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FINITE ELEMENT-BASED EVALUATION OF WALKING-INDUCED VIBRATIONS IN TIMBER-CONCRETE COMPOSITE FLOORS

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ABSTRACT: This study investigates the dynamic behaviour of Cross-Laminated Timber (CLT) and Timber-Concrete Composite (TCC) floor systems under human induced vibrations through parametric analysis. A full-scale 9.35 m TCC floor segment was designed to promote failure in vibration and deflection, using the γ-method from Eurocode 5 with the aim to evaluate the effective bending stiffness. The results show a 63% reduction in midspan deflection for the TCC system compared to the CLT panel, due to stiffness contribution from the concrete layer and composite action. The addition of concrete consistently decreased the natural frequencies due to the increased mass. The TCC system showed a significant reduction in peak acceleration compared to that with CLT alone, demonstrating enhanced vibration mitigation. The study also examined the effects of connection stiffness, occupant weight, gait frequency, and multiple occupants. The findings show the complexity of vibrational behaviour in TCC systems and provide a foundation for validating future experimental work.

KEYWORDS: Timber-concrete composite (TCC), human-induced vibrations, finite elements modelling.

1 – INTRODUCTION

Timber-concrete composite (TCC) floors have become a promising solution in modern wood construction, addressing the growing demand for sustainable, lightweight, and high-performance structural systems. By integrating a reinforced concrete slab into a timber base through shear connectors, a floor system emerges which combines the unique characteristics of both materials. This hybrid system results in enhanced structural efficiency, improved acoustic performance, and a reduced environmental footprint compared to conventional floor systems. Additionally, TCC allows for material optimization, reducing concrete consumption while utilizing renewable resources [1].

Despite the aforementioned advantages, TCC floors are inherently lightweight, which, while beneficial for material efficiency and ease of construction, makes them more susceptible to excessive vibrations under dynamic loading conditions, particularly those induced by human activities such as walking. Uncontrolled floor vibrations can significantly impact occupant comfort, leading to serviceability concerns that limit their application in larger spans or high-occupancy buildings. Current design codes and standards provide limited guidance on vibration performance for TCC floors, leading to a growing interest in gaining a more comprehensive understanding of their dynamic behaviour [2], [3].

To address these gaps and advance knowledge in this area, the current study – part of an ongoing research at the University of Ottawa – explores the effect of human-induced loading on different parameters in TCC systems. Specifically, the research focused on the vibrational performance of TCC floors through experimental of full-scale Cross-Laminated Timber (CLT) and CLT-concrete composite floors. The hybrid floor system was designed to meet the ultimate limit state (ULS) requirements, while intentionally failing the serviceability criteria for deflection and vibration.

This paper presents experimental results for the CLT system only, while numerical simulations have been used to extend the knowledge to TCC configurations. Future phases of the research will involve experimental investigations of the composite TCC system in order to further refine the proposed numerical models. A finite element (FE) model was developed and validated to simulate the response of both systems to walking loads, capturing key parameters such as natural frequencies and amplitude levels. This approach aims to provide insights into the factors influencing the structural behaviour of intricate TCC floor systems.

2 – EXPERIMENTAL TESTS

2.1 DESCRIPTION OF THE TESTED PANELS

The tested floor structure consists of three CLT panels, each measuring 2 × 9.35 m. The panels are made of grade

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"E1" timber and have a five-layer configuration, with each lamination being 35 mm thick, resulting in a total thickness of 175 mm. In the experimental setup, the panels are simple supported by 1.2 m high CLT walls. The walls are anchored to the strong floor using steel brackets and threaded steel rods. Fig. 1. shows the placement of the panels and the ongoing construction process for the full-scale CLT floor.

Figure 1. Full-scale CLT floor under construction.

At this stage, the focus of the study is on evaluating the structural performance of the individual CLT panels separately prior to integrating them into the composite system. In a subsequent phase, adjacent CLT panels will be connected to form a continuous deck, and a 100 mm concrete layer will be added on top. The concrete will be mechanically connected to the timber panels using shear connectors enabling the composite action.

The results obtained from testing the CLT panels in isolation aims to serve multiple purposes: assessing the dynamic and serviceability behaviour of individual elements, validating finite element models, and allowing for a parametric study to be conducted on the hybrid CLT-concrete system to better the parameter to be investigated in the composite floor.

