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Applicability of mid-rise timber structures in the metropolitan area

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ABSTRACT: To advance the goal of a zero-carbon society, promoting the use of wood in building construction is increasingly recognized as a viable solution. Current efforts are directed towards enabling medium to high-rise and large-scale timber buildings. This study aims to evaluate the applicability of steel and timber rigid frames, which offer greater spatial flexibility, in terms of their structural performance and environmental sustainability in urban areas. In this paper, the seismic performance is presented based on static incremental analysis of steel and timber structures. It can be found that when C = 0.2, there is no difference between the two structures. In the full plastic state, the timber structure remains more rigid, with deformation increasing 5–6 times for the timber structure and 9–10 times for the steel structure. At the same time, in the CO_2 emissions comparison of the two buildings, 471 t-CO_2 and 84 t-CO_2 for steel structure and timber structure which shows that the timber structure emits 82% less than the steel structure.

KEYWORDS: rigid frame, seismic response, structural design, CO_2 emission

1 – INTRODUCTION

Due to the concentration of population in urban areas, the demand for buildings per unit area is getting higher, and therefore buildings in urban area are required to secure as much floor space as possible. Steel structure is commonly used in urban area as reasonable space-saving structure due to adopt rigid frame structures which facilitate flexible spatial spaces. As environmental issues are increasingly emphasized, some studies have mentioned CO_2 emissions from the production of steel and wood [1] ~ [5]. Under the same unit of the material, wood is about 3% of the steel. Because of the wood is more environmentally friendly material, promoting the usage of wood in building construction is essential for advancing toward a decarbonized society [6]. And many multi-storey timber structures have been completed in recent years. The characteristics of wood such as lightness, high specific strength, and ease of processing are the advantages that are better than other building material such as steel and concrete [7]. In frequent earthquakes areas or countries, such as Japan, lightweight design is helpful in reducing seismic forces when the buildings under the same period. Based on the advantage of the eco-friendly and the reducing seismic forces, significant efforts to promote to development of multi-rise timber structures in Japan [8].

Even if wood has more advantages than other materials for the environment and its characteristics, it still has some structural performance issues that must be overcome when used as the structural material. Under the same stress in a simple beam, the strains in wood structures become larger due to the lower Young's modulus than steel. Increasing the cross-section of wood members reduces the strain, but makes the components larger, which restricts the spatial flexibility [9].

To clarify the difference between steel and timber building closer to actual cases of achieving a decarbonized society. This study uses same-scale models under the same criteria, when $C = 0.2$ reaches nearly 1/200 rad, to explore the differences in structural performance and CO_2 of each material used in steel and timber buildings. Although wood is a more eco-friendly material than steel, under the situation of achieving similar seismic resistance, the changing of the cross-section and the differences between the two buildings in decoration methods and materials properties such as fireproof make some uncertainties. While previous studies have discussed the CO_2 emissions or structural performance of steel and timber buildings, few have compared the CO_2 emissions and structural performance simultaneously. Therefore, to overcome these uncertainties, in this study uses these two buildings to find the optimal balance between the analysis results and the minimum dimensions of the components. Based on these models, compare and explore the possibilities of promoting timber buildings in the metropolitan area.

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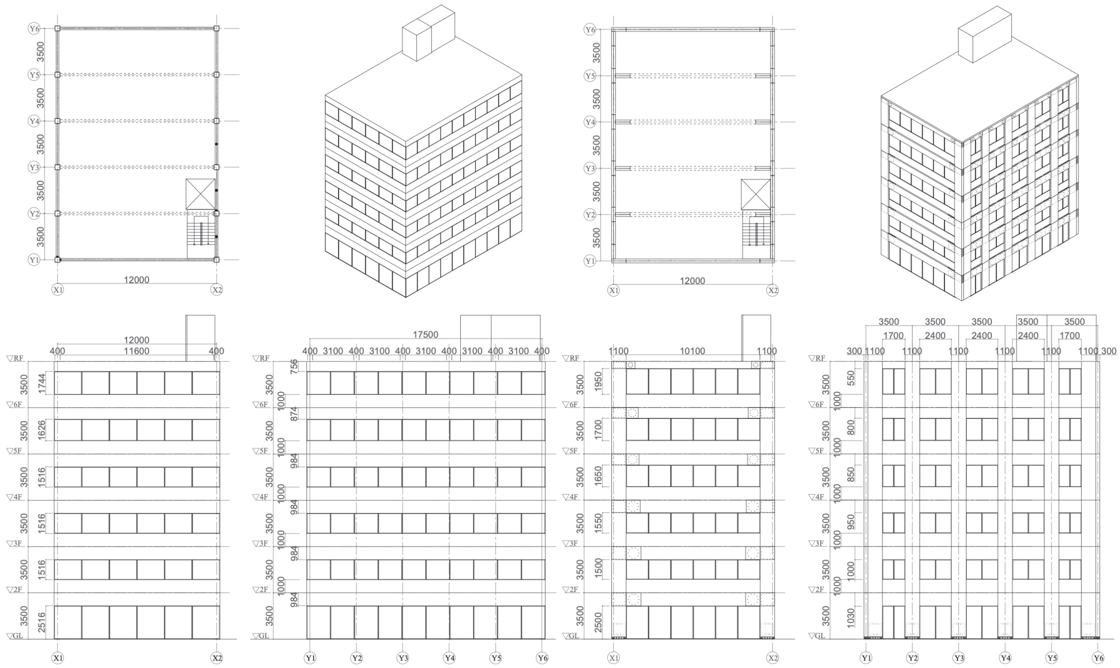


