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STRUCTURAL PERFORMANCE AND APPLICATIONS OF A REVERSED PROFILED STEEL SHEETING DRY BOARD ROOF PANEL SYSTEM

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ABSTRACT

This paper describes the application of the Profiled Steel Sheet Dry Board (PSSDB) system as a structural component in an innovative lightweight composite structural roofing panel system. The composite panel system consists of profiled steel sheet attached to the dry board via mechanical self drilling and self tapping screws. Newly introduced materials for the profiled steel sheet and dry board have been proposed as components of the PSSDB system in this study. In this case, the normal position of the PSSDB system has been reversed. The dry board plays an important role in enhancing the stiffness and strength of the roofing system as well as providing a flat surface which conveniently forms the ceiling inside the room in a building. The behaviour of the PSSDB roofing system in the reversed position was investigated. In addition, the effect timber strips introduced along the side edge of the roof panels was studied. From the test results, it was found that the use of Ajiya Clip-lock 660 profiled steel sheet together with 9 mm Prima*flex* dry board for the roof panel system was acceptable. The stiffness value of the panel system in the reversed position is almost identical to the one in the normal position. It was also found that the application of the timber strips could increase the stiffness of the composite panel by 35.8% compared to the panel without timber strips. The results from the tests also found that the load after failure of the panel with timber strips decreases gradually compared to the panel without timber strips. It can be concluded that the timber strips play an important role in stiffening the roof panel system. Some interesting applications of the system in real buildings are also highlighted in this paper.

Keywords: Profiled steel sheeting; prima*flex*; timber strips; composite structure; reversed position

1. INTRODUCTION

Research and development works have resulted in more effective and innovative construction systems and techniques. Construction is no longer dependent solely on

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traditional concepts of construction which would normally involved materials such as reinforced concrete and timber, but slowly moving towards more dynamic materials and systems. The relatively new concepts in the construction technology such as the steel, composite steel-concrete and systems involving lightweight panels of various materials, concrete hollow blocks and other similar Industrialised Building System (IBS) are becoming more acceptable to the construction technology. IBS has been promoted in the construction industry in order to enhance the efficiency of construction processes, which in turn would allow for a higher productivity and quality, shorter construction time, cost saving as well as environmental friendly. These new materials and systems are introduced in order to meet one or more of the following goals [1]:

- shorter construction time
- less dependent on heavy equipment on job site
- fewer specialised trades
- simplified utility installation
- greater structural integrity
- earlier completion and earlier occupancy
- excellent thermal and sound barrier
- environmentally intelligent
- better quality buildings
- reduce on site labour time and costs
- simple construction methods
- less wastage of materials
- more durable
- avoid using formwork, etc.

In line with the above requirements, a system known as the Profiled Steel Sheeting Dry Board (PSSDB) system as shown in Figure 1 was proposed. The PSSDB system is a lightweight composite system consisting of profiled steel sheet connected to dry board by simple mechanical connectors. The connectors play an important role in transferring horizontal shear between the boarding and the profiled steel sheeting while the board plays dual role, firstly providing a flat surface for the roofing and secondly, enhancing the stiffness and strength of the system through composite action.

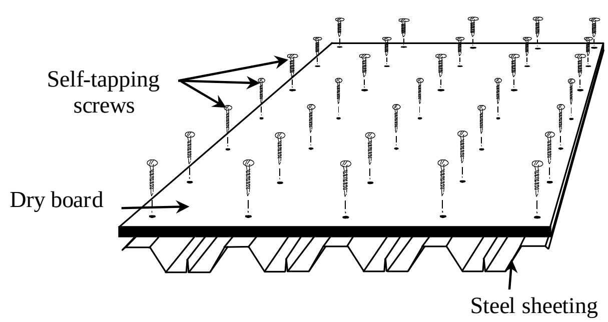


Figure 1. Typical PSSDB system

This research focusses on the application of the PSSDB system as roofing elements. The traditional forms of roof structures, either by using timber or steel materials involve the use of purlins, channels, rafters and trusses. The traditional systems have several disadvantages [2] which can be simplified as follows:-

- Generally, the structure of the roof involves a considerable number of internal elements which impinge on the roof space and sterilise its effective use.
- Considerable numbers of connections between elements are required in the skeletal framing; these are often difficult to form and add to the cost.
- It is often difficult to provide the overall stability of the roof structure and this involves cross bracing and allowance for wind uplift.
- Insect attack and rotting of the timbers are problems that are not always resolved with preservatives and treatments.