2.2 DESCRIPTION OF EXPERIMENTS

A static load test was first conducted on each CLT panel by applying a 1 kN load at their respective midspans. A displacement transducer, with a measurement range of 0-25 mm, was used to measure the resulting midspan deflection. The results obtained from this test highlighted the variability associated with conducting measurements at such a low level of loading In order to better assess the stiffness of the individual panels, an additional test comprised of applying a static load of 5 kN undertaken and the deflection results from that test was also recorded.

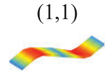
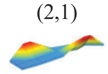
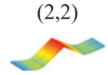
Additionally, impact tests were conducted using a 15 lb (6.8 kg) medicine ball, which was dropped from a consistent height to excite the floor structure. Ten triaxial accelerometers were strategically placed across the panel surface, capturing acceleration responses at a sampling rate of 488 samples per second. The Enhanced Frequency Domain Decomposition (EFDD) technique was employed to analyze the collected data and obtain frequencies, mode shapes and damping ratios.

With the fundamental frequency of the floor identified through impact testing, walking frequencies were selected and walking tests performed. A person with 60 kg weight conducted walking cycles at approximately 2 Hz to capture the panels' response. Accelerations and velocities were recorded using accelerometers positioned along the floor. The collected data was processed through a first order high-pass filter with a cut-off frequency of 0.1 Hz to remove low-frequency noise.

2.3 EXPERIMENTAL RESULTS

The results from the static and dynamic tests are summarized in Table 1. In the table, Δ_{1kN} and Δ_{5kN} represent the midspan deflections resulting from the application of 1 kN and 5 kN loads, respectively. The parameters a_{peak} and v_{peak} correspond to the peak acceleration and peak velocity, respectively, measured at the midspan. The root-mean-square (RMS) values for acceleration (a_{RMS}) and velocity (v_{RMS}) are also provided. Additionally, the first four identified mode shapes for each panel are listed, along with corresponding natural frequencies (f) and damping ratios (ξ).

Table 1. Static and dynamic test results for the tested CLT panels.

	CLT-P1		CLT-P2		CLT-P3	
Δ_{1kN} (mm)	2.09		0.97		1.16	
Δ_{5kN} (mm)	9.73		10.07		9.99	
a (m/s²)	0.580		0.594		0.588	
a_{RMS} (m/s²)	0.163		0.164		0.163	
v (m/s)	0.0230		0.0233		0.0230	
v_{RMS} (m/s)	0.00801		0.00817		0.00809	
Mode Shape	f (Hz)	ξ (%)	f (Hz)	ξ (%)	f (Hz)	ξ (%)
 (1,1)	4.00	5.9	3.94	4.6	3.99	5.7
 (2,1)	15.30	4.3	15.26	4.9	15.36	4.3
 (2,2)	24.35	3.3	24.20	3.3	23.76	3.3
 (3,1)	32.21	3.4	31.20	1.7	32.57	2.0

The results from the static and dynamic tests reveal relatively similar performance characteristics between the three panels with some minor variations. The midspan deflections under 5 kN load are comparable across all panels. Since the deflections at 5 kN are similar, the variance in the 1 kN results is likely due to differences in material properties, manufacturing tolerances, or support conditions which influence the panel at a low load level, without significantly impacting overall structural performance. Peak accelerations and velocities, as well as their RMS values, are also consistent across the panels, indicating similar dynamic responses. The first four mode shapes and their corresponding natural frequencies are nearly identical for all panels, while slight differences are observed in damping ratios. This is expected since damping is a complex phenomena and notoriously difficult to measure experimentally. The fundamental frequency is approximately 4 Hz for all panels, while higher modes show frequencies around 15 Hz, 24 Hz, and 32 Hz for modes (2,1), (2,2), and (3,1), respectively. Damping ratios generally decrease for higher modes, ranging from about 6% for the fundamental mode to around 2-3% for higher modes. These results suggest that the three CLT panels have consistent structural and dynamic properties, with only minor variations in their performance.

3 – FE MODEL AND VERIFICATION

In this study FE models were developed in the Abaqus/CAE software [4] to simulate the dynamic performance of CLT panels and simulated TCC floors with screw connections. Static and modal analyses were carried out using calibrated mesh sizes to obtain mode shapes, natural frequencies, midspan deflections and amplitudes of vibration. The results from the model were validated against experimental data from previous studies [5] as well as those presented in Section 2.

3.1 MATERIAL MODELLING

In the FE model, both CLT and concrete layers were modelled using C3D8R elements, which are eight-node linear brick elements with six degrees of freedom per node.

