Vibration Behaviour of Natural Timber and Timber Concrete Composite Deck System

Jalal Mushina¹, NorHayati Abd Ghafar², David Yeoh², Wissam Mushina³, Koh Heng Boon²

¹ Shatra municipality, Thi-qar municipality, Shatra Iraq
² Department of civil engineering, UTHM University, Parit Raja Malaysia
³ Shatra Technical Institute, Southern Technical University, Shatra Iraq
Corresponding author: jalalmushina@yahoo.com, noryati@uthm.edu.my, david@uthm.edu.my, eng.wesam16@gmail.com, koh@uthm.edu.my

Abstract. Timber–Concrete Composite (TCC) structure consists of timber joists or beams effectively interconnected to a concrete slab cast on top of the timber members. This type of structures has applications in multi-storey buildings and short-span bridges particularly in developed countries such as America, Canada, Australia and New Zealand. In Malaysia, these timber concrete composite (TCC) fields are extremely uncommon compared to European country. This paper is investigated the TCC deck system as a new slab structure element that could be used in Malaysia. The use of TCC deck system with Malaysian Kempas timber and normal weight concrete is advantageous in providing a lighter structure, more sustainable and possibly a smaller foundation. Therefore the main objective of this research is to study the vibration behavior of kempas timber (natural timber) in timber deck and TCC deck by experimental modal testing. The vibration data results were conducted by modal experimental test. Then the model is verified by finite element using SAP 2000 software. The connector type that used is screw in TCC deck. The size of each deck is 3.6m x 0.8m, the thickness of concrete is 65mm and the timber beam unit with dimension 3.6 x 0.09x0.04 m. The specimens of timber and TCC deck were tested using an electrodynamic shaker. The data were analyzed using ME Scope software to determine the natural frequency and mode shape of the timber and TCC deck system. The modal experimental results for all tests were more than 8 Hz, it accepted since the vibration limitation for timber floor is 8 Hz. The TCC deck frequency due to shaker excitation is higher than only timber deck which means that the TCC improve vibration resistance property compared with only timber deck vibration resistance.

1. Introduction
The vibration is a movement that occurs either on the ground or in the structure of the building and it affects the structure of the building and can cause discomfort to the user, vibrations should be dealt with because of the extreme vibration will cause damage to the structure of the building. Human rhythmic activities such as walking, running, dancing, jumping and aerobic are among the causes of vibration on the floor surface. Even during this activity, the occurrence of vibrations caused by humans and the dynamic burden produced by humans. The vibration susceptibility problems of using full timber floors can be solved by combining timber with concrete[1].Timber-concrete composite (TCC) construction may be used to improve the performance of structural timber floor systems[2].The vibration caused by the higher harmonics of the activity frequency can also cause discomfort and excessive deflections in the floor panels[3].The natural frequency and damping of LCC beams decreased if the span length was
increased EC5[4]. For vibration to be acceptable, the natural frequency of the designed flooring systems must be higher than the forcing frequency[5]. This study was conducted to show the effect of concrete topping on timber deck (TCC deck) on the vibration resistance property. The electrodynamic shaker is used as excitation source to report the timber and TCC deck vibration data which express the deck behavior. These tests determine the frequency value at specific mode that reflect the behavior of timber and TCC deck. An electrodynamics shaker has been conducted on surface of timber and TCC deck system. The raw data from shaker testing was exported has been made by using ME Scope software. The other objective of SAP 2000 finite element modelling is regard to transformation from the actual deck to a finite element TCC deck, as well as mesh refinement.

2. Material properties

A—Timber: The type of timber used for this project is Kempas (Scientific name Koompassia malaccensis), it was natural timber in Malaysia. The dimensions of this timber beam was of 40 mm (width) x 90 mm (depth) x 3600 mm (length) and the density of timber was 850 kg/m3 and elastic modulus (G) 12.5 GPa.

B—The shear connectors: The connectors used for this study was screws. It has 68.70 mm length, 5.47 mm diameter and the spacing between the screws was 250 mm from design.

