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Japan's First Pure-Timber and Fire-Resistant High-Rise Building "Port Plus"

Yasuki Byakuno†

Structural Engineering Department, Obayashi Corporation, Japan

Abstract Forests have many-sided functions, which are not only absorbing CO_2 but preserving land, recharging water, and producing timber materials. However, in recent years, it has been concerned in Japan that such functions are declining due to the decrease int the usage of forest resources. In this context, the promotion to use more timber is also attracting attention from the perspective of SDGs, as it will help realizing decarbonized society. "Port Plus", the highest ever pure-timber buildings in Japan having 11-stories, was designed and constructed by OBAYASHI CORPORATION in Yokohama-city, Kanagawa-Prefecture. In order to contribute the expansion of timber usage, all the structural members of its superstructure, such as columns, girders, slabs, and walls, are made of timber materials. This paper reports about the structural design and technologies that enabled the high-rise pure-timber building satisfying the requirements on seismic-resistance and fire-resistance.

Keywords: Pure-Timber High-rise, Fire-Resistant, Seismic Isolation

†Corresponding author:
Yasuki, Byakuno
E-mail:
byakuno.yasuki@obayashi.co.jp

1. Introduction

The promotion to use more timber in urban construction is demanded to revitalize the resource circulation. Urban construction with more timber is also attracting attention from the perspective of SDGs, as it will help realizing decarbonized society. In response to this, "Port Plus", the highest ever pure-timber buildings in Japan was designed and constructed by OBAYASHI CORPORATION in Yokohama-city, Kanagawa-Prefecture. All the structural members of its superstructure, such as column, girders, slabs, and walls, are made of timber materials.

This building area is about 400 m^2, the total area is about 3,500 m^2 and the maximum height is about 45 m. It has 11 floors above ground and 1 floor below ground.

The façade facing the street is composed of the curtain wall of glass and the timber frame. The space on the south side serves as a promotional space, training space, large training room and lounge and on the north side of each floor is space for accommodation room.

2. Building Outlines

"Port Plus" OBAYASHI's training facility designed from four viewpoints: promotion, innovation, wellness, and sustainability. The main theme of this project is to create a place where these "Pluses" could be obtained, and to provide an attractive stay and training experience here.

Figure 2 shows a cross-section of the building, divided into three parts. The lower level, Cross Port, is a promotional space for our works. The middle floor, Living Port, is a working place like a living room for guest rooms. The upper floor, One Port, has unique interiors to provide a special experience for the visitors. Various atriums and terraces inspire awareness of other people and the environment.

Figure 3 shows the 4th floor plan, which is the basic floor. The training area with a 10 meters depth is in the south, and the guest rooms with a 2.8 meters width are in the north. We aimed to find the ideal timber structure frame, resulting in a 2.8-meter module. The space is easy to navigate, allowing the training area to be used as a living room for the accommodation area. The two-sided scissors stairs provide an opportunity to nurture awareness of people and the environment by integrating photo art into the space.

3. Structural Plan

Table 1 shows the overview of structural plan. All the structural members of its superstructure is pure-timber, using LVL (Laminated Veneer Lumber) for the columns and the girders, CLT (Cross Laminated Timber) for the slabs and the shear wall and Laminated wood for the beams. The slabs and the bottom of columns on first floor, the substructure and the foundation are RC. Seismic isolation devices are installed in the position of the capital



Figure 1. Photo of Building "Port Plus".

of the columns on the first basement floor.

Figure 4 shows the overview of the frame plan of the superstructure. This superstructure of X direction has 4 frames which are designed with the rigid-frame system of 2.8m span and Y direction has 2 frames which are designed with the rigid-frame system with the CLT shear wall. In the Y direction, in order that the plan which shear walls and columns receive horizontal forces such as earthquake and wind in well-balanced, girders with the rigid-joints are installed in the intermediate height of each floor for the rigid frame system in the south side. The CLT slabs and the girders or the beams are jointed with the structural screw in order that the CLT slabs behave as one against the horizontal forces.

For high-rise timber buildings where seismic forces are borne by timber columns, seismic isolation could make it possible to keep the building use even after the largest earthquake.