Steel structure　　　　Timber structure

Figure. 1: The outline of the models.

2 – STRUCTURAL DESIGN AND BASICAL DESIGN CONDITION

2.1 SETTING OF THE MODEL

The outline of the steel structure and timber structure are shown in the Figure 1. Both buildings are 6-story which is a 12m one-span, the height is about 21m, and the load width is 3.5m. According to the data investigated in this study [10], in the case of a span of 12m, the total span length on the other side is approximately 17.5 m. The two structures are set as the office buildings. And in accordance with the Building Standards Act Enforcement Order, the fire resistance for 1~2 floors is 2 hours, and the others are 1 hour.

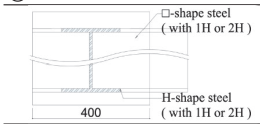
In this study set columns as single-column members. The dimension of the components are shown in Table 1. The opening is set as 30 mm for the aluminum window frame and 10mm for the single glass. In the timber structure, the columns and beams are 300 mm thick GLT. All joints are drift pins, and the beam side joints were designed to yield first. And in the steel structure, the columns are square pipes, the beams are H-shaped, and the joints are rigid. The component detail are based on reference [8][12]~[14] and the outline of the steel and timber structure are shown in Table 2 and Table 3. And the window is calculated by volume and density. The density of aluminum and glass are 26.5 and 24.5 kN/m^3.

Table 1: The information of member.

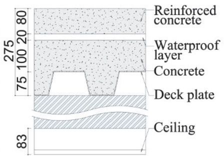
Model	F	Column [mm]	Material	Type	Beam [mm]	Material	Type
Steel	6	□-400×400×19			H-450×200×12×22		
	5	□-400×400×19			H-550×250×12×22		
	4	□-400×400×19			H-650×250×12×22		
	3	□-400×400×19	Steel	STKR400	H-650×250×12×25	Steel	SN490
	2	□-450×450×19			H-650×250×12×25		
	1	□-450×450×19			H-650×250×12×25		
	AB	8-M42		ABR490	-		-
Timber	6	300 × 1100			300 × 600		
	5	300 × 1100			300 × 800		
	4	300 × 1100	GLT & Steel	GLT: E120-F330 Joint_bolt: SNR490B, SN490 Joint_plate: SN490B	300 × 900	GLT & Steel	GLT: E120-F330 Joint_bolt: SNR490B, SN490 Joint_plate: SN490B
	3	300 × 1100			300 × 950		
	2	300 × 1100			300 × 1050		
	1	300 × 1100			300 × 1050		
	AB	4-M30	Steel	ABR490	-		-
Common	Base	-	Concrete	Fc24	-	-	-

Table 2: Detail of the steel structure.

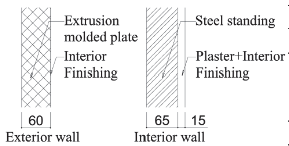
◯ Steel structure



・ Column & beam	
Rock wool_2H	167
Total	167
Rock wool_1H	117
Total	117

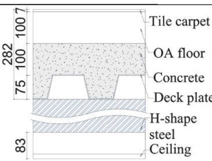


・ Roof	
Reinforced concrete	1840
Waterproof layer	150
Slab Lightweight Concrete	3300
Deck plate	150
Ceiling	300
Small beam	250
Total	5990



・ Non shear wall_exterior_2&1H	
Extrusion molded plate	1100
Total	1100

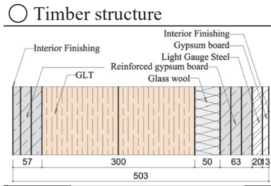
・ Non shear wall_interior_2&1H	
Plaster	300
Cloth finish	100
Fireproof 2H/1H	158/113
Total 2H/1H	558/513



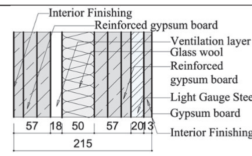
・ Floor_2H & 1H	
Floor Finishing	1000
Slab Concrete	3300
Deck plate	150
Ceiling	300
Small beam	250
Total	5000

Table 3: Detail of the timber structure.