Concrete was modelled as an isotropic elastic material without plastic properties, which is a reasonable assumption for evaluations at service level. Reinforcement was excluded from the model after preliminary studies showed insignificant differences in results between models with and without reinforcement.

The CLT members were modelled as linear elastic orthotropic plates with solid cross-sections, considering different modulus of elasticity (MOE) for longitudinal and transversal layers. The composite beam theory was applied to account for the layered structure and varying material properties. The equivalent width technique addresses this by adjusting the width of each component relative to the principal bending axis, based on their respective MOE [6]. For a CLT beam with width b, the equivalent width of the cross-layer, b_{eq}, can be calculated according to Eq. 1.

$$b_{eq} = \frac{E_{90}}{E_0} b \tag{1}$$

Where E_0 and E_{90} are the MOE for the longitudinal layers and transversal layers, respectively. Fig. 2 shows the real and equivalent cross-section of a 5-layer CLT member.

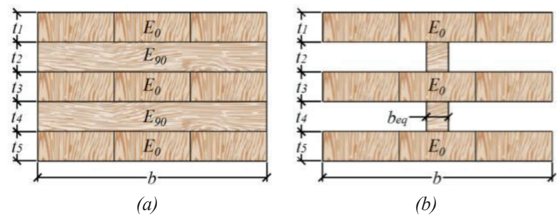


Figure 2. (a) Real and (b) Equivalent cross section for a 5-layer CLT element.

In the model, the modulus of elasticity in the longitudinal E_1 and transversal E_2 directions of the CLT panel was derived by dividing the effective bending stiffnesses $EI_{eff,(L)}$ and $EI_{eff,(T)}$ by the moment of inertia of a solid section with dimensions identical to the real dimensions of the layer. The shear modulus in the longitudinal-transverse plane G_1 was set as $E_1/16$ and in the transverse plane as $G_1/10$, according to CSA O86 [7]. The elastic and shear moduli in the tangential or radial directions are assumed to be the same.

The damping coefficient was implemented using Rayleigh damping constants. An assumed damping ratio of 5% was assigned to the concrete layer, reflecting typical values for reinforced concrete structures. For the CLT layer, the damping ratio was calibrated based on the average values obtained from the experimental results from Section 2.

3.2 COMPOSITE FLOOR MODELLING

In the composite section, to simulate the screw connections between timber and concrete, horizontal elastic linear springs were placed at the location of each shear connector. The spring stiffness (k_{ser}) along the x and z axes was defined based on experimental results from push-out tests [8]. The interface between timber and concrete was modelled using “Surface-to-Surface” contact, with "Hard Contact" for normal behaviour, which prevents penetration between surfaces. In this study, “Small Sliding” was assumed as the contact property for the CLT-concrete interface. This assumption allows for limited relative movement between the surfaces while maintaining a consistent contact area. It simplifies the analysis by preventing significant slipping or separation, consistent with the expected behaviour of the CLT-concrete interface. The model incorporated simply supported boundary conditions, and loads were applied as per the experimental setup.

3.3 WALKING LOAD MODELLING

The walking load can be described as a periodic activity, allowing for its representation through Fourier series decomposition. This approach expresses the walking force as a sum of harmonic components, capturing both the fundamental walking frequency and its higher harmonics

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[9]. Using the Fourier analysis technique, Chao E. et al. [10] conducted an extensive study on gait biomechanics, focusing on force parameters such as amplitude and timing. Their research established a consistent relationship between ground reaction forces and the gait cycle, defining nine key force parameters as a percentage of body weight. Bard D. et al. [11] used a simplified approach to modelling human-induced vibrations by applying force amplitudes on the surfaces in the normal direction to the floor, where the amplitude was calculated as a time history.

Building on these principles, the present model incorporates walking loads applied as pressure forces over the surface. The force amplitude and time intervals between peaks were adjusted according to the gait cycle characteristics suggested by Chao E. et al. [10], and the duration of a single footstep was determined using Eq. 2.

$$f_{walk} = \frac{1}{(gait - 0.1s)} \tag{2}$$

Fig. 3 presents the amplitude of load as a function of time, illustrating the alternating peaks corresponding to the force exerted by each foot during walking at a frequency of 2 Hz. The figure includes a schematic representation of the FE model for walking loads on the TCC system.

