



Density and Strength of Foamed Concrete: The Influence on Dynamic Characteristics of Lightweight Profiled Composite Slabs

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Abstract: This paper presents the experimental study on dynamic characteristics of lightweight profiled composite slabs. The density and strength of foamed concrete as topping material become the subject of interest. This type of floor system offers sustainable and reliable structural component in term of lightness, efficient construction processes and precast element. Although lightweight profiled composite slab may not a new thing in the construction industry, the understanding on the dynamic characteristics in term of natural frequency, damping ratio and mode shape are still ambiguous. Slab specimens, made of foamed concrete and Peva45 steel corrugated deck, were fabricated with size of 840 mm width, 1800 mm length and 125 mm thickness. The density of foamed concrete varies from 1400 kg/m³ to 1800 kg/m³. Within this range, foamed concrete has the compressive strength around 15.43 MPa to 32.23 MPa and the tensile strength approximately 1.06 MPa to 1.97 MPa. The natural frequency was observed to decrease with the increment of density and strength of foamed concrete. The natural frequency of lightweight composite slab is around 30 Hz to 35 Hz. Meanwhile, the damping ratio is considered quite high at the range of 3% to 5% where low density of foamed concrete gave more advantage in dissipating vibration within short period. The mode shape was visually obtained using MEScope and represents the bending behaviour.

Keywords: Foamed concrete, composite slab, corrugated steel deck, strength, vibration

1. Introduction

Recently, foamed concrete composite slab has received inclusive attention as sustainable and reliable structural component. The fascination toward lightweight and ductile materials have directed to the application of foamed concrete and corrugated steel deck. The use of these materials is to avoid the weight penalty and subsequently accelerate the construction processes of building. On the other hand, the performance of foamed concrete composite slab as compared with conventional slab was found very promising. Basically, foamed concrete composite slab, as can

be seen in Fig. 1, consists of foamed concrete as topping material on the top of corrugated steel deck. Although foamed concrete composite slab is not a new thing in the construction industry, its behaviour under dynamic action are still not well understand and hence require further investigations.

In the current practice, composite slab is mainly fabricated using normal concrete that give a perfect interaction with corrugated steel deck. Normal concrete is widely accepted as a material that has density around 2400 kg/m^3 with high characteristic strength of 20 MPa to 80 MPa. However, normal concrete contributes to the weight penalty and thus affect the size of building frame (beams and columns). Therefore, for an efficient design and forming of composite slab, foamed concrete is preferable as it can offer lightness and versatility. Foamed concrete comprises cement mortar matrix that can be manufactured easily with good workability, excellent performance of thermal insulation, fire resistance and absorption [1]. Despite of all these advantages, the main drawback of foamed concrete is its characteristic strength that only can reach around 10 MPa to 16 MPa.

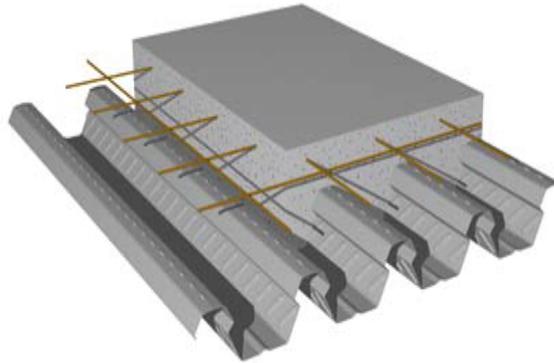


Fig. 1 – Foamed concrete composite slab, as referred as lightweight profiled composite slab.

The modification of foamed concrete with characteristic strength more than 20 MPa by Eva et al. [2], Just & Middendorf [3], Chen et al. [4], Jaini et al. [5] and Abd Rahman et al. [6] have offered enormous turnover. Rum et al. [7] and Jaini et al. [8] exploited this finding by proposing foamed concrete composite slab, where the characteristic strength of foamed concrete is around 22 MPa to 28 MPa. The response of foamed concrete composite slab under hammer-impact test, as compared with normal concrete composite slab, indicated insignificant different. The natural frequency of foamed concrete composite slab lied in between 20 Hz to 30 Hz, which is higher than permissible value. On the other hand, Johnson & Li [9] applied foamed concrete as core material of composite slab and tested under four-point bending test. The finding revealed that the average load in the plateau-like regime is 65% of the average peak failure load.

