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Structural Behavior of Lightweight Composite Slab System

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Abstract: This study investigate the structural behavior of lightweight composite slab system that consist of profiled steel sheet (PSS) attached to dry board (DB) using mechanical screws and with or without infill materials. A total four full-scale panel specimen were tested under four-point bending when subjected under static loading. Result of the four-point test shows that increasing the thickness of profiles steel sheet gives major effect to the deflection and ultimate load. The deflection and ultimate load of 1.0mm thick panel specimen is 16.45% and 34.45% respectively. Therefore, increased the thickness of profiled steel sheet can enhance the stiffness and strength of the lightweight composite slab systems. It also found that the infill material used in these experimental gives minor effect to deflection and ultimate load. The deflection and ultimate load of panel specimen with foamed concrete is 21.18% and 16.66% respectively. Thus, foamed concrete can be used only for non-structural purposed only such as sound proofing and fire resistance.

Keywords: Composite structure, Profiled steel sheet, Dry board, Infill material, Four-point bending test, Deflection, Stress-strain

1. Introduction

Nowadays, researchers and designers have more challenges with introducing low cost, time-saving (in terms of construction), and lightweight structural floor systems. These criteria are even more desirable in composite structural systems. Composite structures provide many benefits compared with simple structures. One of the most significant benefits of composite construction is its flexibility in design, offering the designer virtually infinite possibility to tailor both the geometric shape and material to optimize the structural performance [1].

Using composite systems constructed by profiled sheets and concrete is mainly utilized in buildings [2,3] especially for floors to provide a permanent formwork that also serves as bottom reinforcement [4,5]. That led to the introduction of a steel composite slab system called the Profiled Steel Sheeting Dry Board (PSSDB) system as shown in Fig. 1. The PSSDB system is consists of profiled steel sheet (PSS) attached to dry board (DB) using mechanical screws. It was first studies by Wrights and Evans [6] have shown that the profiled steel sheeting is capable of carrying loads up to 4 kN/m^2 on its own (weight of wet concrete, construction tools, and labors) which surpass the serviceability limit state designed for houses, small offices, classroom and multi-story building [7-9].

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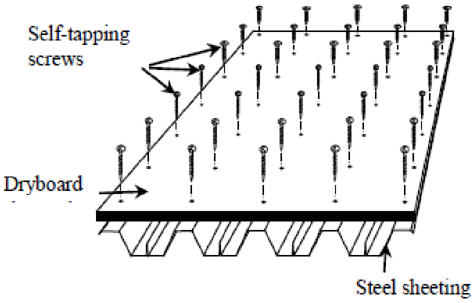


Fig. 1 - Typical PSSDB system

Studies on the behavior of the PSSDB system by using Peva 50 as a profiled steel sheet and Prima*flex* as a dry board has been reported in earlier publications [10-15]. Jaffar et al. [10] were investigated the connection stiffness through the push-out test and deflection in the mid-span through the bending test. The connection stiffness of PSSDB filled with geopolymer concrete is 331% higher compared to PSSDB filled with normal concrete. This contributes to a reduced 21% of deflection in the mid-span for a panel filled with geopolymer concrete. It also found that deflection in mid-span reduced 41% for PSSDB with a half-size dry board filled with geopolymer concrete compared to PSSDB with a half-size dry board filled with normal concrete [11]. This phenomenon making the panel that is filled with the geopolymer concrete 25% stronger than the normal concrete-filled panel.

Jaffar et al. [12] were investigated the mid-span deflection and rigidity of PSSDB systems with 12M of geopolymer concrete. The result shows that the mid-span deflection of the panel has reduced to 52% and 107% increase in rigidity compared with those of the control (without infill). It also illustrates that the rigidity of PSSDB with a half-size dry board filled with geopolymer concrete increases by 43% relative to that of the PSSDB with full-size filled normal concrete [13]. Steel plates can be considered an economic solution to enhance the structural behavior of the PSSDB system. Al-Shaikhli et al. [14] was investigated the stiffness and strength of the PSSDB system when enhanced with a steel plate. From the result, it was found that applying a steel plate can enhance the stiffness and strength of the PSSDB system by approximately 31% and 15%. Applying both steel plate and infill material can enhance 13.6% instead of applying for steel plate alone. It also shows that changing the plate thickness can enhance the PSSDB stiffness. However, increasing the number of plates or changing the plate width doesn’t greatly affect the performance [15].