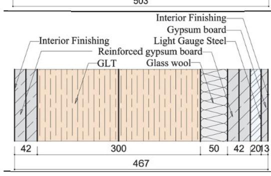
◯ Timber structure



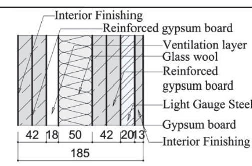
・ Column&beam _interior (2H)	
Interior Finishing	100
Reinforced gypsum board	1060
Glass wool	12
Light Gauge Steel	50
Gypsum board	110
Total	1332



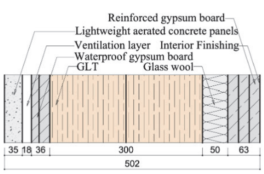
・ Non shear wall_interior (2H)	
Interior Finishing	100
Reinforced gypsum board	100
Frame material	1060
Glass wool	50
Light Gauge Steel	12
Total	1382



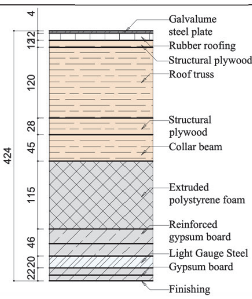
・ Column&beam _interior(1H)	
Interior Finishing	100
Reinforced gypsum board	780
Glass wool	12
Light Gauge Steel	50
Gypsum board	110
Total	1052



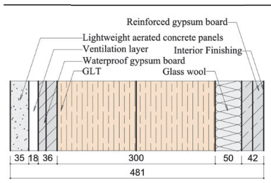
・ Non shear wall_interior (1H)	
Interior Finishing	110
Reinforced gypsum board	100
Frame material	780
Glass wool	50
Light Gauge Steel	12
Total	1102



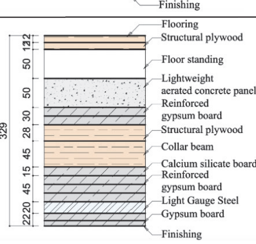
・ Column&beam_exterior(2H)	
Lightweight aerated concrete panel	228
Ventilation layer	50
Waterproof gypsum board	335
Glass wool	12
Reinforced gypsum board	585
Interior Finishing	50
Total	1260



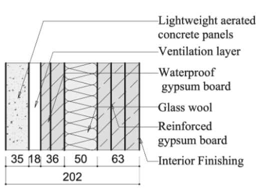
・ Roof	
Galvalume steel plate	36
Rubber roofing	169
Structural plywood	236
Roof truss	300
Collar beam	70
Extruded polystyrene foam	29
Reinforced gypsum board	428
Light Gauge Steel	50
Gypsum board	194
Anti-vibration charcoal bag	110
Cloth finish	10
Total	1632



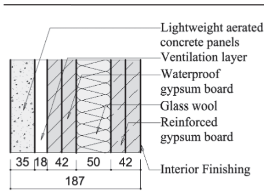
・ Column&beam _exterior(1H)	
Lightweight aerated concrete panels	228
Ventilation layer	50
Reinforced gypsum board	780
Glass wool	12
Interior Finishing	50
Total	1120



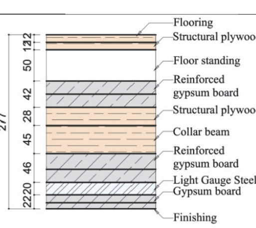
・ Floor(2H)	
Flooring	120
Structural plywood	236
Floor standing	200
Lightweight concrete panels	325
Reinforced gypsum board	700
Collar beam	70
Calcium silicate board	177
Light Gauge Steel	50
Gypsum board	194
Anti-vibration charcoal bag	110
Cloth finish	10
Total	2192



・ Non shear wall_exterior (2H)	
Lightweight aerated concrete panels	228
Ventilation layer	50
Waterproof gypsum board	335
Frame material	50
Glass wool	12
Reinforced gypsum board	585
Interior Finishing	50
Total	1310