C—The concrete: The design of the concrete mix was based on design of experiments British Standards. The target characteristic strength of the concrete for this project is 35 MPa. The w/c ratio is 0.4 and the targeted slump is in the range of 70-120 mm. TCC floor deck is a composite in which a kempas timber was represented as a deck (lamination timber) with 3600 mm length, 800 mm width and 90 mm depth of timber and layer of concrete on top with 65 mm thickness, the two materials are bound together by screw connector.

3. Modal testing

Modal testing is the form of vibration testing of an object whereby the natural frequencies and mode shapes of the timber and TCC under test are determined.

3.1 Grid line for the specimens

The grid lines were drawn along the surface of the specimen for marking point to place the accelerometers, becomes easier for deck of timber and TCC which located at 400 mm along the length and 200 mm along the width, the grid line was made based on the area of the study specimen. The accelerometers nodes were located at intersection points of grid lines and the electrodynamics shaker is located on the top of the floor deck to apply the vibration force, each overlapping point needs to be numbered from one to the last point of the grid as shown in Figure 1.

Grid number on the specimen can be started from either direction that is through vertical or horizontal directions as long as it is easy to read and understood during electrodynamics shaker test. Each grid line had been marked with a number to facilitate the process of retrieving data. The accelerometer placed at each numbered grid line starting from the first row. A wax will be used to make sure an accelerometer stick between plate and the deck. Make sure an accelerometer stick neatly and the connection wires not messy to reduce an error occur during the testing. There are nine rows for vertical direction and 5 rows for horizontal for one deck as shown in Figure 1. Due to limited number of accelerometers, the accelerometers were roving to capture all data from the points on the specimen. Furthermore, one accelerometer was placed as a reference point. The electrodynamic shaker also connected to the data logger. For the shaker, the controller software that been used was spektra software package. Furthermore, the shaker placed at one point and no need to changed places like the accelerometer. The vibration responses were recorded by accelerometers, which are attached along the specimens to measure the vibration response from the specimens and were connected to a data recorder that was connected to the computer.

In this paper study four tests of vibration, the first test is case (A), it means the single timber deck, The second test is case (B), it means the single TCC deck, The third test is case (C), it means the double TCC deck arrange along the width (side to side) and the fourth test is case (D), it means the double TCC deck arrange along the length as shown in Figure 2, 3, 4 and 5 respectively, there were a concrete joint
between the two TCC decks in case (C) and case (D) as shown in Figure 4 and 5. The supports were used in these cases, steel I section support.

**Figure 1.** The Grid lines and Grid number on the specimen were drawn along the Deck of timber and TCC

**Figure 2.** Case (A) single timber deck and TCC

**Figure 3.** Case (B) single TCC deck

**Figure 4.** Case (C) double TCC deck arrange along the width (side to side)

**Figure 5.** Case (D) double TCC deck arrange along the length
3.2. Testing arrangement for Specimens

Twelve accelerometers were mounted at different locations of surface the deck floor to measure their responses. The accelerometer is a device tool that was placed on a specimen to record the response data during the experimental modal testing, using electrodynamics shaker. The accelerometers were connected to data logger to record all the response data as shown in Figure 6 and 7. The computer needs to have the IMC Wave software to generate the data from accelerometer. The equipment that was used during the test has been identified so there was no error during the installation.

Electrodynamics shaker is a tool used to vibrate the specimen. The shaker test was to determine the vibration result at the timber and TCC deck floor specimens. The frequency range for the shaker has been set from 1 Hz to 100 Hz. The time for shaker to running is only for 2 minute 20 seconds. This shaker was connected to the data logger and the data obtained was inserted into the IMC for analysis of the graphic form that occurs when the shaker vibrates as shown in Figure 7, it show the procedure of shaker tool setup.

3.3. Testing of procedure for Specimens

This test was done by using electrodynamics shaker test for the case (A), case (B), case(C) and case (D) in order to determine the natural frequency and mode shape.

The first test is case (A) single timber deck, the vertical force excitation was produced by an electrodynamics shaker, which was placed on top of the specimen at point (13) numbered grid line and placed an accelerometer at one node as the reference point at (38) as shown in Figure 1 and 8. Place an accelerometer at node 1 – 5 follow on the grid. Repeat changing the position of an accelerometer to the node 6 – 10, 11 – 15 until 41-45.

