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RELIABILITY EVALUATION OF TIMBER-CONCRETE COMPOSITE FLOOR SYSTEMS WITH RESPECT TO TIMBER SHEAR FAILURE

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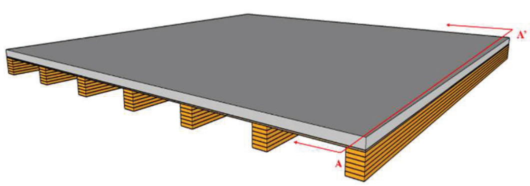
ABSTRACT: Timber-concrete composite (TCC) floors are popular design solutions in mass timber buildings due to their enhanced structural and non-structural (e.g., acoustic and thermal performance) properties. Despite their prevalent use, the structural reliability of TCC floors, consisting of a series of glulam beams and a concrete slab has not been properly evaluated. In this study, reliability analyses of a wide range of TCC floors with self-tapping screws (STSs) as connectors were conducted using the first-order reliability method (FORM) with a special focus on the glulam beam shear failure limit state. The reliability indices associated with the glulam beam shear limit state showed that it was unconservative to use the current resistance factor of 0.9 in the Canadian timber design standard. A similar issue is also observed the design of pure glulam beams when they are not used in timber-concrete composite (TCC) floors. Based on the study conducted, a resistance factor of 0.7 is more appropriate for the design of glulam beams with respect to timber shear in the TCC floors.

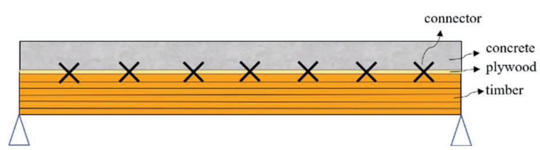
KEYWORDS: Timber-concrete composite (TCC) floors, Self-tapping screw, First-order reliability method (FORM), Shear strength

1 – INTRODUCTION

Timber-concrete composite (TCC) floors are increasingly used in timber construction due to their improved stiffness, acoustic performance, and thermal efficiency. In TCC floors, self-tapping screws (STSs) commonly serve as effective connectors due to their ease of installation, enabling a high degree of composite action between timber and concrete [1-2]. A common type of TCC system is a ribbed-plate type system consisting of a series of glulam beams and a concrete slab, connected by mechanical fasteners (see Fig. 1). Among the various strength limit states considered in the design of TCC floors, such as timber bending, concrete bending, timber shear, concrete shear, and connection shear, timber shear is of particular interest in this study. Timber shear failure is inherently brittle and can occur suddenly, making it a critical concern for reliability assessment [3-4]. Despite the growing adoption of TCC floors in timber construction, the reliability of these systems against timber shear failure remains inadequately studied.



(a) Three-dimensional (3D) view



(b) Sectional (A-A') view

Fig. 1 The schematic view of TCC floors

Existing design provisions in CSA O86-24 [5] apply resistance factors originally derived for stand-alone timber elements without rigorous reliability calibration for TCC systems. This raises questions about the validity of using the current resistance factors in the standard for glulam beams in the design of TCC systems. In an attempt to address this question, a comprehensive reliability analysis study that considered all ultimate and serviceability limit states of TCC systems has been conducted. This paper specifically focuses on the glulam beam shear strength limit state. Specifically, the reliability of one-way TCC floors designed according to CSA O86-24 [5] was assessed using the first-order reliability method (FORM). The reliability indices of TCC floors across a range of design parameters, including concrete slab thickness, beam spacing, and connector spacing were calculated. The findings would lead to reliability-based design recommendations for glulam beams with respect to timber shear limit state of TCC floors.

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While this study primarily focuses on the reliability of TCC floors associated with timber shear failure, the reliability of the design provisions for pure glulam beams is also examined after observing the potential issue of using the current resistance factor of 0.9 in the Canadian timber design standard for TCC systems. As such, a comparative reliability analysis of glulam beams considering the shear failure is also conducted.

2 –METHODOLOGY

To evaluate the reliability of timber shear failure in TCC floors, a three-step procedure was followed. First, the TCC floors were designed such that the factored resistance equals the factored load effect, following the provisions of CSA O86-24 [5]. A wide range of design cases was considered to encompass various scenarios that engineers may encounter in practice. Second, the reliability of the timber shear limit state was assessed using a corresponding limit state function established in the safety margin format. In this step, probability distributions for the basic random variables contained in the limit state function were specified, and the reliability indices for the given designs calculated. Third, the reliability indices for all design cases were compared with the target reliability index specified in CSA S408 ‘Guidelines for the Development of Limit States Design Standards’ [6].

