Recent Trends in Civil Engineering and Built Environment Vol. 1 No. 1 (2020) 9-27

RTCEBE

Homepage: http://penerbit.uthm.edu.my/periodicals/index.php/rtcebe
e-ISSN : 2773-5184

Vibration Response of Composite Slab under Human-induced Dynamic Load: A Review

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DOI: https://doi.org/10.30880/rtcebe.2020.01.01.002
Received 20 August 2020; Accepted 08 December 2020; Available online 13December 2020

Abstract: In the construction industry, especially that related to the application of industrialized building system (IBS), floor system from the composite slab is highly demanded to provide optimum design, cost-saving, and constructional efficiency were lead in offering on an economical solution. One of the most critical elements that should be focused on designing the composite flooring system is serviceability evaluation due to vibration that affectshuman comfort. The design criteria proposed in evaluating the comfort criteria, namely as (i) acceleration limit (ii) natural frequency limit, and (iii) deflection limit. This paper summarized numerous vibration response studies of the composite slab with different material composition types such profiled steel sheet dry board (PSSDB), profile steel sheet with concrete infill (PSSC), and profiled steel sheet dry board with concrete infill (PSSDBC). The effect of various parameters on resonance, vibration response and human comfort was studied and discussed in detail by classification. Finally, on the summary table of the previous study was noted, presenting the parameter studied and the remarks on each study conducted

Keywords: Composite Slabs, Serviceability, Dynamic Load, Human-induced Load, Vibration Response

1. Introduction

Currently, the application of composite construction approach has been become more famous in terms of economy and sustainability as compared to other conventional construction methods [1]. The present technology intended to develop new composite structure and act as an alternative method for conventional steel-concrete structures in-floor system. The application of composite slab can reduce about 30% of weight if adequately associated with the steel frame structures. The development of composite slab with the combination of profiled steel sheet (PSS) and dry board (DB) was conducted in early research by Wright and Evans [2], Wright *et al.* [3], Badaruzzaman and Wright [4], Ahmed *et al*. [5,6], and Hamzah and Badaruzzaman [7]. Later than that, the addition of concrete as infill in

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profiled steel sheet and dry board was introduced in several studies by Badaruzzaman *et al.* [8, 9], Gandomkar *et al.* [10,11], Seraji *et al.* [12] and Jaafar *et al.* [13, 14].

Many investigations have been reported on the design, structural behaviour, and performance of composite slab when subjected to static and dynamic actions. Johnson and Li [15], Yardim *et al.* [16], and Jaini *et al.* [17] introduced composite slab made of foamed concrete and corrugated steel deck that achieves sustainability standard and excellent performance. Another type of the component for the slab is profiled steel sheet plywood, where a series of an experimental study in structural behaviour conducted by Gandomkar *et al.* [10], Jaffar *et al.* [13], Nordin *et al.* [18] and Wright *et al.* [19]. Meanwhile, Jeong *et al.* [20], Johnson and Shepherd [21], and Abbas *et al.* [22] study on the interaction of concrete and shear resistance to the corrugated steel sheet. However, considerable attention needed in terms of comfort criteria of the composite slab in term of vibration response as the competitive trends of the world market driving structural engineers to develop least weight and labor construction leads to rises the difficulties related to undesirable floor vibrations [23]. Figure 1 shows the typical PSSDB panel as a composite flooring system.

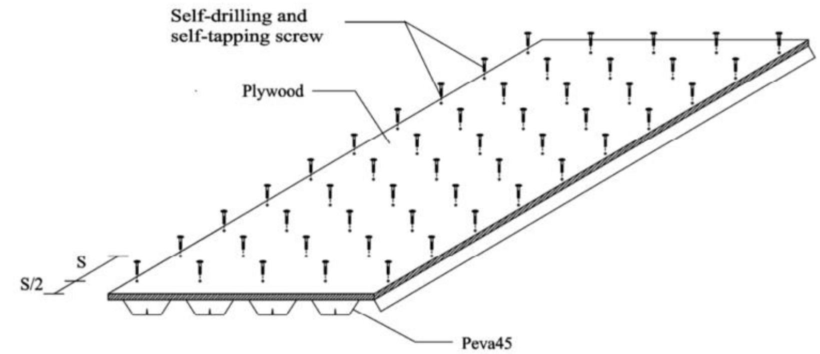


Figure 1: Typical composite floor system [10]

Composite floor structures are one of the examples of slender structures used in multi-story buildings, where vibration problems occur due to dynamic behavior which related to repetitive forces induced by devices, machinery or human activities such dancing, walking and running [23]. For the material with low internal friction and low damping used in structural floors, lightweight floor vibrations can be worse [24]. Generally, vibration is a repeated motion and great movement in the period [25] where acceleration, velocity, and displacement are related matters to vibration. Common sources of vibration are from traffic or heavy vehicles, large machinery, equipment connected with buildings and human activities on floors like walking and jumping, the vibration produced by human activities is the most common on floor structures. In modern structures, the serviceability is mainly affected by a lightweight and high strength materials, and it is the most serious issue for structural safety. The performance deficiencies of structure, where vibration in buildings and causes discomfort to human. Over the year, substantial efforts have been made to determine the human perception toward floor vibrations using different design criteria that have been proposed to developed vibration analysis to minimize the annoying effects of floor vibrations [26]. There are several design criteria for floor vibrations, namely based on acceleration, natural frequency or deflection limit that had widely used in previous research to ensure the flooring systems perform well under dynamic action [27].