・ Non shear wall_exterior (1H)	
Lightweight aerated concrete panels	228
Ventilation layer	50
Reinforced gypsum board	780
Frame material	50
Glass wool	12
Interior Finishing	50
Total	1170



・ Floor(1H)	
Flooring	120
Structural plywood	236
Floor standing	200
Reinforced gypsum board	818
Collar beam	70
Light Gauge Steel	50
Gypsum board	194
Anti-vibration charcoal bag	110
Cloth finish	10
Total	1808

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The rotational springs of the joint, were examined in relation to the bending stiffness *EI* of the member to avoid changing the detailed design each time the member is changed. The relationship with the bending stiffness of the wooden member was organized and the settings shown in Table 4 were used [11]. Both structures are connected on the ground by anchor bolts (AB). The elastic stiffness of the exposed column base K_{BS} was calculated using Eq. (1). The AB joint has the restoring force characteristics of an MN element. And in the setting of two models, the secondary gradient after yielding is set to 0.

Table 4: Stiffness of rotational springs.

Part	K_θ	My
Beam side	$3.95\times10^{-4}\times E_bI$	$6.01\times10^{-3}\times {}_bK_\theta$
Column side	$2.15\times10^{-3}\times E_cI$	$4.90\times10^{-3}\times {}_cK_\theta$
Column base	$1.19\times10^{-3}\times E_cI$	-

$$K_{BS} = [\, E \times n_t \times A_b\,(d_t + d_c)^2\,] \,/\, (2 \times l_b) \qquad (1)$$

where, E is Young's modulus of the anchor bolt, n_t is the number of anchor bolts on the tension side, A_b is the cross-sectional area of the anchor bolt, d_t is the distance from the centroid of the column cross section to the centroid of the anchor bolt group on the tension side, d_c is the distance from the centroid of the column cross section to the outer edge of the column flange on the compression side, and l_b is the length of the anchor bolt. The yield curve was calculated by Eq. (2-1) ~ (2-3) shown in the Architectural Institute of Japan for recommendations for design of connections in steel structures.

$$M_p = \begin{cases} (N_u - N) \times d_t & N_u \geq N > (N_u - T_a) \quad (2\text{-}1) \\ T_a\, d_t + (N+T_a)D/2\,(1-(N+T_a)/N_u) & (N_u - T_a) \geq N > -T_a \quad (2\text{-}2) \\ N + 2T_a \times d_t & -T_a \geq N > -2T_a \quad (2\text{-}3) \end{cases}$$

Where, the axial force of the rigid frame column is N (compression is positive), and the distance between the stress centers is d_t, and the full plastic tensile strength T_a is calculated using Eq. (3).

$$T_a = A_b \times F_{by} \times n_t \qquad (3)$$

Where A_b is the cross-sectional area of the anchor bolt, F_{by} is the yield strength design standard strength of the anchor bolt (ABR490), and n_t is the quantity of anchor bolts. The maximum compressive strength N_u of the foundation concrete is calculated using the following equation.

$$N_u = B \times D \times F_b \qquad (4)$$

In Eq. (4), B is the width of the base plate perpendicular to the structural axis, and D is the width of the base plate in the structural axis direction. The bearing strength of the foundation concrete F_b is calculated using Eq. (5). F_c is the design strength of the foundation concrete. F_c 24 concrete (= 24 N/mm^2) is used.

$$F_b = 0.85 \times F_c \qquad (5)$$

2.2 LOAD CONDITION

According to the Building Standards, the setting of the live loads is set as the office building. This study considered fire resistance and used the dead load from reference [8][12]~[14]. Table 5 shows the design load without structural material for the long-term and short-term condition. The value of the live load for floor is 1800 N/m^2 under the long-term condition, 800 N/m^2 for the short-term condition. And for roof, 600 N/m^2 is for long-term and 400 N/m^2 is for short-term. The long-term and short-term are varied by the structural material dimensions.

Table 5: The design load [N/m^2] of the components of the two models.