In addition to evaluating the shear reliability of TCC floors, an independent reliability assessment of glulam beams was conducted using a similar methodology. This helped determine whether the observed low reliability indices stem from the presence of concrete and thus only exists for TCC designs.

3 –TIMBER SHEAR DESIGN PROVISION FOR TCC FLOORS IN CSA O86

3.1 GAMMA METHOD

The gamma method is commonly used when calculating the effective bending stiffness of TCC floors or composite beams [7]. This method was developed from a closed-form approximate solution, assuming a sinusoidal load applied on a simply supported TCC beam and a constant distributed connection stiffness between concrete and timber layers along the composite beam. The effective bending stiffness of a TCC beam, $(EI)_{eff}$, can be calculated as per (1),

$$(EI)_{eff} = (EI)_c + (EI)_t + (EA)_c a_c^2 + \gamma_t (EA)_t a_t^{2} \quad (1)$$

Here, $(EI)_c$ and $(EA)_c$ are the effective bending and axial stiffnesses of the concrete slab considered, respectively; $(EI)_t$ and $(EA)_t$ are the bending and axial stiffnesses of the wood beam, respectively; a_c denotes the distance between the centroid and the neutral axis of concrete slab, while a_t denotes the distance between the centroid of timber section and the neutral axis of concrete slab. γ_t is a composite factor used to denote the degree of composite action between timber and concrete, which can be determined as per (2).

$$\gamma_t = (1 + \frac{\pi^2 (EA)_t}{KL^2})^{-1} \quad (2)$$

The value of γ_t is a function of the stiffness of shear connection per unit spacing, K, as per (3),

$$K = \frac{k}{s} \quad (3)$$

in which k is the slip modulus of shear connection and s is the spacing of shear connection. When k approaches zero, $\gamma_t = 0$, which signifies the absence of composite action between two materials. In contrast, when k approaches infinity, $\gamma_t = 1$, which indicates full composite action.

Note that $(EA)_t$ and $(EI)_t$ in Eq. (1) can be readily determined for the timber cross-sections, and $(EA)_c$ and $(EI)_c$ can be calculated as per (4) and (5), respectively,

$$(EA)_c = E_c b_c h_{c,eff} \quad (4)$$

$$(EI)_c = \frac{E_c b_c h_{c,eff}^3}{12} \quad (5)$$

in which

$$h_{c,eff} = \min\left(\sqrt{\alpha^2 + \alpha(h_t + 2h_c + 2t)} - \alpha; h_c\right) \quad (6)$$

$$\alpha = \frac{\gamma_t (EA)_t}{E_c b_c} \quad (7)$$

where b_c represents the effective width of the concrete slab, which is determined as (8)

$$b_c = \min(0.25L; 24h_c; b_w) \quad (8)$$

where L is the span length, h_c is the concrete slab thickness, and b_w is the beams spacing, as shown in Fig. 2.

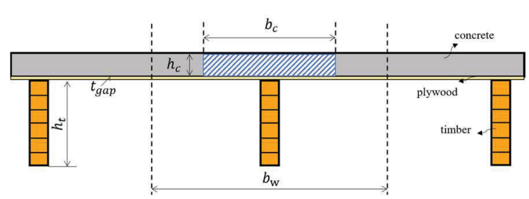

Fig. 2 Effective width of concrete slab in a TCC floor

In (1), the last two unknown terms a_c and a_t can be calculated as per (9) and (10), respectively.

$$a_c = \frac{\gamma_t (EA)_t r}{(EA)_c + \gamma_t (EA)_t} \quad (9)$$

$$a_t = \frac{(EA)_c r}{(EA)_c + \gamma_t (EA)_t} \quad (10)$$

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where r is the distance between the centroids of concrete slab and timber beam (see (11)).

