

A Preliminary Experimental Study on Vibration Responses of Foamed Concrete Composite Slabs

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Abstract. In recent years, composite slab has received utmost demand as a floor system in the construction industry. The composite slab is an economical type of structure and able to accelerate the construction process. Basically, the composite slab can be casting by using a combination of corrugated steel deck and normal concrete in which selfweight represents a very large proportion of the total action. Therefore, foamed concrete become an attractive alternative to be utilized as a replacement of normal concrete. However, foamed concrete has high flexibility due to the presence of large amount of air-void and low modulus elasticity. It may result in vibration responses being greater. Hence, this experimental study investigates the vibration responses of composite slab made of corrugated steel deck and foamed concrete. The specimens were prepared with dimension of 750mm width, 1600mm length and 125mm thickness. The hammer-impact test was conducted to obtain the acceleration-time history. The analysis revealed that the first natural frequency is around 27.97Hz to 40.94Hz, while the maximum acceleration reaches 1.31m/s^2 to 1.88m/s^2 . The first mode shape depicts normal pattern and favourable agreement of deformation.

1. Introduction

Composite slab is widely recognized as durable and efficient replacement to the conventional reinforced concrete slab. The genius preference of composite slab is lay on the fact that it able to speed the construction process, safe method of construction and generally economical for the leisure, commercial, industrial and residential buildings [1]. In addition, composite slab is also regarded as one of the best diaphragm strengthening method that allow higher load bearing capacity with lower thickness and reduction size of structural element [3]. Therefore, it is not surprising that composite slab has received high demand in the construction industry. Code of practice BS EN1994-1-1 [2] defined the composite slab as a structure in which corrugated steel deck is used initially as permanent shuttering, subsequently combine structurally with the concrete and act as tensile reinforcement. The presence of corrugated steel deck not only acts as permeant formwork where it remains for the whole service life, but also provide sufficient shear bond that contribute to the compositeness behaviour.

In the current practise, composite slab is basically constructed using a combination of corrugated steel deck and normal concrete in which the selfweight of topping become a major concern. A recent



study by Hulimka *et al.* [4] revealed huge interest to utilize lightweight concrete as main material in structural element. Zulkarnain and Ramli [5] suggested that the dead load of structural element can be reduced by using lightweight concrete. In many choices of lightweight concrete to be associated with composite slab, foamed concrete is found more practical and sustainable due to its characteristic of low selfweight, excellent acoustic and fire resistance as well as good in shock absorption and thermal properties. Although foamed concrete exhibits drawback in strength but the latest studies by Hadipratama *et al.* [6] and Jaini *et al.* [7] revealed that the mechanical properties of foamed concrete can be improved through modification approach. However, the truncated value of elastic modulus may result in vibration responses being greater.

Many studies were conducted on the design aspect, static performance and structural behaviour of composite slab. Sanchez *et al.* [8], Khalaf *et al.* [9] and Chaudhari *et al.* [10] investigated the structural behaviour of composite slab in term of load bearing capacity, deflection and failure mode. Meanwhile, Abbas *et al.* [3], Cifuentes and Medina [11], Johnson & Shepherd [12] and Lakshmikandhan *et al.* [13] investigated the interaction and shear resistance. Johnson & Li [14] investigated the bearing capacity of foamed concrete composite slab under four-point bending test and found the promising performance. However, the vibration responses of composite slab also need a grave concern. Vibration not just cause discomfort but may lead to undesirable serviceability problems and outright structural failure. Reviews of past studies have shown that the knowledge on the vibration responses of foamed concrete composite slab are currently not readily available. Therefore, this study is necessary to assure the comfortability and applicability of foamed concrete composite slab.

2. Experimental study

2.1. Material preparation

The material preparation involves the provision of mix proportion and required amount of cement, sand, gravel, water and foam agent to produce good quality of foamed concrete and normal concrete. DOE method was employed in the calculation of mix proportion. The targeted compressive strength of foamed concrete and normal concrete is setup at 18MPa. Foamed concrete was designed with density of 1600kg/m³ using cement to sand ratio of 0.50 and water to cement ratio of 0.55. The preformed stable foam was produced by diluting the water and foam agent with concentration of 0.05. On the other hand, the mix proportion of normal concrete follows the cement to sand ratio of 0.67 and sand to gravel ratio of 0.50, while 0.45 for water to cement ratio. Based on the mix proportion, the required quantity was obtained as presented in table 1.