The objective of this study is to investigate the bending behavior of a lightweight composite slab system that was tested under a four-point bending test with different thicknesses of profiled steel sheet (PSS) and without or with foamed concrete. The results observed from this study are to determine the structural behavior of the lightweight composite slab system.

2. Experimental Work

To quantify the amount of vertical and horizontal movements of the lightweight composite slab under the static loading, an experimental test was conducted. The efficiency of lightweight composite slab system developed in this research that comprises of profiled steel sheet (Peva 50) with 0.8mm and 1.0mm thick and attached with the dry board (Prima*flex*) with the thickness of 16mm on top of slab specimen using self-drilling screws connector with 200mm spacing between the screws and without or with infill material. Each lightweight composite slab component has its role. Peva 50 is made from cold forming a steel strip in a rolling mill and steel is coated with zinc or zinc/aluminum alloy [16]. Prima*flex* is composite material flat sheet composed of the top grade cellulose fiber, Portland cement, and finely ground sand that is produced under intense pressure [17]. The self-drilling screws were used have a diameter and length of 8.0mm and 32.0mm respectively. The corrugations in the Peva 50 were filled with foamed concrete with a targeted density of 1600kg/m^3 or compressive strength of 22N/mm^2 in 28 days after mixing and casting. The characteristic of the used material can be found in Table 1.

Table 1 - Material properties

Materials	Thickness/ Diameter (mm)	Modulus of elasticity, E (N/mm^2)	Ultimate strength (N/mm^2)
Profiled steel Sheet (Peva 50)	0.8	275×10^3	350
	1.0	275×10^3	350
Dry Board (Prima*flex*)	16.0	8030	22
Self-drilling screws	8.0	-	-

A total of four full-scale lightweight composite slabs were prepared with the size of 2440mm (length) × 1000mm (width) × 66mm (height). Two-panel specimens without foamed concrete were developed with 0.8mm and 1.0mm thick of profiled steel sheet (Peva 50). Other two-panel specimens were generated with the same characteristics but with foamed concrete as infill material. The test specimen can be found in Table 2.

Table 2 - Test specimens

Group	Specimen Name	The thickness of profiled steel sheet (mm)	With/ Without infill material
1	0.8H	0.8	Without infill
	1.0H	1.0	Without infill
2	0.8FC	0.8	With infill
	1.0FC	1.0	With infill

Simply supported condition is applied in the test to measure the horizontal movement of the specimen at the roller end. The loads will be generated via hydraulic press control and they will be symmetrically distributed on the specimen through four lines of load. The hydraulic press capacity is 1000kN. The Linear Variable Deformation Transducers (LVDT) and strain gauges were used to measure the vertical movement and the strains at important areas. Three LVDT and strain gauges were placed to detect the vertical movements and horizontal movement of the quarter-span and mid-span of the specimen. Fig. 2 shows the slab details and test setup. Monotonic static load was applied in small increments of the load until either onset of the local buckling or 80% of predicted ultimate load each of them happens sooner. The loading would be based on the deflection changes after this point. Therefore, Proper considerations have been made during preparing the specimen and performing the test to maximize the accuracy of the obtained results. Thus, the recorded results of the LVDT and the strain gauges by the data logger are reliable.

