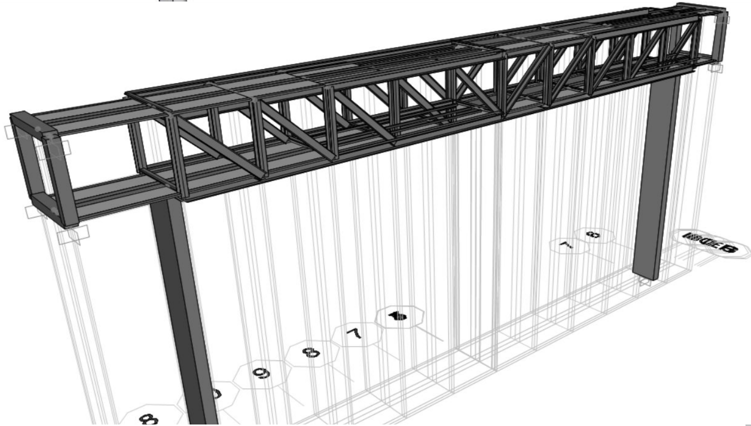
Existing Loads

Modelling and Analysis

Detail Design

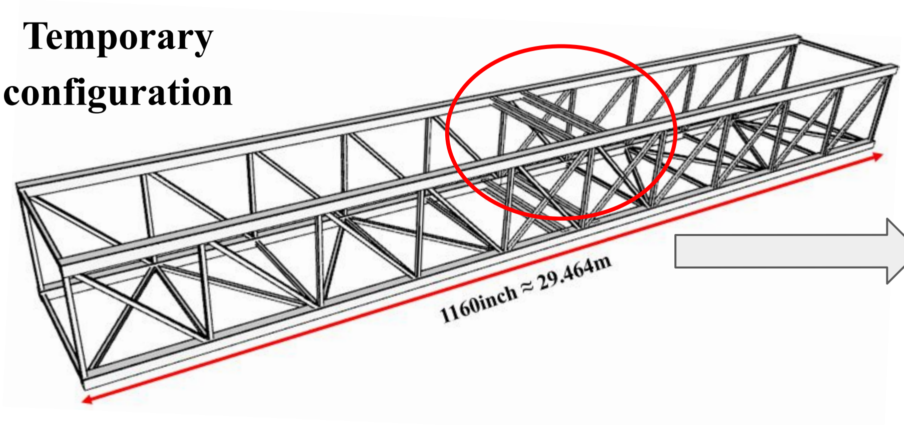
Implementation

SAP2000 modeling

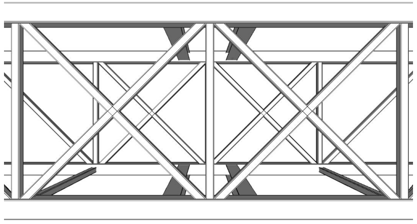
	Bridge (Original)	Bridge (After construction)
SketchUP Models		
SAP2000 Models		

Modeling —— Temporary & Permanent

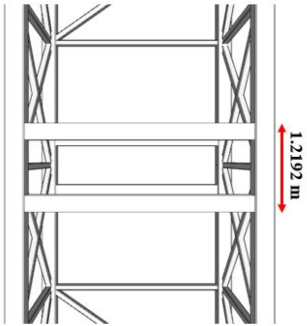
Temporary configuration



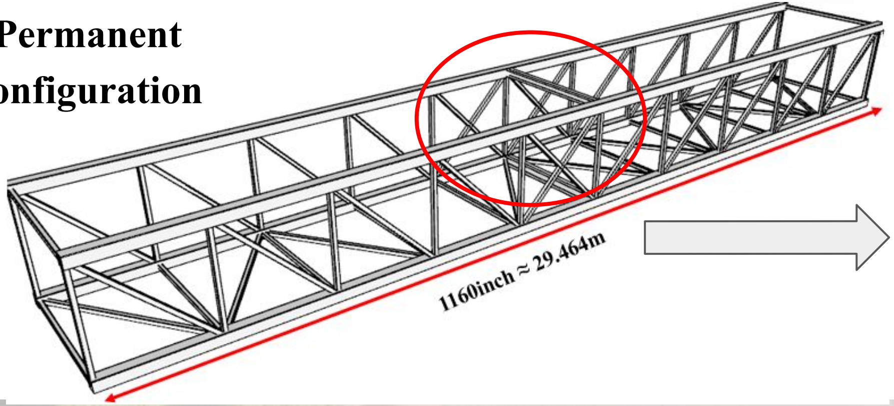
Front view

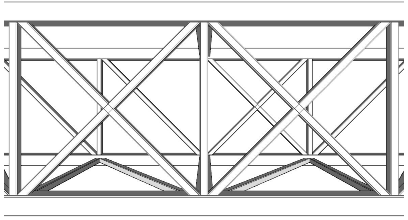


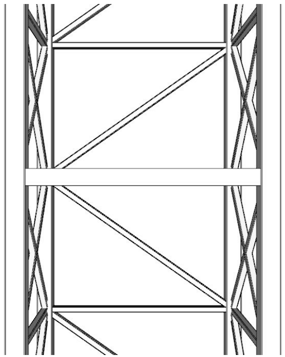
Top view



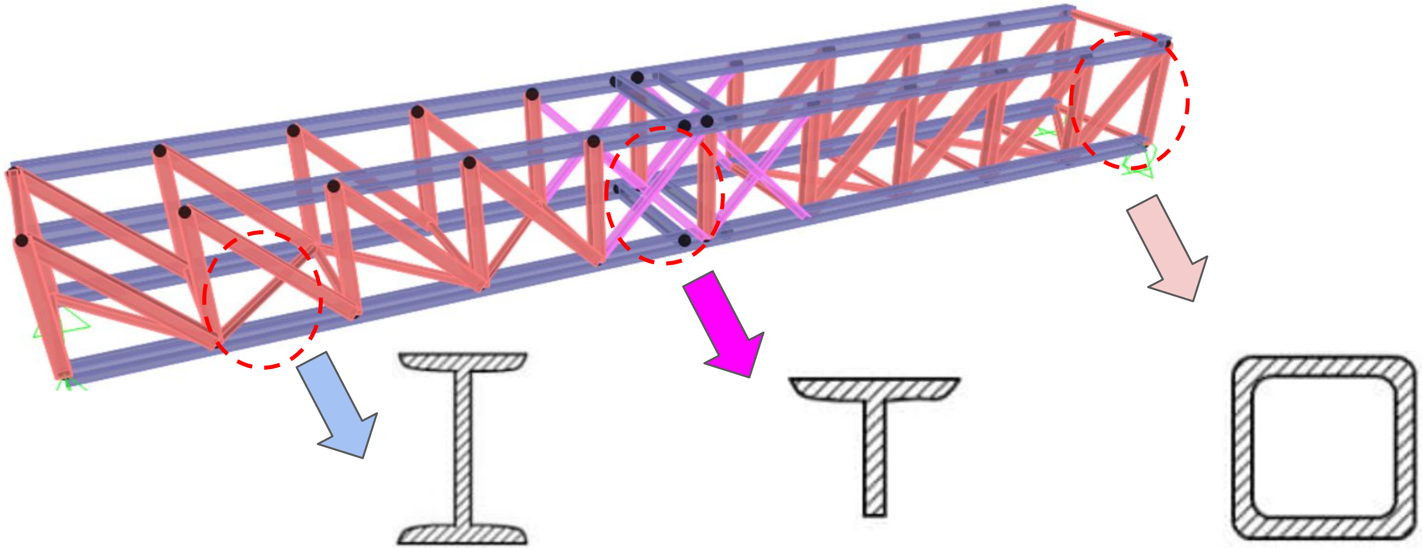
Permanent configuration







Modeling —— Sections & Materials (Temporary)



W section (blue section)

ASTM A992 Grade 50
Fy = 345 MPa
Fu = 450 MPa

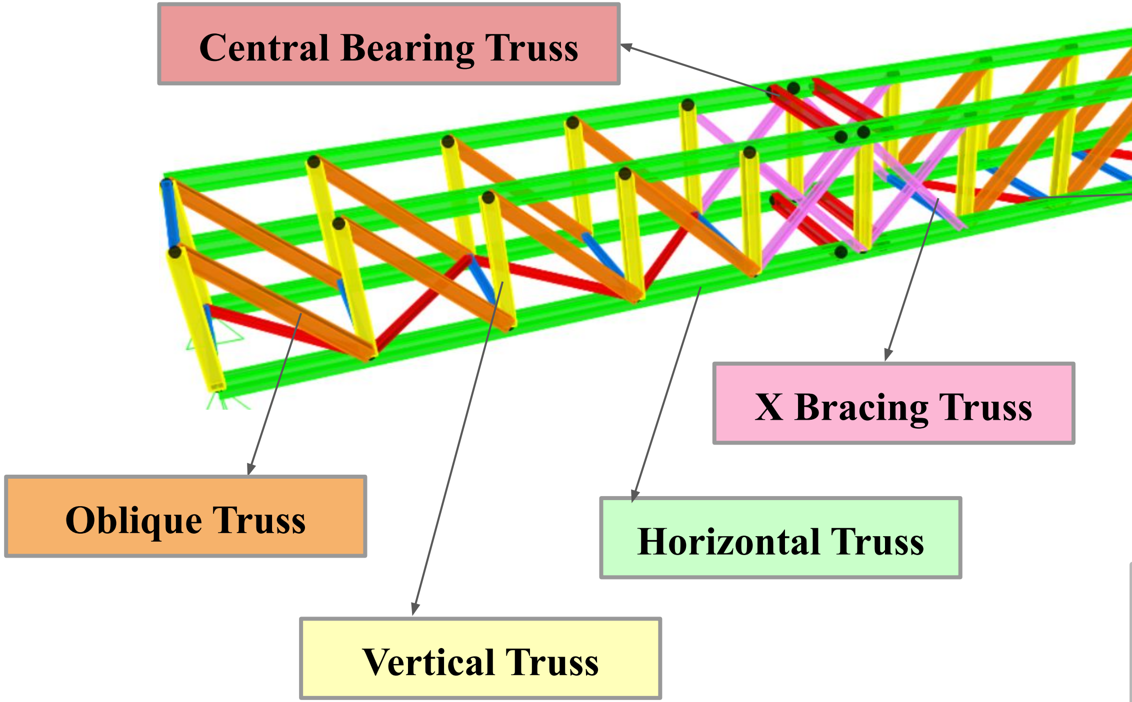
WT section (pink section)

ASTM A992 Grade 50
Fy = 345 MPa
Fu = 450 MPa

HSS section (red section)

CSA G40.21 350W Class H
Fy = 350 MPa
Fu = 450 MPa

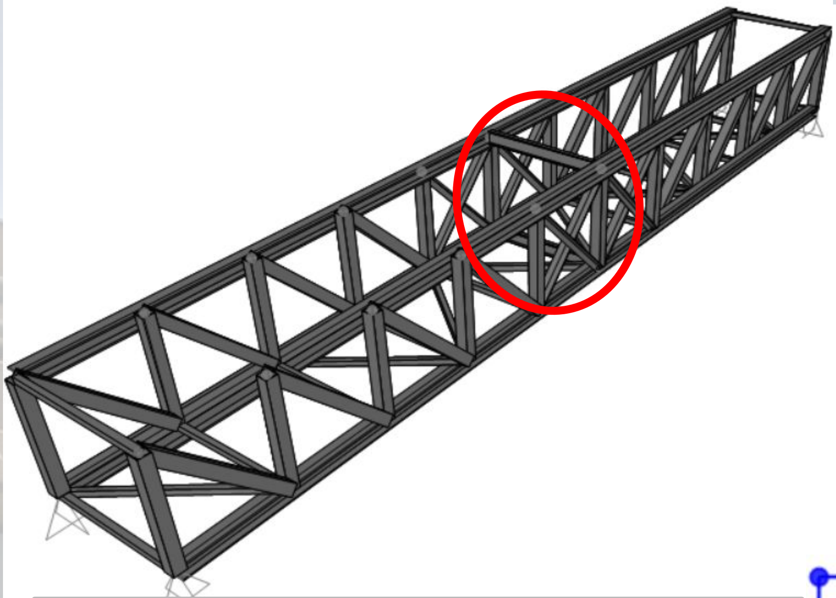
Modeling —— Auto-Selection Setting (Temporary)

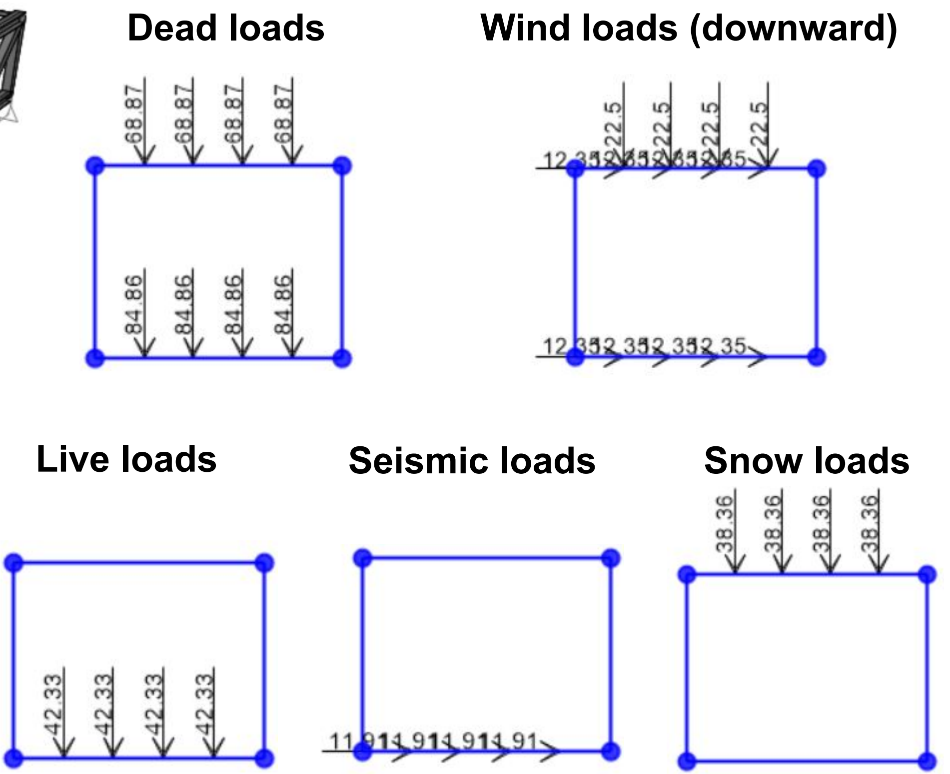


Use **Auto-Selection** function to identify the size of different truss groups. The trusses within a same group should have a same member size as the output of the auto-selection

The permanent configuration follows the same grouping methodology

Analysis —— Assigning Loads



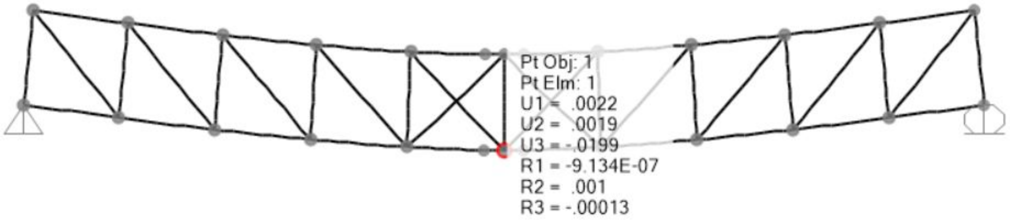


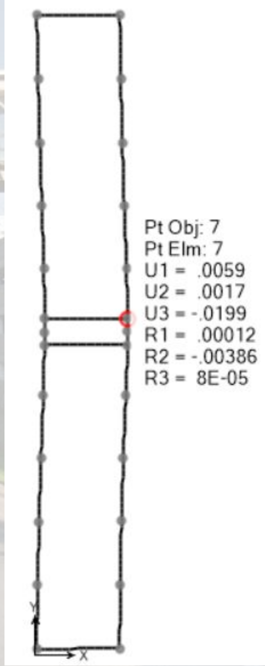
<u>For the permanent configuration</u>, all loads are concentrated on the central bearing truss. *<u>For the temporary configuration</u>*, all loads are divided by two and exert on two temporary bearing trusses

Analysis —— Results for Temporary Config

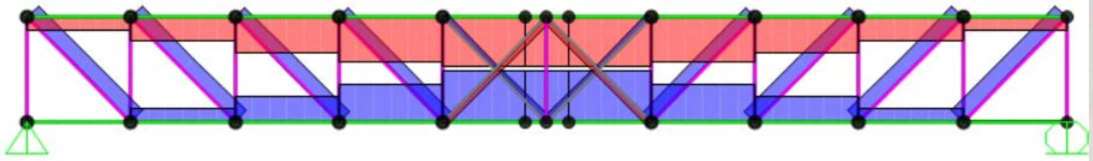
The vertical deflection:
The most severe load combination
1.1D+1.5L+0.45W
The maximum vertical deflection: 19.9mm

The lateral deflection:
The most severe load combination
1.1D+1.5L+0.45W
The maximum lateral deflection: 1.7mm





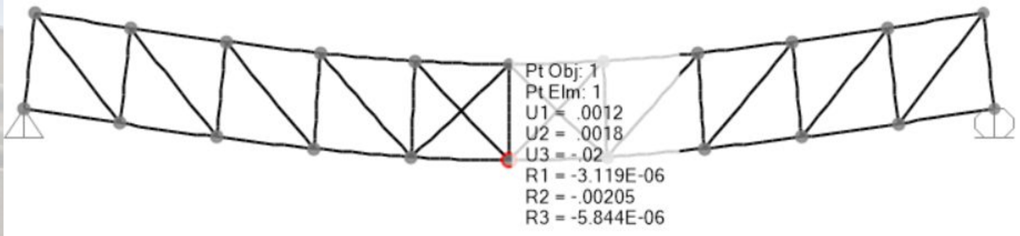
Axial loads —— 1.1D+1.5L+0.45W
Maximum axial loads
Truss along the bridge = 1448.973 kN (T)
Diagonal truss = 466.045 kN (T)
Vertical column = 355.728 kN (C)

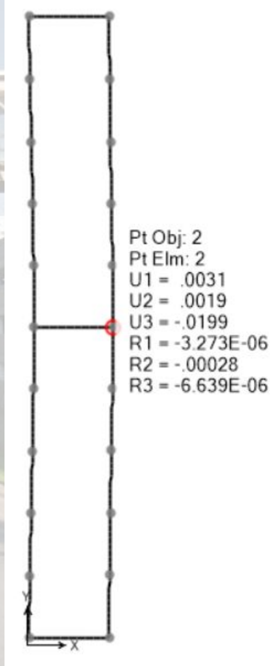


Analysis —— Results for Permanent Config

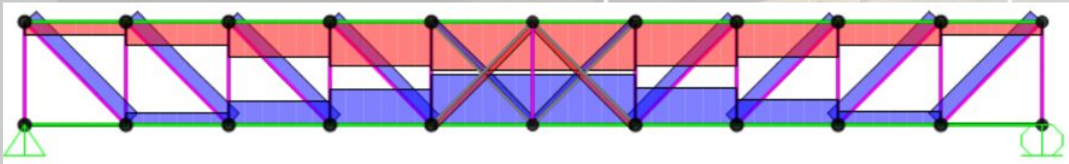
The vertical deflection:
The most severe load combination
1.1D+1.5L+0.45W
The maximum vertical deflection: 20 mm

The lateral deflection:
The most severe load combination
1.1D+1.5L+0.45W
The maximum lateral deflection: 1.9 mm