In general, the characteristic strength of foamed concrete is always governed by its density and hence lead to the complex properties. Although the relationship between the characteristic strength and density of foamed concrete is well established, such as by Ramamurthy & Narayanan [10], Abbas & Suhad [11] and Marcin & Marta [12], the condition as structural component seem still uncertainty. The investigation on structural performance such as conducted by Hulimka et al. [13] and Afifuddin et al. [14] only limited under static action. Therefore, this paper presents the experimental study on the dynamic characteristics of foamed concrete composite slab subjected to vibration. The emphasis is given to the influence of density and strength of foamed concrete to the natural frequency, damping ratio and mode shape. Through out of this investigation, it is hoped to promote and boost the application of foamed concrete as structural component in the construction industry.

Various studies in the dynamic characteristics of composite slab were conducted by previous researchers, as example Yasser & Ahmed [15], Shiming et al. [16], Jose et at. [17] and Sadun & David [18]. However, for foamed concrete composite slab, it is remains untouched. The performance of composite slab under static and dynamic actions are generally overseen by various factors such as the stiffness of corrugated steel deck, type and mechanism of bond, specification of reinforcement and shear connector, span to depth ratio and the characteristic strength of topping material. Meanwhile, the dynamic characteristics which are refer to the natural frequency, damping ratio and mode shape can be influenced by mass, modulus of elasticity, second moment of inertia and acceleration. In the situation where foamed concrete composite slab is designed, the density of foamed concrete may play a vital role. This is because the characteristic strength and density of foamed concrete has a mutual relationship.

Muntahith & Kausar [19] performed three-dimensional finite element modelling to evaluate the minimum thickness and span of slab that can avoid the vulnerability and undesirable vibration. This investigation signifies that the dynamic characteristics, particularly the natural frequency fully dependent on the mass of slab. In the case where the minimum thickness and span become subject of interest in the design of composite slab, Blackhowski & Gutkowski [20] proposed the discrete optimization method that can be simplified and automated. On the other hand, Sanchez et al. [21] tested the serviceability of composite slab under vibration. The response was determined by measuring the

maximum peak acceleration. Although, the composite slab involves long-span, but the natural frequency indicates high value and such floor system generally has adequate resistance to vibration.

2. Materials and Specimens

In preparing the materials for the casting of cube, cylinder and slab specimens, the mix design of foamed concrete was based on the volume rather than the weight. In addition, the mix design was intended to produce foamed concrete with three different densities of 1400 kg/m^3 , 1600 kg/m^3 and 1800 kg/m^3 . As shown in Fig. 2, the materials for foamed concrete consist of sand, rice husk ash, Ordinary Portland cement, mega-mesh 55, foaming agent, superplasticizer and water. The mix design as proposed by Abd Rahman et al. [22] was employed in the production of foamed concrete, where cement-sand ratio is 0.50, water-cement ratio is 0.55, foaming agent-cement ratio is 0.07 and foaming agent-water ratio is 0.05. Rice husk ash was utilised as sand replacement at the maximum content of 40%, whilst mega-mesh 55 was added as fiber reinforcement with proportion of 9 kg/m^3 .

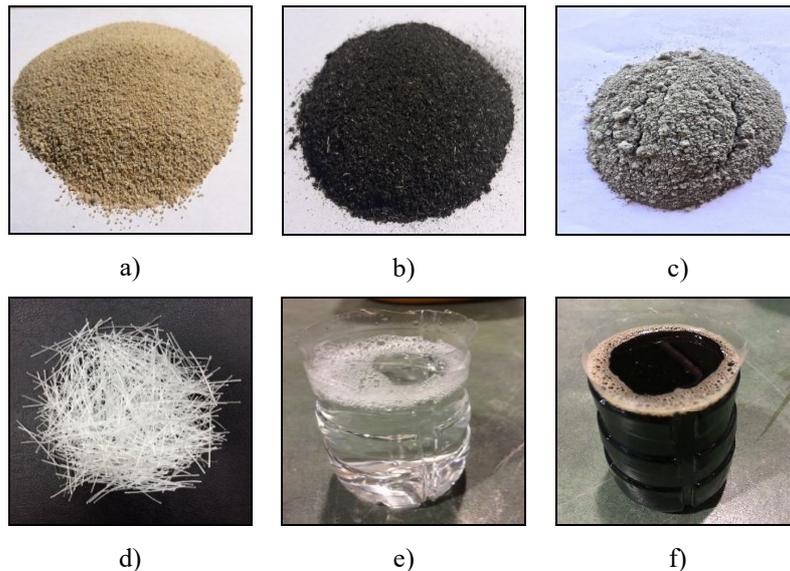


Fig. 2 - Materials for foamed concrete, a) sand, b) rice husk ash, c) ordinary Portland cement, d) mega-mesh 55, e) foaming agent, and f) superplasticizer.

