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AN EXPERIMENTAL STUDY ON DIFFERENT SHEAR RESISTANCE MECHANISMS OF JAPANESE CLT CONCRETE COMPOSITE SLABS

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ABSTRACT: In other countries, composite beam and floor design methods have been established using the Timber Concrete Composite (TCC) system. While the use of TCC is gradually being promoted in Japan, research results are few, and much of the content remains experimental study. The evaluation of shear keys and the establishment of design methods for TCC systems are still needed. Therefore, shear key element tests and full-scale bending experiments were conducted on TCC slabs made of Japanese CLT using screws and notches as shear keys. It was confirmed that the stiffness and bearing capacity could be roughly estimated at the notched joints, and the TCC slab's bending performance could be accurately evaluated by γ-Method in full-scale experiments.

KEYWORDS: Timber Concrete Composite, CLT, Shear Key, Notched connections, Screw connections

1 – INTRODUCTION

In Japan, the use of wood in building structures has been promoted in recent years, and various studies have been conducted on the use of wood in high-rise buildings and medium- to large-scale structures. Large-span floor construction technology is one of the most important factors in the diffusion of wood structures in medium- and large-sized buildings. The authors focused on the Timber Concrete Composite (TCC) system, which combines timber and RC slabs, as a rational method of constructing large spans. TCC is a system in which a beam or slab on the underside is made of timber, and a reinforced concrete (RC) slab is cast on the top surface to unite the two with shear keys. This is a rational arrangement where the RC slab bears the compressive force and the timber bears the tensile force against the bending stress in the floor. In addition, when the underside is a slab, it is possible to shorten the construction period by using both the structural members, the formwork for RC casting and finishing. The floor vibration problem and sound insulation performance, which are often issues in wooden structures, are also expected to be improved.

The design method for composite beam and slab systems is described in Eurocode5 Appendix B [1] and Eurocode5 Composite [2]. It provides calculation methods for the bending performance of multiple members joined by shear keys (γ-method) and formulas for evaluating the stiffness and bearing capacity of TCC system shear keys. This TCC system is widely used not only in Europe but also in other countries.

Beams and slabs using the TCC system have been studied in Japan in recent years [3][4]. In paper [3], the applicability of the γ method using lag screws as shear keys is verified. In paper [4], the applicability of the theoretical model for wooden assembly beams was verified for composite beams using lag screws and round steel as shear keys. It was shown that the theoretical model of wood-assembled beams can be estimated accurately with experiments and FEM analysis.

On the other hand, the number of experiments and research parameters is limited, and further research and experiments are needed to establish a design method in Japan. Aiso, there are few studies on the stiffness and bearing capacity of shear keys, and a theoretical design method for shear key performance must be established to make the design of TCC systems easier in practice design.

Consequently, this study aims to establish a design method for TCC slabs with Japanese CLT that uses screws and notches for shear keys. Elemental shear tests were conducted between RC and CLT with screws and notches as shear keys to validate the stiffness/strength estimation equations. Therefore, full-scale bending tests of TCC slabs were conducted to compare calculated and experimental slab bending performance estimated by the γ-Method.

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2 – SHEAR KEY EXPERIMENT

2.1 MATERIALS AND PARAMETERS

Table 1 shows the specimen list, Figure 1~Figure 5 shows the specimen dimensions, shear key geometry, and name explanatory notes, and Figure 6 shows the test specimen applying force. The test specimens consist of 210 mm thick x 240 mm wide CLT (5-layer-7-ply, Japanese ceder, S60 graded by JAS, thickness of lamina is 30mm, side gluing is not applicate) with the strong axis and force direction aligned, and concrete was placed as the center or side member. The specimen parameters were shape of shear key, influence of friction, and existence of lag screws. The shear key shape has two specifications: a notch type and a screw type. The notch types are U shape type (Type-U, notch depth is 35mm) and L shape type (Type-L, notch depth is 35mm, notch angle is 60 degrees), and for the U type, the CLT and RC notch lengths are also included in the parameters. For the Type-U, a specimen with a lag screw (diameter *d*=16, length *l* is 161mm) inside the notch is also prepared to confirm the effect of the lag screw. The lag screw was placed at the center position of the notch and the length of the wood embedding was 65 mm. Screws shall be made in two types, Full Thread and Half Thread, with two different screw lengths (230 mm or 170 mm) for Full Thread.

For RC, the strength and young's modulus were calculated from the compressive strength test specified by JIS. For CLT, the experimental values for bending young's modulus were obtained from a three-point bending test under centralized loading.

2.2 TEST METHODS

Two types of specimens were tested: specimen A with RC in the center material and specimen B with CLT in the center. The left and right CLTs or RCs were restrained horizontally with Steel jigs, and the specimen were vertically loaded at the top of RC.