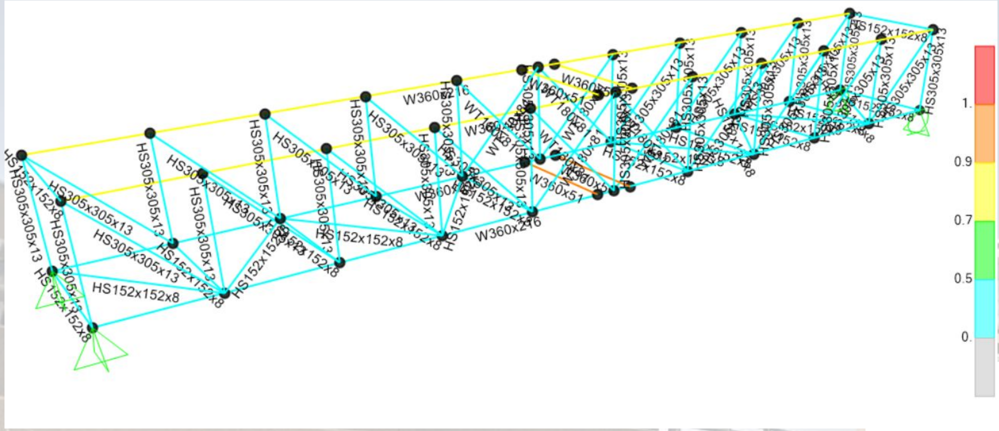




Axial loads —— 1.1D+1.5L+0.45W
Maximum axial loads
Truss along the bridge = 1446.532 kN (T)
Diagonal truss = 466.145 kN (T)
Vertical column = 355.619 kN (C)

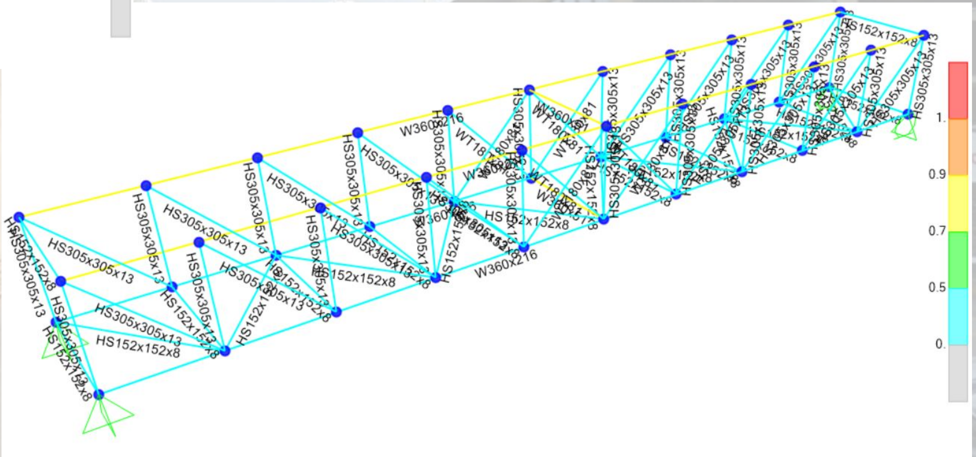


Analysis —— Auto-Selection Results

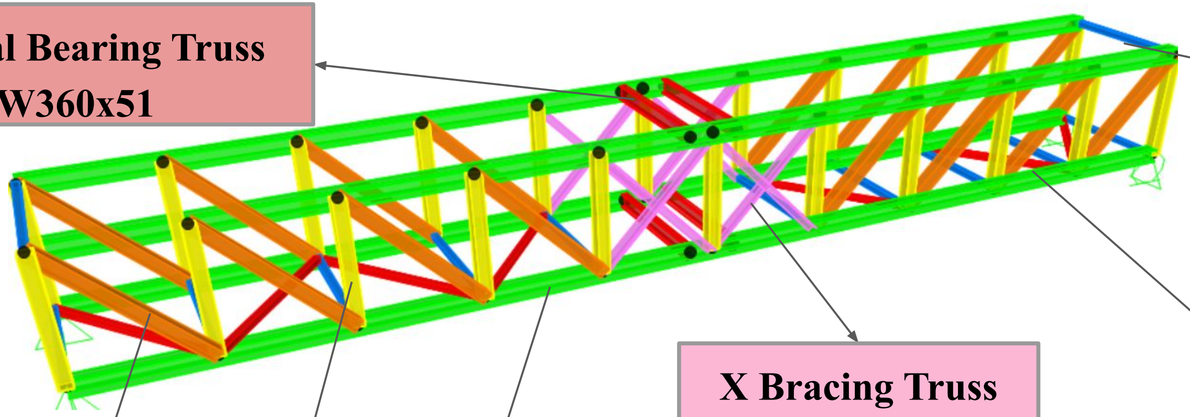


Design result for the temporary configuration: According to the capacity spectrum, all truss sizes fall in to an acceptable range of capacity

Design result for the permanent configuration: According to the capacity spectrum, all truss sizes fall in to an acceptable range of capacity



Analysis —— Auto-Selection Result



By summarizing the design of truss size for both temporary and permanent configurations (as indicated in the previous slide), the final decision for the truss sizes is shown above

Project Overview

Existing Loads

Modelling and Analysis

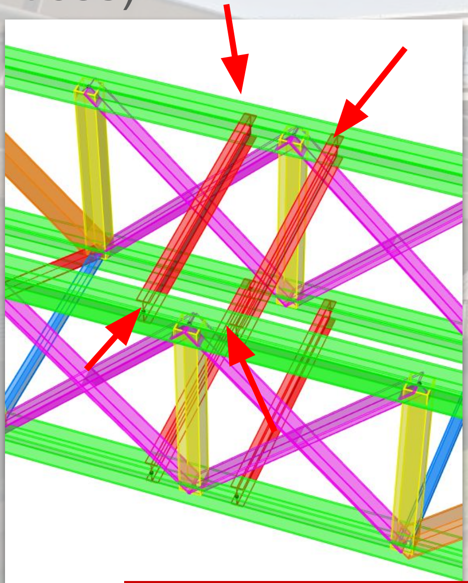
Detail Design

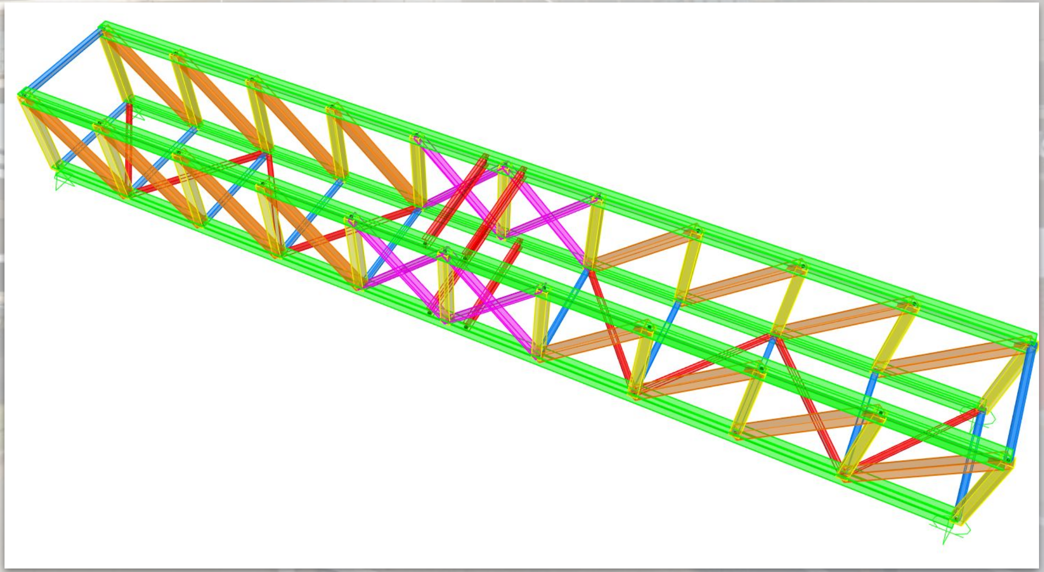
Implementation

Analysis —— Connection Design

Based on results from temporary configuration SAP2000 analysis

<u>Assumption:</u> temporary configuration brings about worst-case stress scenario in **all** members due to inefficiency of central loading (not concentric with truss vertical & diagonal bracing vertices)

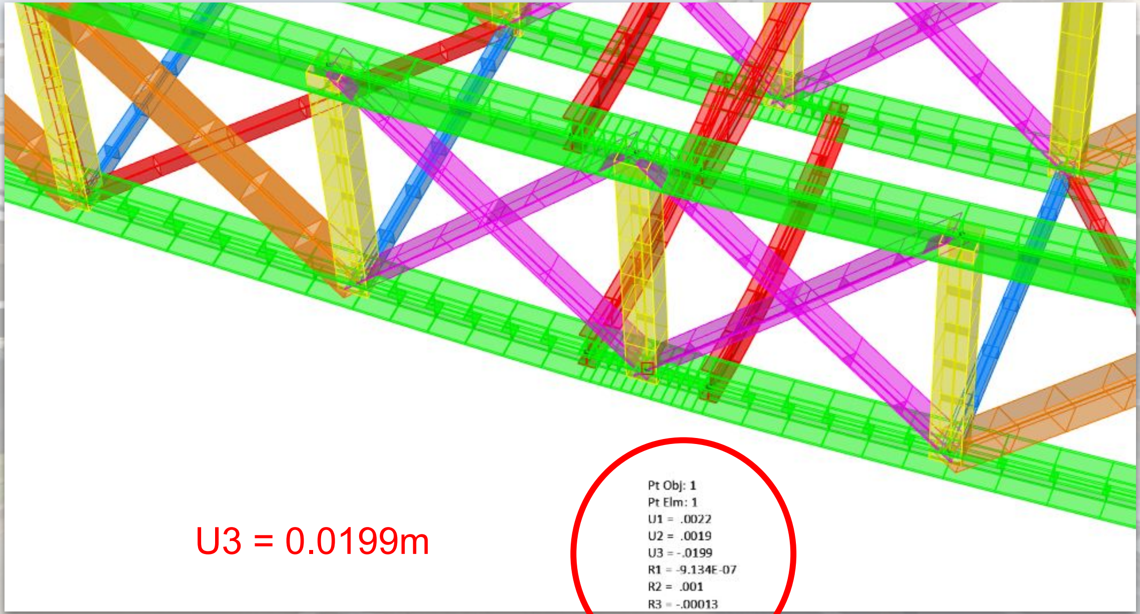




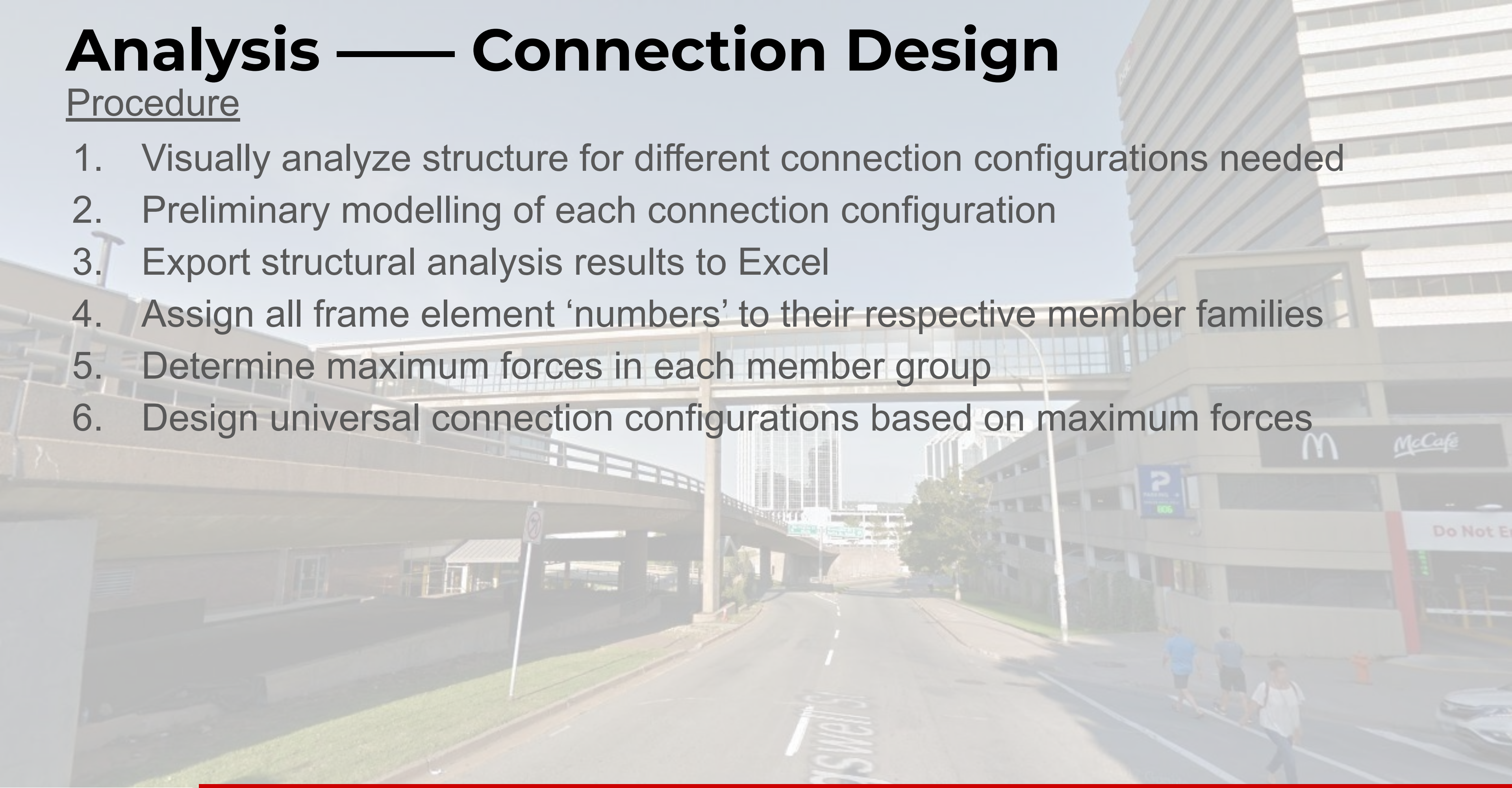
Analysis —— Connection Design

Based on results from temporary configuration SAP2000 analysis

Load case/combo **1.1D + 1.5L + 0.45W** subjects the structure to the worst deflection case at critical central point and the forces induced by this load combination assumed to be worst-case



Analysis —— Connection Design

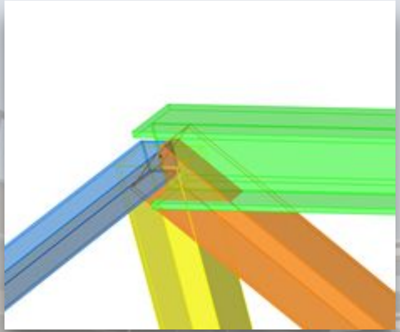


Procedure

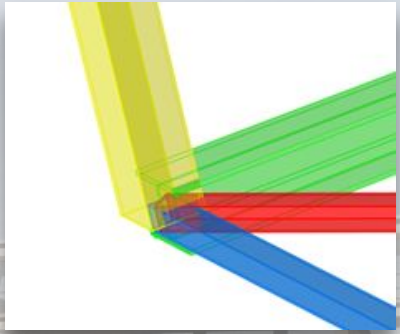
1. Visually analyze structure for different connection configurations needed
2. Preliminary modelling of each connection configuration
3. Export structural analysis results to Excel
4. Assign all frame element ‘numbers’ to their respective member families
5. Determine maximum forces in each member group
6. Design universal connection configurations based on maximum forces

Analysis —— Connection Design

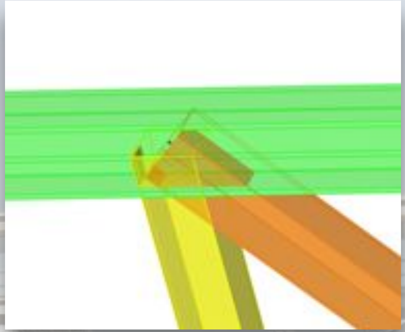
1. Visually analyze structure for different connection configurations needed



Type 1



Type 2



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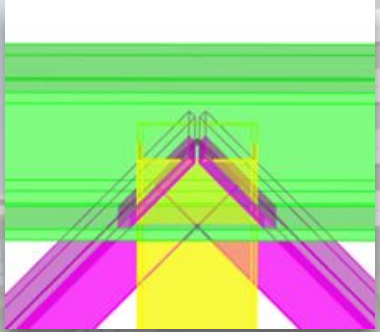

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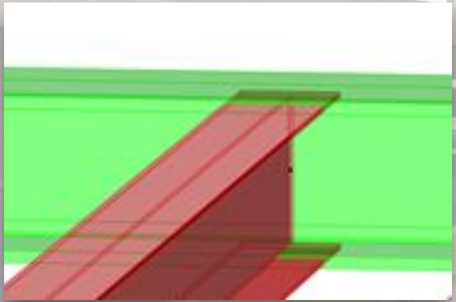

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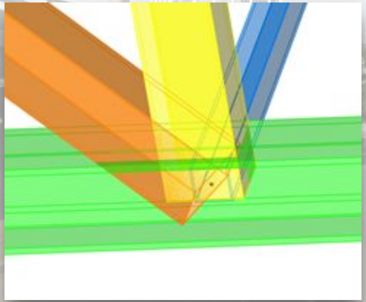

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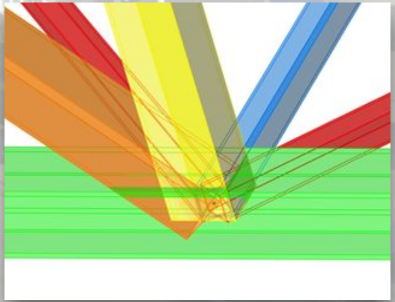
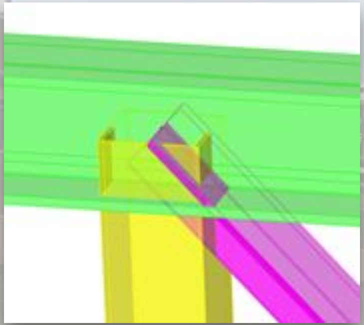


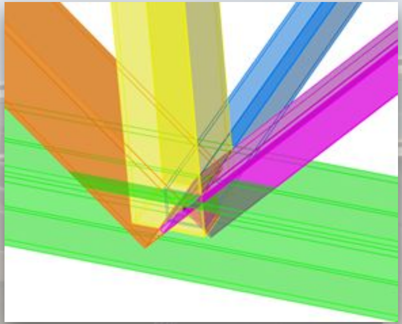
Type 7

Analysis —— Connection Design

1. Visually analyze structure for different connection configurations needed



Type 8



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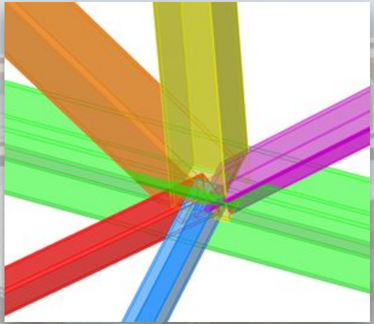
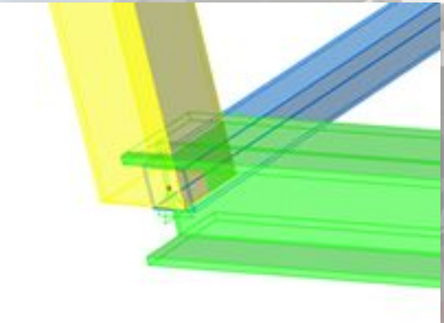


Type 10



Type 11

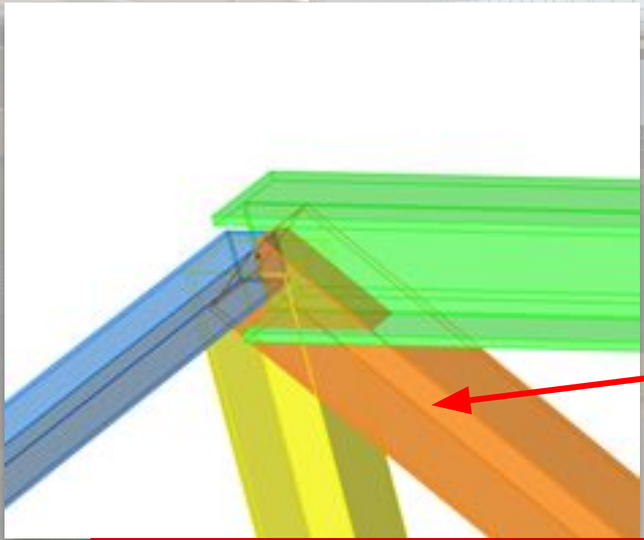
Analysis —— Connection Design

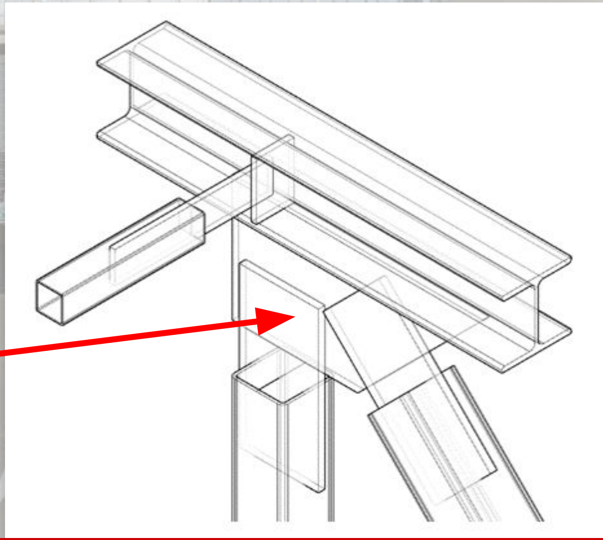
2. Preliminary modelling of each connection configuration

