鋼木合成成結構之永續效益

國立臺灣科技大學建築系

蔡孟廷 教授

內容 · 概要

1. 建築結構的低蘊含碳評估
2. 鋼木混合構造的低蘊含碳比較及分析
3. 鋼木合成構件的類型及應用
4. 防火相關性能的探討

學歷

日本東京大學 建 築 專 攻

國立成功大學 建築研究所

國立成功大學 土木工程系

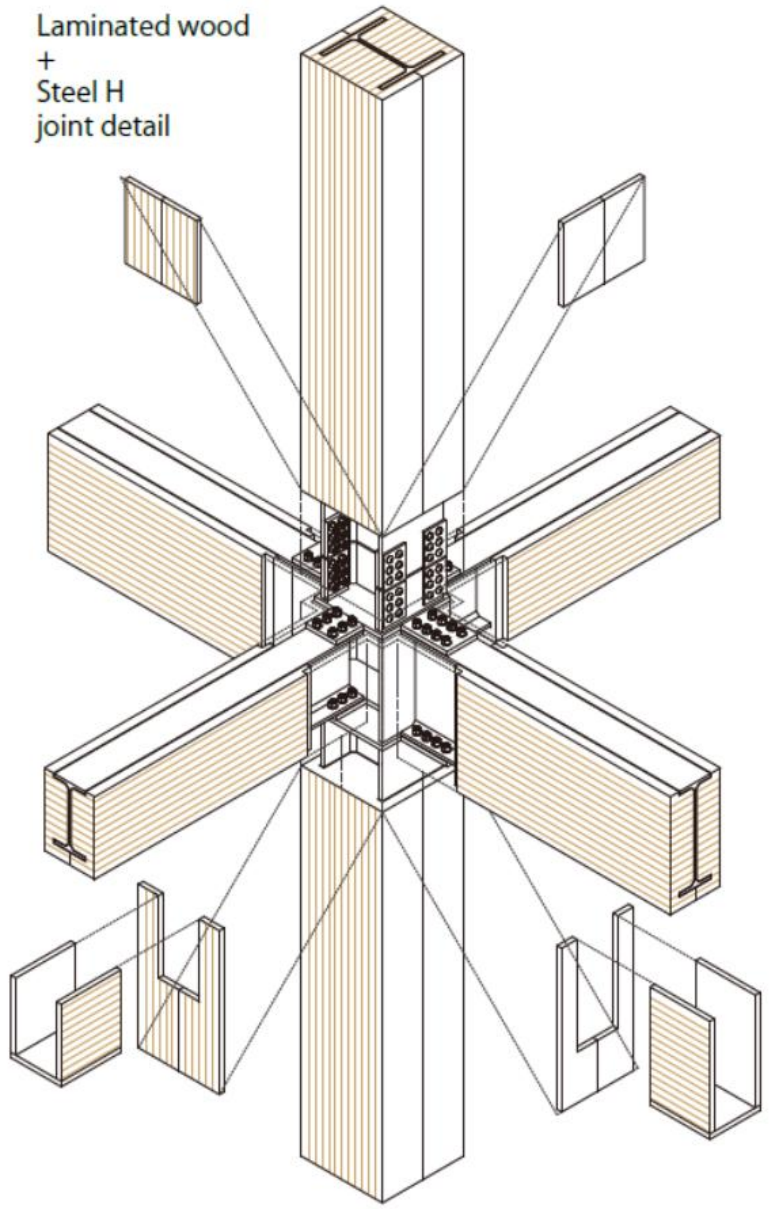
經歷

維也納工業大學 交換研究

新加坡新建設計 設計師

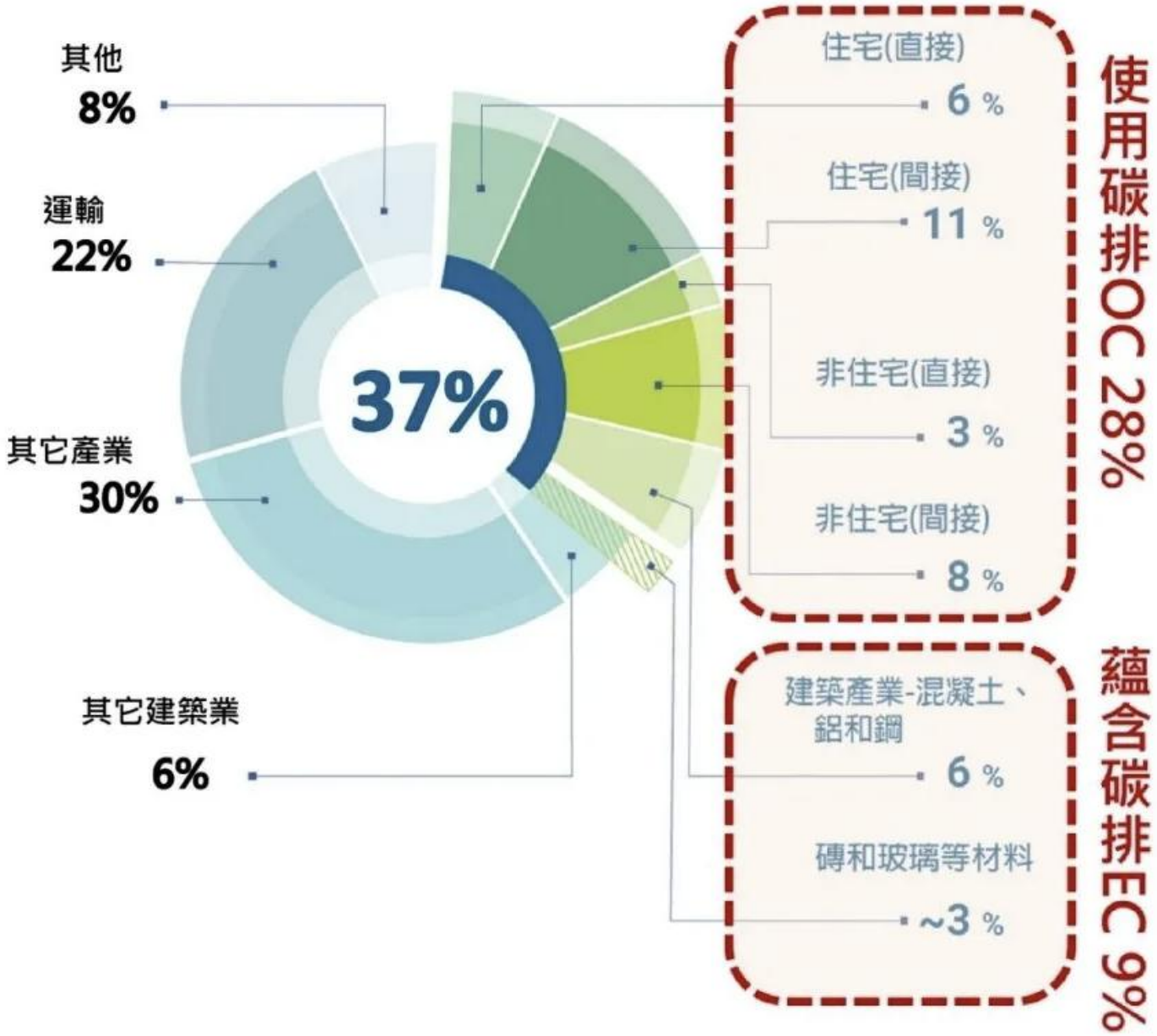
聯鋼營造 工程師

混合構造的樣態



建築結構的低蘊含碳評估

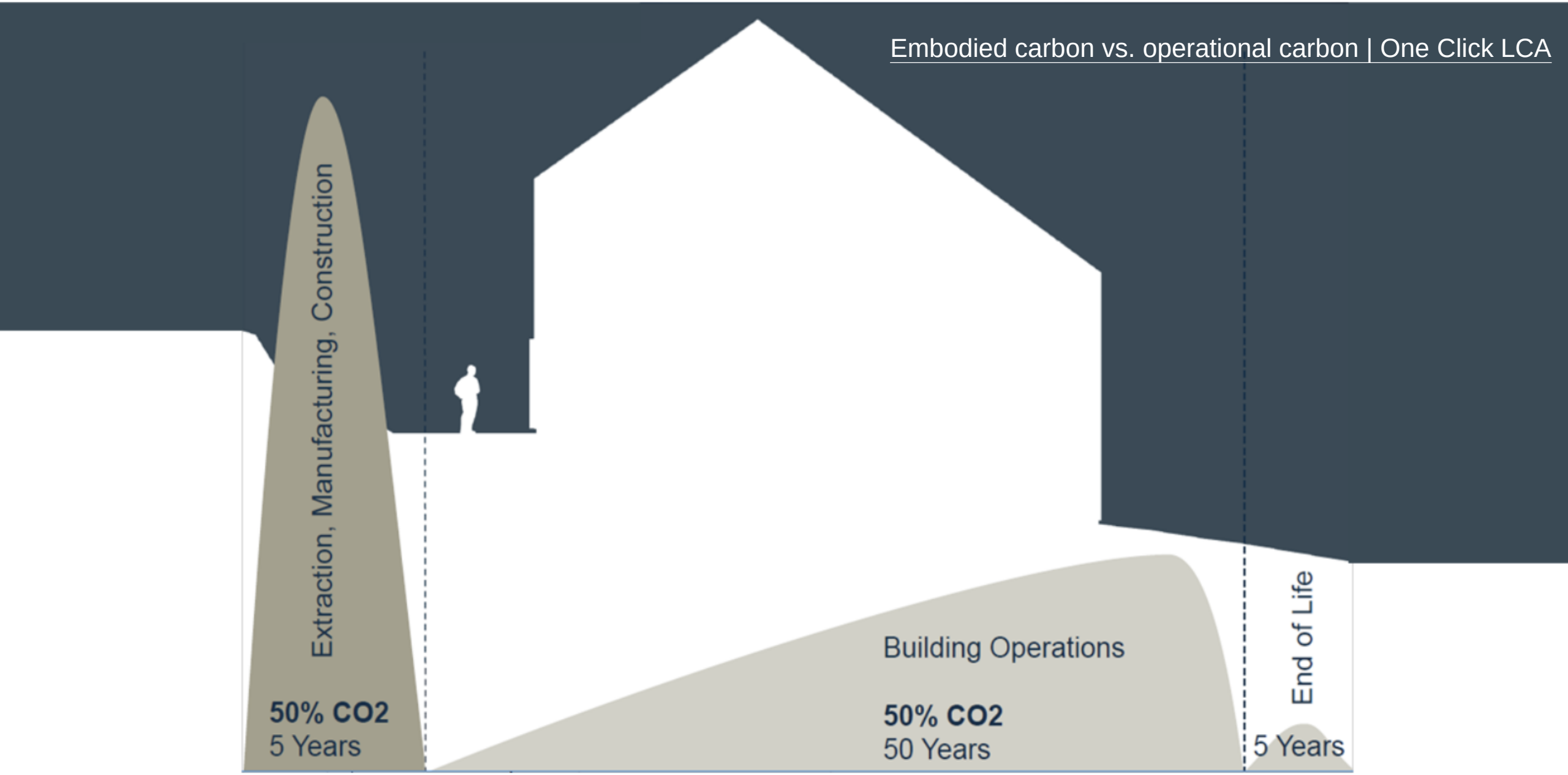
建築全生命週期碳排



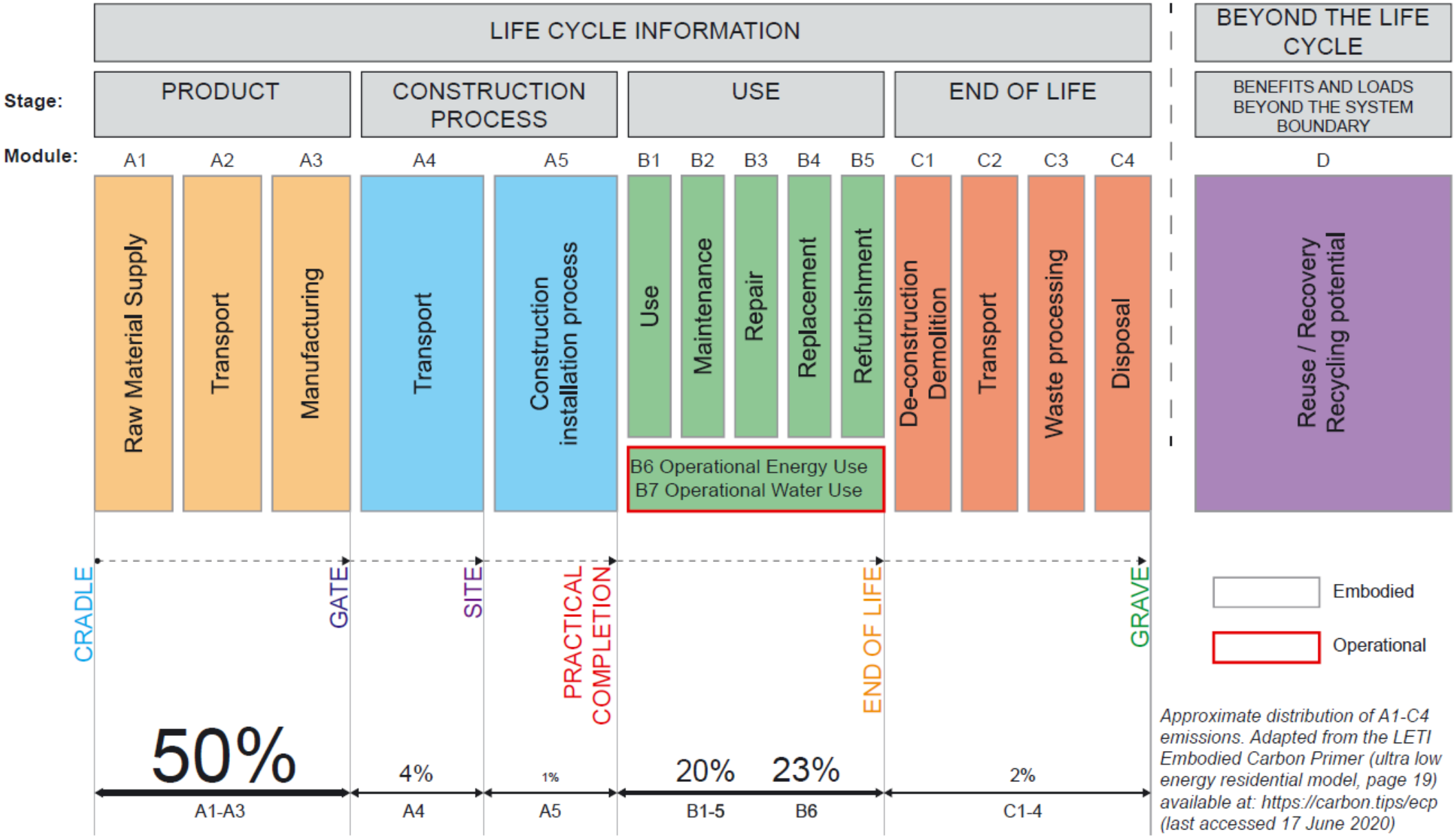
使用碳 Operational Carbon (OC)

蘊含碳 Embodied Carbon (EC)

建築全生命週期碳排


Embodied carbon vs. operational carbon | One Click LCA
Extraction, Manufacturing, Construction
50% CO2
5 Years
Building Operations
50% CO2
50 Years
End of Life
5 Years

建築全生命週期碳排



Approximate distribution of A1-C4 emissions. Adapted from the LETI Embodied Carbon Primer (ultra low energy residential model, page 19) available at: https://carbon.tips/ecp (last accessed 17 June 2020)

建築全生命週期碳排

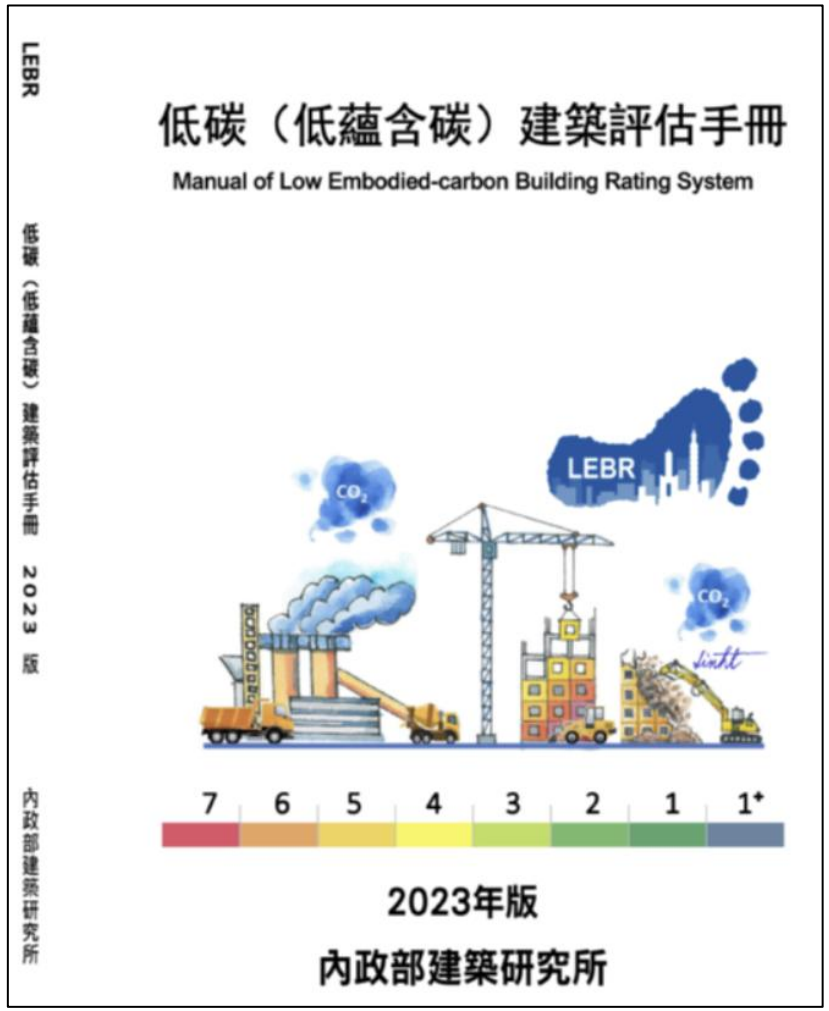


TABLE 2: A1–A3 ECFs for typical structural materials

Material	Type	Specification/details	A1–A3 ECF (kgCO_2e/kg)	Data source
Concrete	*In situ*: piling, substructure, superstructure	Unreinforced, C30/37, UK average ready-mixed concrete EPD[1] (35% cement replacement)	0.103	MPA, 2018[2]
		Unreinforced, C32/40, 25% GGBS cement replacement[3]	0.120	ICE V3[4]
		Unreinforced, C32/40, 50% GGBS cement replacement	0.089	ICE V3
		Unreinforced, C32/40, 75% GGBS cement replacement	0.063	ICE V3
		Unreinforced, C40/50, 25% GGBS cement replacement	0.138	ICE V3
		Unreinforced, C40/50, 50% GGBS cement replacement	0.102	ICE V3
		Unreinforced, C40/50, 75% GGBS cement replacement	0.072	ICE V3
	Precast	Unreinforced, C40/50 with average UK cement mix	0.178	ICE V3
		Reinforced, 150mm prestressed hollow core slab: British Precast Concrete Federation average EPD	50.2kgCO_2e/m²	BPCF, 2017[5]
Steel	Reinforcement bars	UK: BRC EPD	0.684	BRC, 2019[6]
		Worldwide: Worldsteel LCI study data, 2018, world average	1.99	ICE V3
	PT strands	Assume the same as reinforcement bars		
	Structural sections	UK open sections: British Steel EPD	2.45	BS, 2020[7]
		Europe (excl. UK): Bauforumstahl[8] average EPD	1.13	Bauforumstahl, 2018
		Worldwide: Worldsteel LCI study data, 2018, world average	1.55	ICE V3
	Galvanised profiled sheet (for decking)	UK: TATA Comflor EPD	2.74	TATA, 2018
Blockwork	Precast concrete blocks	Lightweight blocks	0.28	ICE V3
Brick	Single engineering clay brick	Generic, UK	0.213	ICE V3
Timber, excl. carbon sequestration[9], [10]	Manufactured structural timber	CLT, 100% FSC/PEFC	0.437	ICE V3
		Glulam, 100% FSC/PEFC	0.512	ICE V3
	Studwork/framing/flooring	Softwood, 100% FSC/PEFC	0.263	ICE V3
	Formwork	Plywood, 100% FSC/PEFC	0.681	ICE V3
Plasterboard	Partitioning/ceilings	Minimum 60% recycled content	0.39	ICE V2
Intumescent paint	For steelwork	Specific EPD: Amotherm steel WB, Amonn	2.31	AMONN, 2019[11]

Cross Laminated Timber CLT

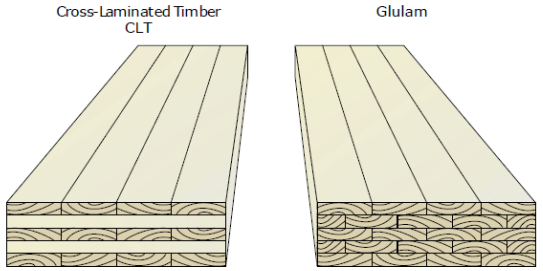


Figure 4
CLT vs. glulam panel

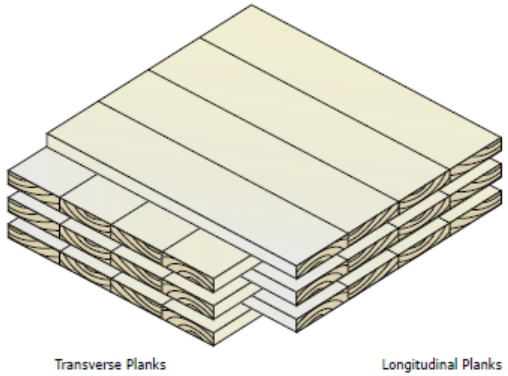


Figure 1
CLT panel configuration

Cross Laminated Timber CLT

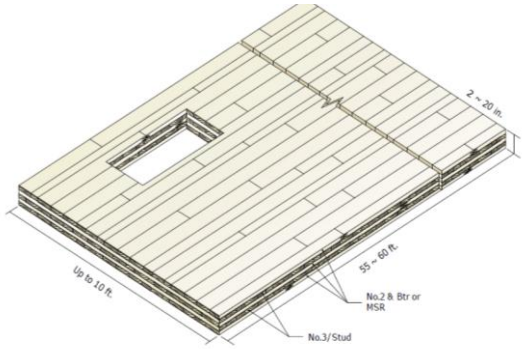


Figure 7
CLT floor or roof

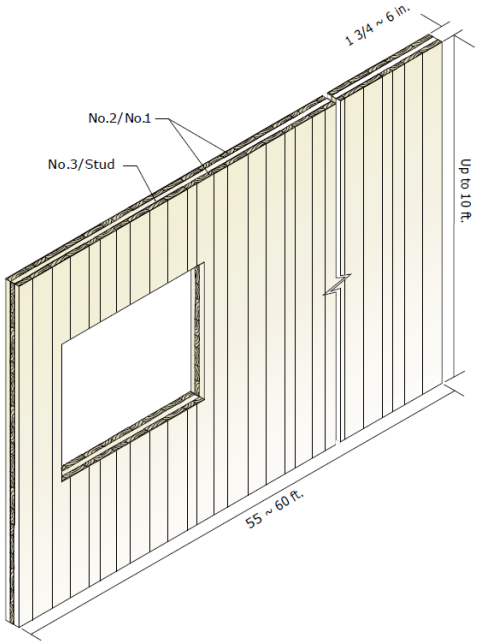


Figure 6
CLT wall

Cross Laminated Timber CLT

鋼木混合構造的低蘊含碳比較及分析

Contents

1
原建築模型
構造對比圖
樑柱接頭示意圖
地震力設定及載重設定

2
鋼結構
鋼木混和結構
木結構
分析結果綜合比較

- 斷面檢核、設定
- 層間位移(Ex)、(Ey)
- 樓層應力及彎矩

3
工期與材料費用

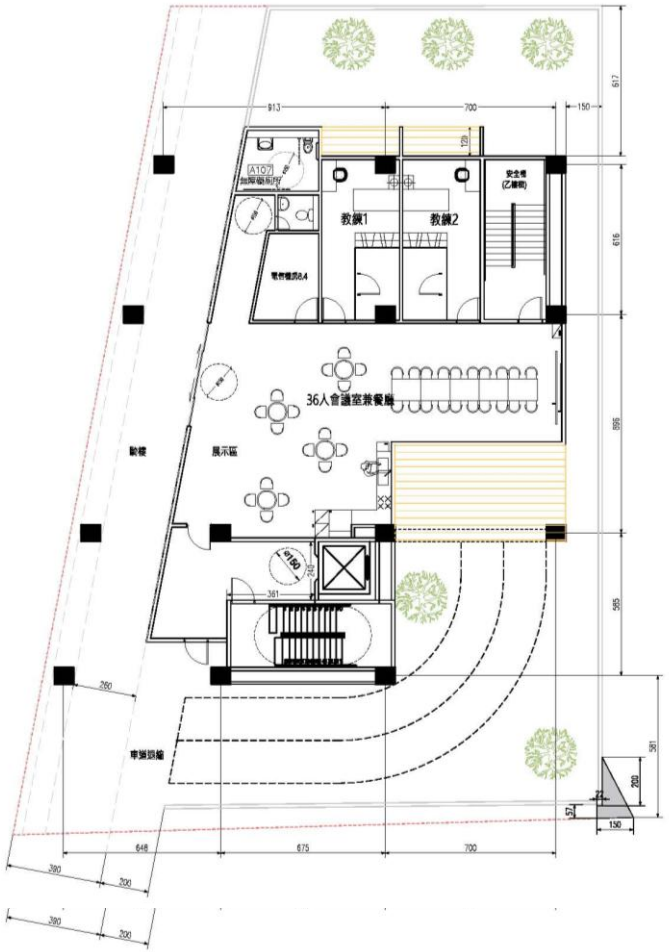
- 台灣市場建築材料單價
- 建築材料使用量
- 建築材料使用量與成本分析
- Type1-3 工期計算

4
碳排放量、碳稅計算

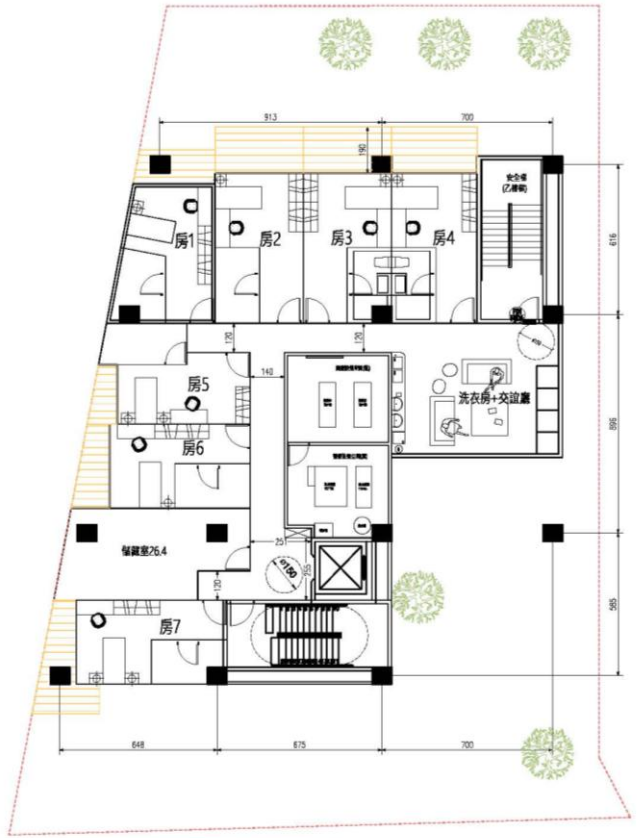
- 鋼結構碳排放量計算
- 木材料運輸碳排放量計算
- 鋼木混合結構碳排放量計算
- Type1-3總碳排放量
- 各國碳稅及台灣碳費
- Type1-3各國碳稅

原建築模型

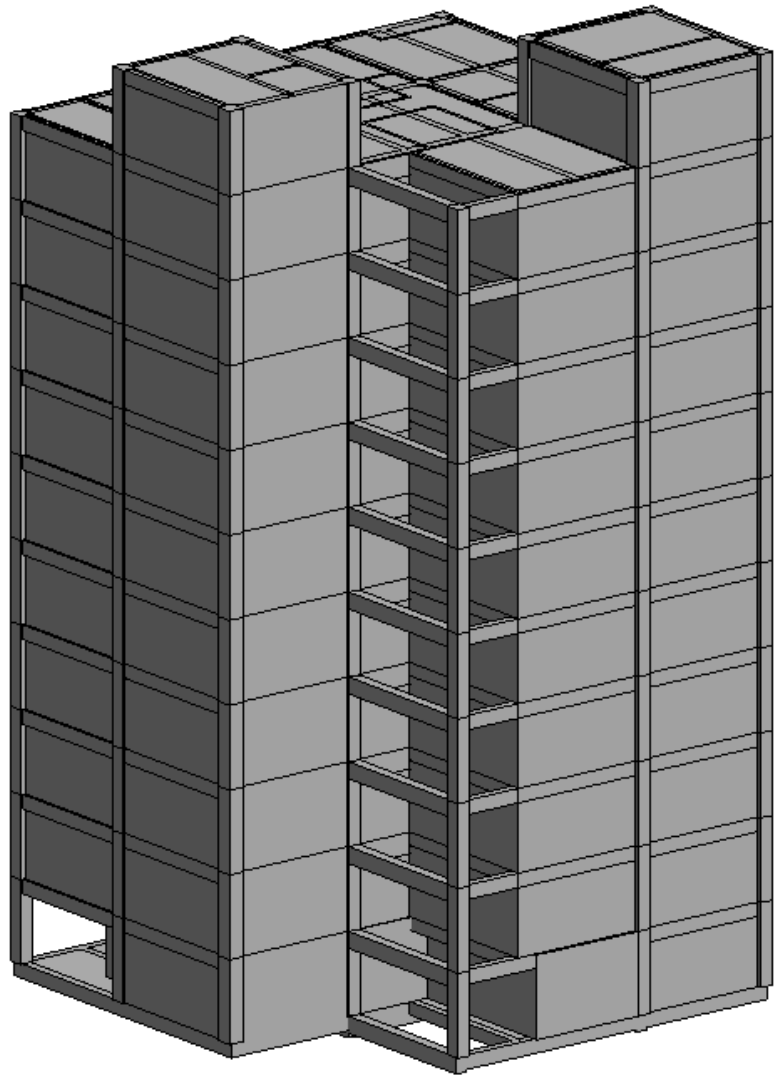
構造：鋼構
樓層：地上十層屋突一層



一層平面圖

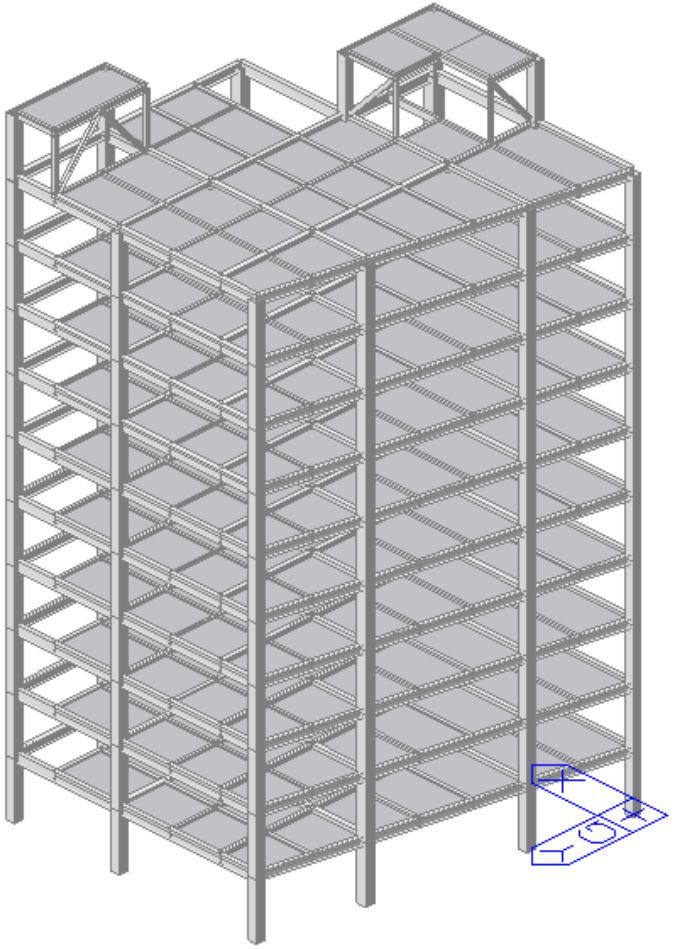


二層平面圖(標準層)

