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Human-Induced on Timber Concrete Composite (TCC) and Reinforced Concrete (RC) Flooring System

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Abstract

The study conducted at a building located in Sri Alam Pasir Gudang, Johor involved walking tests on timber concrete composite (TCC) and reinforced concrete (RC) floors and to stimulate human-induced vibrations the raw data from these experiments will undergo analysis using ARTeMIS software. The result reveals that the natural frequency for both TCC and RC floors ranges from 10.35Hz to 51.27Hz and 13.67Hz to 51.27. These natural frequencies exceed the 8Hz comfort range for human comfort. The wave propagation graph shows the middle floor of both floors is the critical area. The analysis concludes that TCC floors, due to their low-frequency nature, exhibit more significant weakness to deformation vibrations, resulting in weakened serviceability compared to RC floors. Comprehending these vibration behaviour is important in the field of structural design within the construction industry, as discomfort caused by floor vibrations influences how occupants perceive safety and comfort.

1. Introduction

The study of the human-induced timber concrete composite (TCC) and the reinforced concrete (RC) floor has become more of a necessity in recent years because the upgrading of materials in building design creates lighter structures, with improvements that demand a more stable operating environment (Dias, 2016). A major impact on the environment happens within the construction industry activities and there is a demand for the construction industry from society to have a sustainable and healthy development (Cuadrado, et al., 2016). People are anxious and panicky when floor vibration happens which can cause structural collapse even though there are small displacements and stresses produced on the building (Allen & Pernica, 1998).

Walking and running cause annoying levels of floor vibrations due to human movements becoming more frequent in the last two decades (Ibrahim, Nick, Emad, & John, 2006). It is also an interaction of human vibration and the dynamic properties of the floor whether a floor is treated as good or bad by the building occupants (Fredrik, 2006). Previous research from Rijjal has been conducted on the vibration behaviour of both timber-concrete composite and natural timber deck systems. By combining timber with concrete, the vibration susceptibility problems can be solved effectively and also offer a viable solution to enhance the performance of structural timber floor systems compared to other upgrading materials in building design with lighter structures. To ensure the vibration is acceptable, the natural frequency of the designed flooring systems must exceed the forcing frequency (Allen & Pernica, 1998). This past study demonstrated the impact of a concrete topping on the vibration resistance properties of TCC on the vibration resistance property.

In addition, Wheeler conducted a study on vibration caused by pedestrians on footbridges. Six different modes of forward human motion have been considered in the study such as slow walk, normal walk, brisk walk, fast walk, slow jog, and running. The effect on resulting velocity and the type of contact between the feet and the ground involves the variations in those modes. Walking attributed continuous contact which included overlapping steps while jogging and running motions involved discontinuous contact where only one foot was in contact with the ground at the time. The data acquired from the test to relevant vibration criteria can be compared to applicable vibration criteria or standards to ensure whether the floor meets the desired performance benchmarks.

Past research on comfort levels in aircraft and automobiles has revealed that humans exhibit heightened sensitivity to vibration in the frequency range of 5 to 8 Hz. This can be attributed by the fact to the resonance of various organs in the human body at these frequencies (Alvis, 2001). The response of individuals to vibrations is significantly influenced by their activities within a building. In residential and office settings, disturbances are noticeable when peak acceleration reaches around 0.5% of gravity's acceleration. However, when people are actively involved in activities, they tend to tolerate acceleration levels that are 10 times higher or even more, specifically up to 5% above gravity (Murrary, 1997). Figure 1 illustrates the suggested threshold for acceptable peak acceleration in different environments, highlighting the frequency-dependent variations.

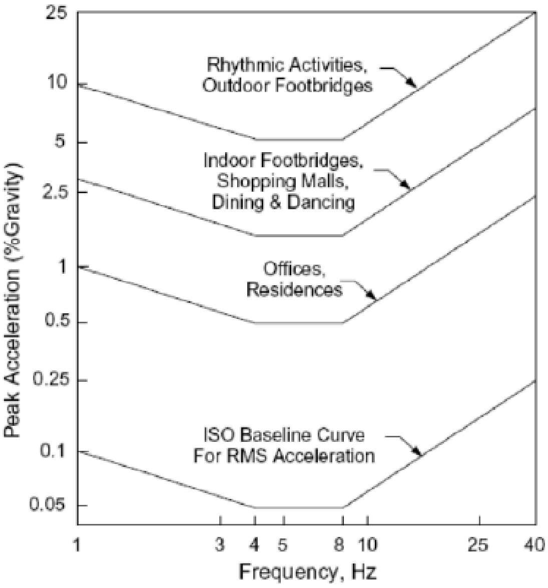

Fig. 1 *Acceptance criteria for human comfort (Ibrahim, Nick, Emad, & John, 2006)*