$$r = \frac{h_t}{2} + t_{gap} + h_c - \frac{h_{c,eff}}{2} \quad (11)$$

3.2 TIMBER SHEAR LIMIT STATE

The factored shear resistance $V_{r,\gamma,t}$ of a TCC floor, which is limited by shear failure of the timber element, can be calculated using (12) and (13) according to CSA O86-24,

$$V_{r,\gamma,t} = \frac{(EI)_{eff} V_{r,t}}{(EI)_t + 0.5\gamma_t (EA)_t (h_t + t_{gap}) a_t} \quad (12)$$

in which

$$V_{r,t} = \phi_t F_v \frac{2A_g}{3}, with\ F_v = f_v(K_D K_H K_{Sv} K_T) \quad (13)$$

where ϕ_t is the glulam shear resistance factor, F_v is the modified glulam shear strength, which accounts for the effects of different factors. These factors include the load-duration factor $K_D = 1$ for standard loading condition, the system factor $K_H = 1$ applied for shear strength, the service-condition factor $K_{Sv} = 1$ for dry-service condition, and the treatment factor K_T=1 for untreated glulam in dry-service condition. Additionally, A_g is the gross sectional area of the glulam beam.

3.3 LOAD EFFECTS

In Canada, the load and resistance factor design (LRFD) method is used to ensure that structural components have adequate capacity to withstand applied load effects. According to LRFD the structural component's capacity is designed to exceed the factored load effect for each load combination, as expressed by

$$\phi R_n \geq \sum \gamma_i Q_i \quad (14)$$

where ϕR_n is the designed resistance, Q_i is the nominal load effect of component i in the load combination considered, and γ_i is the load factor for Q_i used to amplify load effects.

For one-way TCC floors, two load combinations are considered: dead load (DL) only, i.e., $1.4DL_n$, and the combination of dead load and live load (LL), $1.25DL_n + 1.5LL_n$, as specified by NBCC [8]. Thus, the maximum factored load, as per (15), is used for design of the TCC floor with width b_c (See Fig. 2)

$$q_f = b_c \times max(1.4DL_n; 1.25DL_n + 1.5LL_n) \quad (15)$$

where q_f represents the uniformly distributed load density, and DL_n and LL_n represent nominal dead and live loads, respectively. The one-way TCC floor was considered simply supported in the design, which leads to the maximum factored shear force, V_f, expressed as per (16),

$$V_f = \frac{q_f L}{2} \quad (16)$$

3.4 DESIGN CASES

To evaluate the reliability levels of the timber shear limit state for TCC floors and pure glulam beams designed according to NBCC [8] and CSA O86-24 [5], two sets of design cases were generated. The design space of TCC floors includes a wide range of practical scenarios by varying the live load (from:1.9 to 4.8 kPa) and span (from 4 to 10 m), along with three key design variables: concrete slab thickness (from 50 to 150 mm), glulam beam spacing (from 1 to 4 m), and connector spacing (from 100 to 500 mm), as detailed in Table 1.

Similar to TCC floors, the design space of glulam beams includes a wide range of practical scenarios by varying the live load (from 1.9 to 4.8 kPa) and span (from 4 to 10 m), along with one key design variables: beam spacing (from 1 to 4 m), as detailed in Table 1. The TCC floors are assumed to be constructed using 20f-E grade glulam as the timber material and plywood as the interlayer. Note that only one grade for concrete and glulam is considered in this study, with nominal properties of concrete and glulam summarized in Table 2, as these materials are commonly used in TCC floors. In addition, the same glulam grade and material properties are used to evaluate the shear reliability of pure glulam beams, ensuring consistency when comparing the reliability of TCC floors and pure glulam beams.

Table 1 Nominal values for load and geometrical variables of TCC floors considered in the design pool

Parameter	Value
Live load, LL (kPa)	1.9, 2.5, 3.0, 3.5, 4.0, 4.8
Span, L (m)	4, 6, 8, 10
Concrete slab thickness, h_c (mm)	50, 75, 100, 125, 150
Beam spacing, b_w (m)	1, 2, 3, 4
Connector spacing, s (mm)	100, 200, 300, 400, 500

Table 2 Specified properties for glulam and concrete in TCC floors considered

Parameter	Value
Glulam density, ρ_t (kg/m^3)	440
Glulam bending strength, f_b (MPa)	25.6
Glulam shear strength, f_v (MPa)	1.75
Glulam tension strength, f_t (MPa)	12.7
Glulam modulus of elasticity, E_t (MPa)	10300
Concrete density, ρ_c (kg/m^3)	2300
Concrete compressive strength, f'_c (MPa)	30
Concrete modulus of elasticity, E_c (MPa)	24648
Stiffness of STS connection, k_s (kN/mm)	12.0

