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A Preliminary Study on Vibration Response of Profiled Steel Sheet Dry Board (PSSDB) System under Heel-drop Test

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Abstract: This paper aims to evaluate the vibration response of the profiled steel sheet dry board (PSSDB) composite system under heel-drop test. Three (3) specimens with dimensions of 840mm width and 2000mm length were prepared. The specimen consists of a sample without concrete infill (P45HL), foamed concrete as infill (P45FC), and normal concrete as infill (P45NC) material. The specimen was erected using profiled steel sheet (PSS), 1mm thickness, and connected to a dry board (DB), 16mm thickness using self-drilling screws at 200mm screw spacing along the longitudinal direction. A heel-drop test was conducted, and modal analysis was performed using MEscope software. The FRF measurement was carried out using accelerometers, and the time-domain measured responses were converted to FRF to acquire modal characteristics such as natural frequency and mode shape of the structures. The natural frequency of the first mode shape is 17.7Hz, 14.2Hz, and 4.5Hz respectively for specimen P45H, P45FC, and P45NC. It demonstrates that the natural frequency of the specimen without infill and foamed concrete as infill is more than the human comfort limit value of 8Hz, implying that P45HL and P45FC will be comfortable for building occupants.

Keywords: Composite slab, PSSDB system, heel-drop test, vibration response, human comfort

1. Introduction

The PSSDB system is made up of profiled steel sheeting that is composited with a dry board panel utilizing simple mechanical connections. The research on the PSSDB composite system was first published in early 1986 by Wright & Evans [1], and the system may be used as a floor, wall, or roof but it is commonly employed as a flooring system as a substitute for the traditional system. There have been several studies performed on the PSSDB by Badaruzzaman et al., [2], Ahmed [3], Akhand [4], Ahmed et al. [5], [6], Shodiq [7], Seraji et al. [8], Samir et al. [9] and Jaafar et al. [10]. However, most of the studies mainly focused on the structural behavior under the flexural test. The study on vibration behavior on the composite slab using the PSSDB system was started by Ahmed & Badaruzzaman [11], [12] Ahmed & Ahmad [13], and Gandomkar et al. [14]-[16]. Fig. 1 shows the typical composite slab system.

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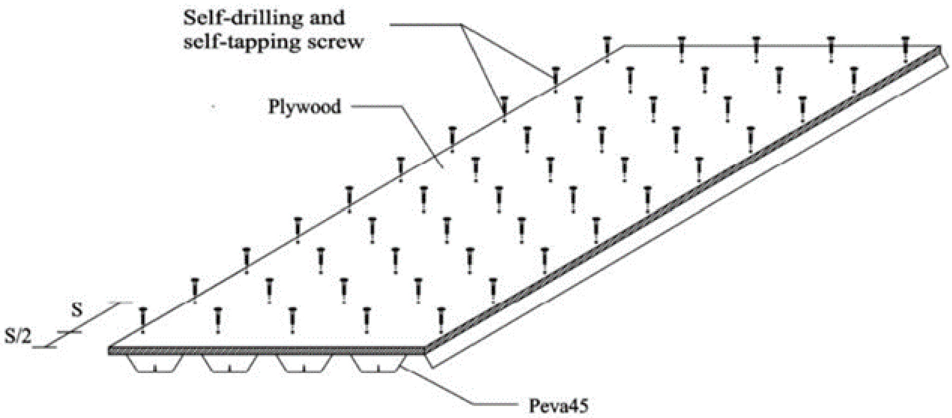


Fig. 1 - PSSDB composite slab system [14]