Issues related to vibrations in timber concrete composite (TCC) flooring systems can be challenging. TCC, a combination of timber and concrete, forms a lightweight material, and lightweight concrete floors may be more sensitive to vibrations compared to heavier slabs. The advantages of lightweight construction include ease of handling during construction, but it comes with lower impact sound insulation due to low density. This construction method requires specific considerations for potential exposure to vibration characteristics. Understanding the vibration behavior and design methods for TCC is crucial in the construction industry, where floor vibrations, caused by human movement like walking and jumping, can make occupants feel uncomfortable, fearing structural instability. Discomfort can happen when people in the buildings cause a vibration of the lightweight floors and resonance at low frequencies. Some factors contribute to these problems which are a decrease in the floor’s natural frequency due to a longer floor span and the number of rhythmic human activities increases (Setareh, 2006).

The growth of timber structures in building construction is increasing, but timber-based floor systems have limitations for medium to long-span structures (Hamid & Johan, 2022). Timber concrete composite technology, gaining popularity in North America, is recognized for achieving extended spans in industrial and commercial buildings. European standards address timber structure design to prevent discomfort from floor vibrations. Reinforced concrete, preferred for high durability, involves a slab with steel reinforcement. While this combination provides durability, it doesn't eliminate the possibility of vibrations in the floor, which arise from dynamic forces impacting the structure and are influenced by various elements within the structure.

Vibration is the swing motion that can be experienced by the building, and it is usually through its floor. The greatest source of floor vibration on floors in buildings is human activities. It is much the same way a guitar string responds to being plucked as a building floor vibrates at its natural frequency in response to a footstep impulse (Jeffrey, 2015). In the same way, when people who walk in the middle of a structural floor produce more vibration than people who walk closer to column areas. Generally, the vibration will increase as a consequence of the speed of people’s footsteps, inducing an upward and downward motion caused by the force applied directly to the floor routine human daily activity. This research aims to thoroughly explore the dynamic responses of both TCC and RC floors when subjected to walking tests. The primary aim is to analyze the vibration behavior of TCC and RC floors in response to walking tests and to govern the wave propagation dynamics between these floors under human load. The study has three main objectives. Firstly, walking tests will be conducted on TCC and RC floors to measure their dynamic reactions to human-induced loads. Following this, the raw data from these experiments will undergo analysis using ARTeMIS, enabling the determination of the natural frequency and mode shape of both TCC and RC floors. Finally, the research aims to characterize and understand the wave propagation phenomena occurring between the two types of floors.

2. Floor Plan Layout

The design layout of the floor structure as depicted in Figure 2, demonstrates the specific location where the test is performed. The test involves accelerometers to measure and determine the frequency. The remarks show the location of the TCC and RC floors on the building at Sri Alam Pasir Gudang.