Part	Timber		Steel	
	Short	Long	Short	Long
Column&Beam_exterior (2H)	1260 *		167 *	
Column&Beam_exterior (1H)	1120 *		117 *	
Column&Beam_interior (2H)	1332 *		167 *	
Column&Beam_interior (1H)	1052 *		117 *	
Roof	2032	2232	6390	6590
Floor(2H)	2992	3992	5800	6800
Floor(1H)	2608	3608	5800	6800
Non shear wall_exterior (2H)	1310		1100	
Non shear wall_exterior (1H)	1170		1100	
Non shear wall_interior (2H)	1382		558	
Non shear wall_interior (1H)	1102		513	
Opening(glass)	245			
Opening(frame)	794			

*: Structural material is exclude

The horizontal load P_{Ei} acting on each story is calculated from the earthquake story shear force Q_{Ei} calculated from Eq. (6). The results are shown in Table 6

$$Q_{Ei} = C_i \times \Sigma w_i \qquad (6)$$

Where, the factor of story shear force C_i is calculated using the equation below, and w_i is the weight of the i-th floor.

$$C_i = Z \times R_t \times A_i \times C_o \qquad (7)$$

In Eq. (6), based on Japanese Article 88 of the Enforcement Order of the Building Standards Act, the earthquake region coefficient Z = 1.0, the vibration characteristic coefficient Rt is the 2nd ground, R_t = 1.0 and the standard shear force coefficient C_0 = 0.2. The story shear force coefficient A_i is calculated from Eq. (8).

$$A_i = 1+(1/\sqrt{(a_i)}-a_i) \times 2T/(1+3T) \qquad (8)$$

Where, a_i is the weight of each level divided by the overall building weight, calculated using Eq. (9). The primary natural period, T = 0.63s, is determined by T = 0.03 H, where the building height H = 21m. The horizontal forces in Table 6 are calculated based on the above.

$$a_i = \sum_{j=i}^{n} w_j \,/ \sum_{j=1}^{n} w_j \tag{9}$$

Table 6: Horizontal forces on each layer.

Model	F	W_i [kN]	ΣW_i [kN]	W_i/A [kN/m²]	a_i [-]	A_i [-]	C_i [-]	Q_{Ei} [kN]	P_{Ei} [kN]
Steel structure	6	310.38	310.38	7.39	0.16	2.02	0.40	125.29	125.29
	5	320.46	630.84	7.63	0.33	1.62	0.32	204.54	79.25
	4	322.14	952.98	7.67	0.49	1.41	0.28	268.03	63.49
	3	324.66	1277.64	7.73	0.66	1.25	0.25	319.01	50.97
	2	327.18	1604.82	7.79	0.83	1.12	0.22	358.47	39.47
	1	329.28	1934.10	7.84	1.00	1.00	0.20	386.82	28.35
Timber structure	6	155.40	155.40	3.70	0.11	2.28	0.46	70.71	70.71
	5	234.36	389.76	5.58	0.27	1.72	0.34	133.79	63.08
	4	241.08	630.84	5.74	0.44	1.46	0.29	184.73	50.94
	3	241.08	871.92	5.74	0.61	1.29	0.26	225.40	40.67
	2	278.88	1150.80	6.64	0.80	1.14	0.23	261.27	35.87
	1	279.30	1430.10	6.65	1.00	1.00	0.20	286.02	24.75

2.3 DESIGN CRITERIA

Table 7 shows the allowable stress of the material, and the design follows the allowable stress design policy to meet the criteria in Table 8. Based on the incremental analysis, the beam joints on each story are designed to yield first, before reaching the safety limit. The parameters of the members and joints are adjusted for optimization. According to the Ministry of Construction Notification, the deformation increase coefficient α is set to 2.0 for timbers structure and 1.0 for steel structure under the long-term condition. Under the short-term condition, both models remain within the elastic range, with the story drift angle less than 1/200 rad when the story shear force coefficient C = 0.2. Long-term and short-term stress checks are calculated by the following equation.

Table 7: The allowable stress of material.

Material	Condition	f_c	f_t	f_b	f_s
Steel_ STKR400	F		235		
	Long term		156.7 *1		90.5 *2
	Short term		235.0 *3		135.7 *3
Steel_ SN490	F		325		
	Long term		216.7 *1		125.1 *2
	Short term		325.0 *3		187.6 *3
GLT_ E120-F330	F	25.9	22.4	33	3.0
	Long term	9.5 *4	8.2 *4	12.1 *4	1.1 *4
	Short term	17.3 *5	14.9 *5	22.0 *5	2.0 *5

※ Unit: [N/mm²], F: Basic strength, fc: Compressive strength, ft: Tensile strength, fb: Bending strength, fs: Shear strength.
*1: F/1.5, *2: F/1.5√3, *3: Long term × 1.5, *4: F × 1.1/3, *5: 2F/3

Table 8: Design criteria.