Most of the specimens were loaded monotonically, but the screw-type specimens for which friction effects were expected (specimens No. 8, 10, and 12), were subjected to repeated loading.. The control method is load control for screw shear capacity with 3-cyclic loading and 1 monotonically loading after the cycle. Displacement gauges were used to measure the relative displacement between the RC and CLT at two points before and after the specimens.

The load was terminated when the displacement gauge reached 30 mm or when the load dropped to 80% of the maximum load after reaching the maximum load.

Table 1: *List and Results of Material Experiments of Specimen*

No.	Name	shear key	specimen type	Notch shape/ Screw shape	Notch：RC notch length/CLT notch length Screw：length/CLT embeded length (mm)	Teflon (friction)	CLT young's modules (N/mm^2)	concrete young's modules (N/mm^2)	concrete compressive strength (N/mm^2)	number carried out
1	NA-UF-w150	Notch	A	Type-U	150 / 150	n/a	8,190	34,609	37.23	5
2	NA-Un-w150			Type-U	150 / 150	availale	8,190	34,609	37.23	6
3	NA-LF-w137			Type-L	150 / 150	n/a	8,190	34,609	37.23	5
4	NA-Ln-w137			Type-L	150 / 150	availale	8,190	34,609	37.23	6
5	NB-UF-w150		B	Type-U	150 / 150	n/a	9,170	22,390	23.30	3
6	NB-UF-w300			Type-U	150 / 307.5	n/a	9,170	22,390	23.30	6
7	NB-UF-c300			Type-U	315 / 142.5	n/a	9,170	22,390	23.30	6
8	NA-UFL-w150		A	Type-U+lag	150 / 150	n/a	9,170	25,900	30.06	6
9	SA-F-Fu230	Screw	A	Full Thread	230 / 160	n/a	7,942	34,673	31.06	7
10	SA-N-Fu230			Full Thread	230 / 160	availale	8,190	34,609	37.23	6
11	SA-F-Fu170			Full Thread	170 / 100	n/a	7,942	34,673	31.06	7
12	SA-N-Fu170			Full Thread	170 / 100	availale	8,190	34,609	37.23	6
13	SA-F-Ha230			Half Thread	230 / 160	n/a	7,942	34,673	31.06	7
14	SA-N-Ha230			Half Thread	230 / 160	availale	8,190	34,609	37.23	6

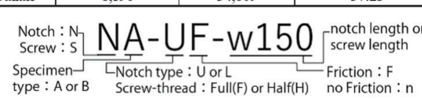


Figure 1: *Name Explanatory notes*

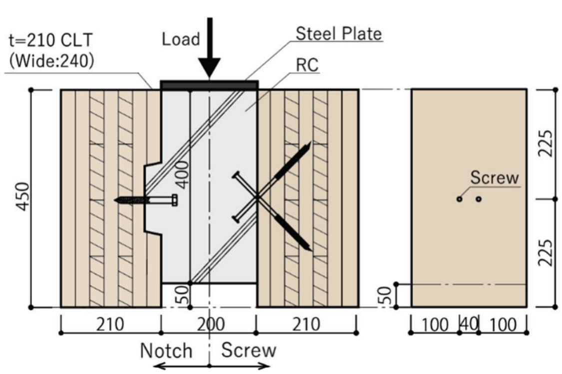
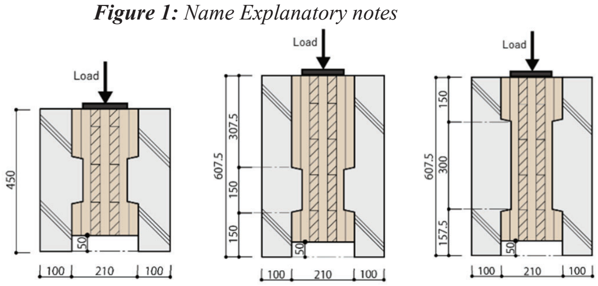


Figure 2: *Test Set up and Specimen Outline (Type A)*



(a) NB-UF-w150 *(b) NB-UF-c300* *(c) NB-UF-c300*

Figure 3: *Test Set up and Specimen Outline (Type B)*

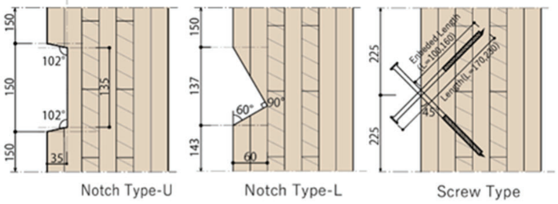


Figure 4: *Shear Key Type Outline*

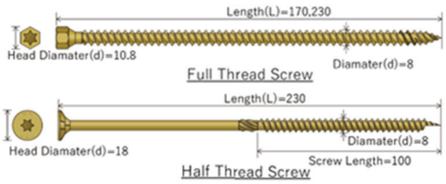
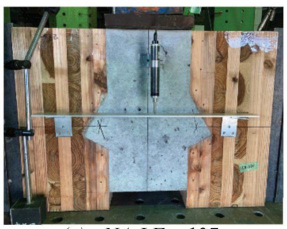
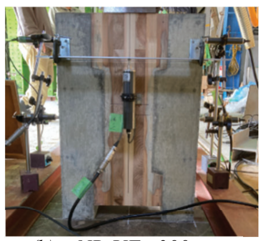


