Technical report

Effects of Shear Connectors on Flexural Properties of RC-CLT Composite Slab

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Abstract

The out-of-panel flexural properties of composite slabs of reinforced concrete (RC) and cross laminated timber (CLT) joined by shear connectors (lag screws) were studied. Firstly, a push-out test was performed on the join surface of composite slabs. As a result, lag screws showed good deformation capacity properties in the push-out test. Then, a bending test was performed on composite slabs. Higher flexural properties were obtained with the deeper insertion of lag screws into CLT. Finally, the $\gamma$-method was applied to calculate initial stiffness and yield load, important factors in evaluating flexural properties of composite slabs. As a result, the calculated values showed a good correlation with experimental values.

1. Introduction

Reinforced concrete (RC) finds widespread applications in Japan in response to a variety of needs such as composite structures comprised only of fiber reinforced concrete and steel frames in the architectural engineering field and hybrid structures of different types of structural materials in the civil engineering field (Concrete Journal Editorial Board 2014). In foreign countries, there are suggestions as to the use of bridges comprised of RC slabs and beams such as lumber and laminated timber beams on the bottom joined by shear connectors (Dias and Skinner 2016).

In Japan, on the other hand, more wood construction has been introduced into mid- and large-scale buildings with the enforcement of the Act for Promotion of Use of Wood in Public Buildings (MAFF 2010). In such this background, the authors carried out a study on the use of cross laminated timbers (CLT), which are gaining attention in the field of wooden structures, as floor panels of mid- and large-scale buildings. As shown in Fig. 1, CLT panels consist of several layers of laminae stacked crosswise (typically at 90 degrees) and glued together on their wide faces and, sometimes, on the narrow faces as well (JAS 2019). In using CLT as floor panels of mid- and large-scale buildings, the challenge is to address an increase in floor vibration caused by insufficient stiffness. This paper suggests the use of composite slab of RC and sugi (Cryptomeria japonica) CLT joined by shear connectors (composite slab) for building floor panels by utilizing technologies developed for bridges in the civil engineering field. The advantage of the composite slab is that an RC slab and wooden material placed under the slab are considered as a structure. This eliminates the need of removal from a concrete form and leads to a shorter construction period.

Many experimental studies on RC and wood composite structures have been published in Europe and the United States. An example is a study of a composite beam of RC and wooden beams joined by shear connectors (Lukaszewska et al. 2008; Piazza and Ballerini 2000). Another example is a study on deformation of shear connectors inserted diagonally into an RC-CLT composite floor panel (Higgins et al. 2017).

For calculations concerning composite beams, Eurocode 5, Annex B (CEN 2004) gives a simplified calculation model for flexural properties of mechanically joined beams ($\gamma$-method).

In this study, shear connectors of different lengths were used. Firstly, a push-out test was carried out to

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evaluate the shear properties of shear connectors that joined RC and CLT. Then, a bending test was conducted on composite slabs joined by shear connectors of different lengths. Based on the test results, an experimental evaluation was made as to the effects of shear connectors on flexural properties of composite slabs with a focus on stress distribution based on the strain measurements of RC and CLT, as well as deformation of shear connectors. Further, the experimental and calculated values of the initial stiffness and yield load of the composite slab were compared.

2. Materials and methods for push-out test

2.1 Specimens

2.1.1 Composition of push-out test specimens

Table 1 shows a list of specimens used in the push-out test of the join surface, and Fig. 2 shows schematic drawings of specimens. The specimen was made of CLT on both sides surface of concrete and one shear surface per each shear connector. CLT was placed with its fiber direction of the outer layer parallel to the loading direction. Lag screws were used as shear connectors because they could be installed easily by a dry construction method without the need of special tools. Five specimens were prepared for push-out test for the two types of shear connectors, respectively.