Item	Long term	Short-term
Story	-	・Story drift angle ≤ 1/200 rad
Column	-	・≤ short sustained
Beam	・≤ long sustained ・≤ deflection 1/250	・≤ short sustained
Joint	-	・≤ short sustained

The combined stress check for axial force and bending in the column under short-term horizontal force is calculated by the following equation.

$$N\,/\,(A_C \times f_c) + M\,/\,(Z_C \times f_b) \leq 1.0 \tag{10}$$

In Eq. (10), N and M represent the axial force and bending moment of the column. A_C and Z_C denote the cross-sectional area and section modulus. f_c indicates the allowable compressive or tensile stress, and f_b is the allowable bending stress under short-term condition. The shear force check for the beam and column under short-term and long-term conditions follows the Eq. (11).

$$(1.5 \times Q)\,/\,(A \times f_s) \leq 1.0 \tag{11}$$

Where, Q is the shear force on the column and beam, A is the cross-sectional area, and f_s is the long-term allowable shear stress. The bending stress and deflection of the beam under the long-term and short-term conditions are checked by Eq. (12) ~ (13). First, the bending allowable stress evaluated is calculated by the below equation.

$$M\,/\,(Z_B \times f_b) \leq 1.0 \tag{12}$$

In Eq. (12), M is the bending moment on the beam, Z_B is the section modulus, and f_b is the long-term or short-term allowable bending stress. Tthe deflection check is based on the following equation.

$$(\delta \times \alpha)\,/\,\delta_a \leq 1.0 \tag{13}$$

Where δ is the maximum deformation of the beam under the design load, and α is the deformation increase coefficient, set 1.0 for steel and 2.0 fpr timber structure. δ_a is calculated by l / 250, the beam length l = 12 m.

3 – PERFORMANCE EVALUATION BASED ON NUMERICAL ANALYSIS

The story drift angle is set to below 1/200 rad when the base shear force coefficient C = 0.2. Figure. 2 shows the skeleton curves from the static incremental analysis.

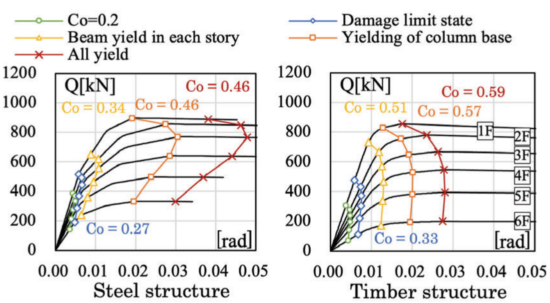

Figure. 2: Skeleton curves of respective structure.

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Figure. 2 shows the occurrence of hinges. It records the C = 0.2, initial yield of the beam, yield of all beams, yield of the column base, and all yield. The results are represented in order by ○ ◇ △ □ ×.

Under the C = 0.2, the timber structure shows the minimum story displacement of 11.3 mm in the 1st layer, with other layers ranging from 13 to 15 mm. For the steel structure, the minimum story displacement is in the top layer at about 12 mm, while the maximum displacement occurs in the 4^{th} and 5^{th} layers at around 16 mm, with other layers ranging 13 ~ 15 mm. The results are also reflected in the rigidity ratio. In the timber structure, the minimum value is 0.82 in the 1st layer and 1.0 ~ 1.06 in the others. In the steel structure, the lowest rigidity ratio is 0.84 in the roof layer, with other layers are 0.93 ~ 1.13.

In all yield state, the timber structure shows the minimum story displacement of about 52 mm in the 1^{st} layer, with other layers are about 70 ~ 88 mm. In the steel structure, the minimum story displacement occurs in the top layer at about 98 mm, while the maximum displacement is in the 4^{th} layer at around 152 mm, with other layers ranging 120 ~ 150 mm. The story displacement in the timber structure during the all yield state is about 4 to 6 times larger than when C = 0.2, and in the steel structure, it is about 8 to 10 times larger. It shows that the rigidity reduction rate of steel structure is higher than timber structure.

Based on the static incremental analysis, the results of the allowable stress checks for short and long term conditions are shown below.

Table 9: The deflection check of the beams.

Model	Steel		Timber	
α	1.0		2.0	
F	δ [mm]	Result	δ [mm]	Result
R	23.36	0.49	21.48	0.89
6	13.62	0.28	16.14	0.67
5	10.93	0.23	12.39	0.52
4	10.15	0.21	10.74	0.45
3	9.37	0.20	9.32	0.39
2	9.17	0.19	8.74	0.36

In Table 9, the deformation of the two structures is similar. However, due to the expansion coefficient α for the timber structure is 2.0, the deflection is nearly at the limit. The short-term allowable stress checks for columns and the long-term and short-term allowable stress checks for beams are shown in the Table 10 and Table 11 . First, Table 10 shows the composite stress results, it can be found that since timber buildings are lighter than steel buildings, the allowable stress in the columns is larger than steel buildings.