A total of 21 cube specimens of foamed concrete were prepared using mould of 100 mm length, 100 mm width, and 100 mm depth. Meanwhile, a total of 21 cylinder specimens were casting using mould of 125 mm diameter and 350 mm height. The cube and cylinder specimens underwent air curing at 7, 14, and 28 days. Meanwhile, a total of 6 slab specimens with dimension of 1800 mm length, 840 mm width and 125 mm thickness were fabricated. The schematic design of slab specimen is illustrated in Fig. 3. The Peva45 with a thickness of 1 mm was employed as the corrugated steel deck. Foamed concrete was reinforced with a steel mesh of H8-250. The composite slab was allowed to adopt the nominal cover of 35 mm. No shear connectors were placed in between foamed concrete and corrugated steel deck. Therefore, the shear strength of composite slab is solely dependent on the bond of foamed concrete and corrugated steel deck. The slab specimens were place at the ambient condition for curing process of 28 days.

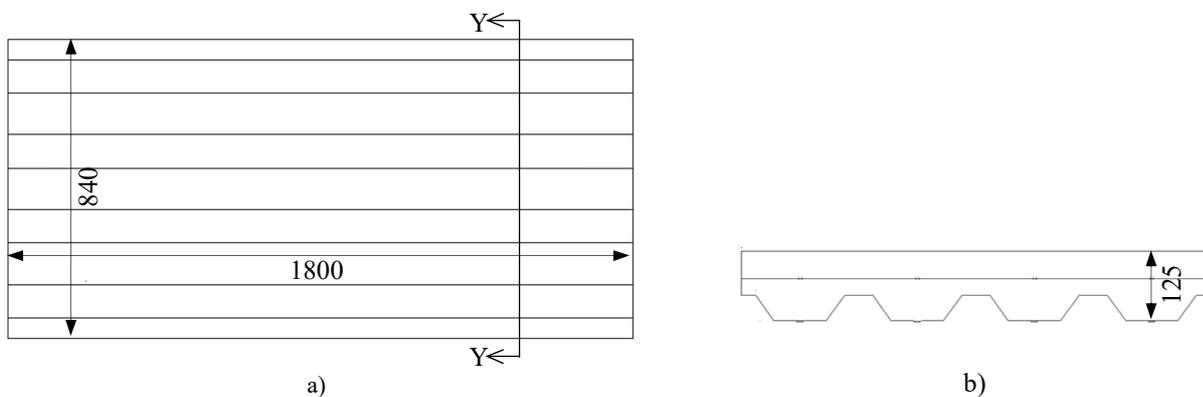


Fig. 3 - Schematic design of slab specimens; a) Plan view, and b) Cross-section Y-Y.

3. Experimental Tests

Cube specimens were tested using the ELE Compact Machine 1500 as accordance to BS EN 12390-3 [23]. This compression test, as shown in Fig. 4, is purposely conducted to obtain the compressive strength of foamed concrete as relation to the density (1400 kg/m^3 , 1600 kg/m^3 and 1800 kg/m^3). The load applied during the compression test is the prescribed rate of 0.14 MPa/minute to 0.34 MPa/minute until the cube specimen experience crushing. On the other hand, splitting-tensile test was conducted to determine the mechanical property of foamed concrete due to the direct tension force. The splitting-tensile test was performed according to BS EN 12390-6 [24]. As shown in Fig. 5, it requires two plates being placed at the top and bottom of cylinder specimen, while the prescribed rate of 450 kg/minute is set constant and continuous that translate the stress rate of 0.69 MPa/minute to 1.38 mPa/minute.



Fig. 4 - Compression test of cube specimen.



Fig. 5 - Splitting-tensile test of cylinder specimen.

Meanwhile, hammer-impact test was conducted on slab specimens. The hammer-impact test requires special instruments, such as a hammer, accelerometers and data logger. The force transducer on the hammer measures the impact force applied to the surface of slab specimens. Meanwhile, the accelerometers were used to measure the wave vibrations produced by the impact of the hammer. Only load of 1N is considered in order to generate modal vibration. The vibration waves were recorded as the acceleration time-history (in fifth-teen locations as depicted as A1 to A15 in Fig. 6) by the data logger and can be plotted/digitally displayed using QuickDAQ. Fig. 7 shows the setup of the hammer-impact test. For one set of hammer-impact test, the measurement was recorded simultaneously in five series, so that the convincing acceleration time-history can be obtained.