The second test was case (B) single TCC deck, it was same the first test (case A) as shown in Figure 8. The third test was case (C) double TCC deck arrange along the width (side to side), the vertical force excitation was produced by an electrodynamics shaker, which was placed on top of the specimens at point (23) numbered grid line and placed an accelerometer at two nodes as the reference point at (29) and (73) as shown in Figure 9. The fourth test was case (D) double TCC deck arrange along the length, the an electrodynamics shaker was placed on top of the specimens at point (13) numbered grid line and placed an accelerometer at two nodes as the reference point at (38) and (82). The shaker test was to determine the vibration result at the timber deck specimen. The accelerometers were attached at these node points to measure the vibration response from the specimens and were connected to a data recorder (Data logger) that was connected to the computer.
Figure 8. Electrodynamic shaker, which was placed on top of the case (A) and Case (B) specimens at point (13) numbered grid line.

Figure 9. Case (C) double TCC deck arrange along the width, electrodynamics shaker, which was place at point (23) numbered grid line.

3.4. Results of test for Specimens

An electrodynamic shaker test has been done, the natural frequency of the first mode shape for case (A), case (B), case (C) and case (D). The raw data of shaker test has been converting in ME Scope to get natural frequency and mode shape of all cases. The results of natural frequency for case (A) was 12.4 Hz, for case (B) was 12.9 Hz as shown in Table 1, while natural frequency of case (C) was 13.7 Hz and 17.5 for case (D) as shown in Table 2. The values of natural frequency were accepted for all cases, since the fundamental natural frequency of residential timber floor must be 8 Hz as a serviceability vibration limitation as states in Eurocode 5.

| Mode | Case (A) Single timber deck | Case (B) Single TCC deck |
|------|-----------------------------|--------------------------|
| Mode 1 | Frequency =12.4 Hz | Frequency =12.9 Hz |

| Mode | Case (C) double TCC deck arrange along the width | Case (D) double TCC deck arrange along the length |
|------|-----------------------------------------------|-----------------------------------------------|
| Mode 1 | Frequency =13.7 Hz | Frequency =17.5 Hz |
4. element method (FEM)

4.1. Modelling procedure of TCC

The first step of the modelling was to insert the material properties of concrete and kampas timber into the SAP 2000. For this study, concrete grade 35 was selected for use. However, the Kempas timber properties needed to be manually inserted. The Kempas is an orthotropic material, which means that the modulus of elasticity of kempas timber is 12.5 kN/mm². In the modelling, the shell element represented the concrete slab, the beam element represented the kempas joists, and the link element represented the screw. For the link element, the shear connector stiffness value was inserted 46.9 kN/mm. The value 46.9 kN/mm was obtained from the push-out test. The rigid link was fixed at all directions. The details that needed to be inserted into the SAP 2000 are listed in Table 3, which covers the shell and beam elements.

| Material Properties                      | Concrete                      | Kempas timber                |
|------------------------------------------|------------------------------|------------------------------|
| Mass, m                                  | 2400 kg/m³                   | 850 kg/m³                    |
| Modulus of elasticity, E                 | 31 kN/mm²                    | 12.5 kN/mm²                  |
| Poisson ratio, U                         | 0.3                          | Modulus of elasticity, E1    | From test 2.037 kN/mm² |
| Shear modulus, G                         | 9.56 kN/mm²                  | Modulus of elasticity, E2    | From test 0.9 kN/mm² |
| Concrete compressive strength, f’c       | 35 N/mm²                     | Poisson ratio, U12, U13      | 0.369, 0.618, 0.428 |
| Shear modulus, G                         | 1.075 kN/mm²                 | G12 = 1.075 kN/mm²           |
| Shell element                            |                              |                              |
| Thickness                                | 65 mm                        |                              |
| Beam element                             |                              |                              |
| Cross section                            | 40 x 90 mm                   |                              |
| Link element                             |                              |                              |
| Direction, U1                            | Fixed                        | Direction, U2 (From test)    | 46.9 kN/mm |

The TCC model was then ready to be analyzed via modal analysis, including for natural frequency and mode shape. Modal Analysis is the study of the natural characteristics of the structures which includes frequency and mode shapes. It is use to design all types of structures including automotive structures, aircraft structures, computers, rackets and etc [7]. Modal Analysis simplifies the vibration response of a complex structure into a set of single degree of freedom systems that can easily be understood [8]. It has become a regular in finding modes of vibration of a machine or structure.