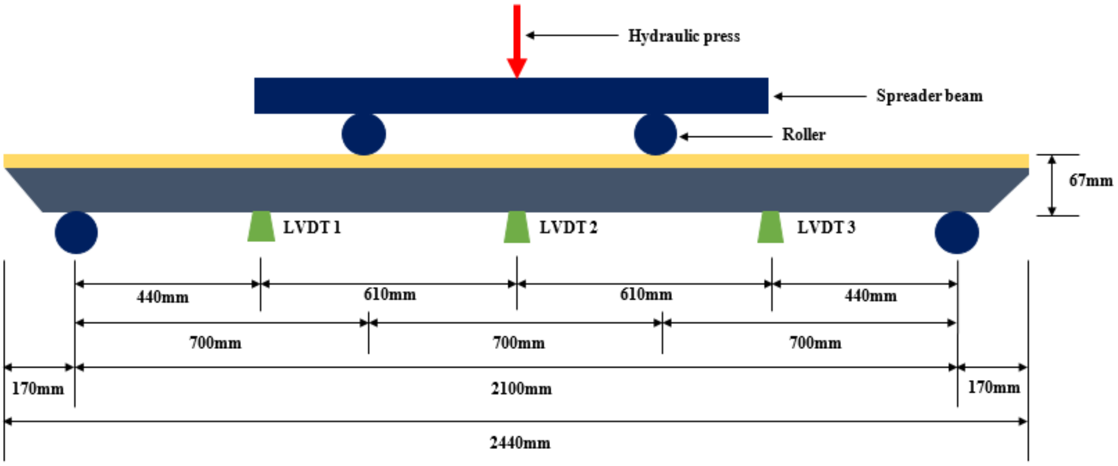


Fig. 2 - Scheme of the experimental setup

3. Results and Discussions

After completing the installation of the measuring devices (transducers and strain gauges) and recording equipment (data logger and laptop), and checking that all equipment were working properly, everything was ready. So the test has begun by applying an incremental load on the lightweight composite slab which has been distributed using the spreader beam and roller (see Fig. 3).

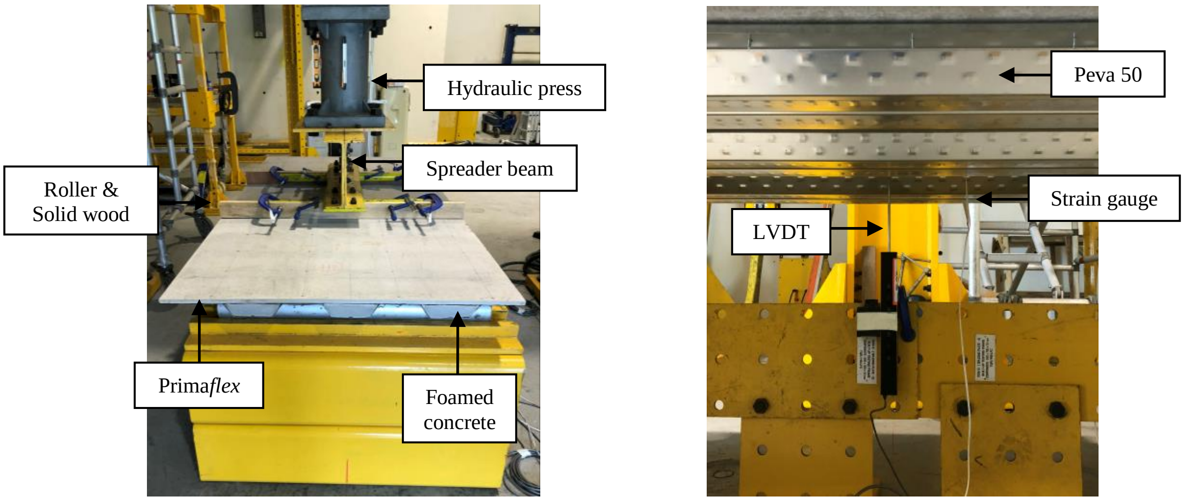


Fig. 3 - Diagonal view of lightweight composite slab

3.1 Load-deflection Curve

As stated above, the obtained data from the hydraulic press, LVDTs, and strain gauges were recorded using a digital data logger which in turn was displayed in a laptop device. The results of the experimental tests will be analyzed and discussed below to predict the structural behavior of the lightweight composite slab system. In the plotted graph in Fig. 4 below, the experimental results show that all tests conducted are showing similar load-deflection characteristics. The four curves show a linear at the beginning of loading and elastic response continued until just before failure. Then, the ultimate load is achieved and the panel specimen will fail. Referring to EN 1992-1-1, Cl 7.4.1, the deflections of the specimen are well within the allowable deflection limit is L/200, where L is the span distance [18]. In this case, the limiting deflection was found to be 10.5mm. The deflections obtained for all the panel specimens were well within the deflection limit.