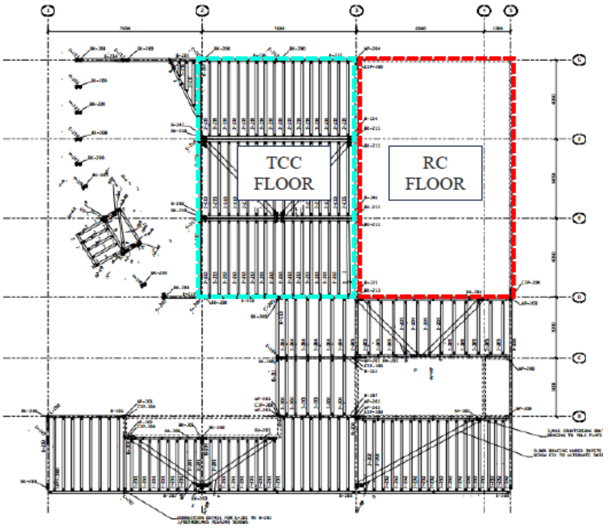

Fig. 2 *Layout Plan of The Building*

Gridlines play an important role in various fields, including data analysis, forming a pattern of vertical and horizontal lines on a surface. Gridlines were drawn on both floors to mark the accelerometer placement locations, crucial for vibration analysis. In Figure 3, there are accelerometers whose placement depends on the application and the type of monitoring system used. In structural monitoring, as used in this study, accelerometers are strategically placed at critical points to measure vibrations or impacts on the floor system. The study utilized a walking test involving five individuals to assess the vibration behavior on TCC and RC floors. By simulating typical walking speeds, this test offers valuable insights into how vibrations impact the tested object and its potential effects on building occupants.

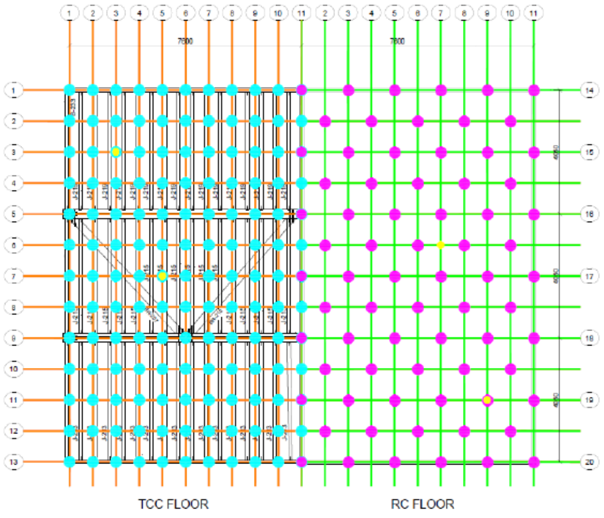

Fig. 3 *The placing of accelerometers on TCC and RC floors*

3. Walking Test

The walking test procedure for determining human-induced vibrations in TCC and RC floors involves setting up the necessary instruments to measure floor vibrations. This includes connecting the accelerometer to a data logger using a provided cable and securing it to the floor slab at the intersection grid line with stationary tape for stability. To observe floor vibration behavior, the data logger is connected to a laptop running ARTeMIS software, ensuring the accelerometer's sensitivity matches the software's settings. 5-6 individuals then walk randomly on both TCC and RC floors, and the ARTeMIS software records the detected floor vibrations captured by the accelerometer. Figure 4 shows the flow procedure on how the walking test has been done for TCC and RC floors.

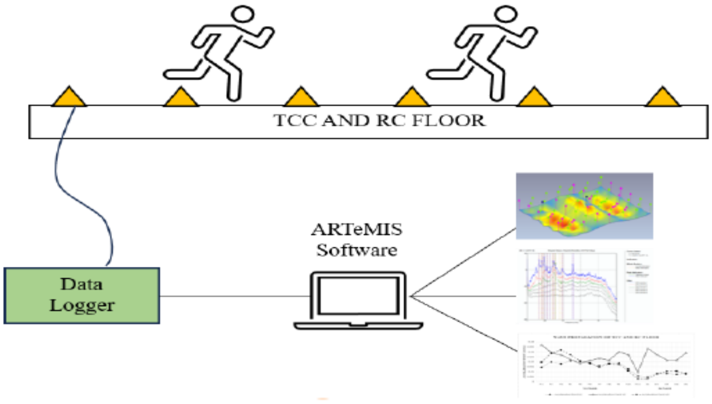

Fig. 4 *Procedure floor of walking test*

4. Data Analysis

To achieve the study's objective, data analysis utilized ARTeMIS software, a tool commonly employed in structural dynamics for vibration analysis. The process involved collecting vibration data using accelerometers, importing the data into ARTeMIS, and visualizing vibration behavior. Modal analysis on ARTeMIS required geometry preparation, proper allocation of coordinate points, and assigning degrees of freedom (DOF) in the z-direction. After connecting the data and running the analysis, the results were examined to identify natural frequencies, mode shapes, and relevant parameters. The extraction of mode shapes involved peak picking from a graph, either manually or automatically, to determine vibration behavior. Figure 5 shows the peak picking method in ARTeMIS software that picks from the graph. In this study, 10 peak points from the graph were selected to create mode shapes for TCC, RC, and a combination of TCC and RC floors.

