Numerical analysis of the flexural characteristics of the profiled steel sheeting dry board (PSSDB) floor system using Finite Element

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Abstract:
The purpose of this paper is inspecting the flexural performance of Profiled Steel Sheeting Dry Board (PSSDB) floor system. A lightweight composite slab consists of a steel deck connected to a dry board using self-tapping and self-drilling screws. The study employed Finite Element (FE) modelling using ABAQUS software. The results were validated with experimental ones, and it has demonstrated the adequacy of the FE model to simulate the performance of the floor panel. Thereafter, three parametric studies were suggested in order to understand the influencing parameters. It is shown that the depth of the dry board can improve the load capacity by no more than 7.5%, while the thickness of steel deck has an enhance it by up to 65%. Finally, it was established that the type of profiled steel sheeting can affect the stiffness and load capacity by up 18%.
keywords: Composite slab, PSSDB, Dry Board, Profiled Steel Sheeting, Finite Element.

التحليل العددي لخصائص الانحناء لنظام أرضية الصفائح الفولاذية المموجة و اللوح الجاف (PSSDB) باستخدام طريقة العناصر المحددة

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الخلاصة :
الهدف من هذه الدراسة هو فحص أداء الانحناء لنظام (PSSDB) .يتكون النظام من سطح فولاذي مموج متصل بلوح جاف باستخدام مسامير لولبية ذاتية الحفر. تستخدم الدراسة طريقة العناصر المحدودة (FE) باستخدام برنامج ABAQUS. تم التحقق من النتائج من خلال الدراسات المختبرية، وقد أظهرت مدى كفاية نموذج الFE للتنبؤ بأداء الPSSDB. بعد ذلك ، تم اقتراح ثلاث دراسات بارامترية لفهم العوامل التي تؤثر على النظام. يتضح أن عمق اللوح الجاف يمكن أن يؤثر على مقاومة الحمل بما لا يزيد عن ٧,٥ ٪ ، في حين أن سمك الصفائح الفولاذية يمكن أن يؤثر بنسبة تصل إلى ٦٥ ٪. أخيراً ، وجد أن نوع صفائح الفولاذ يمكن أن يؤثر على الصلابة وقدرة التحميل بنسبة تصل إلى ١٨٪.

الكلمات المفتاحية: PSSDB ، صفيحة فولاذية مموجة، لوح جاف ، العناصر المحدودة ، بلاطة مركبة.

1. Introduction

The construction industry's focus is to produce cost-effective structures by suggesting new methods and studies. Composite structures are one of the results of these studies. They are made by firmly connecting two or more materials as a single unit, and where the characteristics of each component are utilized by its specified location [1]. Composite structures have various advantages, such as their lighter weight, construction adequacy, enhanced strength and stiffness. Therefore, they provide an economical solution for multiple types of buildings.

The Profiled Steel Sheeting Dry Board (PSSDB) panel has been suggested first in 1986 to be used as a floor unit instead of the traditional timber joist floor [2, 3]. It is a lightweight composite structure which consists of a steel deck attached to a dry board by using mechanical screws (See Figure 1). The system does not require skilled workers or temporary formwork. Furthermore, it is easy to transport, and the renovations are easier to maintain. Further studies have shown the potential of the system to be employed as both roof and wall system [4, 5]. However, most studies have focused on the former (floor panels) since the latter has other alternatives.

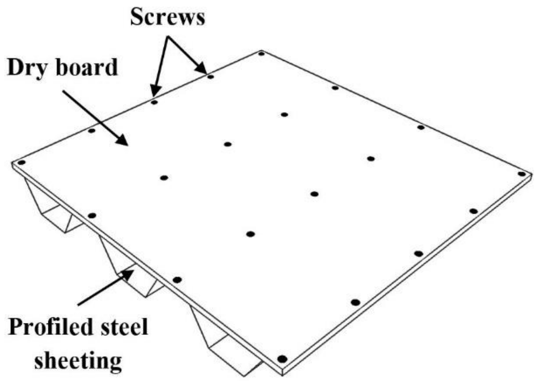
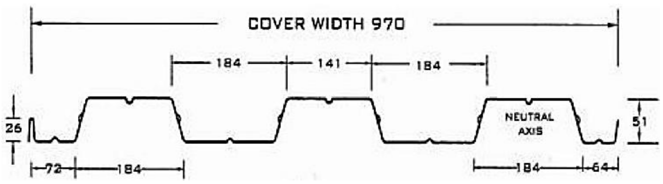