Figure 5: *Screw Type*



(a) NA-LF-w137



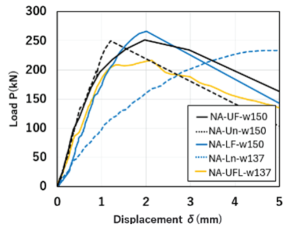
(b) NB-UF-c300

Figure 6: *Applying Shear Force*

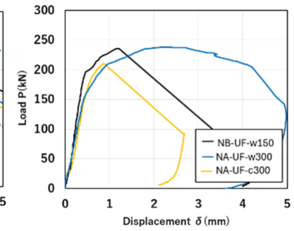
2.3 LOAD DISPLACEMENT AND FAILURE PERFORMANCE

The average load-displacement(P- δ) relationship for each specimen is shown in the Figure 7, and the initial stiffness, yield load, and maximum load for each specimen are shown in Figure 8 ~ Figure 10. The load is calculated as the load per notch or per screw (1/2 of the applied load). The initial stiffness and yield Load follow the test evaluation method in the Elastic-Perfectly Plastic model （equivalent linearization method） [5]used in Japan shown in Fig 11. The initial stiffness of the notched specimen A was defined as the point on the curve between 0.1Pmax and the load around 75 kN (the load before the slip occurred) for specimens with obvious slip to exclude slip due to cracking of the concrete.

Next, the specimen fracture properties are shown in Figure 12, Figure 13. All of notch specimen A cracked and slipped in the direction of the applied force from the lower corner of the notch on the concrete side. The load then continued to increase while the stiffness dropped, and finally the load dropped rapidly with concrete shear fracture at the notch groove. The fracture was brittle. Compressive deformation was observed on the CLT bearing surface after the force was applied. On the other hand, notched specimen B, which used CLT as the center material, had different ultimate fracture properties than A. Specimens NB-UF-w150 and NB-UF-c300 with a



(a) Notch Specimen A



(b) Notch Specimen B

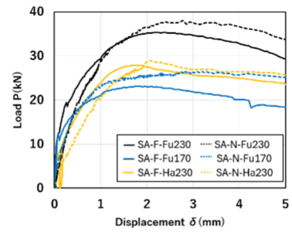


Figure 7: *P- δ Average Curves*

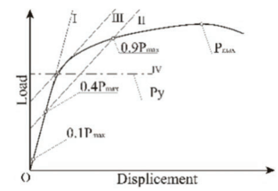


Figure 11: *Yield Load Evaluation*

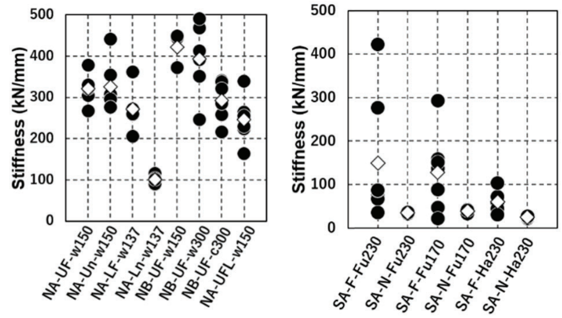


Figure 8: *Stiffness per a Shear Key*

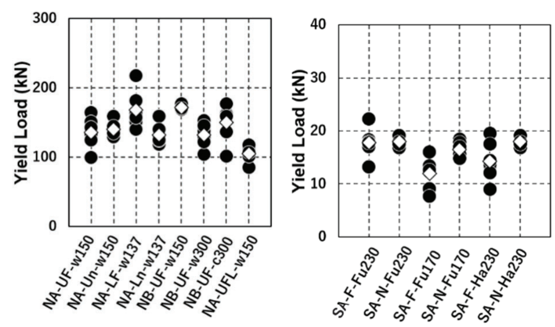


Figure 9: *Yield Load per a Shear Key*

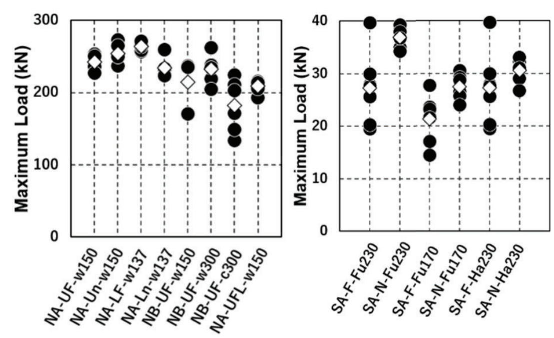


Figure 10: *Maximum Load per a Shear Key*

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timber notch length of 150 mm did not crack from the concrete corner, and the final failure was due to shear fracture of the CLT. On the other hand, specimen NB-UF-w300 with notch wood length of 300 mm had enough wood shear length to cause shear failure on the notch concrete side as in specimen A. In the final fracture properties of the cotter-type specimens, specimen B is considered to be close to the actual fracture properties of the TCC shear key, since the wood shear fracture properties cannot be confirmed for specimen A.