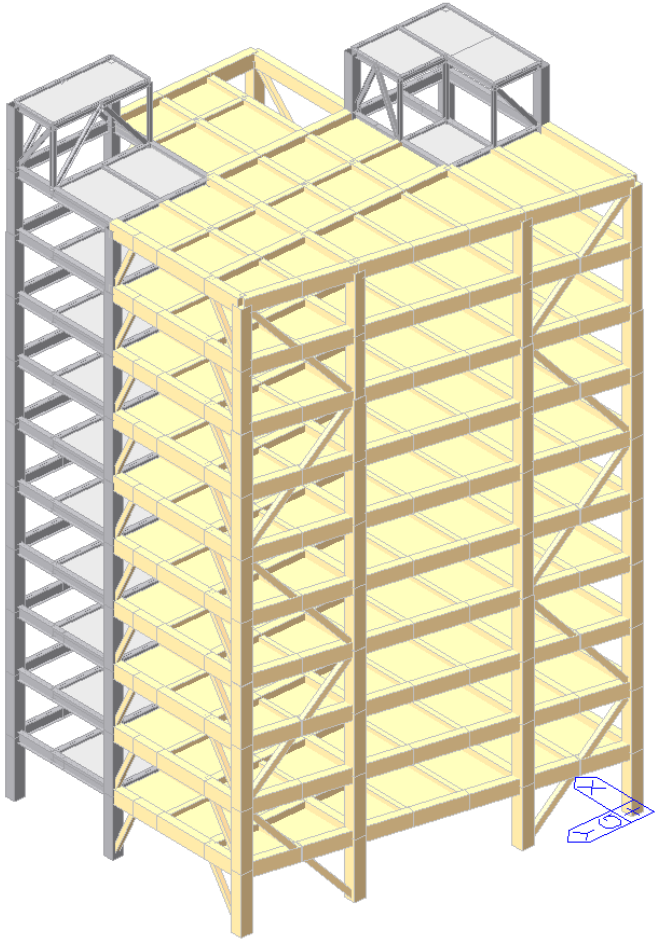


3D模型示意圖

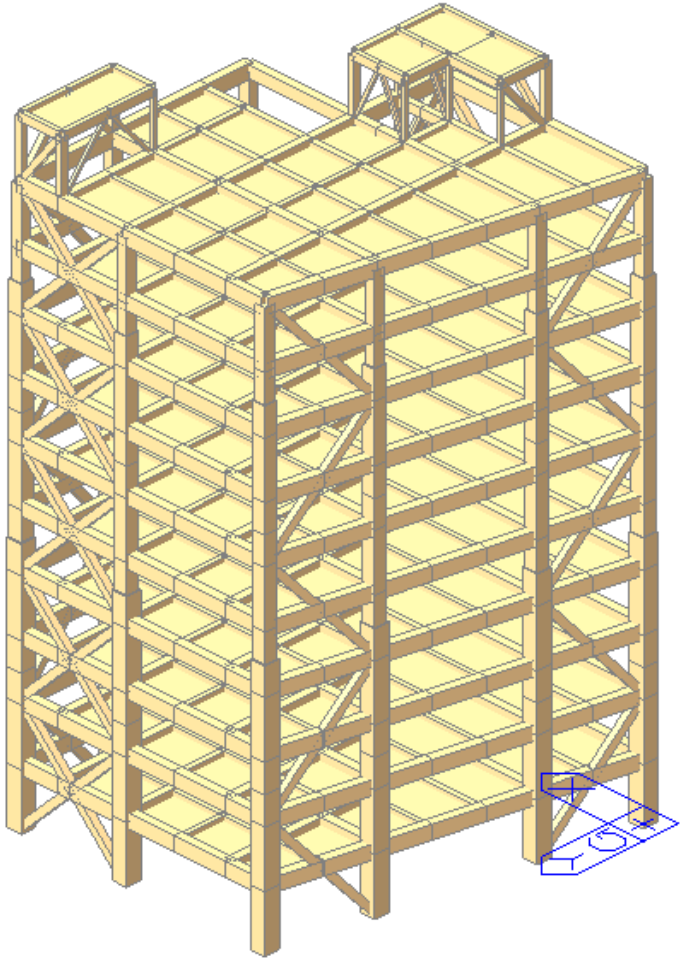
構造對比圖



Type1 (鋼結構)
(原始模型, 特殊抗彎構架)

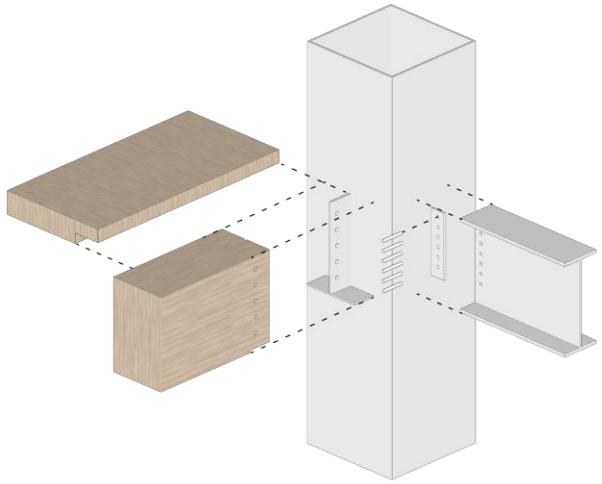


Type2(混合構造)
(特殊抗彎構架+斜撐構架)

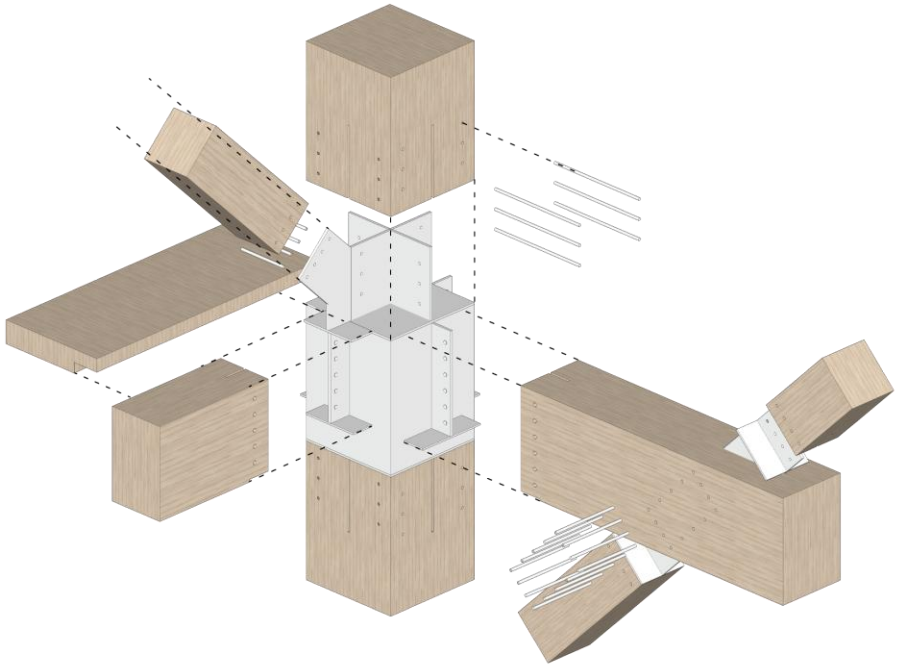


Type3(木構)
(斜撐構架)

鋼木接頭系統與分析材質設定



混構接頭



木構接頭

材質強度設定

鋼結構：SN490B,C

混凝土：4000psi

Rebar : SD420W

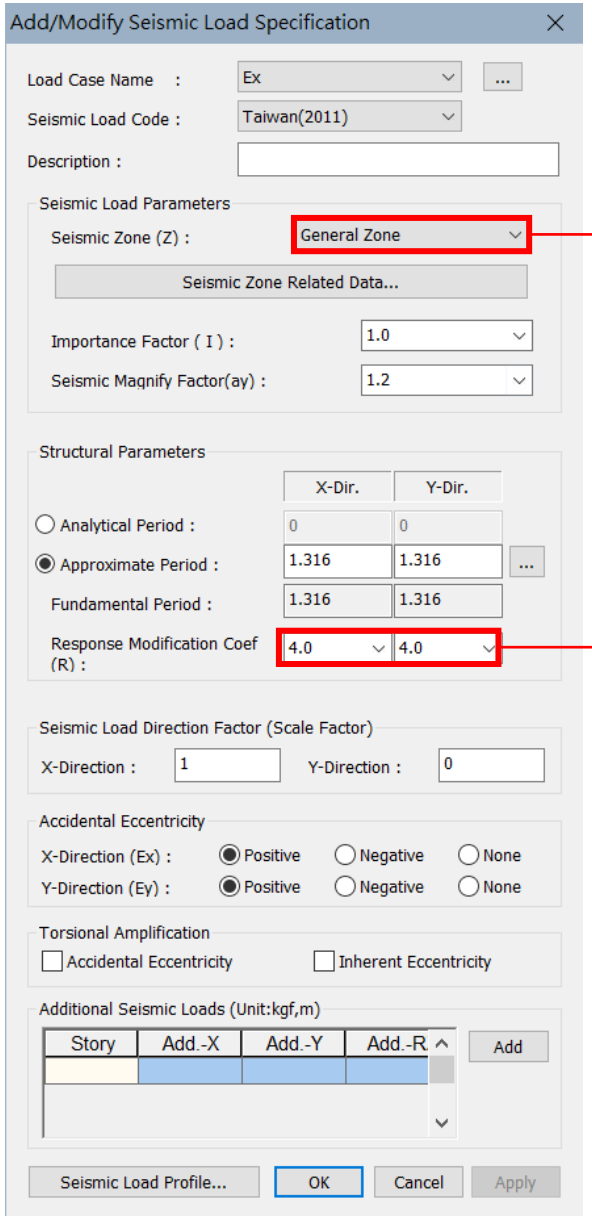
木材 : E105-F345

基地震區譜加速度

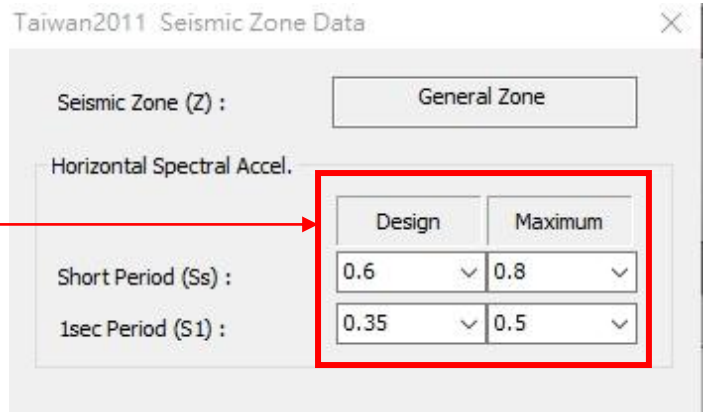
震區譜加速度係數

縣市	鄉鎮市區	S_S^D	S_1^D	S_S^M	S_1^M	鄰近之斷層
高雄市	鳳山區	0.60	0.35	0.80	0.50	
	林園區	0.50	0.30	0.70	0.45	
	大寮區	0.60	0.35	0.80	0.45	
	大樹區	0.70	0.40	0.90	0.50	旗山斷層
	大社區	0.80	0.45	1.00	0.55	旗山斷層
	仁武區	0.80	0.45	1.00	0.55	旗山斷層
	鳥松區	0.70	0.40	0.90	0.50	旗山斷層
	岡山區	0.70	0.40	0.90	0.50	旗山斷層
	橋頭區	0.80	0.45	1.00	0.55	旗山斷層
	燕巢區	0.80	0.45	1.00	0.55	旗山斷層
	田寮區	0.80	0.45	1.00	0.55	旗山斷層
	阿蓮區	0.70	0.40	0.90	0.50	
	路竹區	0.70	0.35	0.90	0.50	
	湖內區	0.70	0.35	0.90	0.50	
	茄萣區	0.70	0.35	0.90	0.50	
	永安區	0.70	0.35	0.90	0.50	
	彌陀區	0.70	0.35	0.90	0.50	
	梓官區	0.70	0.40	0.90	0.50	
	旗山區	0.80	0.45	1.00	0.55	旗山斷層

Midas地震力參數設定



基地位置：高雄鳳山
(非台北市)

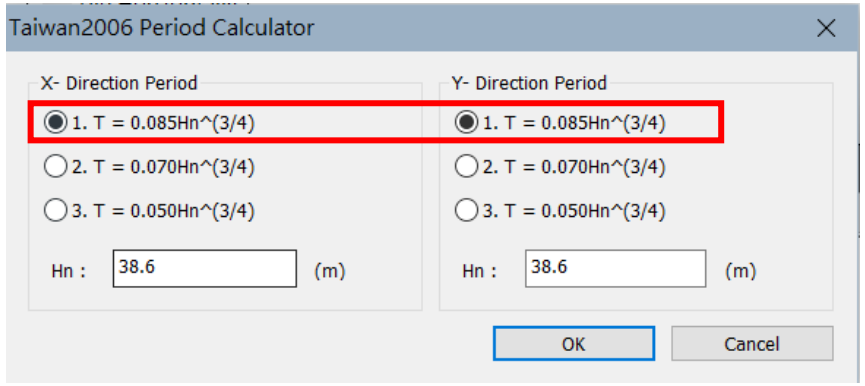


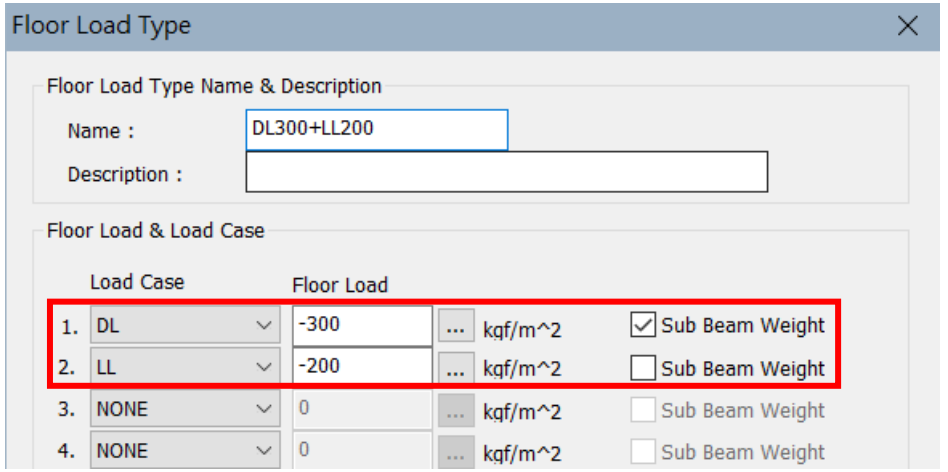
- 建築高度=35公尺
- 用途係數=1.0
- 震動週期=0.085Hn
- 韌性容量=4.0
- 放大係數=1.2

靜載重=300 kgf/m2
活載重=200 kgf/m2
(住宅類建築)

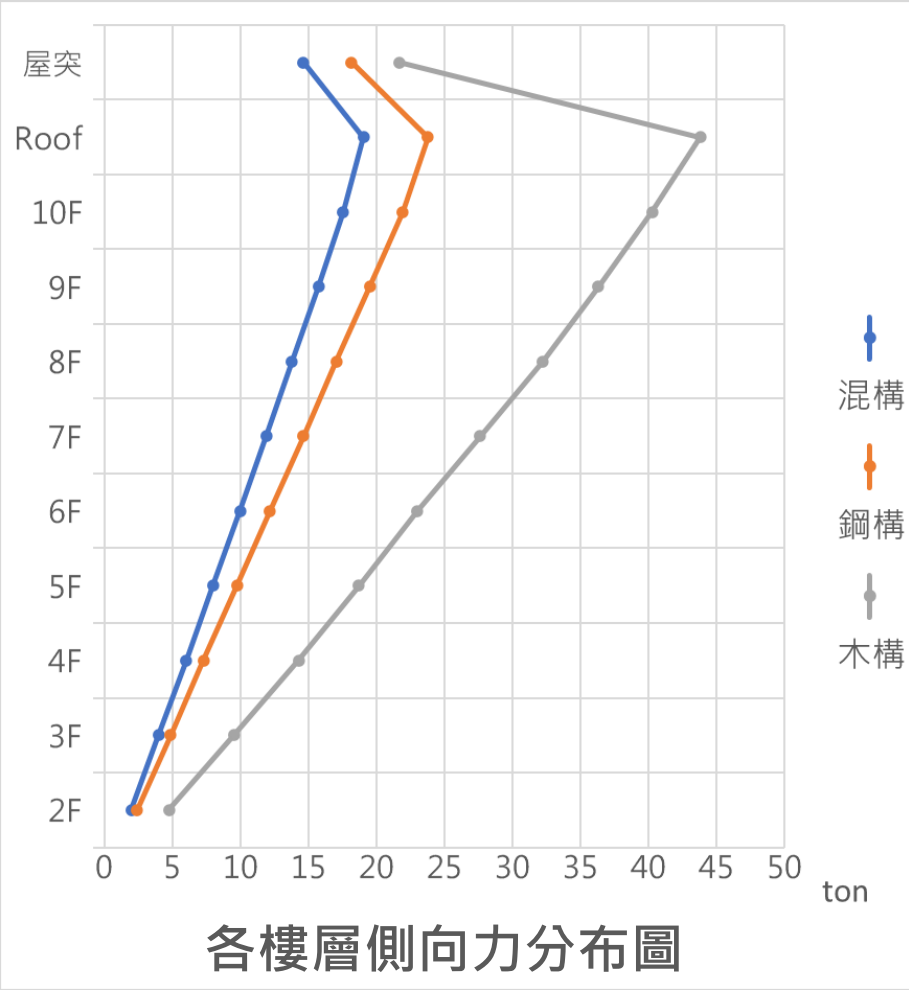
鋼構

鋼構	4.0
木構	2.4

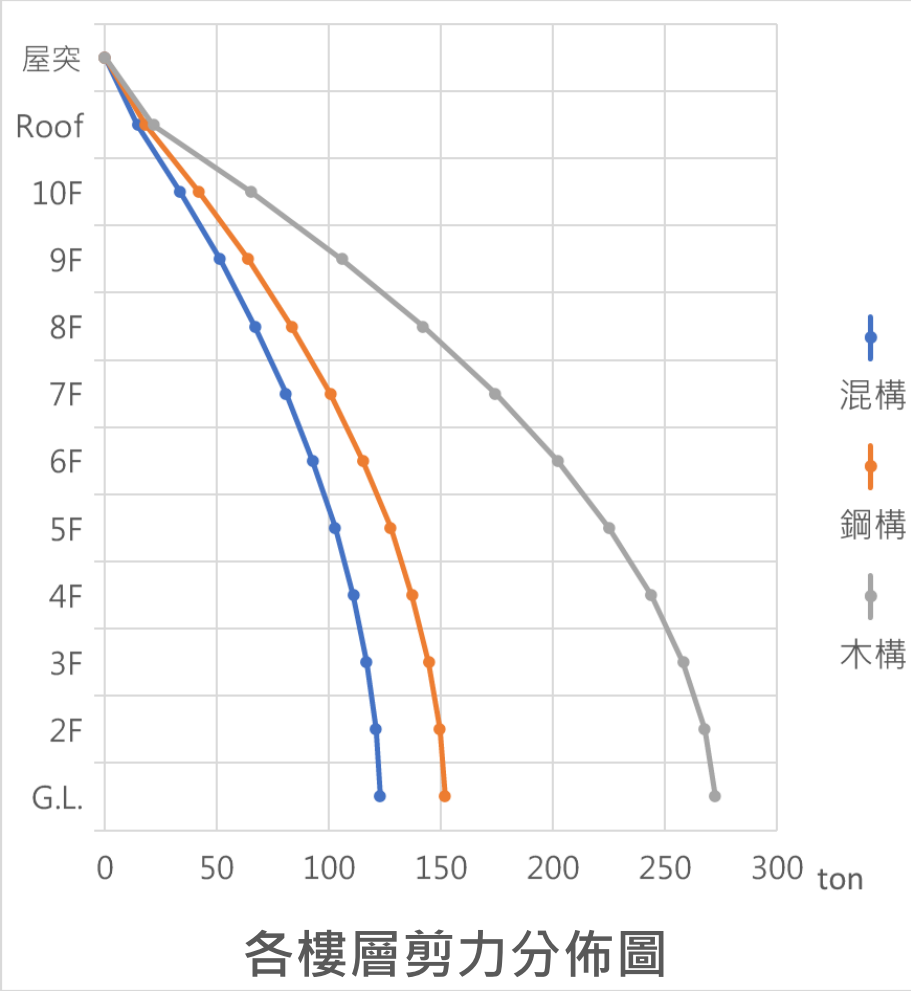




樓層地震力配置



各樓層側向力分布圖



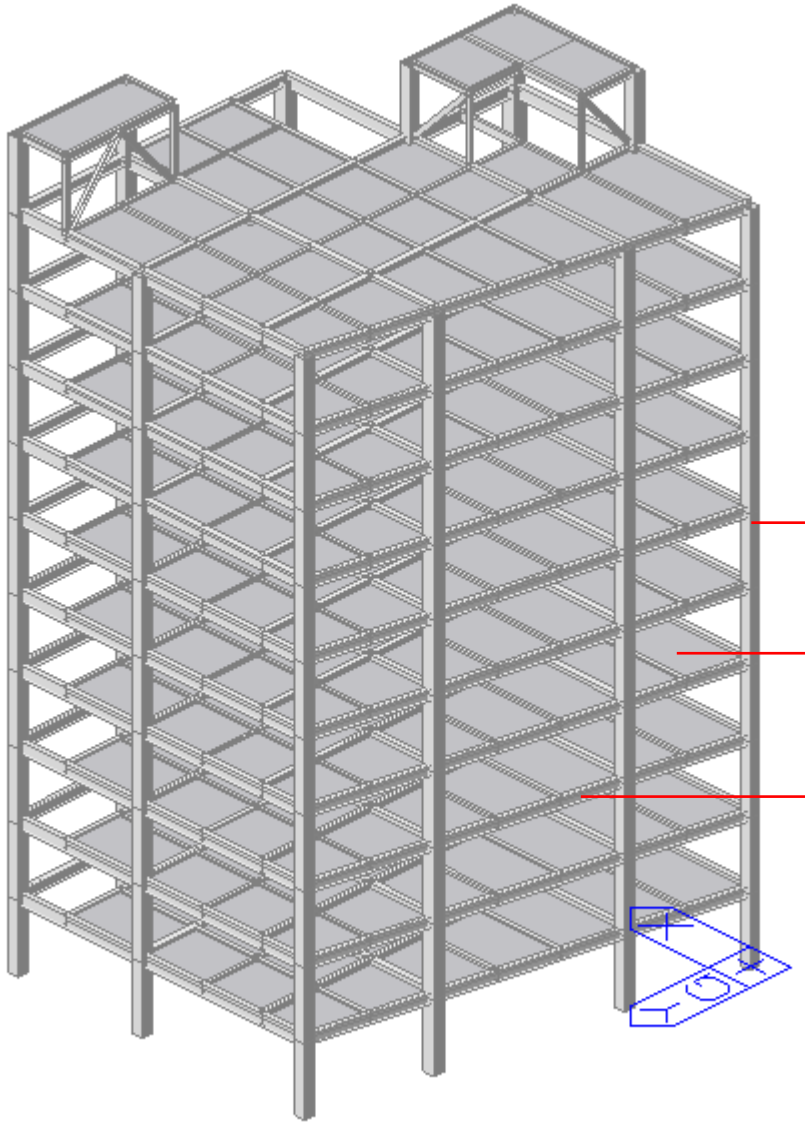
各樓層剪力分佈圖

鋼構與木構基本震動週期依照法定公式假設，混構造則依照Midas軟體計算結果為準

項目	Type1-鋼構		Type2-鋼木混合結構		Type3-木構	
R值(雙向)	4.0		4.0		2.4	
基本震動週期	X: 1.316s	Y: 1.316s	X: 1.1155s	Y: 0.9631s	X: 0.7743	Y: 0.7743