2.1.2 Properties of concrete

Plain concrete 240 mm long and 180 mm wide was used in the test. The part of concrete mating with CLT had a thickness of 90 mm, and other parts were 70 mm thick to reduce friction between CLT and concrete (Fig. 2). Tables 2 and 3 show concrete mix proportion and prop-

![Table 1 Specimen list (Push-out test).](image1)

| Specimen name | Number of specimens | Shear connector  | Insertion depth |
|---------------|---------------------|-----------------|-----------------|
|               |                     | Total length    | Insertion depth |
|               |                     | (Length beneath the head) | CLT | RC |
| 1) ST-L90    | 5                   | 98 (90)         | 38              | 60 |
| 2) ST-L150   | 5                   | 158 (150)       | 90              | 68 |

![Fig. 2 Specimen profile (Push-out test).](image2)
Table 2 Concrete mix proportion.

| Weight (kg/m³) | Water | Cement | Coarse aggregate | Fine aggregate | Chemical admixtures |
|----------------|-------|--------|------------------|----------------|---------------------|
|                | 183   | 321    | 934              | 853            | 4.82                |
| W/C:           |       |        |                  |                | 57.0%               |

Table 3 Properties of fresh concrete.

| Slump (cm) | Air content (%) | Concrete temperature (°C) |
|------------|-----------------|---------------------------|
| 14.5       | 4.7             | 33                        |

Table 4 Material properties of concrete.

| Nominal strength (N/mm²) | Compressive strength (N/mm²) | Modulus of elasticity in compression (kN/mm²) | Splitting tensile strength (N/mm²) |
|--------------------------|------------------------------|-----------------------------------------------|----------------------------------|
| 24                       | 28                           | 21.8                                         | 2.2                              |

Table 5 Material properties of CLTs (Push-out test).

| Density (kg/m³) | Moisture content (%) | Modulus of elasticity (kN/mm²) |
|-----------------|----------------------|-------------------------------|
| Ave.            | 599                  | 12.1                          |
| SD.             | 14                   | 5.85                          |

Table 6 Material properties of Shear connectors (Reference value).

| 0.2% proof strength (N/mm²) | Tensile strength (N/mm²) | Modulus of elasticity in tension (kN/mm²) |
|----------------------------|--------------------------|-------------------------------------------|
| Ave.                       | 508                      | 542                                       |

Table 2 Concrete mix proportion.

Properties of concrete were investigated with test pieces (100 mm in diameter, 200 mm high) that were sealed and cured on site. The compressive Young’s modulus was calculated by the New RC formula (AIJ 2018) given in Equation (1), where \( k_1 \) and \( k_2 \) were 1 as general aggregate and chemical admixture was used.

\[
E = 33.5 \times k_1 \times k_2 \times \left( \frac{gf}{24} \right) \times \left( \frac{F_{c_a}}{60} \right)^{1/3}
\]  

(1)

where \( E \): compressive Young’s modulus of concrete (kN/mm²), \( k_1 \): constant depending on type of aggregate, \( k_2 \): constant depending on type of chemical admixture, \( g_f \): unit weight of test piece (kN/m³), \( F_{c_a} \): compressive strength of test piece (N/mm²)

2.1.3 Properties of CLT

The CLTs used in the test were made of sugi (Cryptomeria japonica) laminae 30 mm thick. CLTs were 3-layer-3-ply lay-ups and the Mx60 strength grade according to the Japanese Agricultural Standard (JAS 2019) for CLTs. The dimensions of the CLTs were 240 mm long, 90 mm thick and 180 mm wide. Each layer was glued together by a water-based polymeric isocyanate resin adhesive. As shown in Figs. 1 and 2, laminae were not edge glued. Table 5 shows the material properties of the CLTs. The Young’s modulus of the CLTs was measured by the longitudinal vibration method (JHWTC 2011) with a CLT 600 mm wide and 2000 mm long before it was cut into specimens. The moisture content was calculated by the oven-dry method with a piece of specimen used in the push-out test. The average of measured Young’s modulus was 5.85 kN/mm². To prevent bond of concrete to CLT, a surface enhancer was applied to a CLT. This allowed evaluation of the direct effects of shear connectors joining concrete and CLT.