Composite floor systems are an example of a slender structure that may face vibration, especially where typically, static techniques are used to design these composite constructions, which do not disclose the true behavior under dynamic loads, resulting in vibration issues. Low-frequency vibration caused by human activities is a key problem for lightweight flooring, according to Ljunggren et al. [17]. Vibration by human activities such as walking and dancing, which influences human comfort, is one of the most important variables to consider throughout the flooring system design process [18]. Excessive vibrations in composite flooring from human activity or other causes may cause human discomfort. There are a variety of design criteria for floor vibrations, such as acceleration, natural frequency, or deflection limit, that are available in design standards that have been widely utilized in past research to guarantee the systems function effectively under dynamic action, as noted by Rijal [19]. The classification of the floor system is necessary for determining the level of human comfort, which is determined by the Fundamental Natural Frequency (FNF). As indicated in Table 1, the cut-off frequency between low and high-frequency floors varies depending on the author and design standards [20]. In this current study for the PSSDB system, the cut-off between low and high frequency was considered as 8Hz.

Table 1 - The cut-off frequency between the low and high-frequency floor [20]

Reference	Cut-Off Frequency
Ohlsson [21]	8Hz
Allen and Murray [22]	9Hz
The Concrete Society [23]	10Hz
The Concrete Centre [24]	10Hz
The Steel Construction Institute [25]	10Hz, for general floors, open-plan offices, etc. 8Hz, for enclosed spaces, e.g., operating theatre, residential
American Institute of Steel Construction [26]	9Hz

Ahmed & Badaruzzaman [11], [12] conducted an experimental study on the PSSDB composite slab that is primarily concerned with determining the vibration response of the system. From the result, the fundamental natural frequency of the specimen with a span length of up to 3.5m is more than the limit value of 8Hz. As a result, it can be concluded that a composite floor panel with a reasonable span length will be comfortable for building occupants in terms of human-induced vibration. Research by Gandomkar et al. [14], [16] on the PSSDB with concrete infill on natural frequencies has been carried out experimentally and numerically. It was found from the experimental tests that the natural frequency of the PSSDB samples without concrete is higher than the PSSDB with infill; however, introducing PSSDB with infill caused an increase in the damping ratio, which then corresponded with the fundamental natural frequency (FNF). A numerical study was conducted by Gandomkar et al. [15] related to the dynamic response of the low-frequency PSSDB system with concrete infill under human walking load. The results revealed that the natural frequency value is in the range of 3.6Hz – 7.32Hz, by means that even though certain variables can reduce the dynamic response, they could reach higher levels of vibration due to decreasing frequency resulting in discomfort to users.

Thus, this research is to evaluate the vibration behavior related to the natural frequency and mode shape of the PSSDB composite flooring system. The heel-drop test was performed, and modal analysis was conducted. From the result, an analysis of the natural frequency and mode shape, the effect of concrete infill, the effect of concrete infill type, and human comfort limitation to floor vibration was performed.

2. Experimental Study

2.1 Preparation of Material

The materials prepared for the casting of the specimen were based on the quality, economic aspect, and great performance to achieve the aim of the study. The materials used for producing two types of infill material which is normal and foamed concrete include cement, sand, gravel, water, and foam agent as shown in Fig. 2. The quantity of materials used for producing two types of infill material which are normal and foamed concrete as listed in Table 1. Foamed concrete mix design is designed to create concrete with a density of 16000kg/m^3 and a compressive strength of 18MPa. Meanwhile, the targeted density for normal concrete is 2400 kg/m^3 and compressive strength of 20MPa. The quantities and material used for foamed and normal concrete as presented in Table 2.

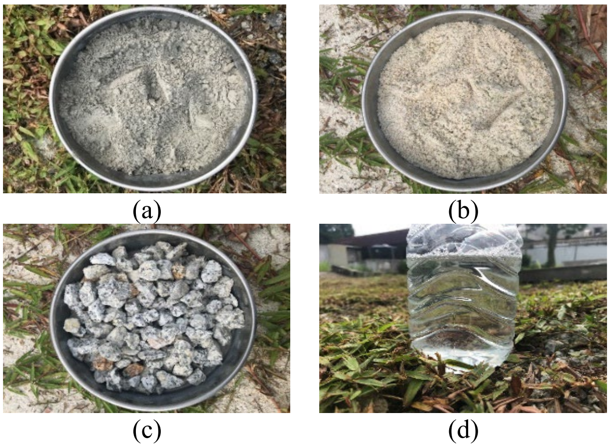


Fig. 2 - Material used for foamed and normal concrete (a) cement; (b) sand; (c) gravel; (d) foam agent