With the resistance equations, load effect calculation, and nominal values for load, geometry, and material variables considered in the TCC designs, TCC floors are designed by selecting an appropriate glulam cross-section. This is achieved through an iterative process in which the cross-section is adjusted until the factored resistance is approximately equal to the factored load effect. Specifically, the ratio between the factored load effect and the factored resistance (referred to as the LR ratio) is close to but less than 1.0. This iterative design process ensures that each TCC floor satisfies the glulam shear requirement, ultimately generating a design space of 2400 one-way TCC floors. Similarly, the same iterative design approach is applied to ensure that the glulam beams meet the shear limit state requirements before reliability assessment, leading to a total of 96 glulam beams designed.

4 – RELIABILITY ANALYSIS

4.1 UNCERTAINTIES OF RESISTANCE DESIGN VARIABLES AND LOAD VARIABLES

Table 3 summarizes the 13 random variables used to characterize the uncertainty in the design parameters. It includes the distribution types, bias factors defining the mean value and the nominal/specified value, and the coefficients of variation (cov) for each random variable.

4.2 LIMIT STATE FUNCTION

According to the LRFD framework, the factored resistance must exceed the factored load effect as indicated in (14). Consequently, the limit state function can be defined in the safety margin format, as the difference between resistance and load effect, see (17),

$$g(\boldsymbol{X}) = R(\boldsymbol{X}) - S(\boldsymbol{X}) \tag{17}$$

where $R(\boldsymbol{X})$ and $S(\boldsymbol{X})$ represent the random resistance and random load effect, respectively, as a function of the vector $\boldsymbol{X}$ containing all basic random variables. Specifically, the limit state function for the shear failure of glulam, is given by (18):

$$g = V'_{r,\gamma,t} - (V_D + V_L) \tag{18}$$

where $V'_{r,\gamma,t}$ denotes the random shear resistance of TCC floors, while V_D and V_L represent the random dead and live load effect, respectively, after considering the uncertainties in basic random variables. Similarly, the limit state function of glulam beam considering shear failure is given by (20),

$$g_1 = V'_{r,t} - (V_D + V_L) \tag{20}$$

where $V'_{r,t}$ denotes the random shear resistance of glulam beams. Note that the dependence($\boldsymbol{X}$) is dropped here for brevity.

Structural failure is indicated when $g(\boldsymbol{X}) < 0$. Reliability analysis is conducted to estimate the probability of limit state exceedance or failure, P_f, and to determine the reliability index β, which is defined by (19),

$$\beta = -\Phi^{-1}(P_f) \tag{19}$$

where Φ represents the standard normal cumulative distribution function.

The First-Order Reliability Method (FORM) is an approximation technique commonly used in reliability analysis to estimate the probability of failure by linearizing the limit state function in the standardized normal space. This method has been widely applied in timber reliability studies [15-18] for its computational efficiency, and will be employed in this study to evaluate the reliability of TCC floors as well, considering the large number of design cases to be evaluated.

5 – RESULTS AND DISCUSSIONS

5.1 RELIABILITY RESULTS OF TCC FLOORS CONSIDERING TIMBER SHEAR LIMIT STATE

Before conducting reliability analysis using FORM, its accuracy is assessed using MCS with a large number of stochastic samples (i.e., 1000000). Fig. 3 illustrates the comparison of the reliability index (β) calculated using FORM and MCS approaches, i.e., β_{FORM} and β_{MCS}, for the design cases with ($L = 10\text{m}, b_w = 3m, h_c = 150mm, s = 500mm$) and increasing live load for timber shear limit state, evaluated using both methods. The relative error of FORM with reference to MCS, calculated as Error $= \frac{\beta_{FORM} - \beta_{MCS}}{\beta_{MCS}} \times 100\%$, ranges from 1.9% to 3.1%, which is considered acceptable. Thus, FORM is adopted for the subsequent reliability analysis.