Table 1. Mix design for foamed and normal concrete.

Material	Quantity of FC for 1m ³ (kg)	Quantity of NC for 1m ³ (kg)	Required quantity FC (kg)	Required quantity NC (kg)	Remarks
Cement	400	320	080	064	OPC Type 1 based on BS EN 197-1
Sand	800	480	160	096	Size less than 3mm based on BS 882:1992
Gravel	-	960	-	192	Size less than 20 mm based on BS 882:1992
Water	220	144	044	28.8	Tap water based on BS EN 1008:2002

*Note: FC = Foamed concrete, NC = Normal concrete, OPC = Ordinary Portland cement

2.2. Specimen preparation

A total of nine cube specimens of foamed concrete were prepared using mould of 100mm x 100mm x 100mm. Meanwhile, another nine cube specimens of normal concrete were casting using mould of 150mm x 150mm x 150mm. Cube specimens of foamed concrete were undergone air curing at the

ambient temperature, whilst cube specimens of normal concrete were submerged in water. It should be noted here that the curing process was conducted at 7, 14 and 28 days. The slab specimens were prepared using the galvanized corrugated steel deck. The composite slab has dimension of 750mm width, 1600mm length and 125mm thickness. The schematic design of composite slab can be seen in figure 1. Bolts were installed with an interval of 250mm center-to-center to provide perfect bond between corrugated steel deck and concrete topping, while wire mesh was utilized as reinforcement. The preparation of mould and hardened composite slab can be seen in figure 2.

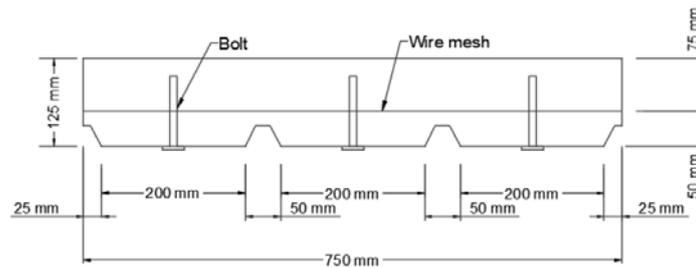


Figure 1. Schematic design of composite slab.



(a)



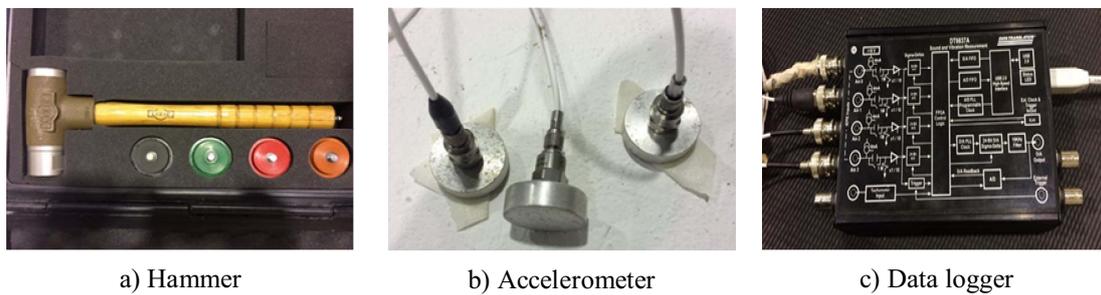
(b)

Figure 2. Specimen preparation of composite slab: (a) mould and (b) hardened composite slab.

2.3. Test programme

The compression test on cube specimens of foamed concrete and normal concrete was conducted accordance to BS EN12390-3:2009 [15]. The Ele Compact Machine 1500 was used in the compression test. Before the compression test take place, the cube specimens were visually inspected, labelled, sized and weighted. Meanwhile, slab specimens were tested under the hammer-impact test after 28 days of curing process. The hammer-impact test requires special instruments of hammer, accelerometers and data logger as can be seen in figure 3. The hammer was designed for use with delicate structure. The force transducer on hammer measures the impact force that applied to the surface of composite slab. Meanwhile, the accelerometers were used to measure the wave vibration due to the impacted of hammer. The wave vibration was recorded as acceleration-time history (in relation to location) by data logger and can be displayed in both plot and digital using QuickDAQ. The set-up of hammer-impact test can be seen in figure 4.