TYPE1-鋼結構

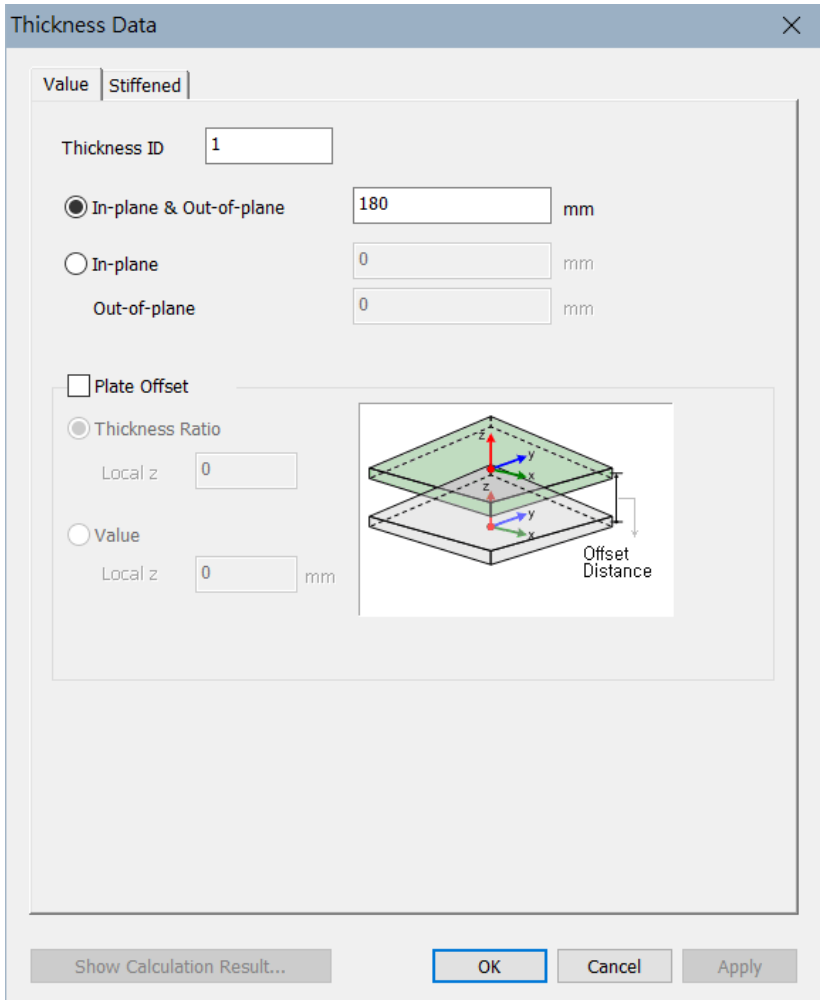
鋼結構斷面檢核



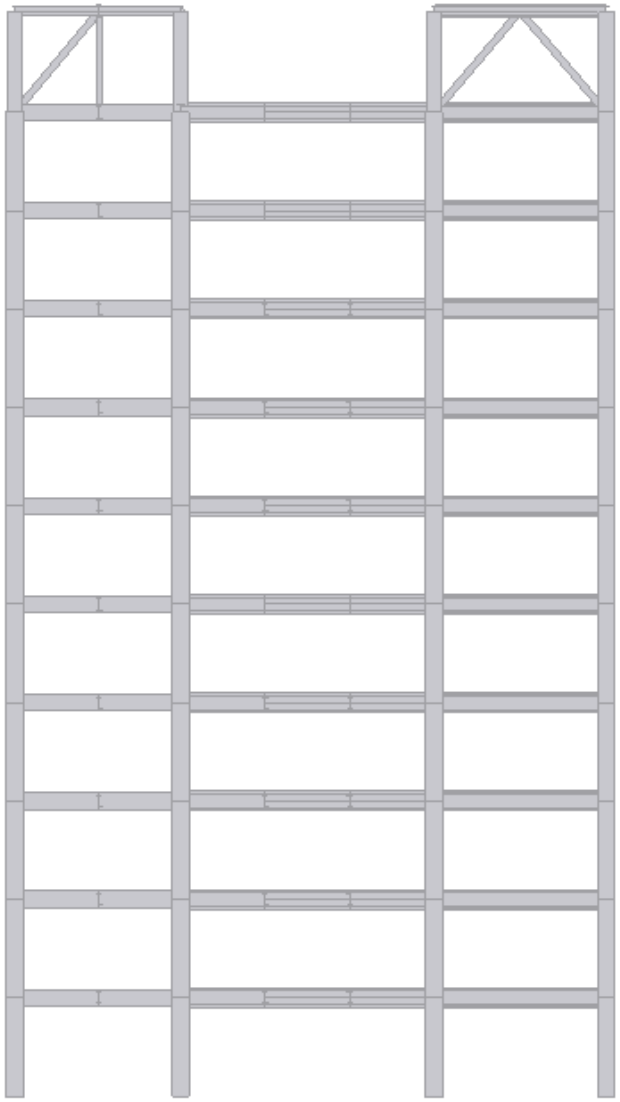
鋼構柱 Box

混凝土樓板 18cm

H字型 鋼梁



鋼結構柱斷面設定



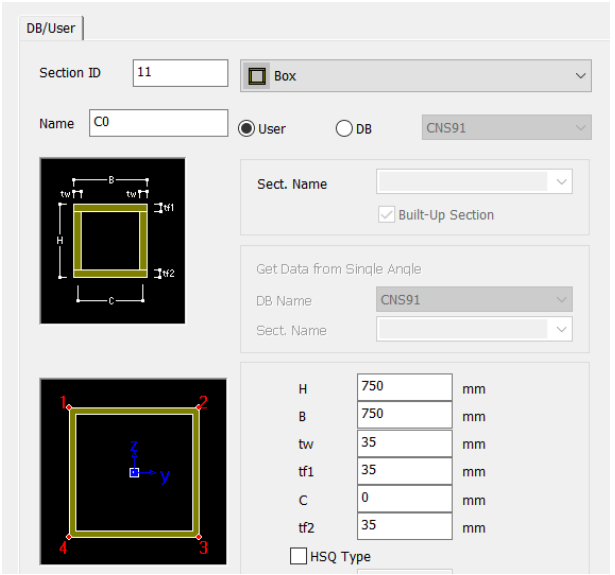
C3/C4

C3

C2

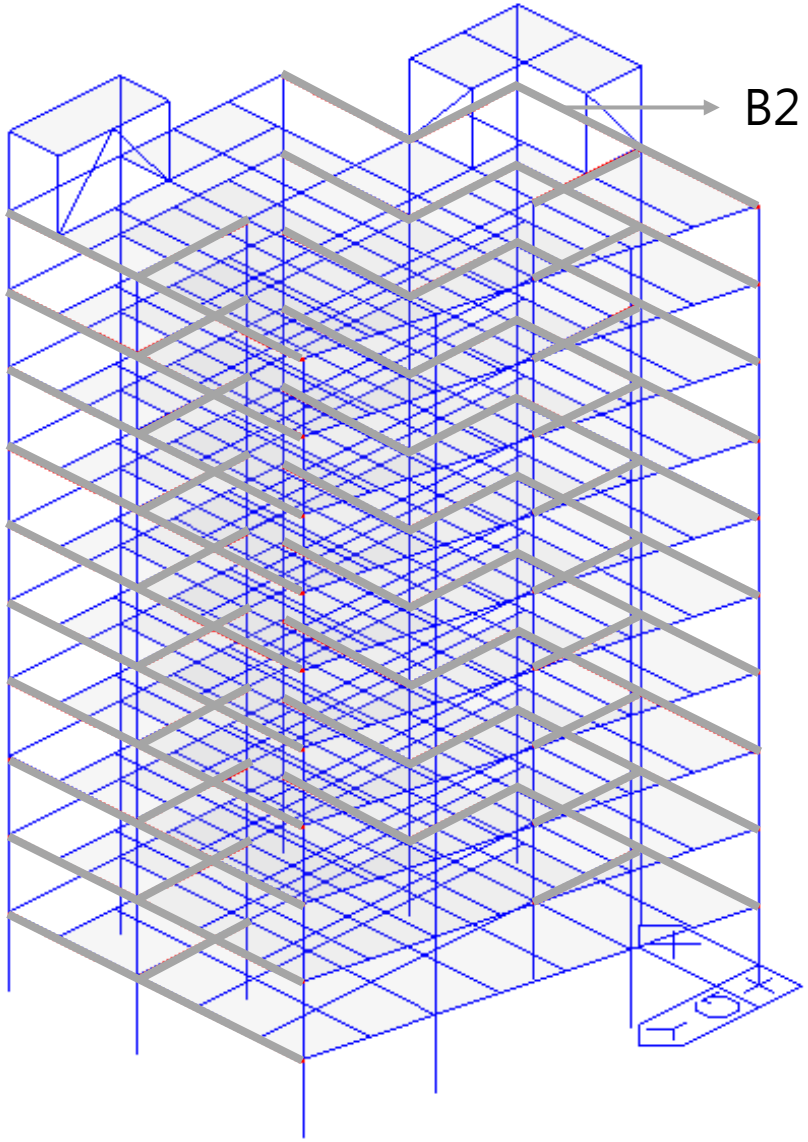
C1

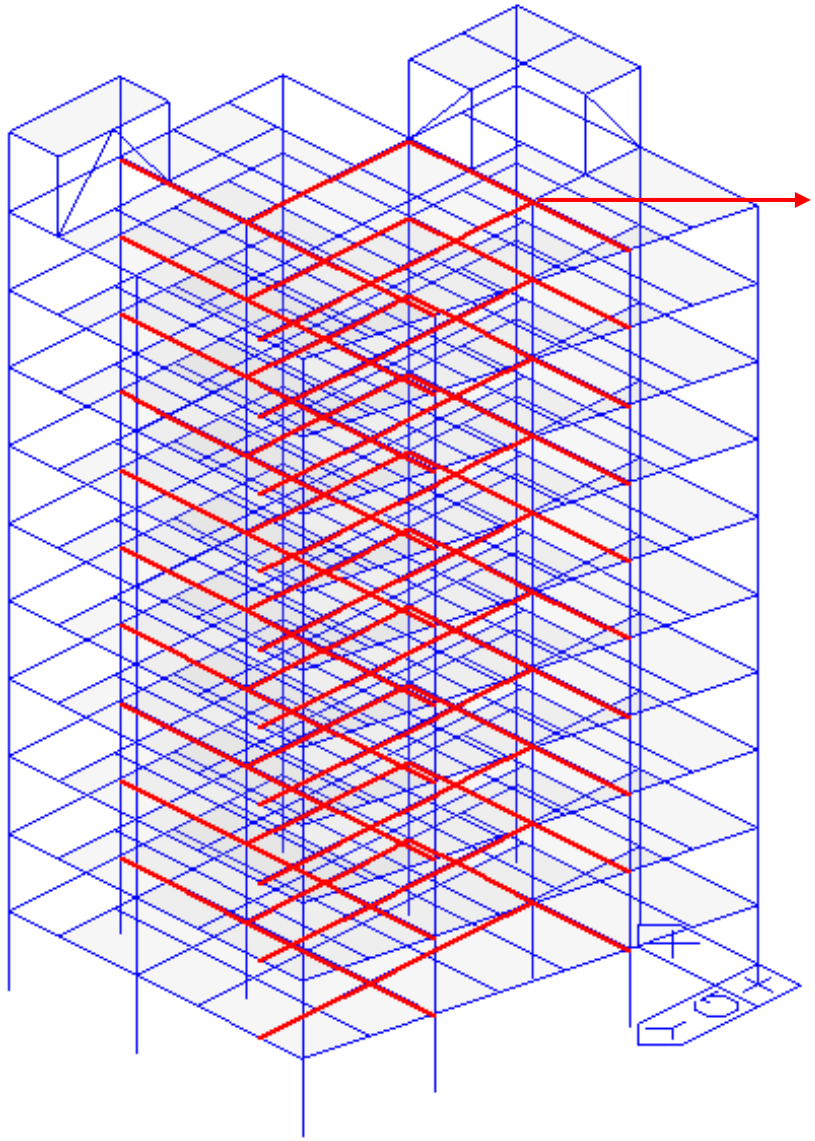
Steel

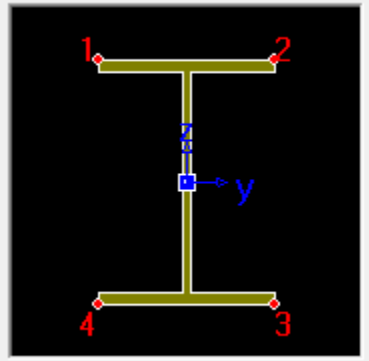


C1	650x650x30
C2	600x600x28
C3	550x550x25
C4	H200x200x8x12

鋼結構梁斷面設定

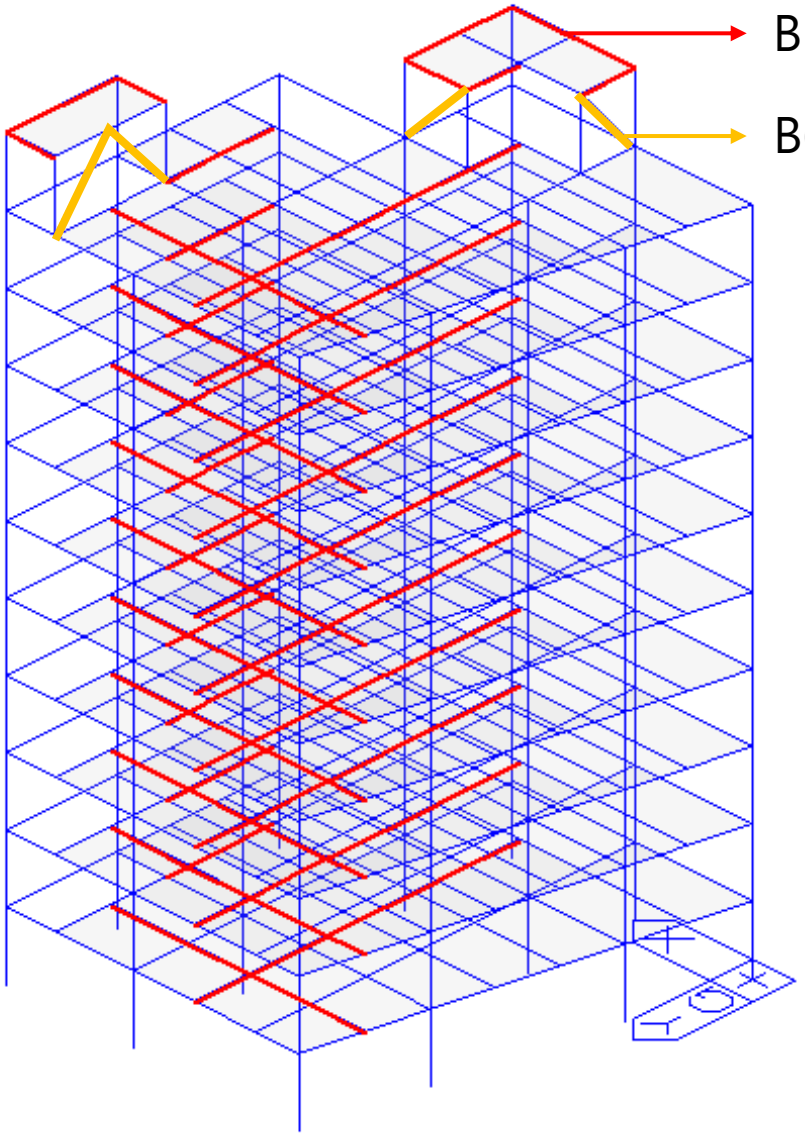


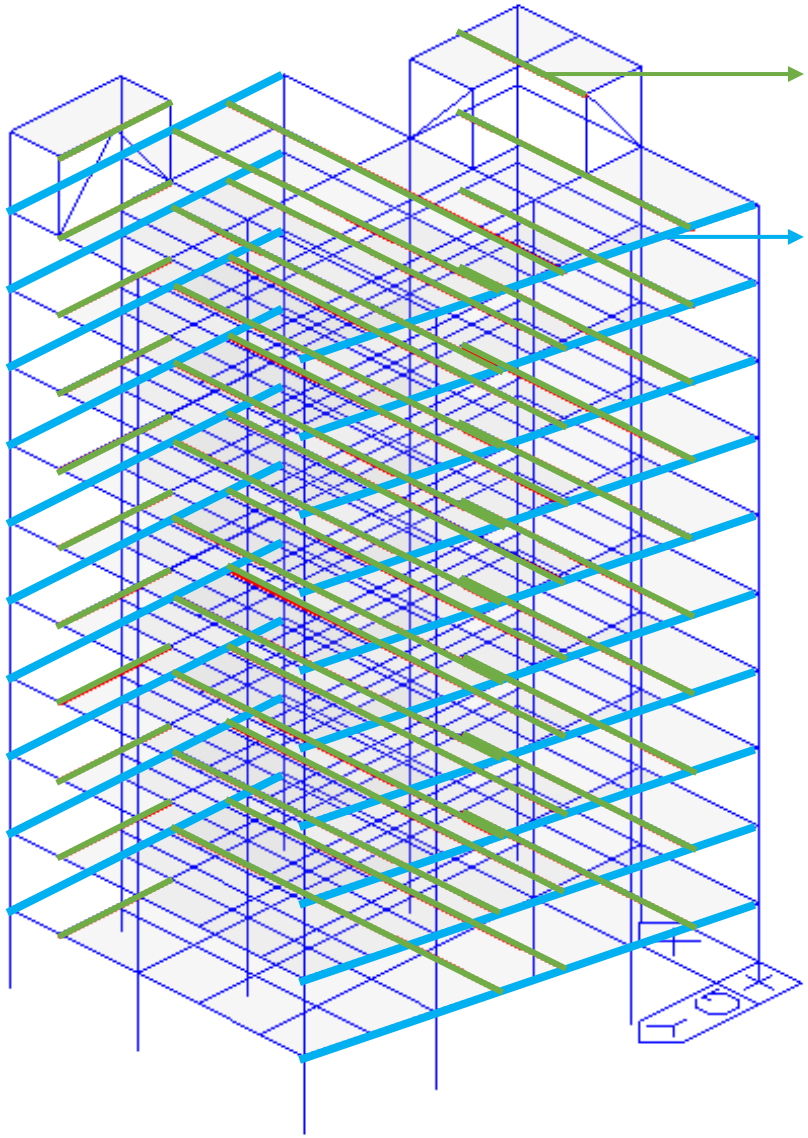


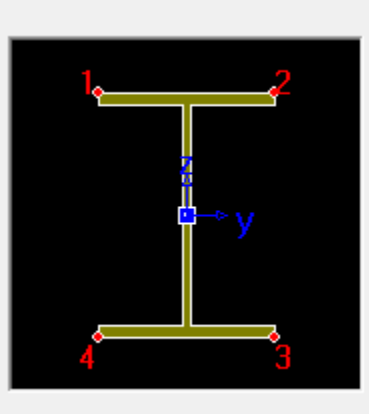


B6	244x175x7/11
B5	350x175x7/11
B4	400x200x8/13
B3	488x300x12/20
B2	588x300x12/20
B1	700x300x13/24

鋼結構梁斷面設定

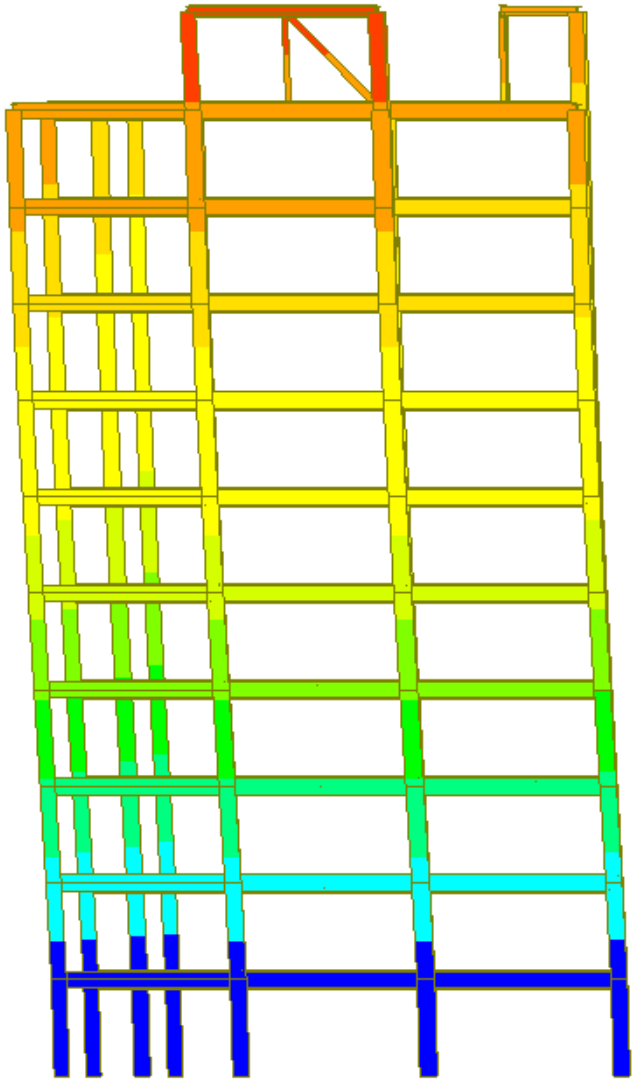






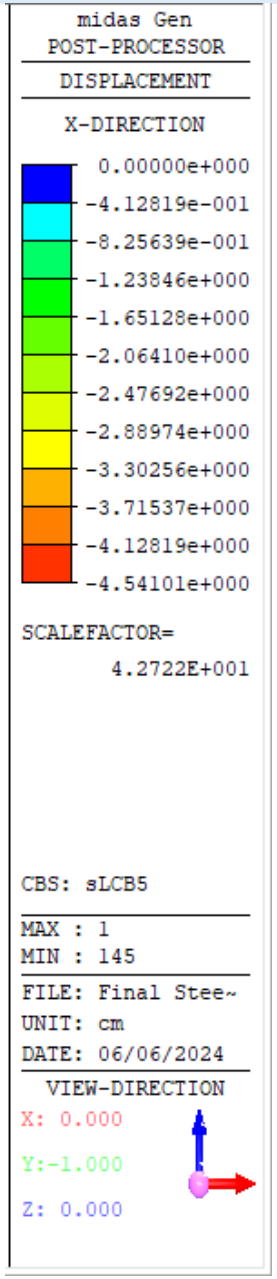
B6	244x175x7/11
B5	350x175x7/11
B4	400x200x8/13
B3	488x300x12/20
B2	588x300x12/20
B1	700x300x13/24

層間位移(Ex)

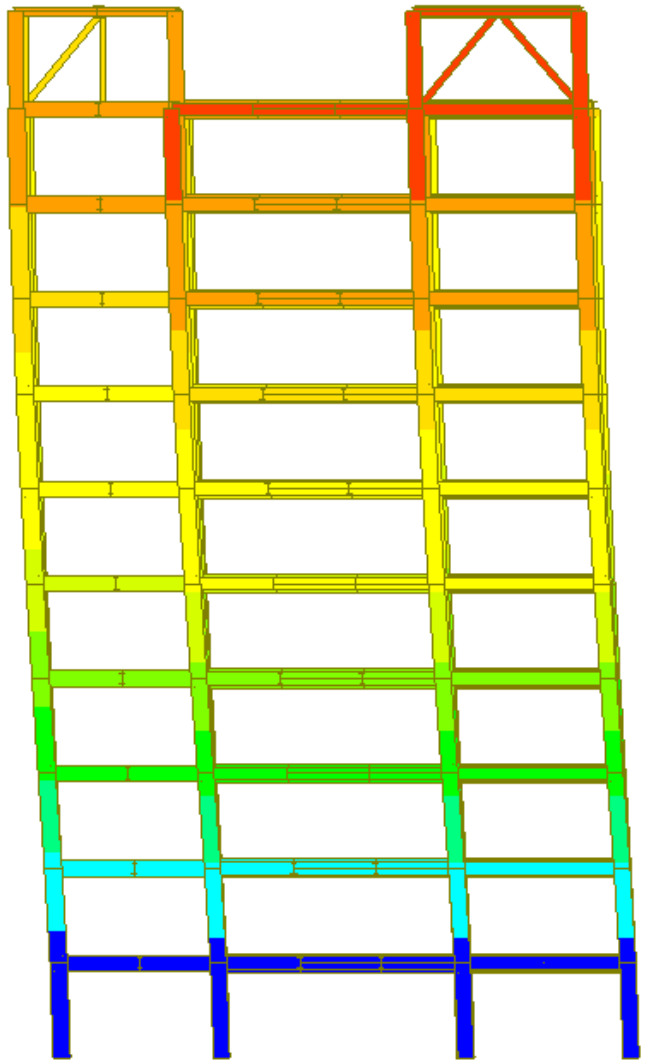


Load combination : 1.2D + 0.5L- Ex

樓層	位移(cm)	層間變位角
屋突	-4.541	0.0013
Roof	-4.0866	0.0008
10F	-3.8006	0.0009
9F	-3.4729	0.0011
8F	-3.094	0.0012
7F	-2.6675	0.0013
6F	-2.2014	0.0014
5F	-1.7059	0.0015
4F	-1.1939	0.0014
3F	-0.6877	0.0013
2F	-0.2389	0.0007
1F	0	0

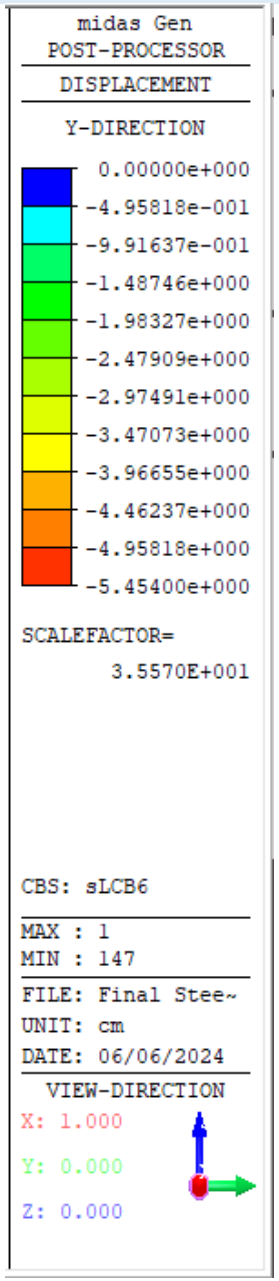


層間位移(Ey)



Load combination : 1.2D + 0.5L- Ey

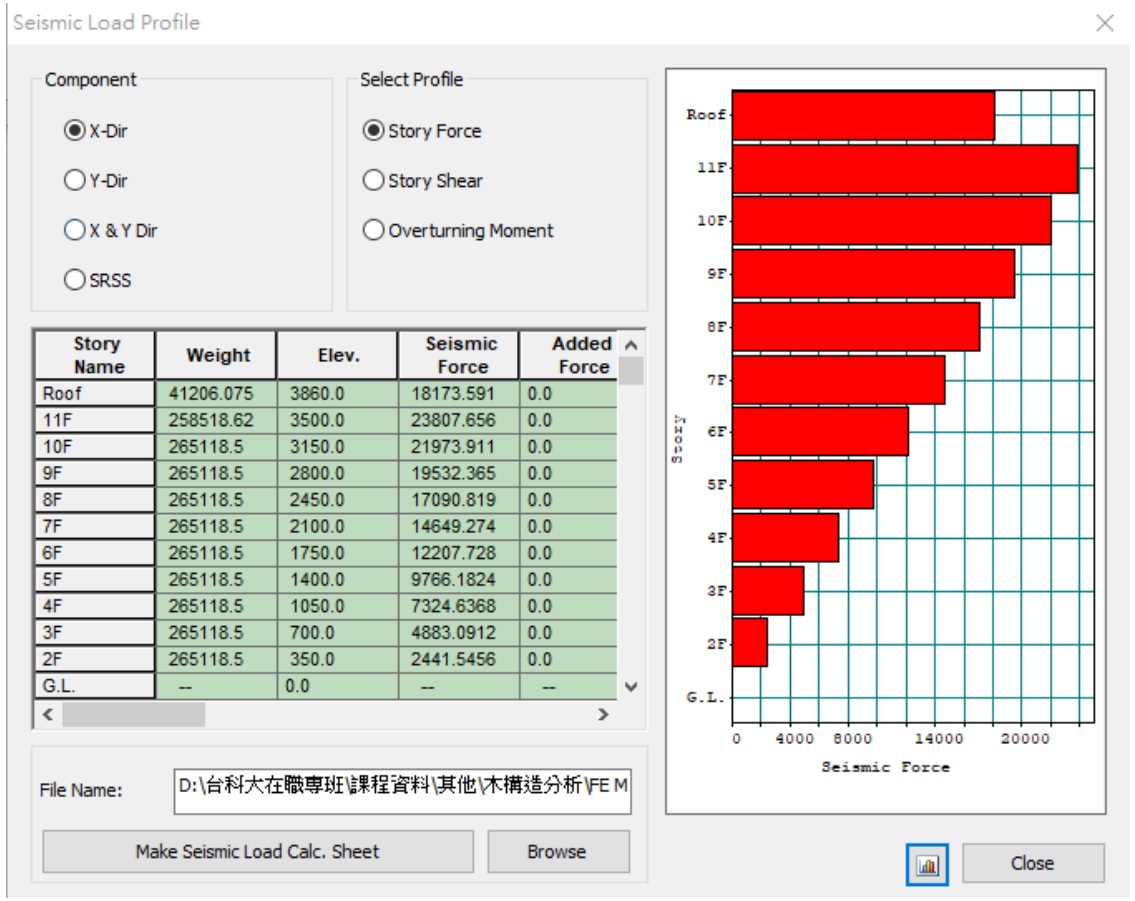
樓層	位移(cm)	層間變位角
屋突	-5.454	0.0007
Roof	-5.2072	0.0007
10F	-4.9494	0.0010
9F	-4.6057	0.0013
8F	-4.1673	0.0015
7F	-3.6399	0.0017
6F	-3.035	0.0019
5F	-2.3679	0.0020
4F	-1.6603	0.0020
3F	-0.9508	0.0018
2F	-0.3246	0.0009
1F	0	0



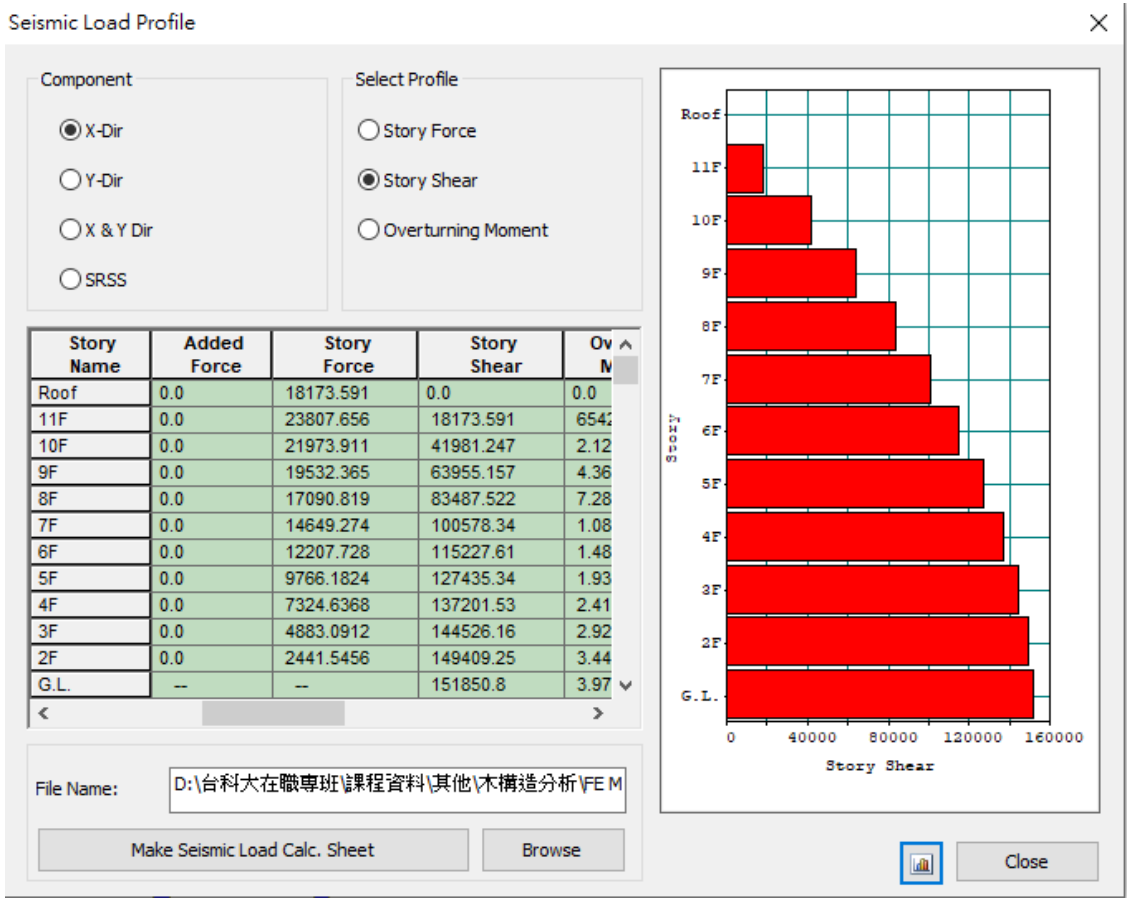
樓層地震力

頂樓地震力 23,807(kg)

基底剪力 151,851(kg)