Table 10: The combined stress check of the columns under short-term.

Model	Steel		Timber	
F	Left	Right	Left	Right
6	0.26	0.42	0.05	0.17
5	0.19	0.35	0.02	0.22
4	0.22	0.41	0.05	0.28
3	0.27	0.47	0.09	0.37
2	0.26	0.46	0.13	0.43
1	0.37	0.44	0.23	0.42

*Left is the compressive side, right is tension side.

And the moment and shear force check of the beams are shown in Table 11. Although the dead load of timber structure is lower than the steel structure, the allowable stress of timber structure is much higher than the steel structures due to the lower material strength of wood. However, under the short-term condition, the weight of the steel structure is heavier than the timber structure, which impacts the result of the earthquake force becomes higher. The results show that even though the material strength of steel itself is higher than the wood, the overall allowable stress is higher than the timber structure.

Table 11: The moment and shear force check of the beams.

Model	Steel				Timber			
Condition	Long-term		Short-term		Long-term		Short-term	
F	*M*	*S*	*M*	*S*	*M*	*S*	*M*	*S*
R	0.37	0.15	0.62	0.17	0.78	0.53	0.51	0.20
6	0.31	0.15	0.52	0.16	0.58	0.52	0.54	0.18
5	0.29	0.13	0.54	0.15	0.46	0.46	0.45	0.15
4	0.23	0.13	0.47	0.15	0.41	0.44	0.49	0.12
3	0.23	0.13	0.49	0.16	0.32	0.38	0.40	0.10
2	0.23	0.13	0.49	0.16	0.32	0.38	0.38	0.10

4 – ASSESSMENT OF CO2 EMISSION

First, the carbon storage is calculated by the below equation based on the Forestry Agency of Japan [17].

$$Cs = V \times D \times Cf \times 44/12 \tag{14}$$

In Eq. (14), C_S is the carbon storage [kg-CO_2], V is timber volume [m³], D is total dry specific gravity [t/m³], Cf is carbon content, and 44/12 is the conversion coefficient from carbon to carbon dioxide. V is 1.0, Cf is 0.5, and the D is 0.40, which is considered the weight per unit volume after artificial drying to 15% moisture content is. The result of Cs is 843 kg-CO_2/m^3.

And, the correlation coefficient used in this study is taken from relevant survey literature in Japan [1] ~ [5]. CO_2 emissions E and carbon storage C_S are calculated per 1m³ of product at the final product stage. First, CO_2 emission E [kg-CO_2] is calculated as follows:

$$E = W \times c \tag{15}$$

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In Eq. (15), W [t] is the weight or [m^3] is the volume of material in the models., and c is the CO_2 emission index [kg- CO_2 / t] or [kg-CO_2 / m^3] is shown in Table 12.

Table 12: CO_2 emission index.

Part	Material	Value	Unit	Ref
Structure	Steel	1303	kg-CO_2/t	[1]
	GLT	400	kg-CO_2/m^3	[4]
Strucutral decoration	Light Gauge Steel	1163	kg-CO_2/t	[2]
	Ventilation layer	373	kg-CO_2/t	[2]
	Waterproof gypsum board	162	kg-CO_2/t	[2]
	Reinforced gypsum board	162	kg-CO_2/t	[2]
	Interior Finishing	162	kg-CO_2/t	[2]
	Gypsum board	162	kg-CO_2/t	[2]
	Lightweight aerated concrete panels	118	kg-CO_2/t	[1]
	Glass wool	2511	kg-CO_2/t	[2]
	Rock wool	209	kg-CO_2/t	[2]
	Light Gauge Steel	1163	kg-CO_2/t	[2]
	Ventilation layer	373	kg-CO_2/t	[2]
Roof &Floor	Galvalume steel plate	1238	kg-CO_2/t	[2]
	Rubber roofing	653	kg-CO_2/t	[2]
	Structural plywood	975	kg-CO_2/t	[2]
	Roof truss	373	kg-CO_2/t	[2]
	Collar beam	373	kg-CO_2/t	[2]
	Extruded polystyrene foam	357	kg-CO_2/t	[1]
	Flooring	975	kg-CO_2/t	[2]
	Floor standing	1163	kg-CO_2/t	[1]
	Reinforced concrete	118	kg-CO_2/t	[2]
	Waterproof layer	653	kg-CO_2/t	[2]
	Concrete	121	kg-CO_2/t	[2]
	Ceiling	162	kg-CO_2/t	[2]
	Cloth finish	4080	kg-CO_2/t	[2]
	Calcium silicate board	603	kg-CO_2/t	[1]
	Deck plate	1489	kg-CO_2/t	[5]
	Small beam	1303	kg-CO_2/t	[1]
	Floor Finishing	975	kg-CO_2/t	[2]
Non shear walll	Frame material	373	kg-CO_2/t	[2]
	Extrusion molded plate	196	kg-CO_2/t	[2]
	Plaster	162	kg-CO_2/t	[2]
	Fireproof	209	kg-CO_2/t	[2]
Opening	Glass	1016	kg-CO_2/t	[2]
	Aluminum frame	4972	kg-CO_2/t	[2]