Divided all connection types into further groups:

<u>Connections involving members in the X-Y plane</u>

- All connections connected by a gusset plate welded to the center of the W-section flange





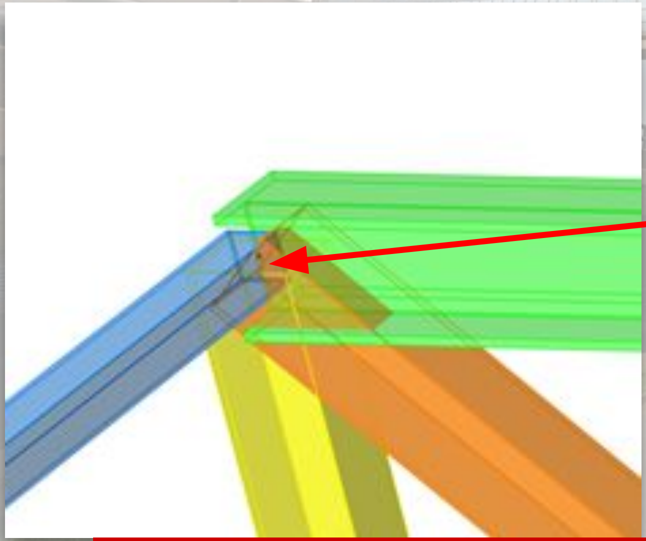
Analysis —— Connection Design

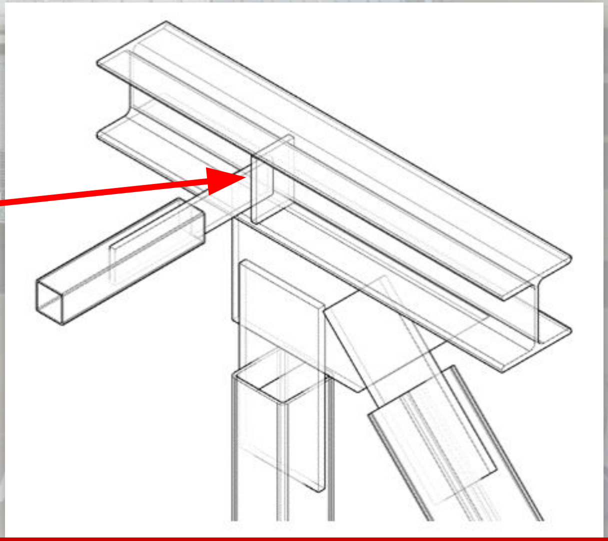
2. Preliminary modelling of each connection configuration

Divided all connection types into further groups:

<u>Connections involving members in the X-Z plane</u>

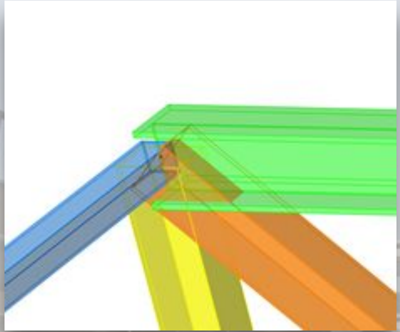
- All connections connected by a shear stiffener-type plate welded to the inside of the W-section web

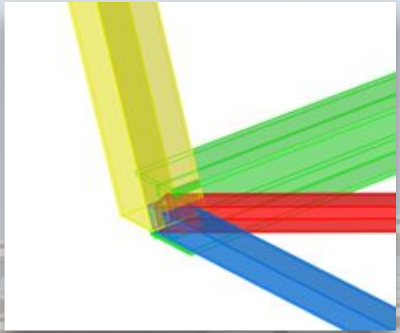


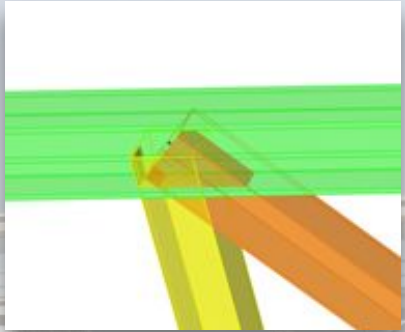


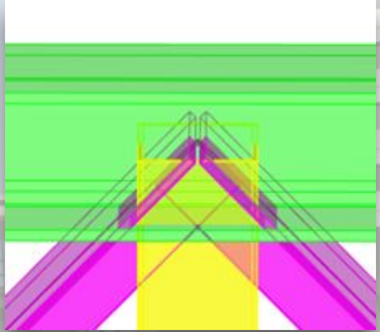
Analysis —— Connection Design

2. Preliminary modelling of each connection configuration

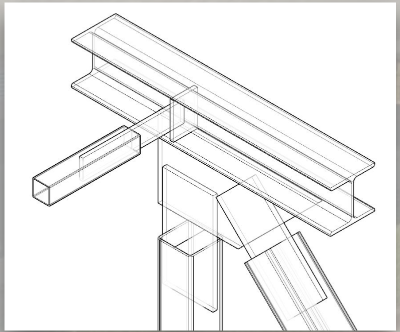


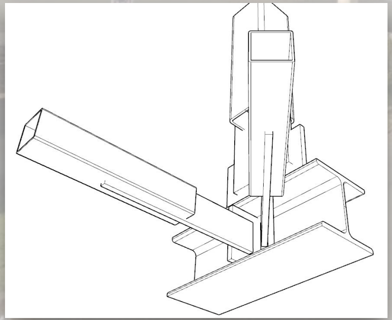


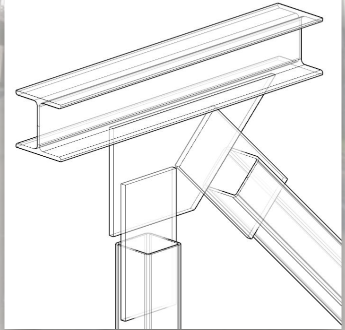


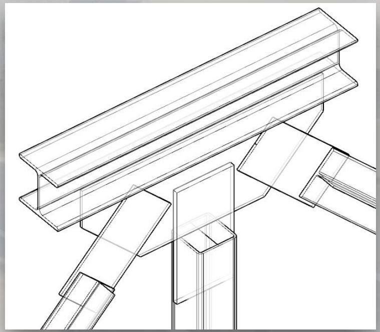


Type 1 *Type 2* *Type 3* *Type 4*



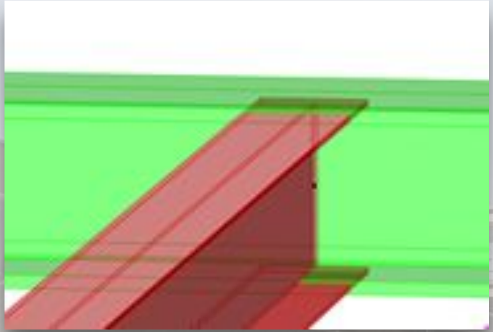


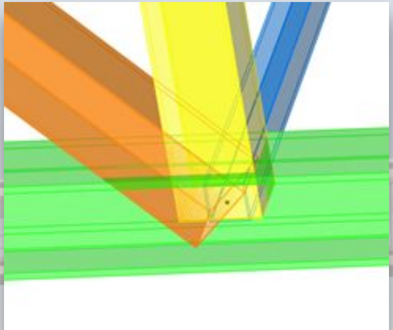


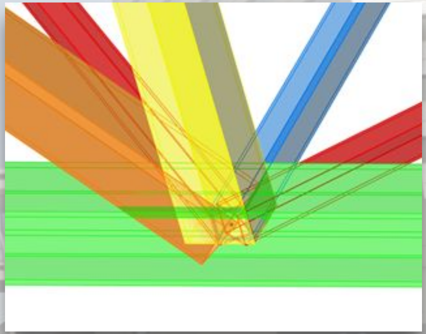


Analysis —— Connection Design

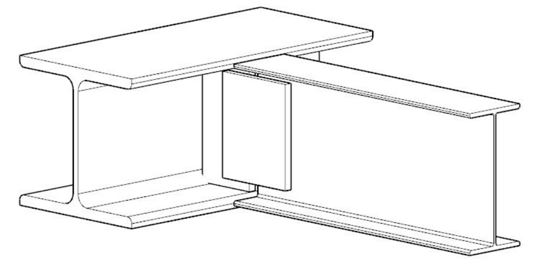
2. Preliminary modelling of each connection configuration

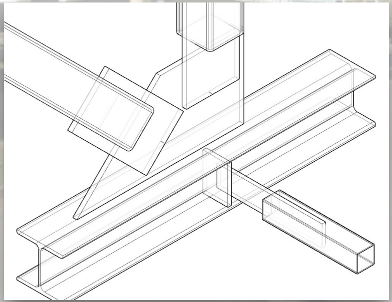


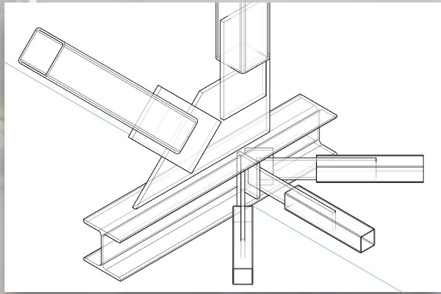




Type 5 *Type 6* *Type 7*

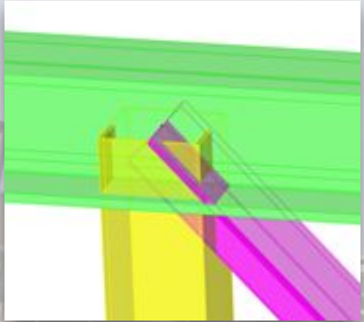
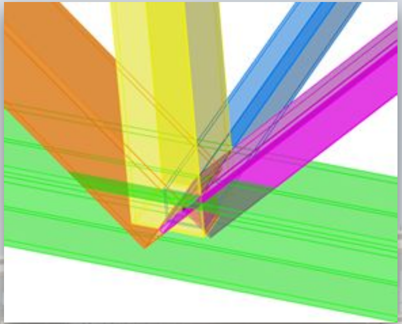
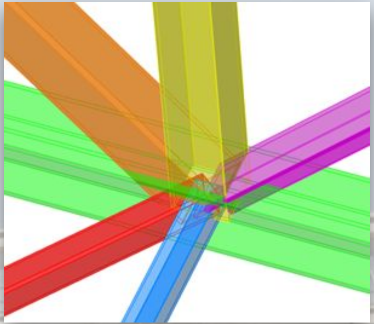
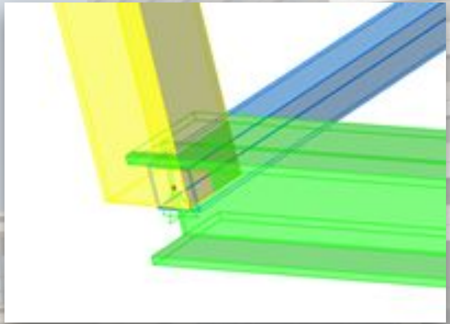






Analysis —— Connection Design

2. Preliminary modelling of each connection configuration

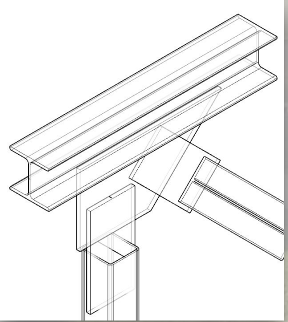
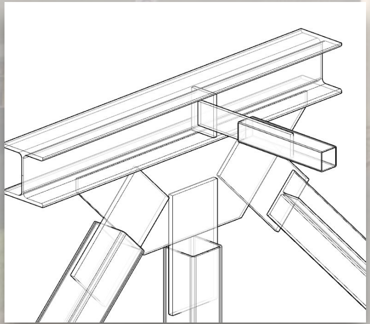
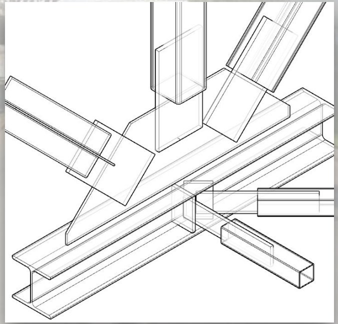
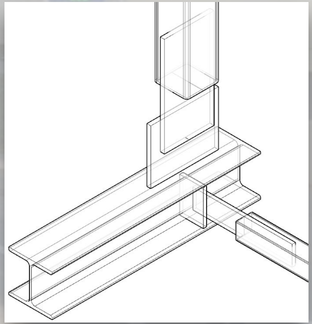





Type 8

Type 9

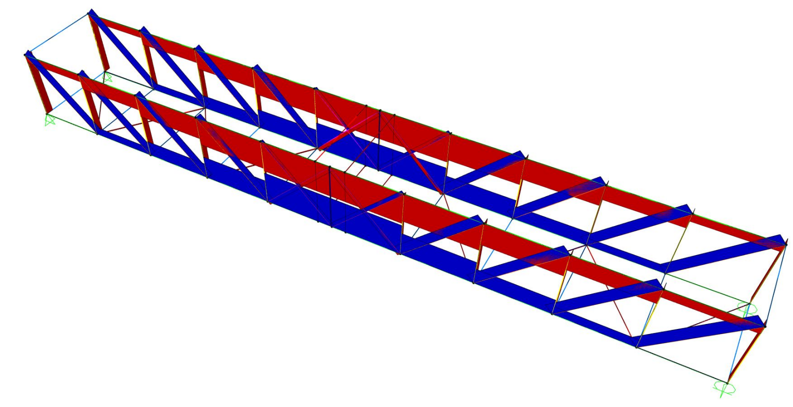
Type 10

Type 11

Analysis —— Connection Design

3. Export structural analysis results to Excel



SAP2000 structural analysis results

x							
Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
6	1.1D+1.5L+0.45W	144.097	1.195	-0.823	0.008	-0.1456	-0.0778
7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

3. Export structural analysis results to Excel

<u>‘Frame Number’ column:</u>

Numerical identification of frame element (individual truss member)

Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
6	1.1D+1.5L+0.45W	144.097	1.195	-0.823	0.008	-0.1456	-0.0778
7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

3. Export structural analysis results to Excel

<u>'Axial Force' column:</u>

Axial force in individual frame element

(negative implies a compressive force)

x							
Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
6	1.1D+1.5L+0.45W	144.097	1.195	-0.823	0.008	-0.1456	-0.0778
7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

3. Export structural analysis results to Excel

<u>'Shear Force' columns:</u>

Shear force in individual frame element.

Assumption: All connections are pinned; shear not considered for any frame elements *except* W-shaped members

Note: minimal shear (<2 kN for all HSS members)

x								
Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
6	1.1D+1.5L+0.45W	144.097	1.195	-0.823	0.008	-0.1456	-0.0778
7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

3. Export structural analysis results to Excel

<u>‘Torsional Force’ columns:</u>
Torsion force in individual frame element.

Assumption: All connections are pinned; torsion not considered for any frame elements.

Note: minimal torsion (<2 kN-m for all HSS members)

x							
Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
6	1.1D+1.5L+0.45W	144.097	1.195	-0.823	0.008	-0.1456	-0.0778
7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

3. Export structural analysis results to Excel

<u>'Moment' columns:</u>

Moments in individual frame element.

Assumption: All connections are pinned; moment not considered for any frame elements.

Note: minimal moment (<2 kN-m for all HSS members)

x							
Frame	OutputCase	P	V2	V3	T	M2	M3
numbe	Text	KN	KN	KN	KN-m	KN-m	KN-m
2	1.1D+1.5L+.45W	151.238	-1.181	-0.775	-0.0133	-2.0418	-0.016
2	1.1D+1.5L+0.45W	149.954	0.104	-0.775	-0.0133	-0.4274	1.1056
2	1.1D+1.5L+0.45W	148.669	1.389	-0.775	-0.0133	1.187	-0.4495
3	1.1D+1.5L+0.45W	148.852	-1.389	0.647	0.015	0.101	-0.45
3	1.1D+1.5L+0.45W	150.137	-0.104	0.647	0.015	-1.2465	1.1055
3	1.1D+1.5L+0.45W	151.422	1.181	0.647	0.015	-2.5939	-0.0158
4	1.1D+1.5L+0.45W	-160.195	-1.114	-1.081	-0.0126	-2.0938	0.1954
4	1.1D+1.5L+0.45W	-158.91	0.17	-1.081	-0.0126	0.1587	1.1789
4	1.1D+1.5L+0.45W	-157.626	1.455	-1.081	-0.0126	2.4111	-0.5144
5	1.1D+1.5L+0.45W	-157.519	-1.455	1.503	0.0094	3.4286	-0.5144
5	1.1D+1.5L+0.45W	-158.804	-0.17	1.503	0.0094	0.2972	1.1789
5	1.1D+1.5L+0.45W	-160.089	1.114	1.503	0.0094	-2.8343	0.1955
6	1.1D+1.5L+0.45W	141.527	-1.375	-0.823	0.008	-3.5754	-0.4518
6	1.1D+1.5L+0.45W	142.812	-0.09	-0.823	0.008	-1.8605	1.0736
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7	1.1D+1.5L+0.45W	-165.444	-1.095	-0.381	-0.0114	-0.5622	0.2082
7	1.1D+1.5L+0.45W	-164.16	0.19	-0.381	-0.0114	0.2319	1.1507
7	1.1D+1.5L+0.45W	-162.875	1.475	-0.381	-0.0114	1.026	-0.5835
8	1.1D+1.5L+0.45W	-162.99	-1.475	0.848	0.0081	2.1623	-0.5837
8	1.1D+1.5L+0.45W	-164.274	-0.19	0.848	0.0081	0.3954	1.1507
8	1.1D+1.5L+0.45W	-165.559	1.095	0.848	0.0081	-1.3716	0.2085

Tabulated SAP2000 analysis results

Analysis —— Connection Design

4. Assign all frame element ‘numbers’ to their respective member families

CONNECTION 1	a
W360x216	83
HS305D	165
HS305V	164
HS152	42
CONNECTION 1	**b**
W360x216	82
HS305D	166
HS305V	162
HS152	42
CONNECTION 1	**c**
W360x216	83
HS305D	171
HS305V	170
HS152	64
CONNECTION 1	**d**
W360x216	82
HS305D	172
HS305V	168
HS152	64

CONNECTION 2	a
W360x216	15
HS152	43
HS152D	76
HS305V	164
CONNECTION 2	**b**
W360x216	15
HS152	66
HS152D	72
HS305V	170

SAP numerical frame identifier is assigned to each member family & then further divided into each connection group

Analysis —— Connection Design

4. Assign all frame element ‘numbers’ to their respective member families

CONNECTION 1	a
W360x216	83
HS305D	165
HS305V	164
HS152	42
CONNECTION 1	b
W360x216	82
HS305D	166
HS305V	162
HS152	42
CONNECTION 1	c
W360x216	83
HS305D	171
HS305V	170
HS152	64
CONNECTION 1	d
W360x216	82
HS305D	172
HS305V	168
HS152	64

CONNECTION 2	a
W360x216	15
HS152	43
HS152D	76
HS305V	164
CONNECTION 2	b
W360x216	15
HS152	66
HS152D	72
HS305V	170

SAP numerical frame identifier is assigned to each member family & then further divided into each connection group