2. PSSDB COMPONENT MATERIAL

The idea of using dry boards as a structural component was first conceived by Wright and Evans [3]. The study of the behaviour of the PSSDB floor, wall and roof systems was conducted by previous researchers [4–14]. These studies include structural and non-structural performance of the system.

2.1 Profiled steel sheeting

Profiled steel sheeting is cold formed from flat steel ‘coil’. The sheeting is coated with zinc/aluminium alloy which is more recognised as zincalume which followed Australian Standard AS 1397:1993. Zincalume is a corrosion-resistant, alloy coated steel produced by a continuous hot dip process. The alloy coating of zincalume provides the optimum composition of aluminium and zinc for corrosion resistance and galvanic protection. Many of the commercially available profiled steel sheets that were used in non load-bearing applications as wall claddings and roof coverings could actually be turned into load-bearing applications as will be shown in this paper. The yield strength of profiled steel sheet is between 350 MPa to 550 MPa. Even though the strength of is high, the stiffness characteristic is low. The thickness of the sheeting for wall and roof applications is relatively thin (0.4mm– 0.6mm).

Based on the studies of over hundreds of different steel sheets, the sheets could be sorted into several groups based on their shape and depth [2]. The difference in shape and depth will greatly influence the performance of the PSSDB system. The stiffness of the sheeting increases with the depth of the profile. For the proposed system, a locally available profiled steel sheet in Malaysia known as Ajiya CL 660 Clip ‘n’ Locking (Figure 2) [15], with the thickness of 0.48mm produced by Asia Roofing Industries Sdn. Bhd. was adopted. The Ajiya CL 660 has three fluted pans with an effective cover width of 660mm, ribs height of approximately 44mm spaced at 221.67mm between the three fluted pans.

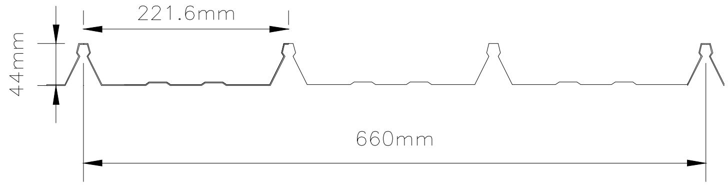


Figure 2. CL 660 Clip 'n' Locking profiled steel sheeting

2.2 Dry board

Wright and Evans [2] has proposed two types of boards to be used in their PSSDB system, namely plywood and chipboard. However, a study done by Wan Badaruzzaman et. al. [1] on a type of cement bonded board, Cemboard, manufactured locally in Malaysia indicates that this board is good in weather, fungal and insect resistance. It is also good in fire resistance and is classified as highly fire-resistant by relevant German and British Standards. Even though the two types of boards were usually used in the PSSDB system, the authors found that Cemboard performed better.

In this paper, a new type of dry board, namely Prima*flex* (also manufactured locally) [16] with the thickness of 9 mm is introduced as an alternative to the other types of dry boards normally used in the PSSDB system. Prima*flex* has never been used before by others researchers. The Young's modulus of Prima*flex* is 8000 MPa, which is higher than the usual dry board used by others researchers such as Cemboard (4800 MPa). Prima*flex* is made from top grade cellulose fibres, Portland cement and finely ground sand. It will not deteriorate when exposed to sun, rain, wind, dampness and dryness. Whilst on the aspect of fire resistance, Prima*flex* is classified as highly fire-resistant in relevant Australia and British Standard.