4.2. Modelling result of TCC

The results of frequency from the finite element for the case (B) single TCC deck system which the cross section area of each TCC deck is 3.6 x 0.8 m, the thickness of the timber deck is 90 mm and thickness of the concrete is 65 mm, was 12.8 Hz, for case (C) double TCC deck arrange along the width was 13 Hz and case (D) double TCC deck arrange along the length was 14.5 Hz as shown in Table 4, Figure 10 and 11.
Table 4. Result of single and double TCC deck into the SAP 2000 software package

| Floor                                           | FEM (Hz) |
|-------------------------------------------------|----------|
| Case (B) single TCC deck system                 | 12.8     |
| Case (C) double TCC deck arrange along the width| 13       |
| Case (D) double TCC deck arrange along the length| 14.5     |

5. Discusses the results

5.1. Discusses the experimental results for specimens

5.1.1. Effect of timber deck on vibration

The results shown that the natural frequency of the single timber deck (case A) for the first mode shape of timber floor was 12.4 Hz more than 8 Hz limitation of code, this mean there was enhancement when used timber lamination to resistance the vibration force.

These laminations of timber give the deck more stability to resistance the human activates (vibration) because its weight, more sustained and less ductile as the number of timber lamination increased as the beam tends to break at lower displacement.

5.1.2 Effect of topping concrete on TCC deck

The results shown of natural frequency of the case (A) single timber deck for the first mode shape was 12.4 Hz and the natural frequency of case (B) single TCC deck was 12.9 Hz as shown in Table 5. This mean the experimental result of case (B) was higher than experimental result of case (A) by the differences 0.5 Hz. The different percentage between them is 0.04%. The additional concrete part in TCC deck gives the deck more stability, increased the stiffness of the TCC floor, due to mass increasing. The connector’s part in TCC deck is responsible for the degree of composite.

Table 5. Experimental result of natural frequency for single timber and TCC Deck

| Floor           | Experimental result of case (B) TCC deck (Hz) | Experimental result of case (A) timber deck (Hz) | Different Hz | Percentage of different (%) |
|-----------------|-----------------------------------------------|-------------------------------------------------|--------------|-----------------------------|
| Floor deck      | 12.9                                          | 12.4                                            | 0.5          | 0.04                        |

5.1.3. Effect of concrete gap on result of natural frequency for TCC floor deck

Based on the result obtained, the result of case (B) single TCC deck (12.9 Hz) was less than case (C) and case (D), this mean the concrete joint was increased the value of frequency, due to stiffness increasing for case (C) and case (D) as shown in Table 6.

The experimental result for case (D) was 17.5 Hz and it was higher than experimental results for case (C) which was 13.7 Hz by the differences 3.8 Hz. The differences between both ways are more than
27.7%, because the case(D) present real continuous TCC deck due to support existence at middle, while the case(C) present concrete joint connection along the total length of deck. Therefore the natural frequency of case (D) was higher than case(C).

**Table 6.** Natural Frequency and Mode Shape of case (A) , (C) double TCC deck arrange along the width and case (D) double TCC deck arrange along the length

| Mode | Case (B) | Case (C) | Case (D) |
|------|----------|----------|----------|
| Mode 1 | Frequency =12.9 Hz | Frequency =13.7 Hz | Frequency =17.5 Hz |

5.2. **Discusses the results of modelling**

From the result of FEM, we note the frequency of case (B) single TCC deck system was 12.82 Hz. The frequency of case (C) was 13 Hz and case (D) was 14.5 Hz were more than frequency case (B). Also it notes the frequency of case (D) was more than case (C). It can see that the concrete joint in case (C) and case (D) were improved the vibration resistance, through increasing natural frequency from 12.822 Hz to 13 Hz and 14.5, because it make the two panel act as one deck to vibration resistance.

5.3. **Comparison between the experimental results and Finite element Modelling.**

The fundamental natural frequency is the most important frequency for serviceability in a structural design compared to the higher frequencies.