2.1.4 Material properties and installation of shear connectors

M12 lag screws were used as shear connectors to join concrete and CLT. Two types of lag screws were used; one had a total length of 98 mm and a length beneath the head of 90 mm (L90), and the other had a total length of 158 mm and a length beneath the head of 150 mm (L150). The lag screws were not long enough to be inserted into the chuck of the testing machine. To obtain reference values for the material properties of lag screws, M12 hex head bolts were used instead to perform a tensile test after it had been confirmed from the manufacturer that the bolts were made of the same steel as the lag screws. The result of the tensile test of the hex head bolts is shown in Table 6. Shear connectors were installed in the
following manner: Firstly, a pilot hole of 6.5 mm in diameter, equivalent to 54% of the outer diameter of lag screw thread was provided. Then, as shown in Table 1 and Fig. 2, ST-L90 was inserted into CLT 38 mm deep through the first lamina 30 mm thick and buried in concrete 60 mm deep. ST-L150 was made to penetrate through the three laminae 90 mm thick in total and buried in concrete 68 mm deep.

2.2 Loading and measuring methods for push-out test

Figure 3 shows the test setup for push-out test. A monotonic load was applied unidirectionally. Load was applied until it reached the maximum load and then declined to its 80% with reference to the guide of load evaluation in the allowable stress design of conventional post and beam structures (JHWTC 2017). The test was conducted with a universal testing machine having a capacity of 2000 kN. The load was measured by a load cell installed on the testing machine. The displacement was measured by displacement gauge of length 50 mm. The slip displacement was evaluated by measuring the relative slip displacement between concrete and CLT in the loading direction.

3. Results of push-out test of join surface

3.1 Relation between load and slip displacement

Figure 4 shows the relation between load and slip displacement in the push-out test. In addition, an enlarged view of the initial displacement is shown in Fig. 4. Loads in the figure mean a load per shear connector, which was determined by dividing the readout of load cell by two, the number of shear connectors installed. Five specimens were tested for ST-L90 and ST-L150, respectively. For the load-slip displacement relation of ST-L90, the slope became smaller, around 5 kN to 9 kN. Then, the load decreased gradually after it reached the maximum load. For ST-L150, the slope became smaller around 7 kN to 15 kN, the load decreased gradually after it reached the maximum load. All specimens of shear connectors showed deformation capacity properties.

Figure 5 shows the examples of final fracture patterns. No apparent cracks were observed in the concrete of all specimens. For fracture properties of shear connectors, ST-L90 had flexural deformation and sank into the CLT. For ST-L150, on the other hand, a shear connector was broken on one shear surface out of the two.

3.2 Mechanical characteristic values

Table 7 shows a list of experimental results of the push-out test. The initial stiffness per shear connector
was calculated as a slope of the load-slip displacement curve within the broadest linear range from 0.1 Pmax to 0.2 Pmax by the least square method. The proportional limit load was the load at a point 5% deviates from the line of initial stiffness. The yield load was calculated by the perfect elastoplastic model described in the allowable stress design of conventional post and beam structures (JHWTC 2017). This model is used to divide an elastoplastic range into segments at specified points on the load-slip displacement curve based on the maximum load (Pmax). Specifically, the yield load was calculated in the manner described in 1) to 4) below and Fig. 6:

1) Draw Line I from 0.1 Pmax to 0.4 Pmax on the load-slip displacement curve.
2) Draw Line II from 0.4 Pmax to 0.9 Pmax on the load-slip displacement curve.
3) Shift the location of Line II in parallel until it is tangential to the load-slip displacement curve, and define the tangent line as Line III.
4) Define the load at the intersection point of Line I and Line III as the yield load (Line IV).

The initial stiffness and proportional limit load per shear connector were 11.49 kN/mm and 2.99 kN, respectively for ST-L90, and 12.97 kN/mm and 3.55 kN, respectively for ST-L150. ST-L150 having a longer total length had larger values. The initial stiffness and the proportional limit load per shear connector obtained as the result of the push-out test of the join surface are used in Section 6, the application of the \( \gamma \)-method to composite slabs.

