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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Characterization of Bond-Slip Behaviour of the Profiled Steel Sheet Dry Board (PSSDB) Composite System

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DOI: https://doi.org/10.30880/ijie.2021.13.01.030
Received 25 July 2020; Accepted 29 December 2020; Available online 25 February 2021

Abstract: This paper presents an experimental study on the shear connector performance of the profiled steel sheet dry board (PSSDB) composite system through the push-out test. The load-slip curve can be obtained from the push-out test where the system reaches its failure point in which the stiffness value was determined. Ten push-out tests were carried out using different connector spacing ranging from 50–250mm. Two types of profiled steel sheets with a thickness of 1mm were used meanwhile, dry board with 16mm thickness were set as constant. From the result, it can be concluded that the connector spacing plays a major role in influencing the stiffness of the PSSDB system compared to the profiled steel sheet types. The selection of suitable connector spacing is essential in determining the shear performance of the specimen. The specimen with 50mm connector spacing has the highest maximum load, which indicates a high stiffness value. However, it is recommended that the spacing of 100-200mm are used to avoid accelerate failure and ultimately more practical and economical.

Keywords: Push-out tests, composite system, shear performance, bond-slip behaviour, connector stiffness

1. Introduction

Currently, Malaysia strives towards conventional construction system traditional concepts in which the application of the composite construction approach has widely used due to the advantages in terms of economy and sustainability [1]. The relatively new construction technology uses steel-concrete structures, especially in the flooring system, to get more attention in the construction approach. The profiled steel sheet and dry board (PSSDB) system are erected using profiled steel sheeting and attached to the dry board by using connectors. The development of the composite slab system with the combination of profiled steel sheet and dry board was introduced in the early research by Wright & Evans [2], Wright et al. [3], Badaruzzaman & Wright [4], Ahmed et al. [5,6], and Hamzah & Badaruzzaman [7] as shown in Fig. 1. After several years, the development of the PSSDB system made changes with the addition of concrete as an infill was conducted by Badaruzzaman et al. [8,9], Gandomkar et al. [10,11], and Seraji et al. [12].

Jaini et al. [13] mentioned that the strength of a composite system is ruled by the shear interaction between concrete and corrugated steel deck, instead of yielding the corrugated steel deck. The connection and interfacial characteristics of concrete and corrugated steel deck play a critical role in constructing the composite to prevent the composite system from slipping [1]. The efficient shear action can be achieved by providing frictional interlock through

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the shape of profiled steel sheeting, mechanical interlock by embossments on the sheet, end anchorage by studs on the profiled steel sheeting, and end anchorage by deformation of the ribs [14]. The failure mode is determined by composite actions which are dependent on the transmission of longitudinal shear bond stress due to pure bond, mechanical interlocking and friction, as well as several factors including material properties of concrete, geometry and thickness of steel sheeting, embossments slenderness ratio of the slab, loading arrangement and shear connectors [15-18].

In early research on the PSSDB system by Badaruzzaman et al. [19], an experimental and theoretical study was conducted using three different types of dry board: plywood, chip board, and cement board. From the push-out test, two primary failures are crushing the board in the connector area and connector shearing off at the base. From this study, it can be concluded that connector modulus and spacing play an essential role in system stiffness. Nordin et al. [20] also investigate the connection stiffness of the PSSDB with different dry board types. The result showed that the Peva-Cemboard has higher stiffness than the Peva-Plywood, which attributes to the brittle nature of the Cemboard. The failure modes observed consist of a combination of sheared screws, a profiled steel sheet tearing, and a crushing dry board.

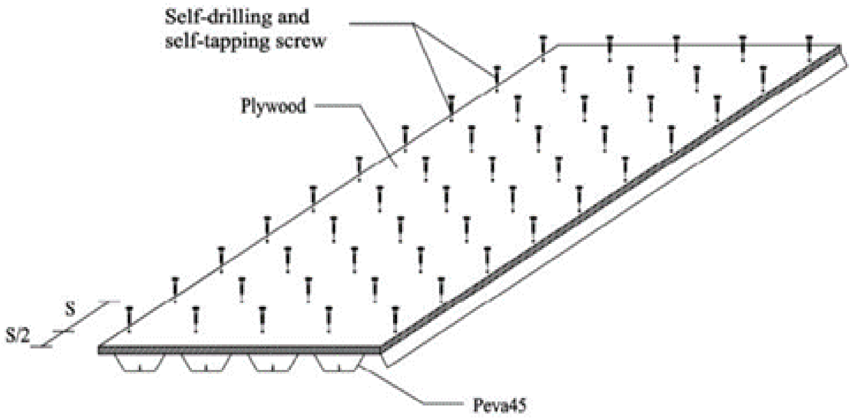


Fig. 1 - A typical of the PSSDB composite system [11]