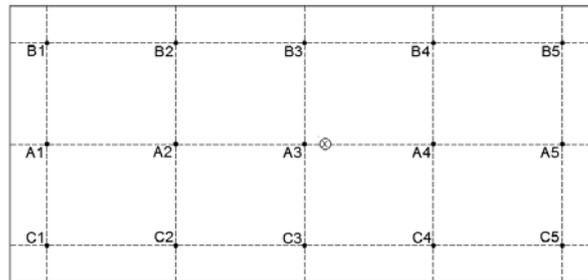
Fifteen (15) points for accelerometers were drawn on top surface of composite slab as shown in Figure 5. Points of A1, A2, A3, A4 and A5 are classified as Series A, while Series B consists of B1, B2, B3, B4 and B5. Points for Series C are dictated by C1, C2, C3, C4 and C5. Hammer was stroked at point X which located at one third span of slab specimens. The hammer was stroked for ten times at point X for the accuracy of data and the wave vibration at A1, B1 and B2 were simultaneously captured until A5, B5 and C5.



a) Hammer

b) Accelerometer

c) Data logger

Figure 3. Instrument of hammer-impact test.**Figure 4.** Test set-up for hammer-impact test.**Figure 5.** The position of the accelerometer during the test.

The raw data obtained from the impact hammer test was examined to get the graph of wave propagation and acceleration-time history, consequently the vibration responses can be determined. The vibration responses are referred to the first natural frequency, maximum acceleration and mode shape. In order to determine the first natural frequency, the average time of natural period need to be calculated using the following equation:

$$T = (T_f - T_i) / n \quad (1)$$

where, T is the average time of the chosen circles period, T_f is the final time of last completed sine cycle, T_i is the initial time of first completed sine cycle and n is the number of completed sine cycle. Therefore, the natural frequency, f of composite slab can be calculated by the following equation:

$$f = 1 / T \quad (2)$$

On the other hand, analytical approach can be used to determine the first natural frequency of composite slab using the following equation:

$$f = \frac{1}{2\pi} \sqrt{\frac{k}{m}} \quad (3)$$

where k is stiffness ratio related by properties of material of composite slab that that can be expressed as EI . Where E is the young modulus of concrete (kN/mm^2) and I is the second moment of inertia of the composite slab for critical axis (mm^4). On the other hand, m is the total mass of composite slab(kg).

3. Results and Discussions

3.1. Compressive strength

Figure 6 shows the compression strength of foamed concrete and normal concrete at 7, 14 and 28 days. It was obtained that foamed concrete and normal concrete achieved the targeted compressive strength. At 28 days of curing process, the compressive strength of foamed concrete is 17.5MPa, while normal concrete achieved 18.2MPa. The difference of compressive strength between foamed concrete and normal concrete is approximately 4%. The compressive strength foamed concrete indicated close compliance with British Cement Association [16]. In addition, investigations by Jaini *et al.* [7] and Abd Rahman *et al.* [17] confirmed that the compressive strength of foamed concrete with density $1600kg/m^3$ should be in the range of 12MPa to 18MPa.

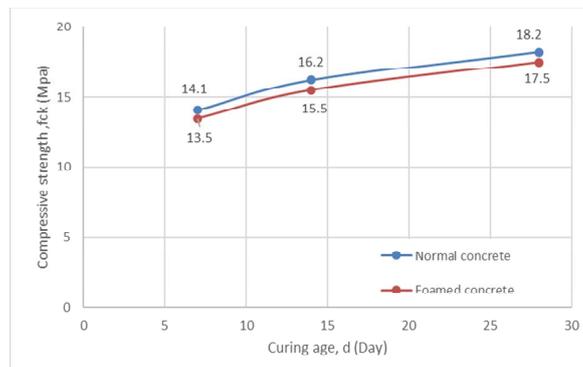


Figure 6. Comparison for compressive strength of foamed concrete and normal concrete.