### 4. Materials and methods of bending test on composite slabs

#### 4.1 Specimen

**4.1.1 Composition of Bending test specimens**

Table 8 shows a list of specimens used in the bending test on composite slabs and Fig. 7 shows the schematic drawings of the specimens. The specimen was comprised of CLT at the bottom, shear connectors inserted into CLT, and concrete was placed into a form with deformed bars inside on the top of CLT. The insertion depth of shear connectors into CLT was used as a parameter of the specimens.

**Table 8 Specimen list (Bending test).**

| Specimen name                  | Total length (Length beneath the head) | Insertion depth | Pitch |
|--------------------------------|----------------------------------------|-----------------|-------|
| Specimen name                  | (mm)                                    | (mm)            | Long side | Short side |
| 1)CS-L90-300                   | 98(90)                                  | 38              | 60     | 300        | 200        |
| 2)CS-L150-300                  | 158(150)                                | 90              | 68     |            |            |

#### 4.1.2 Properties of RC

The same type of concrete as that used in the push-out test was used in the experiment. Concrete was cast so as to provide a thickness of 90 mm with a cover thickness of 30 mm, and then covered with a plastic film for curing under a roof outside. As shown in Table 9, the concrete with a nominal strength of 24 had an average compressive strength of 26.8 N/mm\(^2\) before and after the experiment, a compressive Young’s modulus of 21.4 kN/mm\(^2\), and a splitting tensile strength of 2.1 N/mm\(^2\). Deformed bars of SD295A, D10 shown in Table 10 were used as main bars, and arranged along with shear connectors in a single layer at intervals of 200 mm in the short side direction and 300 mm in the long side direction as shown in Figs. 7 a) and b).

#### 4.1.3 Properties of CLT

CLTs with the same specifications as those used in the
push-out test were used in the experiment. The dimensions were 90 mm thick, 600 mm in the short side direction (weak axis) and 2000 mm in the long side direction (strong axis). The CLTs were arranged with the fiber direction on the outer layer parallel to the long side direction. Table 11 shows the material properties of the CLT. The CLT used in the bending test of composite slab had been manufactured in the same production lot as the CLT used in the push-out test. Therefore, the moisture content measured in the push-out test of the joint surface was given in Table 11.

4.1.4 Material properties of shear connectors and installation method
L90 and L150 types of shear connectors were used to join RC and CLT. The shear connectors were installed in the same manner as in the push-out test. As shown in Table 8, L90 was inserted into CLT 38 mm deep and buried in concrete 60 mm deep. L150 was inserted into CLT 90 mm deep and buried in concrete 68 mm deep. As shown in Figs. 7 a), b), c) and Table 8, all shear connectors were installed at intervals of 300 mm in the long side direction and 200 mm in the short side direction. Fig. 8 shows details of the installation.

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**Table 9 Material properties of concrete (Bending test).**

| Nominal strength (N/mm²) | Compressive strength (N/mm²) | Modulus of elasticity in compression (kN/mm²) | Splitting tensile strength (N/mm²) |
|--------------------------|-------------------------------|--------------------------------|---------------------------------|
| 24                       | 26.8                          | 21.4                          | 2.1                             |

**Table 10 Material properties of main bar (Bending test).**

| Bar size                  | Yield stress (N/mm²) | Yield strain (%) | Tensile strength (N/mm²) | Modulus of elasticity in tension (N/mm²) |
|---------------------------|----------------------|------------------|--------------------------|----------------------------------------|
| D10(SD295A)               | 364                  | 0.20             | 479                      | 198×10⁵                                |

**Table 11 Material properties of CLT (Bending test).**

| Specimen name | Density (kg/m³) | Moisture content (%) | Modulus of elasticity in bending (N/mm²) |
|---------------|-----------------|----------------------|----------------------------------------|
| 1)CS-L90-300  | 407             | 6.85                 | 6.85                                   |
| 2)CS-L150-300 | 414             | 12.1                 | 6.43                                   |

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Fig. 7 Specimen profile (Bending test).
4.2 Loading and measuring methods for bending test

Figure 9 shows the loading direction and the method to measure displacement. A monotonic load was applied uni-directionally to the center of a specimen placed on supports arranged at intervals of 1600 mm. Load was applied until it reached the maximum load and decreased sufficiently. The experiment was conducted with a structure testing and automatic measuring system of capacity 5000 kN owned by the Research Institute of Industrial Technology, Nihon University. The load applied was measured with a load cell installed on the system. The vertical displacement of the composite slab was taken as the relative displacement from the supports of RC. The displacement was measured at three points including the loading point in the center of the specimen in the long side direction (δv-1) and the midpoints between the loading point and the supports (δv-2, δv-3), using a displacement gauge of length 50 mm. The strain of RC and CLT was measured with a uniaxial strain gauge as shown in Figs. 7 a) and 8.