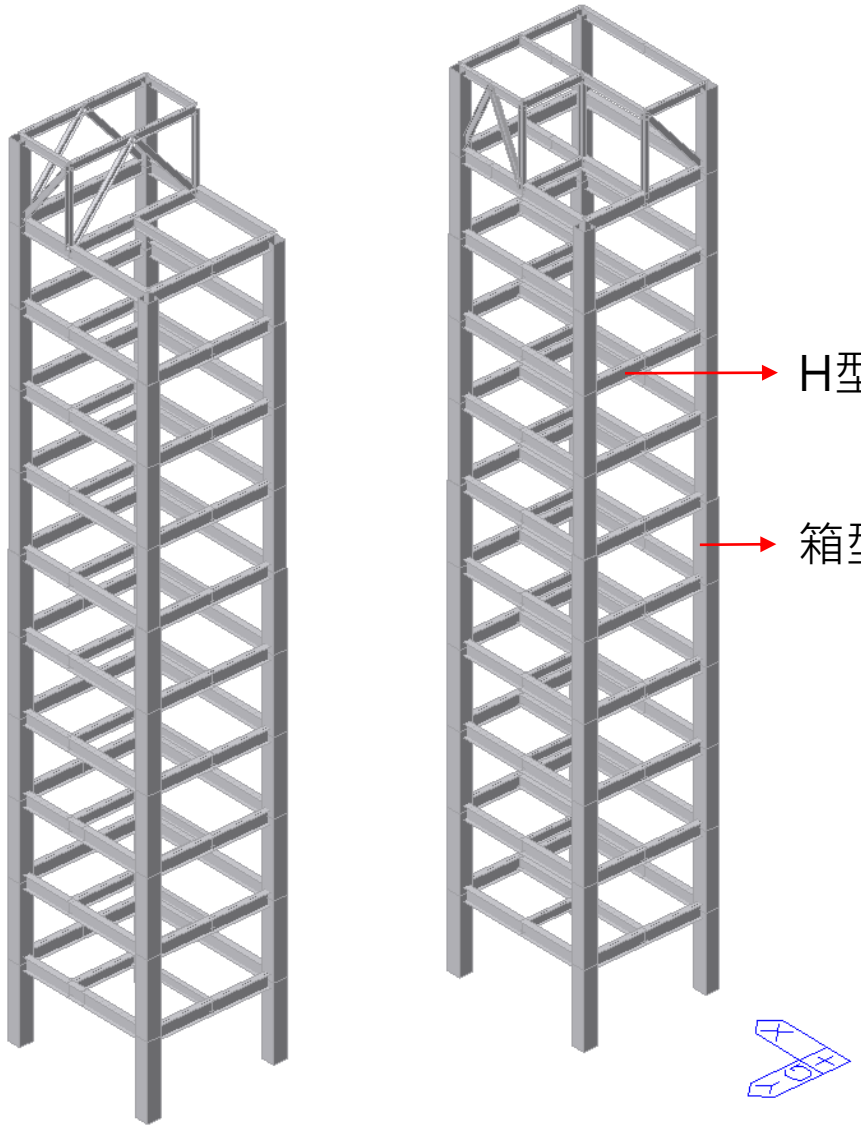
各樓層側向力分布圖



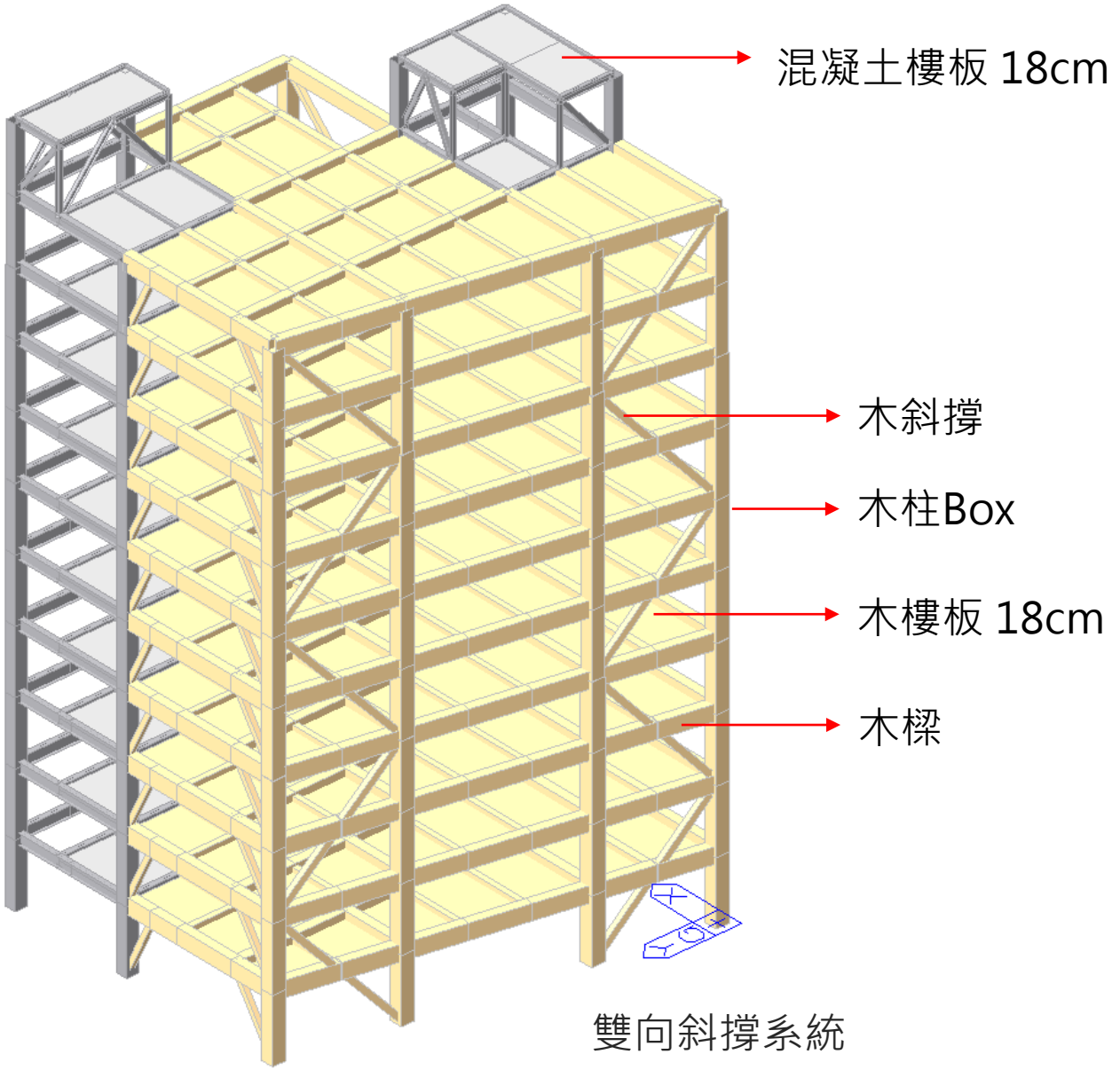
各樓層剪力分佈圖

TYPE2-鋼木混合結構

結構系統配置

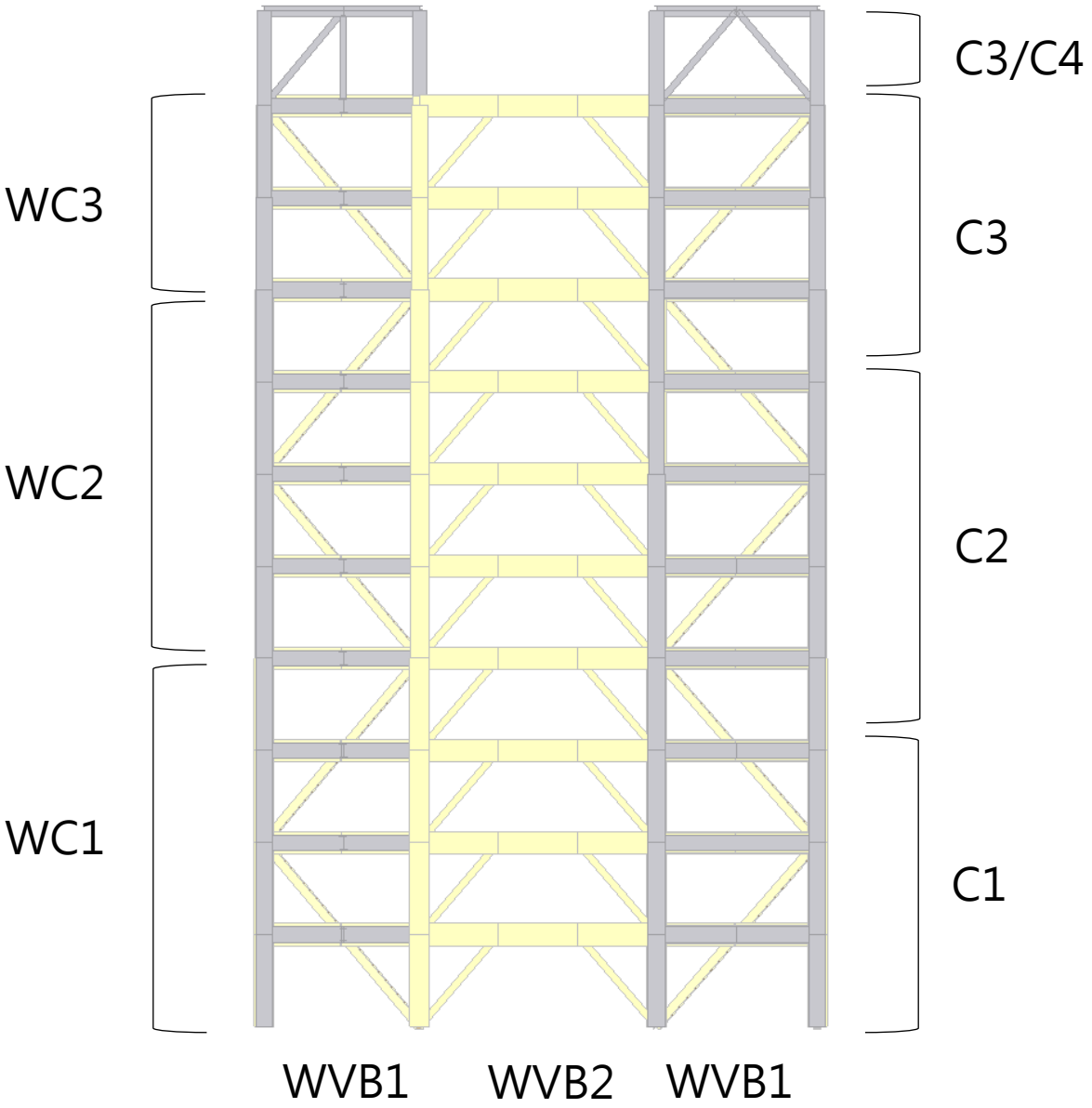


特殊抗彎構架

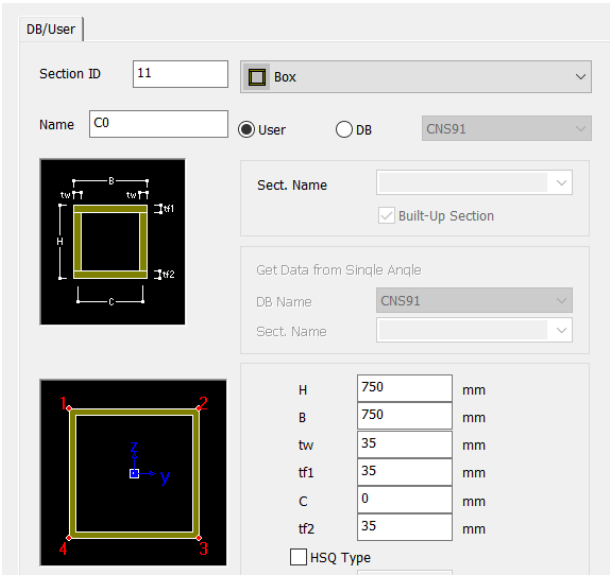


雙向斜撐系統

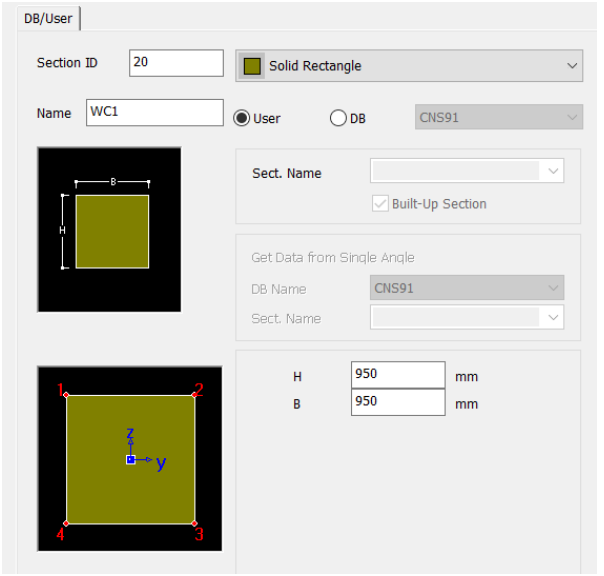
鋼木混合結構柱與斜撐斷面設定



Steel



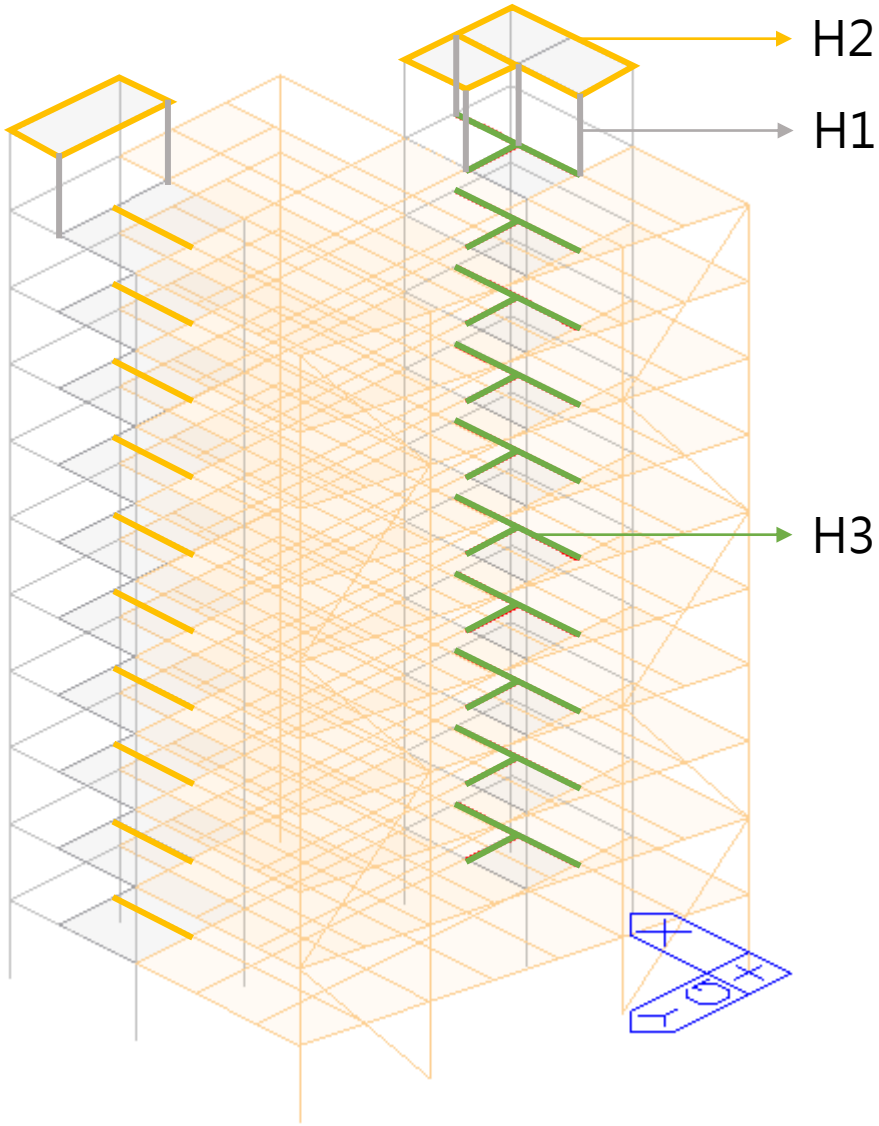
GLT

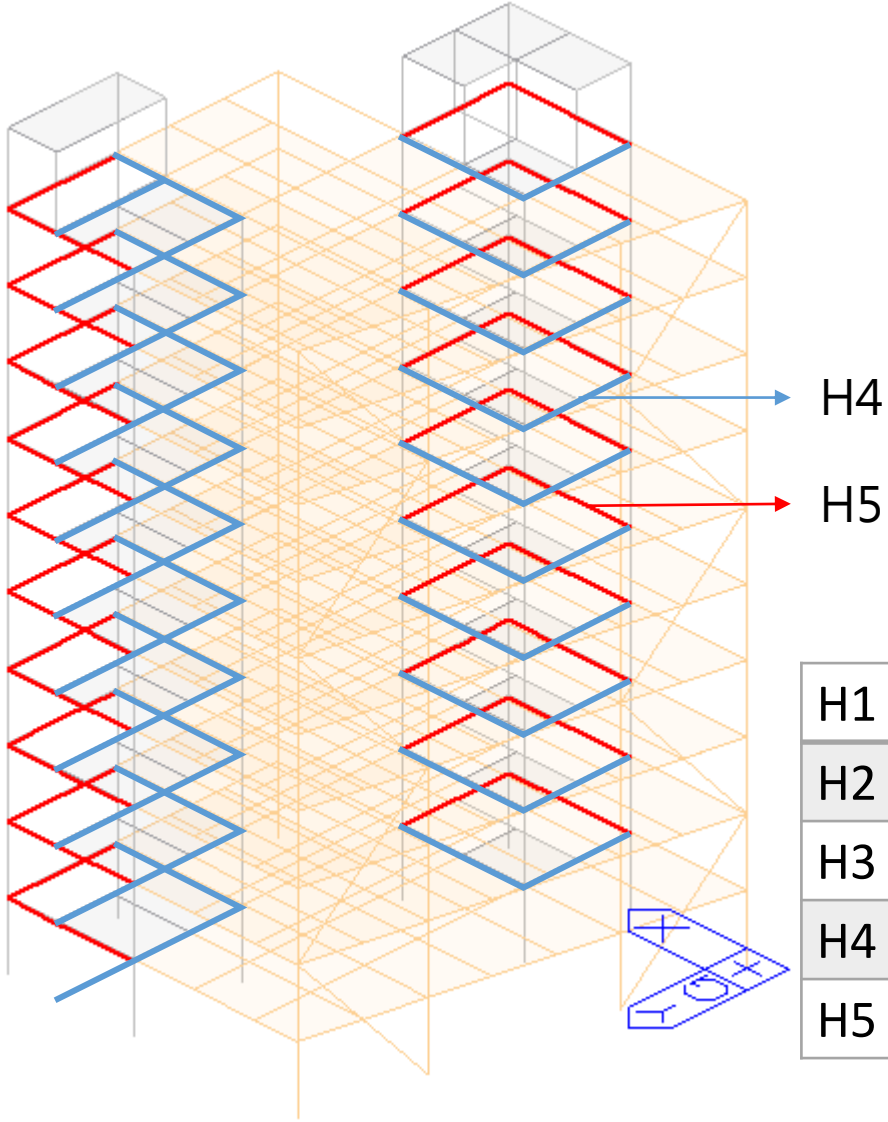


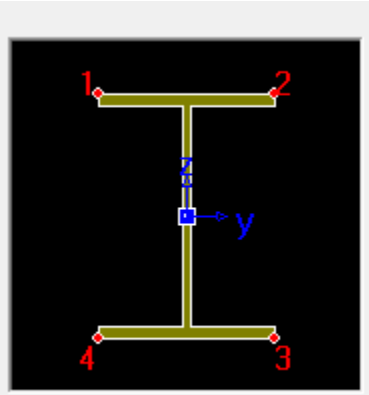
C1	650x650x30
C2	600x600x28
C3	550x550x25
C4	H200x200x8x12

WC1	750x750
WC2	700x700
WC3	650x650
WVB1	330x330
WVB2	270x270

鋼木混合結構梁斷面設定

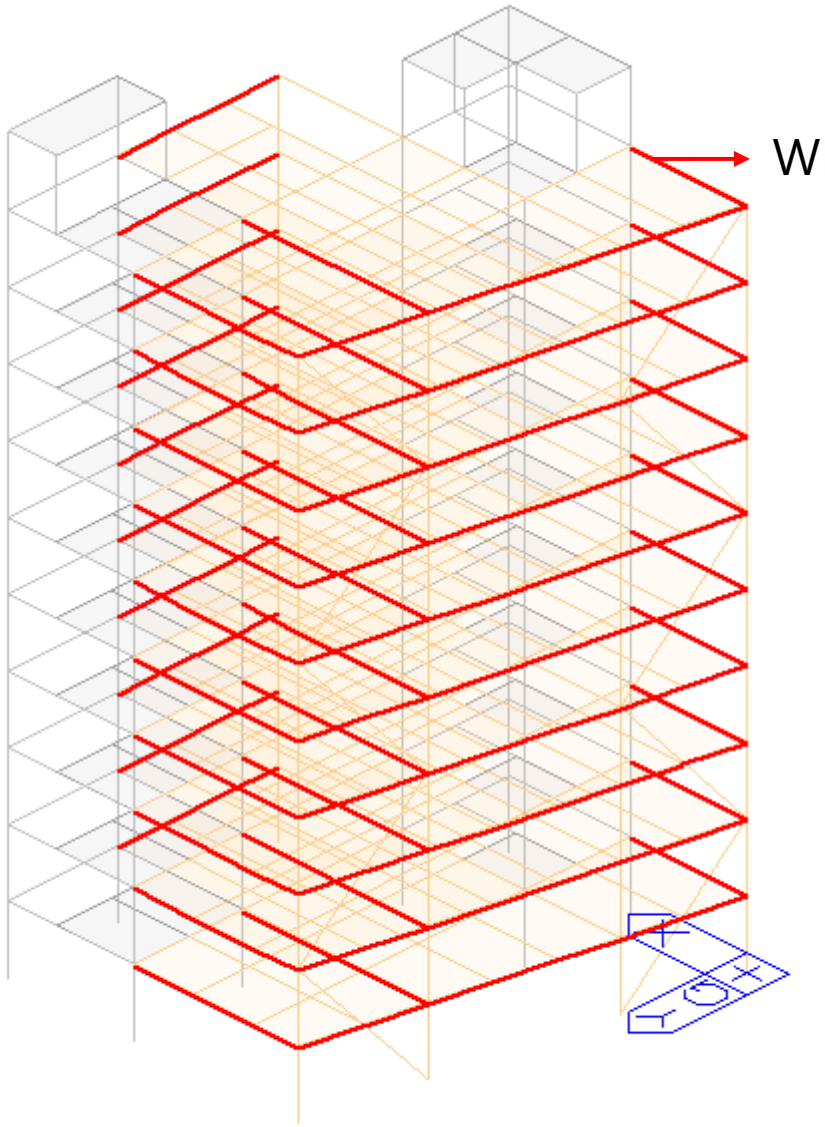


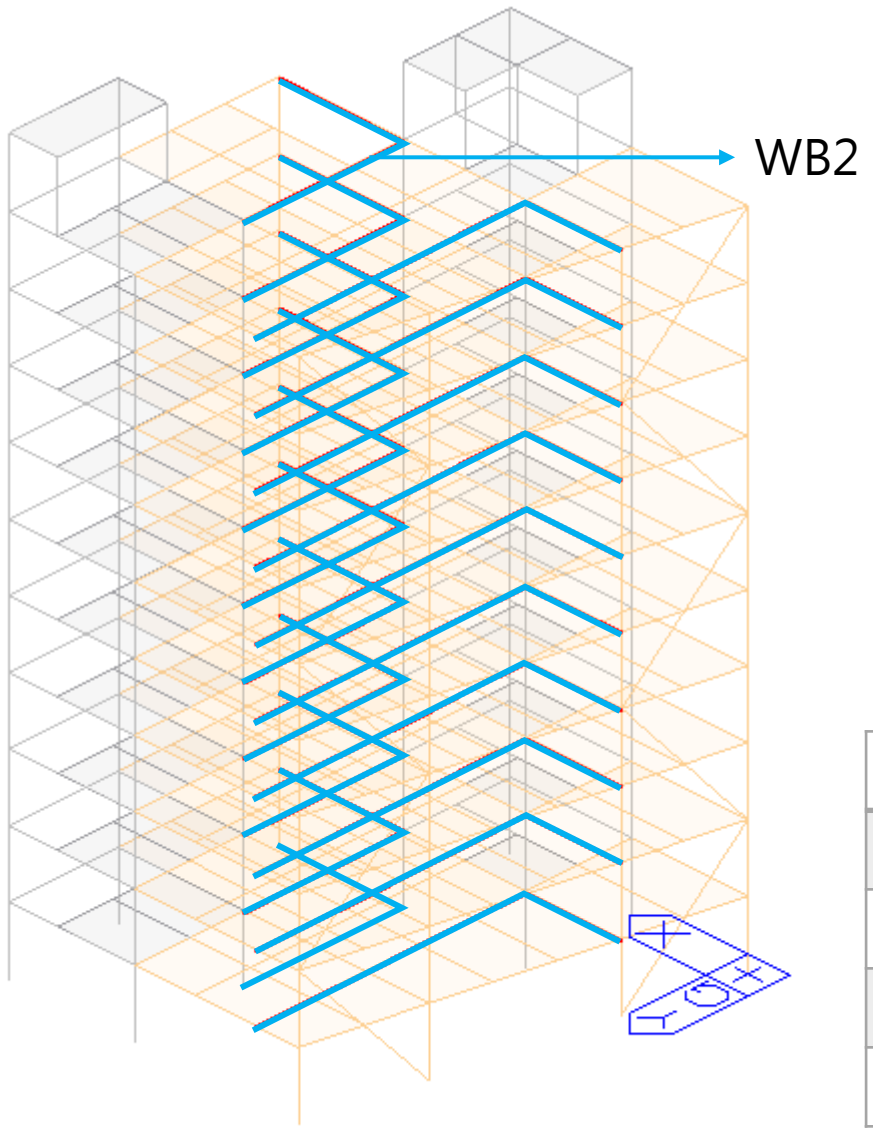


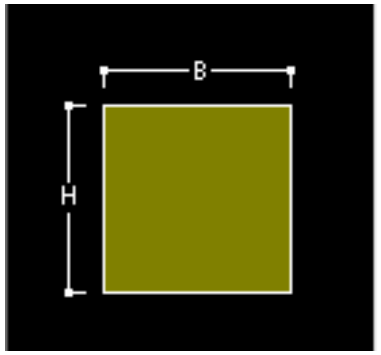


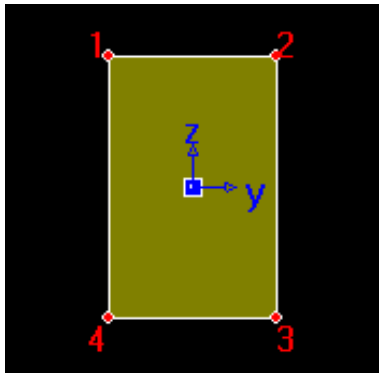
H1	244x175x7/11
H2	400x200x8/13
H3	488x300x12/20
H4	588x300x12/20
H5	700x300x13/24

鋼木混合結構梁斷面設定



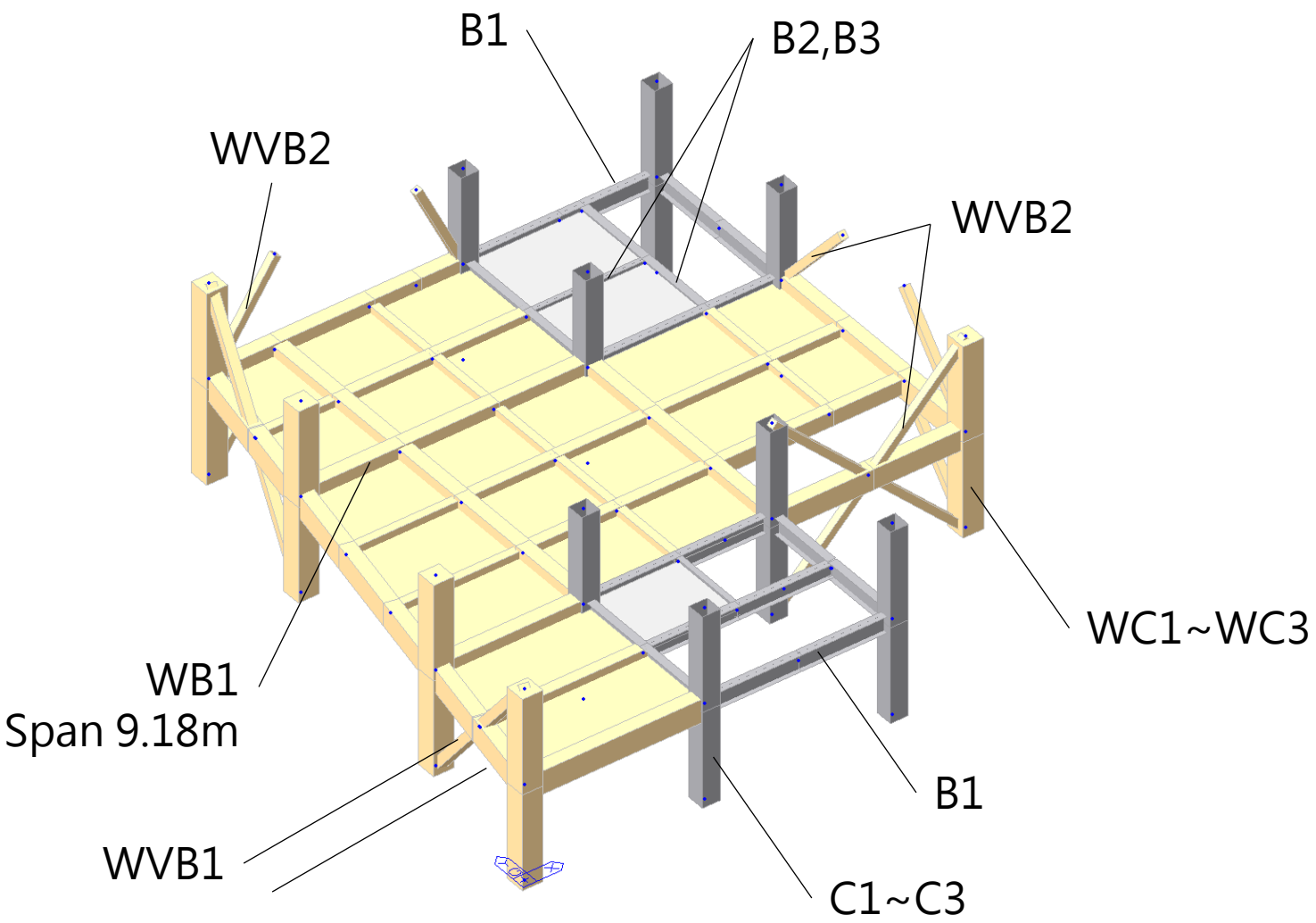






WB1	850x550
WB2	750x500
WB3	550x400
WB4	500x300
WBV1	450x450

鋼木混合結構斷面檢核



鋼結構斷面(mm)		Ratio
C1	BOX650x650x30	0.336
C2	BOX600x600x28	0.103
C3	BOX550x550x25	0.134
C4	H200x200x8x12	0.314
B1	H588x300x12x20	0.276
B2	H488x300x11x18	0.174
B3	H350x175x7x11	0.149
B4	H244x175x7x11	0.351

木結構斷面(mm)		最大壓應力(kg/cm2)
WC1	650x650	64.6 < 95 (η Lfc)
WC2	550x550	52.8 < 95 (η Lfc)
WC3	450x450	30.8 < 95 (η Lfc)
WB1	500x850	85.0 < 115 (Cb Lfb)
WVB1	330x330	65.6 < 79 (η Lfc)
WVB2	270x270	55.9 < 71 (η Lfc)

木結構斷面檢核(Critical Case)

樑斷面參數							
Section	WB1						
	B	H	斷面積 cm2	強軸慣性舉 cm4	弱軸慣性舉 cm4	強軸斷面模數 cm3	弱軸斷面模數 cm3
SECTION size (cm)	50	85	4250	2558854	885417	60208	35417

材料強度與應力調整參數					
跨度cm	918	細長比,λ	63.5256		
側撐材間距cm	340	有效橫向挫屈長度, L_e	646		
材質	E105-F345	折減係數,η	0.66	彈性模數,Exx 或 Eyy	105000.00
容許壓應力 $_Lf_c$ (kg/cm2)	95	載重調整係數, C_l	1.00		
容許拉應力 $_Lf_t$ (kg/cm2)	80	受彎構材橫向挫屈細長比, C_s	4.69	橫向挫屈係數, C_k	24.17
容許剪應力 $_Lf_c$ (kg/cm2)	10	橫向挫屈調整係數, C_b	1.000		
容許翹曲應力 $_Lf_b$ (kg/cm2)	115				