This paper provides an extensive review focusing on the effect of the various parameter,especially in resonance, vibration response and human comfort of the composite slab. Therefore, the significant study was conducted achieving an in-depth understanding of the vibration response of composite slabs, which lead to improving the solution regarding structural problems and discomfort that generally caused by vibrations. The paper also describes the sources of vibration focused on the human-induced dynamic load followed with human tolerance to floor vibrations were included various design criteria such asbased on acceleration, natural frequency and deflection limit to minimizing vibration and satisfying comfort on the floor structure. The influence of materials properties as a structural component in vibration response, including natural frequency, damping ratio, mode shape, or energy dissipation of composite slab detailed discussed.

2. Source of Vibration - Human-Induced Dynamic Loads

The vibration in buildings can be caused by various such as from external source were generated by traffic on or underground, and the wind is buffering [28]. Meanwhile, internal sources of vibrations are mostly from human-induced of machine induced loads [17]. These source of vibration, also known as dynamic loads, where the load is engaging with inertia forces then directly applied to the floor by human or machinery, or others are moving the floor supports [29]. According to Murray *et al.* [30], the dynamic load can be described as harmonic, periodic, transientand impulsive. Formerly, Zivanovic *et al.* [31], Reynolds and Pavic [32], Kerr and Bishop [33] and Pavic and Reynolds [34] investigated that difficulty in satisfying vibration serviceability when human dynamic loads induced which includes walking, running and jumping.

Furthermore, Setareh [35] mentioned that the significant factors that contribute to these issues are decreasing in the system mass due to extensive use of resistant resources, decreasing of the natural frequency of the floors [36]. However, Tilden [37] and Fuller [38] considered as the principal researchers to quantifying the dynamic load effects due to loads. Tilden [37] studies in situ and moving loads; meanwhile, in a gymnasium, Fuller [38] quantifies the dynamic crowd impact for a group of peoples. Besides, Ebrahimpour and Sack [39] also explored the impacts of individuals and groups of people on in situ loads. They considered tests that involve the heel impact on the floors and produced a transient response. Also, in a different type of buildings, Murray and Hendrick [40] have performed a heel drop test to notice the dynamic response in terms of force amplitudes, frequencies and damping ratios of structural systems. Research conducted by Wiss and Parmalee [41] investigated a group of 40 individuals with certain load functionality which intended to predict the vibrations that are frequently occurring in structure conducted human response to transient vertical vibrations with regards to their frequency, displacements and damping ratios.Yao *et al.* [42] investigated on moving platform performed by jumping where the results showed that the strength level achieved and the dynamic response influenced by the flexibility of the structures. Silva and Thambiratnam [43] assessed the dynamic features of the multi-panels floor under human loads utilizing finite element method, and the findings stated that the cause of discomfort and excessive vibration in the ground are due to vibration with greater frequency harmonics. However, Shahabpoor *et al.* [44] reported on dynamic properties occupied by a various number of moving pedestrians. Furthermore, Shahabpoor *et al.* [45] focused on vibrating structures influenced by human loads. Besides that, experimental work conducted by Fiasca [46] on rigid and flexible concrete platforms; both were attached with moveable supports.

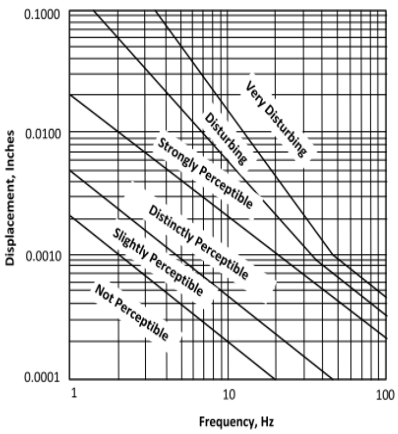
The numerical analysis developed by Mello *et al.* [47,48] evaluated the human comfort on buildings floors by considering models of walking people, which could generate vibrations that can cause discomforts to inhabitants. Another numerical study conducted by Yanghin *et al.* [49] evaluates human comfort on composite floors due to vibration produced through walking peoples. Meanwhile, Varela and Battista [50] investigate by laboratory testing for composite floors under the action of rhythmic loads focused on walking. Campsita and Silva [51] conduct investigation based testing and numerical modelling on the structural reaction of floors, under rhythmic human activities, focused on aerobics. The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

3. Design Criteria for Human Tolerance to Floor Vibration

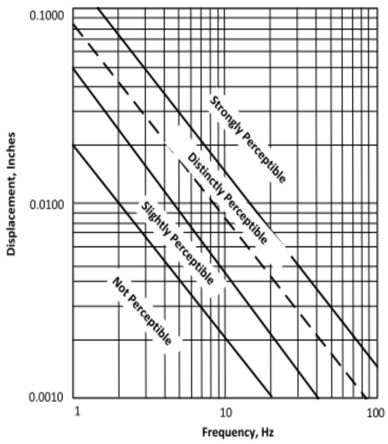
Human tolerance to the motion of the floor is a complicated aspect, and it could be annoying conditions. Murray *et al.*, [30] stated that human tolerance toward floor vibration differently depends on users. However, the human body is susceptible towards vibrations even though the amplitude of vibrations as low as 0.05μm where can reach the levels [52]. Therefore, one of the serviceability limit states (SLS) concerns other than deflection or cracking is on the prevention of human comforts in flooring system [53] where the evaluation of human response can be evaluated using various assessment method. There are various design criteria for floor vibrations, namely based on acceleration, natural frequency or deflection limit that as mentioned by Rijal [27] that can be found in design standards that had widely used in previous research to ensure the systems perform well under dynamic action.

