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DEVELOPMENT OF TEMPORARY STRUCTURE USING CLT PANEL: INVENTION OF CONSTRUCTION AND VERIFICATION BY CONSTRUCTION EXPERIMENT

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ABSTRACT: Temporary buildings have the advantage of being able to meet sudden demand. In recent years, the demand has been affected not only in the event of a disaster but also due to COVID-19 infection. This paper shows a temporary structure that can be used repeatedly for the purpose of constructing a temporary building using Cross Laminated Timber (CLT), and confirmed its practicality through construction experiments.

KEYWORDS: CLT, Temporary Construction, Experimental Study

1 INTRODUCTION

Buildings are divided into temporary buildings and permanent buildings according to the period of use, and in particular, temporary buildings have the advantage of being able to meet sudden demand. In recent years, the demand has been affected not only in the event of a disaster but also due to COVID-19 infection, and the Japanese government has approved the use on the street for the purpose of taking out and installing terrace seats, so temporary buildings are also used in restaurants. Under these circumstances, wood is lightweight and easy to process, and deterioration does not pose a major problem on the premise of dismantling and repairing, so it has the potential as a material for temporary buildings. From the perspective of creating demand for timber in Japan, it is meaningful to aim for the general spread of wood-based materials in the field of temporary construction, where a large amount of demand can be expected from local governments and private companies.

Against this background, we designed a temporary structure that can be used repeatedly for the purpose of constructing a temporary building using Cross Laminated Timber (CLT), and confirmed its practicality through construction experiments. The developed temporary structure is composed of CLT panels with four corners machined and steel joints, which facilitates on-site assembly.

2 DESIGN OF TEMPORARY STRUCTURE USING CLT PANELS

2.1 OUTLINE OF STRUCTURAL SYSTEMS

The temporary structure developed in this paper is composed of four CLT (3-layer, 3-ply, Japanese cider) panels with the same cutting at the four corners and a steel joint with a truss mechanism. Fig. 1 shows the elevation of the temporary structural system on each side, and Fig.2 shows an image of using as restaurant on the street.

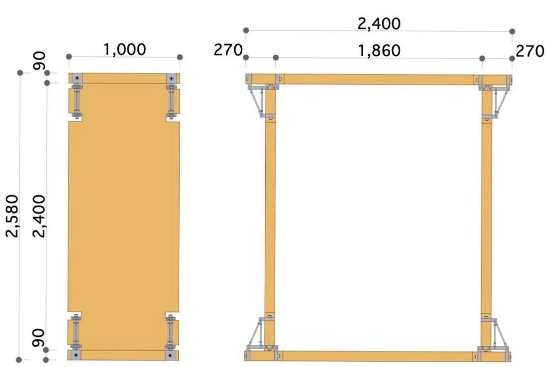

***Figure 1**: Elevation of temporary structural system*

***Figure 2**: Image of terrace seats with the developed unit as the core*

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In Fig. 1, The truss mechanism resists the horizontal force in the frontage direction, and the wall itself resists in the direction of the wall orthogonal to it.

Temporary buildings, which are supposed to be demolished in a certain period of time, consume resources faster, so consideration must be given to material reuse and material recycling, and this project also emphasized this. In particular, the dimensions and fabrication of the four CLT plates were standardized for convenience in repeated assembly and disassembly as a temporary unit, and the shapes of the eight steel joints were also standardized for easily removal.

2.2 COMPONENT DESIGN

All CLT panels are processed in the same way to ensure reusability. At the prototype stage, as shown in Fig. 3, we considered a plan to provide tenons with notches at the four corners of the CLT, and a plan to replace the tenons with steel materials. In consideration of restraint, we adopted a plan to make a through hole at the position where the tenon was supposed and pass a bolt (diameter = 16 mm) through it. As a result, the rattling caused by the error of wood processing can be corrected by tightening the nut. The outline of the processing of the entire CLT panel is as shown in Fig. 4.