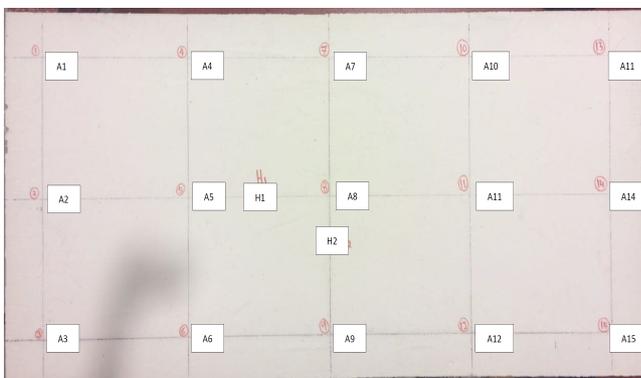


Fig. 6 - Location of accelerometers (A1 to A15).



Fig. 7 - Set-up of hammer-impact test.

4. Results and Discussion

4.1 Compressive and Tensile Strengths of Foamed Concrete

Foamed concrete with different densities of 1400 kg/m^3 , 1600 kg/m^3 and 1600 kg/m^3 were produced with addition of 40% rice husk ash (as sand replacement) and 9 kg/m^3 mega-mesh 55 (as fibre reinforcement). The compressive strength in corresponds to the age of curing is shown in Fig. 8. For foamed concrete with density 1400 kg/m^3 , it can be found that at 7 days, the compressive strength achieves 11.83 MPa and increases as high as 20% for 14.2 MPa at 14 days. The compressive strength further increases approximately 9% to reach 15.43 MPa after 28 days. According to Zhihua et al. [25], the compressive strength of plain foamed concrete with density 1400 kg/m^3 is basically around 4.9 MPa to 6.4 MPa. Therefore, it is well observed that foamed concrete containing rice husk ash and mega-mesh 55 has significant improvement in the compressive strength.

Foamed concrete with density 1600 kg/m^3 also depicted similar trend of improvement. At 7 days, the compressive strength is 17.49 MPa and increases around 18% to 20.59 MPa at 14 days. After 28 days, the compressive strength

becomes 22.97 MPa that indicate the increment of 12%. Foamed concrete with density 1800 kg/m³ has the compressive strength exceeded the target. It was revealed that the compressive strength achieves 25.30 MPa and 29.8 MPa at 7 and 14 days respectively. After 28 days, the compressive strength increases to 32.23 MPa. According to Zhihua et al [25], plain foamed concrete with density 1600 kg/m³ has compressive strength around 7.8 MPa to 9.9 MPa. Meanwhile, the compressive strength for plain foamed concrete with density 1800kg/m³ is around 15 MPa to 18 MPa [5].

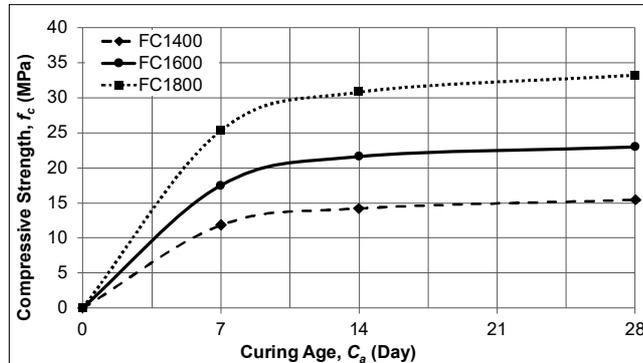


Fig. 8 - Compressive strength of foamed concrete.

Therefore, there is no doubt that rice husk ash and mega-mesh 55 able to contribute significant effect on the compressive strength of foamed concrete. The addition of 40% rice husk ash and 9 kg/m³ mega-mesh 55 were found perfect to produce sufficient characteristic strength for the application of foamed concrete as structural components. In addition, foamed concrete with rice husk ash and mega-mesh 55 is compliance with the requirement of Eurocode. High contain of rice husk ash contributes to the good compressive strength as rice husk ash itself is pollozanic material and react as filler in foamed concrete. Hadipramana et al. [26] used 25% of rice husk ash in foamed concrete with water-cement ratio of 0.33 and obtained the compressive strength around 1.9 MPa to 2.0 MPa for density 1400 kg/m³, 2.5 MPa to 7.0 MPa for density 1600 kg/m³ and 6.0 MPa to 11 MPa for density 1800 kg/m³.

Fig. 9 shows the results of tensile strength for foamed concrete containing 40% rice husk ash and 9 kg/m³ mega-mesh 55 at density 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³. For foamed concrete that has density 1400kg/m³, the tensile strength increases according to the age of curing. At 7 days, the tensile strength is 0.75 MPa and further increases around 11% and 27% at 0.83 MPa and 1.06 MPa for 14 and 28 days. A similar trend of tensile strength was also observed for foamed concrete with density 1600 kg/m³. The tensile strength at 7, 14 and 28 days are 1.15 MPa, 1.26 MPa and 1.62 MPa respectively. There is a huge increment around 29% to 40%. Other that, for foamed concrete with density 1800 kg/m³, the tensile strength increases around 13% from 1.13 MPa at 7 days to 1.52 MPa at 14 days. At the matured age of 28 days, the tensile strength becomes even stronger whivh achieved as high as 1.97 MPa with 29% of rise.