Figure 1. Typical PSSDB system

The studies regarding the floor panels have investigated various parameters, such as the infill material [6-11], fire resistance [12-15], and sound isolation [16-22]. Recent studies have even considered the behaviour of the PSSDB as two-way slabs [23-28]. However, most studies regarding the one-way approach have considered the bending behaviour using only one type of steel deck or one dry board. Therefore this study aims to conduct a Finite Element (FE) analysis under various parameters such as the depth of the dry board, the thickness and.

2.Simulation

As previously noted, a numerical study shall be conducted using Finite Element (FE) method. The models were produced using ABAQUS software, and were based on the experimental specimens of Ahmed and Ahmad [17]. The specimens they consisted of 12-mm thick Plywood connected to a 1-mm SDP-51 steel deck (see Figure 2a) using self-tapping and self-drilling screws (200 mm distance between screws). The panel was simply supported and subjected to a line load at the centre, as illustrated in Figure 2b.



(a)

(b)

Figure 2. (a) Cross-section of SDP-51 steel deck, (b) Experimental test conducted on the PSSDB system [17]

2.1. Materials definition

Obtaining accurate results requires a realistic representation of materials. The profiled steel sheet is an orthotropic material consisting of assembled multiple thin plates. Since the corrugated geometry can achieve an orthotropic response, it was modelled using isotropic material features [29]. The Plywood consists of sheets of wood glued or cemented together with the grains of adjacent layers having rotated up to 90 degrees to one another. Therefore, an isotropic performance was used to model it. The physical characteristics of materials are illustrated in Table 1 below.

Table 1. Materials description

Component	Young's modulus (MPa)	Poisson's ratio	Yield strength (MPa)
Plywood	5277	0.3	45
SDP-51	210000	0.35	550

2.2. Model elements

Both of the steel deck and dry board have been modelled using shell since their depth are relatively smaller regarding their size [27]. ABAQUS has two types of shells: continuum and conventional (Figure 3). The latter can express the bending performance better since it has rotational degree and displacement degree of freedom. Therefore, a conventional shell was used. Various types of elements are available in the software. For this research, the S4R shell element was used to model the dry board and steel deck.

The screwed connection between the components of the PSSDB defines the composite action. A correct simulation of this connection is essential for FE modelling. For the proposed model, the CARTESIAN connection element has been employed to simulate the connector.

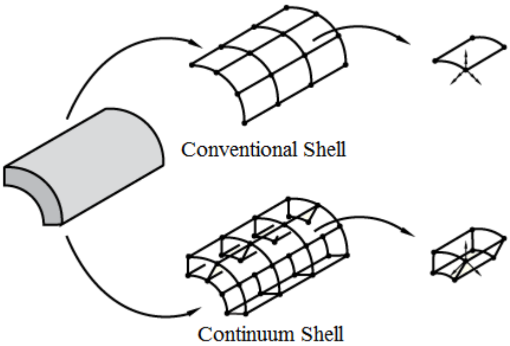


Figure 3. Conventional shell versus continuum shell

2.3 Boundary conditions

The experimental panel was simply supported on the transverse edges (see Figure 2b). For the FE simulation, the nodes of the steel deck lower flanges were restrained in the Y and Z direction. As to line load modelling, an incremental displacement is defined along the centre line, and the required load is obtained through reactions. Figures 4&5 illustrate the boundary conditions and loading.