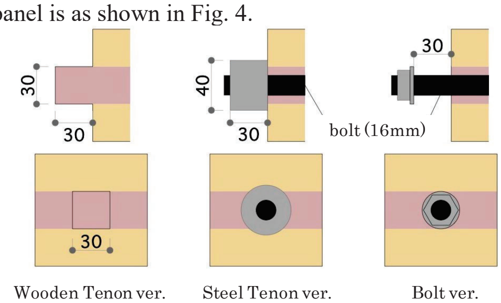

Figure 3*: Wood processing and trial production of joints*

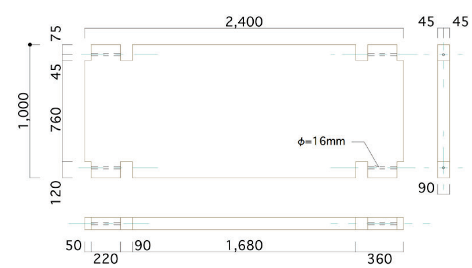

Figure 4*: Outline of CLT panel processing*

Fig. 5 shows an outline of the steel joint and the parts of each part constituting the joint. All parts are made of steel (ss400) and are integrated into one joint with four pins, which can be easily assembled and disassembled by attaching and detaching them. In order to reduce the cost of electric discharge machining, the member B was divided into three parts and fixed with M8 countersunk screws. For member C, since it is a truss mechanism that applies only axial force to the member, it is necessary to use a pin joint, and rod end bearings are used at both ends of the M10 bolt.

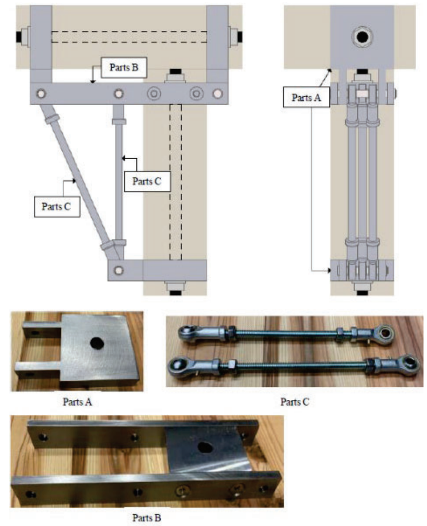

Figure 5*: Steel joint configurations and parts*

In the design of this joint, the dimensional error of each member was also examined in consideration of on-site work. Compared to wood processing, steel processing causes almost no dimensional error, so for the hinge part that is completed only with steel, the hole diameter and hinge pin diameter are both 10 mm, and a hinge pin with a negative tolerance was selected. The through hole of the bolt, which is expected to be affected by the processing error of the wood, was 0.5 mm larger and the wood was processed. In addition, in order to absorb dimensional errors in the CLT cutting process, the bolts of part C are designed to have a margin of 5 mm between the rod end bearings, and the length of the entire member C can be adjusted by fastening the bolts during construction.

3 INVESTIGATION OF STRUCTURAL PERFORMANCE

3.1 OVERVIEW OF INVESTIGATION

The temporary units proposed in this research do not examine the basic conditions that the building must satisfy, such as ensuring fire resistance and fixing methods to the ground. Safety based on allowable stress calculations against long-term loads and rarely occurring loads and external forces, with the goal of ensuring performance equivalent to temporary structures according to the Japanese Building Standards Law, considering the assumed usage. We decided to verify the Tables 1 & 2 list the mechanical properties of the steel and wood used in the study.

Table 1: *Mechanical property of steel*

Steel type	Reference strength [MPa]	Long-term allowable stress		Short-term allowable stress
		σ	τ	
SS400	$F = 235$	$F/1.5$	$F/1.5\sqrt{3}$	F

Table 2: *Mechanical property of Wood*

Species	Design strength [MPa]			
	Comp-ression	Tensile	Bending	Shear
Japanese cidar	17.7	13.5	22.2	1.8

Structural performance was confirmed by the following procedure. Since this temporary structure is a composite structure of wood and steel, we first verified the safety of the steel joints against the assumed external force, and then modelling the joints on the upper part of the unit as a static rigid frame assuming rigid joints. Considered the safety of wood. According to the design guidelines for temporary structures, when the scale is small, the external force assumed in the design against snow load and wind load is often reduced, but with reuse in mind, each member should have a certain amount of surplus performance. Therefore, we decided not to conduct this study.

3.2 EVALUATION OF STRUCTURAL PERFORMANCE

Fig. 5 shows the mechanical model of the steel joint. In the actual design, bolt fastening force is generated against the steel plate sandwiched between the stud bolts (φ = 16 mm) passed through the CLT, but this model ignores that effect as an evaluation on the safe side. Then, consider only the effect of preventing the bolt from coming off.