It is important that the timber structure should remain elastic without plasticization, and seismic isolation reduces the seismic forces to be borne by timber columns. If Port Plus has no seismic isolation, the building would have needed a lot of bearing walls and braces that it could not be used as a training facility or workplace.

Considering how to make the most of the limited site in the urban area, this building is isolated building with small horizontal displacement at the seismic isolation layer. The clearance in the seismic isolation layer is



Figure 2. A cross-section of "Port Plus".

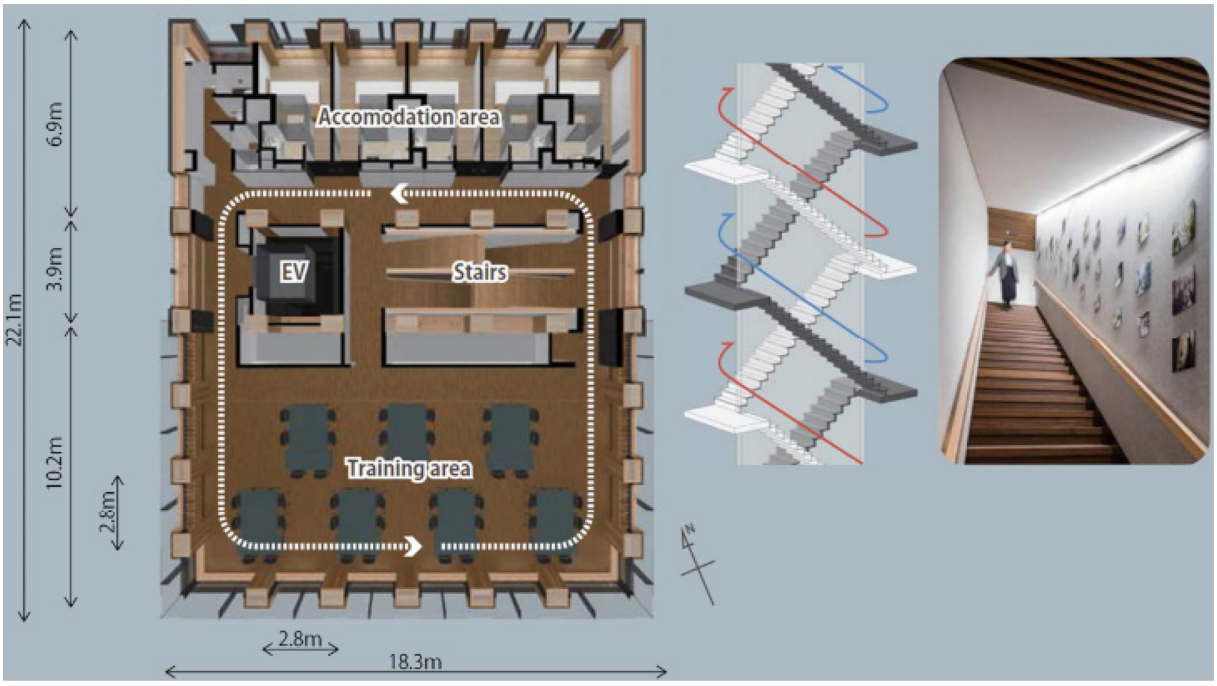


Figure 3. The 4th floor plan of "Port Plus"

450 mm.

Figure 5 shows a layout of the seismic isolation device. For the seismic isolation device, 10 Spherical Sliding Bearing (SSB) are adopted. SSB that is based on the pendulum mechanism is a fitting one for the lightweight buildings such as pure-timber building. It contributes to