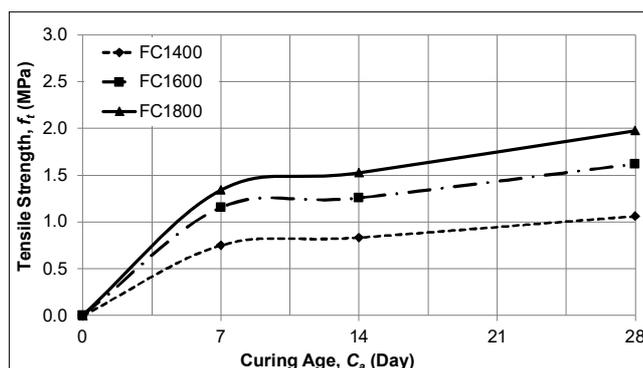


Fig. 9 - Tensile strength of foamed concrete.

It was found that the addition of mega-mesh 55 in foamed concrete has vital contribution (as main factor) to increase the tensile strength. The presence of mega-mesh 55 able to resist cracks and prevent sudden failure. There is also an improvement on the brittle behaviour of foamed concrete. It was found that the tensile modulus and yield strain of foamed concrete increases drastically by fibre reinforcement. The dosage of 9 kg/m³ in the mixture was found perfectly to increase the tensile strength. Samir & Mohammed [27] proved that by using mega-mesh 55, the tensile strength of foamed concrete can achieve as maximum as 3.26 MPa to 3.5 MPa. Hilal et al. [28] studied the controlled foamed concrete with water-cement ratio of 0.5 and obtained the tensile strength around 0.9 MPa to 1.5 MPa for density of 1600 kg/m³ and 1.5 MPa to 1.8 MPa for density of 1800 kg/m³.

The relation of compressive strength and density of foamed concrete is displayed in Fig. 10. It can be observed that the relation is formed as an exponential trendline. This is similar to Abbas & Suhad [11] and Marcin & Marta [12]. Meanwhile, the relation of tensile strength and density of foamed concrete can be referred in Fig. 11. The tensile strength has second order polynomial function with the density of foamed concrete. It is noticeable that the compressive and tensile strengths of foamed concrete increase due to the density. For foamed concrete with density 1600 kg/m³ and 1800 kg/m³ where the compressive strength retains at 22.97 MPa and 29.8 MPa, it is already complied to the code of practise. The compressive and tensile strength of foamed concrete also on a par with normal concrete, but with significant advantageous in the density.

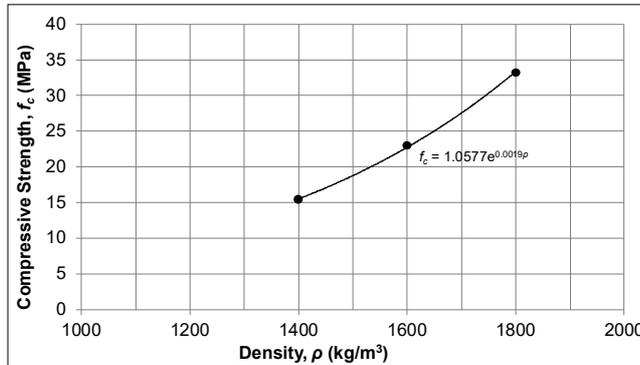


Fig. 10 - Relation between compressive strength and density.

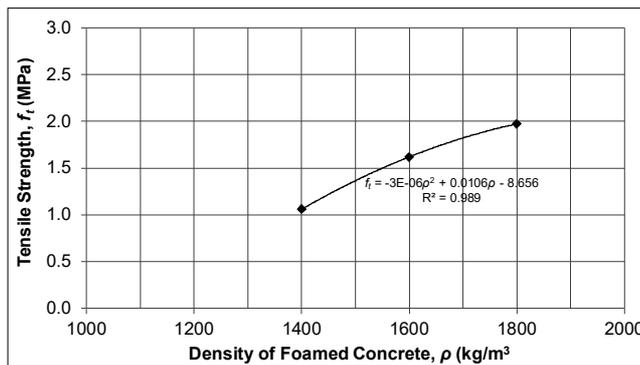


Fig. 11 - Relation between tensile strength and density.