Later that, Gandomkar et al. [10] performed a push-out test to determine the stiffness between profiled steel sheet Peva45 and concrete infill with various grades of C25, C30, and C35. Plywood that acts as covering was attached on the top of Peva45 by screw connectors. The results show that concrete grade C30 has higher stiffness compared to grade C25 by 10.3%. Meanwhile, concrete grade C35 able to increases stiffness by 8.2% higher than grade C30. Jaafar et al. [21,22] conducted the experimental and finite-element modeling study on the PSSDB system by introduced geopolymer concrete as infill. PSSDB with geopolymer concrete has higher stiffness than the PSSDB with normal concrete through a push-out test.

Rehman et al. [23] performed an experimental study on shear connectors with a profiled deck in shear capacity, stiffness, and ductility. The results showed that the shear capacity of demountable shear connectors with similar performance as-welded shear studs has fulfilled 6mm ductility by Eurocode 4. Mechanical connectors connected each of the elements used in the PSSDB composite system which the design depends on the shear transfer mechanism provided by the shear connectors [18]. Thus, it is important to perform study related to this issue. This study aimed to investigate the shear connectors performance of the composite PSSDB system. The result of the bond-slip behaviour curve and stiffness of the PSSDB system was obtained through the push-out test. From the result, an analysis of the modes of failure, the effect on connector spacing, and the effect on profiled steel sheet type was performed.

2. Experimental Study

2.1 Specimen Preparation

A total of ten specimens were prepared with different screw spacings and profiled steel sheet types. Table 1 shows the specimen details for the push-out test. The profiled steel sheet and dry board (PSSDB) composite system comprising of 1.0mm thick profiled steel sheet type Peva45 and Peva50, attached to the Primaflex dry board with a thickness of 16mm. The profiled steel sheet consisted of one corrugated part from the actual width of the steel sheets for Peva45 and Peva50. Self-drilling screws with a diameter of 4.2mm and 32mm length have been used to connect the profiled steel sheet to the dry board at various spacing ranges from 50 to 250mm in the longitudinal direction. The schematic diagram for the push-out specimen erected using Peva45 and Peva50 illustrated in Fig. 2 and Fig. 3, respectively.

Table 1 - Specimen details for push-out test

Group	Profiled steel sheet type	Specimen size (Length x width) mm	Spacing (mm)	Specimen code
G1	Peva45	232.5 x 550	50	P45-50
			100	P45-100
			150	P45-150
			200	P45-200
			250	P45-250
G2	Peva50	330 x 550	50	P50-50
			100	P50-100
			150	P50-150
			200	P50-200
			250	P50-250

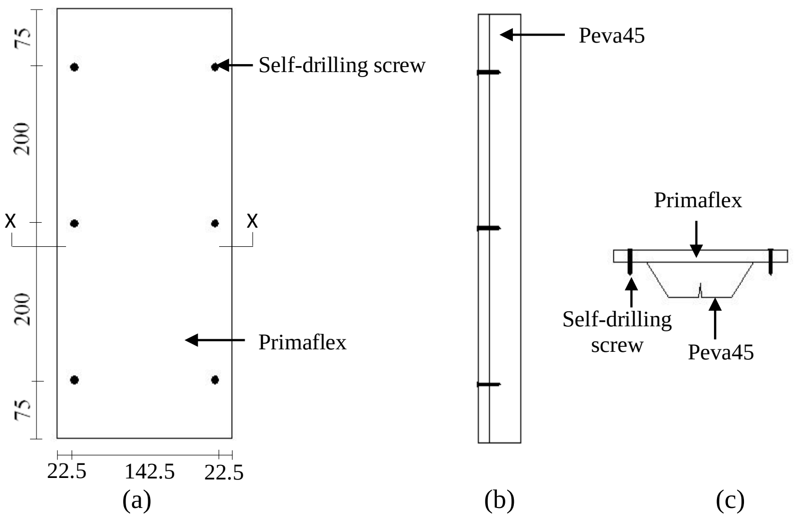


Fig. 2 - The schematic diagram for the push-out test using Peva45 (a) front view; (b) side view; (c) section X-X