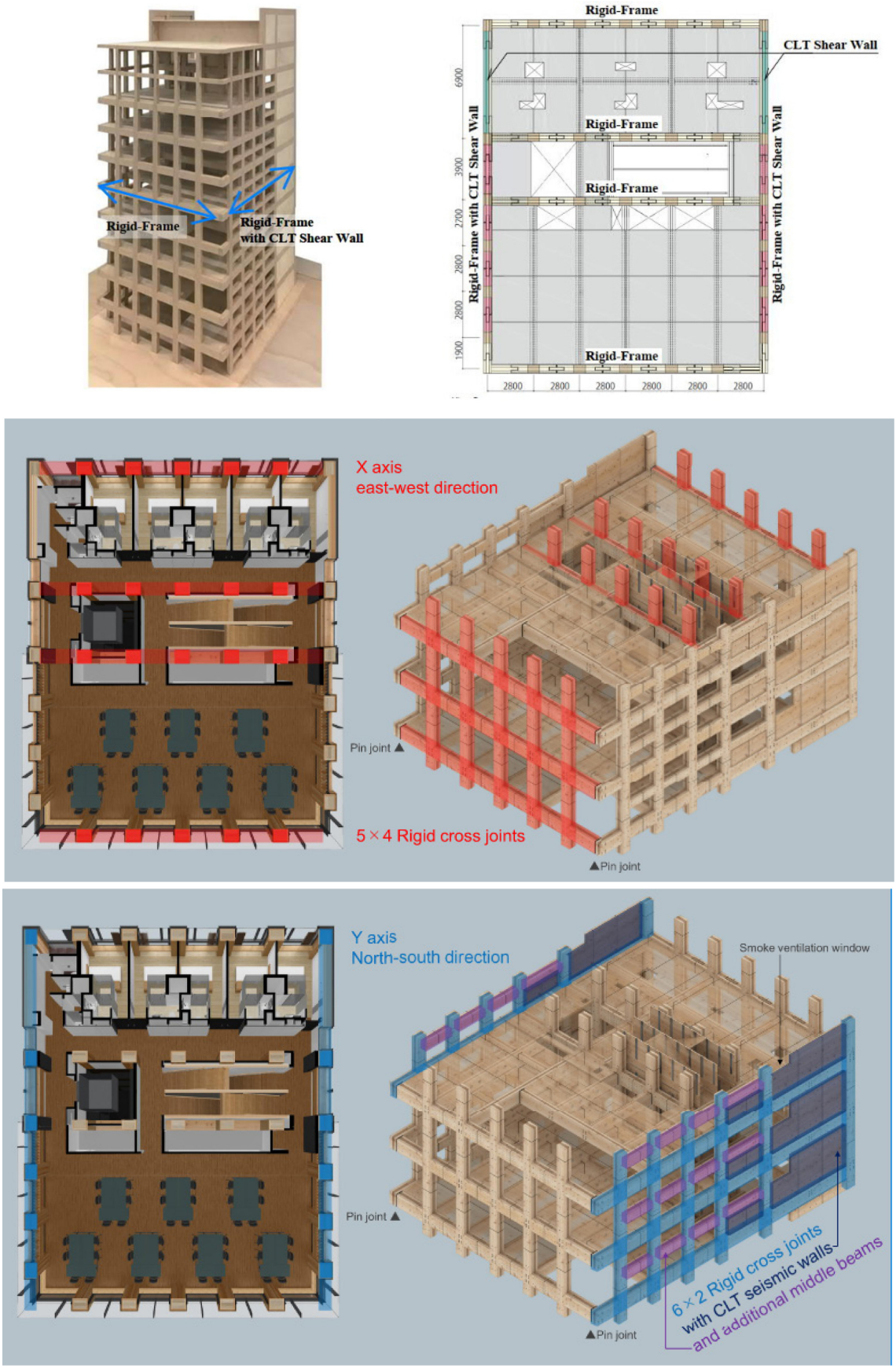


Figure 4. Overview of the frame plan of superstructure.

Table 1. Overview of structural plan

Superstructure	Frame Plan	X	Timber／Rigid-Frame	
		Y	Timber／Rigid-Frame with shear wall	
	Column & Girder		LVL(Laminated Veneer Lumber)	
			Column	B×D=500×700 etc
			Girder	B×D=500×900 etc
	Shear-Wall & Slab		CLT (Cross Laminated Timber)	
			Shear Wall	t=300 etc
			Slab	t=150 etc
	Materials		Laminated Wood	120E (For Beams)
			LVL	60E, 90E, 120E (For Columns and Girders)
			CLT	Mx60 (For Shear-Walls and Slabs)
			Timber-joint-panel	120E (For "Nuki")
Substructure	Frame Plan	X	RC／Rigid-Frame with Shear Wall	
		Y		
	Foundation Girder		B×D=500×1500～1600×1900	
	Foundation Slab		t=1000	