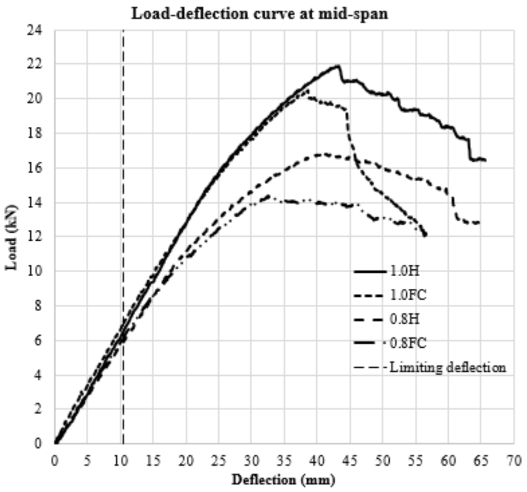


Fig. 4 - Load-deflection curve at mid-span

3.1.2 Effect of Profiled Steel Sheet Thickness

From the observation (see Fig. 4), the panel specimen 0.8H and 1.0H show deflection amount of 41.40mm and 43.47mm respectively. The ultimate load for panel specimens 0.8H and 1.0H is 16.78kN and 21.64kN correspondingly. The deflection of panel specimen 1.0H is higher compared to deflection of panel specimen 0.8H with a percentage difference of deflection is 4.88% and the ultimate load of panel specimen 1.0H also higher compared to ultimate load 0.8H with a percentage difference of ultimate load is 25.30%. While the deflection of panel specimen 0.8FC and 1.0FC is 33.47mm and 39.47mm respectively. 14.20kN and 20.11kN of ultimate load for panel specimen 0.8FC and 1.0FC respectively. The deflection of panel specimen 1.0FC is higher compared to deflection panel specimen 0.8FC with a difference of 16.45% and the ultimate load panel specimen of 1.0FC also higher compared to the ultimate load of panel specimen 0.8FC with a difference of 34.45%. From both results, increasing the thickness of Peva 50 from 0.8mm to

1.0mm gives a major effect on the deflection and ultimate load. Therefore, increased the thickness of profiled steel sheet can enhance the stiffness and strength of the lightweight composite slab systems.

3.1.3 Effect of Infill Materials

By comparing the deflection and ultimate load, the panel specimen of 1.0H is higher compared to 1.0FC with a different percentage of deflection is 9.65% and the different percentage of ultimate load is 7.33%. Whereas, the deflection of panel specimen 0.8H is higher than the deflection of panel specimen 0.8FC and the ultimate load of panel specimen 0.8H also higher than the ultimate load panel specimen 0.8FC with a difference of deflection is 21.18% and the difference of ultimate load is 16.66%. From both results, it is found that the infill material (foamed concrete) used in these experimental gives a minor effect on deflection and ultimate load. Thus, foamed concrete can be used only for non-structural purposes only such as soundproofing and fire resistance. It is because the lightweight composite slab with foamed concrete already sustains their heavy self-weight and cannot sustain more load from others.

3.1.1 Symmetrical Deflection

As mentioned before, the use of LVDT 1 and LVDT 3 is to record the symmetrical deflection at quarter-span locations. The load-deflection curves for the four cases are shown in Fig. 4 till 7. From the graphs, the deflections are seen almost identical for symmetrically positioned LVDT 1 and LVDT 3 for all samples. This situation shows the deflections recorded by the LVDTs at quarter-span locations are considered symmetrical, hence verifying the reliability of the experimental data.