4.2 Natural Frequency of Foamed Concrete Profiled Composite Slabs

Prior to the hammer-impact test, the acceleration time-history were obtained and analysed. The natural frequency was determined using the following equation:

$$f = \frac{n}{T_f - T_i} \tag{1}$$

where n is the number of completed sine cycle, T_f is the final time of the last completed sine cycle and T_i is the initial time of the first completed sine cycle. All parameters in Eq. (1) must be determined from the acceleration time-history. An example of acceleration time-history is shown in Fig. 12. On the other hand, the natural frequency can be empirically determined using the following equation:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \tag{2}$$

where k and m are denoted as the stiffness and mass of foamed concrete profiled composite slab.

Natural frequency is the rate at which a structure vibrates continuously when displaced and then quickly released [29]. Falati & Williamns [30] stated that if a structure is set in motion and then allowed to vibrate freely, then the natural frequency is the number of cycles of motion that will occur in one second. Taking this principal in the analysis, the natural frequency of foamed concrete composite slab (due to hammer-impact test at point H1 and H2) can be seen in Table 1 and Table 2. It can be observed that the slab specimen FC1800 (foamed concrete with density 1400 kg/m³)

has the lower natural frequency, while the higher value belongs to the slab specimen FC1400 (foamed concrete with density 1800 kg/m³). At the constant thickness and span, it can be clearly observed that the difference of natural frequency due to the density of foamed concrete is relatively small. However, the effect of density is critical for the long-span slab as resonant may become severe.

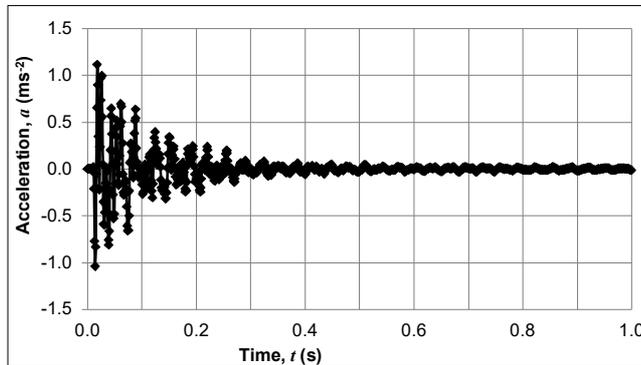


Fig. 12 - An example of acceleration time-history from slab specimen with FC1600.

Table 1 - Natural frequency of foamed concrete composite for hammer-impact test at point H1.

Specimen	Density, ρ (kg/m ³)	Compressive Strength, f_{cu} (MPa)	Period, T (sec)	Natural Frequency, f (Hz)
FC1400	1400	15.43	0.0296	33.78
FC1600	1600	22.97	0.0314	31.80
FC1800	1800	32.23	0.0337	29.70

Table 2 - Natural frequency of foamed concrete composite slab for hammer-impact test at point H2.

Specimen	Density, ρ (kg/m ³)	Compressive Strength, f_{cu} (MPa)	Period, T (sec)	Natural Frequency, f (Hz)
FC1400	1400	15.43	0.0280	35.71
FC1600	1600	22.97	0.0300	33.33
FC1800	1800	32.23	0.0314	31.81

In general, the natural frequency enhances when mass of structure is increased. The mass has direct relation with either density or thickness of topping material. According to Vasile & Cedric [31], the influence of strength characteristic of topping material is substance, where the natural frequency significantly enhanced. For normal concrete C16/20 to C45/55, the natural frequency can be increased around 10% to 25%. Since the density of foamed concrete governs its characteristic strength, hence the natural frequency may change accordingly. Previous studies by Abd Ghaffar et al. [32] and Rum et al. [7] revealed that the natural frequency of lightweight composite slab is approximately around 20 Hz to 30 Hz. If compared with normal concrete composite slab, foamed concrete composite slab still indicates good performance and comfortability.

The addition of rice husk ash and mega-mesh 55 may have no tendency in absorbing wave of energy and contribute to the lower transient behaviour. However, these materials affect the strength characteristic that noticeably contribute to the better serviceability. Low density of foamed concrete could give more benefit to the composite slab as long as the natural frequency is under the permissible limit. Murray [33] stated that occupants giving negative responses on the natural frequency between 5 Hz to 8 Hz. For the office and residential buildings which have the natural frequency better than 10 Hz, it will decrease the problem related to vibration. Referring to the natural frequency from this study, it is proved that foamed concrete composite slab passed the range of human comforts. This is also providing an evident that the lightweight profiled composite slab can sustain dynamic loading and be used as floor system.