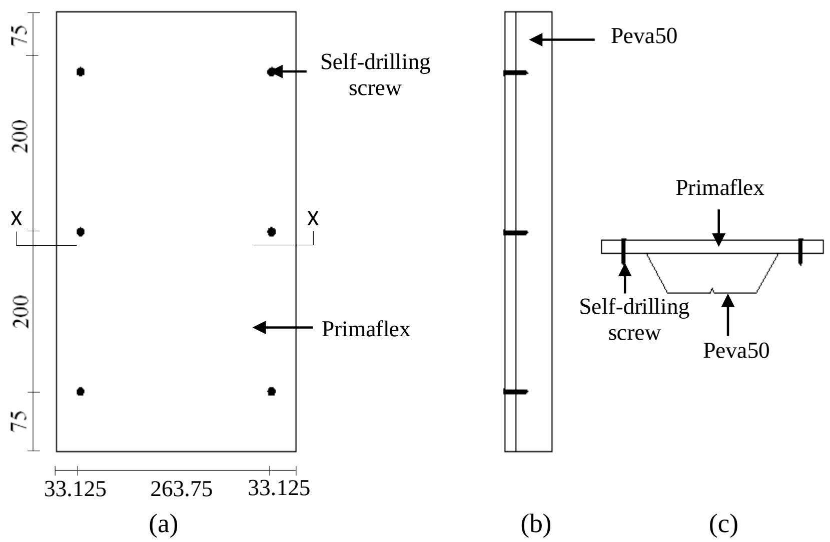


Fig. 3 - The schematic diagram for the push-out test using Peva50 (a) front view; (b) side view; (c) section X-X

2.2 Push-Out Test

The push-out test was carried out to determine the stiffness of the shear connector and infill material. The test comprised several samples, the main difference in the screw spacing and profiled steel sheet type. All samples were tested to failure using Universal Testing Machine (UTM) with a 1mm/min loading rate. The specimen was supported by a steel plate on a dry board surface meanwhile, the profiled steel sheet part was elevated. A steel plate with a thickness of 10mm was placed on top of the profiled steel sheet surface to ensure that the load is uniformly distributed, as shown in Fig. 4 and Fig. 5.

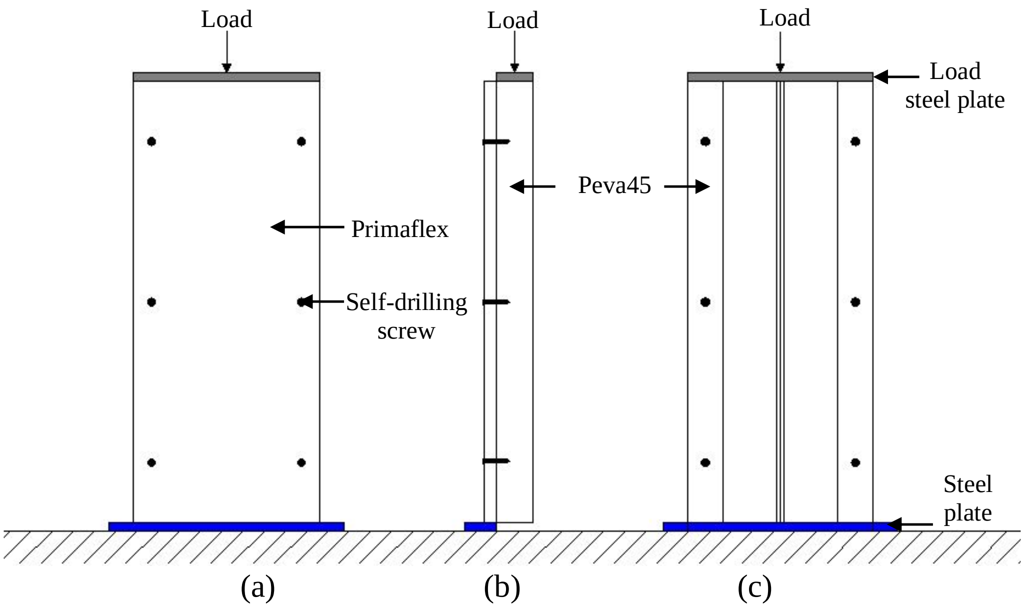


Fig. 4 - Typical setup diagram for push-out test (a) front view; (b) side view; (c) back view