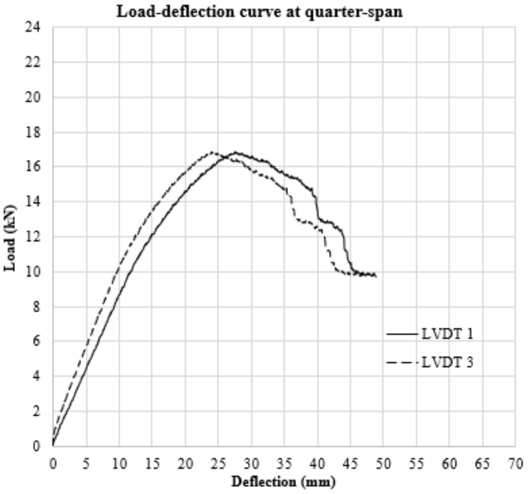


Fig. 5 - Symmetrical deflections at quarter-span for 0.8H

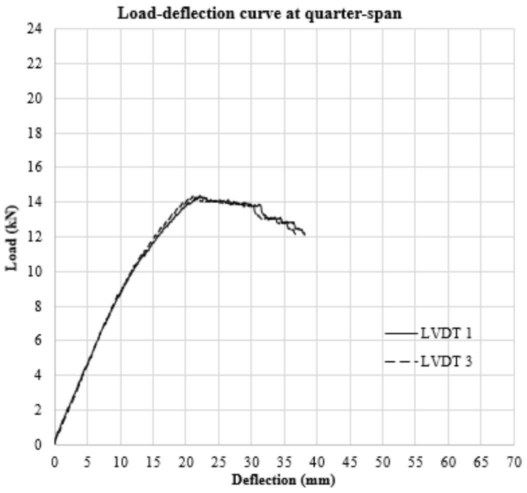


Fig. 6 - Symmetrical deflections at quarter-span for 0.8FC

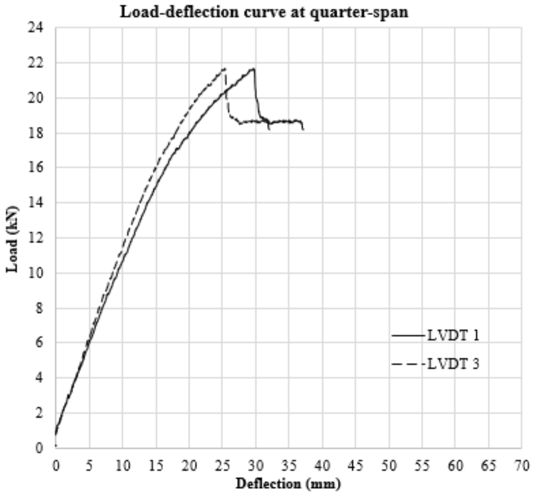


Fig. 7 - Symmetrical deflections at quarter-span for 1.0H

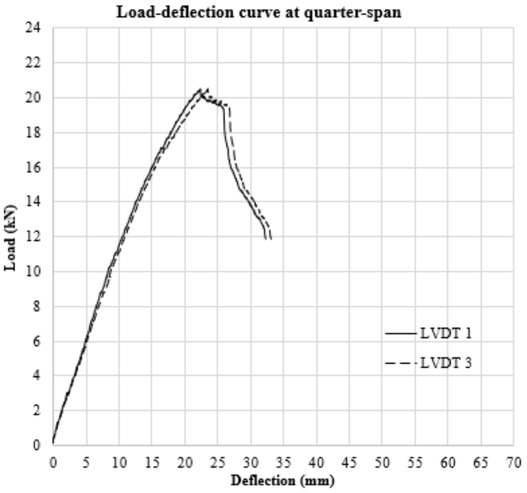
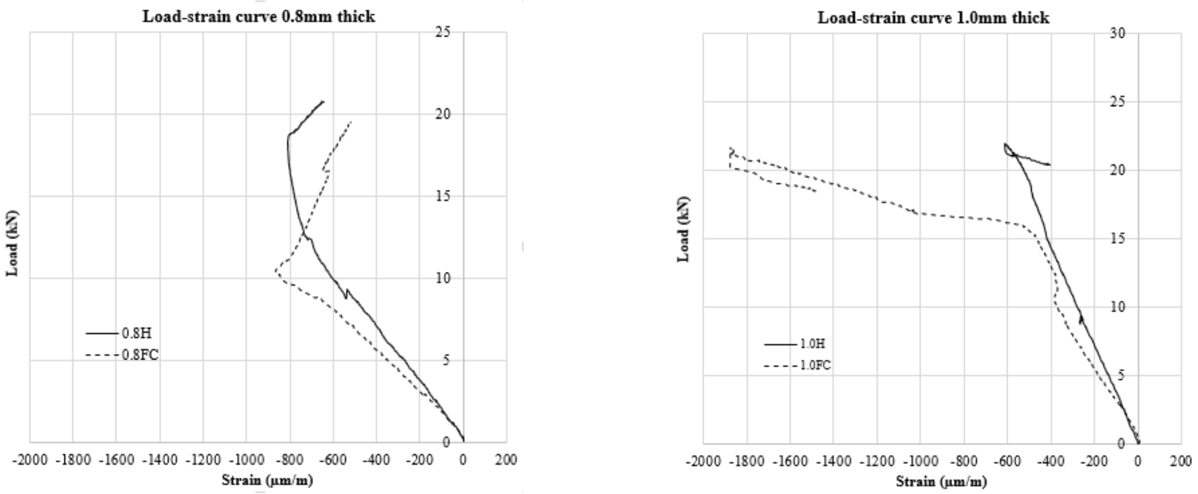