Based on the dimensions of the columns and beams are shown in Table 3, and the detail materials of each components are shown in Table 1. The CO_2 emission of structures, non shear walls, roof and floor, openings, structure's decoration material, and Joints are shown in Figure. 3.

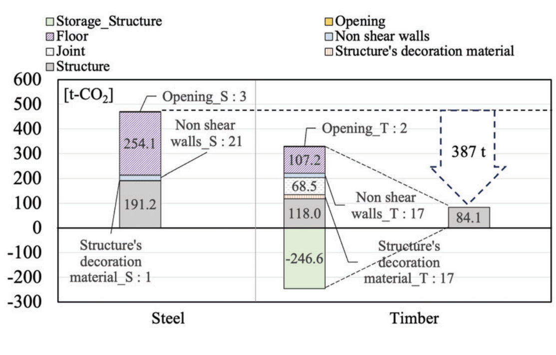

Figure. 3: The result of the CO_2 emission.

It can be found that GLT is 18 % lower than the steel. Even if the components of cross-section in timber building is increased due to earthquake resistance requirements, CO_2 emission of timber building can fix 129 t-CO_2. Compared with steel, wood has obvious advantages. However, the decoration materials of column and beam, timber building is 17 times larger than steel building. It can be attributed to the detailed design and large cross-section of the timber building itself. Then, about 68 t-CO_2 are generated for the steel joints in the timber building. The other difference is the roof and floor, under the same area, the timber building is 42% lower than the steel building. This can be directly attributed to the detail designs. In addition, the difference of the opening and the non-shear wall between and timber building and steel building is relatively small. The difference is about 1t and 4t.

The total CO_2 emission of steel and timber structure are 472 t-CO_2 and 84 t-CO_2. It can be found that even though the cross-sectional area of the structural material in timber strcuture is larger than the steel structure, the overall CO_2 emission are about 82% less than the steel structure.

5 – CONCLUSION

In this study, under the steel and timber structures which the basic design policy was based on allowable stress design, and the sturctural performance in the elastic range and the story drift angle was less than 1/200 rad when C = 0.2. And the differences of the structural performance and CO_2 emission are shown below:

・In terms of building weight, it shows that at the top layer, the timber structure is only 50 % of the steel structure, while at the other layers it is about 74 ~ 85 %. The total weight of the timber structure is about 26 % less than the steel structure.

・ It can be found that the weakest layer of the timber structure when C = 0.2 is focus on the 1st floor, and the steel structure is shown on the top floor. In terms of deformation, the difference is almost the same. When reaching all yield state, the overall balance of the timber structure remains almost the same, while the steel structure is shown the greater difference. The deformation in the case of timber structure, is 5 ~ 6 times when C = 0.2, while the steel structure is 9 ~ 10 times. It can be found that in the all yield state, the timber structure retains a certain degree of rigidity compared to the steel structure.

・ The CO_2 emissions of the whole building, the timber structure is about 82 % lower than steel structure. But in the timber structure, the materials that produce more amount of CO_2 emission are GLT, joints, and roofs and floors, which account for 36%, 21% and 32% of the total,

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respectively. Although the carbon fix of wood is still greater than the emission of production when considering carbon balance, if the CO_2 emission of wood production can be reduced, it can make up for the CO_2 emission of some materials in the overall building that cannot effectively reduce CO_2 emission, which can make the entire building closer to zero carbon building. In addition, compared to the steel used in the joints, the floor slab is the part that is less affected by the structural design than the joint. If the detailed design of the floor slab uses more low- CO_2 emission materials it can more effectively reduce the overall carbon emissions of the large-scale structure.

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