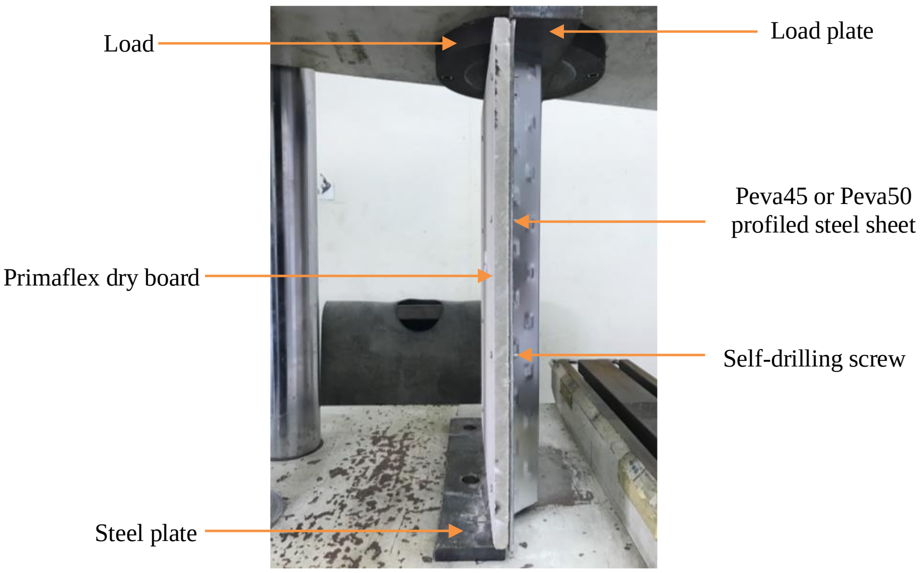
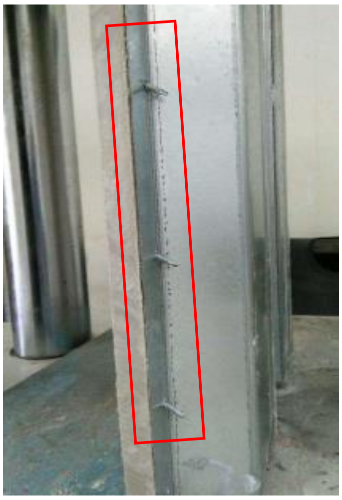


Fig. 5 - Push-out test on the shear connector

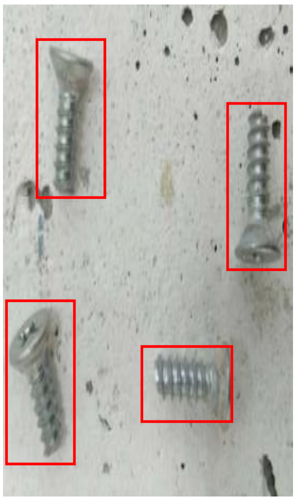
3. Experimental Results

3.1 Modes of Failure

Two main failure modes were observed in these tests for all ten specimens that occurred on the connectors and dry board. The first mode of failure is on the shear connectors. The connector specimens condition was slightly tilted or fractured after the test, as shown in Fig. 6. As the load increase until the connectors fail, it has reached its maximum limit then cause the connector to fracture. The connectors failure due to the buckling of the specimen cause splitting of the profiled steel sheet and dry board.



(a)



(b)

Fig. 6 - Shear connectors failure: (a) shear connector slightly titled from the origin; (b) shear connector fractured after the test

The second mode of failure is crushed on the dry board, which undergoes failure, especially on the surface layer as the connector was directly installed on the dry board. Considering the profiled steel sheet having higher strength than the dry board, this can explain why the dry board is affected by the shear connectors failure. Most of the specimens undergo circular shape crushed, especially around connectors, as shown in Fig. 7. When the excessive load was applied, the dry board can reach the cracked effect, which caused it to split into two.