Dry board is a very important component in the PSSDB system which provides for a flat surface to carry load. The board is attached to the profiled steel sheeting by self drilling and self tapping screws. It interacts compositely with the profiled steel sheet to form a composite section resulting in either full or partial interaction behavior. It is also very instrumental in delaying local buckling of the thin profiled steel sheet under compressive load and elastic deflection of the PSSDB system besides carrying a small portion of the load [17]. The properties comparison of the materials of the four chosen types of dry boards is shown in Table 1.

Table 1. Structural properties of dry boards.

Type of board	**Young's modulus (MPa)**		**Bending strength (MPa)**	
	Parallel to grain	**Perpendicular to grain**	**Parallel to grain**	**Perpendicular to grain**
18 mm plywood	5300	9775	40.4	66.5
18 mm chipboard	1950	1950	11.4	11.4
12 mm Cemboard	4800	4800	8.4	8.4

9 mm Prima*flex*	8000	8000	14	22

2.3 Connection

The connection between the components (profiled steel sheet and dry board) is very important in the composite PSSDB system. Studies on the connection of the PSSDB system was carried out by Wright and Evans [2] and Ahmed [5]. The self-drilling and self-tapping screws were found to be the most suitable connectors for the system. These types of screws are also locally produced in various sizes and shapes. The screws in the system will transfer the horizontal shear force between the dry board and the profiled steel sheeting. The performance of a connection depends on the type of screw and spacing used, and this will determine the degree of composite action achieved (full or partial interaction) which will in turn determine the stiffness of the structural composite unit. Properties of the screws of type 14DX-RW produced locally in Malaysia and used for the investigation are shown in Table 2.

Table 2. Properties of 14DX-RW screw connectors

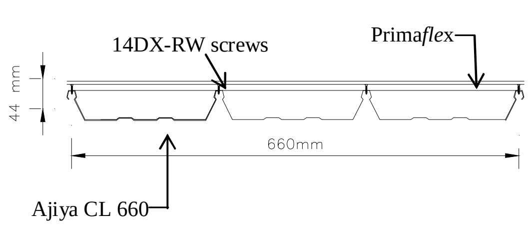
Properties	
Material	Carbon steel
Surface coating	10 -15 mm Zinc Chromate
Length	25 mm
Diameter of thread	4.2 mm
Tensile breaking load	6.3 kN
Shear breaking load	4.35 kN
Twist-off torque	4.7 Nm
Pull-out load from 0.8 mm steel plate	0.75 kN

3. EXPERIMENTAL PROGRAMME

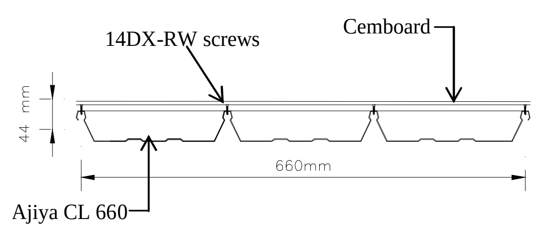
The experimental study was conducted to investigate the flexural strength of the PSSDB roof panels. The test parameters considered here are the types of dry boards, positioning (normal or reversed) of the panels and the presence of timber strips along the edges of the panels. The thickness of CL 660 used was 0.48 mm in all the cases. The thickness of Prima*flex* used is 9 mm, while for the Cemboard, 12 mm is used. The spacing of the screws considered is 100 mm centre to centre in the longitudinal direction on each rib of the profiled steel sheet. The length of the sample is 2000 mm. The test programme consisted of five (5) series of full scale tests as given in Table 3. Figure 3 shows the cross-sections of all the test samples.