Fig. 8 - Symmetrical deflections at quarter-span for 1.0FC

3.2 Strain-load Curve

Figs. 9 present the load-strain graphs which were obtained from the applied strain gauges. The strain gauge was placed at the mid-span of the panel specimen. It is clarified from the obtained results that the profiled steel sheet (Peva 50) hasn’t reached the yielding point. Based on Fig. 9 (a), from the vertical strain gauges that lie on the upper flanges of the profiled steel sheet (Peva 50), it can be seen that the 0.8FC has reached –526 at the load 19kN while for 0.8H has reached –724 at the same load. Both values are very low comparing to the yield strain of Peva 50 which is approximately equal to –1667. The same can be said for panel specimens of 1.0H where the strain values at the same load are –508 and –1497 respectively. In addition, it’s worth noting that the strain gauge reading lies in the tension region which is consistent with the bending behavior demonstrated in the failure mode. The results of the strain-load curve are concordant with the failure modes where the failure occurs in the dry board (Prima*flex*) and the breaking of the self-drilling screws which connect the profiled steel sheet (Peva 50) and dry board (Prima*flex*).



(a) **(b)**

Fig. 9 - Load-strain curve (a) 0.8mm thick; (b) 1.0mm thick

3.3 Failure Mode

In the experiment conducted on a lightweight composite slab panel, failure was found to occur on the panel specimen because of local buckling, especially on the top flange of the profiled steel sheeting in the mid-span (see Fig. 10 and Fig. 11). The loading imposed on the panel specimen caused the dry board (Prima*flex*) to bend and the steel sheeting (Peva 50) to experience high tension, which further caused local buckling on the web of steel sheeting. The web part of the steel sheeting exhibited a remarkable deformation because of local buckling, which resulted in a non-linear relationship in the plastic range of the load-deflection graph. The curve relationships observed in all the panel specimens tested were almost linear initially and subsequently became non-linear as a load was added continuously. The non-linear characteristics observed in all the load-deflection plots are due to the load buckling of the under compression as described in section 3.2 [19]. It can be seen that the panel specimen without foamed concrete developed local buckling only at the mid-span position. On the other hand, the panel specimen with foamed concrete demonstrated quarter span position load buckling as well that took place sometime after the mid-span local buckling. As for the panel specimen with foamed concrete, it's worth noting that the presence of embossments at the webs and bottom flanges of the profiled steel sheet (Peva 50) has managed to establish a partial interaction between Peva 50 and the foamed concrete, and it was enough to prevent a slip between the layers (see Fig. 11)