3.2. Natural frequency

The raw data from the hammer-impact test was examined to plot the acceleration-time history. Figure 7 shows the acceleration time-history of foamed concrete composite slab while the acceleration time-history of normal concrete composite slab can be seen in figure 8. It was identified that there are more completed sine cycles in the similar time interval for the wooden support condition. This is due to the wooden material can absorb the wave energy generated by the forced applied and dissipated it easily. This situation causes it had to take short time to complete one sine cycle. However, steel material will reflect the wave and mix with generated wave. Thus, it need longer time to complete one sine cycle of the wave. Natural frequency value is inversely proportional to the time. Therefore, the longer the time to complete a sine cycle, the smaller the fundamental natural frequency. Table 2 shows the summaries of fundamental natural frequency for foamed concrete and normal concrete composites slabs due to wooden and steel supports. It can be observed that the composite slabs with steel support have the lower fundamental natural frequency if compared to that supported by wood, which is 31.7% for foamed concrete composite slab while 13.9% for the normal concrete composite slabs. Moreover, an investigation by Emad El-Dardiry & Tianjian [18] showed that the fundamental natural frequency profiled composite floors are less than 40Hz.

A comparison of fundamental natural frequency discovered that foamed concrete composite slab has the highest value, which is 12.3% than normal concrete composite slab for wooden support. Despite that normal concrete slightly strong in term of compressive strength. However, under the

influence of steel support, foamed concrete composite slab shows contradict behaviour. The design density of foamed concrete used was 1600 kg/m³, while the density of normal concrete used was 2400 kg/m³. There was 33% increment of mass of the specimen. Thus, this would explain the lower natural frequency occur on normal concrete composite slab.

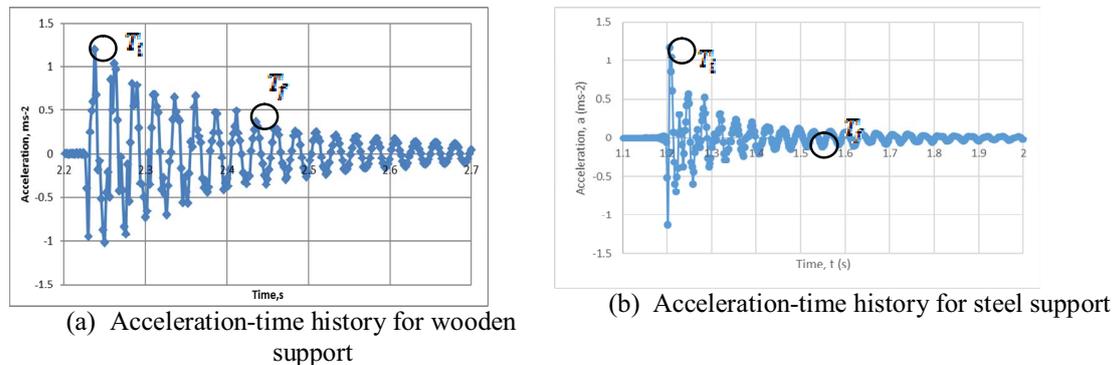


Figure 7. Acceleration-time history of foamed concrete composite slab at mid span (A3) for different type of support.

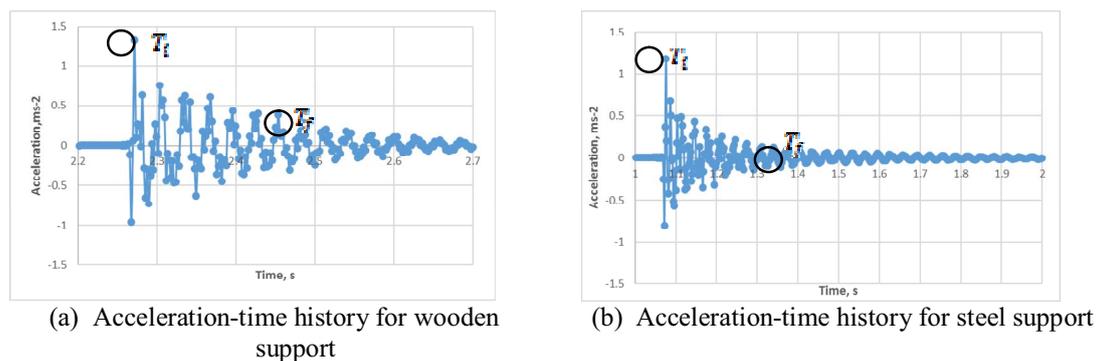


Figure 8. Acceleration-time history of normal concrete composite slab at mid span (A3).

Table 2. First natural frequency of composite slabs.