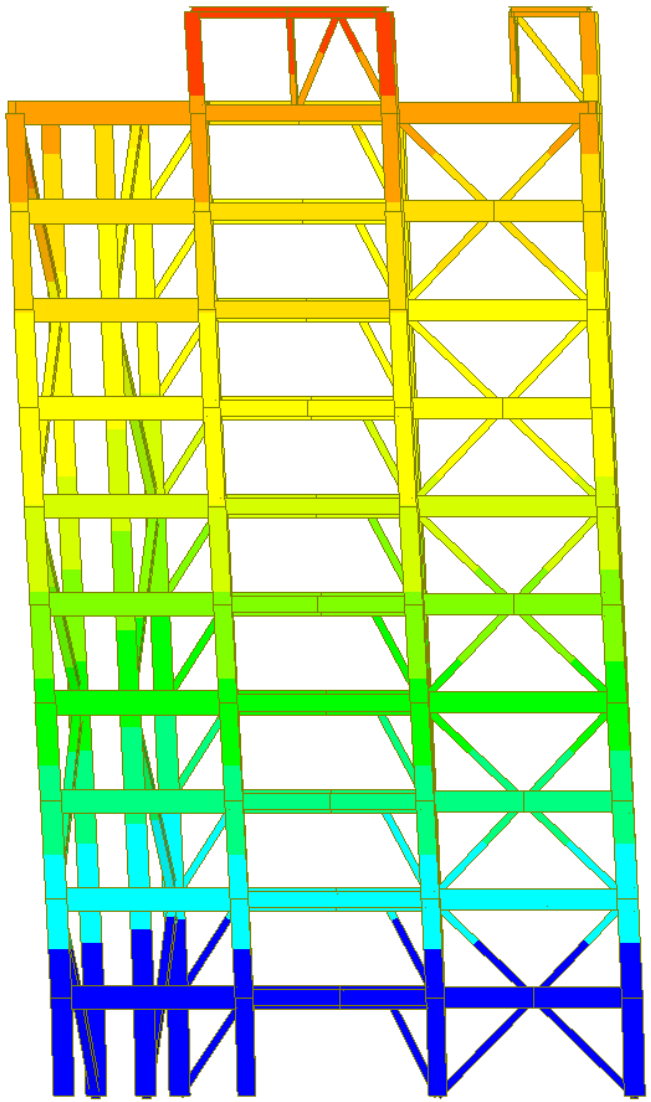
Elem	Load	Part	Axial (kgf)	Shear-y (kgf)	Shear-z (kgf)	Torsion (kgf*cm)	Moment-y (kgf*cm)	Moment-z (kgf*cm)
247	sLCB2	J[155]	0	0	-11709.44	47749.19	5117755.52	0

最大壓應力

=5117755.52 / 60208

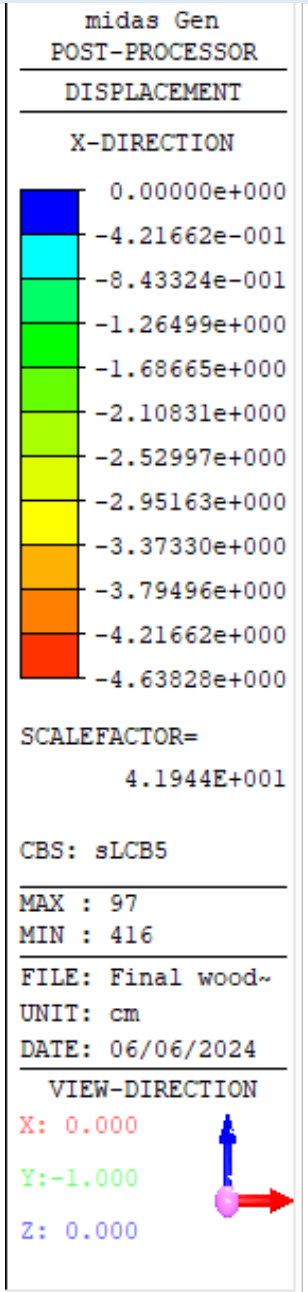
= 85.0 kg/cm2 < Lfb = 115 kg/cm2 ,ok

Type2層間位移(Ex)

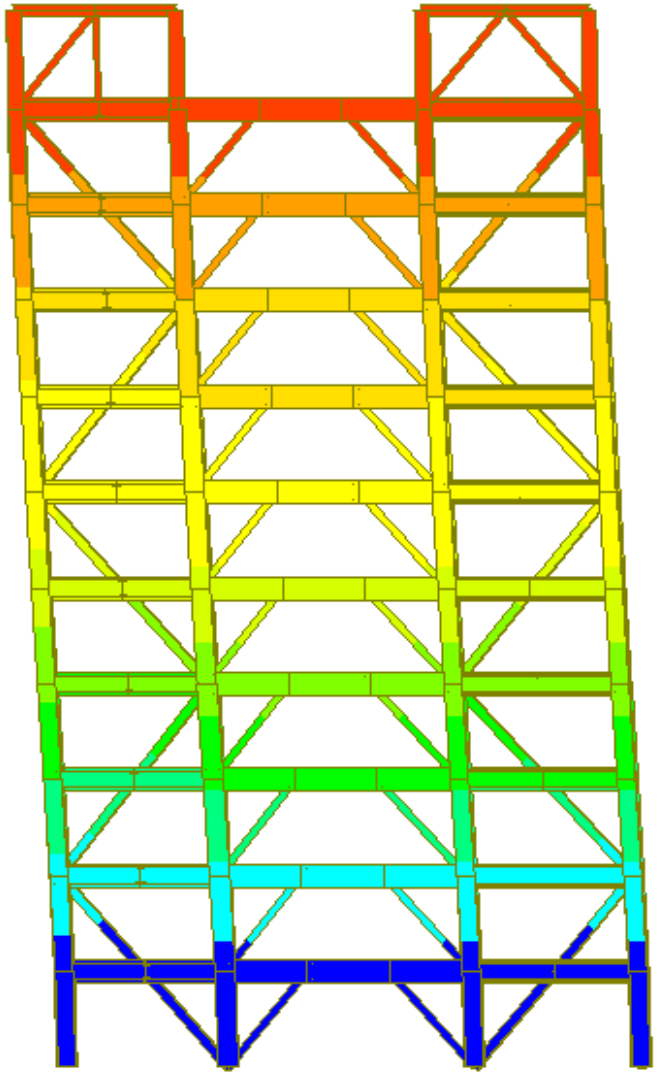


Load combination : 1.2D + 0.5L- Ex

樓層	位移(cm)	層間變位角
屋突	-4.6383	0.0013
Roof	-4.1669	0.001
10F	-3.8052	0.0011
9F	-3.431	0.0012
8F	-3.0181	0.0013
7F	-2.5641	0.0014
6F	-2.0799	0.0014
5F	-1.5919	0.0014
4F	-1.1079	0.0013
3F	-0.6459	0.0012
2F	-0.2231	0.0006
1F	0	0

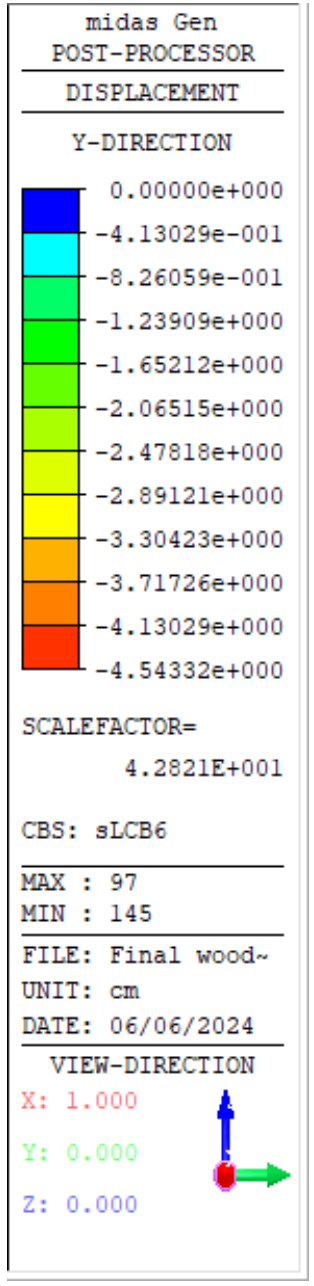


Type2層間位移(Ey)



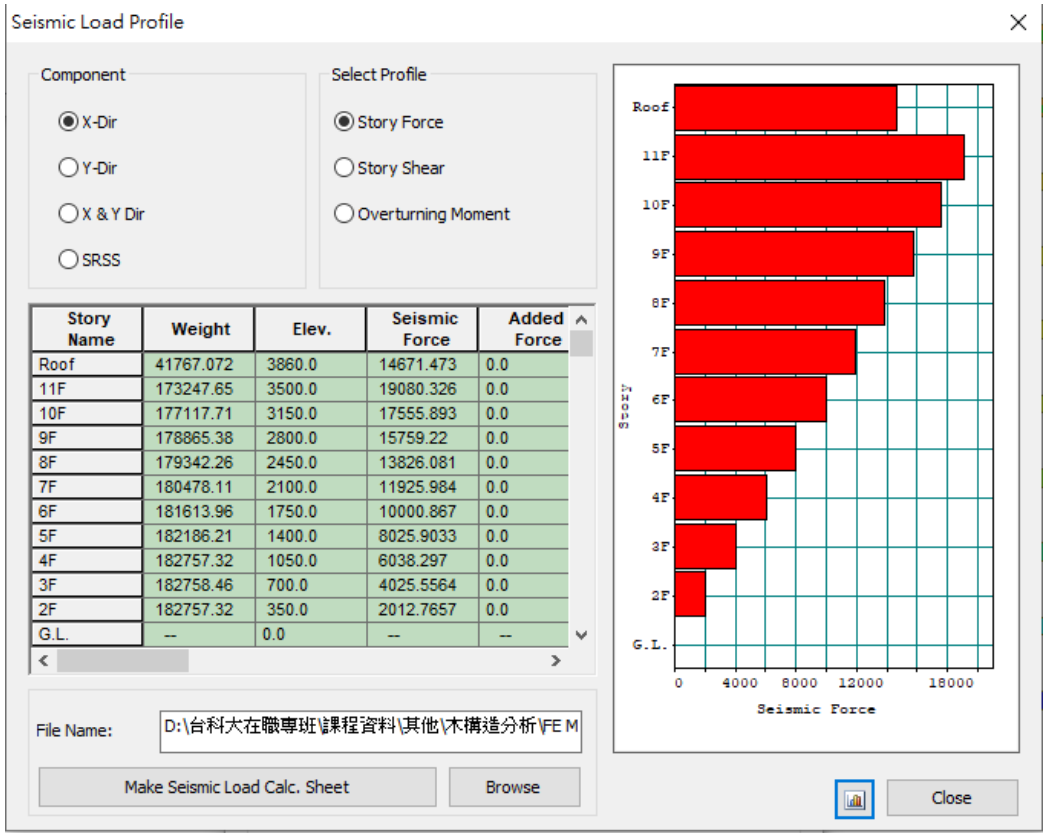
Load combination : 1.2D + 0.5L- Ey

樓層	位移(cm)	層間變位角
屋突	-4.5433	0.0001
Roof	-4.5	0.001
10F	-4.133	0.0014
9F	-3.6486	0.0015
8F	-3.1393	0.0014
7F	-2.6536	0.0013
6F	-2.1953	0.0014
5F	-1.7059	0.0015
4F	-1.1979	0.0014
3F	-0.6926	0.0013
2F	-0.2425	0.0007
1F	0	0

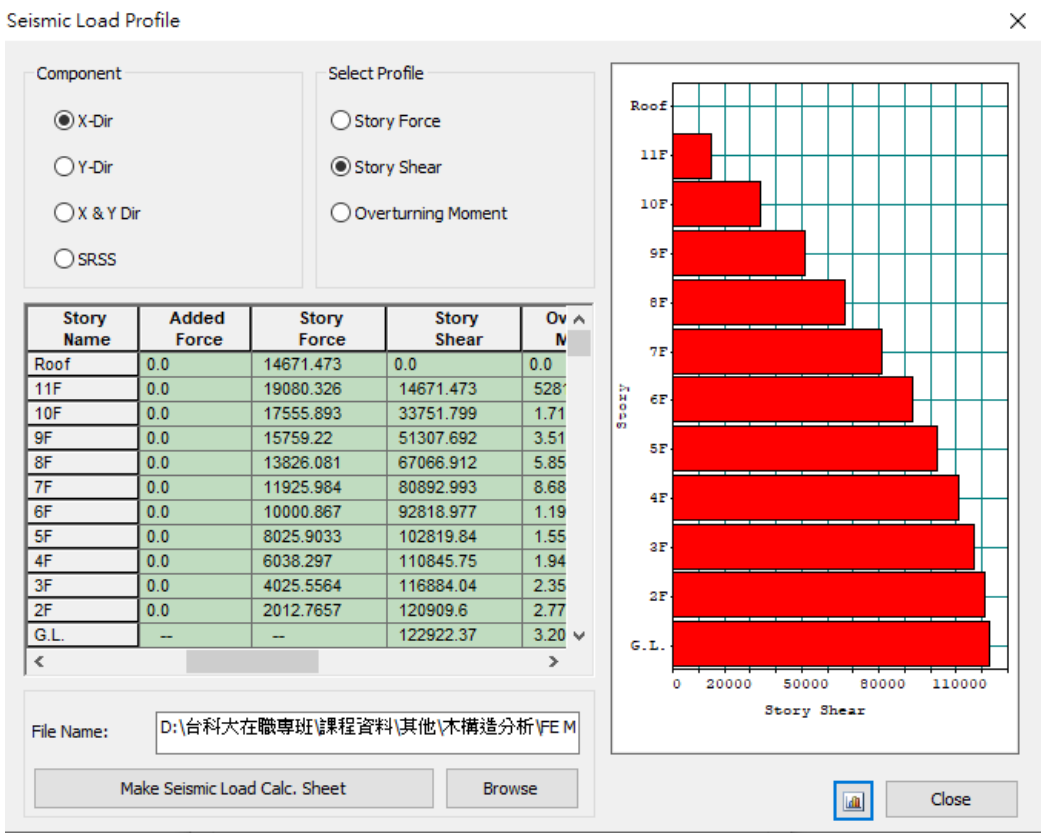


樓層剪力配置圖(X向)

X向頂樓地震力 19,080(kg)



X向基底剪力 122,922(kg)

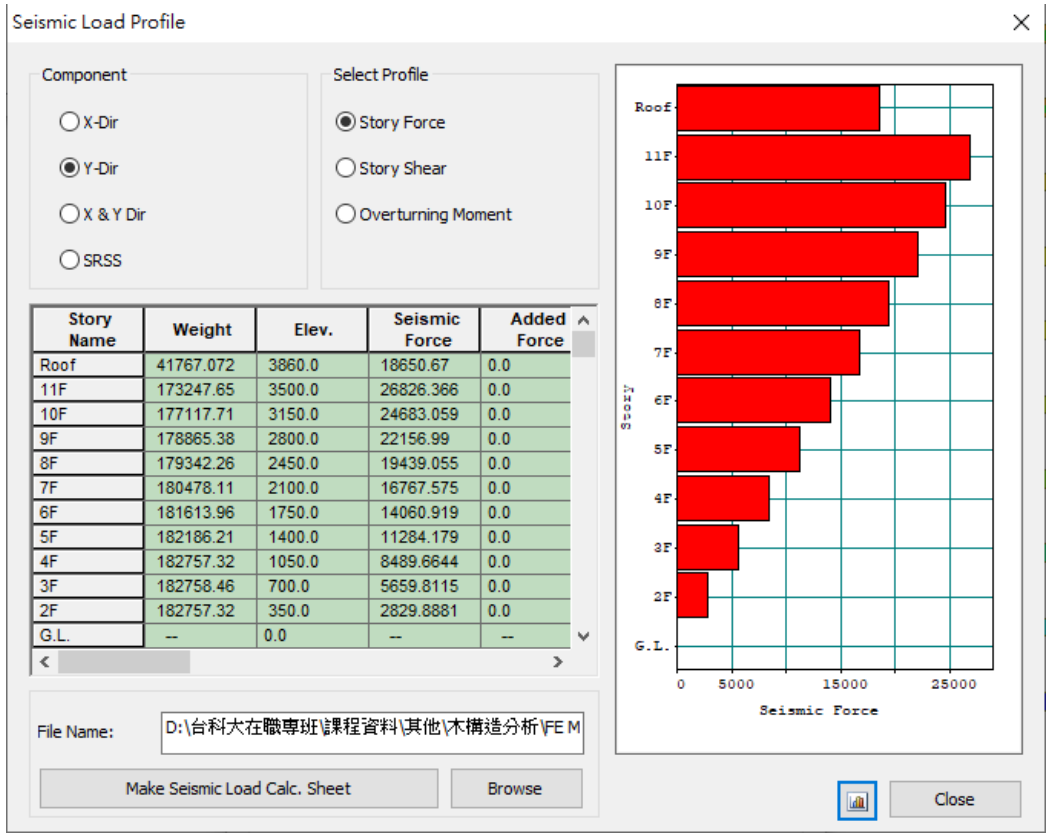


各樓層側向力分布圖

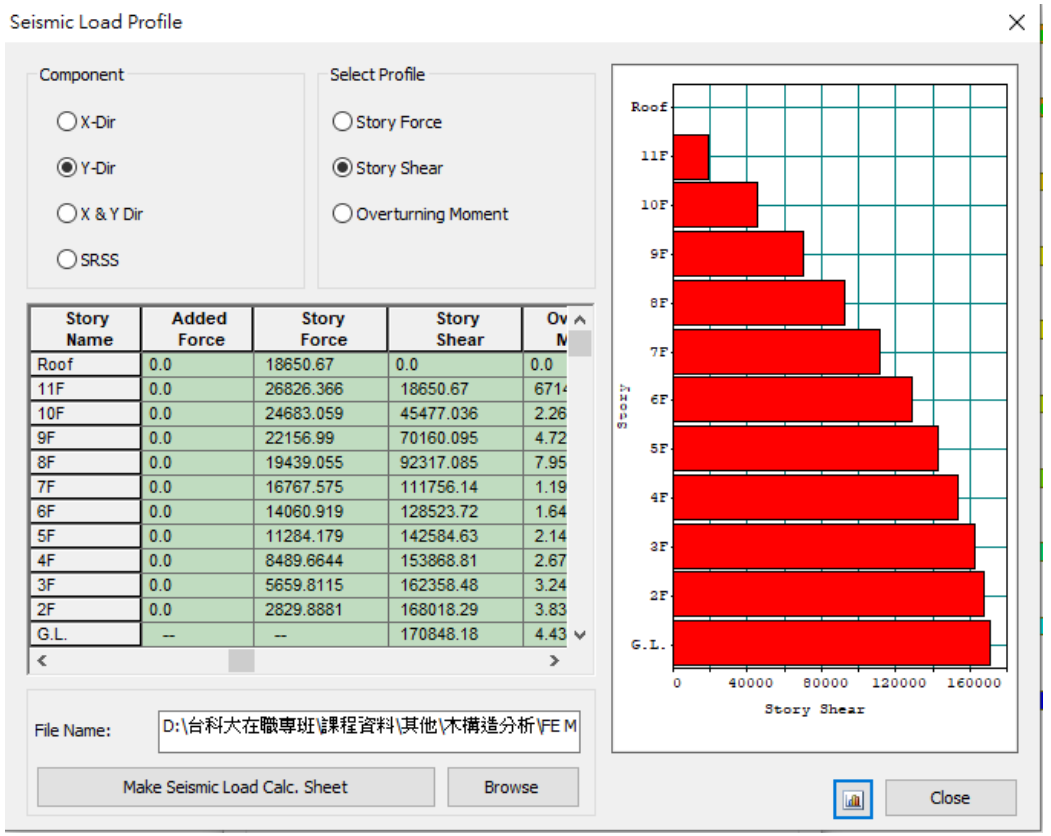
各樓層剪力分佈圖

樓層剪力配置圖(Y向)

Y向頂樓地震力 26,826(kg)



Y向基底剪力 170,848(kg)