Member Family
W360x216
HS305D
HS305V
HS152
HS152D
W360x51
WT180

Analysis —— Connection Design

5. Determine maximum forces in each member group

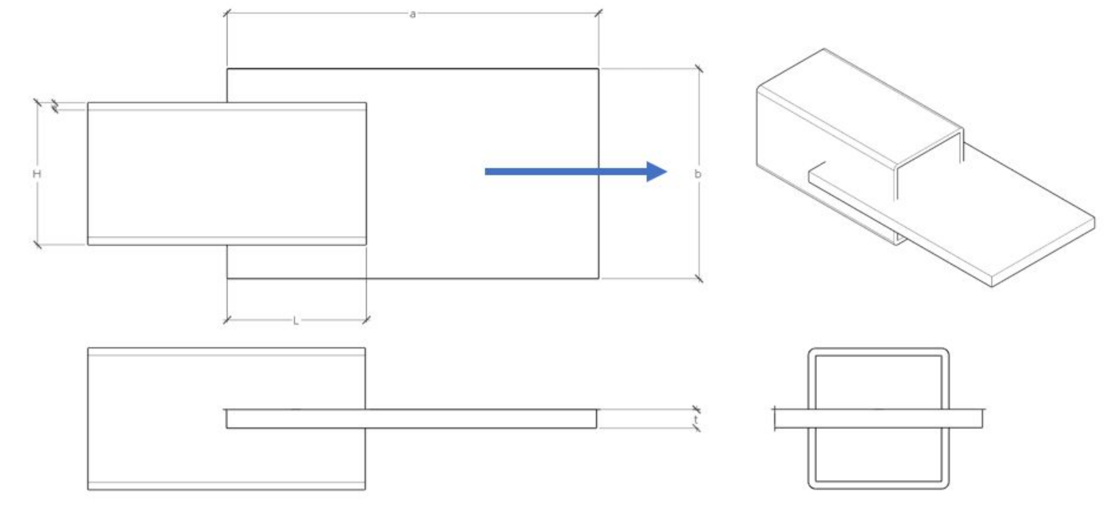
Using *array lookup functions* within excel, maximum and minimum (opposite direction) forces are determined for each member family

	Maximum Forces in Members						
	Member Family	P (kN)	V2 (kN)	V3 (kN)	T (kN-m)	M2 (kN-m)	M3 (kN-m)
Max +ve	W360x216	1449.0	135.4	8.9	6.6	15.7	72.1
Max -ve		-1390.9					
Max +ve	HS305D	466.0	6.2	0.7	0.6	2.4	10.3
Max -ve				-0.8		-3.6	
Max +ve	HS305V	75.0	0.9	17.8	0.5	27.4	12.3
Max -ve		-355.7	-5.6	-18.5	-3.3		
Max +ve	HS152	11.0	2.9		0.1	1.8	3.8
Max -ve		-7.3		-0.9	0.0		
Max +ve	HS152D	42.9	1.0		0.1	0.5	1.9
Max -ve		-30.5	-1.8	-0.2			
Max +ve	W360x51	10.3	158.4			0.9	173.0
Max -ve				-0.5	0.0		
Max +ve	WT180	151.4	1.5	1.5	0.0	3.4	1.2
Max -ve		-165.6		-1.1		-3.6	

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

HSS 305 - end sandwich plate weld design



Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

HSS 305 - end sandwich plate weld design

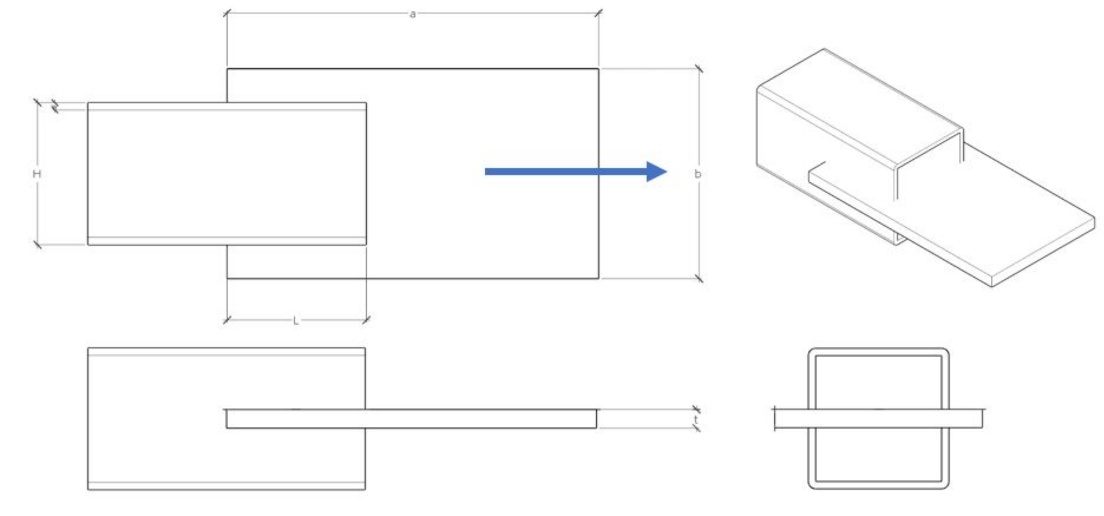
Member Family	P (kN)	V2 (kN)	V3 (kN)	T (kN-m)	M2 (kN-m)	M3 (kN-m)
HS305D	466.0	6.2	0.7	0.6	2.4	10.3
	0.0	0.0	-0.8	0.0	-3.6	0.0
HS305V	75.0	0.9	17.8	0.5	27.4	12.3
	-355.7	-5.6	-18.5	-3.3	0.0	0.0

Weld designed to resist strongest axial force in all HSS 305 members (vertical and diagonal members)

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

HSS 152 - end sandwich plate weld design



Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

HSS 152 - end sandwich plate weld design

	P (kN)	V2 (kN)	V3 (kN)	T (kN-m)	M2 (kN-m)	M3 (kN-m)
HS152D	42.9	1.0	0.0	0.1	0.5	1.9
	-30.5	-1.8	-0.2	0.0	0.0	0.0
HS152H	11.0	2.9	0.0	0.1	1.8	3.8
	-7.3	0.0	-0.9	0.0	0.0	0.0

Weld designed to resist strongest axial force in all HSS 152 members (horizontal and diagonal members)

Universal end-plates & welds

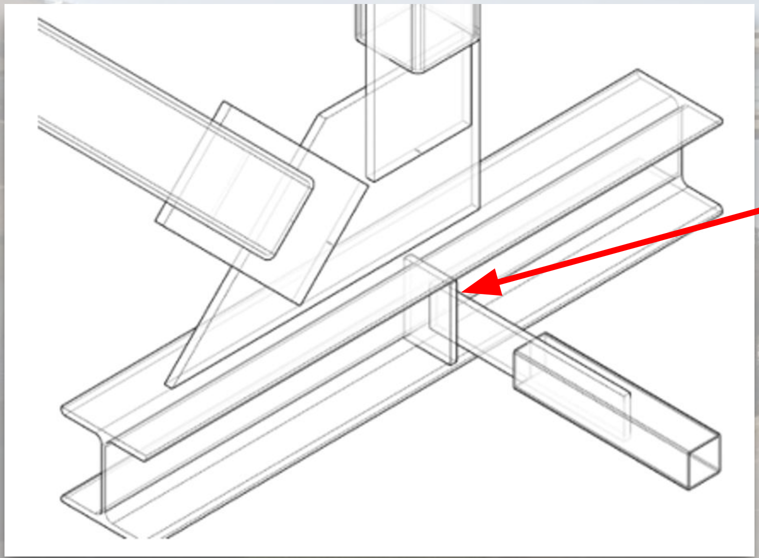
To reduce final cost, the strongest weld is applied to all end-plate welds for HSS members

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

HSS 152 - end sandwich plate weld design

Additional physical restraints:



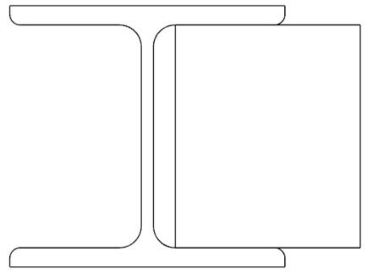
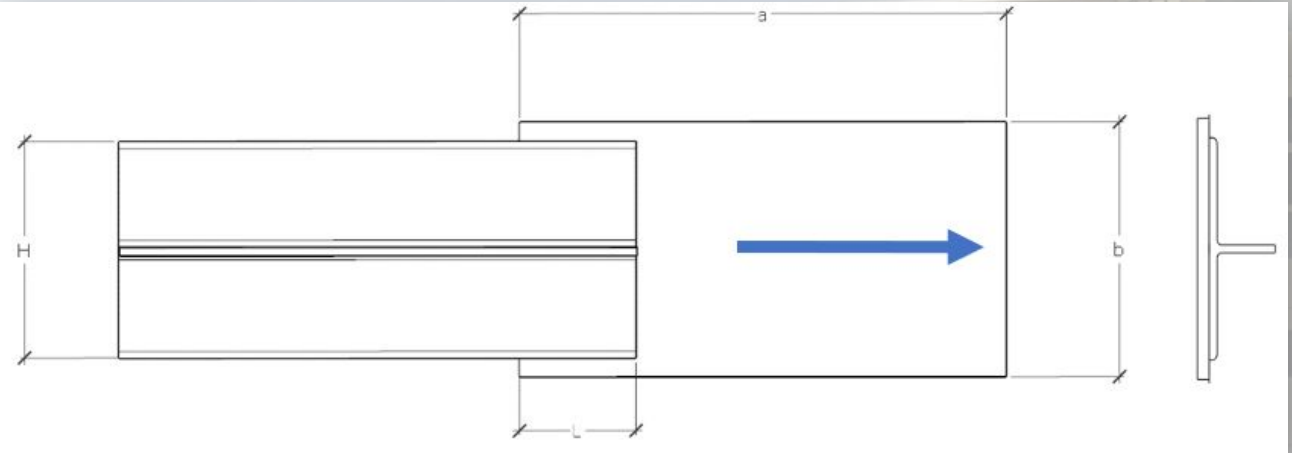


Plate width must be able to fit inside the web area of the W-member

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

WT 180 - end plate weld design



Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

WT 180 - end plate weld design

Weld designed to resist strongest axial force in all WT 180 members

	P (kN)	V2 (kN)	V3 (kN)	T (kN-m)	M2 (kN-m)	M3 (kN-m)
WT180	151.4	1.5	1.5	0.0	3.4	1.2
	-165.6	0.0	-1.1	0.0	-3.6	0.0

Universal end-plates & welds

To reduce final cost, the strongest weld is applied to all end-plate welds for X-Y plane members.

A universal plate size (width & thickness) is also assigned to all end-plates

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Member End-Plate Weld Design: (E49 Electrode)

Weld Metal Controls as Base Metal resistance is greater than Weld Metal resistance. Largest Minimum L value chosen as standard for all welds (50mm)

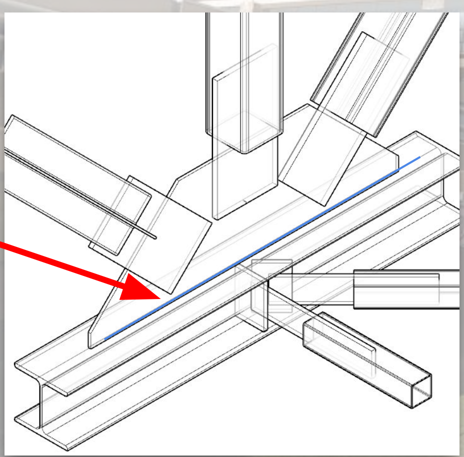
Name	*P (kN)*	*V2 (kN)*	*Fillet Weld Size (mm)*	*Weld Metal Resistance Vr per 1mm weld length (kN/mm)*	*Minimum L (mm)*	*Required t of HSS (mm)*	*Actual t (mm)*
HS305D	466.045	6.2	10	0.1555	38.709	0.515	12.7
HS305V	75.012	0.916	10	0.1555	15.530	0.190	12.7
HS305V	-355.728	-5.589	10	0.1555	33.819	0.531	12.7
WT180	151.422	1.475	10	0.1555	22.065	0.215	370.0
WT180	-165.559	0	10	0.1555	23.072	0.000	370.0
HS152D	42.851	1.044	10	0.1555	11.738	0.286	7.9
HS152D	-30.537	-1.817	10	0.1555	9.909	0.590	7.9
HS152H	10.985	2.904	10	0.1555	5.943	1.571	7.9
HS152H	-7.26	0	10	0.1555	4.831	0.000	7.9

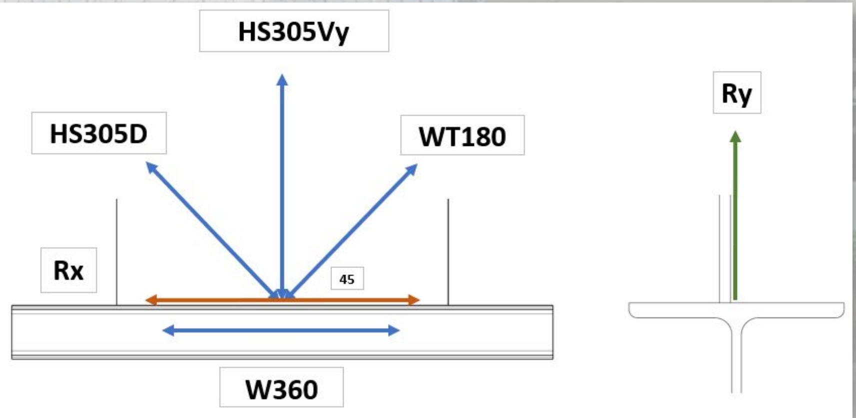
Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

<u>Gusset Plate Weld Design (X-Y axis)</u>

Gusset plate designed to resist worst loading case scenario (contribution from multiple angles & members



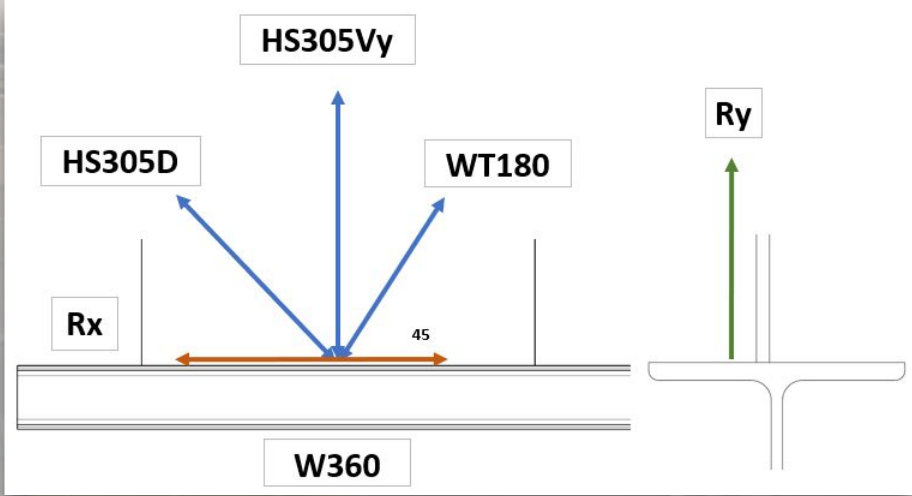


Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Gusset Plate Weld Design (X-Y axis)

Every combination (each member either in compression or tension) evaluated for the maximum resultant - 8 scenarios



HS305D	HS305V	WT180
T	T	T
T	T	C
T	C	T
T	C	C
C	C	C
C	T	T
C	T	C
C	C	T

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Gusset Plate Weld Design (X-Y axis)

HS305D	HS305Dx x (kN)	HS305Dy y (kN)	HS305V y (kN)	WT180	WT180x x (kN)	WT180y y (kN)	Rx (kN)	Ry (kN)	RESULTANT (kN)
466.0	-244.8	396.6	355.7	165.6	87.0	140.9	-157.9	893.2	907.0
466.0	-244.8	396.6	355.7	-165.6	87.0	140.9	-157.9	893.2	907.0
466.0	-244.8	396.6	-355.7	165.6	87.0	140.9	-157.9	181.7	240.7
466.0	-244.8	396.6	-355.7	-165.6	87.0	140.9	-157.9	181.7	
466.0	244.8	-396.6	-355.7	-165.6	87.0	140.9	331.8	-611.4	
466.0	244.8	-396.6	355.7	165.6	87.0	140.9	331.8	100.0	346.6
466.0	244.8	-396.6	355.7	-165.6	87.0	140.9	331.8	100.0	
466.0	244.8	-396.6	-355.7	165.6	87.0	140.9	331.8	-611.4	

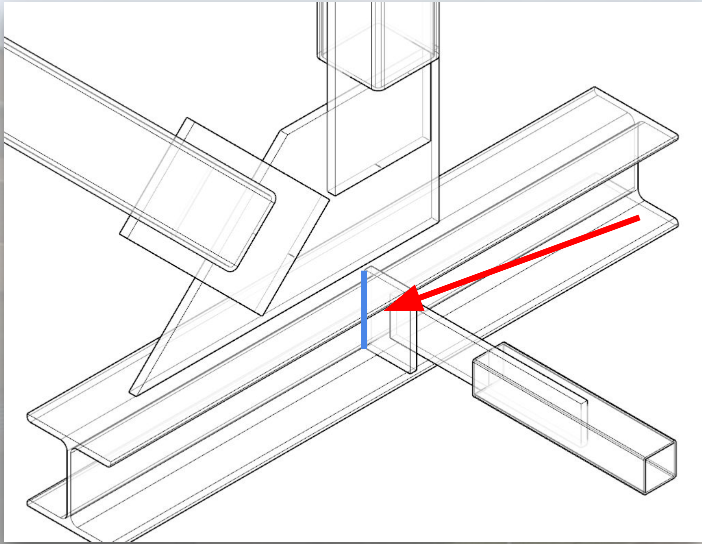
Note: Resultants involving vertical HSS 305 members in compression (pushing down on weld) not considered since won't affect weld resistance

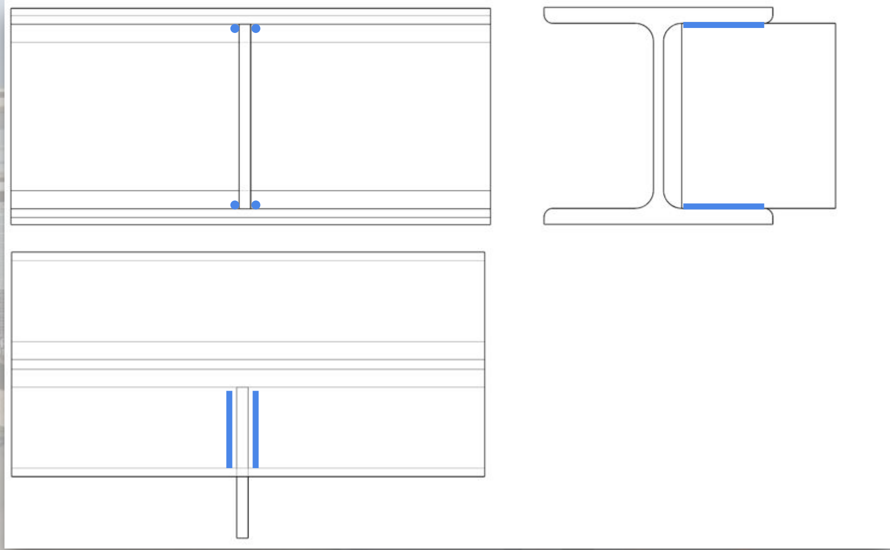
Maximum Resultant

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Oblique web weld for X-Z members connecting plate





Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Gusset Plate to W-shape member Weld Design:

Minimum Weld length = 574.3 mm. Since Plate length is greater, weld length is extended to the entire length of the interface.