3.1 Acceleration Limit

The development of acceleration responses as primary tools in designing floor system in line with the human perception against floor vibrations. In the early 1930s, Reiher and Meister [54] introduced Reiher-Meister scale developed based on acceleration limits subjected to the people load to steady-state vibrations with a variation of displacement amplitude from 0.00254 to 2.54 mm with the frequency in the range of 1 to 100 Hz as shown in Figure 2(a). The scale was classified into six divisions based on the peoplesubjective experience and response. From the scale, it can be concluded that larger displacements are acceptable if the frequency is lower which means for 0.002 inch displacement, it is not perceptible if the frequency is 1Hz while distinctly perceptible if the frequency is 10 Hz. However, study by Lenzen [55]on steel joist-concrete slab found that the existing Reiher-Meister scale is not suitable for flooring systems with critical damping value less than 5%. If a factor of ten increases the displacement, the modified Reiher-Meister scale has been introduced with a new vibration-based curve, as shown in Figure 2 (b). Comparing to existing Reiher-Meister scale, the modified scale simplified into four categories. A previous study by Murray [56] on steel beam-concrete slab reported flooring system with damping 4% to 10%, resulting in occupant complaints. The modified Reiher-Meister [55] scales are usually used with another additional method for assessing design criteria because the damping value in the flooring system is not being taken into consideration. The system damping and mass play an important role in preventing the floor system vibration behaviour and more critical than the system stiffness.



(a)



(b)

Figure 2: Design criteria based on acceleration limit (a) Reiher-Meister scale [54], (b) Modified Reiher-Meister scale [55]

The International Standards Organization (ISO 2631-2:2003)[57] proposed the acceptance criteria of the vibration developed from the acceleration limit in terms of the root mean square (RMS) for various applications of floors, as shown in Figure 3. The RMS method is used in determining the equivalent magnitude and compared to the acceleration limit to find out whether the level is acceptable or not [58]. The lowest acceptance acceleration levels as 4 – 8 Hz according to the shape of the baseline curve. The two primary reasons for the lowest rate of acceptance acceleration are due to human physiology, which makes the occupants more susceptible in the 4-8 Hz rangeand as Allen *et al*. [59] have pointed out typical walking excitations contains harmonics of 4,6 and 8 Hz which lead to more frequent resonant occurrences.

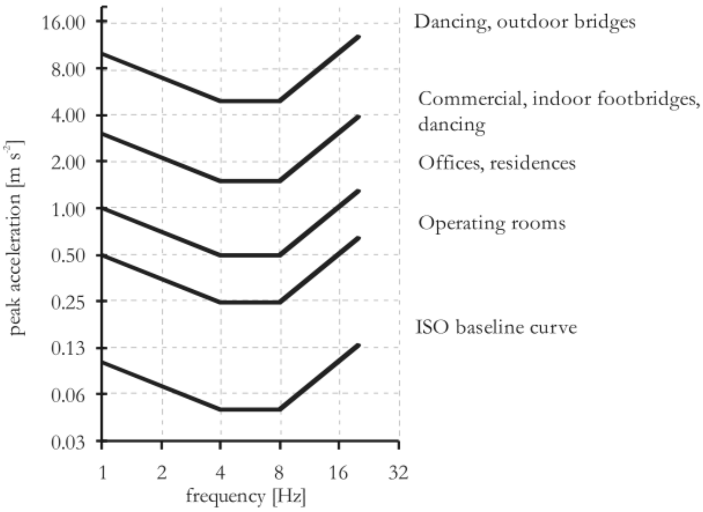


Figure 3: Limitation of acceptable acceleration levels for various usage of floors [58]

Following Allen and Murray [60] recommendation, the Applied Technology Council (ATC) [61] predicted steady-state acceleration due to human walking excitation. According to the design, criteria were considering the peak acceleration, a_p/gestimated by using Eq. (1), by choosing the lowermost harmonic, i, where the excitation frequency, $f = i f_{step}$, matches with the frequency of composite as shown in Table 1. The peak acceleration value is then compared to the recommended limit to ensure the personal comfort are satisfied, as illustrated in Figure 3.

$$\frac{a_p}{g} = \frac{R\alpha_i P}{\beta W}\cos\left(2\pi i f_{step} t\right) \tag{1}$$

Where P is the person weight where taken as 0.7 kN to 0.8 kN α_i is the dynamic coefficient for the i^{th} harmonic force component, W is the effective weight of the floor, R is a reduction factor taken as 0.5 for floor structures and 0.7 for footbridges, β is a modal damping ratio, i is a harmonic multiple of the step frequency, f_p is the step frequency, and t is time in seconds.