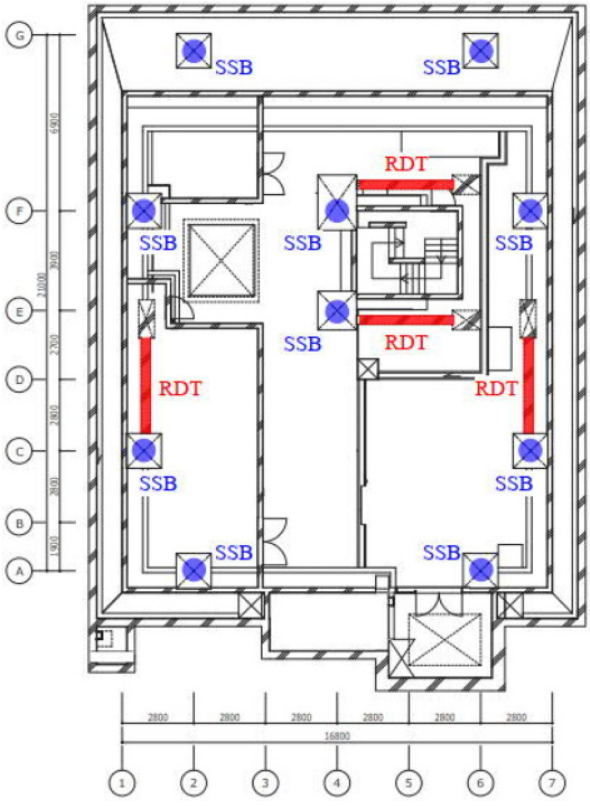


Figure 5. Layout of the seismic isolation device.

the realization of the high-rise pure-timber building. For the vibration control device, 4 Rotary Dumping Tube (RDT) which is the viscous-type damper are adopted.

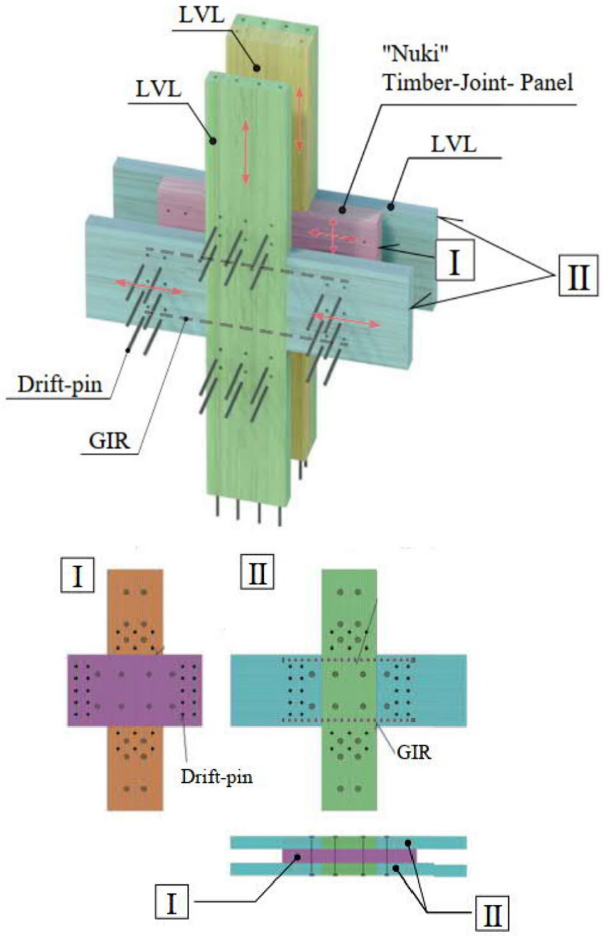


Figure 6. Overview of Rigid-cross-joint-unit

4. Timber Seismic-resistance Technologies

In order to realize the high-rise pure-timber building, the girder-to-column joint required high stiffness and high strength. In this context, Rigid-cross-joint-unit without any metal pieces was developed for this building.