Combo	P (kN)	V2 (kN)	Fillet Weld Size (mm)	Weld Metal Resistance Vr per 1mm weld length (kN/mm)	Required Area for Shear (mm2)	Required L for Shear Load (mm)	Required L for Axial Load(mm)
1	-157.9	893.2	10	0.1555	5743	574.3	22.53
2	-157.9	893.2	10	0.1555	5743	574.3	22.53
3	-157.9	181.7	10	0.1555	1168	116.8	22.53
4	-157.9	181.7	10	0.1555	1168	116.8	22.53
5	331.8	-611.4	10	0.1555	3932	393.2	32.66
6	331.8	100.0	10	0.1555	643	64.3	32.66
7	331.8	100.0	10	0.1555	643	64.3	32.66
8	331.8	-611.4	10	0.1555	3932	393.2	32.66

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Interaction Equation Check for Gusset Plate Weld Design:

Pf/Pr + Vf/Vr < 1.0

157.9/4205 + 893.2/933.2 = 0.9947 < 1.0 (Using 600mm Weld Length)

157.9/4906 + 893.2/1089= 0.8524 < 1.0 (Using 700mm Weld Length)

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

<u>Bolt Groups</u>

Three different bolt groups connecting member end-plates to W360-welded gusset plates

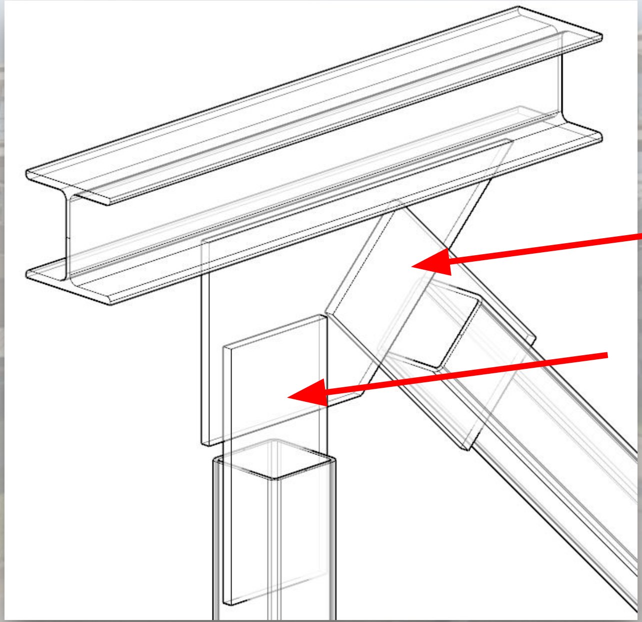
- X-Y Plane Bolt Groups (for HSS 305 & WT 180 connections)
- X-Z Plane Bolt Groups (for HSS 152 lateral bracing connections)
- Central bearing beam bolt group

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

<u>Bolt Groups</u>

<u>X-Y Plane Bolt Groups (for HSS 305 & WT 180 connections)</u>



I.e. the bolt groups that will connect all welded member end-plates to the gusset plates in the X-Y plane

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Plate to Gusset Plate Bolt Design: (M20 A325 Bolts)

Largest # of Bolts chosen for bolt connections to standardise design. Limited by the P=466kN of the HS305D plate. Configuration passed the Shear Design (ULS), Bearing Design ULS), and Slip Critical Design (SLS) checks.

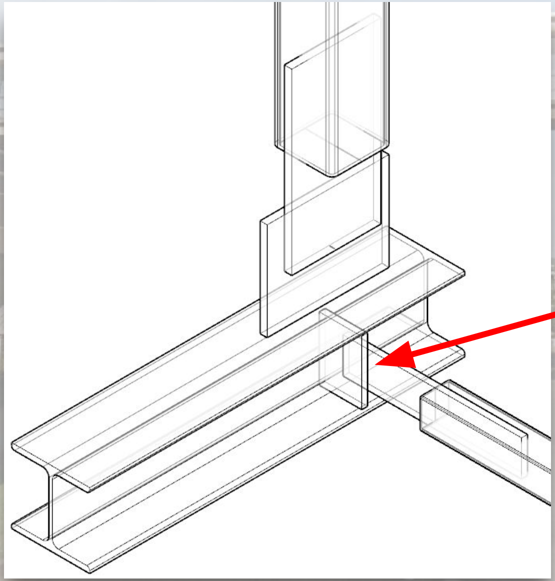
Name	*P (kN)*	*Pitch (mm)*	*Gauge (D) (mm)*	*Moment Arm (L) mm* *Assumed 50mm (minumum)*	*Required 'C'*	*# Bolts per Vertical Sides (min)*	*Total (min)*
HS305D	466.045	100	200	50.0	3.728	3	6 Bolts
HS305V	75.012	100	200	50.0	0.600	3	6 Bolts
HS305V	-355.728	100	200	50.0	2.846	3	6 Bolts
WT180	151.422	100	200	50.0	1.211	3	6 Bolts
WT180	-165.559	100	200	50.0	1.324	3	6 Bolts

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Bolt Groups

X-Z Plane Bolt Groups (for HSS 152 connections)



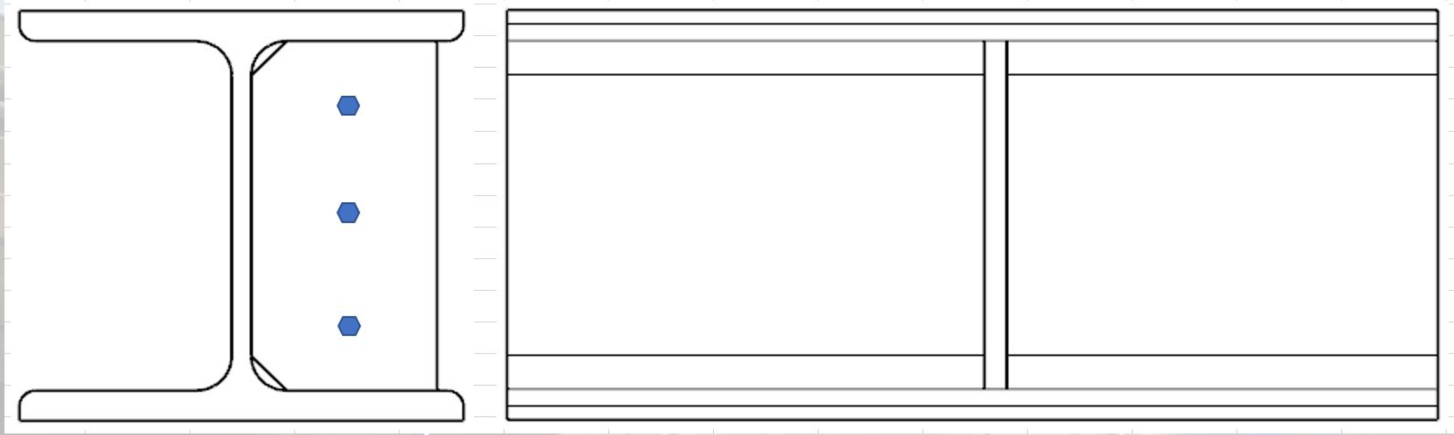
I.e. the bolt groups that will connect all HSS 152 welded member end-plates to the gusset plates in the X-Z plane

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

<u>Bolt Groups</u>

<u>X-Z Plane Bolt Groups (for HSS 152 connections)</u>

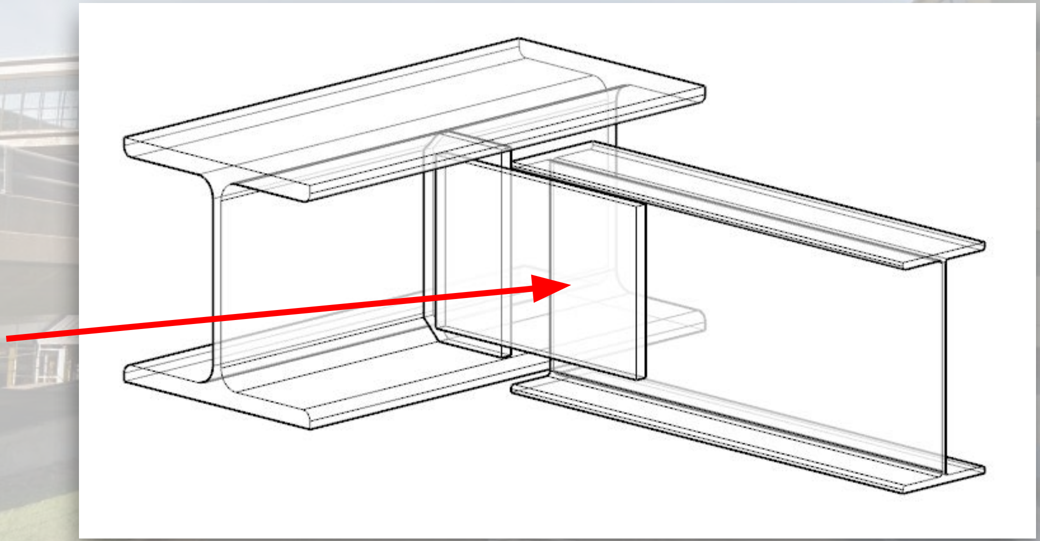


Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Weld & Bolt Groups

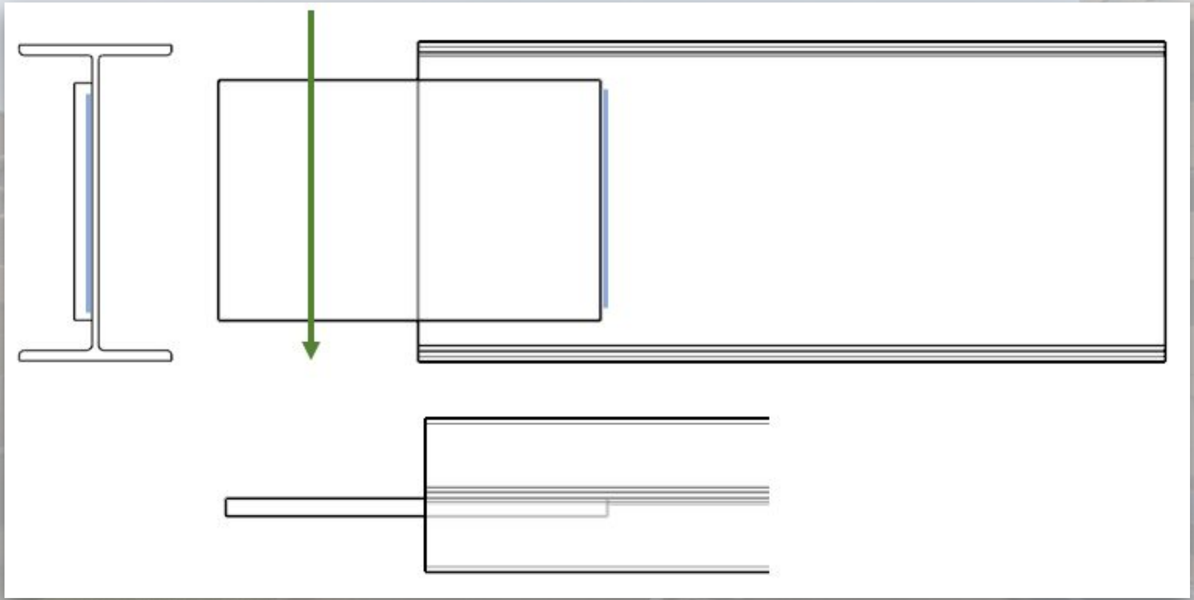
Central Bearing Beam



Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Central Bearing Beam End-Plate Weld



Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

<u>Central Bearing Beam End-Plate Weld</u>

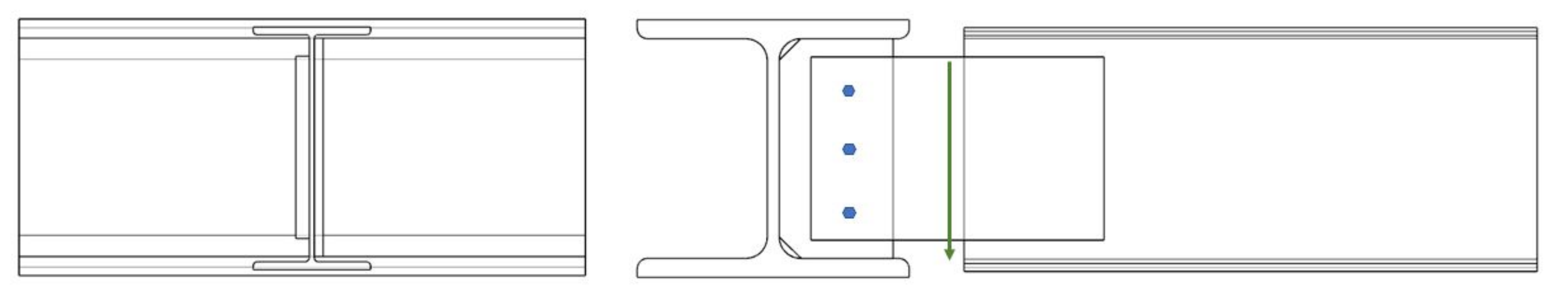
Minimum Weld length = 22.57 mm. Since Plate length is greater, weld length is extended to the entire length of the interface.

Name	P (kN)	V2 (kN)	Fillet Weld Size (mm)	Weld Metal Resistance Vr per 1mm weld length (kN/mm)	Required L (mm)
W360x51	10.337	158.41	10	0.1555	22.57

Analysis —— Connection Design

6. Design universal connection configurations based on maximum forces

Central Bearing Beam End-Plate & Stiffener Connection Bolt Group



Support Connection Design

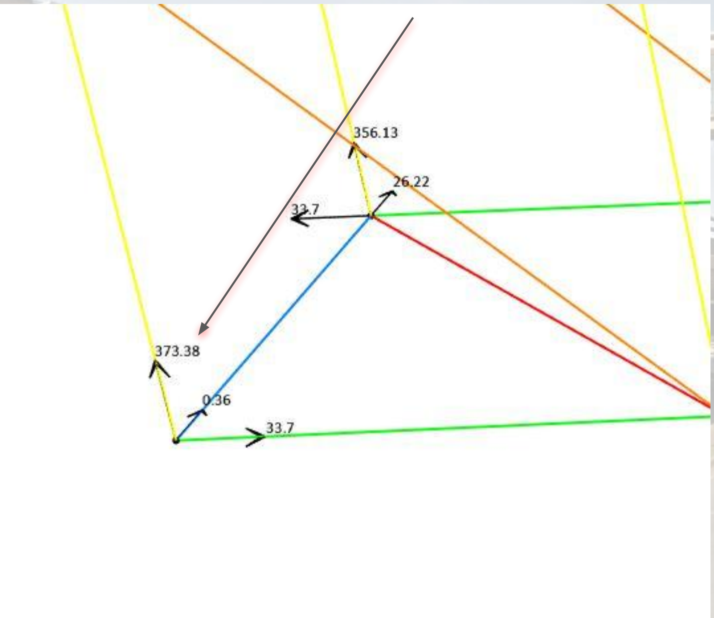
- Composed of 3 primary components
  - Base Plate
  - Anchor Rods
  - Elastomeric Bearing
- 2 Types: Guided and Fixed
  - Guided allows for longitudinal deformation of truss due to thermal expansion and compression forces
  - Fixed restrains truss in all 3 directions

- Steps
  - 1: Determine loads and geometrical and material constraints
  - 2: Determine elastomeric bearing geometry
  - 3: Determine base plate geometry and material
  - 4: Determine anchor rod diameter and length
- Assumptions:
  - Anchor rods resist transverse shear, while fillet welds resist longitudinal shear
  - Friction coefficient of 0.7 between steel

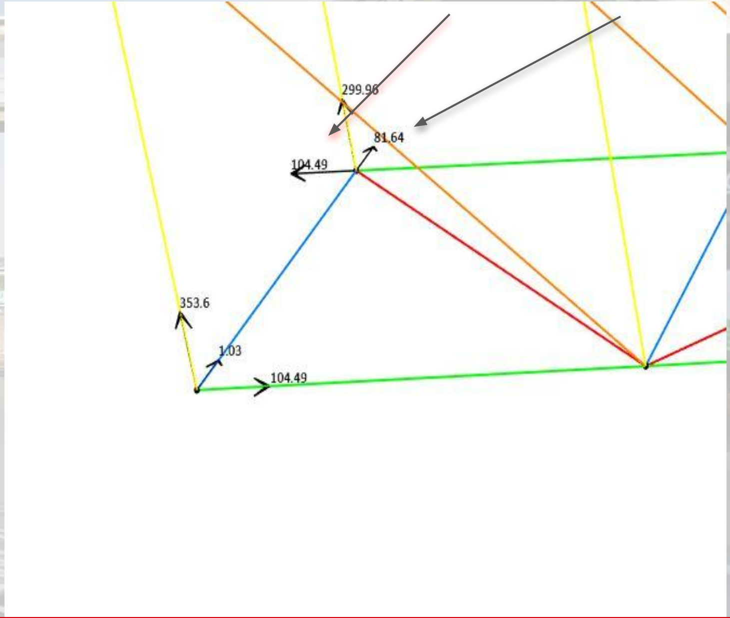
Support Connection Design- Loads

- All Forces are modelled in SAP2000

ULS 3: Worst Case Vertical Reaction Load Combination (373.38kN)



ULS 4: Worst Case Lateral and Longitudinal Reaction Load Combination (104.49, 81.64 kN)



Support Connection Design- Constraints, Requirements

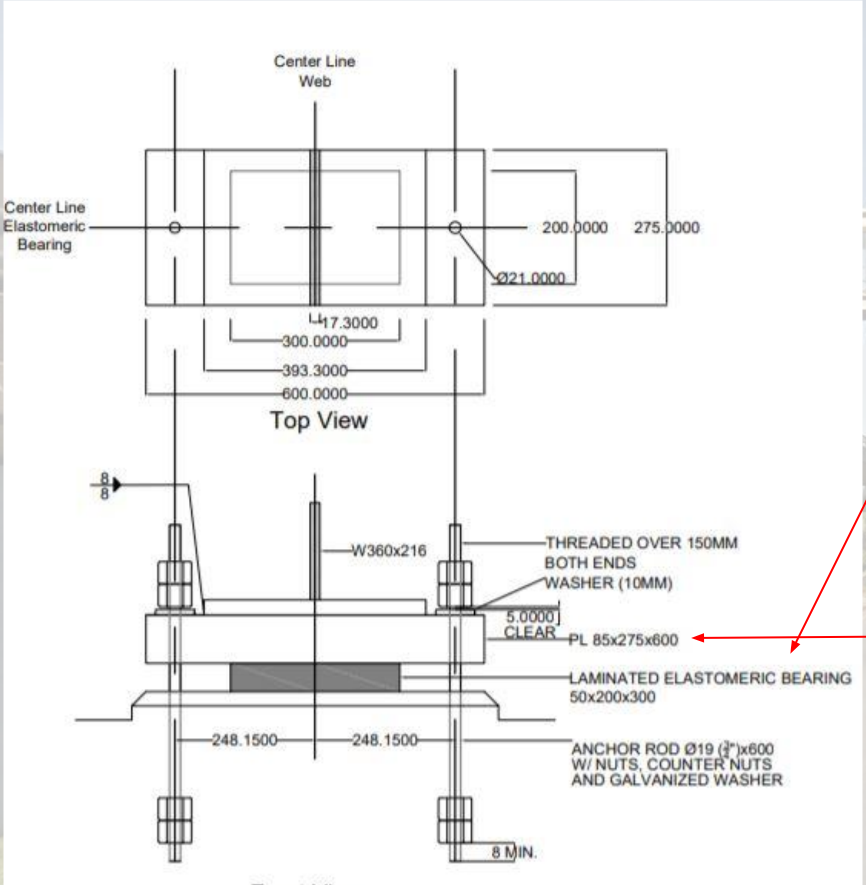
Constraints

- Width of Pile Cap- limits the width of the elastomeric bearing and base plate.
- Height of Pile Cap- limits the height of the baseplate and elastomeric bearing as well as length of anchor rods
- Flange size- limits the minimum length of the base plate
- Allowable pressure of elastomeric bearing- requires a minimum geometry

Requirements

- **Fixed**
    - Weld along edges of I Beam and base plate to ensure beam does not move
    - Fixed diameter holes for anchor rod placement restricting lateral and longitudinal movement of I beam
- **Guided**
    - Weld along edges of I beam and base plate to ensure beam moves with base plate during thermal expansion forces
    - 10M bars between elastomeric bearing and base plate to ensure base plate can translate longitudinally due to thermal expansion forces
    - Sufficient length for anchor rod holes to allow longitudinal base plate translation

Support Connection Design: Fixed



- Elastomeric Bearing: Load is divided by area- ensuring that it is within allowable limits. Consulted “Elastomeric Bearings”- Goodco Z-Tech manufacturer product specifications.