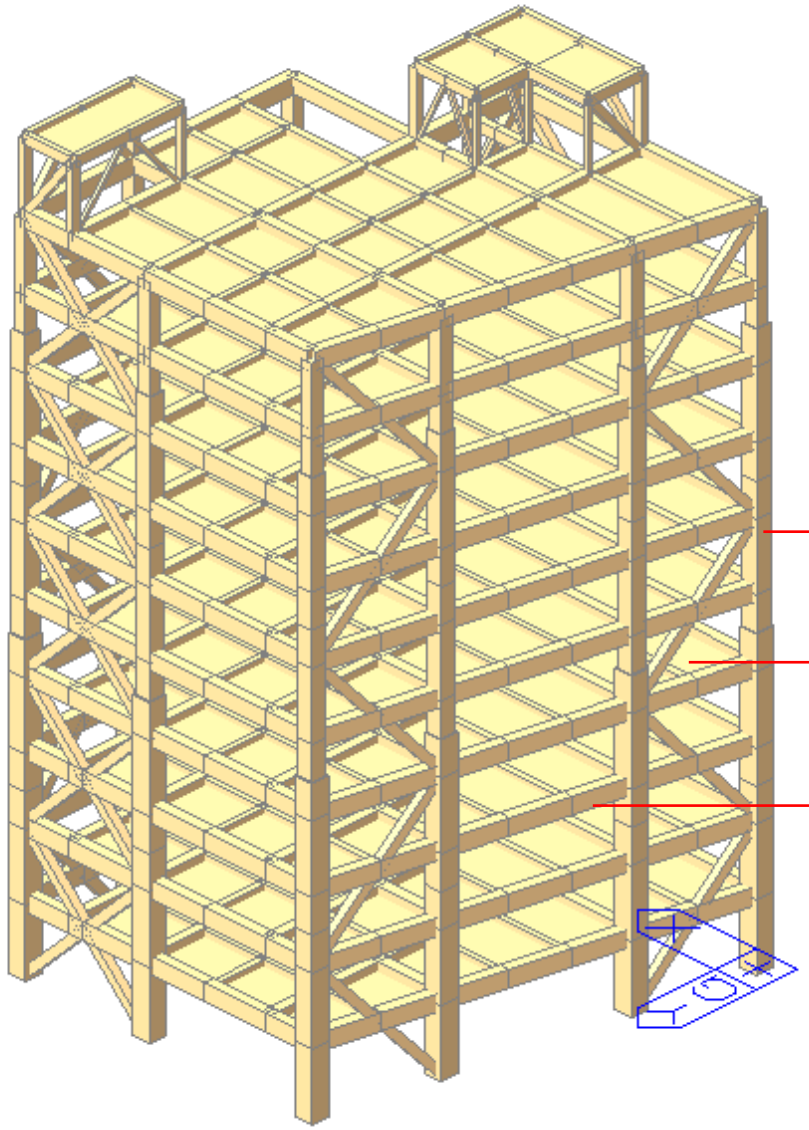


各樓層側向力分布圖

各樓層剪力分佈圖

TYPE3-木結構

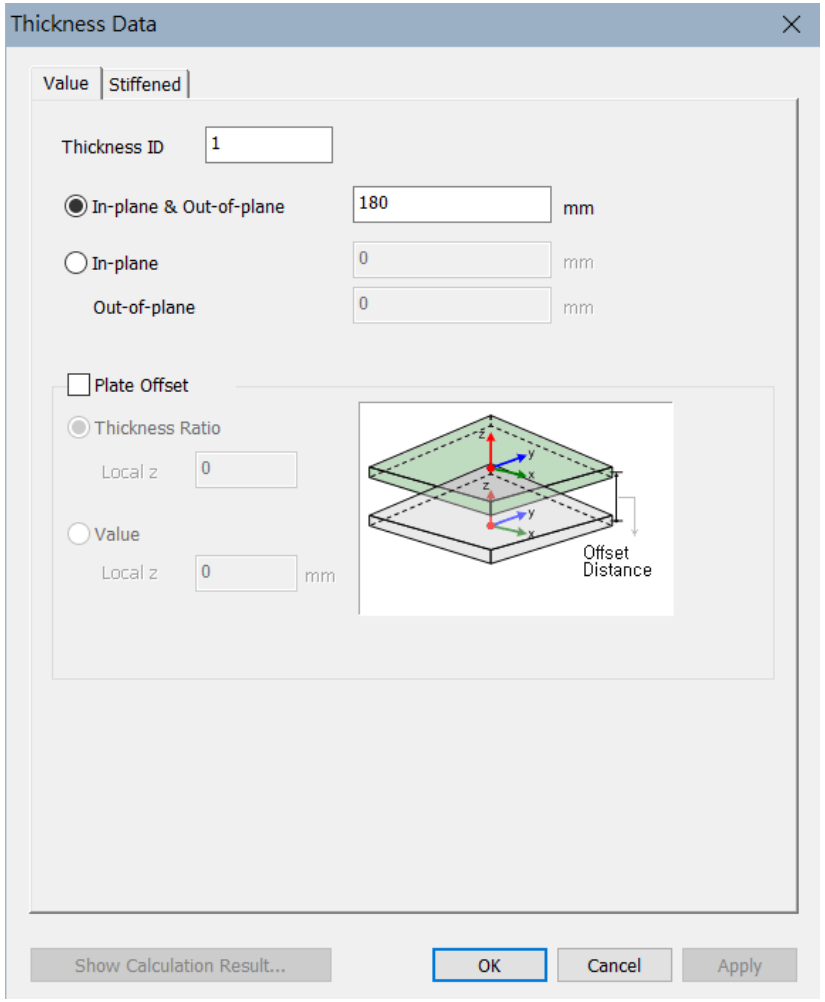
木結構斷面檢核



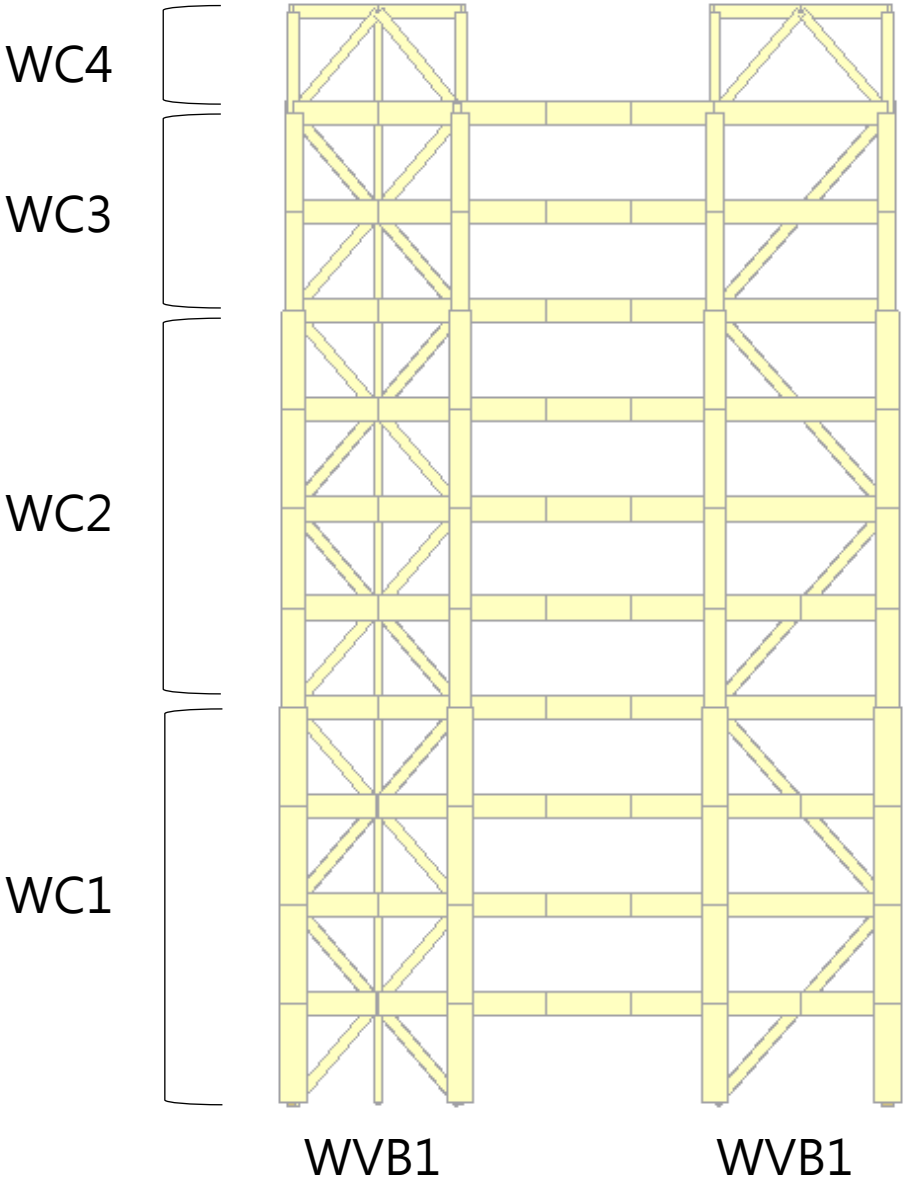
木柱 Solid Rectangle

木樓板：18cm

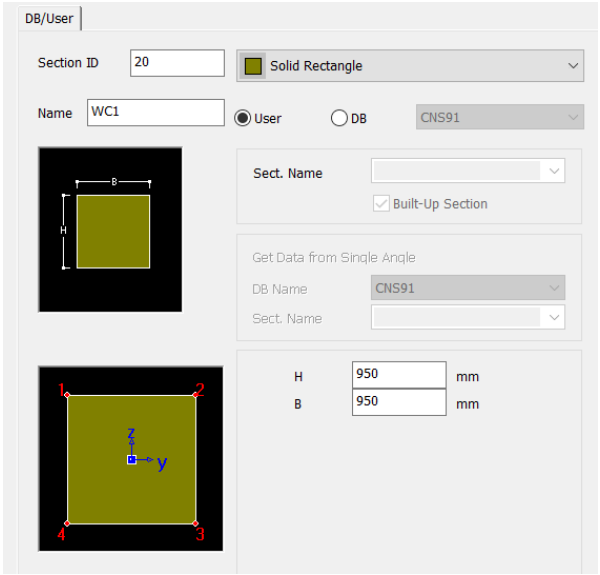
木梁



鋼木混合結構柱與斜撐斷面設定



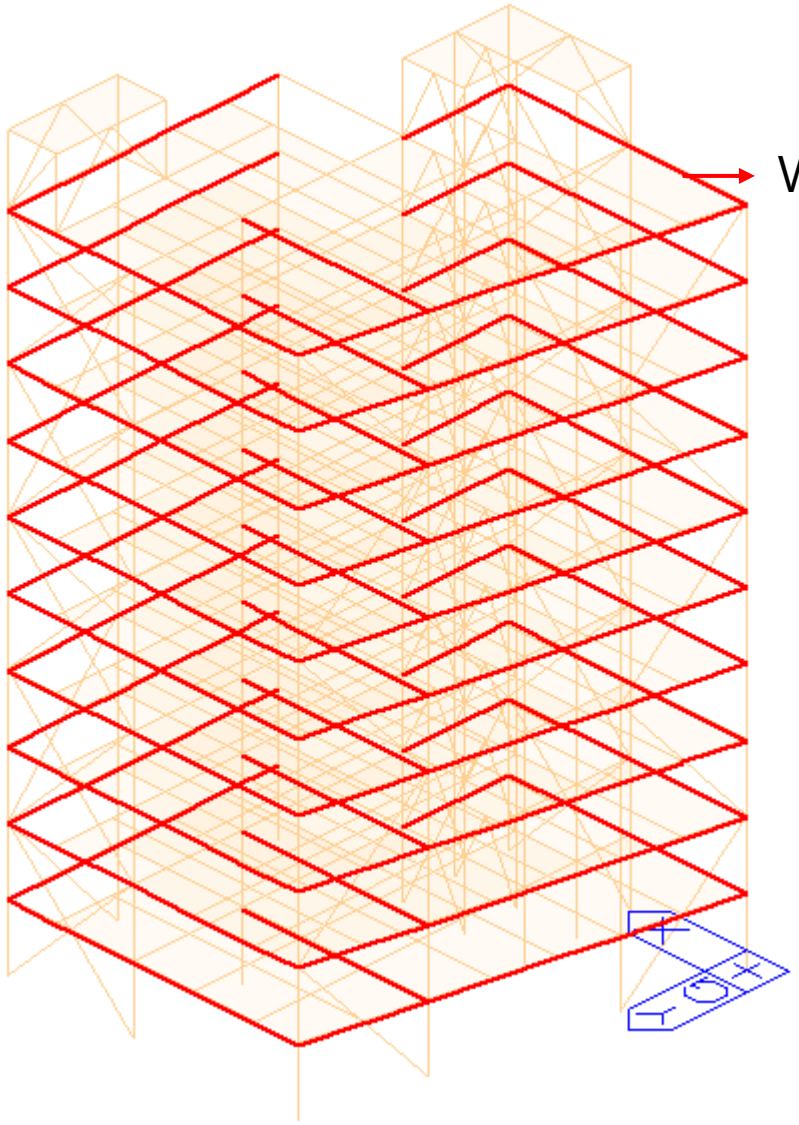
GLT

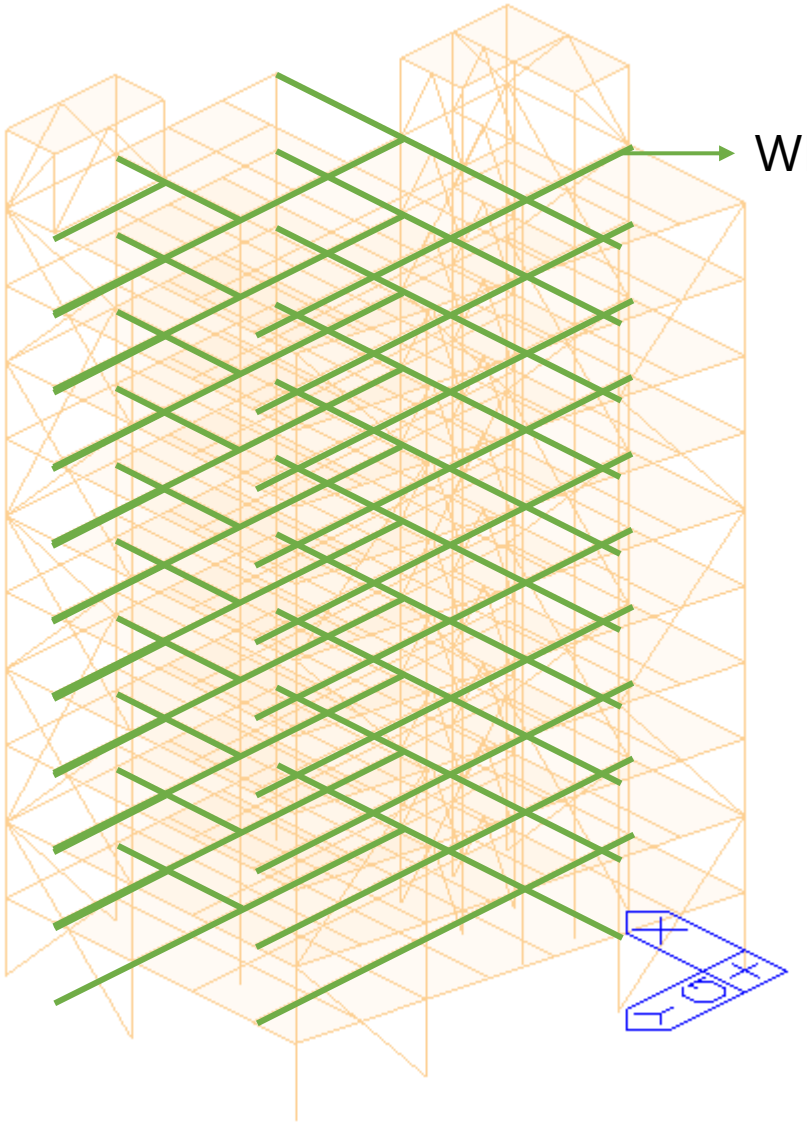


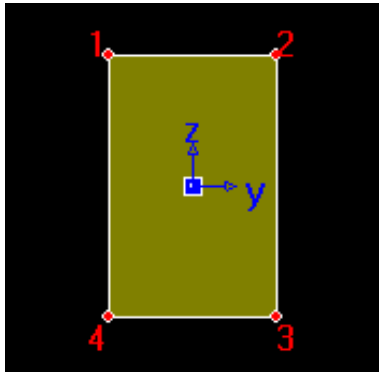
主桿件斷面尺寸

WC1	850x850
WC2	700x700
WC3	550x550
WC4	400x400
WVB1	400x400
WVB2	300x300

木結構梁斷面設定

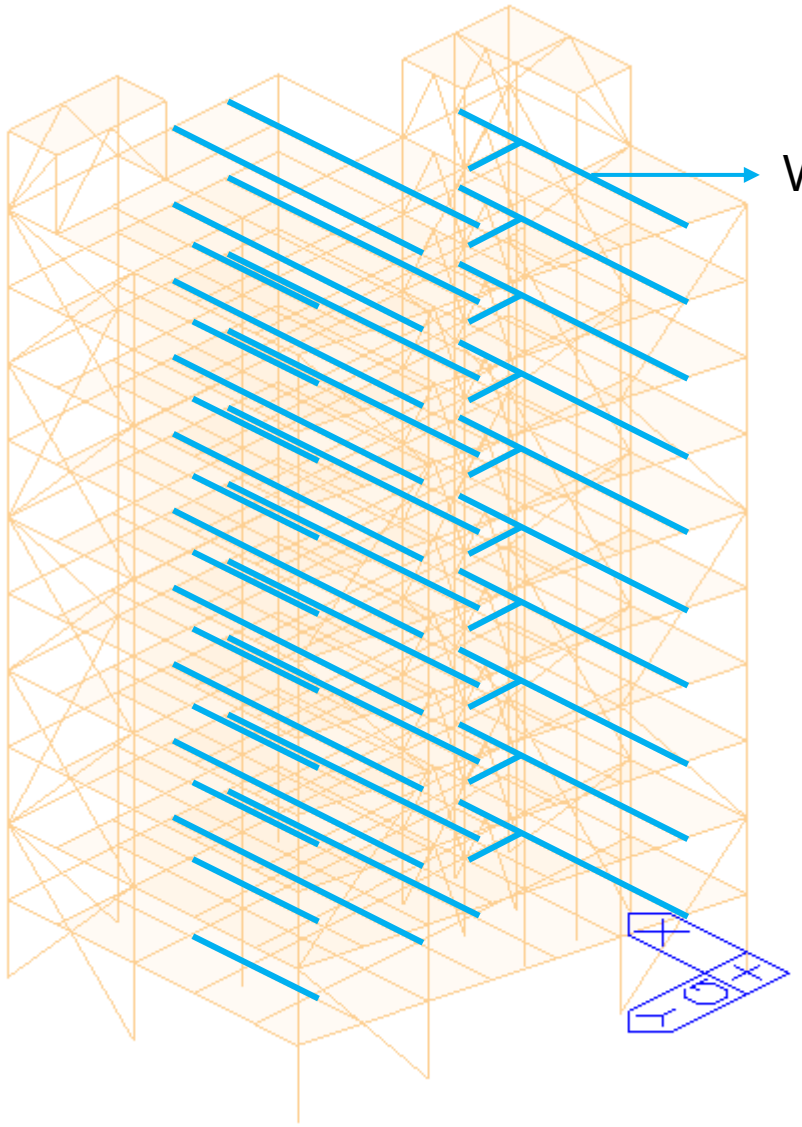


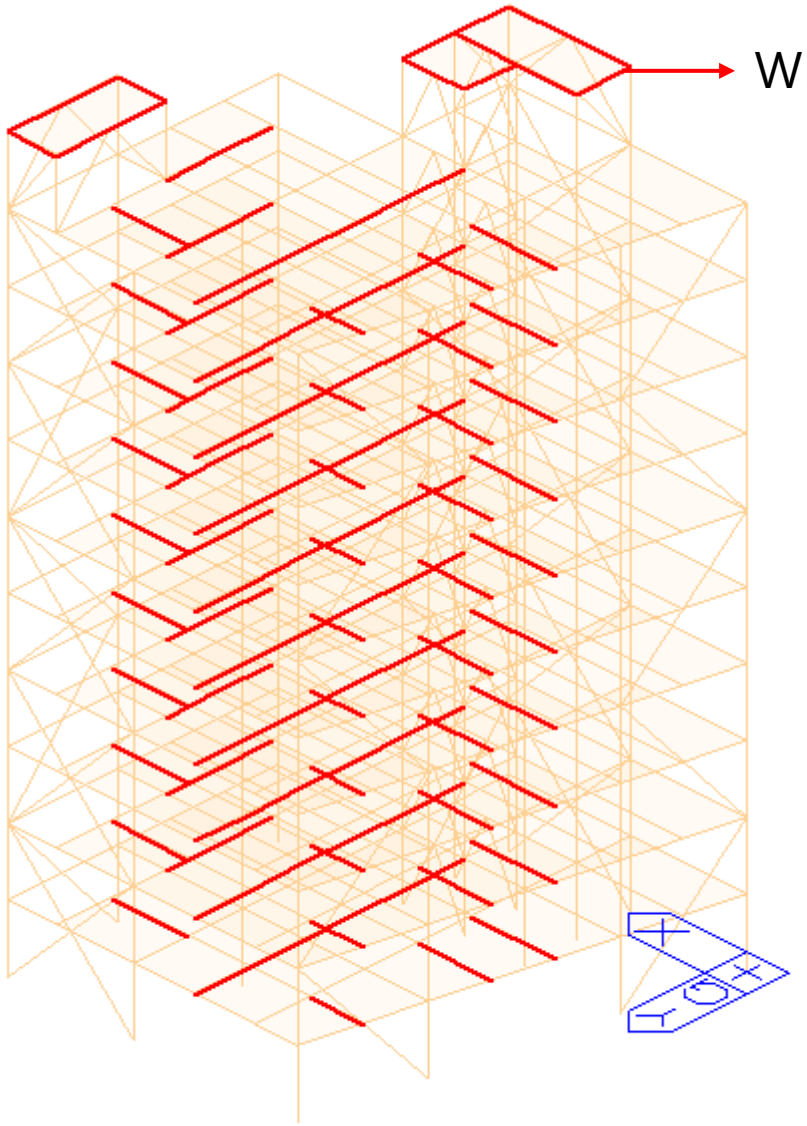


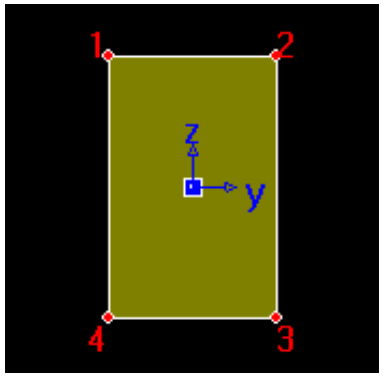


WB1	850x550
WB2	750x500
WB3	550x400
WB4	500x300

木結構梁斷面設定

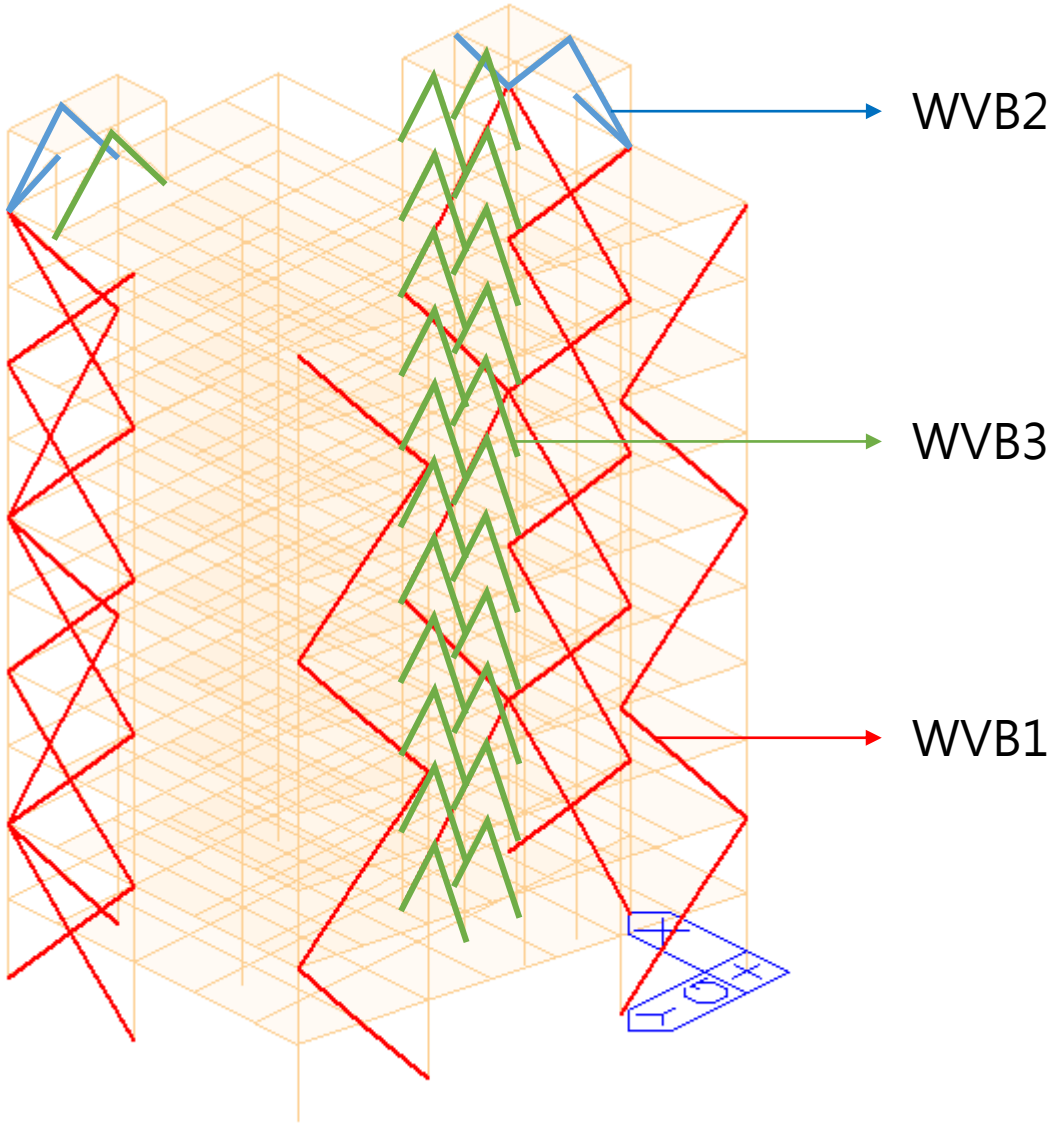


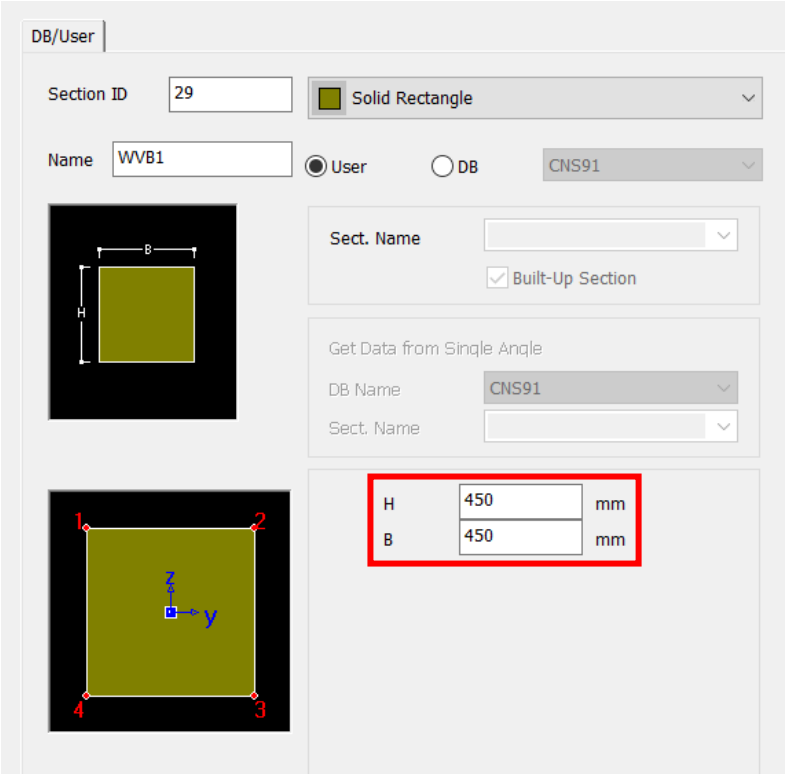




WB1	850x550
WB2	750x500
WB3	550x400
WB4	500x300

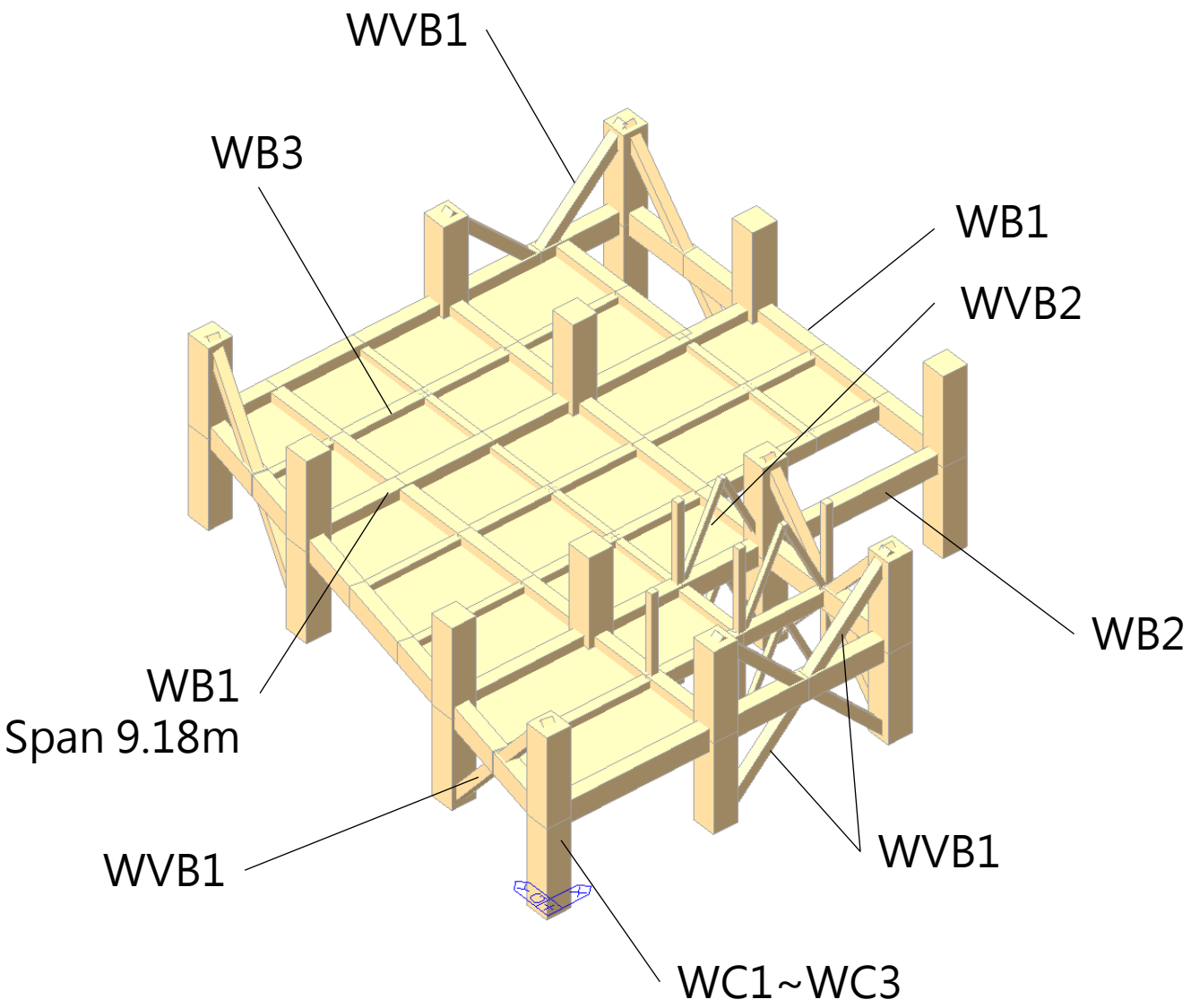
木結構斜撐斷面設定





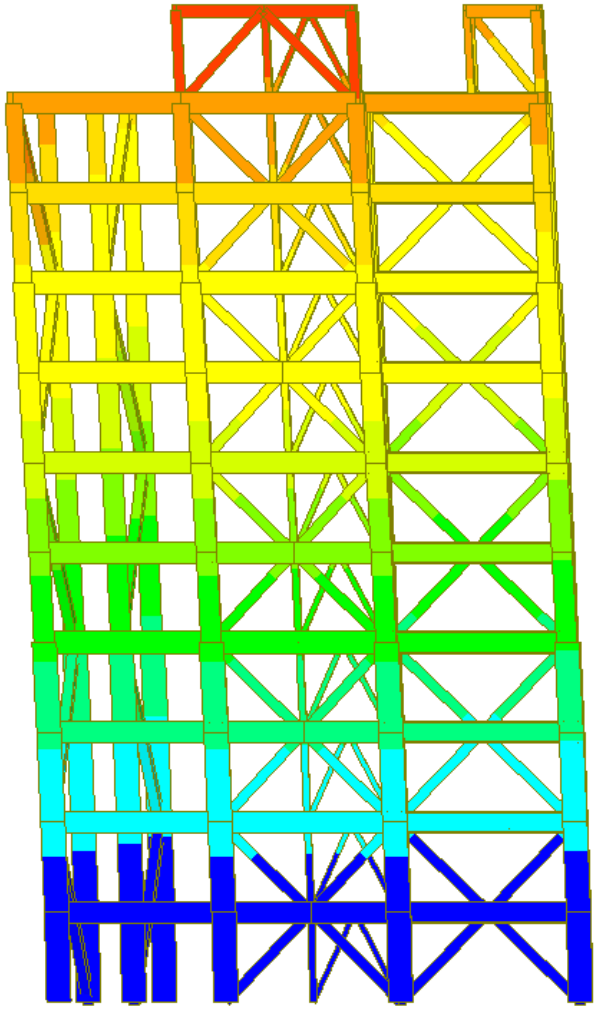
WVB1	450x450
WVB2	350x350
WVB3	180x180

木結構斷面檢核



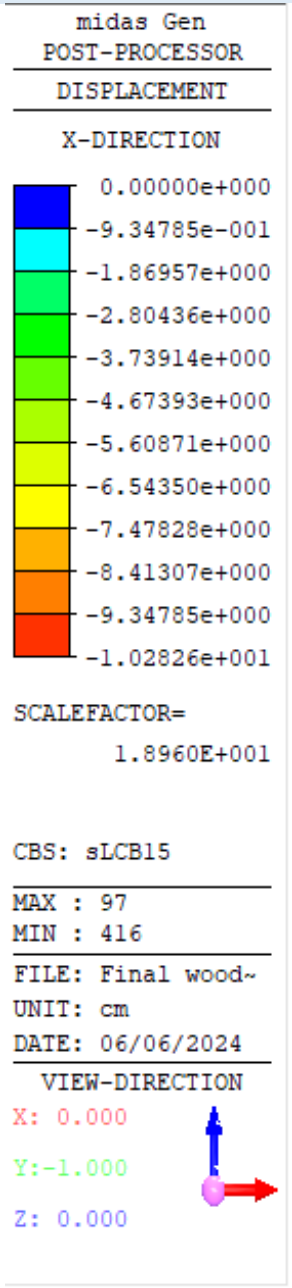
木結構斷面(mm)		最大壓應力(kg/cm2)
WC1	850x850	75.8 < 95 (η Lfc)
WC2	700x700	53.6 < 95 (η Lfc)
WC3	550x550	27.8 < 95 (η Lfc)
WC4	400x400	1.9 < 95 (η Lfc)
WC5	300x300	27.8 < 95 (η Lfc)
WB1	500x850	75.5 < 115 (Cb Lfb)
WB2	450x750	66.0 < 115 (Cb Lfb)
WB3	400x550	35.0 < 115 (Cb Lfb)
WB4	300x500	31.3 < 115 (Cb Lfb)
WVB1	400x400	81.7 < 86.5 (η Lfc)
WVB2	300x300	43.8 < 77.0 (η Lfc)
WVB3	270x270	55.2 < 67.5 (η Lfc)

Type3層間位移(Ex)

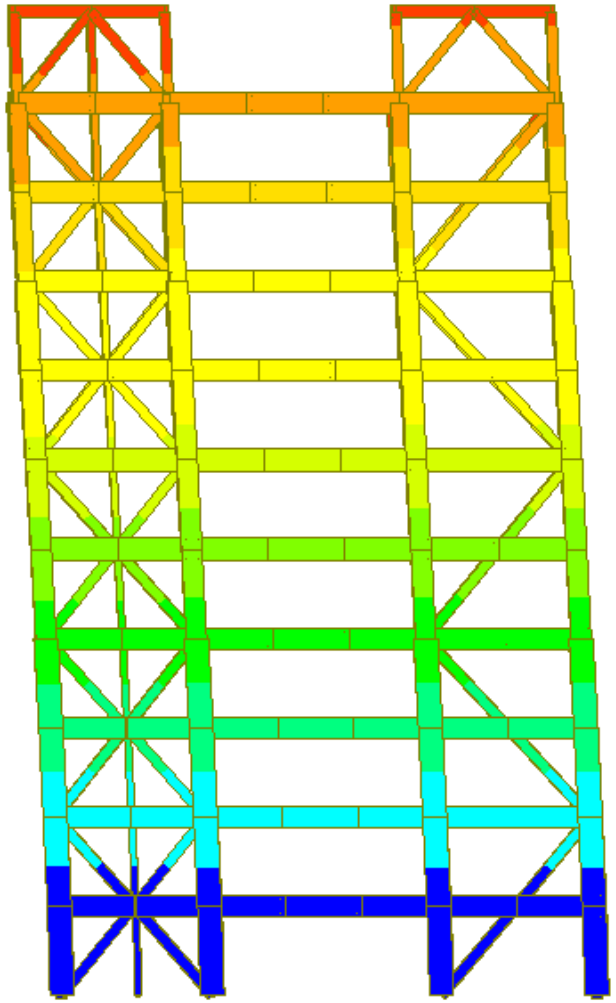


Load combination : 1.0D + 1.0L- Ex

樓層	位移(cm)	層間變位角
屋突	-10.2826	0.003
Roof	-9.2254	0.003
10F	-8.1862	0.003
9F	-7.1201	0.0032
8F	-6.0025	0.0031
7F	-4.9155	0.0032
6F	-3.7939	0.0027
5F	-2.8338	0.0027
4F	-1.8726	0.0021
3F	-1.1215	0.0021
2F	-0.3854	0.0011
1F	0	0

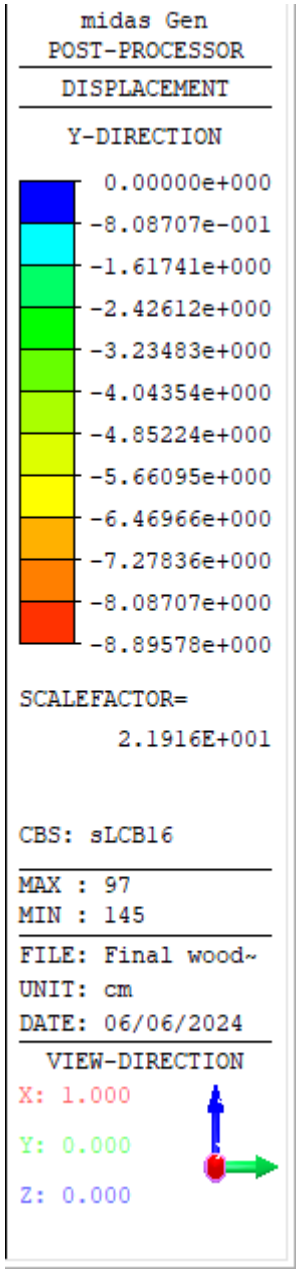


Type3層間位移(Ey)



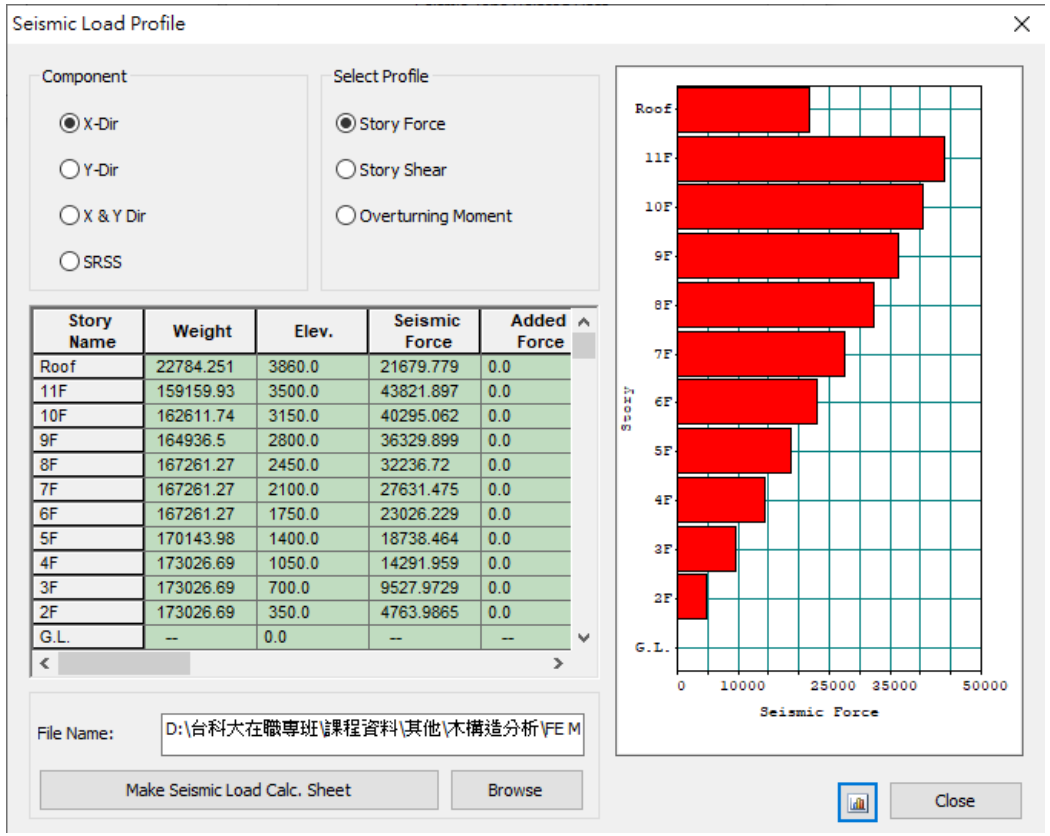
Load combination : 1.0D + 1.0L- Ey

樓層	位移(cm)	層間變位角
屋突	-8.8958	0.0013
Roof	-8.4525	0.0022
10F	-7.6691	0.0029
9F	-6.6619	0.0027
8F	-5.7094	0.003
7F	-4.6694	0.0028
6F	-3.6895	0.0026
5F	-2.783	0.0026
4F	-1.872	0.0022
3F	-1.1172	0.002
2F	-0.426	0.0012
1F	0	0