Table 1: Standard forcing frequencies (f) and dynamic coefficient (α_i)* [62]

Harmonic	Person walking		Aerobics Class		Group Dancing	
(i)	Fs (Hz)	α_i	Fs (Hz)	α_i	Fs (Hz)	α_i
1	1.6 – 2.2	0.5	2.2 – 2.8	1.5	1.8 -2.8	0.5
2	3.2 – 4.4	0.2	4.4 – 5.6	0.6	3.6 – 5.6	0.1
3	4.8 – 6.6	0.1	6.6 – 8.4	0.1	-	-
4	6.4 – 8.8	0.05	-	-	-	-

* dynamic coefficient = peak sinusoidal force/ weight of the person (s)

American Institute of Steel Construction (AISC) Design Guide [30] recommendation for design criteria presented to fulfil the comfort criteria for the design of floor systems supporting the sensitive equipment due to human walking excitation. The first harmonic for the design purpose, Eq. (1) can be used to calculate the peak acceleration limit as in Eq. (2). The criterion mentions that the floor system satisfying the comfort criteria if,

$$\frac{a_p}{g} = \frac{P_O e^{-0.35 f_1}}{\beta W} < \frac{a_o}{g} \tag{2}$$

Where, a_p/g is the projected peak acceleration ratio in the unit of gravity, P_o is the constant force, f_1 is the natural frequency of floor structure, β is the damping ratio, W is the effective weight of the floor, and a_o/g is the acceleration limit. The recommended value of parameters for P_o, β, and a_o/g as given in Table 2. The acceleration limits are multipliers of the ISO baseline curve as in Figure 3.

Rhythmic activities are also one of the contributing factors in increasing vibration problem building as cyclic floor acceleration with the value of 0.5g where lead to the fatigue problems in the structure [27]. In the 1990s, the design standards for floor structures due to the rhythmic activities have been developed by Allen [63,64] and National Building Code (NBC) [65] by focusing on acceleration limits to resolve the fatigue issue in the structure due to the rhythmic activities. By assuming the floor structure only has one mode of vibration, the peak acceleration of the floor obtained from the following Eq. (3).

$$\frac{a_p}{g} = \frac{1.3\alpha_i w_i / w_f}{\sqrt{\left[\left(\frac{f_n}{f}\right) - 1\right]^2 + \left[\frac{2\beta f_n}{f}\right]^2}} \tag{3}$$

Where a_p/g is the projected peak acceleration ratio in the unit of gravity, αi is the dynamic coefficient (recommended value in Table 1), $w_p$is the effective weight per unit area where distributed to floor panel, $w_t$is the effective distributed weight per unit area of floor panel including the occupants, f_n is the natural frequency of floor structure, f is a forcing frequency, and β is the damping ratio.

Table 2: The recommended value for parameters P_o, β anda_o/g [30]

	Constant Force P_o	**Damping Ratio *B***	**Acceleration Limit a_o/g x 100%**
Offices, Houses, Churches	0.29	0.02–0.05	0.5%
Shopping Malls	0.29	0.02	1.5%
Footbridges -Indoor	0.41	0.01	1.5%
Footbridges - Outdoor	0.41	0.01	5.0%

3.2 Natural Frequency Limit

The serviceability limit in designing flooring systems also depends on the natural frequency [66] were determining the natural frequency in a structure is crucial for the prediction of the occurrence of resonance conditions from a design viewpoint, comfortableness, and design criteria for any floor systems. There are various literature and studies in exploring the dynamic features of the structural system focusing on the natural frequencies to reveal the floor systems serviceability under human activities [67-70].The design criteria for the rhythmic excitation as according to the AISC Design Guide [30] based on the dynamic response and dynamic loading function of the structural system supporting aerobics, dancing, audience participant, and similar events where the design criterion based on Eq. (4). The limit of the ratio of peak acceleration due to gravity in the frequency ranging from 4-8 Hz.

$$f_n \geq (f_n)_{req} = f\sqrt{1+\frac{k}{a_o/g}.\frac{a_i w_p}{w_t}} \tag{4}$$

Where $(f_n)_{req}$ is minimum natural frequency required in preventing undesirable vibrations at each forcing frequency, f_n, k is the constant (1.3 for dancing, 1.7 for lively concert or support and 2.0 for events), $\alpha_i$is a dynamic coefficient, and a_0/g is the limit of ratio of peak acceleration due to gravity in the frequency ranging from 4-8 Hz. The recommended value for parameters $\alpha_i$and a_0/g, [57].

Johnson and Shepherd[21], focused on the vibration from installed machinery and residential floors and human activities as the two most significant sources of excitation in timber structures. The residential floors with a fundamental natural frequency less than 8Hz, an exceptional checking should be made meanwhile, if the fundamental natural frequency is more than 8 Hz, the following checking using Eq. (5) also, Eq. (6) should be satisfied. The approximate value of v estimated by using Eq. (7).

$$\frac{w}{F} \leq a \qquad \text{(mm/kN)} \tag{5}$$

Where w is the maximum short-term vertical deflection (mm) due to the concentrated load, F at any point of the floor and a is the flexibility coefficient od the floor.

$$v \leq b^{(f_1\zeta - 1)} \qquad (\text{m/Ns}^2) \tag{6}$$

Where v is the unit impulse velocity response (m/s) caused by unit impulsive (1 Ns) applied at the point that giving a maximum response on the floor, ξ is the modal damping ratio and the natural frequency of 40Hz considered as control of vibration in this method.

$$v = \frac{4(0.4 + 0.6n_{40})}{mbl + 200} \tag{7}$$

Where $n_{40}$is the number of first-order modes with the natural frequency value reaching 40Hz and can be calculated using Eq. (8), m is the mass of floor per unit area (kg/m^2), and b is the width (m), and l is the span of the floor (m).

$$n_{40} = \left\{\left(\left(\frac{40}{f_1}\right)^2 - 1\right)\left(\frac{b}{l}\right)^4 \frac{(EI)_l}{(EI)_b}\right\}^{0.25} \tag{8}$$

Where $(EI)_l$ is the equivalent plate bending stiffness (Nm^2/mm) of the floor about an axis parallel to the beams, where $(EI)_b < (EI)_l$.