The following is a comparison of specimens for each notch parameter. Note that since the CLT and RC Young's Modulus and strength differ depending on the specimens, simple comparisons based on characteristic value results are made only for specimens using the same CLT and RC

(i) Friction Effect of Teflon

In Type-U (NA-UF-w150, NA-Un-w150), the effect of friction by Teflon did not clearly appear. On the other hand, the initial stiffness of the Type-L specimens (NA-LF-w150 and NA-Ln-w150) was greatly reduced by the application of Teflon. As shown in the Figure 13(c), the Type-L specimens with a large inclination angle of the notched bearing surface show a greater effect of friction.

(ii) Difference in Notch Shape

Comparing Type-U (NA-UF-w150, NA-Un-w150) and Type-L (NA-LF-w137, NA-LF-137), the Type-U specimens were higher than the Type-L in initial stiffness. The inclined CLT bearing surface of the Type-L is thought to have increased vertical deformation due to deformation in the direction orthogonal to the applied force.

(iii) Effect of Lag screw

Comparing specimens with and without lag screws in Type-U (NA-UF-w150, NA-UFL-w150), specimens with lag screws tend to have lower stiffness and bearing capacity. Although a simple comparison cannot be made due to the different CLT and RC strength of the specimens, the CLT strength of the specimen without lag screws (NA-UF-w150) was about 1.33 times higher than that of the specimen with lag screws (NA-UFL-w150), and there was no clear increase in stiffness or bearing capacity with the addition of the lag screw. The effect of the lag screw is considered to be almost negligible.

(iv) Notch Length

Compare the effect of notch length on Type-U specimens B (NB-UF-w150, NB-UF-w300, and NB-UF-c300). The NB-UF-w150 specimen, in which both the CLT and concrete notch lengths are 150 mm, has the highest initial stiffness.

(a) Type-U *(b) Type-L* *(a) Concrete Shear Fracture*

Figure 12: *Initial Concrete Cracks*

(b) Timber Compressive Deformation *(c) Type-L Notch Compressive Deformation*

(d) Screw Type Final Deformation *(e) Specimen NB-UF-w150 Timber Shear Failure*

(f) Specimen NB-UF-w300 Concrete Shear Failure *(g) Specimen NB-UF-c300 Timber Shear Failure*

Figure 13: *Typical Ultimate Fracture*

Comparing the NB-UF-w150 specimen with the NB-UF-c300 specimen, it is clear that the stiffness is low even after accounting for variation, indicating that notch shear stiffness may contribute to the specimen stiffness. The final fracture properties were also different depending on the notch length, confirming that the notch length also affects the bearing capacity.

Next, the results of the screw specimen experiment are discussed. For specimens with friction effect without Teflon affixed (SA-F-Fu230, SA-F-Fu170, SA-F-Ha230) , a sudden drop in load was observed at 0.2 mm to 0.5 mm of displacement. This is due to the significant frictional effect caused by the screw tensile force between RC and CLT. It is assumed that the inclined screws generate axial force in the direction perpendicular to the applied force, which causes a greater effect of friction. After a sudden decrease in load, the load continued to increase again due to the tensile force of the screws, and finally, the screws showed tough fracture properties due to flexural yielding. No significant destruction was observed in the RC and timber.

Due to the frictional effect of the inclined screws , there was considerable variation in the initial stiffness of the specimens without Teflon affixing. On the other hand, the Teflon-applied specimens (SA-N-Fu230, SA-N-Fu170, SA-N-Ha230) showed stable behavior with little variation.

The following is a comparison of the specimens for each screw parameter.

(i) Screw Embedded Length

No clear difference in initial stiffness was observed in the specimens with different screw lengths (SA-N-Fu230 and SA-N-Fu170) for Full Thread screw. On the other hand, the specimen with a screw length of 230 mm (SA-N-Fu230) was 1.26 times greater than that of 170 mm (SA-N-Fu170) in terms of yield strength and about 1.3 times greater in terms of maximum strength. In particular, it can be seen that the increase in bearing capacity due to the screw length can be expected.

(ii) Screw Thread Specification

In the Half-threaded screw specimen (SA-N-Ha230), the initial stiffness tended to be about 1.5 times lower than that of the fully threaded 170 mm screw specimen (SA-N-Fu170) with the same thread length. No clear trend was observed in bearing capacity compared to the Full-thread screw. Further validation with more parameters is needed.