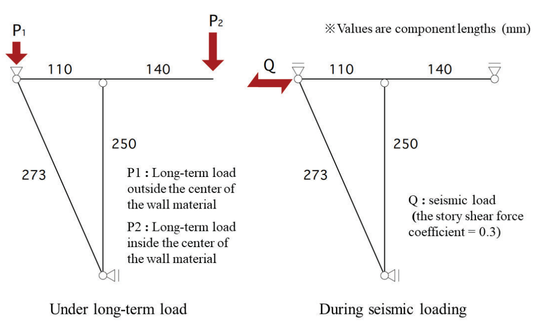

Figure 6: *Mechanical model of steel joints*

Regarding the long-term load P shown in Fig. 6, the dead load is generally calculated as a uniformly distributed load. The conditions were set such that the portions inside the wall material act on both ends of the joint as concentrated loads P_1 and P_2, respectively. Assuming a cedar density of 0.38 and a gravitational acceleration of 9.8 [m/s^2]

$$P_1 = 0.38 \times 10^{-6} \times 500 \times 225 \times 90 \times 9.8 = 37.8 \, [\mathrm{N}]$$

$$P_2 = 0.38 \times 10^{-6} \times 500 \times 975 \times 90 \times 9.8 = 163.4 \, [\mathrm{N}].$$

Similarly, regarding the seismic load Q in Fig. 5, the dead weight of the ceiling material, two wall materials, and steel joints (approximately 9.0 kgf) is assumed to be the fixed load used to calculate the story shear force, and the story shear force coefficient was set to 0.3 as a safe side evaluation. From the above conditions

$$Q = 0.3 \times W / 2 = 415 \, [\mathrm{N}].$$

The reason for dividing by two in the above formula is that when the unit is viewed from the frontage direction, it is assumed that the two steel joints at the front and back will simultaneously resist the seismic load.

Table 3 shows the maximum stress in each member of the steel joint as a result of the investigation based on the above. From the results shown in Table 3, all values are well within the allowable stress shown in Table 1, confirming its safety.

Table 3: *Maximum stress of steel joints members*

Load	Member	σ_{max} (axial) [MPa]	σ_{max} (bending) [MPa]	τ_{max} [MPa]
Only dead load	Diagonal	5.2	–	–
	Vertical	4.8	–	–
	Horizontal	–	0.52	7.7
Seis mic force	Diagonal	13.2	–	–
	Vertical	12	–	–
	Horizontal	–	1.4	19

Following the investigation of the steel joints, Fig. 7 shows the mechanical model used for investigation of CLT panel.

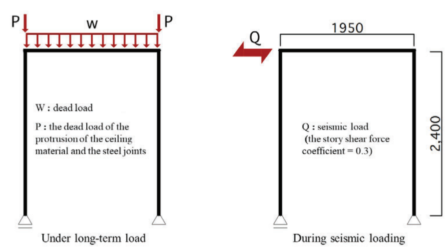

Figure 7: *Mechanical model for investigating CLT panel*

Regarding the long-term load shown in Fig. 7, the uniformly distributed load w in the figure represents the dead load of the ceiling material, and the vertical load P represents the dead load of the protrusion of the ceiling material and the steel joints. Each value is

$$w = \frac{0.38 \times 10^{-6} \times 1000 \times 1950 \times 90 \times 9.8}{1950} = 0.34 \, [\mathrm{N/mm}]$$

$$P = \left(0.38 \times 10^{-6} \times 1000 \times 225 \times 90 + 9.0 \times 2\right) \times 9.8 = 252 \, [\mathrm{N}]$$

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The seismic load Q shown in Fig. 7 is the same as in the investigation of steel joints, but since it is a model of the entire unit here, it is set to 830 N before dividing by two. Table 4 summarizes the maximum stress generated in the CLT based on the calculation results of the stress in each part based on the above discussion. As with steel joints, all values in Table 4 are within the allowable stress shown in Table 2, confirming its safety.