Table 2 - Quantities of material used for foamed concrete

Materials	Require quantity for foamed concrete	Required quantity for normal concrete
Cement (kg)	100	45
Sand (kg)	200	110
Gravel (kg)	-	150
Water (liter)	55	28

2.2 Preparation of Specimen

For the heel-drop test, three (3) specimens were prepared. The specimen was categorized into three different groups which are specimen without infill, with foamed concrete infill, and with normal concrete infill as listed in Table 3. For the test, only one sample was prepared for each specimen due to the test was non-destructive. The specimen was erected using a Peva45 profiled steel sheet and connected to a Primaflex dry board using self-drilling screws at 200mm screw spacing along the longer span. After 28 days of curing, the dry board was bonded to a profiled steel sheet for the specimen with infill materials. Fig. 3 and Fig. 4 represent an illustration of a composite slab without and with infill material respectively.

Table 3 - Specimen details for PSSDB composite slab system

<table>
<tr><th rowspan="2">Specimen code</th><th rowspan="2">Specimen size (width x length)</th><th colspan="4">Characteristics of specimen</th></tr>
<tr><th>Profiled steel sheet</th><th>Dry board</th><th>Connector</th><th>Infill material</th></tr>
<tr><td>P45HL</td><td rowspan="3">840mm x 2000mm</td><td rowspan="3">Peva45 (1.0mm thickness)</td><td rowspan="3">Primaflex (16mm thickness)</td><td rowspan="3">Self-drilling screw (200mm spacing)</td><td>-</td></tr>
<tr><td>P45FC</td><td>Foamed concrete</td></tr>
<tr><td>P45NC</td><td>Normal concrete</td></tr>
</table>

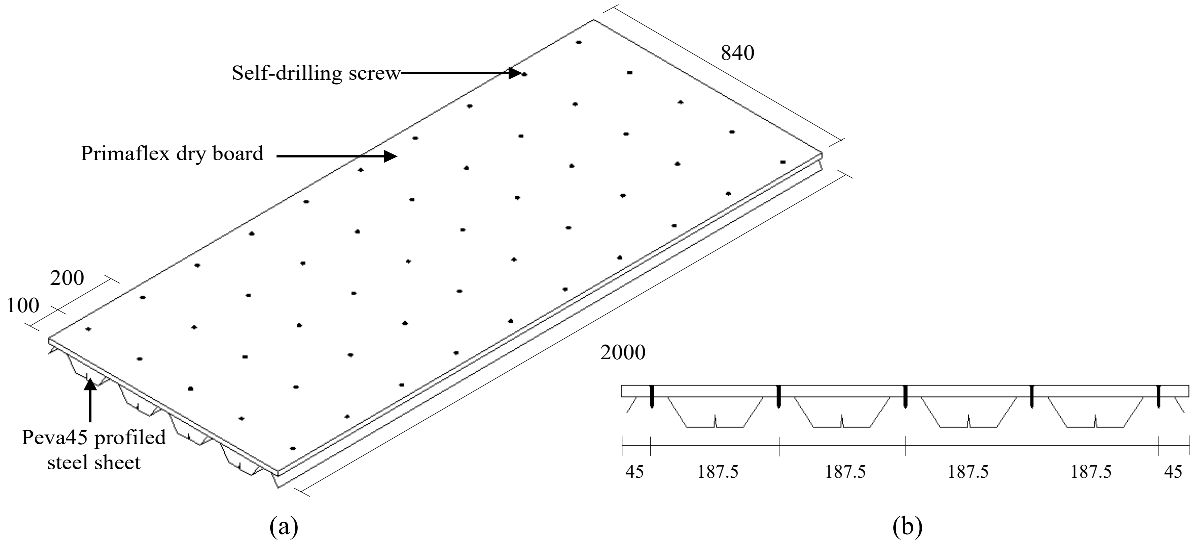


Fig. 3 - Schematic diagram for PSSDB composite slab system without infill material (a) 3D view; (b) cross-section