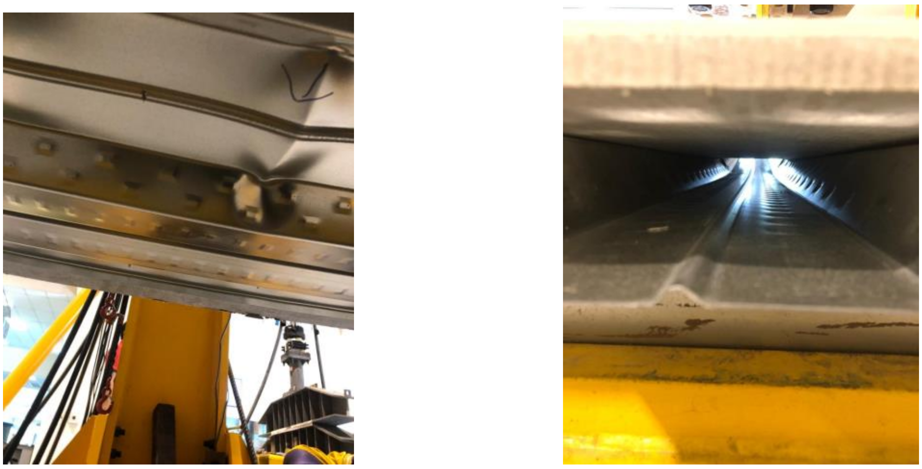


Fig. 10 - Buckling of Peva 50 without foamed concrete

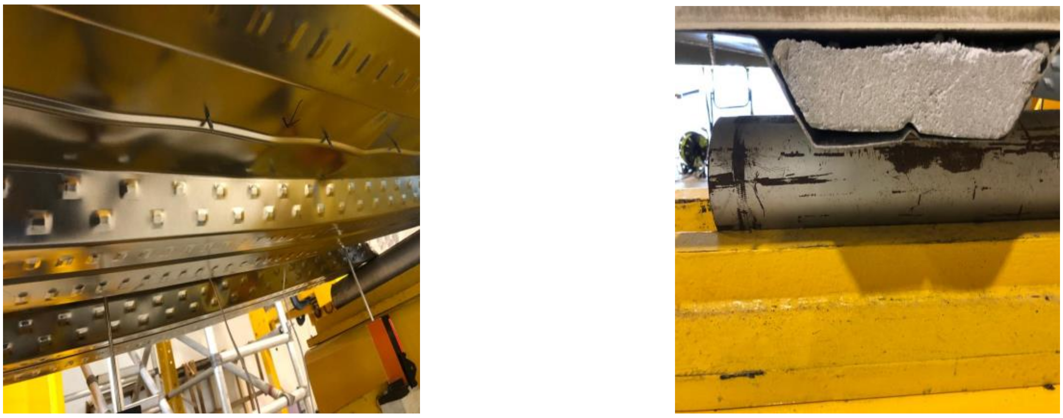


Fig. 11 - Buckling of Peva 50 and condition of foamed concrete

Failure of the panel specimen started at mid-span within the vicinity of the point of application of loading. It began with the appearance of a crack near to the mid-point of the dry board (Prima*flex*). With further increase in loading, the crack pattern propagated further perpendicular to the corrugation of the steel sheeting along the whole width of the panel specimen. It worth noting that the parallel edges didn't rise, and the failure of the specimen didn't occur because of the dry board (Prima*flex*), although some minor cracks have appeared around the mid-span as displayed in Fig. 12. As the panel specimen is loaded, the sheeting (Peva 50) will deform, allowing the screws (self-drilling screws) to lean and bite into the boarding as illustrated in Fig.13. Depending on the board types, two major modes of failure may occur here; firstly crushing of board surrounding the connectors, and secondly, screw connectors shearing off at the base. From the observation, all tests show similar and consistent behavior

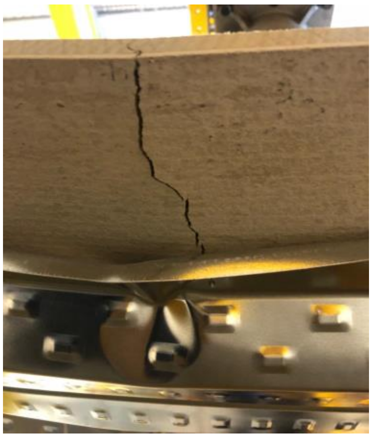


Fig. 12 - Cracking occur at mid-span

Fig. 13 - Shearing of screw connector

4. Conclusion

This study investigates the structural behavior of lightweight composite slab systems with the effects of different thicknesses of profiled steel sheets and without or with foamed concrete when tested subjected to bending loads. From the experiment conducted, it is found that increasing the thickness of profiles steel sheets gives a major effect on the deflection and ultimate load. Therefore, increased the thickness of profiled steel sheet can enhance the stiffness and strength of the lightweight composite slab systems. It also found that the infill material used in these experimental gives minor effect to deflection and ultimate load. Thus, infill material can be used only for non-structural purposes only such as soundproofing and fire resistance. Overall, the objectives of this study were achieved and enough to optimize the structural behavior of the lightweight composite slab system. Furthermore, it can provide an economical solution to enhance the stiffness and strength of lightweight composite slabs without affecting the system's efficiency. Further studies considering the other types of infill material must be investigated in the future.

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