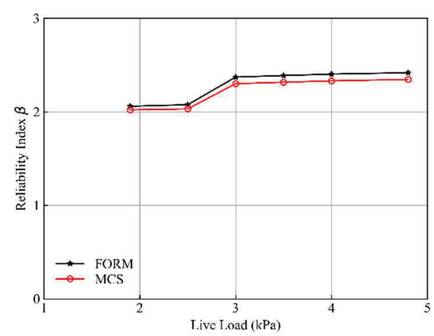

Fig. 3 β vs live load using different reliability methods

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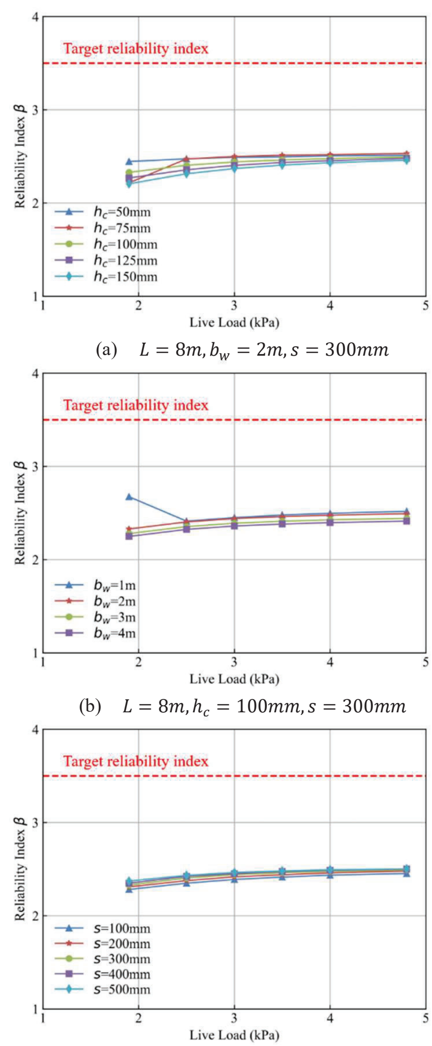
Table 3 Probabilistic descriptions for basic random variables used to model the uncertainty in design parameters

Basic random variable		Distribution	Bias factor	cov	Reference
Load	Dead load X_1	Normal	1.05	0.10	[9]
	Live load X_2	Gumbel	0.90	0.17	[9]
Material	Concrete modulus of elasticity X_3	Lognormal	1.00	0.15	[10]
	Glulam modulus of elasticity X_4	Lognormal	1.00	0.1	[11]
	Shear strength X_5	Lognormal	0.99	0.15	[11]
	STS stiffness X_6	Normal	1.20	0.099	[12]
	Model uncertainty of STS stiffness X_7	Lognormal	1.24	0.26	[12]
Geometry	Concrete width X_8	Normal	1.00	0.02	[13]
	Concrete depth X_9	Normal	1.00	0.02	[13]
	Glulam depth X_{10}	Normal	1.00	0.01	[14]
	Glulam width X_{11}	Normal	1.00	0.01	[11]
	Span X_{12}	Normal	1.00	0.02	[10]
	Connector spacing X_{13}	Normal	1.00	0.02	[10]

For timber shear, the reliability index β ranges from 1.99 to 2.62 for all the designed TCC systems considered. The average β is 2.42, with reliability indices exhibiting minimal variation (cov=0.046). The reliability indices for the timber shear limit state are significantly lower than the target reliability index $\beta_T = 3.5$, indicating that the current design provisions for timber shear in TCC floors may not provide adequate safety margins.

Fig. 4(a), (b), and (c) illustrate the variation of β with increasing live load for TCC systems with different concrete slab thickness, beam spacing and connector spacing, respectively, while keeping other design parameters constant. The red dashed line in Fig. 4 is the target reliability index. The results show that β decreases slightly as the concrete slab thickness increases, though this reduction is less pronounced at higher live loads. For example, for $LL = 1.9kPa$, the difference in β between $h_c = 50mm$ and $h_c = 150mm$ is 0.24, whereas for $LL = 4.8kPa$, the difference is only 0.06. Additionally, as concrete thickness increases, a larger glulam cross-section is required to resist the TCC shear force, leading to an overall increase in the self-weight of TCC floors. However, at higher live loads, the self-weight contribution becomes relatively small compared to the total load effect, leading to a diminishing influence on β.