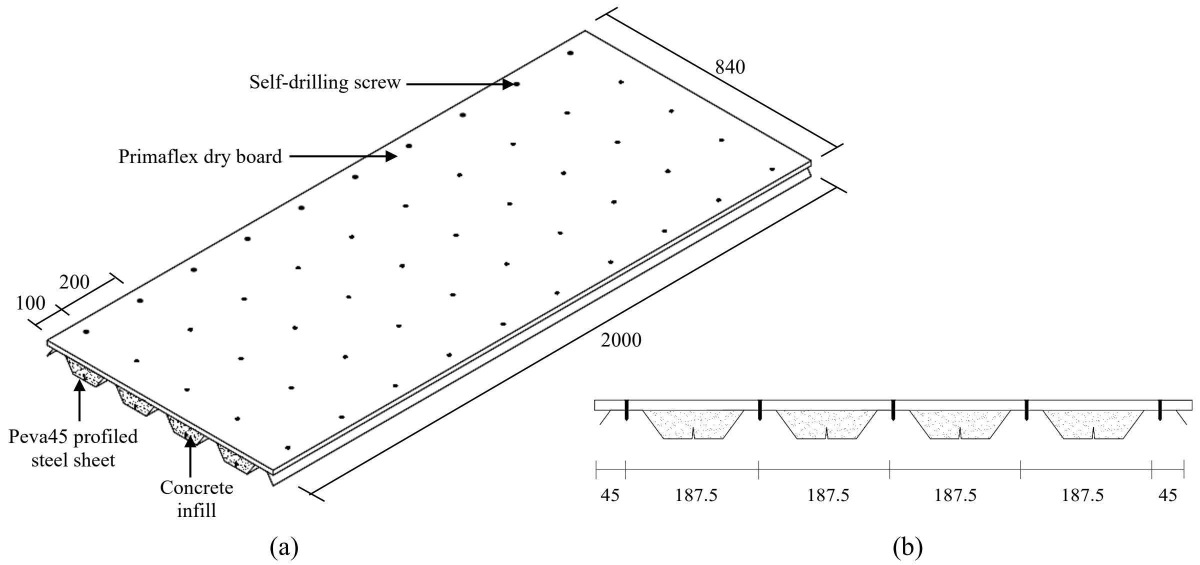


Fig. 4 - Schematic diagram for PSSDB composite slab system with infill material (a) 3D view; (b) cross-section

2.3 Test Setup and Instrumentation

The gridline was drawn on the surface of the dry board and numbered accordingly to place the accelerometers. Meanwhile, the input load or heel-drop point was indicated around the middle of the specimen on right and left sides. The load cell was connected at both heels to collect the force applied to the floor. The accelerometer arrangement and heel drop point are illustrated as in Fig. 5 meanwhile, the complete test setup is shown in Fig. 6.

The vibration response of the PSSDB composite slab system can be obtained once the structure is excited. Once the structure is excited during the test, the vibration response is measured. The Dynamic Signal Analyzer is a vibration measuring equipment that captures signals and transforms them into frequency domain data. The accelerometer, on the other hand, is an electrical sensor that transforms signals into accelerations. To read the test response, the Dynamic Signal Analyzer was connected to a laptop device. Fig. 7 shows an illustration of the modal testing system.