Table 3. Samples for the flexural test

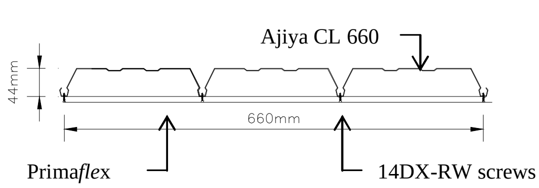
Sample	**Board type**	**Thickness (mm)**	**Description of sample**
S1	Prima*flex*	9	This sample consists of single panel in the normal position as per S1. The difference between S1 and S2 is in the type of boarding used (see Figure 3(a)). Total width = 660 mm.
S2	Cemboard	12	This sample consists of single panel in the normal position. The position in which the board is at the top and the sheeting is at the bottom (see Figure 3(b)). Total width = 660 mm.
S3	Prima*flex*	9	This sample consists of single span panel in the reversed position (see Figure 3(c)). Total width = 660 mm.
S4	Primaflex	9	This sample consists of actual size of proposed single span panel in the reversed position (see Figure 3(d)). Total width = 750 mm.
S5	Primaflex	9	This sample consists of actual size of proposed single span panel in the reversed position as per S4. The difference between S5 and S4 is in the timber strips introduced in S5 at the edges along the span of the S5 (see Figure 3(e)). Total width = 750 mm.



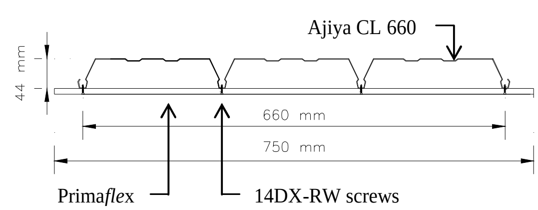
(a). Sample S1



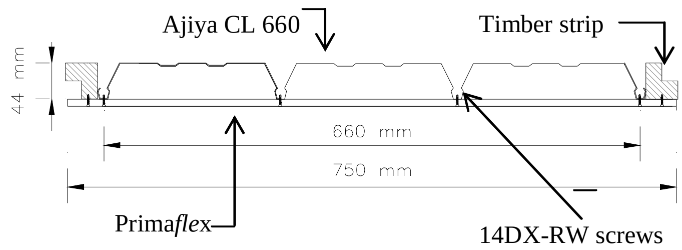
(b) Sample S2



(c) Sample S3



(d) Sample S4



(e) Sample S5

Figure 3. Cross sections of samples

The panels were tested on a simple span using the concepts of whiffle-tree loading to simulate a uniformly distributed load. The load was applied through four steel loading beams to the sample. The deflection values were measured using displacement transducers. The transducers were located at the middle and quarter span along the mid span line. The transducers were also located at both ends of the mid-width line to detect any unintentional eccentricity of loading. Figure 4 shows a typical test set-up.

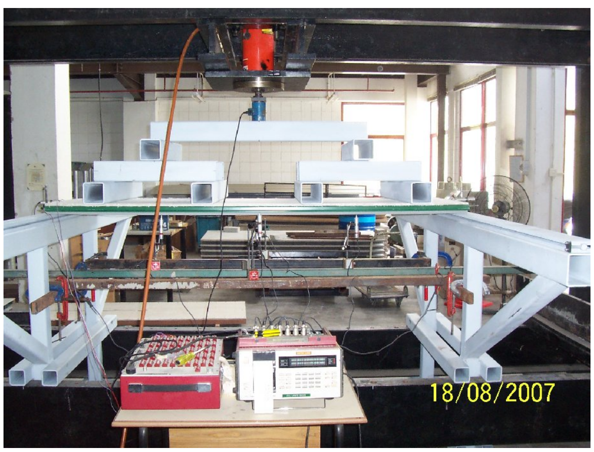


Figure 4. A typical test set-up

4. TEST RESULTS AND DISCUSSIONS

4.1 General

The load-deflection curves obtained from the samples in the experiment exhibit similar characteristic. At the initial stage of load-deflection, the curves show a linear and elastic relationship. This elastic response continued into a non-linear range until failure.