Figure 6 shows the overview of Rigid-cross-joint-unit. This unit is consist of three layers as (I) :the girder through layer and (II) :the column through layer. This structural design is inspired by traditional Japanese construction method called "Nuki". Timber-joint-panel was newly developed for this unit is adopted for "Nuki" in (I). It is made by laminating and bonding the veneers alternately in the fiber direction. For transferring bending moment, the column and the girder in (II) are jointed by the rebar of GIR joint method. This unit that are integrated (I) and (II) is accurately fabricated and assembled in a factory before being brought to the site. As a result, ensuring stable quality of this unit and improving on-site workability through prefabrication.

Figure 7 shows view of full-scale performance test of Rigid-cross-joint-unit. High stiffness, high strength and ductility of Rigid-cross-joint-unit were investigated by full-scale performance test. It was confirmed that the elastic status is maintained against repeated deformation test up to 1/100 of inter-story drift angle, and after the rebar of GIR joint method yields, the timber-joint-panel is possible to prevent the decrease of strength of this unit due to following the deformation even after pullout of the rebar or split of timber. It was confirmed that adopting Timber-joint-panel instead of the general LVL for "Nuki", it has better ductility performance against large story drift.

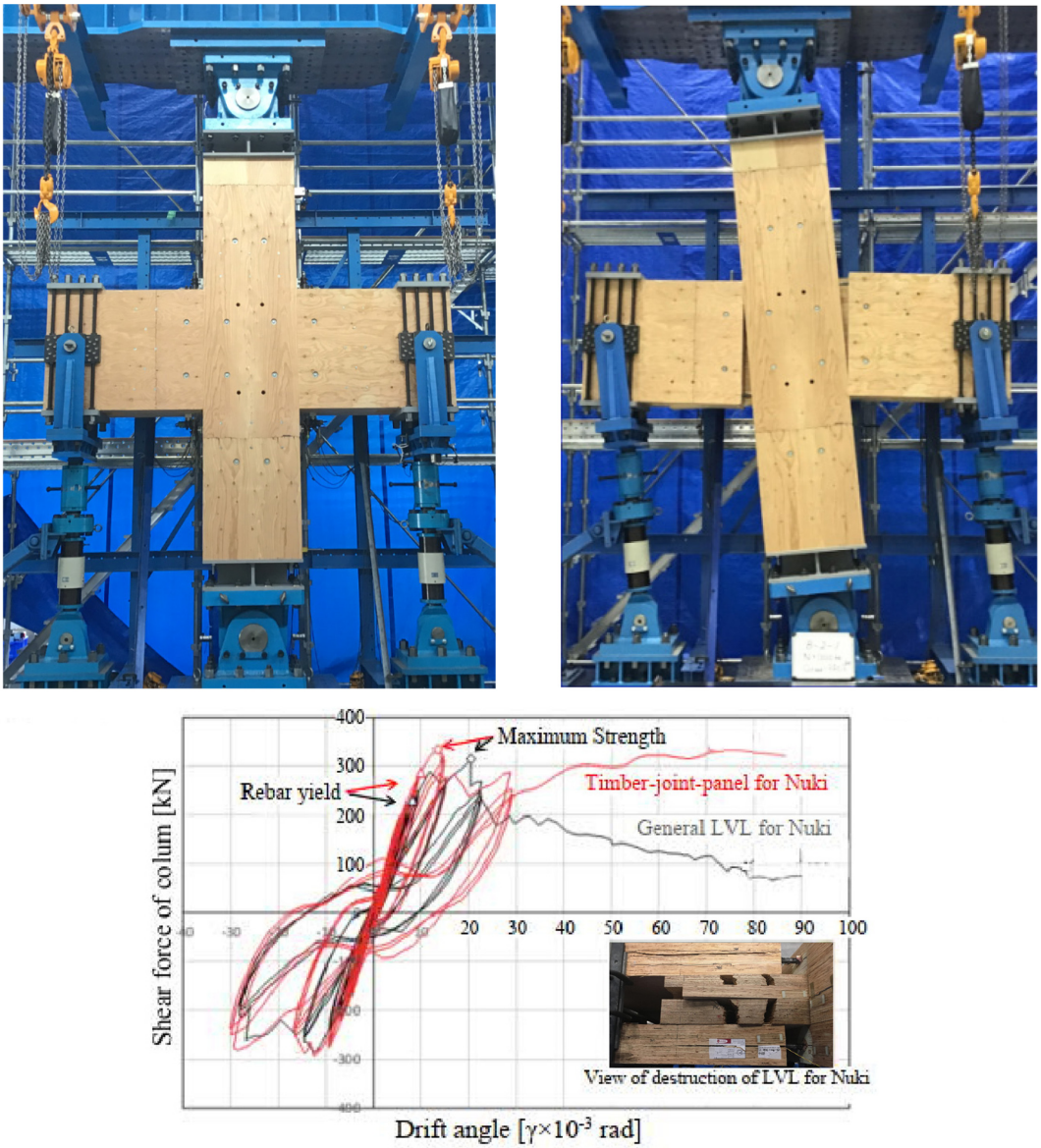


Figure 7. View of full-scale performance test of Rigid-cross-joint-unit.

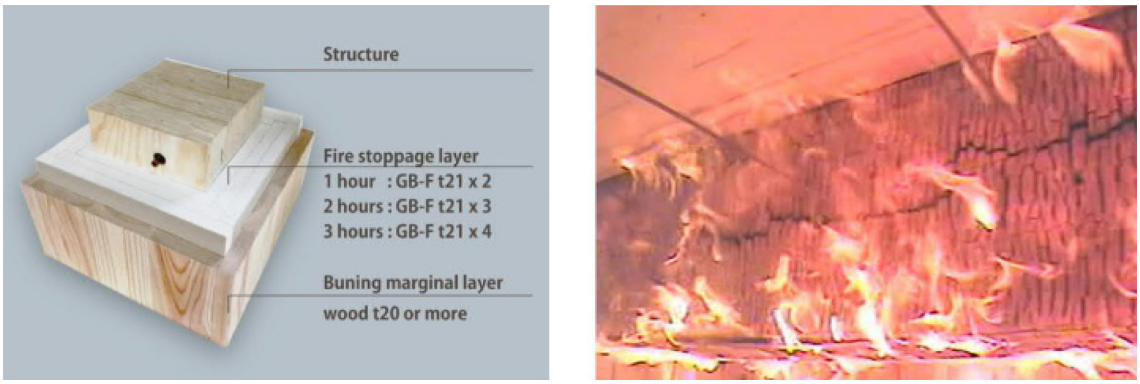


Figure 8. Overview and view of fire resistance test of Omega Wood (fire-resistant).

Table 2. Seismic design criteria

		Level 1※1	Level 2
Superstructure	Stress	Elastic	Elastic
	Drift Angle	1/200	1/120
	Drift Disp.	20.0mm	33.3mm
Seismic Isolation	Disp.	400mm	400mm
	Pressure (Compression)	Short-Term Allowable	Short-Term Allowable
	Pressure (Tensile)	No Uplift	No Uplift Against Horizontal Motion※2

※1 Level 1 : rarely occurring seismic motion
※2 Allowing uplift against combination of horizontal and vertical motion.

5. Timber Fire Resistance Technology

In this Building, Fire-resistance for 2 hours is required by the Building Standard Law in Japan. Therefore, the columns and girders are made of Omega Wood (fire-resistant) that is timber fire-resistance technology of OBAYASHI CORPORATION.

Figure 8 shows overview and view of fire resistance test of Omega Wood (fire-resistant). It consists of three layers that are timber for the structural member, gypsum board for the flame-stop layer and timber for the burner layer which carbonizes the timber and reduces the speed at which it burns. It is confirmed that it has fire-resistance performance up to 3 hours by fire resistance test.