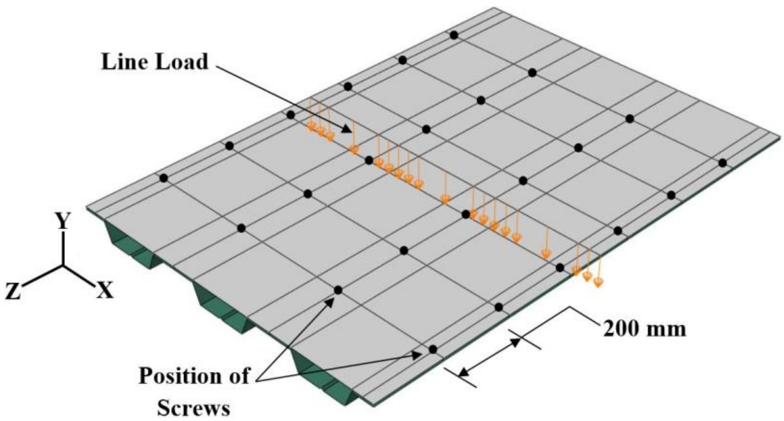


Figure 4. PSSDB finite-element model.

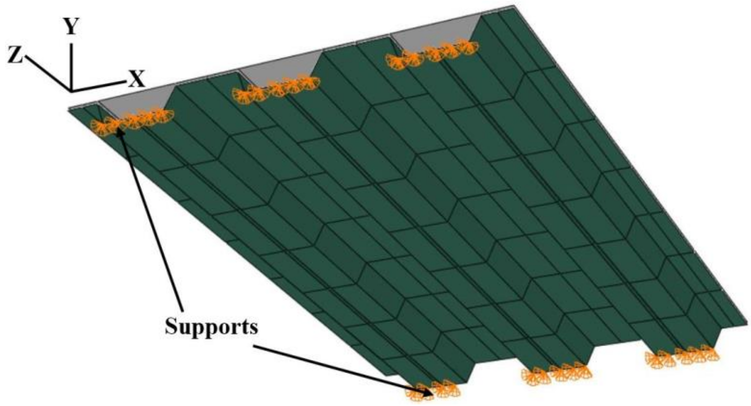


Figure 5. Supports location.

2. Results & Verification

In FE modelling, although increasing the elements shall raise the accuracy of results, it also lengthens the time needed for analysis. Therefore, reducing the elements while preserving the accuracy is the optimum solution. In Figure 6, it was shown that the variation in results becomes negligible once the number of elements exceeds 9000, and the difference between the FE and experimental results is around 5 %. Thus, it is acceptable to conduct the FE analysis within these limits.

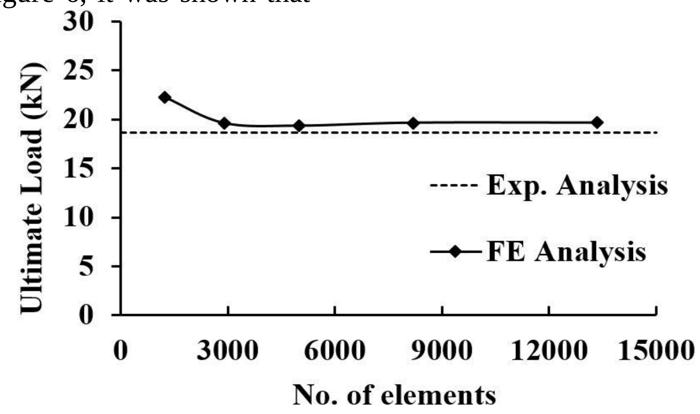


Figure 6. Convergence study for the number of elements.

As for verification, the comparison of the FE results with the Experimental ones displayed in Figure 7 has demonstrated that the maximum variance is approximately 7%, within the acceptable range of 15% [23]. Thus, we can presume that the reliability of the FE model to simulate the behaviour.

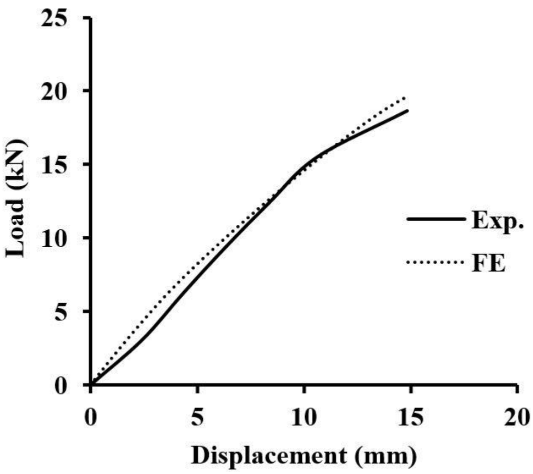


Figure 7. Results demonstration between experimental and FE.