5. Results of bending test on composite slabs

5.1 Relation between load and displacement, and mechanical characteristic values

Figure 10 shows the relation of load and displacement in the center of the specimen in the long side direction (δv-1). Both specimens show similar behavior under an initial loading up to around 20 kN. Then, the slope of the curves becomes smaller around 25 kN to 40 kN in CS-L90-300, and around 25 kN to 50 kN in CS-L150-300. The maximum load on the specimens was determined as the point where the CLT had fractured. The compression failure of concrete was observed beside a loading panel placed on the loading point.

Mechanical characteristic values were calculated in almost the same manner as in the push-out test of the joint surface. The yield load was calculated in the manner described in 1) to 4) below and Fig. 11:

1) Draw Line I from 0.1 Pmax to 0.15 Pmax on the load-displacement curve.
2) Draw Line II from 0.15 Pmax to 0.9 Pmax on the load-displacement curve.
3) Shift the location of Line II in parallel until it is tangential to the load-displacement curve, and define the tangent line as Line III.
4) Define the load at the intersection point of Line I and Line III as the yield load (Line IV).

Table 12 shows the initial stiffness, the proportional limit load and the yield load of composite slabs determined by the procedure mentioned above. The proportional limit load, yield load, and maximum load tend to increase with deeper insertion of shear connectors into the CLT.

5.2 Final fracture patterns

Figure 12 a) shows the final fracture patterns on the side of specimens in the long side direction after the specimens were placed under the maximum load. Figure 12 b) shows the sections of specimens that were cut in the
middle in the short side direction in which shear connectors were arranged. Flexural cracks in concrete occurred at almost the same locations on the side and the center of specimens in the short side direction. This suggests that flexural cracks had developed through the specimens in the short side direction.

5.3 Relation between a degree of joint and initial stiffness and yield load of composite slabs

Figure 13 shows strain distributions before the proportional limit load in a), under the proportional limit load in b), and under the yield load in c). CS-L90-300 and CS-L150-300 showed similar trends in strain distribution. Since it is considered that stress is not transmitted to the bottom of RC under the yield load shown in c) due to flexural cracks of the concrete, the strain from the main bars to the concrete lower surface and from the bottom of RC concrete to the top of CLT is shown by broken lines. In a), the strain distribution before the proportional limit load, a slight difference in strain was observed between the bottom of RC and the top of CLT. This means that composite slabs joined by shear connectors were semi-rigid composite beams (Thelandersson and Larsen 2003) in which their cross sections had not been planar in the axial direction due to deformation since the initial loading.

In b), the specimens under the proportional limit load had a larger difference in strain between the bottom of RC and the top of CLT in comparison with a). In c), it is obvious that the specimens under the yield load provide no planar cross sections in the axial direction. In Fig. 12 b), the sections of composite slabs that were cut in the middle in the short side direction, almost no flexural deformation was observed visually on the shear connectors near the loading point. On the other hand, flexural deformation of shear connectors was observed noticeably in CS-L90-300, for example, at the locations S-A and S-F toward the end in the long side direction.

This suggests that shear connectors sunk into the CLT and were subjected to flexural deformation near the interface of CLT and RC. As a result, the composite slabs could not provide planar cross sections anymore and finally yielded.