Table 4: *Maximum stress of CLT panel*

Load	Member	σ_{max} (axial) [MPa]	σ_{max} (bending) [MPa]	τ_{max} [MPa]
Only dead load	Wall	6.5×10^{-3}	–	–
	Ceiling	–	5.6×10^{-3}	0.12
Seis mic force	Wall	1.2×10^{-2}	1.4×10^{-2}	1.5
	Ceiling	9.2×10^{-3}	1.7×10^{-2}	1.5

As the final part of the member study, the results of other parts such as bearings and pins, as well as the buckling of bolts, are summarized below. The bearing used this time has a radial static load rating of 13.2 kN. It can be seen that there is sufficient margin even when compared with the axial force of 1445 N, which is the largest stress shown in Table 3, 18.4 (N/mm2), multiplied by the cross-sectional area of 78.5 mm2 of member C (Fig. 5).

According to the results in Table 3, the largest force acting on the pin is the axial force acting on the diagonal member, which is 13.2 [MPa] x 78.5 [mm^2] = 1036 N. These are divided into two components, vertical and horizontal. We evaluated the stress generated in the hinge pin using two simple beam models. Fig. 8 shows the dynamic model used in the study of the pin, and Table 5 shows the calculation results using it.

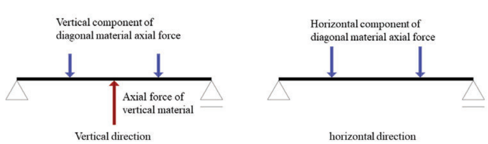

Figure 8*: Mechanical model for evaluating hinge pin stress*

Table 5: *Maximum stress of hinge pin*

Direction	σ_{max} (bending) [MPa]	τ_{max} [MPa]
Horizontal	41.2	4.29
Vertical	78.5	9.71

The hinge pin adopted in this research is carbon steel S35C for machine structural use. Although this is stronger than SS400 material, the maximum stress of the hinge pin is within the allowable stress of SS400 shown in Table 1, so the safety can be confirmed.

The double-ended bearing material (member C) does not become plastic within the design load range, but confirms that buckling does not occur within the elastic range. The buckling stress σ_{cr} is generally obtained from the following equation.

$$\sigma_{cr} = \frac{\pi^2 E}{\lambda^2} \quad \text{where} \quad \lambda = \frac{L_k}{i} \qquad (1\text{-}1, 2)$$

In the above equations, E : Young's modulus, λ : slenderness ratio, L_k : buckling length, i : cross-sectional secondary radius. The buckling length L_k is the same as the length of the member because the double-end bearing material can be regarded as a double-end pin. As the Young's modulus of SS400 is 205 [GPa] and member cross section is circular with a diameter of 10 mm,

$$\text{Diagonal : } \sigma_{cr} = \frac{\pi^2 \times 2.05\times10^5}{(273/2.5)^2} = 169\ [\text{MPa}]$$

$$\text{Vertical : } \sigma_{cr} = \frac{\pi^2 \times 2.05\times10^5}{(250/2.5)^2} = 202\ [\text{MPa}]$$

is calculated. Comparing this with the stress shown in Table 3, it is considered that buckling does not occur within the range of the design load this time.

4 VERIFICATION OF EFFECTIVNESS BY CONSTRUCTION EXPERIMENT

4.1 OUTLINE OF CONSTRUCTION TEST

A construction experiment was conducted to verify the effectiveness of the temporary unit. At the design stage, we were thinking of a procedure to assemble the unit with the unit laid on its side, and then pull the roof panel to raise it. However, in this experiment, from the viewpoint of ensuring construction space and safety, we adopted the method of attaching the wall panel first and joining it with the roof panel with a crane as shown in Fig. 9.

In this construction experiment, it took about 2 hours to rework the wood part due to the small error of the hinge part. The actual assembly time was about 30 minutes, and After the completion of the construction experiment, no distortion or twisting was observed in the entire unit within the range of visual observation. It was confirmed that it was very stable under the load of its own weight, which is enough to lift the whole with a crane, and no large gaps were found in the joints.

4.2 EXAMINATION OF PROBLEMS SEEN DURING CONSTRUCATION

(a) Hinge part

First of all, the poor workability of the hinge part was a problem. At the design stage, there was no dimensional leeway in the hinge part, but with only the negative tolerance of the hinge pin, the workability was poor, and there were some cases where the pin did not pass through.