4.2 Effect of types of boards.

The increase in stiffness values of the panel PSSDB system by attaching dry board to profiled steel sheet was reported by Wan Badaruzzaman et al. [1]. The type of dry board and its thickness have a direct effect on the behaviour of the PSSDB system. It is obvious from the load-deflection curves for S1 and S2 plotted in Figure 5 that both the samples behaved in a very similar manner throughout the linear elastic range and partly through the non-linear range. The stiffness value of S1 (involving Prima*flex*) is observed to be higher than S2 (involving Cemboard) due to the higher Young's modulus of Prima*flex* compared to the lower value for Cemboard. At a load of about 4.5 kN/m^2, the load-deflection curve of S1 deviated away from S2, where S1 did not fail under the applied load in the test, i.e. it kept on deflecting under an increased load and showed no sign of failure of the sample (Prima*flex* did not shown any sign of crack). This could be expected as the 9 mm Prima*flex* possesses a high bending strength value of 22 MPa compared to 8.4 MPa for the 12 mm Cemboard.

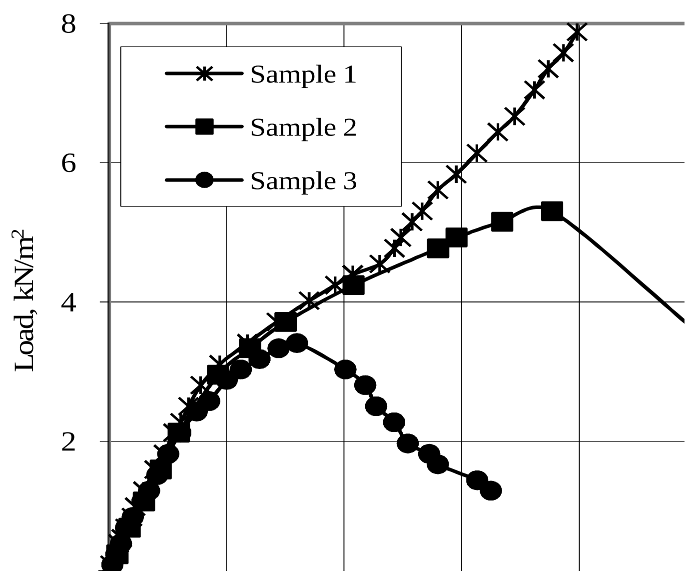


Figure 5. Flexural load-deflection behaviour of PSSDB for test S1- test S3

The load-deflection curve of S2 on the other hand reached a maximum load value before the load dropped in value until ultimate failure of the sample after a while as can be observed from Figure 5. It can be seen that in curve S2 the load-deflection curve response is fairly straight until the formation of non-linear behaviour at a load about 3kN/m^2. After the formation, the slope of the load-deflection curve is reduced until the load reached the maximum load at about 5.3kN/m^2. The non-linearity in the load-deflection curves can be linked to the buckling of the lower flanges in the transverse direction perpendicular to the span direction that has caused a variation in the cross-sectional shape thus leading to a change in the stiffness value as the samples are loaded (see Figure 6). In the case of S2, the non-linearity in results was also due to local buckling of the upper flange of Ajiya CL 660 under compression in the span direction and cracking of Cemboard, which became the ultimate mode of failure of S2.

Figure 6. Buckling of lower flange of Ajiya CL660

From the above, Prima*flex* can be concluded to be the better choice when compared to Cemboard to be used in the PSSDB system. It was shown that, Prima*flex* is very good in resisting bending load with an increased stiffness value (for S1) of 21.1% when compared to the sample using Cemboard (S2). It is also able to help prolong or delay the failure of the PSSDB system.

4.3 Effect of panel position/configuration

The load-deflection relationship for the PSSDB sample in the reversed position was also shown in Figure 5 (S3). From the results obtained experimentally, the curve shows that the initial load-deflection response is linear and elastic and almost identical to S1 (as expected), and this continued into a non-linear stage (at load about 2.5 kN/m^2). After the non-linear stage, the structures continues to sustain increasing load until a maximum load (at 3.4 kN/m^2) is achieved before the load dropped in value until ultimate failure of the sample as for S2.