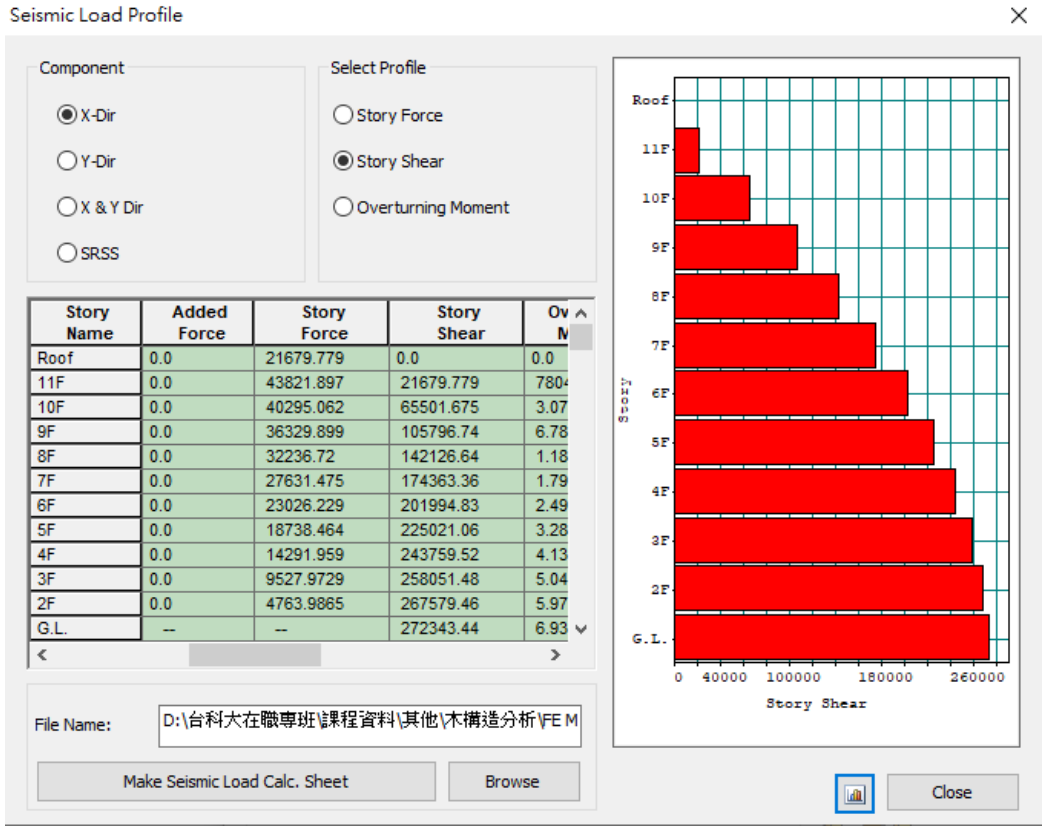
樓層應力及彎矩

頂樓地震力 43,822(kg)



各樓層側向力分布圖

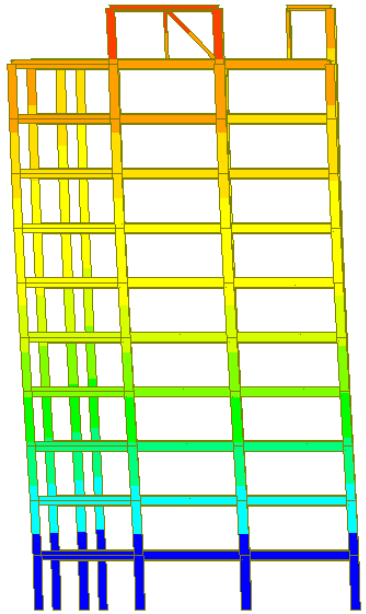
基底剪力 272,343(kg)



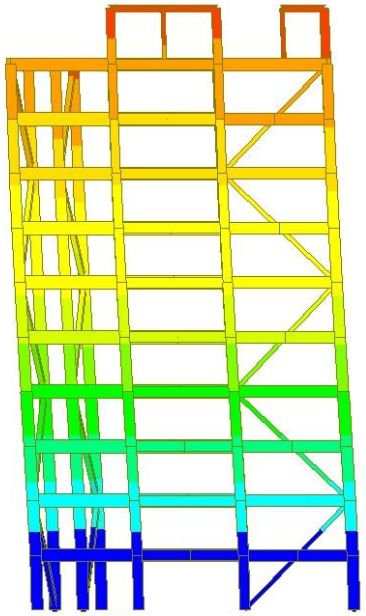
各樓層剪力分佈圖

分析結果及蘊含碳評估

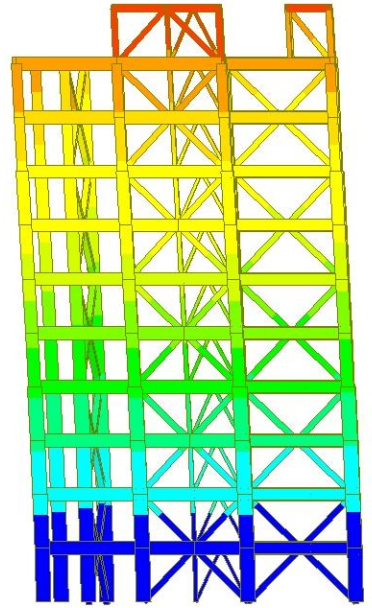
Type1-3 差異比較



Type1-鋼構 (Ex)



Type2-鋼木混合結構 (Ex)



Type3-木構 (Ex)

項目		Type1-鋼構		Type2-鋼木混合結構			Type3-木構	
R	週期	4.0	雙向 1.316s	4.0	X: 1.1155s	Y: 0.9631s	2.4	雙向 0.774s
結構總重(ton)		1,878.3 + 818.7 (樓板設計靜載重)		900.7 + 818.7 (樓板設計靜載重)			598.7 + 818.7 (樓板設計靜載重)	
基底地震力		151.9 (ton)		122.9 (ton, x)		170.8 (ton, y)	272.3 (ton)	
X向位移量		4.54		4.64			10.28	

鋼結構碳排放量計算

建材相關產品生產與運輸CO排放量表

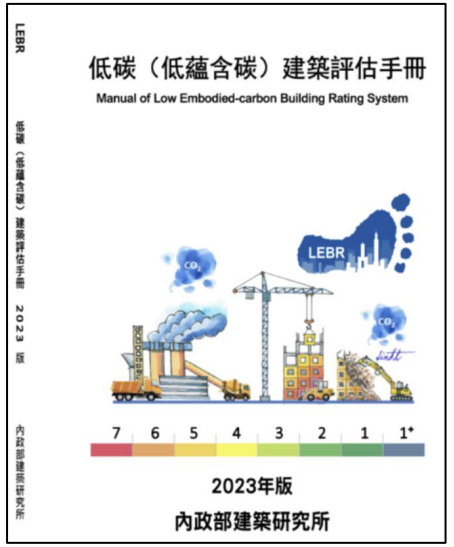
材料分類	材料名稱	單位	kgCO2e				
			原料取得	原料運輸	生產階段	成品運輸	總碳排量
鋼鐵	鋼筋及鐵件	kg	0.954		0.168	0.017	1.14
	型鋼	kg	0.954		0.185	0.013	1.15
水泥	預拌混凝土(4000psi)	m^3	4.8	17.42	343.09	4.57	369.88

資料來源：綠建築評估手冊-基本型 2023版本

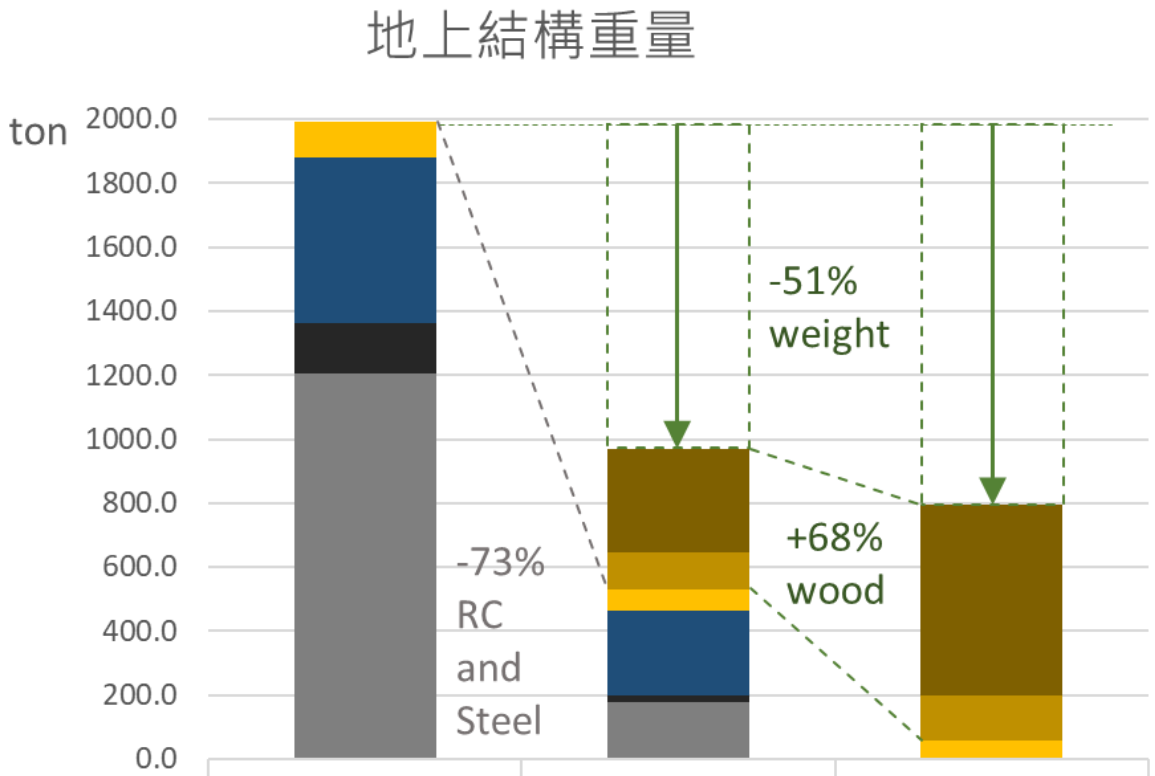
預拌混凝土： 1 m^3 = 2400 kg　　369.88 / 2400 = 0.154　　1kg預拌混凝土= 0.154 kgCO2e

A5 Waste factors for typical structural materials

Material/product	Waste rate (WR)	Waste factor (WF)[1]	WRAP Net Waste Tool reference
Concrete *in situ*	5%	0.053	Table 2, concrete *in situ*
Concrete precast (beams and frames)	1%	0.010	Table 2, concrete precast (large precast elements)
Steel reinforcement	5%	0.053	Appendix 1, frame: *in situ* concrete frame generic; Table 2, ferrous metals
Steel frame	1%	0.010	Appendix 1, frame: steel frame generic



鋼結構碳排放量計算



	鋼構	混構	木構
GLT C&B	0.0	321.0	598.7
CLT roof slab	0.0	116.9	136.9
Deck / remainder	111.9	67.3	59.9
Steel frame	516.8	263.7	0.0
Rebar	157.5	23.0	0.0
Concrete	1204.0	176.1	0.0
Total (ton)	1990.2	968.0	795.5

建築材料	重量(ton)	kgCO2e
Rebar	157.5	1.14
Steel frame	516.8	1.15
Concrete	1204	0.154
Deck / remainder	111.9	0.053/0.001

A1-A4

157500x1.14+516800x1.15+1204000x0.154
=959,286

A5w

(15700+1204000)x0.053+516800x0.001
=65,160.9

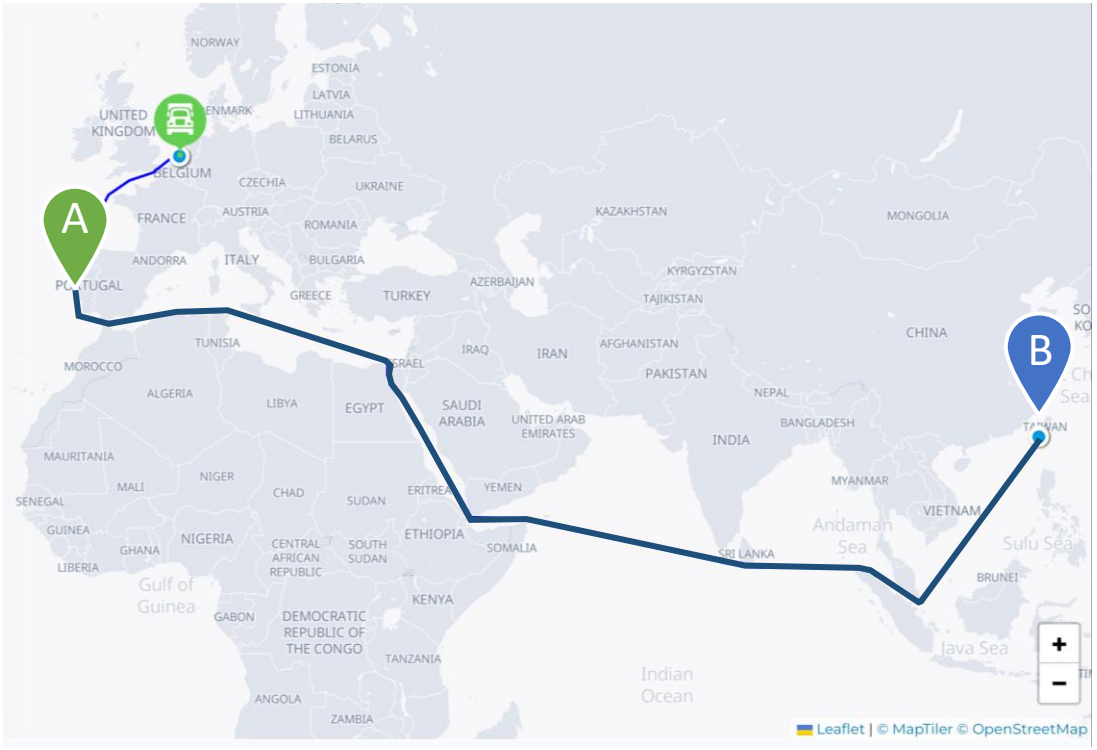
959,286+65,160.9= **1,024,446.9**(kg)

木材工廠至港口碳排放量計算

木材來源:KLH Massivholz GmbH

奧地利木材加工廠至鹿特丹港口
共 **1127** 公里

海運碳排放量計算



航線名稱	North Europe Service 7
裝載港	NETHERLANDS - ROTTERDAM
卸貨港	CHINA - NINGBO
距離 (公里)	25928
碳排放量 (公斤)	47.725002

資料來源：EVERGREEN 碳排放計算機

鹿特丹港口至寧波

距離 25925 (km)

碳排放量 47.72 (kg)

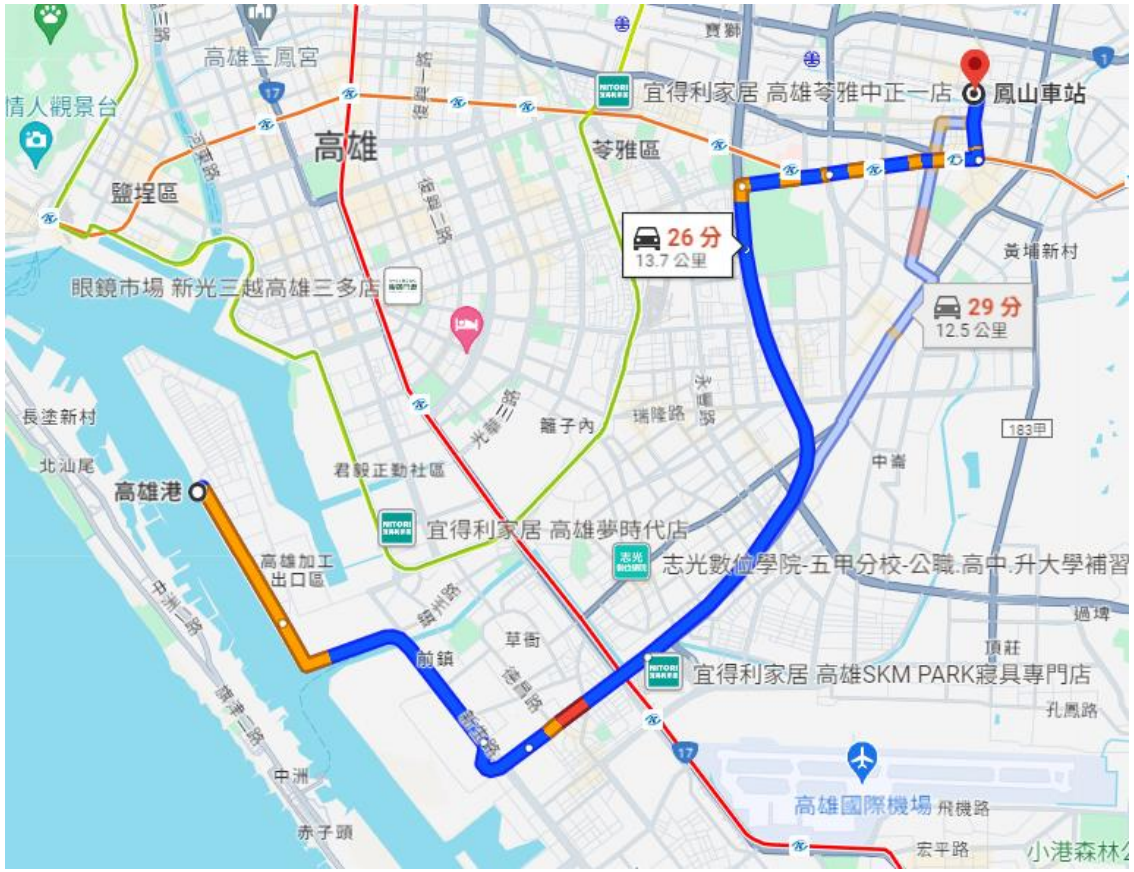
鹿特丹港口至高雄港

航線距離共 **18221.86** 公里　每噸碳排放量 **33.54** (kg)

船名	航次	安特衛普	漢堡	費里克斯托	鹿特丹	沛瑞爾斯	蘇伊士運河	可倫坡	丹戎帕拉帕斯	巴生西港	高雄
EVER APEX 長穎輪	1290-007E (CEM)	-----	05/29	05/21	06/03	-----	-----	06/25	06/29	-----	07/06
EVER ACE 長範輪	1291-011E (CEM)	-----	06/02	05/29	06/05	-----	-----	07/03	07/08	-----	07/13

資料來源：EVERGREEN台灣地區船期表 歐洲-地中海-台灣航線 May 30,2024

港口至基地碳排放量計算



高雄港至基地位置(鳳山車站)
共13.7公里

開車(40頓卡車)
國道(時速80)
546.24 x 6=3277.44

省縣道(時速50)
543.20 x (4.7+3)=4182.64

總碳排系數
3277.44+4182.64=7460.08 (g)

交通部運輸研究所動態CO2排放係數單位：g/km		距離 (km)	碳排系數計算(g)
國道 (時速80)	546.24	6	3277.44
省縣道 (時速50)	543.20	7.7	4182.64

資料來源：交通部運輸研究所公路車輛燃料成本及動態碳排係數對照表

合計: 7460.08 (g) = **7.46** (kg)

A1–A3 ECFs for typical structural materials

Material	Type	Specification/details	A1–A3 ECF ($kgCO_2e/kg$)	Data source
Timber, excl. carbon sequestration[9], [10]	Manufactured structural timber	CLT, 100% FSC/PEFC	0.437	ICE V3
		Glulam, 100% FSC/PEFC	0.512	ICE V3
	Studwork/framing/flooring	Softwood, 100% FSC/PEFC	0.263	ICE V3
	Formwork	Plywood, 100% FSC/PEFC	0.681	ICE V3

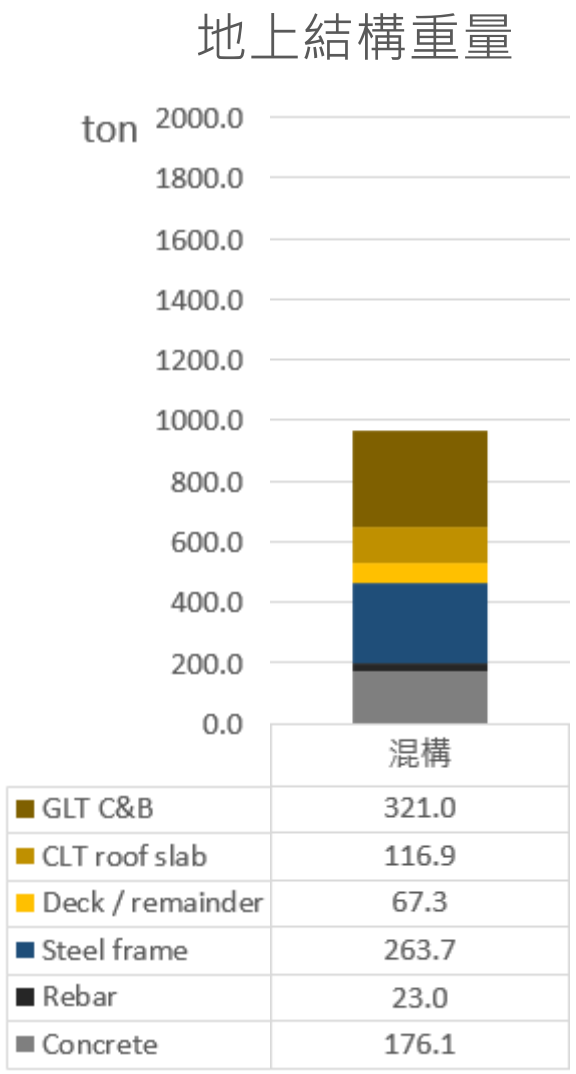
A4 ECFs for typical transport scenarios (UK)

A4 Transport scenario	km travelled by road	A4 ECF ($kgCO_2e/kg$)
Locally manufactured	50	0.005
Nationally manufactured	300	0.032
European manufactured	1500	0.160

A5 Waste factors for typical structural materials

Material/product	Waste rate (WR)	Waste factor (WF)[1]	WRAP Net Waste Tool reference
Timber frames (beams, columns, braces)	1%	0.010	Appendix 1, frame: timber frame
Timber floors (joists, boards)	10%	0.111	Appendix 1, floor: wooden floor

鋼木混結構碳排放量計算



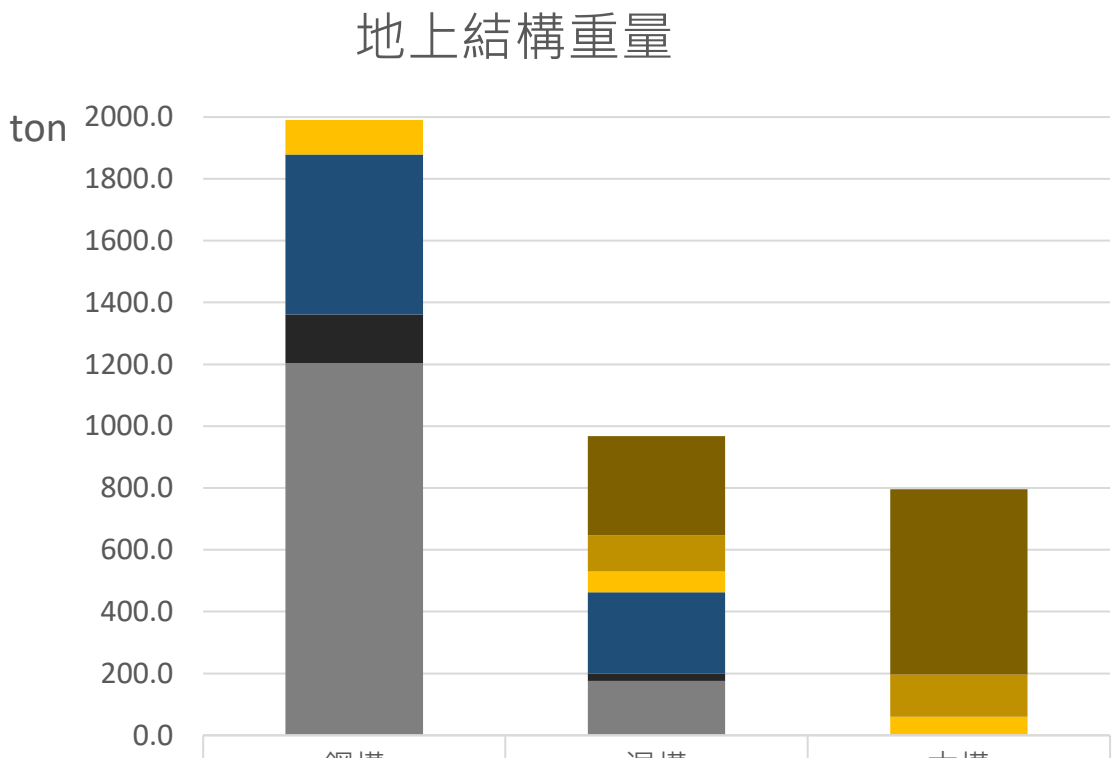
建築材料	重量(ton)	kgCO2e
Rebar	23	1.14
Steel frame	263.7	1.15
Concrete	176.1	0.154
GLT C&B	321	0.521
CLT roof slab	116.9	0.437
Deck / remainder	67.3	0.053/0.001/0.111/0.01

A1-A4
23000x1.14+263700x1.15+176100x0.154=356,594.4
A5w
(23000+176100)x0.053+263700x0.001= 10,816

A1-A3
321000x0.521+116900x0.437=218,326.3
A4
(321000+116900)x0.16=70,064
A5w
321000x0.111+116900x0.01=36,800

356,594.4+10,816+218,326.3+70,064+36,800= **692,600.7** (kg)

木結構碳排放量計算



	鋼構	混構	木構
GLT C&B	0.0	321.0	598.7
CLT roof slab	0.0	116.9	136.9
Deck / remainder	111.9	67.3	59.9
Steel frame	516.8	263.7	0.0
Rebar	157.5	23.0	0.0
Concrete	1204.0	176.1	0.0

建築材料	重量(ton)	kgCO2e
GLT C&B	598.7	0.521
CLT roof slab	136.9	0.437
Deck / remainder	59.9	0.111/0.01

A1-A3

598700x0.512+136900x0.437= 366,359.7

A4

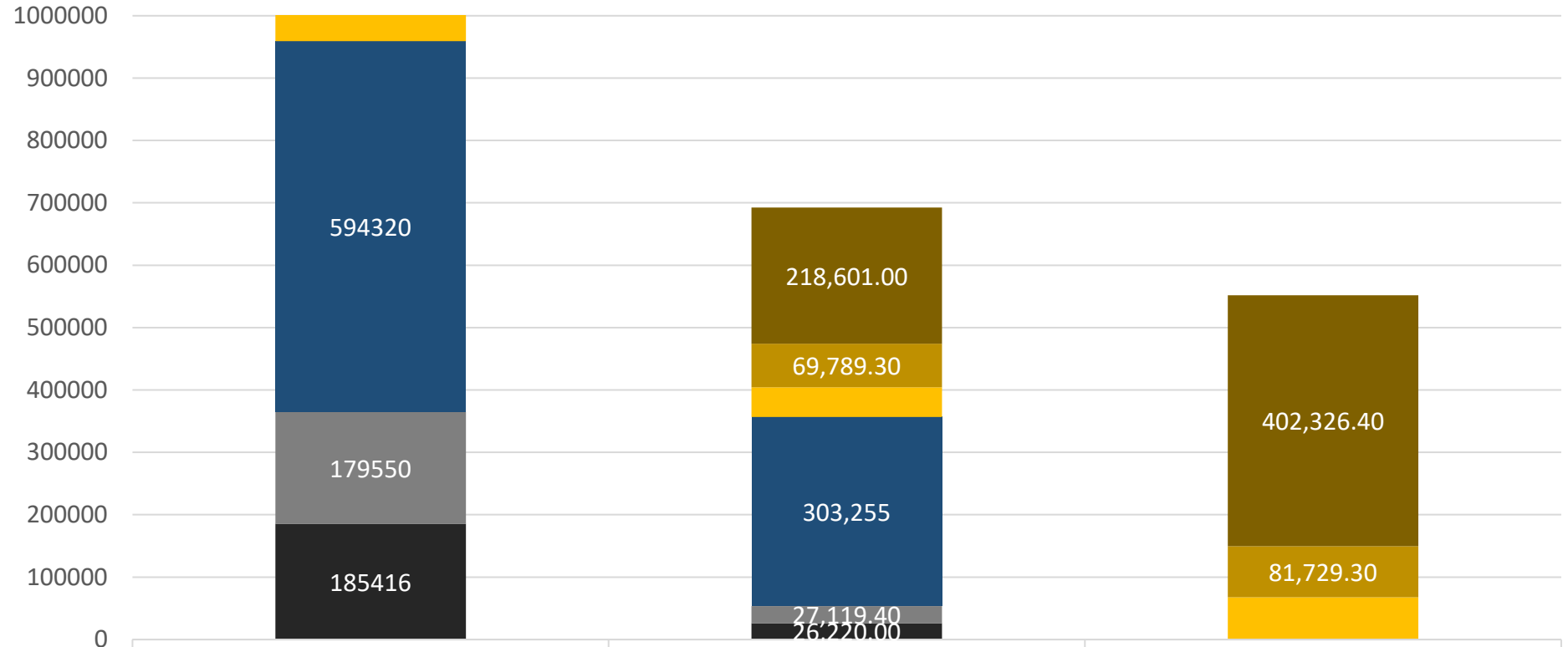
(598700+136900)x0.16= 117,696

A5w

(598700x0.111)+(136900x0.01)= 67,824.7

366,359.7+117,696+67,824.7= **551,880.4** (kg)