2.4 COMPARISON OF CALCULATION

Based on the results of shear key experiments, this paper proposes an equation for estimating the stiffness and yield strength of Type-U specimens notch shear key without the influence of friction.。

(i) Stiffness Estimation Equation

In the Eurocode5 composite, stiffness is given by notch depth.However, the experimental results show that the notch shape and the presence or absence of friction have a large influence on the stiffness, and determining the stiffness only by the notch depth may be a judgment on the dangerous side. From the Type-U experimental results, it is inferred that timber compressive stiffness, timber shear stiffness, and RC shear stiffness will contribute to shear key shear stiffness. Therefore, the shear key stiffness K_{sk} can be calculated as follows.

$$K_{sk} = \frac{1}{\frac{1}{K_{wc}} + \frac{1}{K_{ws}} + \frac{1}{K_{cs}}} \tag{1}$$

$$K_{wc} = K_{em} A_{wc} \tag{2}$$

$$K_{ws} = \frac{G_w A_{ws}}{H_n} \tag{3}$$

$$K_{cs} = \frac{G_c A_{cs}}{H_n} \tag{4}$$

where, K_{wc} is compressive stiffness in timber fiber direction, K_{ws} is the shear stiffness of timber, and K_{cw} is the shear stiffness of concrete, A_{wc} is the compressive area of timber, A_{ws} is the shear area of timber, H_n is notch depth, G_c is shear stiffness of concrete, A_{cs} is shear area of concrete, K_{em} is surface pressure stiffness of timber and calculated using equations(5),(6) as follows [6]。

$$K_{em} = \frac{5}{5\,sin^2\,\theta + cos^2\theta} K_{em90} \tag{5}$$

$$K_{em90} = \frac{E_w(0.02 + \frac{1}{L_n})}{(140 - 0.6 L_n)} \tag{6}$$

where, E_w is bending young's modules of timber, θ is the notch angle.

The calculated values based on the stiffnesses of CLT and RC obtained from material experiments were compared with the Type-U experimental values in the above equation, and the results are shown in the Figure 14. As mentioned earlier, Notch Type-L is out of the scope of this estimation formula because the vertical deformation of the CLT is increased due to its inclined compressive surface. The evaluation of timber compressive stiffness is important factor because the contribution of timber compressive stiffness is the largest in the calculated shear key shear stiffness values. According to the surface pressure stiffness calculation method for wood referred to in this paper, the calculated values were evaluated on the safe side for all specimens, although a general trend was captured for each specimen.

(ii) Estimation of Yield Strength

The yield strength F_{sk} is calculated by the following equation based on the experimental results and the notch shear key proportional limit load calculation formula described in Eurocore5 composite.

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$$F_{sk} = min \begin{cases} f_{cs} b_n l_{nc} & a) shear\ of\ cocrete \\ f_{cc} b_n h_n & b) crushing\ of\ concrete \\ f_{ws} b_n l_{nw} & c) shear\ of\ timber \\ f_{wc} b_n h_n & d)\ crushing\ of\ timber \end{cases} \quad (7)$$

where, f_{cs} is the shear strength of the concrete, b_n is the notch width, l_{nc} is the notch length of the concrete, f_{cc} is compressive strength of the concrete, h_n is the notch depth, f_{ws} is the shear strength of the timber, lnw is the notch length of the timber, f_{wc} is the compressive strength of the timber.

Concrete compressive strength is based on material test results. Concrete shear strength was assumed to be 1/6 of the compressive strength. CLT shear strength (average 3.72N/mm^2) was obtained from CLT material experiments only for the NB-UF-w150, NB-UF-w300, and NB-UF-c300 specimens. The results are compared only for the above three specimens to ensure consistency in the calculation conditions. Comparison with experimental values is shown in Figure 15. As in the experimental results, the yield strength of the specimens with timber notch length of 150 mm (NB-UF-w150 and NB-UF-c300) were determined by timber shear fracture, and that of the specimen with a timber notch length of 300 mm (NB-UF-w300) was determined by concrete shear fracture. Compared to the experimental values, the results generally capture the trend of the experimental results.

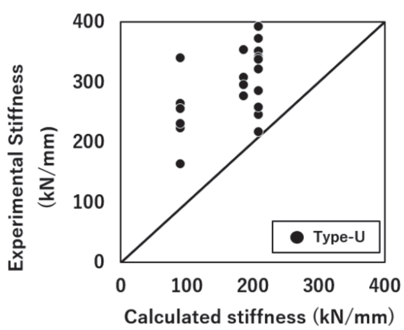


Figure 14: *Relationship between calculated and experimental stiffness*

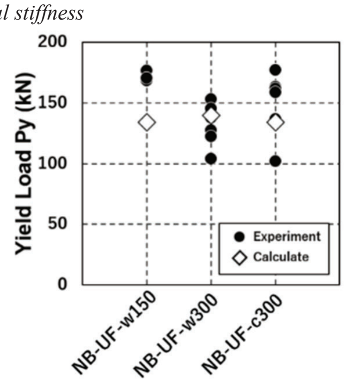


Figure 15: *Relationship between calculated and experimental yield strength*

3 – SLAB BENDING EXPERIMENT

3.1 MATERIALS AND PARAMETERS

The List of specimen and materials used are shown in the Table 2, and the test specimen shape and dimensions are shown in the Figure 16. The specimen was 6.0 m long and 1.0 m wide, and the TCC slab cross-section was the same as in the shear key element experiment, with a 100 mm RC slab cast on a 210 mm CLT（5-layer-7-ply,Japanese cedder,S60 graded by JAS, thickness of lamina is 30mm,side gluing is not applicate） bottom surface.