Type	Wooden Support				Steel Support			
	T_i (s)	T_f (s)	n	f (Hz)	T_i (s)	T_f (s)	n	f (Hz)
Foamed concrete composite slab	2.241	2.412	7	40.94	1.212	1.498	8	27.97
Normal concrete composite slab	2.272	2.467	7	35.89	1.076	1.335	8	30.89

3.3. Mode shape

The peak acceleration of each point in series A, B and C were plotted to form the first mode shape as can be seen in figures 9 and 10. In addition, it was also found that the series B and C show the nearest of acceleration at each side of the composite slab during the first mode of composite slab. This may be the reason of first natural frequency of composite slab was synchronized. Table 3 shows the highest of maximum acceleration of the slab with its location. The highest maximum acceleration of the composite slab with wooden support is approximately same which is 1.881 m/s⁻² for foamed concrete composite slab while 1.867 m/s⁻² for normal concrete composite slab. For the steel support, the highest maximum acceleration of the foamed concrete composite is 1.886 m/s⁻² which approximately while acceleration of the normal concrete composite slab of 1.305 m/s⁻². This indicates that the foamed concrete composite slab has the higher acceleration compare to normal concrete.

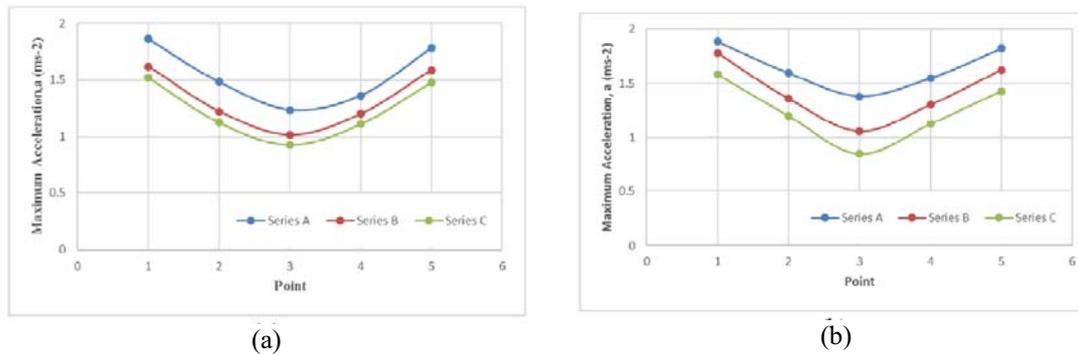


Figure 9. First mode shape of foamed concrete composite slab under: (a) wooden support (b) steel support.

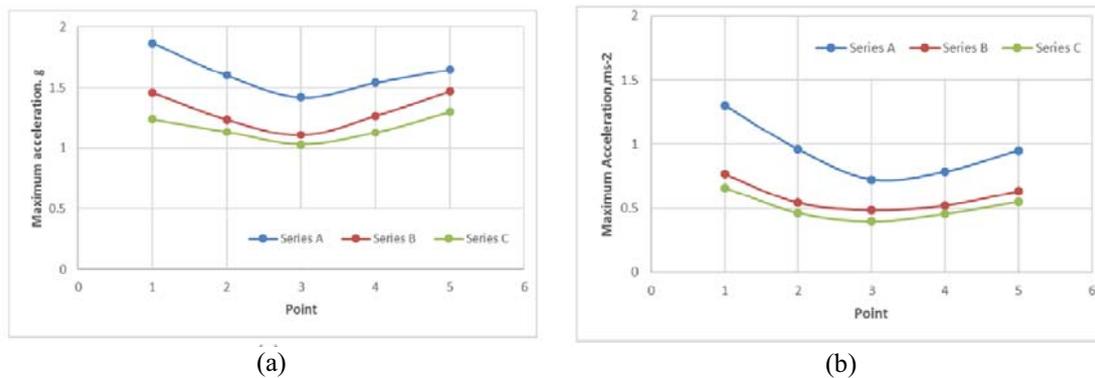


Figure 10. First mode shape of normal concrete composite slab under: (a) wooden support (b) steel support.

Table 3. Maximum acceleration of composite slabs.