6. Structural Analysis for Seismic Force

Figure 9 shows the overview of the seismic response analysis model. To evaluate the behavior of this building during earthquakes, seismic response analysis with a lamped mass model is implemented. Analytical model is equivalent shear spring model with 11 nodes at which the

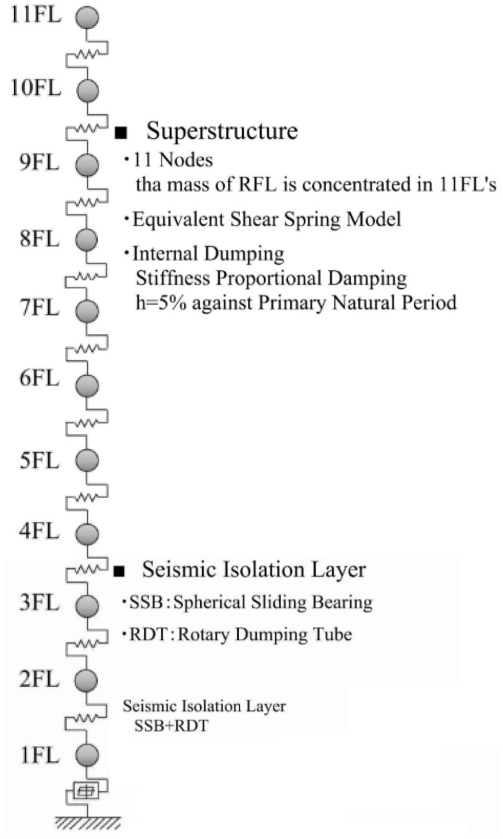


Figure 9. Overview of the seismic response analysis model.

mass of each story from the 1 level to the 11 level is concentrated. The mass of RF is concentrated in 11FL. Spherical Sliding Bearings (SSB) is modeled as bilinear with displacement-dependent and Rotary Dumping Tube (RDT) is modeled as a Maxwell model in which a viscous damping with velocity-dependent and the stiffness.

Table. 2 shows the seismic design criteria of the building. Figure 10 shows velocity response spectra of the input seismic motions. A total of 10 waves as "extremely rarely occurring seismic motion" (Level 2 seismic motion) are set for the verification.

Figure 11 shows the response analysis result. (Maximum

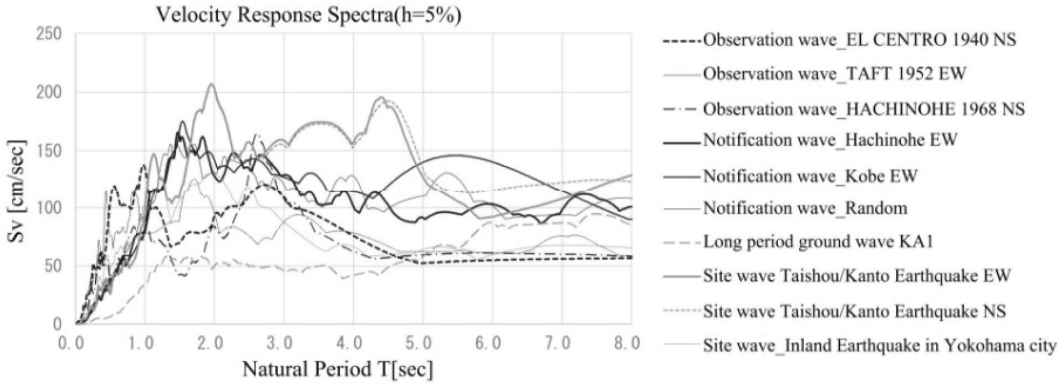


Figure 10. Velocity response spectra of the input seismic motions.