Reinforcing bars were placed as singles (SD295 graded by JIS, D13@150) both horizontally and vertically. Shear keys were notched or screwed, and lag screws (diameter *d* =16, Length *l*=150mm, CLT embedded length=65mm) were used for notched specimens to prevent delamination between RC and CLT. One lag screw was placed in the center of the notch for specimen N-c150-p450, and two were placed 250 mm from each end for specimens N-c150-p1050 and N-c300-p450. Notch specimen parameters are notch dimensions and placement intervals, one for each of the three specimens. The screw specimen was tested with one Half-threaded screw type.

For RC, strength and Young's modulus were calculated from the compressive strength test specified by JIS.For CLT, bending young's modulus was calculated experimentally from a three-point bending test under centralized loading.

3.2 TEST METHODS

three-point bending test were performed on a 5.7 m span TCC slab as shown in the Figure 17. The applied force was monotonic, and the loading rate was such that the specimen failed in more than 10 minutes up to the maximum load.

The displacement measurement positions were not only the absolute displacements of the center displacement, force point displacement, and point of support displacement, but also the relative horizontal displacements of the RC and CLT at the edge of the specimen and 950 mm from the point of support to measure the displacement between RC and CLT. To measure the strain at each specimen location, strain gauges were affixed at five locations on each specimen at regular intervals, three per location on the top of the RC, the top of the CLT, and the bottom of the CLT, as shown in the Figure 18.

The Figure 19 shows the situation during force application.

__Table 2:__ List and Results of Material Experiments of Specimen

No.	Name	shear key	Notch shape/ Screw shape	Notch：RC notch length/ notch pitch Screw：Screw length/ pitch(span) / pitch(wide) (mm)	CLT young's modules (N/mm^2)	concrete young's modules (N/mm^2)	concrete compressive strength (N/mm^2)
1	N-c150-p450	Notch	Type-U	150 / 450	8,190	29,430	33.83
2	N-c150-p1050	Notch	Type-U	150 / 1050	9,170	22,390	23.30
3	N-c300-p450	Notch	Type-U	300 / 450	9,170	23,300	30.46
4	S-Ha230-p100	Screw	Half Thread	230 / 100 / 210	7,942	34,673	31.06