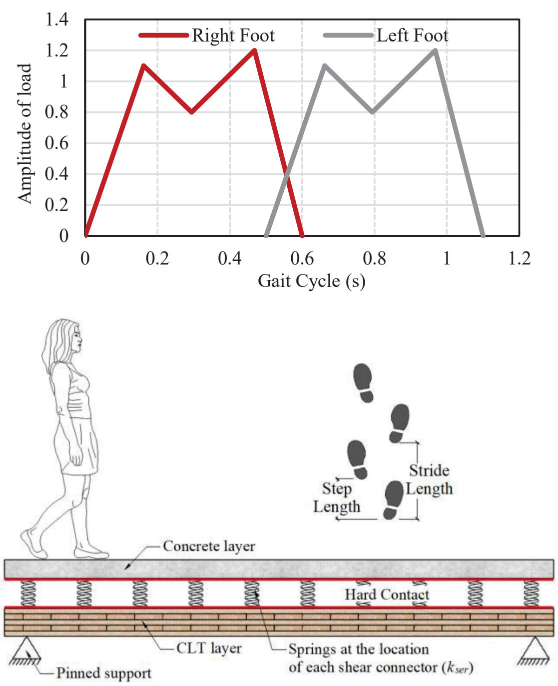

Figure 3. Reaction forces of a gait cycle and finite element model representation of walking load.

3.4 MESH CONVERGENCE ANALYSIS

A mesh convergence analysis was conducted considering seven different mesh densities, using modal analysis to compute the natural frequencies. Convergence was assessed using a relative difference parameter, comparing each mesh to the finest mesh (approximate elements size of 25 mm, and 2.7×10^6 nodes). Based on a balance between accuracy and computational time, a mesh with an approximate 50 mm global size was selected. Discretization errors for the chosen mesh were calculated. The errors for the first seven natural frequencies ranged from 0.05% to 2.07%, with most being under 1.5%.

3.5 MODEL VALIDATION

The numerical model developed in this study was validated through a two-stage process. First, the FE was validated against the experimental data obtained from the CLT panels tested in this study (see Section 2.3). This validation included a comparison of natural frequencies, mode shapes (both qualitative and quantitative), static deflection under a 5 kN midspan load, and dynamic response characteristics, such as acceleration and velocity, recorded during simulated walking tests.

In the second stage, the model was further validated against CLT-concrete section using experimental data from Quang Mai K. et al. [5]. Their study involved testing five full-scale specimens (6 × 9 m) to assess the effects of connector angles, connector types, and connector spacing on structural performance. Four of the specimens were hybrid CLT-concrete floors, while one consisted of a bare CLT panel, and was referred to as “Standard” floor. Each CLT panel comprised five layers, each 30 mm thick, topped with a 100 mm concrete layer. The specimens were simply supported and tested under four-point bending, as well as impact tests to evaluate both bending stiffness and vibration behaviour. The geometries and testing details for the specimens are summarized in Table 2.

Table 2. Description of CLT-concrete composite floor specimens [2].

Specimen	Connec. insertion angle	Connec. spacing (mm)	Nº of rows	Total nº of Connec.
Standard	-	-	-	0
B-45-s150	45°	150	4	160
SFS-45-s150	45°	150	4	160
SFS-45-s300	45°	300	4	160
SFS-90-s150	90°	150	4	160

Table 3 presents a comparison between the numerical model predictions and the experimental results, detailing deflections (Δ) and the first three natural frequencies (f_1, f_2 and f_3) for both the bare CLT and CLT-concrete specimens. The numerical model demonstrates strong agreement with experimental data. Deflection predictions tend to slightly underestimate flexibility, with relative differences ranging from 1.9% to 11.1%, indicating that the model assumes a slightly stiffer response compared to the tested specimens.

Moreover, the first three vibration modes identified in the FE model closely match those observed in the experimental tests (see Table 1 and 4).

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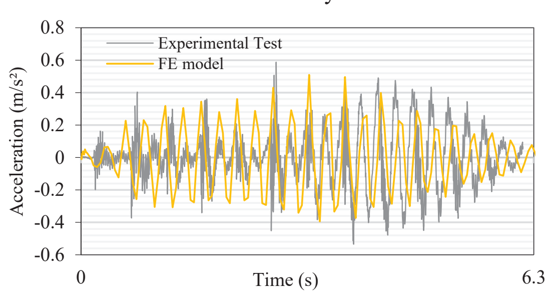
Table 3. Comparison of results obtained from FE model and experimental test.