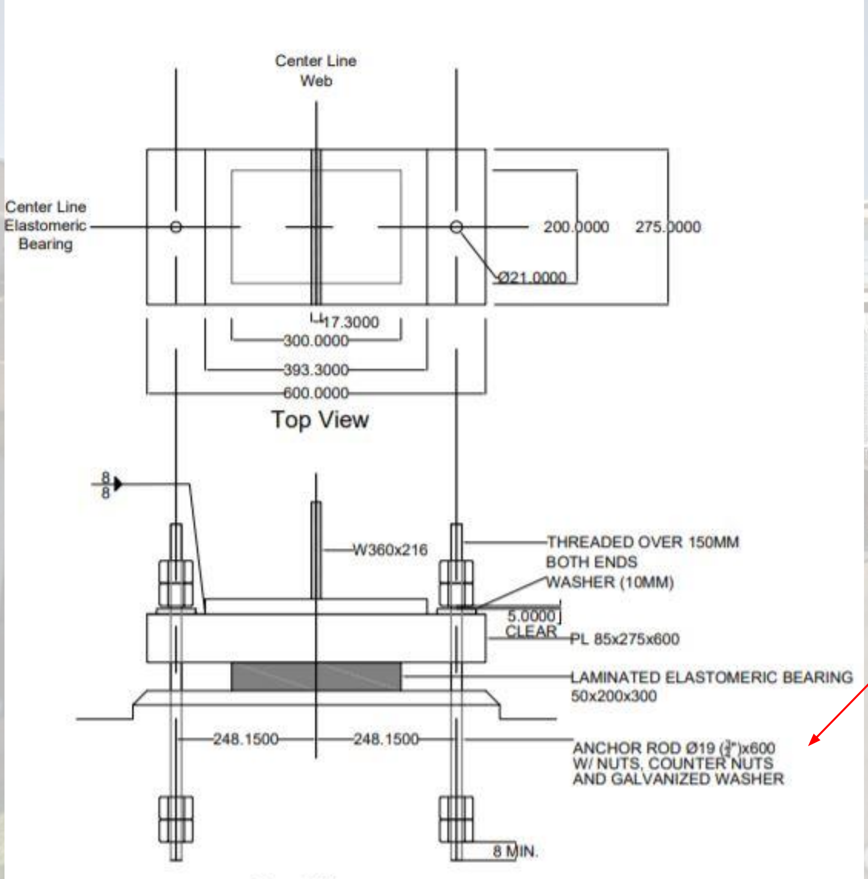
  SLS Load/Area=0.6 MPa < 4.5 Mpa, but <1.5 Mpa: anchor rods required

  ULS Load/Area=6.27 MPa < 10 MPa

- Base Plate: Ensure sufficient area and thickness, given I beam and pile cap constraints.

  Web local plastic buckling (Br)=1752 kN, Web overall buckling (Br)= 1127 kN: No web stiffeners needed

Support Connection Design: Fixed (continued)



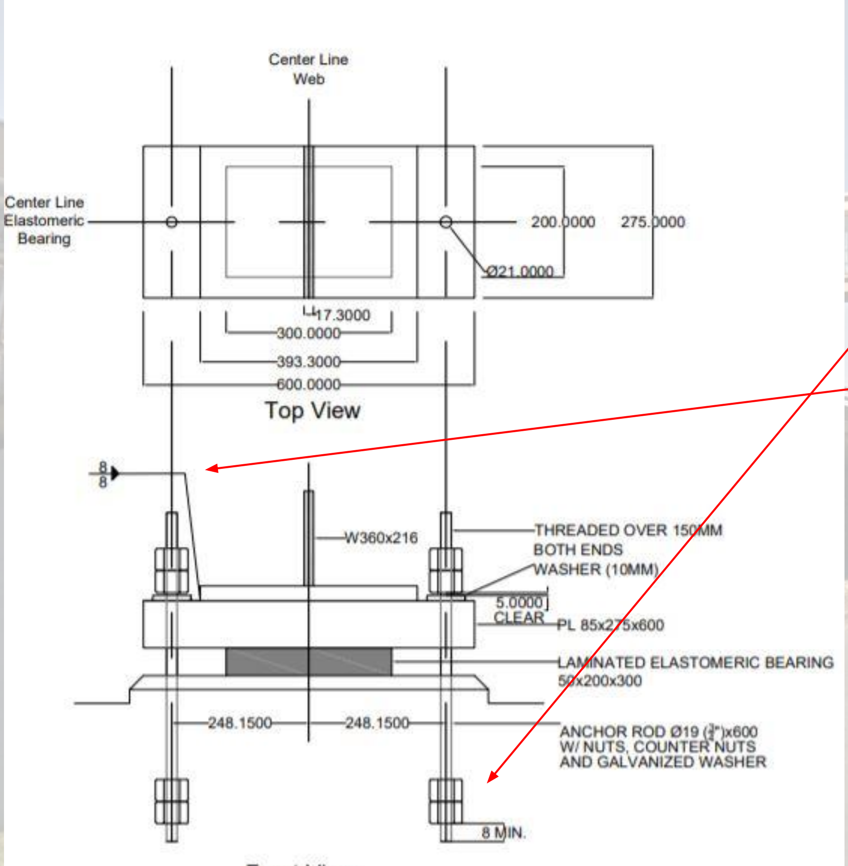
- Base Plate Thickness: By equating the moment resistance to the factored moment, t= 85 mm > 80 mm,

  Bearing area must be sufficient and resist yielding: Area=165,000 mm2 > Area Required=27,980 mm2

- Anchor Rods: Cross-section must be large enough for given transverse shear loads. (No tension loads are possible). Sufficient embedded length concrete and interfacial area for shear transfer into concrete.

  Cross sectional area: By equating the shear resistance to the factored shear, A >

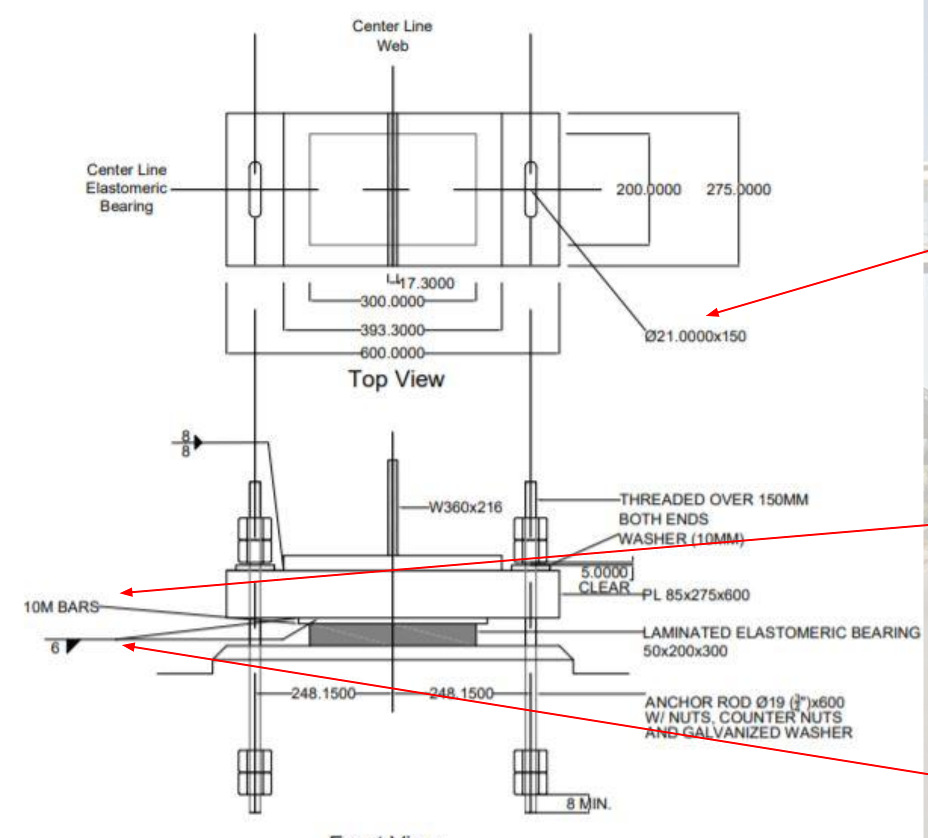
Support Connection Design: Fixed (continued)



- Shear transfer to concrete: Min. embedded length: Concrete bearing resistance= factored anchor rod shear, L(min)=152 mm < L(rod)=600 mm
- Fillet Welding of I beam and base plate: Weld metal and base metal shear resistance must be greater than longitudinal shear load.

If welded along length of flange edge, Vr> Vf and no corrosion will occur at interface that can cause damage and weaken the materials over time

Support Connection Design: Guided



- Same procedure and requirements as fixed connection
- Guided Holes allow for thermal expansion of truss. Max translation estimate can be found using thermal expansion coefficient, length of truss and maximum effective temperature range = 27 mm < 150/2 mm
- Fillet Welding: Must be greater than longitudinal shear load and frictional force between 10M bars and elastomeric bearing (i.e. base plate, I beam and 10M Bars must move in unison due to thermal expansion)

Base metal and weld metal must be stronger than factored shear + friction (0.7*Normal Force)

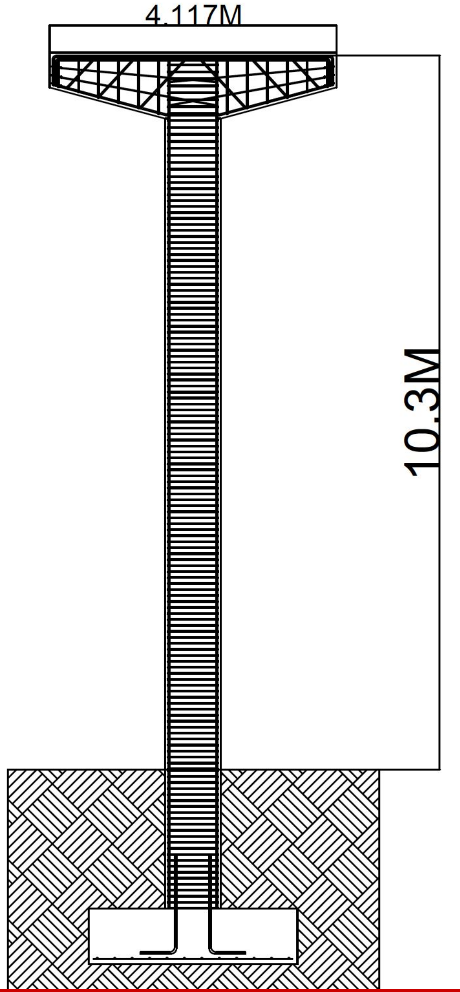
Reinforcement Structure

- **Consists of 3 Sub-structures**
  - Reinforced Column Cap
  - Reinforced Concrete column
  - Reinforced Square footing

Dimensions :

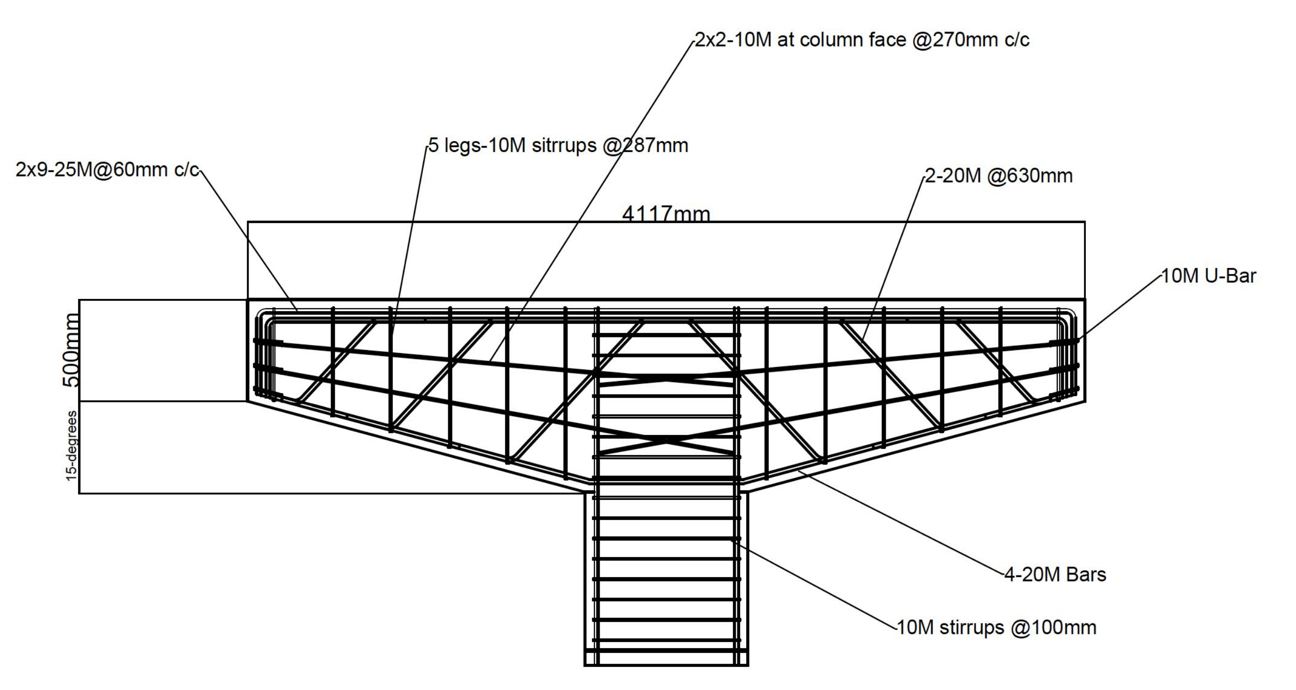
- Total height of 10.3M
- Span at 4.117M

Objective is to funnel and transfer loads vertically across the structure to the ground. A total of **two Reinforced structures** supporting the truss



R.S- detailed Column Cape Design

- Span= 4117mm
- Thickness = 800mm
- Depth 1= 500mm
- Depth 2= 950
- 2x9-25M@60mm c/c horizontal bars spanning the cape
- 10M U-Bars
- 5 legs-10M stirrups @287mm
- 2x2-10M at column face
- 2-20M inclined bars @558mm
- 4-20M bars
- 10M stirrups @100mm



R.S- detailed Column Cape Design

Cape analyzed at both critical depths

- Dv1=500.625mm
- Dv2=811.025mm

Moment at face of supporting columns Mf = 1907.98KN/m

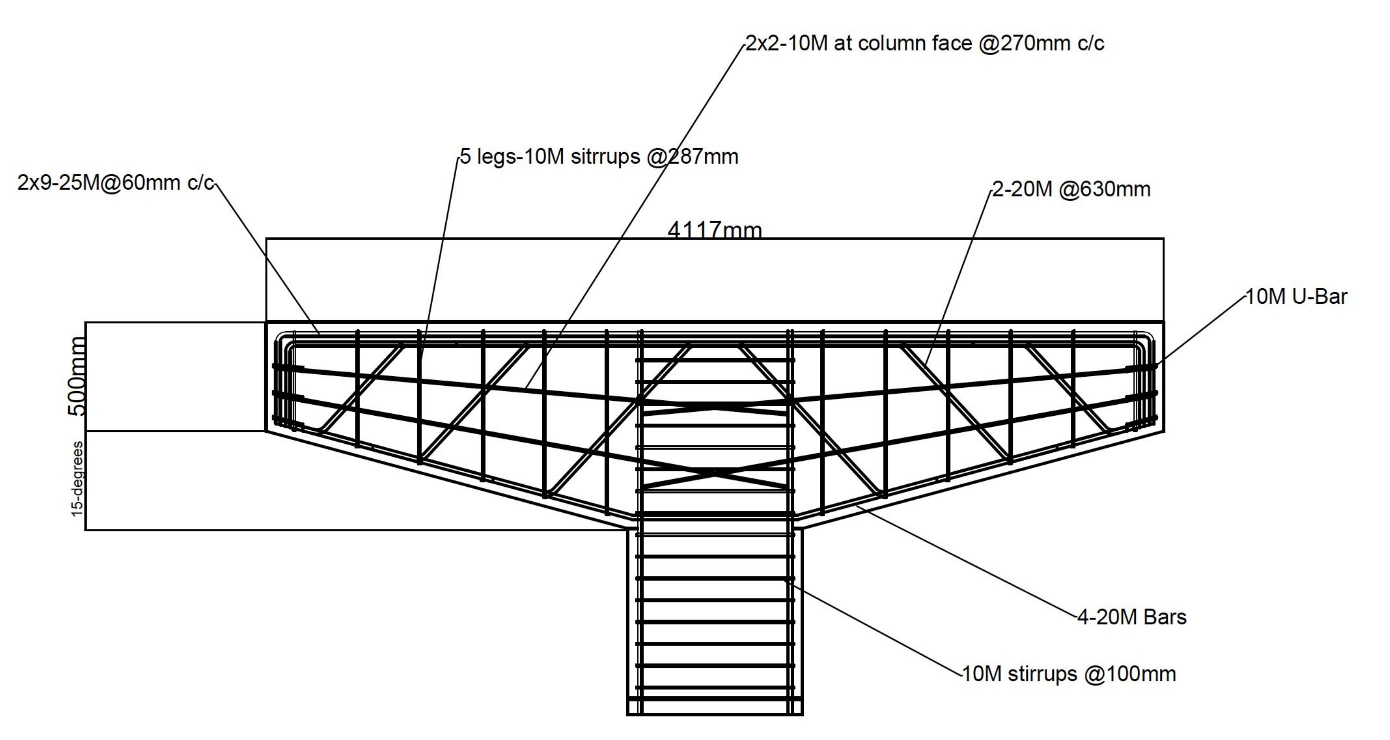
Mr =3624KN/m → Mr>Mf

Minimum flexural reinforcement at critical sections = 901.2 mm2 and 1190mm^2

Shear strength was analyzed using both **Simple** and **General method**

Vr>Vf

Min. reinforcement ratio = 0.003



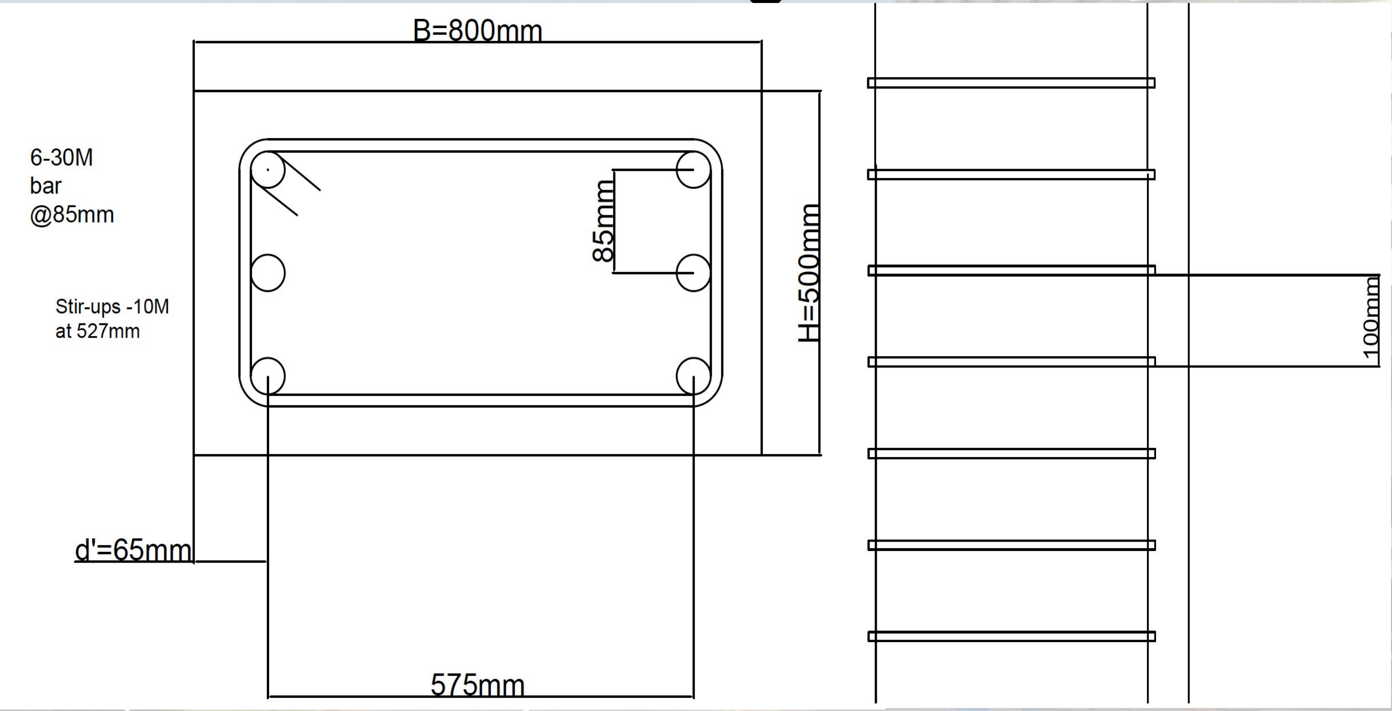
Reference: CSA and (ASCE) Orcutt Cook Mitchell BE.1943-5592.0001548

R.S- Reinforcement Coloumn Design

- 800X500mm
- 6-30M Bar @85mm
- stir-ups -10M @527mm
- Cover d'= 65mm
- Vertical stir-up spacing @100mm
- Pr > Pf→ 3140.89KN>1033.2KN
- Mbr =1095 KN/m

- Passes all checks in CSA

Section in strong and more than capable.