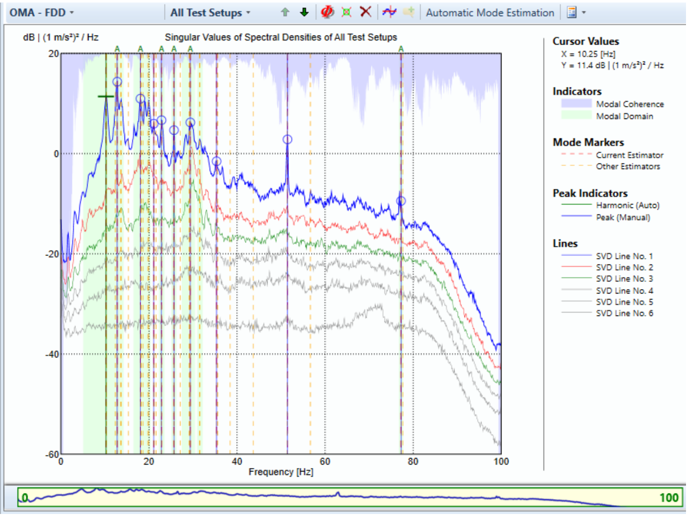
Cursor Values
X = 10.25 [Hz]
Y = 11.4 dB | (1 m/s²)² / Hz

Fig. 5 *Peak picking method in ARTeMIS software*

5. Result

The natural frequency, mode shape, and wave propagation have been analyzed by using ARTeMIS Modal Pro Software. From the analysis, 10 natural frequencies for TCC and RC floors have been picked. Therefore, the natural frequency has been picked from the singular value of spectral densities of all setups at the peak acceleration. The walking test has been carried out on these floor areas to determine the vibration behavior of the floors. The analysis in this study which to govern the floor behaviour was divided into three parts: (1) TCC floor, (2) RC floor, and (3) a combination of TCC and RC floors.

5.1 Vibration Behaviour of TCC Floor

The analysis of the TCC floor consists of 13 sets of data for 3 bays of the TCC floor which are induced by a walking load to discover the floor vibration. Figure 6 shows the behaviour of the TCC floor for the first ten (10) natural frequencies. The first natural frequencies mode shape was obtained at 10.35Hz where the global 3-bay TCC floor deformation is governed. The first natural frequency is the important parameter that needs to be considered to ensure the design of floor limitation, the TCC floor can be categorized as a low-frequency floor with passes the comfort range of human comfort between 5 to 8 Hz.