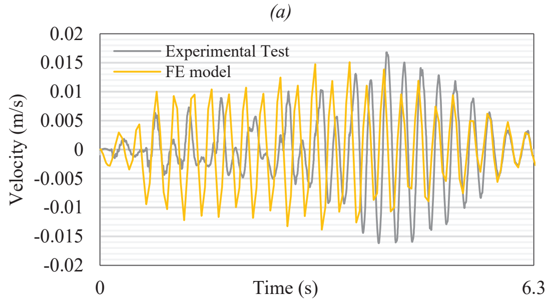
Specimen	Δ (mm)			f_1 (Hz)			f_2 (Hz)			f_3 (Hz)		
	Test	Model	%	Test	Model	%	Test	Model	%	Test	Model	%
CLT-P1	9.73		11.1	4.00		0.0	15.30		3.0	24.35		8.0
CLT-P2	10.07	10.81	7.3	3.94	4.00	1.5	15.26	15.76	3.3	24.20	26.31	8.7
CLT-P3	9.99		8.2	3.99		0.3	15.36		2.6	23.76		10.7
Standard	33.29	31.57	5.2	8.77	8.76	0.1	23.76	30.78	1.2	58.21	54.23	6.8
B-45-s150	20.86	20.39	2.3	12.01	11.91	0.8	23.86	31.54	32.2	44.01	41.33	6.1
SFS-45-s150	19.98	19.61	1.9	12.03	11.85	1.5	23.50	30.26	28.8	34.25	40.82	19.2
SFS-45-s300	16.44	14.91	9.3	11.48	11.58	0.9	38.26	39.35	2.8	44.52	44.40	0.3
SFS-90-s150	13.78	14.48	5.1	11.65	11.71	0.5	18.99	20.92	10.2	34.25	33.56	2.0

The fundamental frequency (f_1) is well captured, with errors generally below 1.5%, suggesting that the model effectively represents global stiffness. However, differences become more pronounced for higher-order frequencies (f_2 and f_3). These deviations may be attributed to simplifications made in the model related to the boundary conditions or the modelling of material interactions, particularly in the composite systems.

As previously mentioned, the three tested CLT panels were subjected to a walking excitation at a frequency of 2 Hz. The results were nearly identical across the three panels, and their acceleration and velocity responses for panel CLT-P3 were compared with the FE model predictions. As shown in Fig. 4, the model reasonably follows the measured acceleration and velocity curves.



(a)



(b)

Figure 4. Validation of FE Model: Experimental vs. Numerical: (a) Acceleration and (b) Velocity Results.

The experimental test recorded a peak acceleration a_{peak} of 0.588 m/s², while the FE model predicted 0.510 m/s², indicating a slight underestimation of 13.3% Conversely, the model marginally overestimated a_{rms}, projecting 0.192 m/s² compared to the experimental value of 0.163 m/s². These discrepancies are within an acceptable range for dynamic structural analysis. Several factors could account for these variations, including natural variability in human gait patterns, assumptions made in damping calculations, and subtle differences in boundary conditions. Despite the differences, the FE model successfully captures the essential trends of the dynamic response.

4 – PARAMETRIC STUDY ON TCC PANELS

This section focuses on the parametric analysis of CLT-concrete composite systems. A full-scale 2 × 9.35 m CLT-concrete composite specimen was specifically designed to obtain failure in vibration and deflection. The effective bending stiffness of the system was evaluated using the γ-method, adopted in Eurocode 5 [10]. This method is particularly suitable for composite structures and provides a simplified calculation approach for determining the effective bending stiffness of the panel. The composite floor consists of a grade "E1" CLT slab (5 laminations, 35 mm each, totalling 175 mm), a 100 mm thick standard-weight concrete slab (25 MPa compressive strength), and self-tapping screws (STS) cross-inserted at a 45° angle as shear connectors. The shear connector arrangement features 4 rows per meter width with a 250 mm longitudinal spacing. The screws are 8 mm in diameter, 180 mm in length, and embedded 100 mm into the CLT panel. This configuration results in a serviceability shear stiffness (k_{ser}) of 21.2 kN/mm [11], allowing for the consideration of semi-rigid composite action between the CLT and concrete layers. Fig. 5 depicts the details on the spacing of the connections for a 1 meter panel.