The results also indicate that, compared to concrete slab thickness, variations in beam spacing and connector spacing have a limited impact on β in the timber shear limit state in general. Notably, the β value for the design case with $b_w = 1m$ and $LL = 1.9kPa$ deviates significantly from other cases. This is because under these conditions the factored resistance exceeds the factored load effect with a relatively low LR ratio (i.e., much less than 1.0), even with the smallest glulam cross-section (80mm × 114mm) available in the industry, resulting in a higher reliability index.



(a) $L = 8m, b_w = 2m, s = 300mm$

(b) $L = 8m, h_c = 100mm, s = 300mm$

(c) $L = 8m, h_c = 100mm, b_w = 2m$

Fig. 4 β vs live load for different design parameters: a) concrete slab thickness, b) beam spacing, and c) connector spacing

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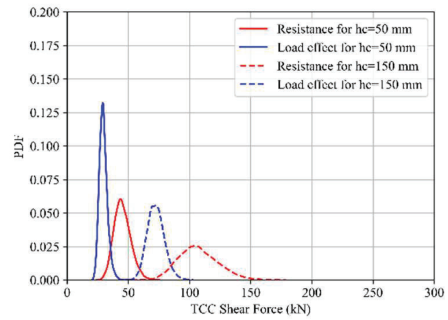
To provide insights into the calculated probability of failure, MCS is used to simulate the probability distributions of resistance and load effects for several design cases. Fig. 5 illustrates the probability density functions (PDFs) of resistance and load effect. The red lines represent shear resistance, while the blue lines represent maximum shear force in the TCC. Fig. 6 illustrates the PDFs of resistance minus load effect ($R - S$). The probability of failure can be visually interpreted as the area under the PDF curve where the values are less than zero, indicating cases where the load effect exceeds the resistance.

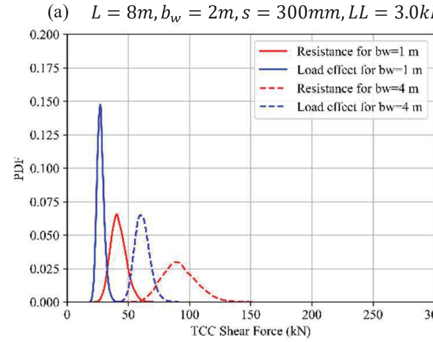
For the timber shear limit state of the designed TCC systems, both resistance and load effect increase as concrete slab thickness increases, as shown in Fig. 5(a). A thicker concrete slab contributes to a higher load effect due to the increased self-weight of the concrete, resulting in a rightward shift in the PDF of the load effect. At the same time, resistance also increases because a thicker slab necessitates a larger glulam cross-section, thereby improving the shear resistance of the TCC floor. Fig. 6(a) further illustrates the shifts of PDFs of $R - S$ rightwards for different concrete slab thicknesses. The PDF of $R - S$ for the case with $h_c = 150\ mm$ exhibits a fatter bell-shaped curve, with the centre shifted to the right. Due to the heavier tail in the PDF of $R - S$ for the case with $h_c = 150\ mm$, the probability of failure, indicated by the area under the PDF curve on the left of vertical axis, is higher for $h_c = 150\ mm$. As a result, Fig. 4(a) shows a slight reduction in the reliability index as concrete slab thickness increases. Although the additional resistance from the thicker concrete slab mitigates some of the adverse effects of the increased load, it does not fully compensate for them, leading to a moderate decrease in structural reliability.

Similarly, both shear resistance and load effect for the designed TCC systems increase as beam spacing increases, as shown in Fig. 5(b). Note that the resistance of the designed TCC floor system naturally increases in response to the increased load effect. As illustrated in Fig. 6(b), a similar trend is observed when increasing the beam spacing for the PDFs of $R - S$, compared to when increasing concrete slab thickness. It shows a slight reduction in the reliability index as the beam spacing increases. This implies that the increase in load effect is counterbalanced by the corresponding increase in resistance, leading to only a minor reduction in the reliability index.