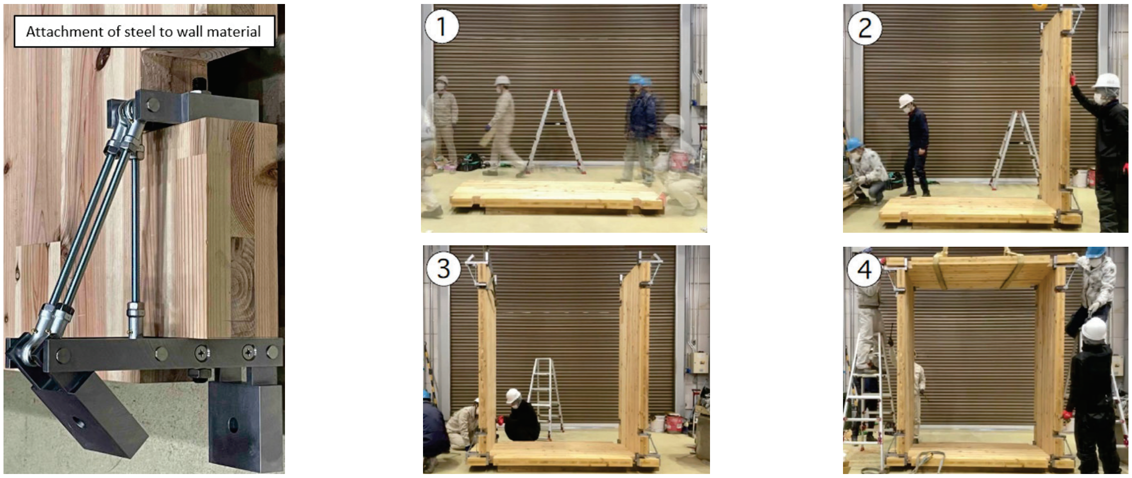

***Figure 9**: Procedure of construction experiment*

We think that the diameter of the through holes at both ends of the member B should have been designed to be 0.5 to 1 mm larger.

(b) Weight

The second point is the problem of weight. In this construction experiment, a overhead crane was used, so there were no particular weight problems, but considering the actual operation as a small-scale temporary unit, it is necessary to consider the possibility of assembling and dismantling only by human power. Especially, the weight of CLT is a problem, and at present it is about 85 [kgf] per piece even after processing, which is likely to adversely affect workability. In order to be able to flexibly respond to changes in shape and processing during the design process, including the steel joints, there was an aspect of giving a margin to the cross section of each member at the initial stage of selecting members. Considering the surplus performance, it may be necessary to reconsider the thickness of the laminated board and the cross-sectional area of each steel material to optimize the weight.

(c) Machining accuracy

The CLT prepared in this study was not pre-cut at the factory, but was hand-processed at the site. A particular problem was the machining error in machining the 16mm through-hole for the stud bolt to pass through, which exceeded the expected error in the design stage. The cause was thought to be the storage method of the CLT before processing, and about 2 mm of warpage occurred in the long axis direction during processing. In manual drilling, it is difficult to keep vertical and horizontal, but warping made this process even more difficult. As a result, in this construction experiment, as shown in Fig. 10, the hole drilled during processing was expanded to a maximum of 21 mm and assembled. If the steel joints are assembled first, as in this case, the error absorption performance of the steel cannot be fully demonstrated, so it can be said that it is necessary to improve it to absorb the deformation of the wood after processing, assuming reuse.

***Figure 10:** Through hole in CLT before and after modification*

(d) Truss members

When I checked the condition of each part after the unit was assembled, it was found that among the members (member C) with bearings attached to both ends in the steel joint, six at the bottom of the unit were clearly in a state where no axial force was generated. The reason is that the initial deformation of the wall material during assembly is within the error absorption range assumed at the design stage, and no force is generated in the member in the first place, or the stud bolt passed through the CLT is tightened with nuts from both sides. Therefore, it is conceivable that the force is concentrated on the bolt and the horizontal member (member B). Since the load is only due to its own weight, it is a matter of speculation. It is considered desirable to have a design that can adjust the axial force before and after assembly by applying two chamfers between materials for right-hand and left-hand threads.

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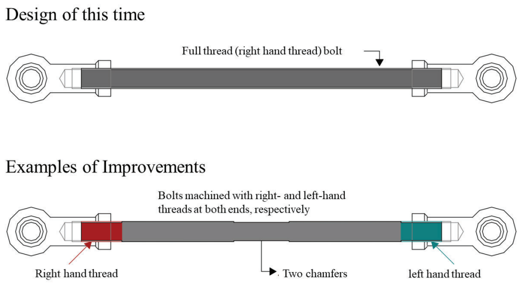

Figure 11: *Example of improved ended bearing members*

5 CONCLUSIONS

In this study, we designed a temporary unit using a CLT panel and confirmed its effectiveness from construction experiments. The findings obtained are as follows.