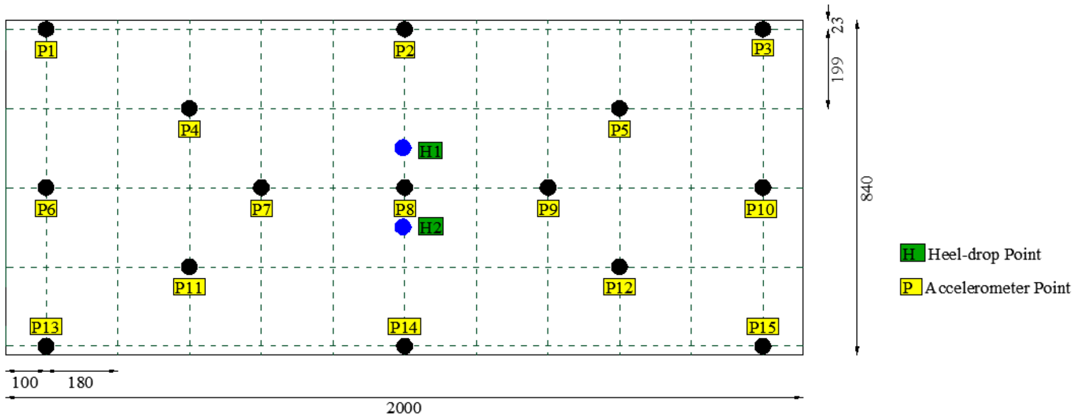


Fig. 5 - Accelerometer and heel-drop point arrangement

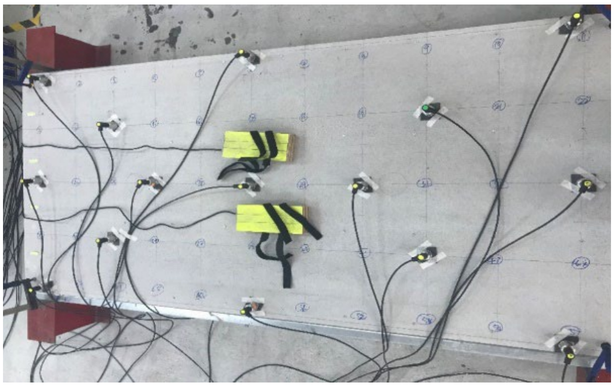


Fig. 6 - Heel-drop test setup for PSSDB composite slab system

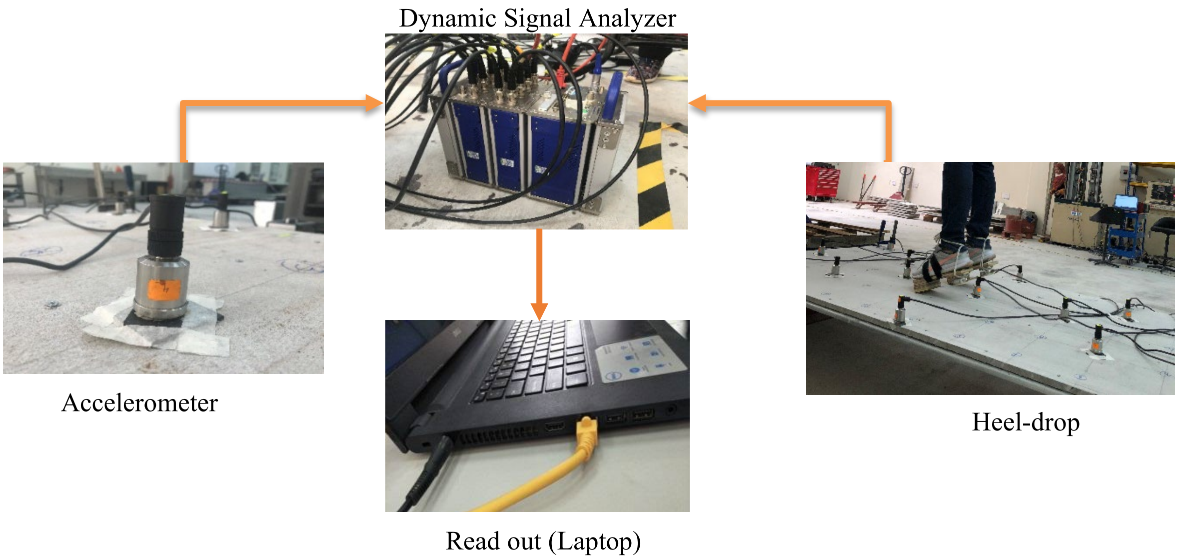
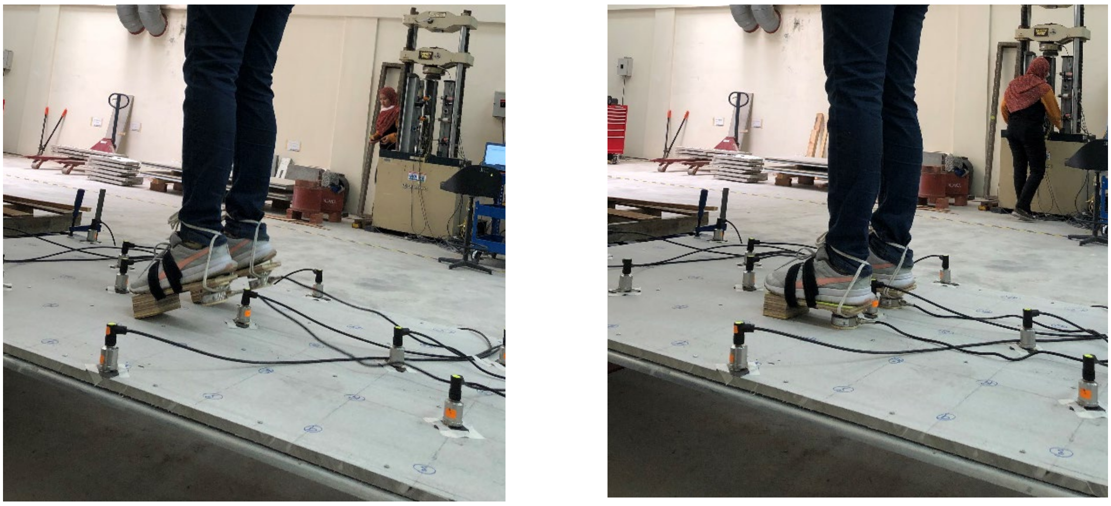


Fig. 7 - Heel-drop test setup for PSSDB composite slab system

2.4 Modal Testing and Analysis

The heel-drop test was conducted on a specimen by a person with a 65kg weight at the location as illustrated in Fig. 3. In this test, a person stands in the middle of the specimen and rises the toes (refer to Fig. 8a), and makes a sudden drop to ensure the heels strike the floor (refer to Fig. 8b). To gather more precise results and decrease the uncertainty, each test was repeated ten times.