Murray [71] investigated more than 100 problems occurs on the floors, and the result shows that most of these floors have natural frequency in the range between 5-8 Hz where the following frequency value must avoid, (i) frequency below 3Hz to prevent walking resonant and (ii) frequency range of 5-8 Hz to prevent human discomfort. The natural frequency limitation in controlling the problem of serviceability was proposed between 5-10 Hz depending on the floor material and the applied dynamic force. Allen and Rainer [72] suggested minimum frequency for natural loads is between 5Hz when floors under rhythmic load. Moreover, Ungar [73] proposed a limitation natural frequency of 5 Hz where: (i) if the frequency is less than 5 Hz, the mass of the floor is a governing parameter and (ii) if frequency is higher than 5 Hz, the stiffness governing the response of the floor.

Furthermore, the resonance issues square measure a lot of possible to occur as a consequence of second and third harmonics since the natural frequency of the floors square measure sometimes over 3 Hz and fall within the vary of 4 to 8 Hz. However, the lower the harmonic, the more significant square measure the vibration created. Minimum acceptable natural frequencies for various combination of human activities and flooring systems are given in Table 3 [74]. The resonance problem may happen on the floors having fundamental frequencies larger than 8 Hz if the damping is low. Hence, vibration can be a causes discomfort to the occupants to a broad range of natural frequencies of the flooring systems.

Table 3: Minimum acceptable value of floor frequencies [74]

Rhythmic activities	Steel/concrete-floor	Light-frame floor
Dancing and dining	5Hz	10Hz
Aerobics	9Hz	13Hz

In addition, a more advanced method based on the nature of the vibration response [75,76] was categorized as low-frequency floors (LFF) and high-frequency floors (HFF). As summarised by Mohammed *et al*. [77] in Table 4, the cut-off frequency differed comparatively according to distinct writers and design rules.

Table 4: The cut-off frequency between low and high-frequency floors, taken by distinct writers and design instructions [77]

Reference	Cut-off frequency
[78]	8Hz
[75]	7Hz
[60]	9Hz
[79]	10Hz
[80]	10Hz
[81]	10Hz, for general open floors 8Hz, for enclosed spaces, like operating theatre
[82]	9Hz

3.3 Deflection Limit

Traditionally, the vibration serviceability assessment according to a static technique of deflection resulting from a nominal live load has been limited by the span-deflection between SPAN/180 or SPAN/360 and SPAN/480 [83,84]. Allen and Pernica [74] stated that the deflection criterion for the unit point load should be applied to the design of the light-frame floor when vibration subjected to walking load. For floors with spans less than 3m, the limit for unit load deflection is ≤ 2 m, and the deflection limit for a span ≥ 3 m decreases exponentially. The deflection of about 0.6mm below the applying 1 kN point load is suitable to all floor spans.

Ohlsson [78] has recommended the static deflection method for deflection on average span were not greater than 1.5mm when subjected to a 1 kN concentrated force, as published in the Swedish Building Code. The deflection limitation for a uniformly distributed force can be calculated by Eq. (9).

$$\frac{5Wl^4}{384EI_x} < \frac{l}{600} \tag{9}$$

Where W is the uniformly distributed load, l is a span length, E is a modulus of elasticity, and I_x is the moment of inertia.The limitation of the maximum floor deflection, which in certain instances is subjected to concentrated live load, is due to the more limited floor behaviour under human footfalls impacts. The limitation for deflection under rectangular plan floors with parallel closely spaced joists can be calculated by Eq. (10) [85].

$$d_1 \leq 2mm \quad \text{for } l \leq 3\text{m}, \quad \text{and} \quad d_1 \leq \frac{8}{l^{1.3}} \quad \text{for } l \geq 3\text{m} \tag{10}$$

Where l is the span (m), and d_1 is the deflection due to the 1 kN concentrated load on the floor center. Additional deflection constraints are calculated by using Eq. (11), supplemented for timber joist products [86]. However, for floors with heavy toppings or inter long bracelets, this equation is unreliable [87].

$$d_1 \leq \frac{2.55}{l^{0.63}} \quad \text{for } 5.5\text{m} \leq \text{l} < 9\text{m}, \quad \text{and} \quad d_1 \leq 0.6mm \quad \text{for l} \geq 9\text{m} \tag{11}$$

The control of static defecation in evaluation vibration serviceability of floors is not adequate, as Ellingwood and Tallin [88] have stated. Several researchers have reported that floor vibration serviceability could not be achieved by controlling static deflection like SPAN/360 or inadequate to prevent annoying floors vibrations, according to Al- Faqoha *et al*. [89].

4. Vibration Response of Composite Slab

The original idea in the design of composite flooring systems using profiled steel sheets and dry board as the component structure began in 1986 by Wright *et al*. [2]. The profiled steel sheet and dry board (PSSDB) system have many advantages as it can shorten the time, simplifying the installation process and also lasting longer than conventional method were allowed the application in office building domestic buildings, or during the renovation for a various structure such as roofing, flooring, and walling [5]. Subsequently, the advancement of technology attracts researchers developing various type of floor system with a different type of material used. The development of the floor system covers a vast scope and aspects such as design, manufacture, connectivity, and installation as well as testing on strength stability of the floor. The study on the serviceability of composite slab under vibration action may lead to the high renewed interest and precise design on the composite slab. Vibration knows as a repeated motion and extensive movement in a certain period and parameter related to vibration is acceleration, velocity, and displacement.