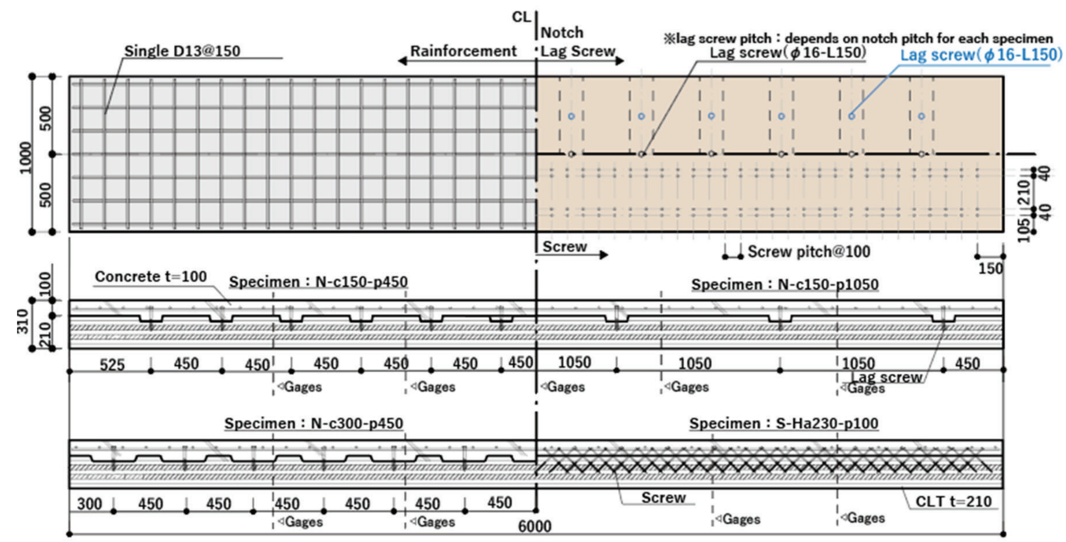


__Figure 16:__ Bending Specimen Outline

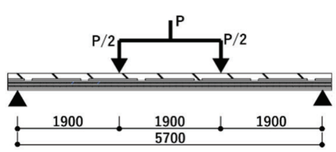


__Figure 17:__ Bending Experiment Outline

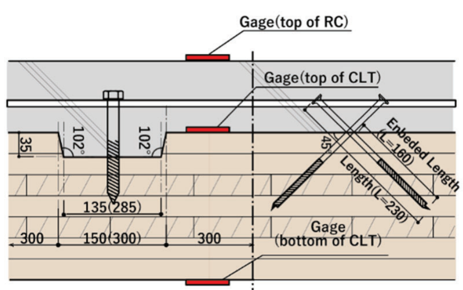


__Figure 18:__ Shear Key and Gages Outline

__Figure 19:__ Applying Force

3.3 LOAD DISPLACEMENT AND FAILURE PERFORMANCE

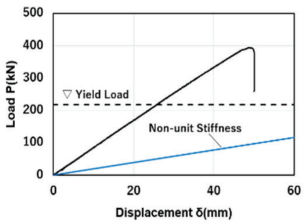
Figure 7 shows the P-δ curves, yield load, and slab stiffness when RC and CLT are not integral due to shear keys. The characteristic values follow the evaluation method described in the Figure 11 as well as the elemental experiments. For all specimens, the initial stiffness without integral shear keys ranged from 2.8 to 3.2 times the slab stiffness, indicating that the TCC behaved in an integral manner.

All specimens reached yield load at a displacement of around 25 mm. Specimens N-c150-p450 and N-c150-p1050 began to crack diagonally toward the direction of concrete load from the notched corner after yield load. Thereafter, cracking progressed gradually without significant reduction in stiffness, and some areas of lifting were observed at notches near the point of application. Finally, the experiment was terminated when the load dropped rapidly due to shear failure at the notch. The maximum horizontal misalignment of the CLT-RC was about 1 mm until final failure.

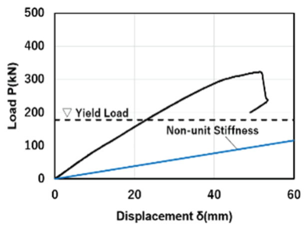
Specimen N-c300-p450 also exhibited relatively elastic behavior after yield load. Fracture sound started to occur from the CLT, and the load dropped rapidly due to bending failure at the bottom edge of the CLT. Some notches near the point of application showed slight cracking on the concrete side at ultimate fracture.

Screw specimen (S-Ha230-p100) also occurred fracture sound at the CLT after the yield load, and the ultimate fracture properties were determined by the bending failure of the bottom edge of CLT. This specimen showed no significant fracture behavior on the RC side or shear key after the ultimate fracture.

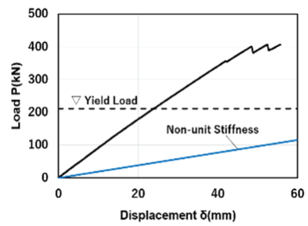
https://doi.org/10.52202/080513-0385



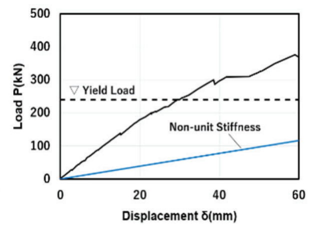
(a) N-c150-p450



(b) N-c150-p1050



(c) N-c300-p450



(d) S-Ha230-p100

Figure 20: *P- δ curves and characteristic values*

Figure 21: *Ultimate Fracture of N-c150-p450*

Figure 22: *Ultimate Fracture of N-c150-p1050*

Figure 23: *Ultimate Fracture of N-c300-p450*

Figure 24: *Ultimate Fracture of S-Ha230-p100*

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3.4 APPLICATION OF γ-METHOD

Attempt to apply the γ-method described in Eurocode5. The γ-method is a design method based on the theory of linear elasticity for timber beams connected by mechanical joints. The effective bending stiffness *(EI)ef*, member stress σ_i, $\sigma_{m,i}$ and shear key stress F_i calculated by γ-method are shown below.

$$(EI)_{ef} = \sum_{i=1}^{2}(E_i I_i + \gamma_i E_i A_i a_i^2) \qquad (8)$$

$$\gamma_i = [1 + \pi^2 E_i A_i s_i/(K_i l^2)]^{-1} \qquad (9)$$

$$a_2 = \frac{\gamma_1 E_1 A_1 (h_1 + h_2)}{2\sum_{i=1}^{2}\gamma_i E_i A_i} \qquad (10)$$

Where, E_i is young modules of the specimen, I_i is the moment of inertia of area, γ_i is a non dimensional factor for the composite action, γ_2 is a fixed number 1, Ai is the cross sectional area of the specimen per shear key, a_i is the distance from specimen height center to neutral axis, s_i is the specing of the fasteners.

$$\sigma_i = \frac{\gamma_i E_i a_i M}{(EI)_{ef}} \qquad (11)$$

$$\sigma m,_i = \frac{0.5 E_i h_i M}{(EI)_{ef}} \qquad (12)$$

where M is the design bending moment of TCC.

$$F_i = \frac{\gamma_i E_i A_i a_i s_i}{(EI)_{ef}} V \qquad (13)$$

where, V is the design shear force of TCC

Equations from (8) to (13) were quoted from Eurocode5 equations[1]. Compare the stiffness calculated from γ-method with the experimental initial stiffness. However, the material stiffness and shear key stiffness used in the calculated values are experimental values. As shown in the Figure25, all specimens were evaluated slightly on the dangerous side, but generally agreed with good accuracy. The reason for the dangerous evaluation is assumed to be that the shear stiffness of CLT is not taken into account in the case of the γ-method.