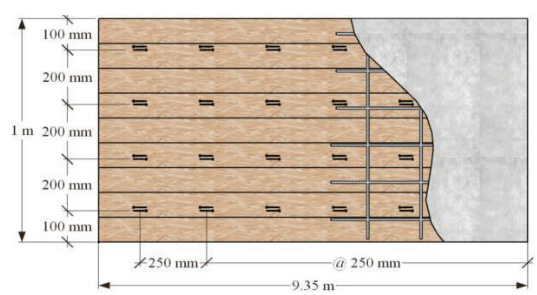


Figure 5. Parametric study: details on the connection spacing.

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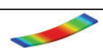
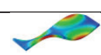
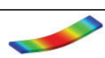
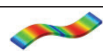
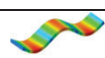
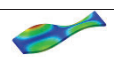
4.1 PERFORMANCE EVALUATION OF CLT VERSUS TCC FLOOR SYSTEMS

The results obtained from the FE modelling revealed that the midspan deflection under a 1 kN load decreased from 2.05 mm for CLT to 0.76 mm for the TCC system, representing a 63% reduction. This stiffness increase can be attributed to added stiffness of the concrete layer and by the composite action achieved using self-tapping screws as shear connectors.

The natural frequencies of the system were also modified with the addition of the concrete layer, as observed in Table 4.

Table 4. FE model comparison of frequencies and mode shape for CLT and TCC panels.

	f_1 (Hz)	f_2 (Hz)	f_3 (Hz)	f_4 (Hz)
CLT	 4.00	 15.76	 26.31	 34.61
TCC	 3.47	 10.64	 21.86	 28.26

The consistent reduction in natural frequencies for the TCC system indicates an increase in the system's mass, which is expected due to the addition of the concrete layer. The highest reduction was observed in the second mode (32.49%), while the first mode showed the smallest reduction (13.25%). Notably, there was a switch in the pattern between the third and fourth modes of vibration, highlighting the complex influence of composite action and the addition of mass on the structure's vibrational behaviour. A comparison between the accelerations derived from the FE model for the CLT and TCC systems under a walking frequency of 2 Hz for a single 60 kg individual is presented in Fig. 6.

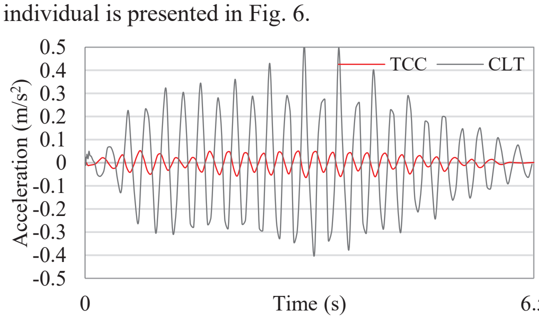


Figure 6: Time-history response: comparison between the CLT and TCC systems under a walking frequency of 2 Hz.

The CLT system exhibited a_{peak} of 0.510 m/s² and a_{RMS} of 0.191 m/s², while the TCC system yielded significantly lower values with a_{peak} of 0.0640 m/s² and a_{RMS} of 0.0272 m/s². This reduction demonstrates the TCC system's effectiveness in mitigating floor vibrations induced by human walking. The improved performance is attributed to the increased mass and stiffness provided by the concrete layer and the composite action enabled by the shear connectors.

4.2 CONNECTION STIFFNESS

The impact of connection stiffness and spacing was examined in this study since the stiffness of these connections plays a significant role in determining the floor's bending stiffness and overall composite efficiency. Initially, the model was analyzed by varying the interlayer connection stiffness from very flexible (10 kN/mm) to very stiff (200 kN/mm), while keeping the other parameters constants. Although it is well-established that connection stiffness affects the effective bending stiffness of composite systems, this study found no major effects on the fundamental frequency or mode shapes of the floor. This finding aligns with previous research on screws and notched connectors [13], [14].

4.3 OCCUPANTS' WEIGHT

The impact of occupant weight on floor system vibrations was also investigated. To simulate the loading conditions, weights of 60 kg, 70 kg, and 100 kg were applied while maintaining a walking frequency of 2 Hz. These weights were represented as pressure loads at various points on the surface to simulate waalking of a single occupant. The model analyzed the effects of each scenario on acceleration and velocity, with the results shown in Fig. 7.