The critical parameter related to the vibration problem is the natural frequency (NF) and damping ratio (DR). Natural frequency defined as the frequency at which the structurevibrate when displace and quickly released, while damping of the structure is essential in mitigating the excessive vibration response [90]. The frequency that interpreted in the slab by the slab vibration influenced mode shape where understanding the resulting mode shapes lead to the construction of floor structure that can withstand more massive vibration. Damping ratio correspondingly identified as the crucial factor that related to the energy dissipation compared to the natural frequency and damping ratio. Details explanation of the material, interaction and loading type were explain in detail through the classification for each research.

4.1 Profiled Steel Sheet-Dry Board (PSSDB)

The combination of steel and board for floor system had been introducing during 1986, known as profiled steel sheet dry board. From the early study conducted by Wright and Evans [2] and Wright *et al*. [19] focused on the development of the PSSDB system as a floor panel in building construction to replace the timber formwork as PSSDB is known as a lightweight composite floor system. There are various types of the board, such as plywood, chipboard, dry board, and cement-bonded mineral board that can be obtained on the market to use as a structural element in the construction field.

Ahmed & Ahmad [90] investigated the vibration response of the PSSDB flooring system by theoretical and experimental study. The assessment of the NF in the PSSDB panel was conducted following the standard impact heel test where an average person was sit-up at the middle of the panel, raising the heel to 50 mm and suddenly impacting the floor [91]. Four heel impact test is carried out to get a reliable result, resulting in acceleration time history graph that measures by an accelerometer placed near the feet of the test person where the damping coefficient is calculated as proposed by Ellis [92]. The spacing and rigidity of connectors contributing to the stiffness of the panel system, thus affecting the NF. A longer span generate more vibration due to the decreased of NF where should take into consideration when designing a floor panel with a long span.

Ahmed and Badaruzzaman [91] performed studied on the PSSDB composite panel system to evaluate the NF and damping coefficient by theoretically and experimentally. The evaluation of the dynamic response of a floor system related to natural frequency by using the analytical solution as used by the previous researcher [91] is essential, especially in design criteria against floor vibration. By applying the theoretically and experimentally rigid bending of panels, dynamic parameters such as NF are determined. The influence of span length, dry board thickness, and connector spacing on NF are investigated.The result suggested that the actual panel rigidity calculated to the NF value. The test resulted in precise panel damping of 1.5% when 50% of the log decrement damping was considered modal by a medium of 3% [93] as the structure provides additional damping owing to the presence of objects, furniture and furnishing.

On the PSSDB composite floor panel, Ahmed and Badaruzzaman [94] concentrated primarily on the system NF. The impact on the NF value of different board types board thickness and connectors spacing is assessed. The evaluation of natural frequency using the analytical approach as conducted previously [90,91] and experimentally by impact tests. Numerical analysis using finite element (FE) code LUSAS programmed [95] are used to investigate the dynamic parameters then the result compared to the experimental and analytical results. The modelling of the system in LUSAS using the eight nodes (QSL8) elements for PSS, DB, and dummy plate as shear [96, 97]. The results from the numerical, experimental, and analytical study could be used to determine the NF of the floor panel as it provides accurate stiffness (EI) value of composite panels. The closer spacing of screw connectors increases the stiffness of the PSSDB panel, hence giving higher NF. The vibration response can be improved by increasing the damping of the flooring system from the addition of mass using a thicker board as the performance-related to the stiffness to mass ratio [91,94]. However, a different type of board used not significantly give effect to vibration performance.

Gandomakar *et al*. [98] presented the study on the PSSDB system on the effect of the partial interaction between PSS and DB on the NF of the PSSDB system conducted experimentally by impact test as for threedifferent samples to measure the NF and DR for the studied system with 100 mm, 200 mm, and 300 mm screw spacing. PSSDB system with lower screw spacing has higher NF and DR as the DR is s related to the stiffness of the system resulted in the higher value [91]. The NF and DR values from impact test used to verify the FE models implemented by the ANSYS program [99] and the vibration response of the system under human walking load is evaluated [11]. The parametric study on the fifteen FE models focused on the effect of PSS and DB thickness and boundary condition of the PSSDB system to the NF value. From the result [98] , it proved that the NF influenced by the screw spacing, the thickness of PSS and DB and boundary condition by (i) controlling the sliding of PSS along the strong direction (ii) provide support on top and bottom flanges of the PSS (iii) number of side edges being supported.

The main objective of the study by Gandomkar *et al*. [11] to assess the vibration serviceability of the PSSDB system under human walking load. Twelve PSSDB panels that categorized as LFF developed by using the ANSYS program [99]. From the developed FE models, the NF and mode shape of the panes were determined. However, the dynamic response of panels like peak acceleration was obtained by comparing to the limiting values as proposed by ISO 2631-2 [57] to reveal the vibration acceptance to floor panels. It was observed that the peak acceleration for third and fourth dynamic load models higher than those on the first and second loads as well as limiting value of the ISO 2631-2 [57]. Panels that undergo third and fourth loads models show the low comfortableness level then discovered that changing the load position is a practical item in the response of panel [48]. By increasing the thickness of PSS and DB, decreasing the screw spacing and enhancing the DR of the PSSDB system, consequently decreasing the peak acceleration. The result on the DR presented in

Table 2 useful for designers reducing the response of the floor by equipment and types of partitions [81].