A comparison of the natural frequency between experimental study, theoretical and previous study was conducted. Eq. (2) was used to calculate the natural frequency for theoretical, where the stiffness is based on the function of isotropic Young's modulus multiple with the moment of inertia of slab specimen. The Young's modulus of foamed concrete is changeable to its density that can be depicted by the following equation:

$$E = 0.42\rho^{1.18} \tag{3}$$

where E is the Young’s modulus of foamed concrete and ρ is density of foamed concrete. Meanwhile, a simple formula as proposed by Jaini et al. [8], as in Eq. (4), was considered.

$$f = \alpha_\rho \left[0.033 \left(\frac{S}{h} \right)^2 - 0.842 \left(\frac{S}{h} \right) + 36.145 \right] \tag{4}$$

where h is the thickness of the composite slab, S is the span of the composite slab, and α_ρ is the multiplying factor related to the density (0.78 for foamed concrete with density of 1400 kg/m³, 0.89 for foamed concrete with density of 1600 kg/m³ and 1.0 for foamed concrete with density of 1800 kg/m³).

Fig. 13 shows the natural frequency between experimental study (with linear projection), theoretical and Jaini et al [8]. Natural frequency from theoretical is significantly higher than that obtained from experimental study. This is due to the condition where the vibration fully dependent on the self-weight of slab specimen, without taking the applied load. The errors of natural frequency between experimental study and theoretical are around 38.3% to 53.8%. A few factors were identified that may affect the natural frequency during experimental study, such as the bouncing between the slab specimen and steel-beam supports. The bouncing might lead to inadequate systematic data reading while conducting the experimental study. Indoor noises due to the rhythmic activities also the identified factor. Chik et al. [34] stated that rearranging the rattling of board and opening of window become a main source of indoor noises.

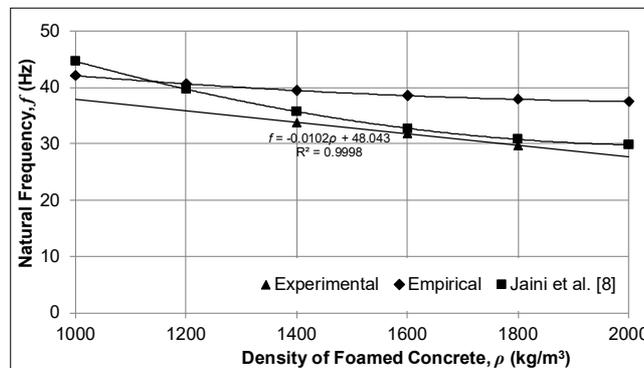


Fig. 13 - Comparison of natural frequency between experimental, theoretical and Jaini et al. [8].

4.3 Damping Ratio and Mode Shape

Damping ratio is an amplitude of oscillation that will diminish at a predictable rate and highly associated with dissipation of mechanical energy. Eq. (5) was employed to determine the damping ratio of slab specimens, as follows:

$$\zeta = \frac{1}{2\pi j} \ln \frac{u_i}{u_{i+j}} \tag{5}$$

where ζ is damping ratio and u is amplitude or acceleration based on hammer force output. Composite slabs with different densities of foamed concrete have different values of damping ratio as can be seen in Fig. 14. The damping ratio is considered quite high at the range of 3% to 5%. According to Murray [33], the range of damping ratio for floor system is normally around 1% to 3%. The system for damping is lightly damped when the value obtained smaller than 0.1%. If the damping ratio achieves less than 0.1%, it will oscillate or ring for the long time period when activities occur on the floor. Jaini et al. [8] proposed an equation to determine damping ratio of composite slab based on the natural frequency as follows:

$$D = -0.725f + 26.854 \tag{6}$$

The comparison with experimental study resulted in small differences, where the damping ratio is 2.36%, 3.78% and 5.32% for slab specimens with density of 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³ respectively. It should be emphasized here that the damping ratio calculated from Eq. (6) is a direct proportion of natural frequency. Therefore, when natural frequency become high, the damping ratio consequently increased. Ta et al. [35] reported that the damping ratio has a critical function with the natural frequency, while Varela & Battista [36] clarified that for the natural frequency of 7.57Hz to 12.21Hz, the damping ratio is 0.25% to 0.64%.

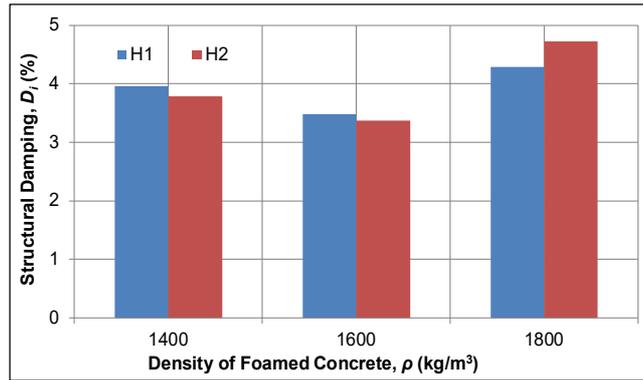


Fig. 14 - Damping ratio of slab specimens.