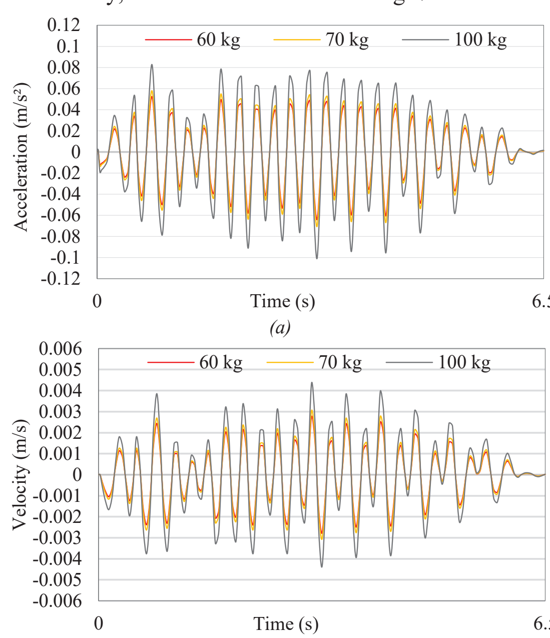


Figure 7. Impact of occupants' weight on (a) acceleration and (b) velocity of TCC specimens.

The analysis reveals that occupant weight significantly influences the vibration behaviour of the floor system. As occupant weight increases, both peak and RMS accelerations also increase. Specifically, peak accelerations for occupant weights of 60 kg, 70 kg, and 100 kg were 0.0641 m/s², 0.0707 m/s², and 0.101 m/s², respectively.

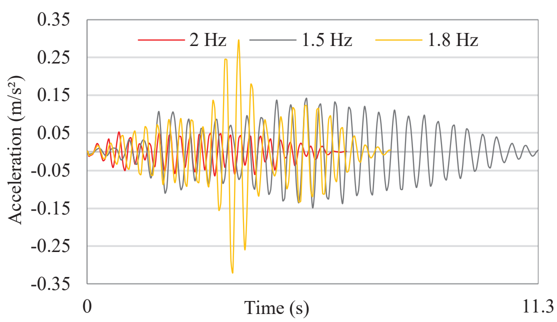
Correspondingly, RMS accelerations were 0.0272 m/s², 0.0301 m/s², and 0.0430 m/s². The results also show a proportional increase in both peak and RMS accelerations as occupant weight increases. Notably, the 70 kg and 60 kg occupants experience approximately 70% and 63.5% of the acceleration obtained for the 100 kg occupant, respectively.

4.4 GAIT FREQUENCY

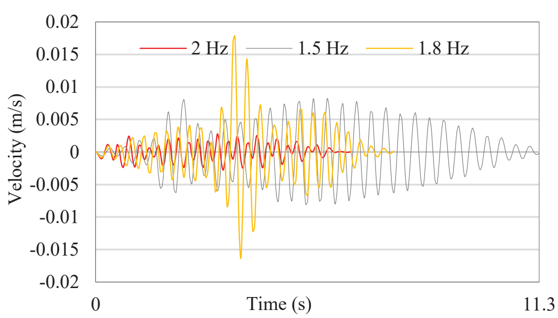
The effect of the walking frequency was also examined. To simulate realistic ranges of pedestrian movement, walking frequencies of 1.5 Hz, 1.8 Hz, and 2.0 Hz were applied, representing slow, normal, and fast walking speeds, respectively. These frequencies were modelled as time-dependent pressure loads distributed across the floor surface to represent a single pedestrian weighing 60 kg, while all other parameters were kept constant. The walking cycle properties used in the model are summarized in Table 5. For instance, at a walking frequency of 1.5 Hz, each pair of steps lasted 1.4 seconds with a step length of 0.6 meters. The results for acceleration and velocity are presented in Fig. 8.

Table 5. Properties of the walking cycle.

Gait	f_{walk} (Hz)	Duration (s)	Step length (m)
Slow	1.5	1.4	0.60
Normal	1.8	1.2	0.70
Fast	2.0	1.1	0.75



(a)



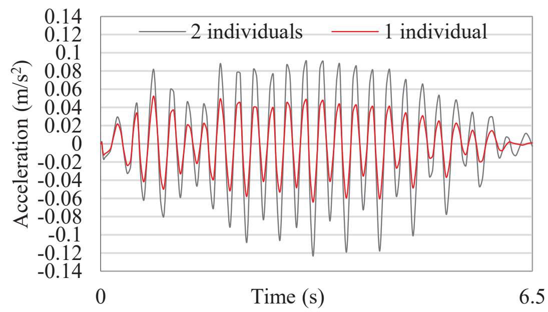
(b)

Figure 8. Impact of gait frequency on (a) acceleration and (b) velocity of TCC specimens.