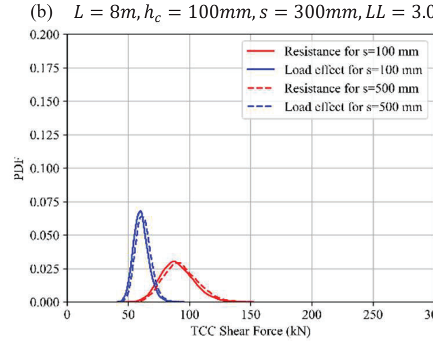
In contrast, variations in connector spacing, as shown in Fig. 5(c), exhibit only a minor influence on the shear resistance and load effect of the designed TCC systems in the timber shear limit state. As illustrated in Fig. 6(c), the PDFs of both resistance and load effect remain relatively unchanged across different connector spacing values, indicating that the effect on the reliability of the TCC floor under the timber shear limit state is minimal. Note that γ_t represents the composite action of TCC floors, where a higher value indicates stronger composite behaviour. In the analysed design cases of Fig. 5(c), γ_t are equal to 0.64 and 0.23 when the connector spacings are 100 mm and 500 mm, respectively. It can be observed that as connector spacing decreases, the composite action increases. However, this primarily affects the overall bending stiffness, while its influence on TCC shear resistance and shear load effects remain relatively small.



(a) $L = 8m, b_w = 2m, s = 300mm, LL = 3.0kPa$

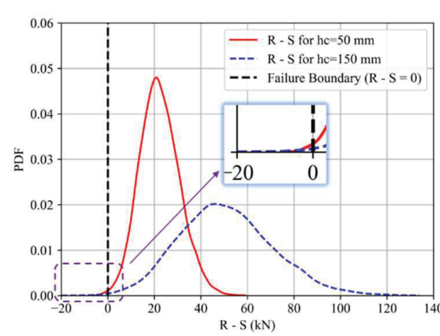


(b) $L = 8m, h_c = 100mm, s = 300mm, LL = 3.0kPa$



(c) $L = 8m, h_c = 100mm, b_w = 2m, LL = 3.0kPa$

Fig. 5 PDFs of resistance and load effect for different design parameters: a) concrete slab thickness, b) beam spacing, and c) connector spacing



(a) $L = 8m, b_w = 2m, s = 300mm, LL = 3.0kPa$

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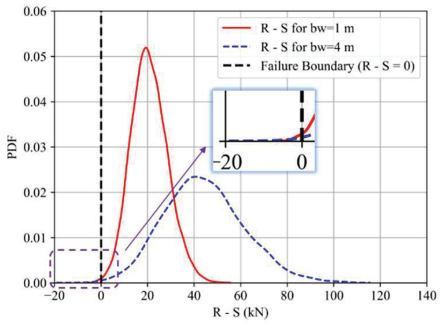
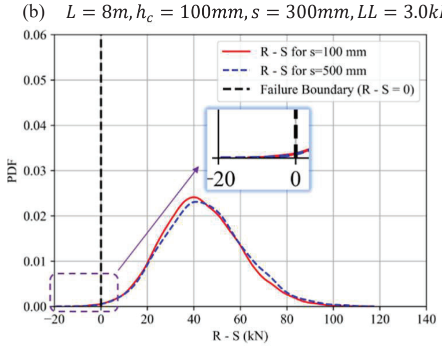


(b) $L = 8m, h_c = 100mm, s = 300mm, LL = 3.0kPa$



(c) $L = 8m, h_c = 100mm, b_w = 2m, LL = 3.0kPa$

Fig. 6 PDFs of resistance minus load effect (R-S) for different design parameters: a) concrete slab thickness, b) beam spacing, and c) connector spacing

The reliability indices for TCC floors under shear limit state were found to be significantly lower than the target level, raising concerns about whether this is due to the presence of concrete or the shear design provisions of glulam beams. To further investigate this, the next section examines the shear reliability of pure glulam beams.

5.2 RELIABILITY OF GLULAM BEAMS CONSIDERING SHEAR LIMIT STATE

This section conducted independent reliability evaluation of pure glulam beams, following the same methodology used for TCC floors, but without the influence of the concrete slab.

The results show that the reliability index β ranges from 2.13 to 2.57 across all the designed glulam beams, which is below the target reliability index. Fig. 7 illustrates the variation of β for glulam beams under different live load and beam spacing configurations. The figure shows that the reliability index varies little across different live loads. Additionally, the effect of beam spacing (b_w) on β is minimal, in spite of a slight decrease in reliability.

It can be seen that even without the influence of concrete, the reliability index for shear failure of glulam beams was still lower than the target reliability index of 3.5 when using $\phi_t = 0.9$. This suggests that the low reliability issue of the designs with respect to timber shear failure not only exists for TCC floors but also for glulam beams.