It can be seen that, the maximum load for S3 is lower than maximum load for S2 even though S3 involved Prima*flex* and S2 involved Cemboard. In terms of stiffness value, S3 has the same stiffness value as S1 and should be higher than the stiffness value of S2. However, in the reversed position, the cross-sectional area of the profiled steel sheet subjected to compressive bending stresses is greater than the sample in the normal direction due to the varying position of the composite section's neutral axis. As the profiled steel sheet falls under the category of thin-walled section, under compressive stress, it is very susceptible to local buckling, and hence the lower maximum and ultimate loads for S3 detected in the experiment. However, it must be noted that Prima*flex* which is weak in tension did not show any sign of crack when the sample failed.

4.4 Effect of timber strips

Figure 7 shows the comparison of the flexural performance of the panel system using timber strips at both the side edges along the span line. The graphs were plotted based on the results obtained from S4 and S5. From the results, the sample with timber strips (S5) seems to perform relatively better than sample without timber strips (S4). As expected, the use of timber strips in the PSSDB roof panel will increase the stiffness of the panel. The experimental flexural stiffness values of the composite panels are shown in Table 4. The flexural stiffness of the panel without timber strip was found to be 57.6 kNm^2/m, whereas that for panels using timber strips was 78.2 kNm^2/m. Comparison of the stiffness values shows that there was a 35.8% increase in stiffness of the panel when timber strips are introduced. Therefore, for practical considerations, panel with the timber strips is recommended for the PSSDB roof panel.

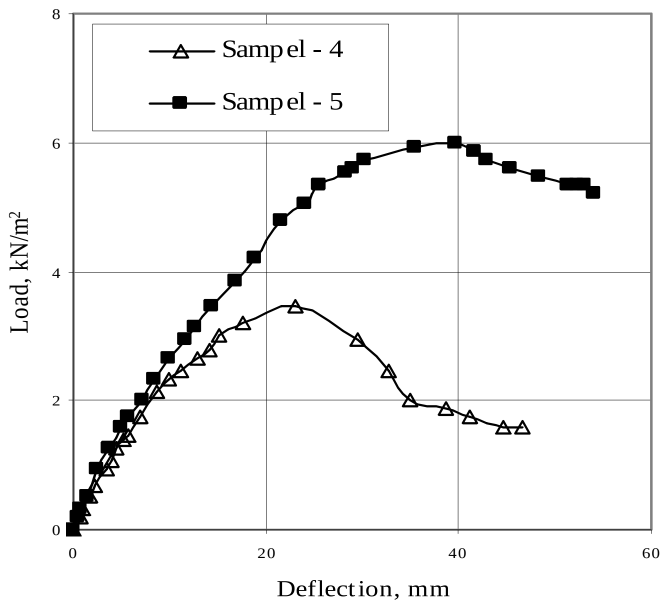


Figure 7. Load-deflection behaviour of PSSDB with timber strips

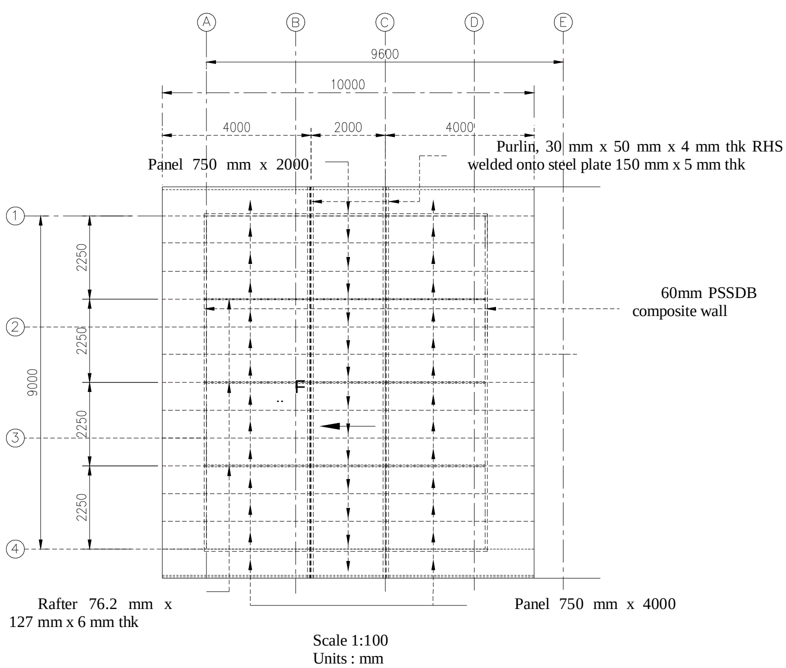
Table 4. Stiffness of composite panels with application of timber strips