Type	Wooden Support		Steel Support	
	Maximum Acceleration (m/s ²)	Location	Maximum Acceleration (m/s ²)	Location
Foamed concrete composite slab	1.881	A1	1.886	A1
Normal concrete composite slab	1.867	A1	1.305	A1

4. Conclusions

An investigation on the vibration responses of foamed concrete composite slab with different type of support were compare with normal concrete composite slab. From the result, it showed that the lowest fundamental natural frequency of corrugated steel-foamed concrete slab was 40.94 Hz with wooden support while 27.97 Hz with steel roller support. According to the BS EN 1994-1-1 [2], the floor may be designed to have a fundamental frequency of at least 8.4 Hz vertically and at least 4 Hz horizontally, in which case the resonant effects need not be evaluated. The lowest fundamental natural frequency of the composite slab has fulfilled the minimum requirement of the design of floor based on the standard code of practice. Thus, it can conclude that the natural frequency of composite slab was reduced by replacing the wooden support with the steel roller support. Furthermore, the maximum acceleration obtained, the corrugated steel-foamed concrete slab has a highest maximum acceleration recorded. Hence, corrugated steel-foamed concrete slab has a higher vibration compared to corrugated steel-normal concrete slab.

5. References

- [1] Rackham J W, Couchman, G H and Hicks S J 2009 Composite Slabs and Beams Using Steel Decking: Best Practice for Design and Construction *MCRMA Technical Paper SCI Publication* **13** 3550-3560
- [2] BS EN 1994-1-1 2004 Design of composite steel and concrete structures Part 1-1: *General Rules and Rules for Buildings*, (British Standard Institution, London)
- [3] Abbas H S, Bakar S A, Ahmadi M and Haron Z 2014 Experimental studied on corrugated steel-concrete composite slab *Journal Civil Engineering* **67(3)** 225-233
- [4] Hulimka J, Krzywo Ę, and Agnieszka J Ć 2017 Laboratory tests of foam concrete slabs reinforced with composite grid *Procedia Eng.* **193** 337-344
- [5] Zulkarnain F and Ramli M 2008 Durability performance of lightweight aggregate concrete for housing construction (*Icbedc*) 541–551
- [6] Hadipramana J, Samad A A A, Zaidi A M A, Mohammad N and Riza F V 2013 Effect of uncontrolled burning rice husk ash in foamed concrete *Adv. Mater. Res.* **626** 769-775
- [7] Jaini Z M, Mokhtar S. N, Mohd Yusof A S, Zulkipli S and Abd Rahman M H 2016 Effect of pelletized coconut fiber on the compressive strength of foamed concrete *MATEC Web of Conf.* **47** 01013
- [8] Sanchez T A, Davis B and Murray, T M 2011 Floor vibration characteristics of long span composite slab systems *Proceeding of Structure Congress* Las Vegas, United States 360-370
- [9] Khalaf M, El-Shihy A, Shehab H and Mustafa S 2013 Structural behaviour analysis of two-ways composite slab. *Journal of Engineering and Innovative Technology* **2(12)** 47-54
- [10] Chaudhari T, Macrae G, Bull D, Chase G and Hobbs M 2014 Composite slab effects on beam-column subassemblies *Proceeding of the International Conference on Structural and Earthquake Engineering* (Christchurch, New Zealand) 1-9
- [11] Cifuentes H and Medina F 2013 Experimental study on shear bond behaviour of composite slabs according to eurocode 4 *Journal of Construction Steel Research* **82(3)** 99-110
- [12] Johnson R P and Shepherd A J 2013 Resistance to longitudinal shear of composite slabs with longitudinal reinforcement *Journal of Construction Steel Research* **82(3)** 190-194
- [13] Lakshimikandhan K N, Sivakumar P, Ravichandran R and Jayachandran S A 2013 Investigations on efficiently interfaced steel concrete composite deck slabs *Journal of Structures* **13(6)** 1-10
- [14] Johnson E A F and Li Q M 2012 Structural behaviour of composite sandwich panels with plain and fibre-reinforced foamed concrete cores and corrugated steel faces *Composite Structures* **94(5)** 1555-1563
- [15] BS EN 12390-3:2009 *Testing Hardened Concrete - Compressive Strength of Test Specimens* (British Standard Institution, London, 2011)
- [16] British Cement Association 1994 *Foamed concrete: Composition and properties*, Report 46.042 (Slough, United Kingdom)
- [17] Abd Rahman N, Jaini Z M and Mohd Zahir N N 2015 Fracture energy of foamed concrete by means of the three-point bending test on notched beam specimen *ARPJ. Eng. Appl. Sci.* **10** 6562-6570
- [18] Emad El-Dardiry and Tianjian Ji 2006 Modelling of the dynamic behaviour of profiled composite floors *Engineering Structures* **28** 567-579

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