(a)

(b)

Fig. 7 - Dry board failure: (a) crushed on dry board; (b) circular crushed on the dry board

3.2 Load-Slip Behaviour

The load-slip curves of all push-out specimens are presented in Fig. 8 and Fig. 9, respectively, for Peva45 and Peva50. The load-slip curves show that the curves have a plastic and elastic deformation where the curves are almost linear for all specimen in the elastic region however the slip change rapidly when it is in the plastic region. The connectors behaved similarly for a specimen with spacing 100, 150, 200, and 250 for both specimen groups. However, a specimen with a spacing of 50mm shows a different pattern of slip-curves. Generally, the curves have two parts; in the early stages, all curves show a linear relationship over the elastic range from zero and end up at maximum load. As the loading was continuously applied, the curves suddenly move to lower values from maximum until it reaches the failure level.

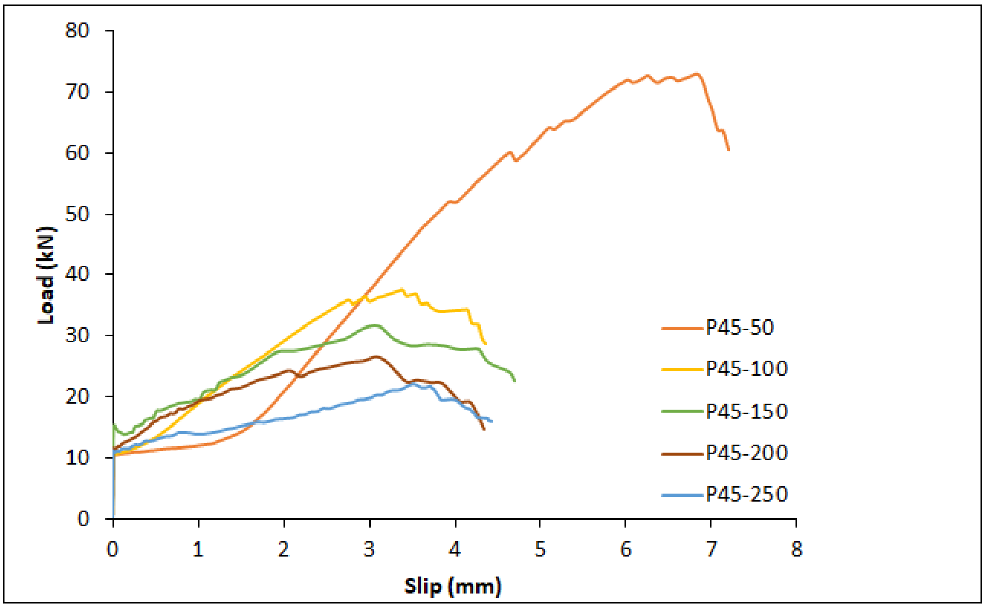


Fig. 8 - Load slip curves for specimen using Peva45

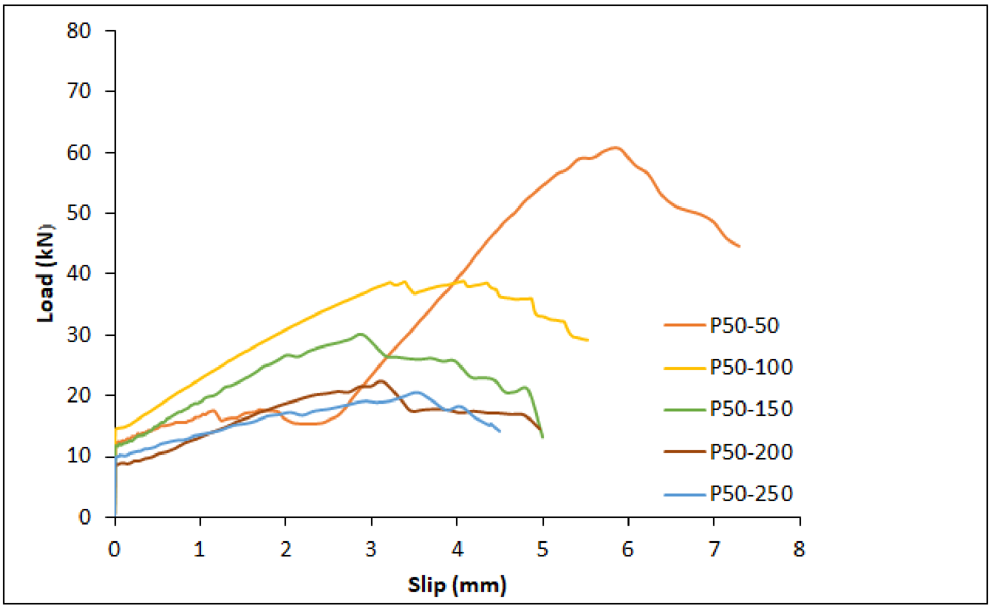


Fig. 9 - Load slip curves for specimen using Peva50

4. Discussion

The strength of the shear connector is the maximum load obtained from the test result. Meanwhile, the connector stiffness is determined from load slip curves using the initial slope of the load versus slip for each curve as suggested by Jaffar et al. [24]. Table 2 shows the stiffness result from the push-out test. From the result obtained, the typical load-slip curves by varying connectors spacing ranging from 50 to 250mm, the spacing, and profiled steel sheet type were studied. There are two types of profiles steel sheet used for this research which are Peva45 and Peva50, as shown in Fig. 9 and Fig. 10, respectively. The result obtained shows the differences in the maximum load that the specimen can support before reaching failure. It shows that 50mm connector spacing has the highest ability to resist maximum load for both specimen groups, which is for specimen P45-50 (72.02 kN) and P50-50 (60.77kN). Meanwhile, 250mm connector spacing has the lowest ability to resist maximum load for specimens P45-250 (21.5kN) and P50-250 (20.65kN). The closer spacing was providing higher stiffness values. However, the connector spacing of 50mm is considered unpractical and uneconomical [19]. Al-Shaikhli et al. [25] recommended keeping spacing as higher as possible to avoid the dry boards accelerated failure. The reduction of connector spacing eventually increases the interaction between the profiled steel sheet and dry board, enhancing the structural performance and stiffness of the PSSDB system.