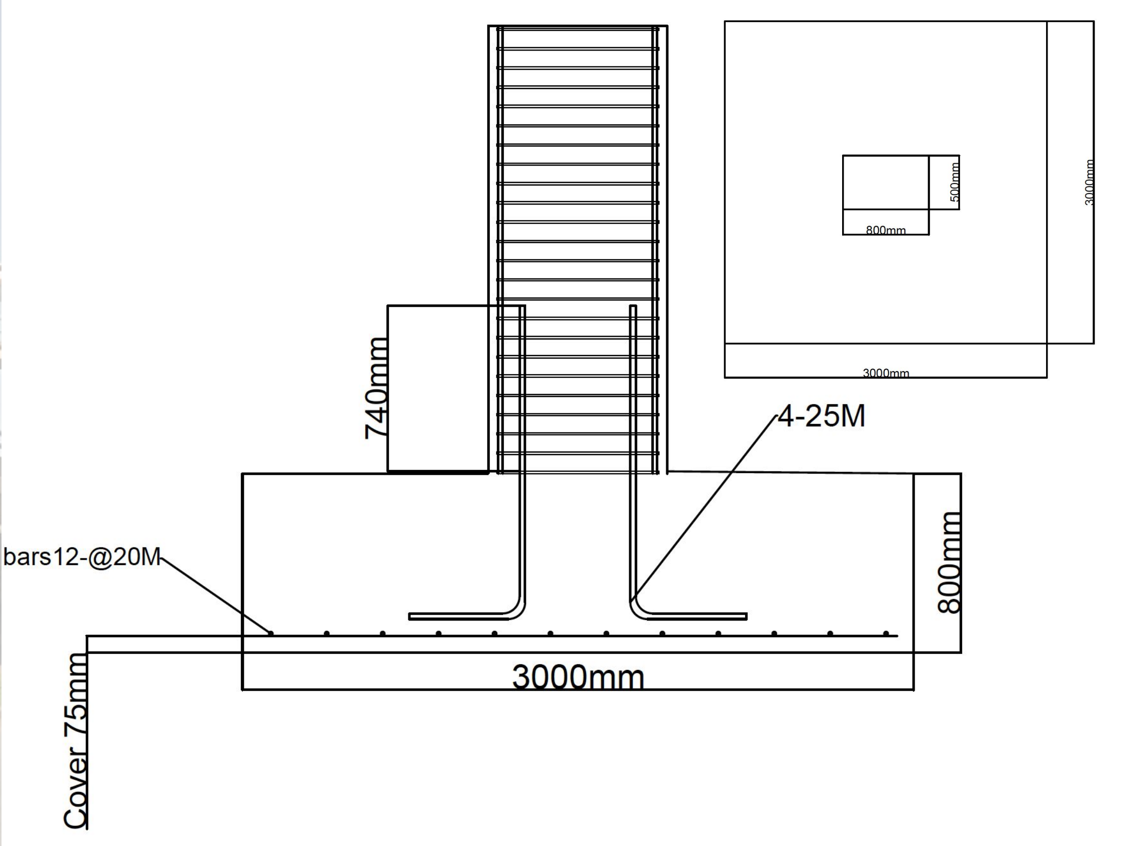


Reference: CSA code

Reinforcement structure- Square Footing

- Designed in accordance with CSA
- Checks all CSA requirements
- Depth of 2.8m under ground level
- 3X3m square footing supporting rectangular reinforced column
- Thickness = 800mm
- bars 12-20M
- 4-25M hooked bars
- Hooked bars height L2= 750mm
- Cover 75mm

Bearing capacity= 17680KN



Project Overview

Existing Loads

Modelling and Analysis

Detail Design

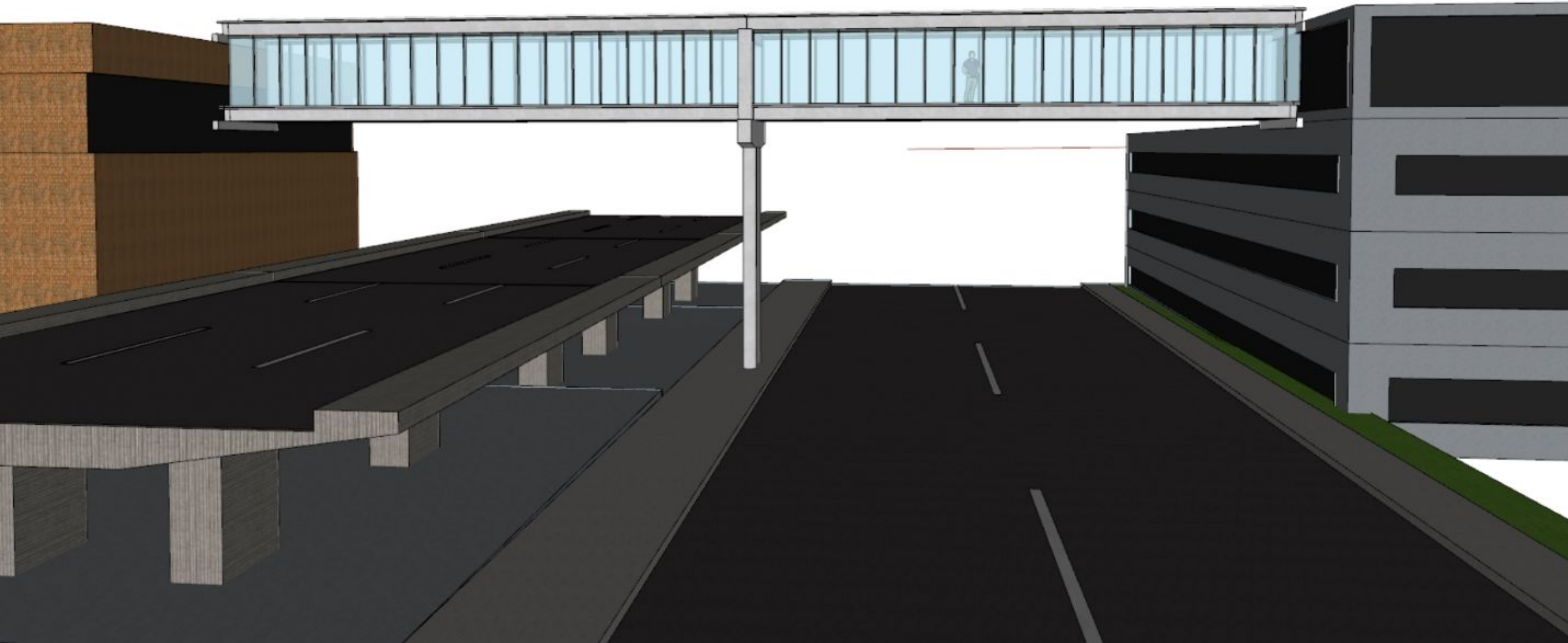
Implementation

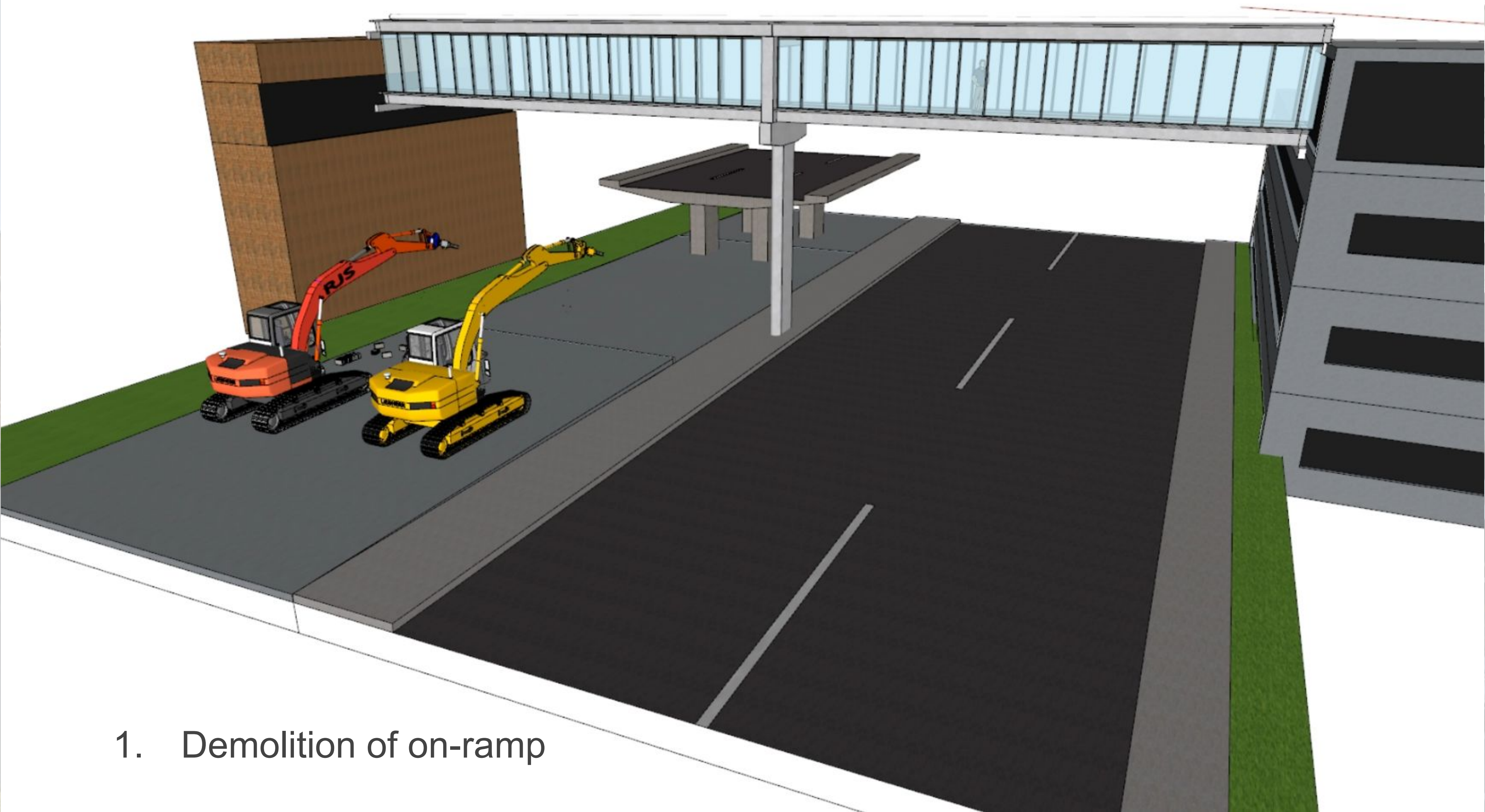
Construction Phases & Special Design Considerations

1. Deconstruction of Cogswell St. on-ramp
2. Installation of reinforced concrete support columns
    - Ensure positioning is off & away from property lines
3. Installation of truss cage structure
    - Consider clearances for removal of central support system (working area)
    - Lateral support must be provided by the rigging contractor to ensure vertical panels do not sway during construction
4. Jacking existing bridge off central supports
    - Ensure deflections are satisfactory (20mm by design)
    - ‘Lower’ structure back on raised supports to ‘cancel’ deflection
5. Removal of existing RC supports
6. Installation of central bearing beam & truss completion
7. Lowering of spans onto bearing beam
8. Removal of temporary support members
9. Landscape renewal

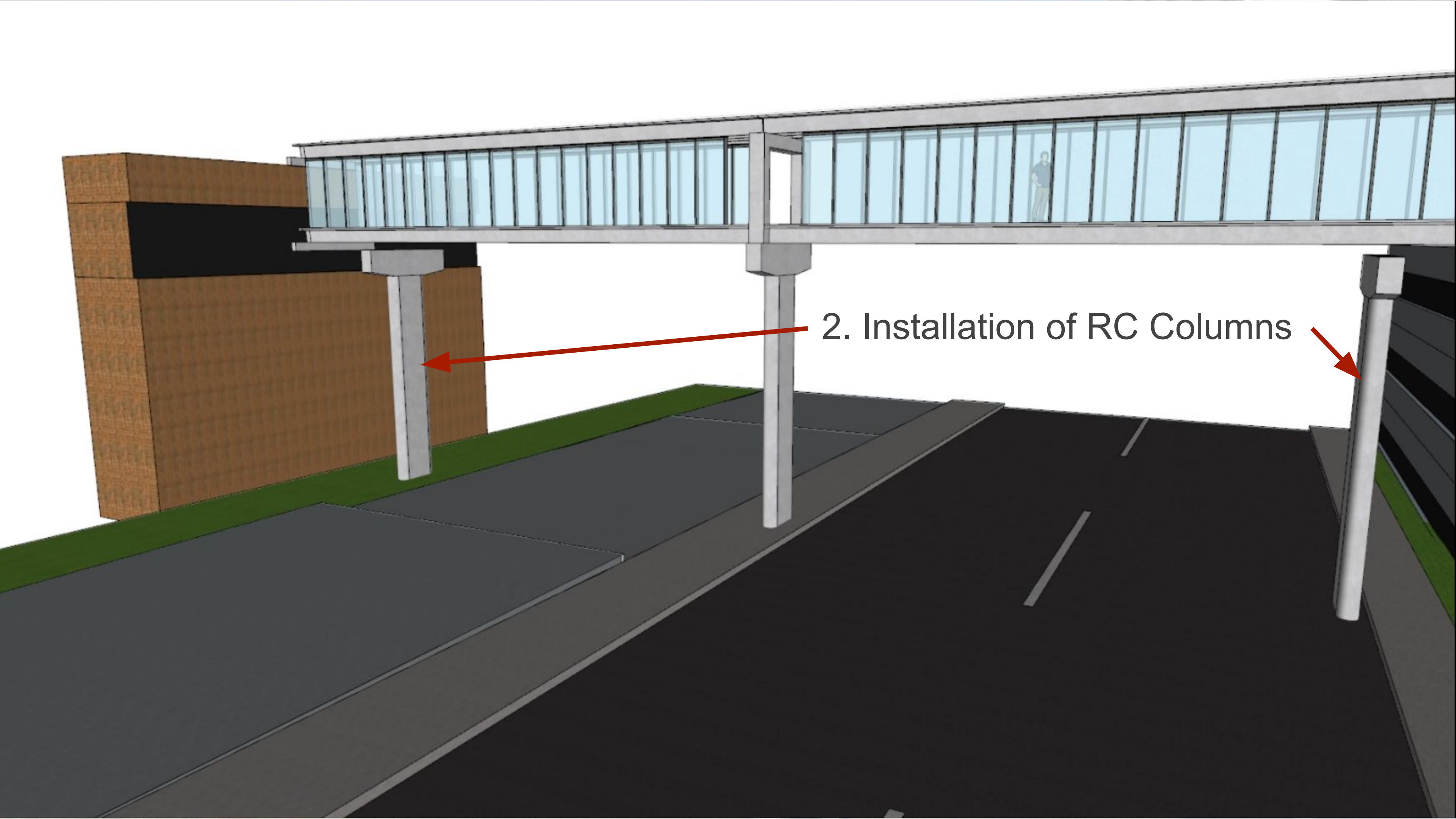
Construction process video animation:
https://drive.google.com/file/d/1H6VKHuLWvIDN59KwoDIT60mDdOdzCLyU/view?usp=sharing

3D Sketchup of Cogswell St.