4.2 Profiled Steel Sheet with Concrete as Infill

A composite member formed when a steel element such as profiles steel sheet or steel deck component associated with the concrete element. Alternatively, the composite floor slab consists of profiled steel sheets not only act as formwork but also as tensile reinforcement [3]. Various types of profiled steel sheets or corrugated steel sheets are available and commonly used in research such as BONDEK II, BUILDECK, PMFL.D35, PMFL 60, PEVA45, and PEVA50. The addition of a different type of concrete such as standard concrete, foamed concrete, geopolymer concrete, and other as infill in the composite floor system is found suitable to replace the conventional flooring system.

Silva *et al*. [23] presented a numerical study with the primary objective to study the structural behavior of vibrations that cause discomfort. The assessment of the composite slabs system vibration in term of serviceability limit state must be followed using design standards. The existing composite floor used in this work currently used for gymnastics was developed by the computational model, developed using the mesh refinement techniques present in the FE method implemented in ANSYS program [99]. Seven different computational models were developed based on the variations of degrees of freedom ere resulted in a slight difference of results in term of ND, displacement, velocities, and accelerations. Silva *et al*. [100] intended a study to classify an appropriated finite element model for composite steel deck floors to be used in study related to dynamic behavior. The existing composite floor now used for dancing in rock concerts and it was observed that every investigated model, although a significant difference in the NF values, the vibration modes shows similarity. Dynamic response in terms of acceleration was investigated and indicated that the floor does not comply with the human comfort level.

Sanchez *et al*. [66] presented a study to investigate the vibration serviceability of long span composite deck (LSCD) for a laboratory floor, full-scale mockup, laboratory footbridges and thirteen in-situ floors for residential buildings to obtain the results of natural modes and responses to walking excitations by a laboratory test. The results of tested specimens indicate that LSDC has very good resistance to floor vibrations due to walking load. The NF of the measured floor is in the range above the 3Hz [48] limit for composite slab and composite beam floor system to avoid vandal jumping. For the test conducted with walkers traversing directly through the middle of the bay and the accelerations were measured at the mid-bay, which the location of maximum response. The in-situ tests show the performance of floor vibration is very satisfactory when the LSDC is supported by steel stud or CMU walls behave as HFF with NF above10Hz [101]. The combination of slab and wall have good potential to be utilized in eliminating the vibration problems.

A vibration response experimental research on the foamed concrete composite slab with different support has been conducted by Rum *et al*. [102]are tested with fifteenunder a hammer-impact test. The outcome showed that the NF of the corrugated steel formed concrete slab with wooden support was 40.94 Hz. Meanwhile, an experimental investigation performed by Jaini *et al*. [17] focused on the effect of the thickness on the natural frequency. In this study, the addition of foamed concrete as topping to corrugated steel deck was introduced to reduce the self-weight of composite slab. Ten specimenswith different thickness ranging from 75 mm and 175 mm were tested under hammer-impact test. The results of NF of this study that value decreases along with the slab thickness, but slightly increases with the thickness larger than 150mm. According to Khan *et al*. [103], increasing the thickness leads to the high mass of the structure, which decreases the NF. In contrast, the DR show contradicts behavior where the value increases along with the thickness of up to 125mm before start decreasing. The damping ratio of the composite slab suppose lies in the range of 2.0% to 3.0 [30], but for the composite slab made of foamed concrete, the value is approximately 1.5% to 5.0%

[17] which is relatively high. The energy dissipation increases along to the thickness of composite slab in the range between 0.10 J and 0.55 J were considered convincing as according to Brownjohn[104], the energy dissipation of lightweight precast composite slab is approximately 0.1 J to 0.2 J.

Chen *et al*. [105] revealed the vibration behavior of the profiled composite steel deck under human walking and rhythmic activities numerically for one-unit and four-unit floors FE models that were developed using the ANSYS program where the concrete slab used solid element while the steel deck used shell elements. The verification of the computational technique used in modelling and analysis of the floor system was validated by comparing the model analysis for four-unit floors with a study conducted by Silva and Thambiratnam [43]. The result obtained indicate that factor influenced the vibration due to human-induced load. Under human walking or rhythmic activities, the vibration of the high-order modes is rapidly excited, particularly for the multi-unit composite floor system. The selection of appropriate load models to evaluate the floor vibration response plays an important role in the composite floor dynamic behavior.

4.3 Profiled Steel Sheet-Dry Board with Concrete as Infill

The research on the use of infill in the PSSDB scheme was initiated by experiments with the use of rock wool and sand [106] and used for concrete [107] to evaluate the PSSDB system performance to fire resistance. Previously, studies on enhancing PSSDB system stiffness by applying concrete as an infill was conducted by incorporating concrete as PSS infill and DB topping [9], experimental and theoretical evaluation [108], and familiarising two sophisticated PSSDB infill units with the concrete bending performance [109,110]. However, the study on the vibration of the composite slab using a PSS and DB infill with concrete was not broadly conducted as the researcher was focused more on the static compared to the dynamic condition.