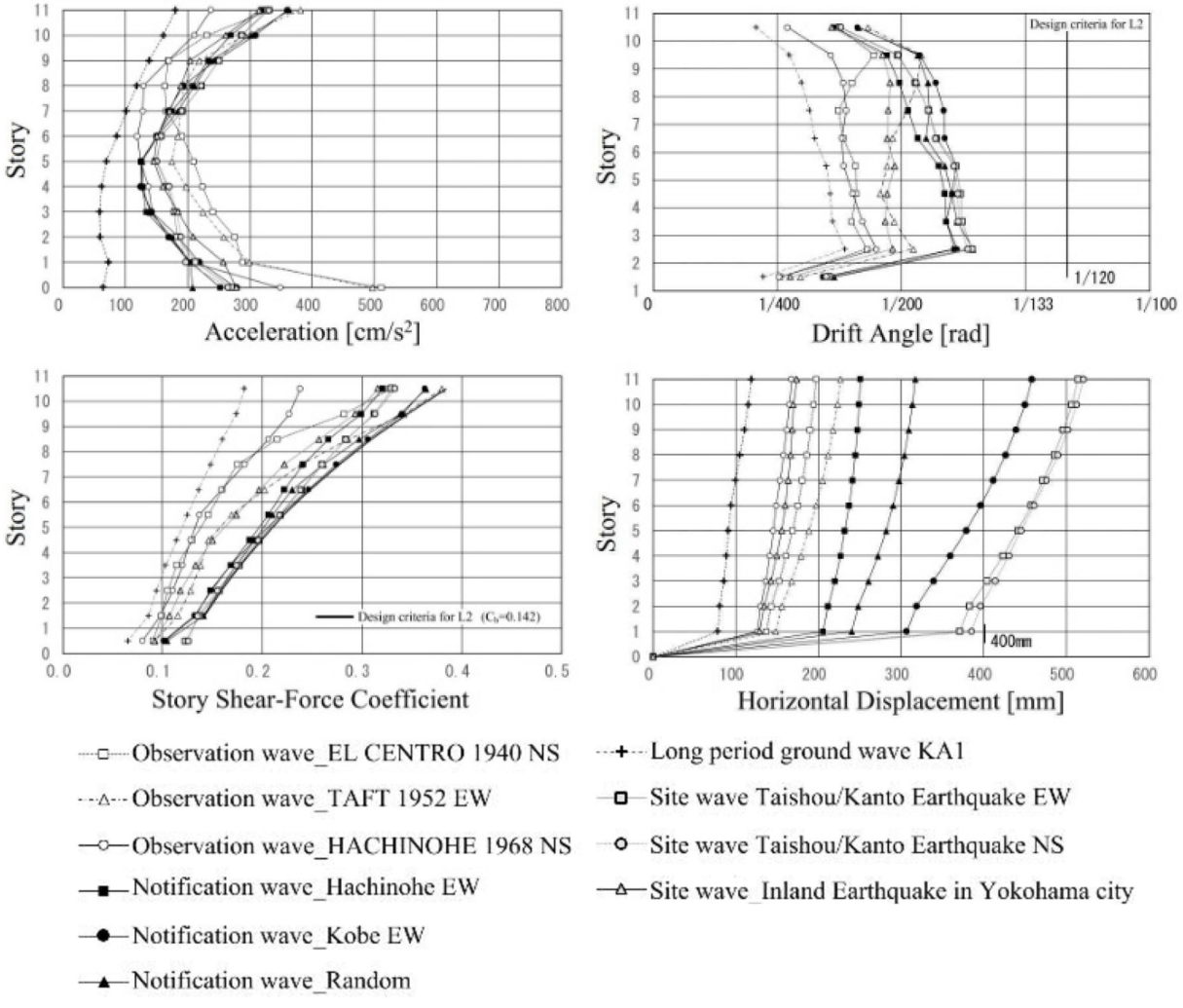


Figure 11. Response analysis result.

acceleration, story shear-force coefficient, inter-layer deformation angle and horizontal displacement.)

It can be confirmed that Maximum horizontal displacement of the seismic isolation layer is 385mm and maximum inter-layer deformation angle is 1/155, thus these satisfy the seismic design criteria.

7. Conclusions

This report presents the highest ever pure-timber buildings in Japan as which was worked on to promote the use more timber in urban construction that will help realizing decarbonized society. The summary that enabled

the high-rise pure-timber building is follows,

1. Realized the pure-timber rigid-frame system which has high stiffness and high strength, due to the development and adoption of rigid cross joint unit.
2. Adoption of Omega Wood (fire-resistant) that is timber fire-resistance technology satisfy the fire-resistance which is required by the Building Standard Law in Japan.
3. This building is seismic isolated building. By seismic response analysis, this building satisfies the seismic design criteria against "extremely rarely occurring seismic motion".

Acknowledgement

The challenge of constructing the highest ever pure-timber buildings in Japan was completed with the guidance and advice of many people. Author would like to appreciate everyone who cooperated.