Next, the stress levels at each member position, derived from strain gauge results at P-100 kN and at yield load, which are within the proportional range shown in Figure 26, were compared with the stress level at each member position calculated from the γ-method. In all specimens, good relationships were observed between the experimental and calculated values.

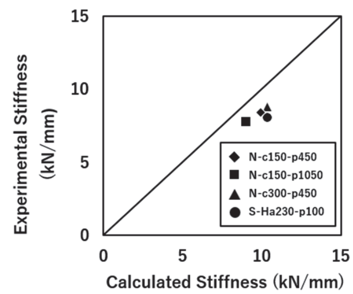
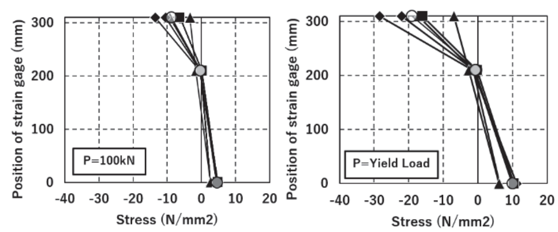
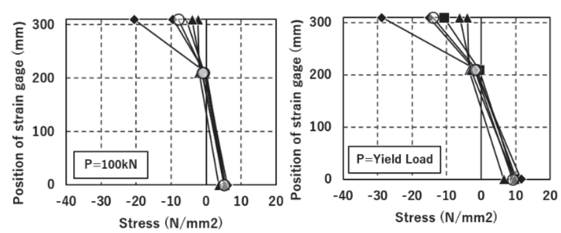


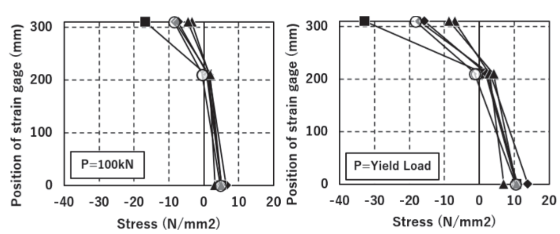
Figure 25: *Relationship between calculated and experimental values of stiffness*



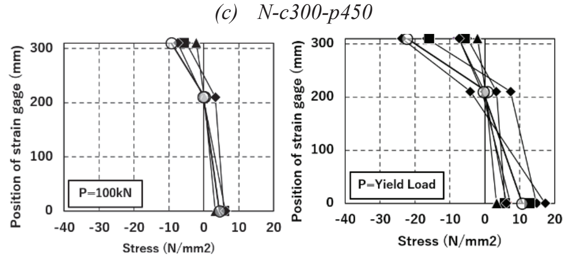
(a) N-c150-p450



(b) N-c150-p1050



(c) N-c300-p450



(d) S-Ha230-p100

Figure 26: *Relationship between calculated and experimental values of TCC stress*

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4 – CONCLSIONS

In order to establish a TCC slab design methodology in Japan, shear key element experiments with screw and notch as shear key and TCC slab bending experiments were conducted. The stiffness and bearing capacity estimation equations for shear keys of the notch type were proposed and their suitability was confirmed. In addition, the possibility of estimating TCC slab bending performance was verified by applying the γ-method to the results of bending experiments. The knowledge obtained is presented below.

1) Experiments were conducted using notch shape, notch length, and with/without lag screw as parameters for the notch type, and length and thread length as parameters for the screw type. It was confirmed that the shear key has sufficient stiffness and bearing capacity.

2) Equations for estimating stiffness and bearing capacity in the case of notch type U are proposed and compared with experimental values. The stiffnesses were generally correlated, although the estimation of the timber compressive stiffness was slightly on the safe side. Yield strength was confirmed to be accurately estimated for both specimens that fructured in shear at the CLT and those that fructured in shear at the RC.

3) Full-scale bending experiments were conducted using notches or screws on shear keys. The stiffness of all specimens was 2.8~3.2 times higher than that of the non-integrated slabs, confirming that they behaved as an integral part of the TCC.

4) From the γ-method shown in Eurocode5, the stiffness and the stress levels of each member in the elastic range and at yield strength were compared. Both stiffness and bearing capacity generally show a good relationship, and it is considered possible to calculate the TCC slab using γ-method within the scope of this study.

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