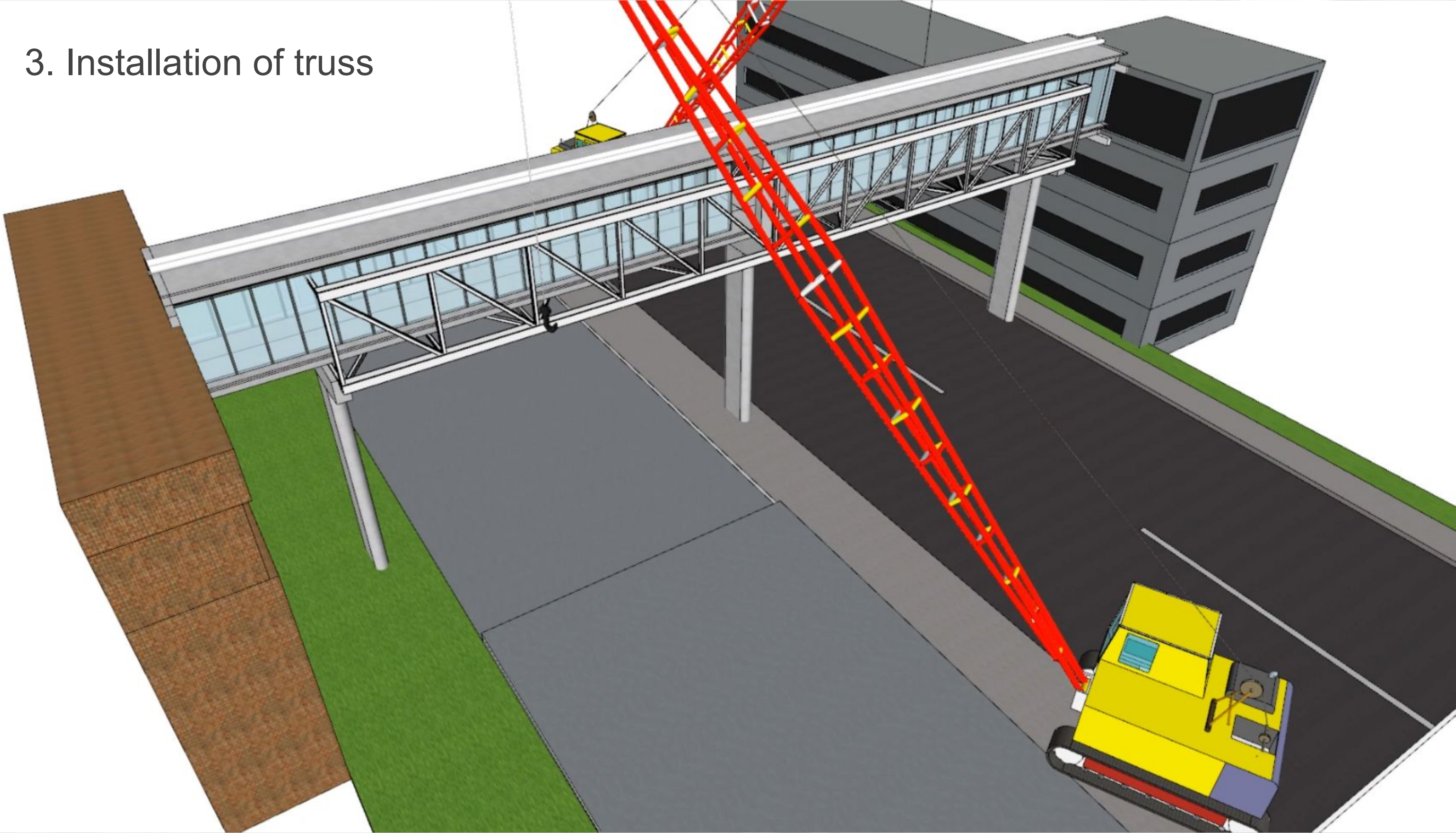


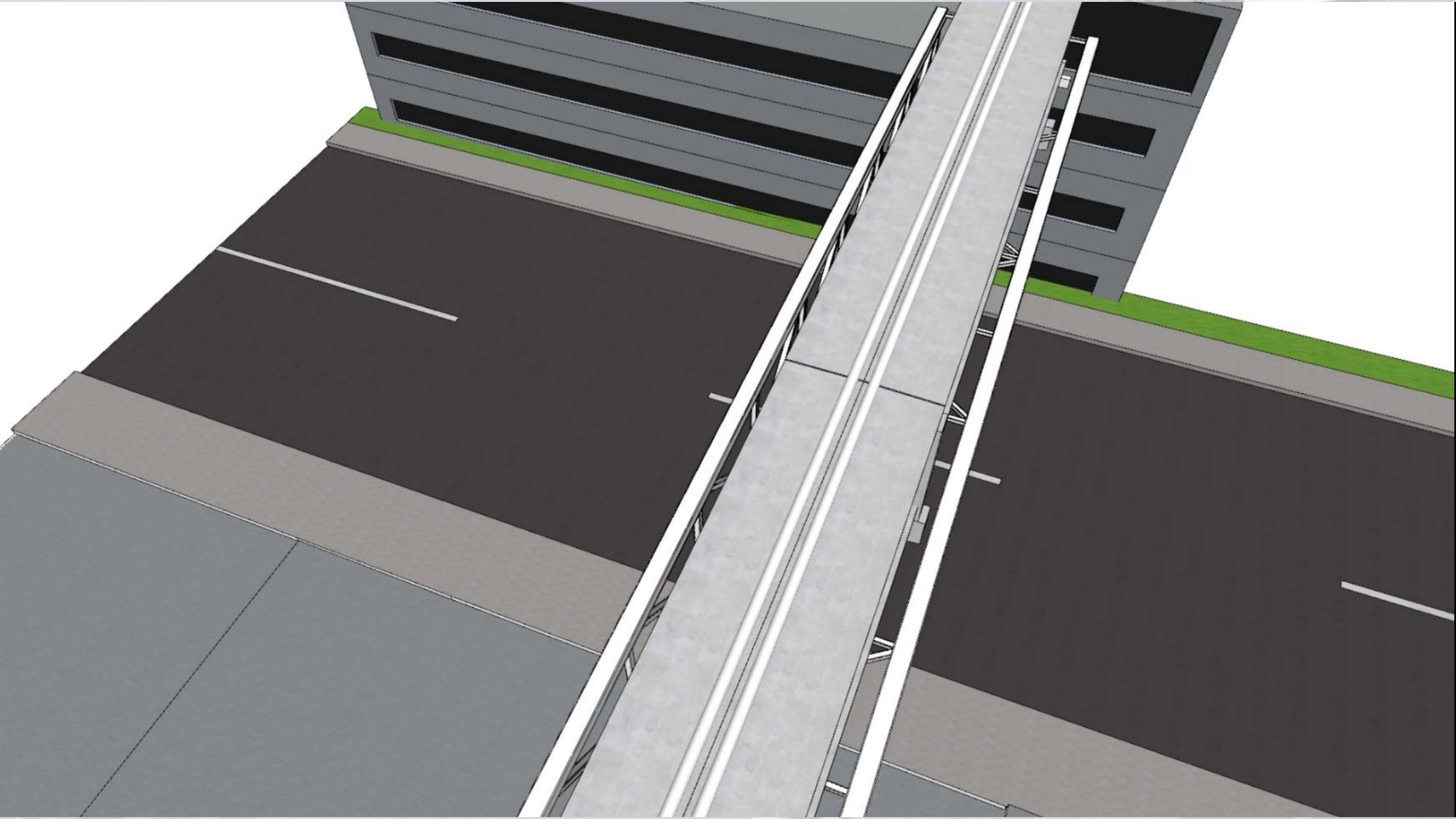


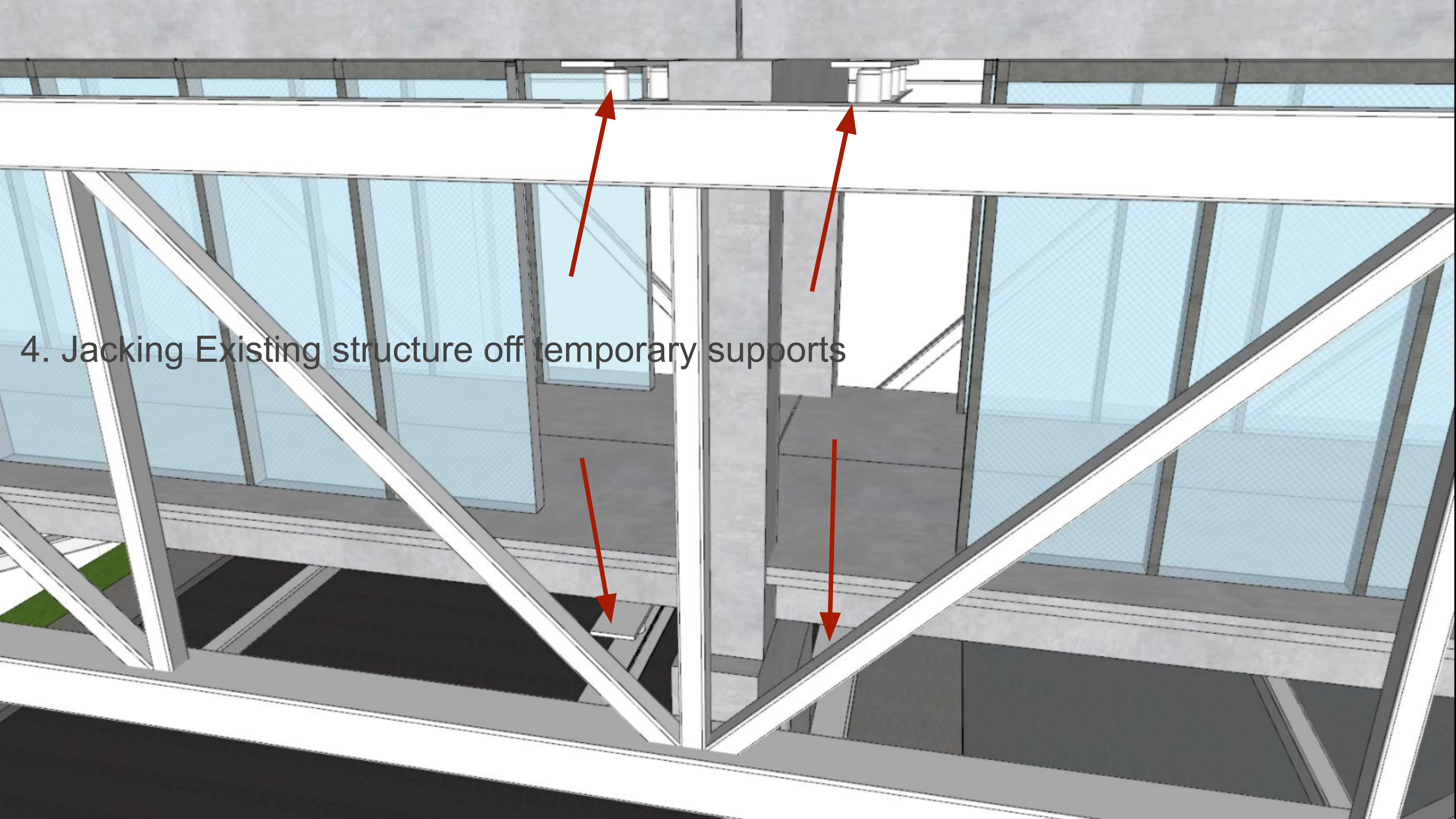
1. Demolition of on-ramp

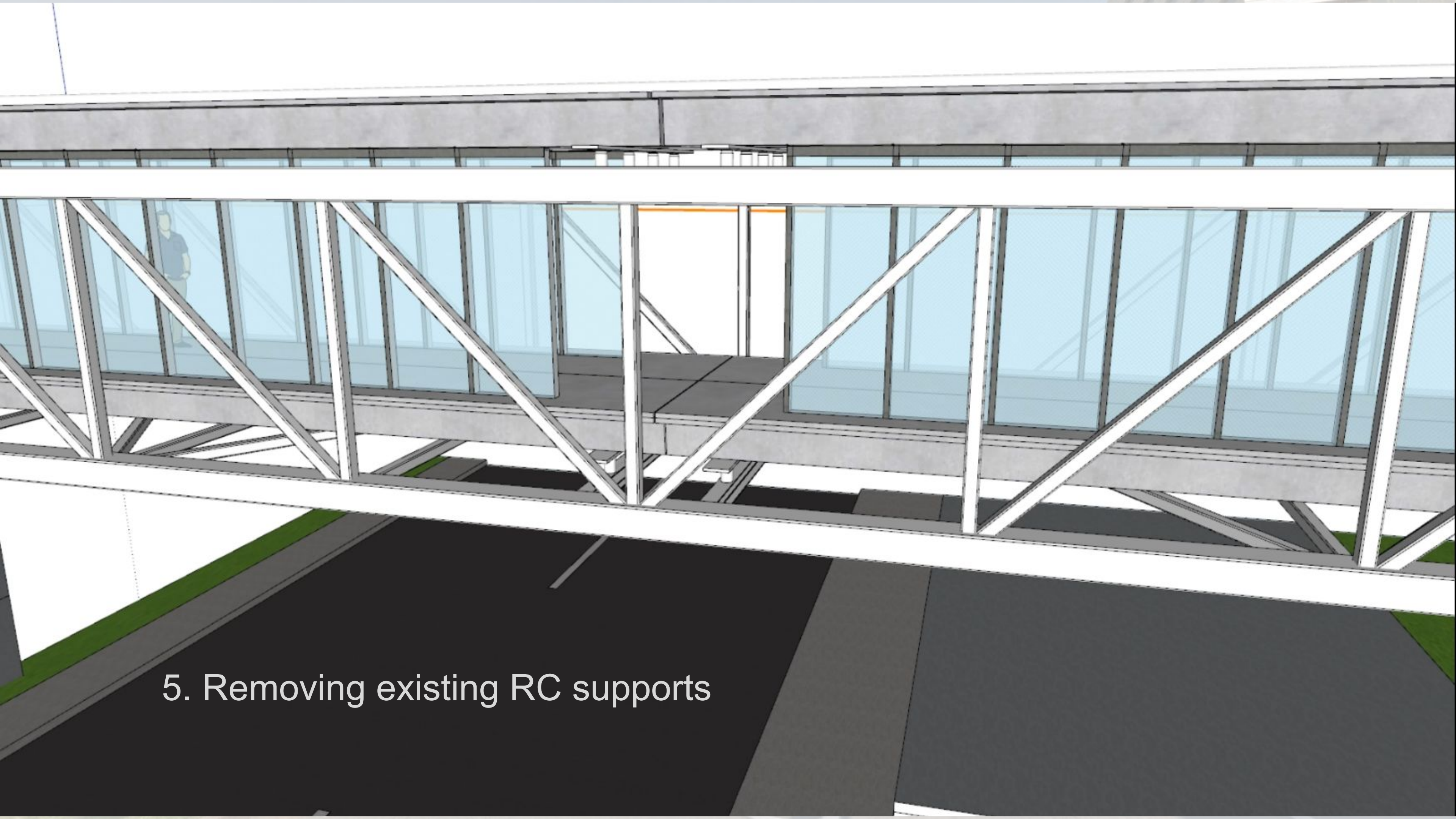

2. Installation of RC Columns

3. Installation of truss

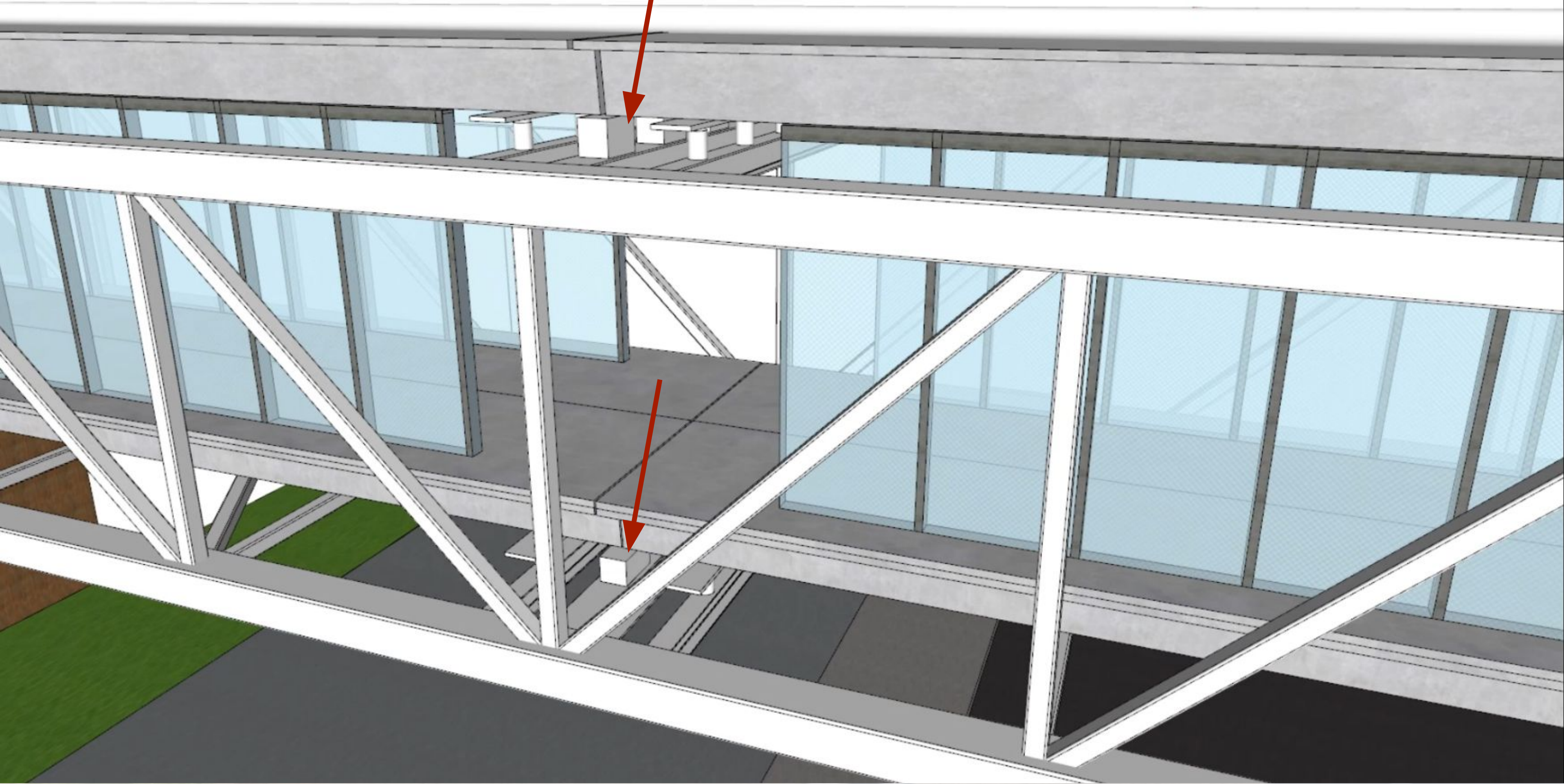




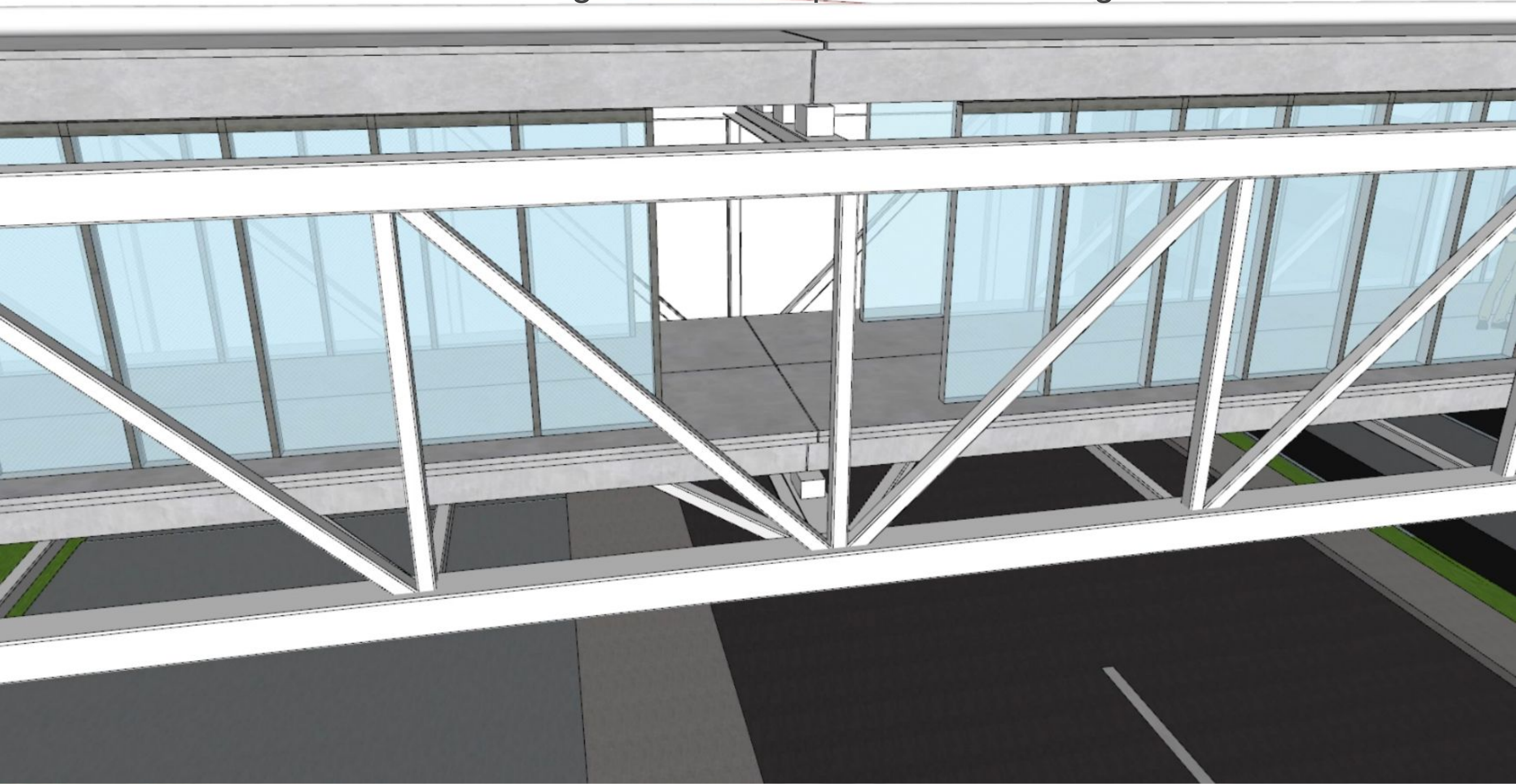

4. Jacking Existing structure off temporary supports


5. Removing existing RC supports

6. Installing central support beams



7. Lowering double-tee spans onto bearing beams



Construction Phases & Special Design Considerations

- Add laminated elastomeric bearing 50x200x300 (same geometry as support bearings) underneath central lateral W360x51 beams (4 total)- Implementation is to be decided by contractor
- All connection design steel is galvanized to protect from weathering and corrosion effects

Cost Estimates

Materials	0.83$M
Labour	1.09$M
Equipment	0.92$M
Overhead Costs	0.54$M
Administration	0.51$M
Subtotal	**3.89$M**
Markup (12%)	0.47$M
Total	**4.36$M**

Sustainability Considerations

Resource Efficiency
-Minimize required material needed
-Reduce temporary framework/scaffolding needed
-Simplify connection design and element types

Reduced CO_2 Emissions
-Minimise disturbance to public transit routes, cycle lanes and pedestrian lanes
-Source materials locally when possible


McCafé
Do Not E

Acknowledgements

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- Professor William E. Taylor
- Professor Colin Rogers

MAPLE
ENGINEERING SERVICES