3. Parametric studies

After verifying the FE model, several parametric studies were suggested to examine the impact of the steel sheeting thickness, type, and dry board depth on the PSSDB bending behaviour. The verified model (called S1 in the studies) are regarded as the control sample or each study, which will be discussed below .

4.1 The dry board thickness

The purpose is to comprehend the PSSDB bending behaviour using different dry board thicknesses. Four samples (including the control sample) were employed, as shown in Table 2. All have the exact dimensions, materials and boundary conditions. However, the plywood dry board's depth is different for each.

Table 2. Characteristics of models with various dry board depths.

Sample	Profiled Steel sheeting	Thickness (mm)	Dry Board	Depth (mm)	Ultimate Load (kN)
S1	SDP-51	1.0	Plywood	12	19.64
S2	SDP-51	1.0	Plywood	9	18.83
S3	SDP-51	1.0	Plywood	15	20.38
S4	SDP-51	1.0	Plywood	18	21.11

It was shown from the load-displacement results in Figure 8 that the dry board depth demonstrate a negligible effect on the stiffness. As to load capacity, the influence is minor. For example, increasing the depth to 18 mm has enhanced the load by no more than 7.5 %, while reducing the depth to 9 mm has only decreased it by approximately 4.1 %.

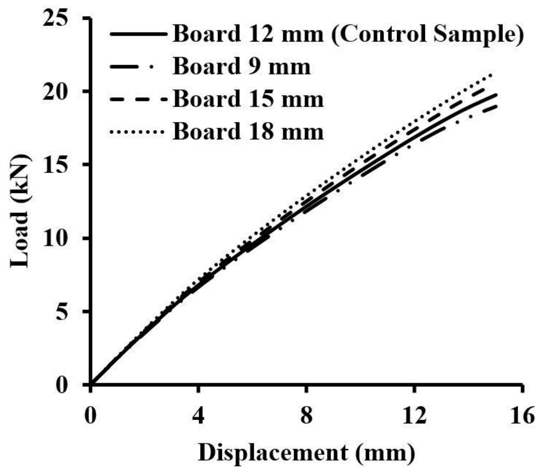


Figure 8. Load-displacement graph for the first parametric study.

4.2 The steel deck thickness

The aim is to inspect the influence of changing the thickness of steel deck on the performance of the PSSDB system. Five samples used for this study. Except for the steel deck thickness, all have identical properties and boundary conditions as demonstrated in table 3 below.

Table 3. Properties of PSSDB models with different Profiled steel sheet thickness.

Sample	Profiled Steel sheeting	Thickness (mm)	Dry Board	Depth (mm)	Ultimate Load (kN)
S1	SDP-51	1.0	Plywood	12	19.64
S5	SDP-51	0.9	Plywood	12	17.24
S6	SDP-51	0.8	Plywood	12	14.97
S7	SDP-51	1.2	Plywood	12	24.52
S8	SDP-51	1.5	Plywood	12	32.31

It can be seen from the load-displacement graph in figure 9 that the profiled steel sheeting produce a significant impact on both the stiffness and load capacity when changing its thickness. For instance, reducing the thickness to 0.8 shall decrease the load capacity by up to 23%, while increasing the thickness to 1.5 mm can enhance it by up to 65%.

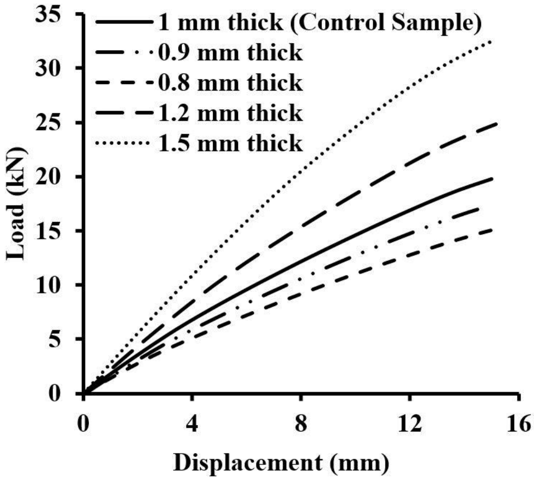


Figure 9. Load-displacement graph for the second parametric study.