However, the different types of profiled steel sheets slightly affect the shear connectorr performance from the result for both groups. By comparing the connector spacing to each specimen group, specimen erected using Peva50 has the highest stiffness value than specimen using Peva45. Specimen P50-50 has a higher stiffness value than specimen P45-50 by 13.36 %. Meanwhile, for other specimen using Peva50, the stiffness value is higher by 1.79 %, 10.76 %, 5.56 %, and 7.5 % than specimen using Peva45, respectively, for the spacing of 100, 150, 200, and 250 mm. The result shows that shear connector spacing has a significant effect on the maximum load and stiffness value compared to the profiled steel sheet type.

Table 2 - Stiffness result from push-out test

Group	Specimen code	Maximum load (kN)	Stiffness (kN/mm)	Stiffness per strip (kN/mm)
G1	P45-50	72.02	12.78	6.39
	P45-100	36.45	7.73	3.87
	P45-150	31.56	6.24	3.12
	P45-200	25.50	4.54	2.27
	P45-250	21.50	2.82	1.41
G2	P50-50	60.77	14.61	7.31
	P50-100	38.61	7.87	3.94
	P50-150	30.84	6.95	3.48
	P50-200	22.39	4.80	2.4
	P50-250	20.65	3.04	1.52

5. Conclusion

This paper has described in detail the shear connector performance of the PSSDB system. From the push-out test result, it has been shown that the spacing of the connector plays an important role in obtaining the maximum load and stiffness of each specimen. Spacing 50mm shows a higher maximum load and stiffness than the 100, 150, 200, and 250mm spacing. However, the recommended spacing value for the PSSDB system is ranging in between 100 and 200mm, which more practical and economical and can avoid the accelerated failure, especially on the dry board. The type of profiled steel sheet, either Peva45 or Peva50, slightly affects the specimens load-slip behaviour. The primary failure mode for the specimen is on the connector and the dry board. Since the profiled steel sheet has higher strength than the connector and dry board, it can withstand the maximum load.

Acknowledgement

The authors have gratefully acknowledged the financial support provided by Universti Tun Hussein Onn Malaysia through research grant Postgraduate Research Grant (GPPS) Vot. No. H294 and Research Fund E15501 by Research Management Center (RMC) UTHM.

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