### Table 12 Results of experiment (Bending test).

| Specimen name | Initial stiffness (kN/mm) | Proportional limit load (kN) | Yield load (kN) | Pmax (kN) |
|---------------|--------------------------|-------------------------------|----------------|----------|
| 1) CS-L90-300 | 22.6                     | 19.2                          | 33.9           | 109.4    |
| 2) CS-L150-300| 29.2                     | 23.9                          | 35.2           | 122.2    |

Pmax: Maximum load

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Fig. 12 Final fracture patterns of bending test.
6. Application of γ-method to composite slabs

6.1 Outline of γ-method
The γ-method is a linear analysis method developed for mechanically joined wooden beams and detailed in Eurocode 5 (CEN 2004). Equations (2) through (6) are calculation formulas by the γ-method to determine the effective bending stiffness \((EI)_{eff}\) of composite slabs. By the γ-method, the effective bending stiffness \((EI)_{eff}\) is calculated considering of the cross-sectional performance of the composite slab, the stiffness of the surface joined by shear connectors, the intervals of shear connectors, etc. Figure 14 shows an assumed cross section for calculation. The main bars inside RC supported a compressive load and bore less stress during initial de-

![Fig. 13 Strain distribution.](image)

![Fig. 14 Assumed cross section for γ-method adaptation.](image)
formation. Therefore, the effective bending stiffness of RC was calculated considering only the concrete part:

\[
(El)_{eff} = \sum (E_i I_i + \gamma E_i A_i a_i^2)
\]

\[
= E_i I_i + \gamma E_i A_i a_i^2 + E_i I_2 + \gamma E_i A_i a_2^2
\]

\[
\gamma_1 = \frac{1}{1 + \pi^2 E_i A S}
\]

\[
\gamma_2 = 1 - \frac{\gamma E_i A_i (h_1 + h_2)}{2 (\gamma E_i A_i + \gamma_2 E_i A_i)}
\]

\[
a_i = \frac{(h_1 + h_2)}{2} - a_2
\]

where \((El)_{eff}\): effective bending stiffness (kN·mm²), \(E_i\): compressive Young's modulus of concrete (kN/mm²), \(E_i\): bending Young’s modulus of CLT (kN/mm²), \(I_i\): area moment of inertia of CLT per line of shear connectors (mm⁴), \(I_i\): area moment of inertia of RC per line of shear connectors (mm⁴), \(\gamma\): connection efficiency factor between RC and CLT, \(\gamma_2\): constant, \(A_i\): cross-sectional area of RC per line of shear connectors (mm²), \(A_i\): cross-sectional area of CLT per line of shear connectors (mm²), \(a_i\): distance from the center of RC to the neutral axis vertically (mm), \(\pi\): ratio of circumference of any circle, \(S\): intervals of shear connectors in the long side direction (mm), \(K\): initial stiffness of join surface determined in the push-out test (kN/mm), \(\ell\): distance between supports (mm), \(h_1\): height of RC (mm), \(h_2\): height of CLT (mm)

As discussed in Section 3, the effects of shear connectors that joined concrete and CLT were demonstrated from the measurements of slip displacement in the push-out test of the joint surface. Accordingly, the initial stiffness determined in the push-out test shown in Table 7 was used as \(K\) in Equation (3).

6.2 Calculation of initial stiffness by \(\gamma\)-method

The initial stiffness of composite slabs was calculated by Equation (7) using \((El)_{eff}\) determined by the \(\gamma\)-method. \((El)_{eff}\) was calculated in unit width (\(h_1\) and \(h_2\) per line of shear connectors in the short side direction as shown in Fig. 14 a). Accordingly, the initial stiffness was expressed as the product of \((El)_{eff}\) and the number of shear connectors (n) installed in the short side direction:

\[
P/\delta_{cal} = \frac{48}{\ell^2} (El)_{eff} n
\]

where, \(P/\delta_{cal}\): calculated initial stiffness of composite slab (kN/mm), \(n\): number of shear connectors installed in the short side direction

In Fig. 15, the relation between experimental and calculated values of initial stiffness is plotted by white marks with a black outline and the ratio of experimental values to calculated ones is given as \(m\). Value of \(m\) was 1.53 in CS-L90-300 and 1.96 in CS-L150-300, and both types of shear connectors provided a margin of safety. A comparison was made between the effective bending stiffness \((El)_{eff}\) obtained and the calculated bending stiffness of non-joined members, \((El_i + El_i)\). The ratio was between 1.11 and 1.38, and this showed an improvement in bending stiffness provided by shear connectors.