From the experimental results obtained from the heel-drop test, the data were analyzed using MEscope Software Package then the data will be displayed in animation. The Frequency Response Function (FRF) measurement data are directly imported from the heel-drop test to get the graphical image of vibration behavior of the PSSDB composite slab system. The FRF measurement was performed using accelerometers where the measure responses in the time-domain were converted to FRF before the modal parameters of the structures were obtained.



(a) (b)

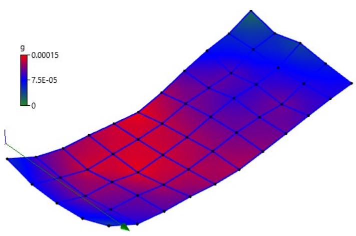
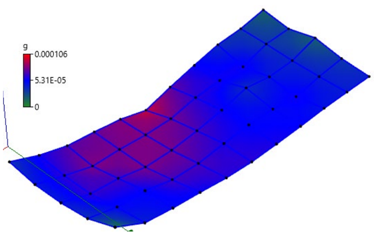
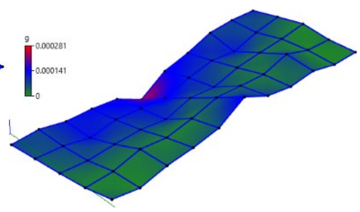
Fig. 8 - Heel-drop test position (a) rises toes; (b) sudden drop