4.2 The effect of the steel sheeting type.

Since it is the load-bearing part of the PSSDB, a parametric study has been conducted to inspect the effect of employing different profiled steel sheeting on the system's behaviour. Three models were prepared for the study. They all have the same dry board, dimensions, boundary conditions and loading. However, a different profiled steel sheeting was used for each one (See Table 4). SDP-51 steel sheeting was used for the control sample (S1), while Peva 50 and MIPL 960 were used for the other two. Figure 10 below illustrates the cross-section and dimensions of the employed steel decks.

Table 4. Characteristics of models with various types of Profiled steel sheeting.

Sample	Profiled Steel sheeting	Thickness (mm)	Dry Board	Depth (mm)	Ultimate Load (kN)
S1	SDP-51	1.0	Plywood	12	19.64
S9	Peva 50	1.0	Plywood	12	15.85
S10	MIPL 960	1.0	Plywood	12	23.14

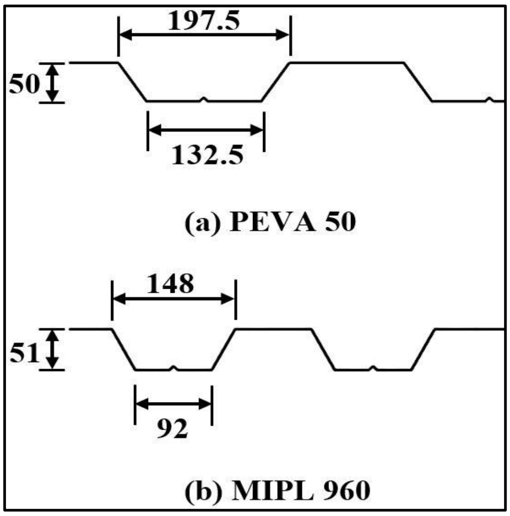


Figure 10. Cross section of the profiled steel sheetings employed for the study (dimensions in meters).

From the load-displacement graph shown in figure 11, it is demonstrated that steel deck can influence the behaviour of the system. For instance, the sample with Peva 50 has a lower load capacity than the control sample (with SDP-51) by approximately 8 %. That is to be expected since the yield strength of Peva 50 is lower than SDP-51. As for the sample with MIPL 960, the load capacity was higher by 18 %, even though both steel decks have the same yield strength. That is because the MIPL 960 has an extra upper flange, which increases the number of screws connecting the dry board to the steel deck. Therefore, the composite action between the components has been optimized, thus, optimizing the stiffness and strength of the sample.

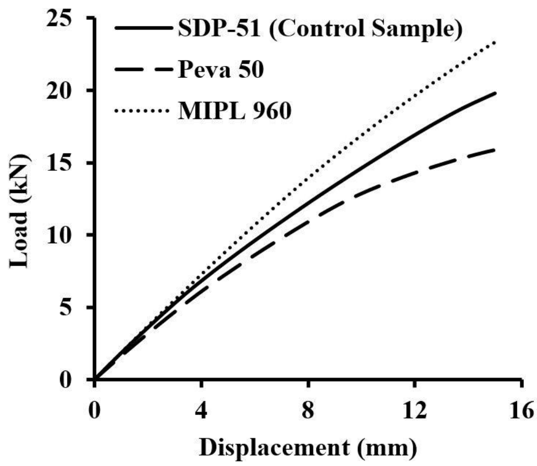


Figure 11. Load-displacement graph for the third parametric study.

4. Conclusions

The aim of this paper is to investigate the bending behaviour of the PSSDB floor system using FE analysis. The conclusions are as follows:

- The FE modelling can predict the behaviour of the PSSDB panel.
- The number of elements employed in FE modelling affects the accuracy of results.
- A minor influence is observed from changing the depth of dry board on the performance of the system.
- The steel deck thickness has a notable impact on the system.
- The type of steel deck used can significantly affect the strength of the floor panel.

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