蘊含碳綜合比較



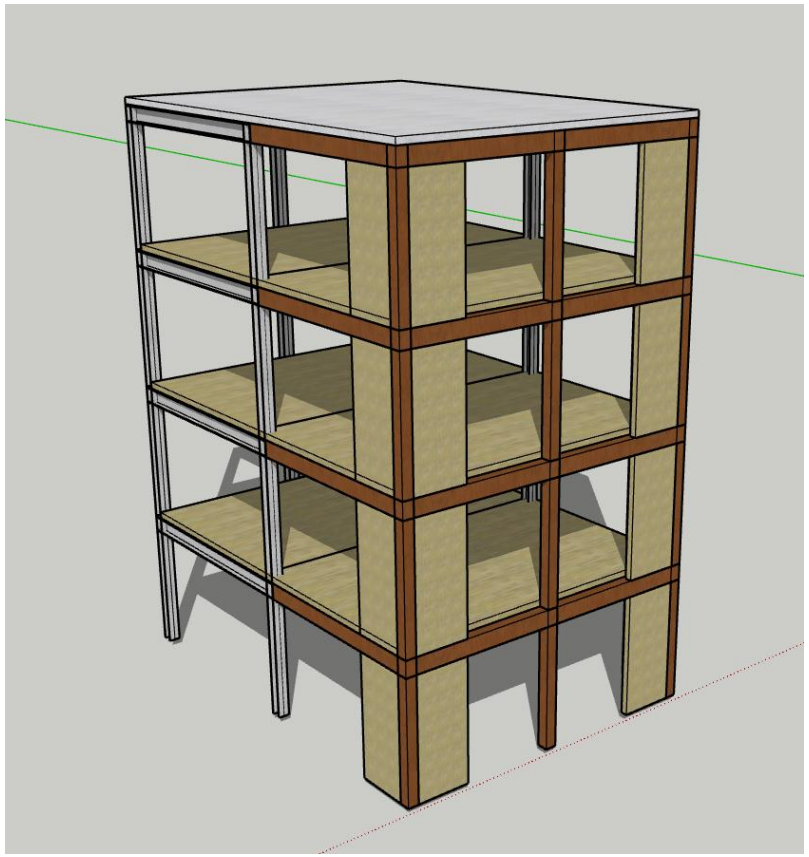
	鋼構	混構	木構
GLT C&B		218,601.00	402,326.40
CLT roof slab		69,789.30	81,729.30
deck / remainder	65,160.90	47,616	67,824.70
steel frame	594320	303,255	
concrete	179550	27,119.40	
rebar	185416	26,220.00	

總碳排放量(kg)	1,024,446.9	692,600.7	551,880.4

Steel-Timber 可能的混用型態

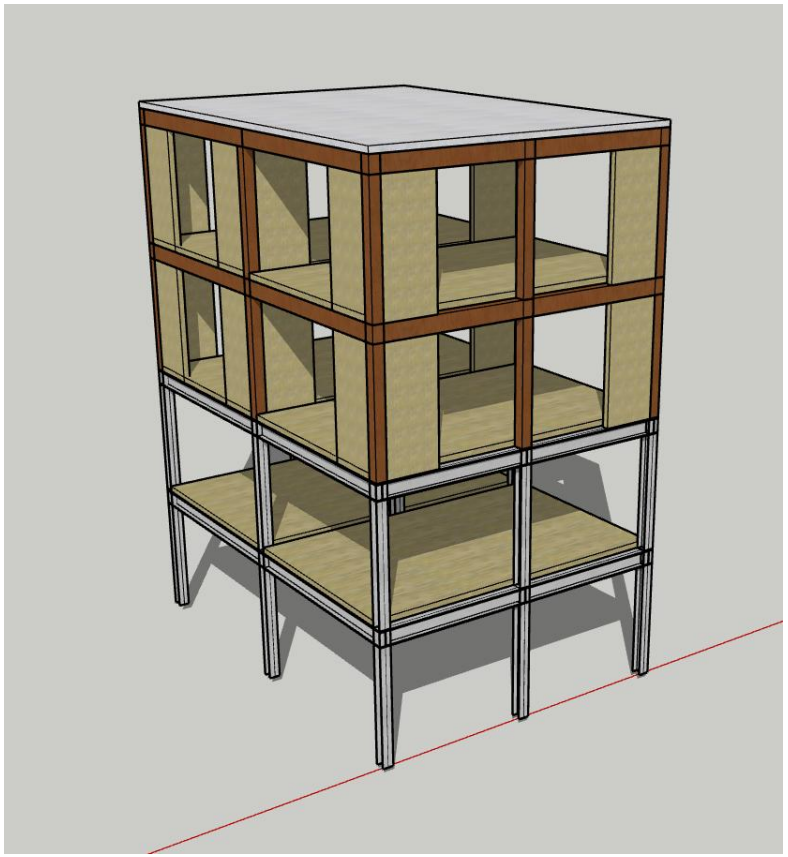
現行法規

1. 4層樓以下可行
2. 樓板滿足2小時防火則4層樓以上亦可行



現行法規

僅4層樓以下可行



現行法規

僅4層樓以下可行

Steel-Timber 可能的混用型態

■ 新竹華德福北平國小木構造屋頂設計 / 2018-20

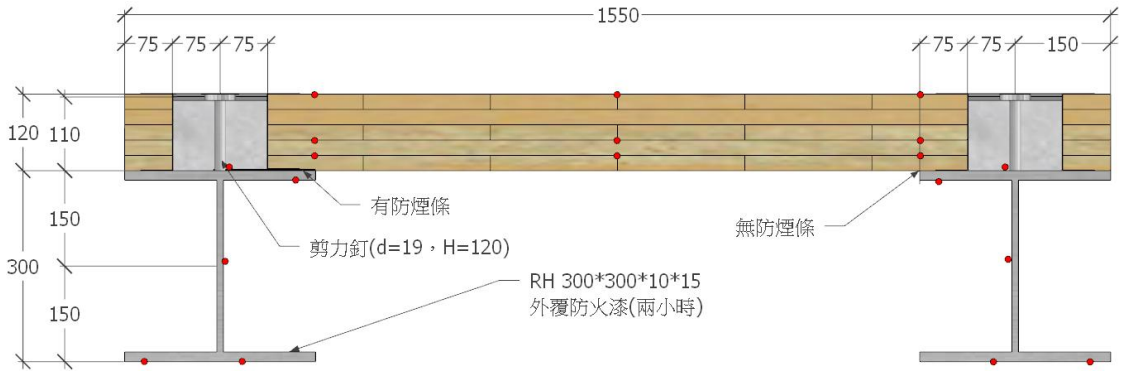
由黃珠茵建築師事務所委託進行木構造屋頂之設計，
透過數位工具整合鋼木混合結構系統的屋頂設計。

Steel-Timber 可能的混用型態

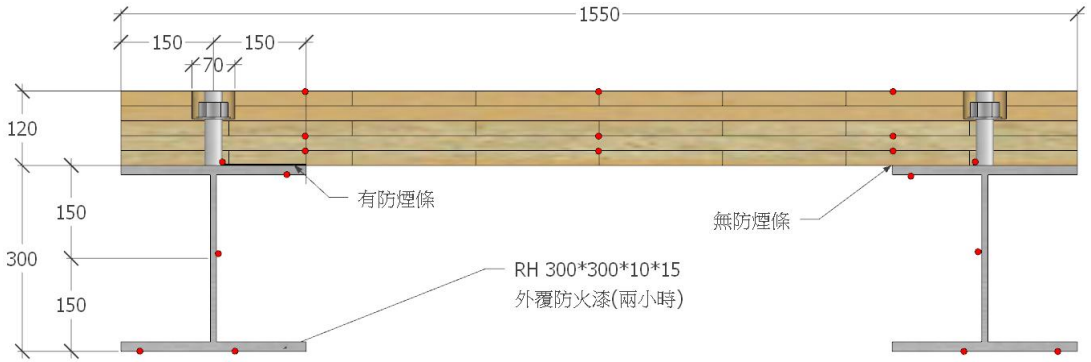
Steel-Timber 可能的混用型態

防火相關性能的探討

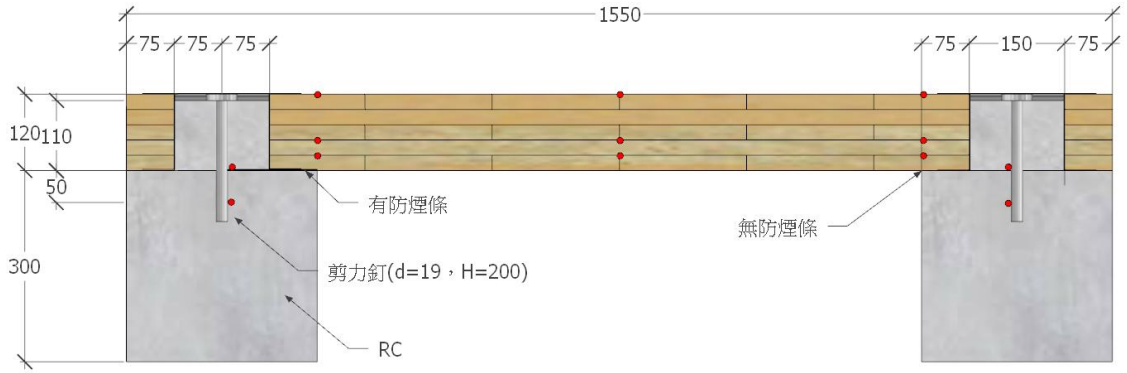
鋼梁/RC梁混用直交集成板CLT樓板



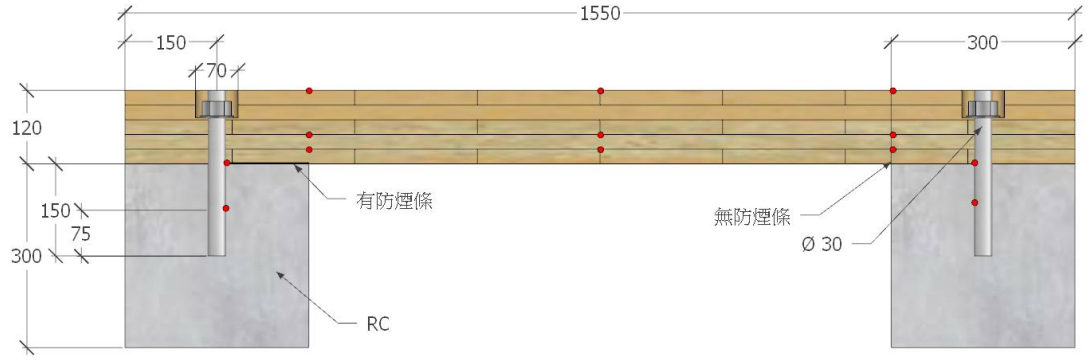
鋼梁、剪力釘+RC接合型式
CLT-S/SN



鋼梁、螺栓接合型式
CLT-S/B



RC梁、剪力釘+RC接合型式
CLT-RC/SN



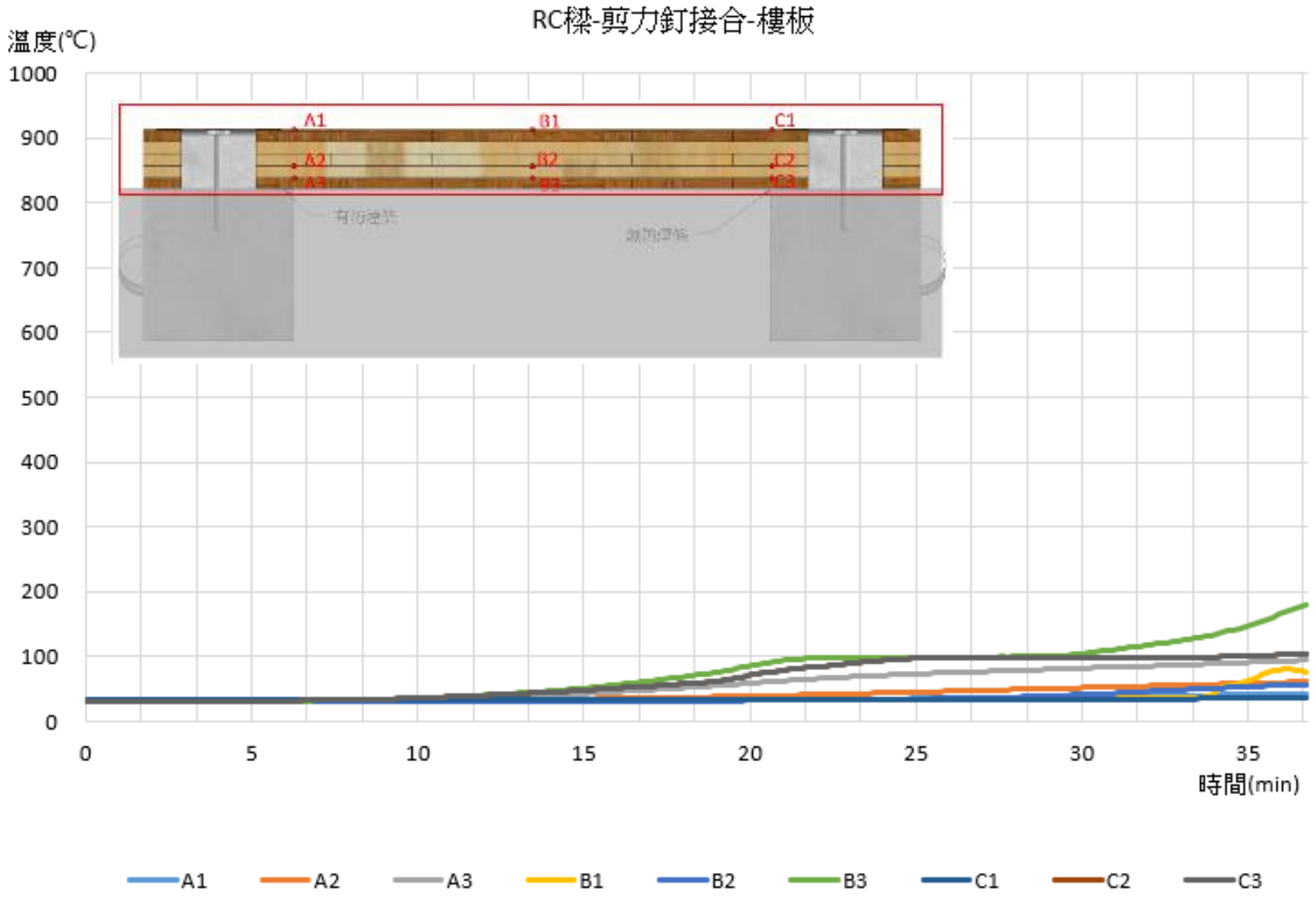
RC梁、螺栓接合型式
CLT-RC/B

RC-CLT混合構造

1. RC樑內溫度(D2、E2)無明顯變化，最高到達到54℃。

2. 接合處D1(有防煙條)、E1(無防煙條)整體無明顯升溫，E1最後達到72℃。

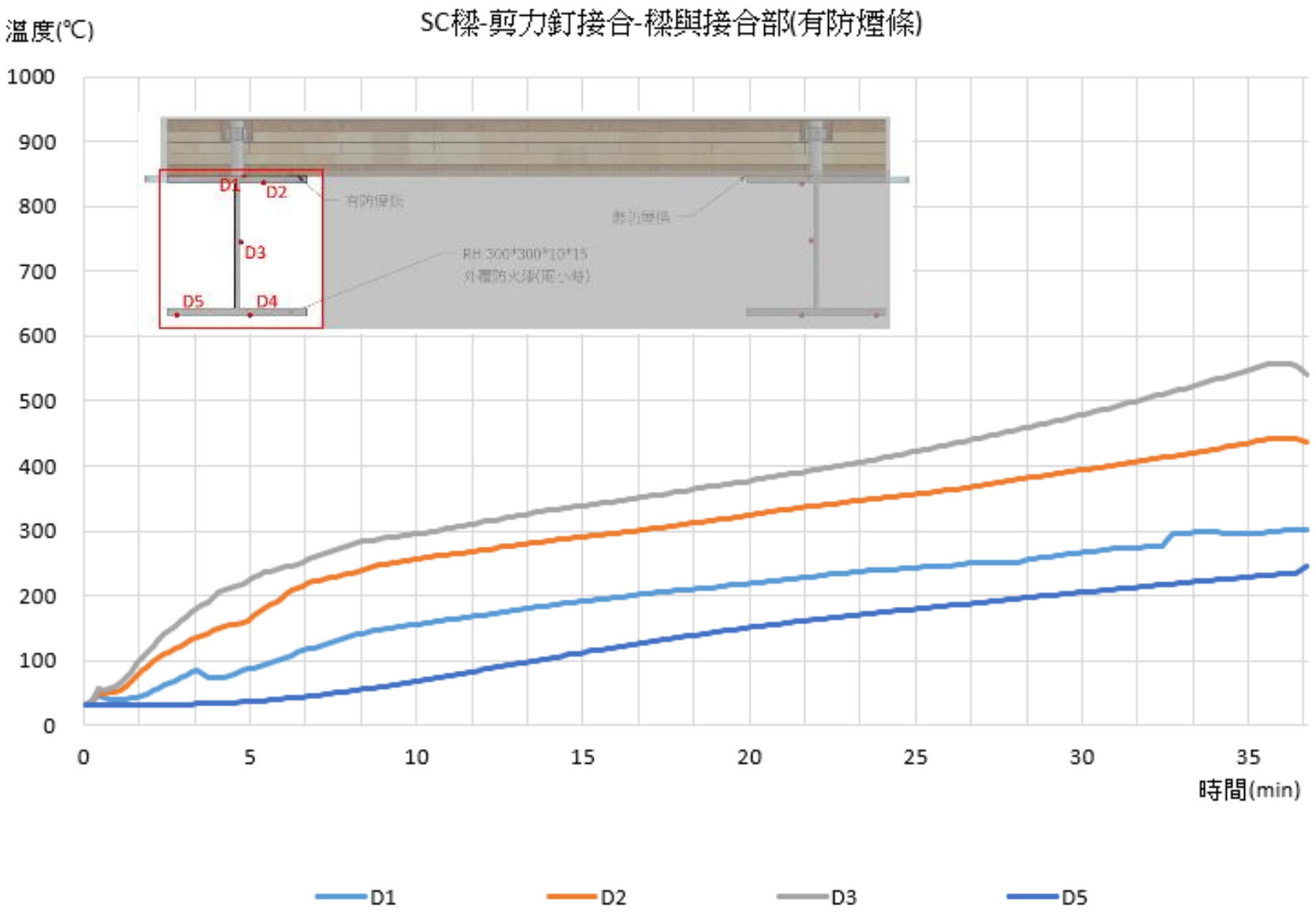
3. D1在實驗室間36:00時開始劇烈升溫，達到227℃，推測由於試體及火爐之間的防火岩棉有被燒穿，火焰串出燒到表面的熱偶線測溫點。



Steel-CLT混合構造

1. 鋼梁與剪力釘接合部的測溫點中，鋼梁最高溫達到550℃，同樣位於腹板處(D3)，而接合處**D1(有防煙條)**、E1(無防煙條)則分別為**302℃**、151℃(圖)。

2. 與鋼梁接合的CLT樓板受到鋼梁本身熱傳導效應的影響較大，因此鋼梁的防火被覆效能則是熱能是否會透過接合部傳導至CLT樓板的關鍵。



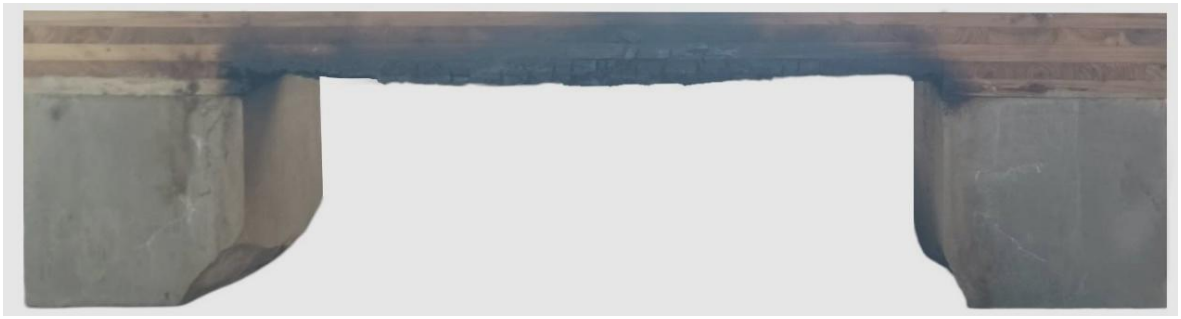
Steel/RC-CLT混合構造

火後整體試體側面的炭化情形。其中，RC梁部分基本上除了因碰撞缺失，沒有明顯變化；而鋼梁部分能明顯看到內側腹板的防火漆有些許脫落脫落，而外側相對完好，與前面試體溫度曲線做印證，RC梁接合部比較穩定，不會像鋼梁接合部受到大量熱傳導而升溫導致強度受影響。

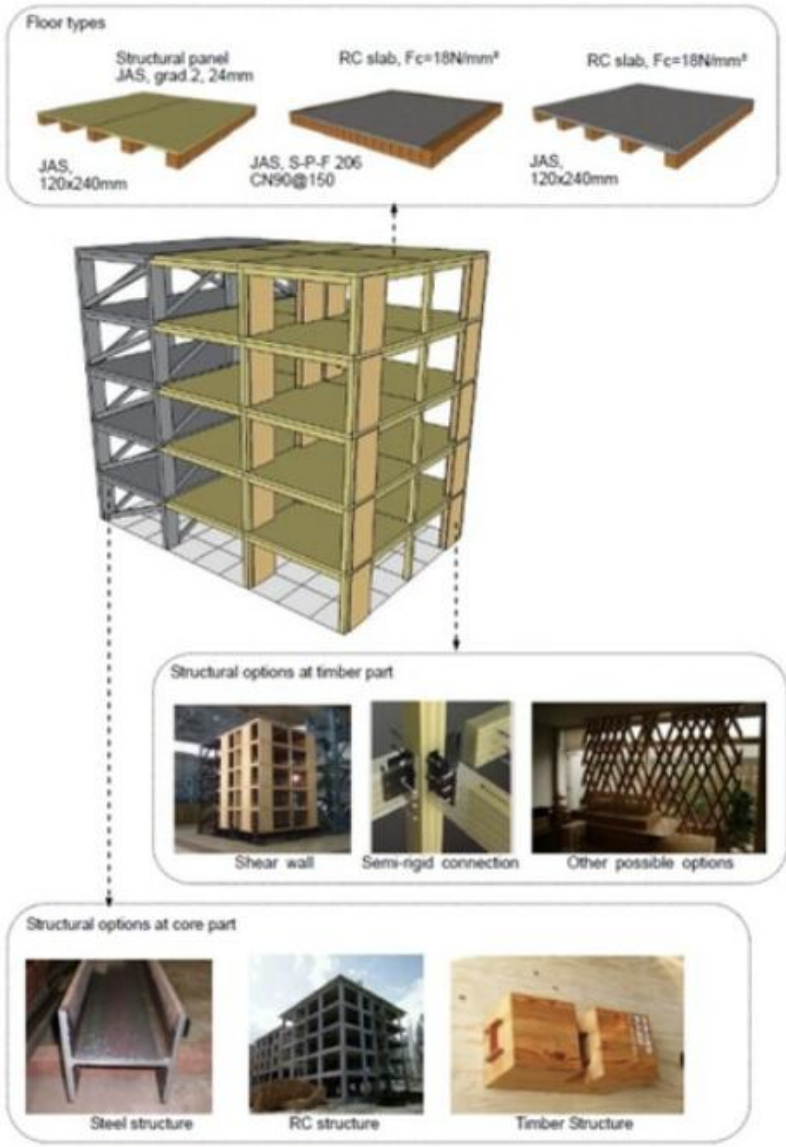
(a)腹板內側

(b)腹板外側

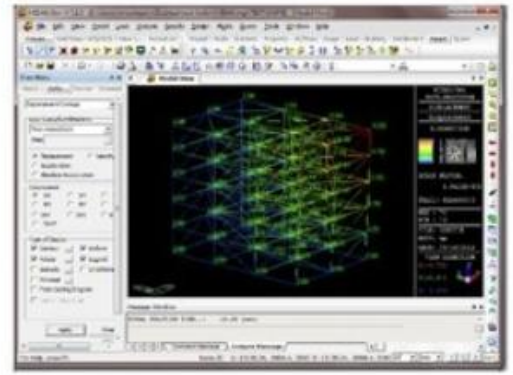
鋼梁防火漆火後狀態



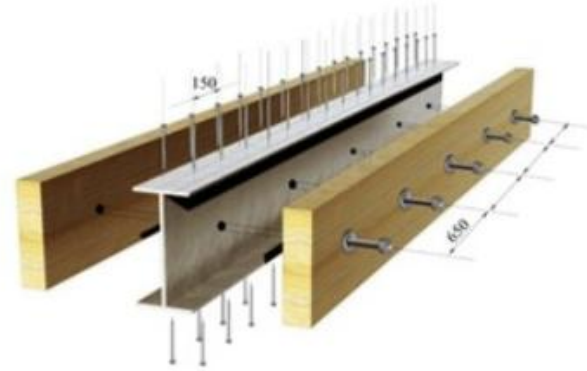
鋼木合成構件的類型及應用

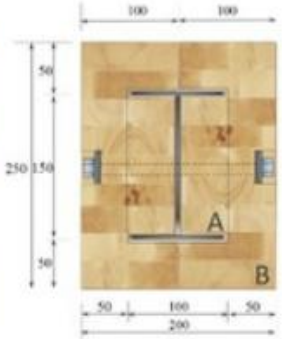


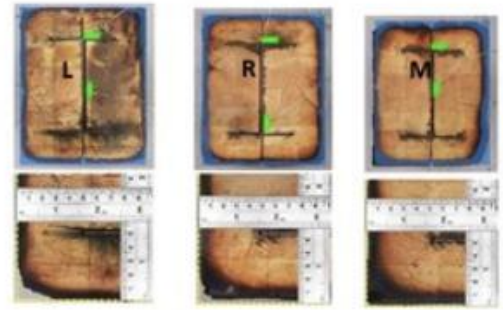
Based on the simulation results, hybrid timber structural system makes it possible to design a big opening without any shear wall or brace installed, as well as creating an indoor wall-free space, even an asymmetric building with large eccentricity ratio on structure stiffness.



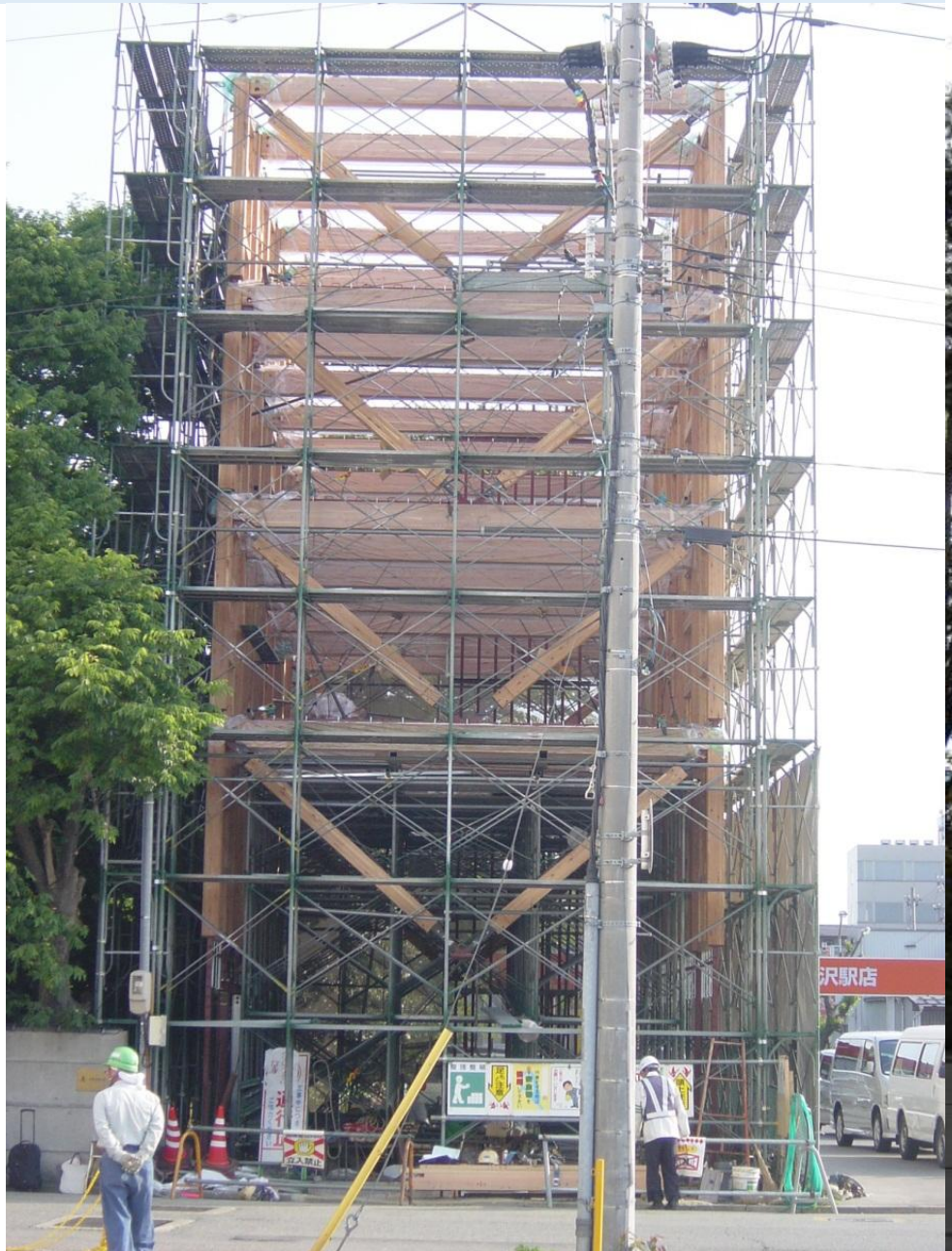
Steel reinforced Timber component are light, fast and clean. In addition, the economic and ecologic benefits have made the mixture of these two materials become an important objective in the modern multi-storey buildings.







鋼木合成構件的應用



M-Building
金沢市, 日本
Kanagawa, Japan

鋼木合成構件的應用

鋼木合成構件的應用

鋼木合成構件的應用

鋼木合成構件的應用

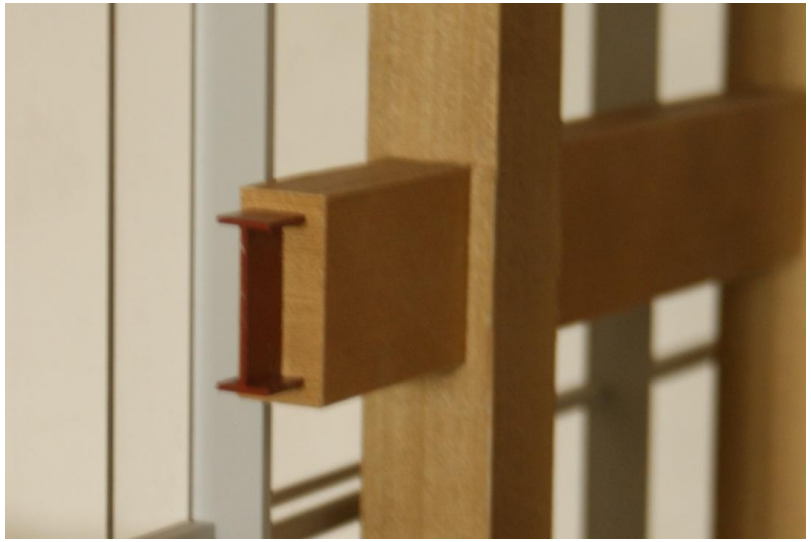
丸美産業株式会社
名古屋市, 日本
Nagoya, Japan

鋼木合成構件的應用

WOOD SQUARE
埼玉県越谷市, 日本
Saitama, Japan

鋼木合成構件的應用

鋼木合成構件的應用



Thank you for your attention