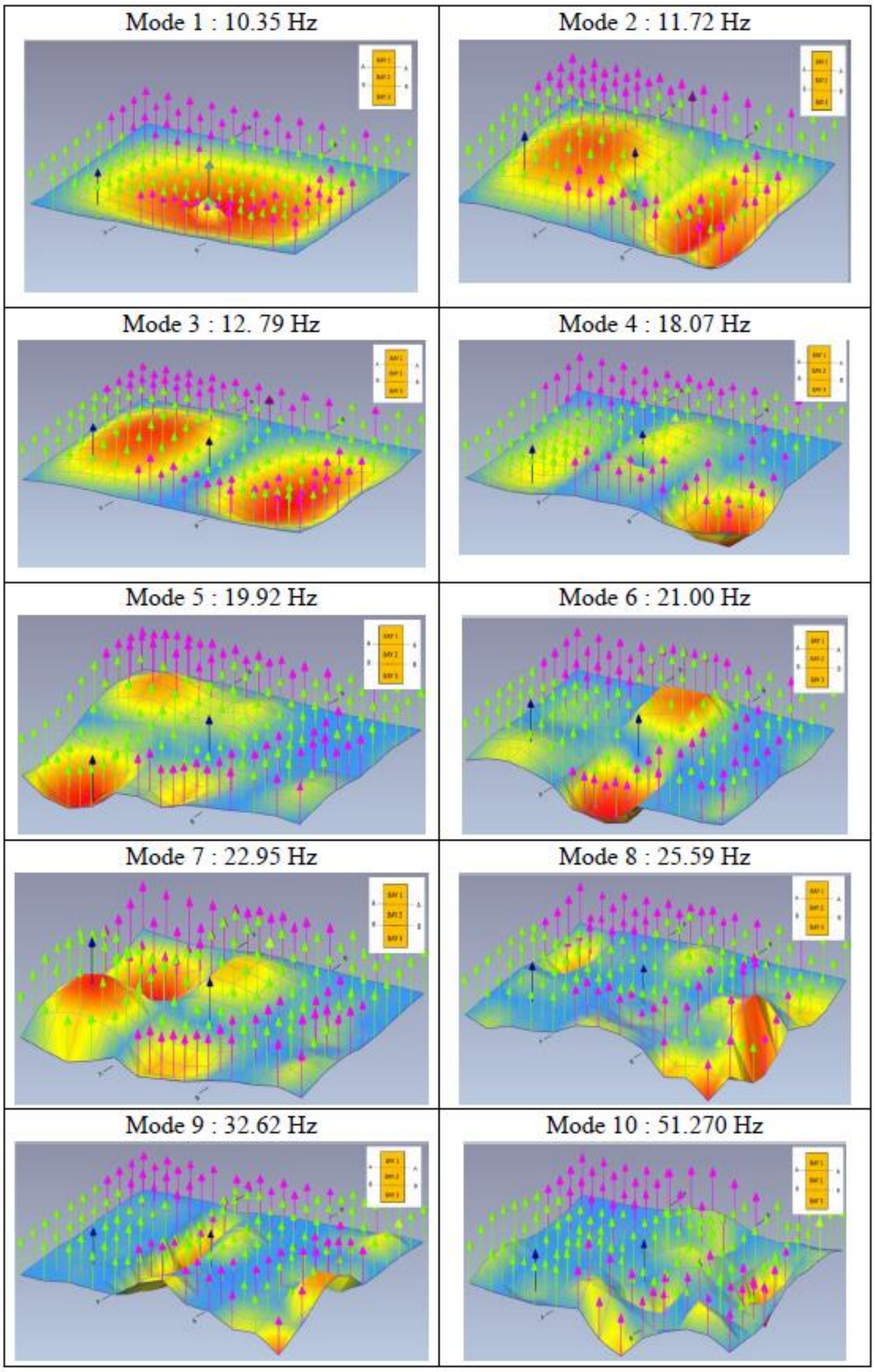

Fig. 6 *Mode shape of TCC floor*

5.2 Vibration Behavior of RC Floor

The analysis of the RC floor consists of 13 sets of data for 3 bays of the RC floor which are induced by a walking load to discover the floor vibration. The data has been extracted from 10 peak points, producing the 10-mode shape for the reinforced concrete (RC) floor. Figure 7 shows the behaviour of the RC floor for the first ten (10) natural frequencies. The local vibration is produced on the RC floor where it appears in smaller-scale movements that occur for each bay. Besides, the first natural frequency is an important parameter that needs to be considered to ensure the design of floor limitation. The initial frequency for mode 1 on the RC floor is 13.67Hz, categorizing the RC floor as a high-frequency structure. This exceeds 10Hz, surpassing the typical comfort range for human comfort, which is between 5 to 8Hz.