Sample	Maximum load, (kN/m^2)	Deflection at maximum load (mm)	Flexural stiffness, EI (kNm^2/m)
S4	3.5	23.1	57.6
S5	6.0	39.7	78.2

5. PRACTICAL APPLICATIONS

The PSSDB roof panel system was commercially implemented for the first time in two (2) school classroom modules at Sekolah Kebangsaan Telok Mas, Melaka, Malaysia. The total area of the roof are approximately 105 m^2. The roof system was designed to cater for a dead load of 0.31 kN/m^2, and an imposed load of 0.25 kN/m^2. The system used consisted of two sizes of panel; 750 mm x 2000 mm (14 nos) and 750 mm x 4000 mm (28 nos). The individual panels are arranged side by side as shown in Figure 8(a). Panels without timber strip were used in this system even though it was proven that the stiffness of the panel with timber strips was higher compared to panel without timber strip. This is due to the higher cost involved in producing a small quantity of special timber strips needed.

Figure 8(a) shows the arrangement of the PSSDB roof panels on a plan view. The end panels (4 m long) were connected onto the front or back PSSDB wall at one end, and specially designed purlins (inverted T-shaped structural members – 30 mm x 50 mm x 4 mm RHS welded onto 150 mm x 5 mm thick mild steel plate) at another end. On the other hand, the interior panels (2 m long) were connected to the specially designed purlins at both ends. The purlins were placed and screwed onto mild steel rafters (76.2 mm x 120 mm x 6 mm RHS) and two side PSSDB walls, whilst the rafters span in between the front and back PSSDB walls. All connections were simple screwed connections. The panels were finally connected and covered by an additional top layer of profiled steel sheet which act as a cladding system. The rafters play an important role in transferring load from the purlins onto the load bearing PSSDB walls. The elevations of the school cabin are shown in Figure 8(b), (c) and (d).



(a) Roof plan

(b) Front elevation

(c) Side elevation

(d) Rear elevation

Figure 8. Plan and elevation of the school classroom module

5. CONCLUSIONS

This paper has described in detail the structural behaviour and experimental investigations of an innovative PSSDB roof panel system. Two different type of board have been considered in the study. Prima*flex*, a new material proposed for the panel system exhibits a good performance in resisting bending load can be concluded to be the better choice when compared to Cemboard to be used in the PSSDB system. It was shown that, Prima*flex* is very good in resisting bending load with an increased stiffness value of 21.1% when compared to the sample using Cemboard. It is also able to help prolong or delay the failure of the PSSDB system.

The stiffness value in the reversed position of the panel system is identical to the one in normal position. However, in the reversed position, the cross-sectional area of the profiled steel sheet subjected to compressive bending stresses is greater than the sample in the normal direction due to the varying position of the composite section's neutral axis. As the profiled steel sheet falls under the category of thin-walled section, under compressive stress, it is very susceptible to local buckling, and hence the lower maximum and ultimate loads for reversed panel detected in the experiment.

The timber strip plays a very important role in increasing the stiffness of the panel system. The application of the timber strip in the PSSDB roof panel system could increase the flexural stiffness of the composite PSSDB roof panel without timber strip 35.8 %. It can be concluded that the panel with timber strip does have great potential to be used in load bearing structural system.

The system has its own advantage for the building structure in that it can reduce the self-weight of the component of the structure. It is also for economical and environmental-friendly concerns. The major concern here is, by using this system it has significant advantages by removing the skeletal internal bracing of normal roof truss construction, thus reducing the cost.

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