1) Even with CLT panels, it is more difficult to secure machining accuracy than steel materials, and appropriate error management is required.
2) It was a rather heavy unit to assemble manually after undergoing construction experiments. It is necessary to consider whether to assemble with heavy machinery and to optimize the dimensions and weight in consideration of the balance with the structural performance.

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APPENDIX

(A) Processing CLT Panel

Figure A shows how the notch was processed manually by a skilled carpenter. The notch portion was processed by first making cuts from both sides of the laminated board using a circular saw, and then using a multi-tool to cut the portion that could not be completely cut due to the circular saw.

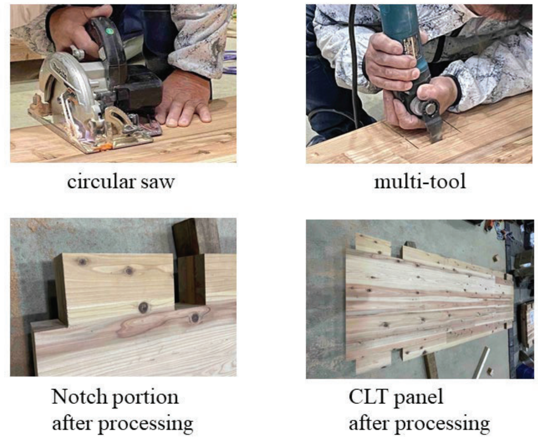

Figure A: *Photos of the notch being processed*

(B) Records of construction experiments

On January 18, 2022, we conducted a construction experiment of a temporary unit using CLT panels, which is the subject of this research. The experiment was conducted in a large-scale experimental facility at a university. The experiment is roughly divided into the steps shown in Fig. B, and the records of each step are summarized as supplements.

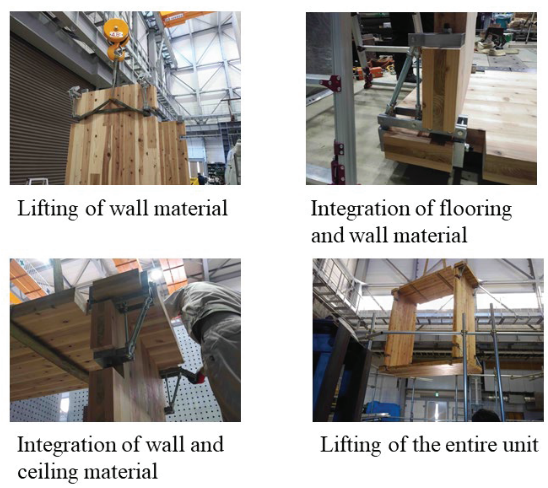

Figure B: *Experiment process and photos*

(1) Lifting wall panels
The wall panels were lifted by an overhead crane by attaching a belt to the notch of the CLT panel. The ceiling material was lifted by passing two belts through the middle of the material. The overhead crane used here has a capacity of 4.8 tonf.

(2) Integration of floor and wall materials
Regarding the unification of the flooring and wall panels, in this construction flow, the wall panels were constructed while they were being lifted by an overhead crane. We were able to put it in place. However, since it

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is difficult to secure means to replace cranes at actual sites, this point needs to be examined in the future.

(3) Integration of ceiling and wall materials

Regarding the integration of the wall material and the ceiling panels, in the previous procedure, there were two steel joints. As a result, it was confirmed that the error was concentrated in the final joint and the stud bolt could not pass through. As mentioned above contents, the expansion of the through hole of the CLT panel was made the largest in this part, and it is necessary to review the assembly error.

(4) Movement of the whole unit

After completing the construction experiment, the entire unit was moved by an overhead crane. In the study of structural performance shown in this paper, such a situation is not assumed, but for example, when a temporary unit is assembled at a factory and then transported to the place of use, there is no situation in which the entire unit is lifted and moved. Easy to imagine. This time, as shown earlier, there was a considerable amount of leeway in the stress generated in the members, so there was no deformation of the unit within the scope of visual confirmation even after the move, but in the future, we will be able to operate under such special conditions. It is considered necessary to conduct a safety evaluation as well.

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