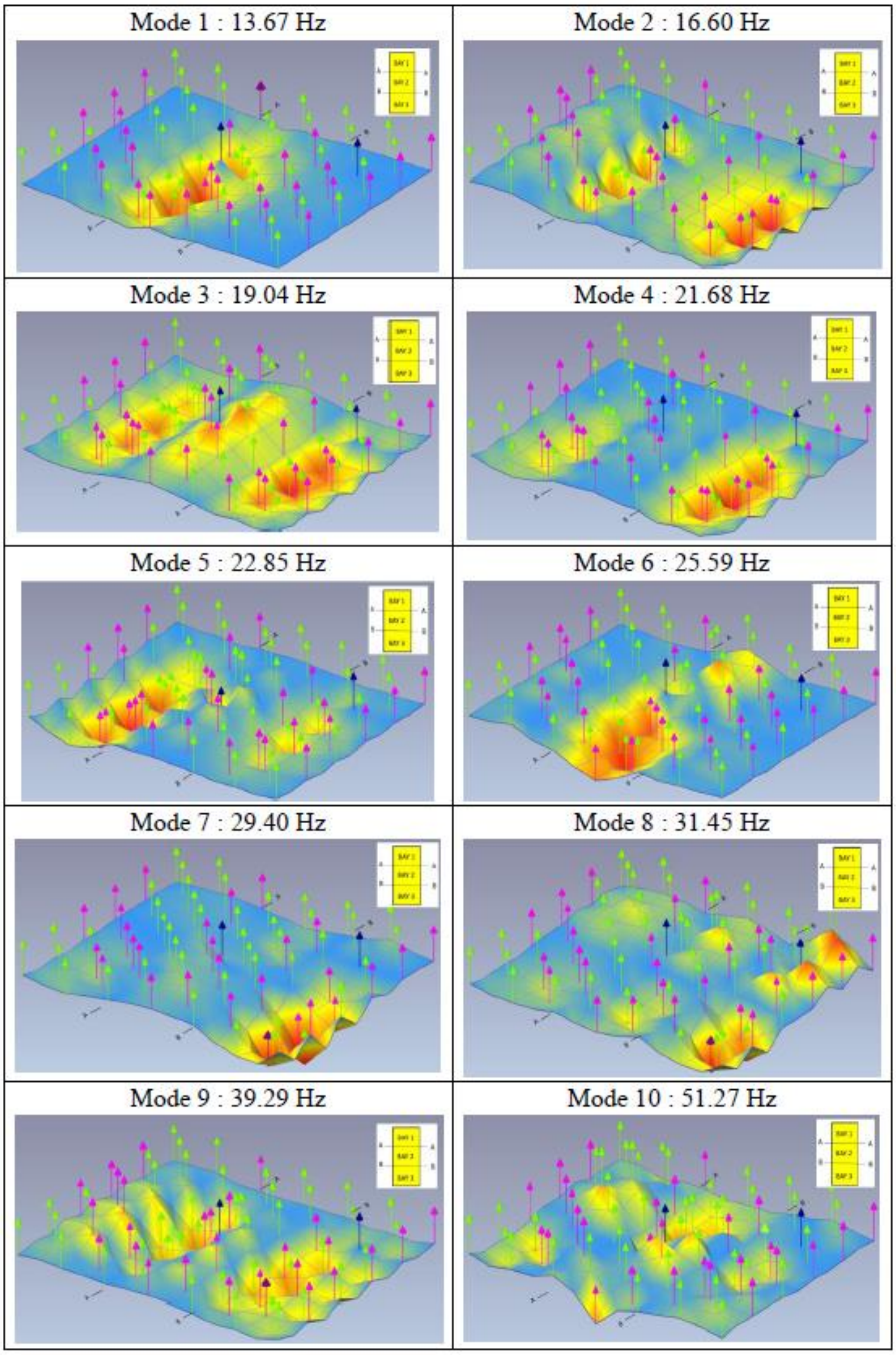

Fig. 7 *Mode shape of RC floor*

6. Discussion

The timber concrete composite (TCC) and reinforced concrete (RC) floor have been conducted for walking tests to discover the vibration behavior. Both TCC and RC floors have different characteristics of vibrations for the first natural frequency mode shape which is obtained at 10.25Hz and 13.67Hz representing global vibrations that indicate overall movement across the entire TCC floor. Typically, such vibrations involve the entire building, yet the RC floor did not exhibit any reaction to these vibrations on the TCC floor. The RC floor displays a minimal response to the vibration-induced deformation, where this scenario can be felt by occupants standing on the TCC floor experiencing more vibration compared to those on the RC floor. It can be concluded that the most critical area of deformation vibration appeared mostly on the TCC floor which can be categorized as a low-frequency floor. Reinforced concrete floor generally experiences less vibration on the floor compared to timber concrete composite due to its natural stiffness. RC floor consists of concrete and steel reinforcement known for its rigidity and resistance to deformation and also provides structural stability and reduces vibrations when subjected to dynamic loads.

7. Conclusion

The test results compared the vibration behavior of both TCC and RC floors. Both types of floors had natural frequencies exceeding the comfort range of 8Hz. The TCC floor fell into the low-frequency category (below 10Hz), while the RC floor was classified as high-frequency (exceeding 10 Hz). Additionally, the research included an analysis of the mode shape for each floor. The findings suggested that the TCC floor, with its low-frequency nature, exhibited a more critical area of deformation vibration, indicating reduced serviceability compared to the RC floor. Wave propagation analysis identified the middle floor as a critical area for high acceleration. In conclusion, the research successfully achieved its objectives of determining the vibration behavior of TCC and RC flooring systems and understanding wave propagation.

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