Gandomakar and Badaruzzaman [111] provided the information of an experimental study on the effect of concrete infill on the dynamic behaviour of the PSSDB system under human walking load. The research considers two different kinds of human walking, which is slow and normal speed. The effect of concrete recognized for two PSSDB samples without concrete infill and PSSDB with concrete infill on the dynamic behaviour of the PSSDB system. The result shows that the concrete usage as infill in the PSSDB system reduced the displacement by 36.91% and 63.94%, respectively, for slow and normal speed under human walking conditions. The same goes for accelerations of the PSSDB systems reduced to 29.58% and 39.19% under slow and normal speed due to human walking, respectively.

Gandomkar *et al*. [10] investigated on the NF of the profiled steel sheet dry board with concrete (PSSDBC) infill subjected to human walking load. The experimental investigation focused on the impact of concrete as infill in the PSSDB system while the design of PSSDBC model using ANSYS program was studied under various parameters such as the impact of concrete grades, PSS and DB thickness and boundary condition. The structural modelling of the PSSDBC specimen (2400 mm x 795 mm) was demonstrated by linking Peva45 and plywood infilled with concrete using screw connectors [99]. The outcome showed that the PSSDB system NF was greater than the PSSDBC system where it happened could be due to the increased stiffness and system mass [43, 45-47]. The DR was measured by 1.40% and 2.90% respectively, corresponding to the NF of thePSSDB and PSDDBC system. The assessment of the impact of concrete grade on the PSSDBC system NF with three different concrete grades of C25, C30, and C30 led in the concrete grade having no critical impact on the NF value. The outcome found that through supports under the top and bottom flanges of the PSS, control of sliding along the PSS strong path at the end support, and several side edges supported influence the enhanced of the NF of the PSSDBC system

Later on, Gandomkar *et al*. [11] created models of finite elements to examine the PSSDBC system dynamic response to assess serviceability owing to human walking. ThirteenPSSDBC panels with difference support in the LFF categorywere developed to determine the structural floor system NF and mode shapes values [8]. All panels were regarded under various parameters on the dynamic system response such as boundary conditions, damping ratio, PSS and DB thickness, screw spacing, concrete grade, and floor span, and the results were achieved using finite element ANSYS program parametric assessment [99]. Evaluation of serviceability due to the vibration of the PSSDBC panels under four dynamic load models determined by the highest peak acceleration value. The increase in plywood and Peva45 thickness decreased and increased the PSSDBC system NF, respectively, while the decrease in screw spacing enhances the NF because of the panels are going to be stiffer [8]. Improving the DR value can decrease the maximum system acceleration while increasing concrete grades enhances the PSSDBC panel NF.

5. Conclusion

Based on the review of the present knowledge, in-depth literature on the vibration performance of composite slab when induced by human load was studied and summarized in this paper. The increasing trend in the use of lightweight materials in designing flooring system was regulated by limiting serviceability, particularly for vibration rather than ultimate strength limit state. As the serviceability of the lightweight structures is the most critical issue, the evaluation of human comfort should be taken into consideration in addition to the safety criteria. The vibration serviceability criteria have difficulty to be satisfied when dynamic loads, mainly when induced by a human. In order to prevent discomfort, damage, or outright structural failure due to excessive vibration, the evaluation of serviceability is essential for the safety of the building. Numerous study conducted previously introduced the design criteria for satisfying the serviceability, such as using acceleration limit, (Reiher- Meister scale, ISO-2631-2, ATC, AISC, NBC, etc.), natural frequency limit (AISC, BS EN 1995-1-1, cut-off frequency, etc.) and deflection limit (Swedish Building Code). However, several researchers mentioned that the evaluation of serviceability is not sufficient by using the static deflection method. Despite that, earlier work has been presented and summarized containing the parametric studies, results, discussion, and conclusion in paragraph form.

Recently, the vibration response of the composite slabs has been widely focused. The understanding of the real behaviour of the composite flooring systems was conducted through experimental, analytical, and numerical solutions as proposed by authors. The verification and development of FE method were played vital roles in the phase of designing and analyzing the composite slabs system. The study on the effect of various parameters (span length, stiffness, thickness of PSS & DB, thickness of slab, support condition, addition of concrete, grade of concrete, and etc.) on the vibration response (NF, DR, mode shape, energy dissipation, and etc.) were conducted numerically generated using FE program such as ANSYS and LUSAS which relatively low in cost either for full scale or prototype. The analytical solution was applied in the various study either in evaluating the serviceability or vibration response of composite floor.

Vibration response of composite slab system is well understood for different three different material composition of composite slab. However, the gaps, weak facts, and recommendation were listed for future research to be conducted. The evaluation of serviceability of composite slab must take into consideration by the researcher, primarily when related to the dynamic load. An inadequate number of the study investigated on the addition of concrete as infill between PSS and DB, with different study parameters (depth of PSS &DB, connectors types, type of human-induced loading type, and etc.) which is gain full attention in order to help the designers and architects in the development of high strength structure. In-depth studies are required to resolve the problem related to the dynamic performance of composite slab systems mainly for PSSDB composite slab with the addition of infill simultaneously enhance the knowledge on each type of composite floor systems.

Acknowledgement

The authors have gratefully acknowledged the financial support provided by Universti Tun Hussein Onn Malaysia through research grant Postgraduate Research Grant (GPPS) Vot. No. H294 and Research Fund E15501 by Research Management Center (RMC) UTHM.

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