6.3 Calculation of yield load by \(\gamma\)-method

The relation between an out-of-plane load supported by a composite slab and an axial shear force on the interface between RC and CLT is expressed by Equation (8) using the \(\gamma\)-method:

\[
F_i = \frac{\gamma E_i A_i a_i S}{(El)_{eff}} Q
\]

where \(F_i\): axial shearing force developed on the interface between CLT and RC (kN), \(Q\): vertical shearing force supported by a composite slab (kN)

As discussed in Section 5.3, it was assumed that a composite slab reached a yield point when it became impossible to keep planar cross sections in the axial direction due to flexural deformation of shear connectors. Flexural deformation defined when a shearing force on shear connectors inside a composite slab reached the proportional limit load shown in Table 7 that was determined in the push-out test of the join surface discussed in Section 3. The yield load of the composite slab was calculated under this condition. In the experiment, a load was applied intensively to the center of specimens. Therefore, the yield load of the composite slab \(P_y\) is expressed by Equation (9), considering the formula of \(Q = P_y/2\) and Equation (8):

\[
F_i = \frac{\gamma E_i A_i a_i S}{(El)_{eff}} Q
\]

where \(F_i\): axial shearing force developed on the interface between CLT and RC (kN), \(Q\): vertical shearing force supported by a composite slab (kN)

As discussed in Section 5.3, it was assumed that a composite slab reached a yield point when it became impossible to keep planar cross sections in the axial direction due to flexural deformation of shear connectors. Flexural deformation defined when a shearing force on shear connectors inside a composite slab reached the proportional limit load shown in Table 7 that was determined in the push-out test of the join surface discussed in Section 3. The yield load of the composite slab was calculated under this condition. In the experiment, a load was applied intensively to the center of specimens. Therefore, the yield load of the composite slab \(P_y\) is expressed by Equation (9), considering the formula of \(Q = P_y/2\) and Equation (8):
where \( F_y \): the proportional limit load of joint surface determined in the push-out test (kN), \( P_{yield} \): yield load of the composite slab (kN)

As mentioned above, the proportional limit load determined in the push-out test of the joint surface discussed in Section 3 was assigned to \( F_y \) of Equation (9). In Fig. 15, the relation between experimental and calculated values is plotted by solid black marks. The value of \( m \) was 1.08 in CS-L90-300 and 1.05 in CS-L150-300, and both showed a good correlation.

### 7. Conclusion

This study experimentally demonstrated the behavior of composite slabs of RC and CLT joined by lag screws with different lengths under the condition that an out-of-plane load was applied to them up to a yield load. Further, it studied the application of the \( \gamma \)-method provided in Eurocode 5 to some calculations and estimated the flexural properties of composite slabs within the elastic region. As a result, the findings below were obtained within the scope of this study:

1. In push-out test of the joint surface, lag screws used in the experiment showed a sufficient slip displacement up to the maximum load and demonstrated deformation capacity properties.
2. In a push-out test of the joint surface, the initial stiffness, the proportional limit load, the yield load and the maximum load increased with the deeper insertion of lag screws into the CLT.
3. In a bending test on composite slabs, the initial stiffness, the proportional limit load, the yield load and the maximum load increased with the deeper insertion of lag screws into the CLT.
4. After the experiment, sections of specimens cut in the middle in the short side direction were observed. It was supposed that the composite slab reached a yield point when it became impossible to provide planar cross sections in the axial direction due to flexural deformation of shear connectors.
5. The application of the \( \gamma \)-method provided in Eurocode 5 was studied. The result suggested the possibility of calculating initial stiffness and yield load of composite slabs by the \( \gamma \)-method. The calculated initial stiffness provided a larger margin of safety than that of experimental values. The calculated yield load showed a good correlation with experimental values. These findings demonstrated new possibilities for use of RC to address problems in wooden floor panels used in mid- and large-scale buildings.

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