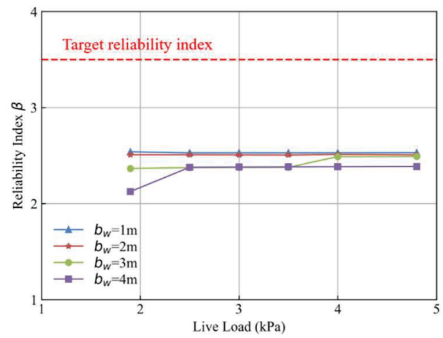


Fig. 7 β vs live load for different beam spacing (L=8m)

5.3 RECOMMENDED TIMBER SHEAR RESISTANCE FACTOR IN TCC FLOORS

As pointed out earlier, a resistance factor of $\phi_t = 0.9$ as specified in CSA O86-24 [5] for the timber shear limit state both in TCC floor and pure glulam beam design fails to meet the target reliability level prescribed in CSA S408-11 [6]. Thus, a more appropriate resistance factor ϕ_t associated with the glulam shear design equation needs to be proposed aiming to achieve the desirable reliability level $\beta_T = 3.5$. To this end, different resistance factors are used for design and the reliability levels achieved are evaluated. Fig. 8 illustrates reliability indices corresponding to different values of resistance factor ϕ_t in timber shear limit state for a TCC floor. It can be observed that as ϕ_t increases, reliability index decreases. Table 4 presents the reliability results of all design cases for the timber shear limit state when different values of ϕ_t are used, with the mean value shown in parentheses. The results indicate that the reliability indices in all TCC floor cases can achieve the target reliability level when $\phi_t = 0.7$. Furthermore, the reliability index of pure glulam beams considering shear limit state ranges from 3.56 to 3.70 across all designed glulam beams, suggesting that a lower resistance factor may be necessary to achieve sufficient shear reliability. Therefore, $\phi_t = 0.7$ is deemed more appropriate for the TCC design against the timber shear failure to reach the required safety level specified in CSA S408-11 [6].

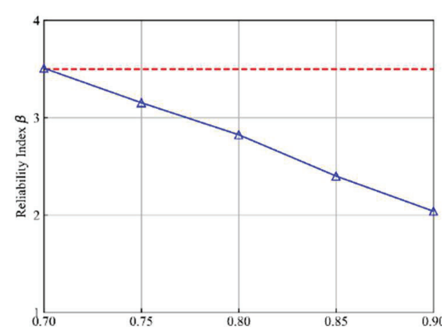


Fig. 8 β vs resistance factor of timber
$(L = 10m, b_w = 2m, h_c = 150mm, s = 100\ mm, LL = 1.9kPa)$

Table 4 Reliability results in timber shear limit state for different ϕ_t

ϕ_t	β (Mean)	cov
0.9	1.99~2.67 (2.42)	0.047
0.85	2.29~2.94 (2.71)	0.038
0.8	2.60~3.23 (3.03)	0.030
0.75	3.05~3.54 (3.36)	0.023
0.7	3.42~3.88 (3.71)	0.018

6 – CONCLUSION

This study presented a reliability evaluation of TCC floors designed according to CSA O86-24, with a focus on timber shear failure. The reliability indices obtained using FORM demonstrated that the current resistance factor of $\phi_t = 0.9$ results in a reliability index lower than the target level prescribed for brittle failures in CSA S408-11.

Additionally, the parametric studies revealed that increasing concrete slab thickness slightly reduces the reliability index, whereas variations in glulam beam spacing and connector spacing have a negligible impact on the reliability level when the same design provisions are followed.

An additional analysis on glulam beams without concrete was conducted and the results showed that pure glulam beams also exhibited low shear reliability at $\phi_t = 0.9$, suggesting that the reduced reliability in TCC floors was not solely due to the presence of concrete in TCC systems.

As such, a reduced resistance factor of $\phi_t = 0.7$ is recommended for glulam shear design in TCC floors in order to achieve the desired safety margin.

Similar reliability assessments for other limit states, including timber bending, concrete bending, concrete shear and connection shear failure, as well as for serviceability limit states, have been conducted to establish a comprehensive reliability-based design for TCC floor systems. These results will be reported in future publications.

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