3. Results and Discussion

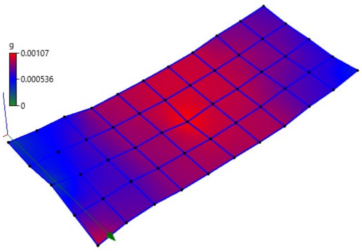
Based on the experimental result, the modal analysis using MEscope software was performed to obtain the vibration response of the PSSDB composite system. A small number of specimens with a large-scale size were prepared for the heel-drop test as it was a non-destructive test, then the test can be repeatedly conducted on the same specimens to obtain a reliable result. The data from the modal analysis were classified into three groups as shown in Table 4. As shown in Table 4, the specimen without infill material has a higher natural frequency than the specimen with infilled material. Meanwhile, a specimen with normal concrete as infill material has a lower natural frequency compared to a specimen with foamed concrete as infill. As mentioned before, two different types of concrete with different densities were used where the increase of the system mass will eventually be decreasing the natural frequency value [12]. The natural frequency result on the first mode for specimen P45HL is 17.7Hz which is higher by 21.47% and 74.8% respectively for specimen P45FC and P45NC.

The first three modes shape were considered in this study which represents the specific pattern of vibration of certain natural frequencies. The determination of the shape of this model is quite difficult where many modes will tend to be excited and vibrate together. Variation of mode shape is associated with the natural frequency where each natural frequency had its shape. The natural frequency value increases accordingly to the number of modes. As illustrated in Table 4, the area with the red color indicates the high displacement area, meanwhile, the blue color in the area with minimum displacement.

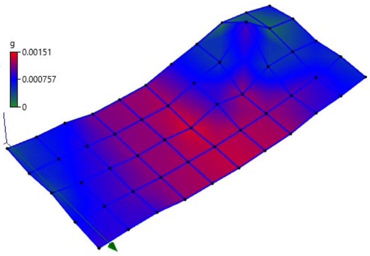
Table 4 - Natural frequency and mode shape of the PSSDB composite system

	Mode 1	**Mode 2**	**Mode 3**
P45HL			
	17.7Hz	21.3Hz	30.7Hz

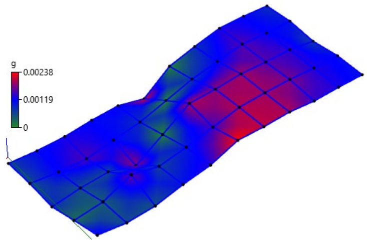
P45FC



14.2Hz

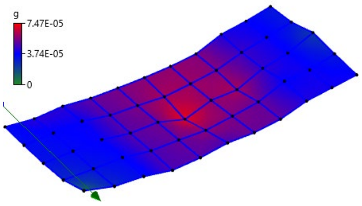


16.2Hz

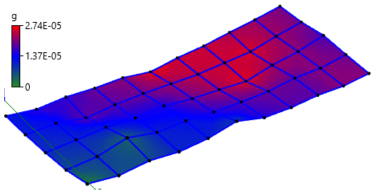


21.4Hz

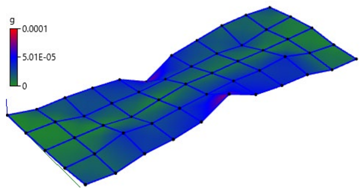
P45NC



4.5Hz



10.4Hz



25.1Hz

4. Conclusions

From the experimental study conducted, the conclusion that can be made are:

- The natural frequency of the first mode shape is 17.7Hz, 14.2Hz, and 4.5Hz respectively for P45HL, P45FC, and P45NC specimens. The increase of the mass system will eventually decrease the natural frequency of the PSSDB composite slab system.
- The specimen P45HL and P45FC have a natural frequency higher than 8Hz, which is above the human comfort limit for building occupants. However, specimen P45NC has a natural frequency of less than 8Hz which can cause uncomfortableness to the users.

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