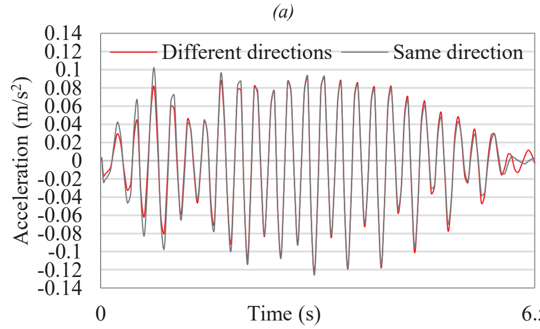
It can be observed that the peak acceleration is highest at a walking frequency of 1.8 Hz (0.319 m/s²), followed by 1.5 Hz (0.149 m/s²), and lowest at 2.0 Hz (0.0641 m/s²). Similarly, the RMS acceleration values demonstrate a frequency-dependent trend. The highest RMS acceleration is observed at 1.8 Hz (0.0842 m/s²), while lower values are recorded at 1.5 Hz (0.0640 m/s²) and 2.0 Hz (0.0272 m/s²). This suggests that the floor system is more sensitive to dynamic loading at 1.8 Hz, likely due to resonance effects.

4.5 EFFECT OF TWO OCCUPANTS WALKING

The model further investigated the impact of multiple occupants on the floor. Two individuals weighing 60 kg each were modelled walking at a frequency of 2.0 Hz. Two scenarios were explored: first, the occupants were simulated walking in opposite directions, representing unsynchronized movement; then, they were modelled walking together with synchronized gait. The model analyzed the effects of each scenario on acceleration, comparing the results to single-occupant simulations. The findings are illustrated in Fig. 9.



(a)



(b)

Figure 9. Impact of two occupants on floor's acceleration: (a) Single occupant vs. dual occupants, (b) Asynchronous vs. synchronized dual-occupant gait patterns.

The analysis shows that when two occupants walk asynchronously, the peak and RMS accelerations are 0.123 m/s² and 0.0517 m/s², respectively. Compared to a single occupant (0.0641 m/s² and 0.0272 m/s²), this represents an increase of approximately 92.2% in peak acceleration and 90.1% in RMS acceleration.

When the occupants walk synchronously, the peak and RMS accelerations are 0.126 m/s² and 0.0532 m/s², respectively. This corresponds to only a slight increase of about 2.0% in peak acceleration and 2.9% in RMS acceleration, compared to the asynchronous walk.

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5 – CONCLUSIONS

This study presented a comprehensive parametric analysis of a TCC systems, focusing on its vibrational behaviour under various loading scenarios. The research highlighted the effectiveness of TCC systems in enhancing structural performance. Key findings from this investigation are as follows:

- A substantial reduction in midspan deflection was observed, indicating enhanced stiffness attributed to the concrete layer and the composite action facilitated by self-tapping screws. Nevertheless, the natural frequencies of the TCC system consistently decreased across all modes, with the most pronounced reduction was observed in the second mode. Despite lower natural frequencies, the TCC system exhibited significantly reduced acceleration values under simulated walking loads.
- The connection stiffness in TCC systems, while crucial for effective bending stiffness, has minimal impact on natural frequencies and mode shapes.
- A proportional increase in peak and RMS accelerations was found with increased occupant weight. Specifically, accelerations increased by approximately 58% when the occupant's weight was increased from 60 kg to 100 kg.
- The investigated TCC system is most sensitive to vibrations at a walking frequency of 1.8 Hz, where peak and RMS accelerations were highest. This suggests resonance effects at this frequency.
- The presence of two occupants walking asynchronously increased peak accelerations by approximately 92.2% compared to a single occupant. Synchronized walking resulted in slightly higher accelerations due to the constructive interference of dynamic forces.

This study underscores the potential of TCC systems to significantly enhance floor vibration performance, offering a sustainable and efficient alternative to traditional floor systems. The findings contribute to the understanding of the dynamic behaviour of TCC systems and provide valuable insights for optimizing design parameters, including connection stiffness, occupant loading, and walking frequencies. Future research will involve experimental validation of the parametric model and further exploration of damping characteristics to refine predictive accuracy and enhance vibration control strategies in TCC floor systems.

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