The mode shape is influenced by the vibration of composite slab due to appointed loading. Basically, the mode shape gives information in which the design of floor system can be produced to withstand larger vibration. Fig. 15 illustrates the mode shape of slab specimens which induced by vibration at H1. The mode shape was visually obtained using MEScope program. Ahmeed & Mohammad [37] stated that the mode shape is represent the bending for the slab when load is applied on the surface of structure. The first mode shape is determined with one peak value and mostly occur on the slab [36]. According to Aaton & Jianqioa [38], the mode shape from vibration testing can appear at different value of natural frequency, where the range value of natural frequency for the first mode shape is between zero to 44Hz. Therefore, the range value of natural frequency obtain in this study is 29.71Hz to 32.78Hz within the range of first mode shape.

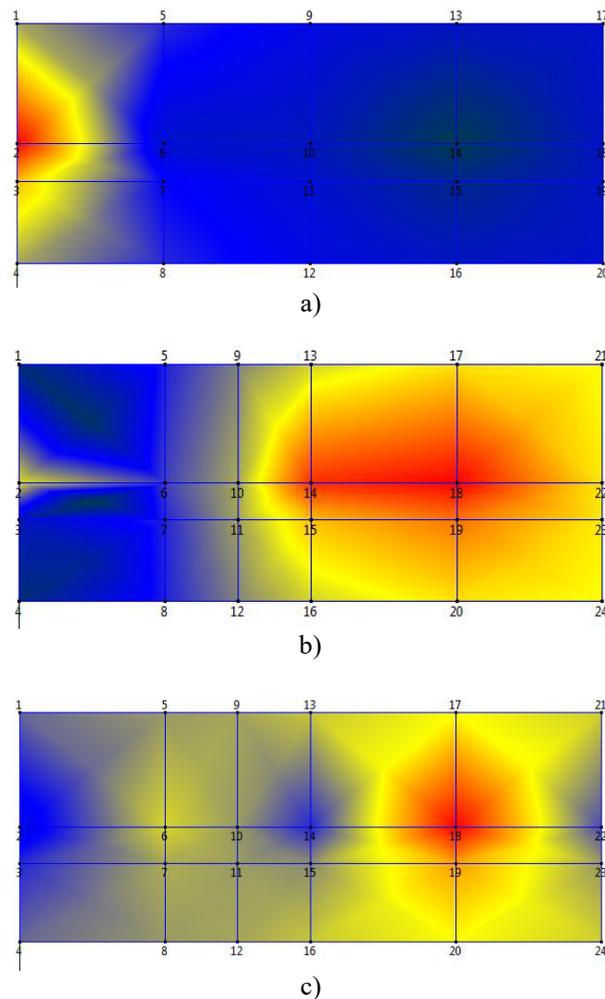


Fig. 15 - First mode shape of slab specimens, a) Composite slab FC1400, b) Composite slab FC1600, and c) Composite slab FC1800.

5. Conclusion

In the lightweight profile composite slab, foamed concrete was used as topping material. Foamed concrete was designed to include rice husk ash as sand replacement and mega-mesh 55 as fibre reinforcement. The effect of density on the dynamic characteristics is a major concern. It was confirmed that foamed concrete achieves satisfactory compressive and tensile strengths. Foamed concrete with density 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³ has the compressive strength of 15.42 MPa, 22.97 MPa and 32.23 MPa respectively. Meanwhile, its tensile strength reaches 1.06 MPa, 1.62 MPa and 1.97 MPa. Rice husk ash is highly pozzolanic and its fine particles act as filler in foamed concrete that make the porosity become fully occupied. In addition, the use of mega-mesh 55 enables to enhance the strength due to ability in resisting cracks. The foamed concrete is suitable to be used in the composite slab.

The dynamic characteristics were investigated from a series of acceleration-time history. The foamed concrete profiled composite slab indicates satisfactory performance under vibration. The natural frequency is quite high at value of 29.71 Hz, 32.78 Hz and 31.80 Hz for composite slab with density 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³ respectively. In this study, only first mode shape was successfully obtained using MEScope software. It was found that high density of foamed concrete produces high damping ratio. The damping ratio for composite slab with density 1400 kg/m³, 1600 kg/m³ and 1800 kg/m³ is 3.78%, 3.37% and 5.03% respectively. The foamed concrete composite slab is proven suitable to be used as floor system. The worry on vulnerability of foamed concrete composite slab as replacement to the conventional floor can be eliminated.

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