The comparison between the experimental results and finite element Modelling only focuses on the fundamental frequency, the experimental results for frequency of modal test of case (B) is 12.9 Hz and it is 12.82 Hz for FEM, this mean the experimental result is very little higher than FEM by the differences 0.08 Hz. The different percentage between them is 0.006 %. The small differences between the natural frequencies for experimental results and FEM results for case(A) and case(B) prove that the FEM results from sap 2000 were accepted and the model can be used to extend the results to other cases. For the second case, the experimental results for frequency of modal test of case (C) is 13.7 Hz and is 13 Hz for FEM, also mean the experimental result is little higher than FEM by the differences 0.7 Hz. The different percentage between them is 0.05 %.

For the third case, the experimental results for frequency of modal test of case (D) is 17.5 Hz and is 14.5 Hz for FEM, also mean the experimental result is higher than FEM by the differences 3 Hz. The different percentage between them is 20 % as shown in Table 7. The rigidity of the support systems in the tests probably caused the big differences in case (D). The variable of individual timber beam stiffness of the TCC deck panel may effect the overall vibration behaviour of the specimens. While, the TCC deck systems in FEM modelling have constant stiffness and rigid support compared to real specimen.

**Table 7.** The differences in natural frequency between vibration test results and analytical modelling

| Floor | Experimental (Hz) | FEM (Hz) | Different Hz | Percentage of different (%) |
|-------|-------------------|----------|--------------|----------------------------|
| Case (B) | 12.9 | 12.82 | 0.08 | 0.006 |
| Case (C) | 13.7 | 13 | 0.7 | 0.05 |
| Case (D) | 17.5 | 14.5 | 3 | 20 |

6. **Conclusion**

The modal experimental results for all tests were more than 8 Hz, it is accepted since the vibration limit for timber floor is 8 Hz according to EC5. The TCC deck frequency due to shaker excitation is higher than only timber deck which mean that the topping concrete in TCC improve vibration resistance property compared with only timber deck vibration resistance, it can concluded that the TCC slab is comfortable solution for vibration due human activities. The laminations timber are given the deck more stability to resist the human activates (vibration) because its weight, more sustained and less ductile as the number
of timber lamination increased as the beam tends to break at lower displacement. The additional concrete part in TCC deck gives the deck more stability, increased the stiffness of the TCC floor, due to mass increasing. The connector’s part in TCC deck is responsible for the degree of composite.

The case(D) present real continuous TCC deck due to support existence at middle, while the case(C) present concrete joint connection along the total length of deck. Therefore the natural frequency of case (D) was higher than case(C). From FEM, it can see that the concrete joint in case(C) and case (D) were improved the vibration resistance, through increasing natural frequency from 12.8 Hz single TCC deck (case B) to 13 Hz case(C) and 14.5 case (D), because it make the two panel act as one deck to vibration resistance. The small differences between the natural frequencies for experimental results and FEM results for case (A) and case(B) prove that the FEM results from sap 2000 were accepted and the model can be used to extend the results to other cases.

7. References

[1] Rijal R, Samali B and Crews K 2010 Dynamic performance of timber-concrete composite flooring systems: Incorporating Sustainable Practice in Mechanics of Structures and Materials pp 315-319.
[2] Ghafar A 2008 Forced vibration testing on LVL-Concrete composite floor systems: In 7th fib PhD Symposium in Stuttgart, Germany pp 1-6
[3] De Silva S S and Thambiratnam D P 2009 Dynamic characteristics of steel–deck composite floors under human-induced loads: Computers & Structures, 87(17-18), pp.1067.
[4] Eurocode 5 2004 Design of Timber Structures Part 1-1: General – Common rules and rules for buildings. (London: British Standard)
[5] Allen D E and Pernica G 1998 Control of floor vibration: Ottawa, ON Canada: Institute for Research in Construction National Research Council of Canada
[6] Amaruddin H I, Hassan R, Amin N M and Malek N J 2014 Finite Element Model of Mortise and Tenon Joint Fastened with Wood Dowel Using Kempas Species: In InCIEC Springer, Singapore pp 3-14
[7] Avitabile P 2001 Experimental modal analysis Sound and vibration 35(1) 20-31
[8] Tech Note 2007 Basics of Modal Testing and Analysis: TN-DSA-003