Jurnal Kejuruteraan 35(6) 2023: 1455-1465
https://doi.org/10.17576/jkukm-2023-35(6)-18

Structural Performance Evaluation of Horizontally Light Reinforced Dapped for Vertical Wall-To-Wall Connection of Precast Wall Panel

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Received 13 April 2023, Received in revised form 6 May 2023
Accepted 6 June 2023, Available 30 November 2023

ABSTRACT

Precast concrete buildings in Industrialised Building Systems (IBS) are constructed of multiple pieces of structural members joined together using a variety of methods. The use of precast concrete wall panels has become increasingly popular in modern construction practices. One critical aspect of precast concrete wall panels is their connection to the adjacent walls. Various of wall-to-wall connections have been used in the IBS based construction. However, for non-load bearing application, the use of dapped connections for precast wall made with recycled concrete aggregate (RCA) is still limited and unexplored. This study aims to evaluate the structural performance of horizontally light reinforced dapped (HLRD) connections for precast wall panels made with RCA. The investigation includes experimental testing that includes three pair of specimens subjected to uniformly distributed monotonic loading to evaluate their strength capacity, strain, and deflection behaviour as well as the resulting crack propagation throughout the test. The connection displays brittle behaviour by developing a few line cracks and having a significant deflection before failure. The findings of this study will contribute to a better understanding of the behavior of HLRD connections and provide preliminary guidance for their design in precast concrete wall panels.

Keywords: Dapped connection; industrialised building system; precast wall panel; recycled concrete aggregate; Strength Compressive Test; uniform distributed load

INTRODUCTION

Industrialised Building System (IBS) or prefabrication is not a new idea in Malaysia's construction field, and it is widely regarded as an alternate strategy to replace conventional buildings to increase sustainable outputs. The term "Industrialised Building System" (IBS) was introduced in Malaysia to define the use of automation, mechanisation, and prefabrication of components in the construction sector. Since IBS components are manufactured off-site, they need little further site work once installed, resulting in shorter project completion times, more productivity, less waste, fewer accidents, and reduced overall costs (CIDB Malaysia 2016). In 1964, the government made the bold decision to try two pilot projects based on the IBS concept, the first of which was built on 22.7 acres of land along Jalan Pekeliling and consisted of the construction of 7 blocks of 17-story flats, 4 blocks of 4-story flats, 3,000 units of low-cost flats, and 40 storey shop lots by Gammon/Larsen Nielson as a contractor, using the Danish System of large panel industrialised prefabricated systems (Thanoon et al. 2003).

Industrialised Building Systems (IBS) are classified into five types which are precast concrete systems, steel formwork systems, steel framing systems, prefabricated timber framing systems, and block work systems. One of the common uses of precast concrete members in building construction is precast concrete walls. They are generally simple to construct, efficient, and long-lasting, and they are appropriate for low to medium-rise commercial and industrial projects (Vaghei et al. 2014). However, the design of connections is a critical concern in the construction of precast reinforced solid structures, particularly precast concrete walls. Along these lines, the connecting section should be designed to guarantee that strengths are effectively transferred between the precast wall panels, affecting the building's constructability, rigidity, quality, and flexibility (Karthikeyan et al. 2019).

In the previous decade, several types of wall-to-wall connections, such as loop connections, wire loops, and U-shape steel channels, have been developed for the building industry (Abdullah et al. 2019). Wet joints and dry joints are two types of precast component connections that are characterized by the technique of connection. Dry joints are constructed of steel plates that are bolted or welded together, whereas wet joints are formed of cast-in-place concrete, or grout poured between the precast panels (Rossley et al. 2014). Since these precast members are casted off-site, there are some problems occurred during the transportation of the panels to be erected on site due to the size and heavy weight (Blismas & Wakefield 2009). Additionally, the critical session during the launching of the panels tend to induce human or error due to low tolerance of connection interface between each panel (Jamil et al. 2012), hence will pose problem not only in instant while connecting, but also in the future of post-construction period where cracks and leaking might occur due to incorrect connection procedure (Jabar et al. 2013). Moreover, the expansive use of natural aggregates in producing the precast panels pose an environmental issue in depleting the natural resources of natural aggregates (Hamid 2006), which will then increase the future cost of the resource and directly affecting the construction cost (Shaban et al. 2019). Furthermore, no type of dapped connection is designed or used on precast wall panels. Since there has been minimal research on employing dapped as a vertical wall-to-wall connection, this type of connection acts as a gap.

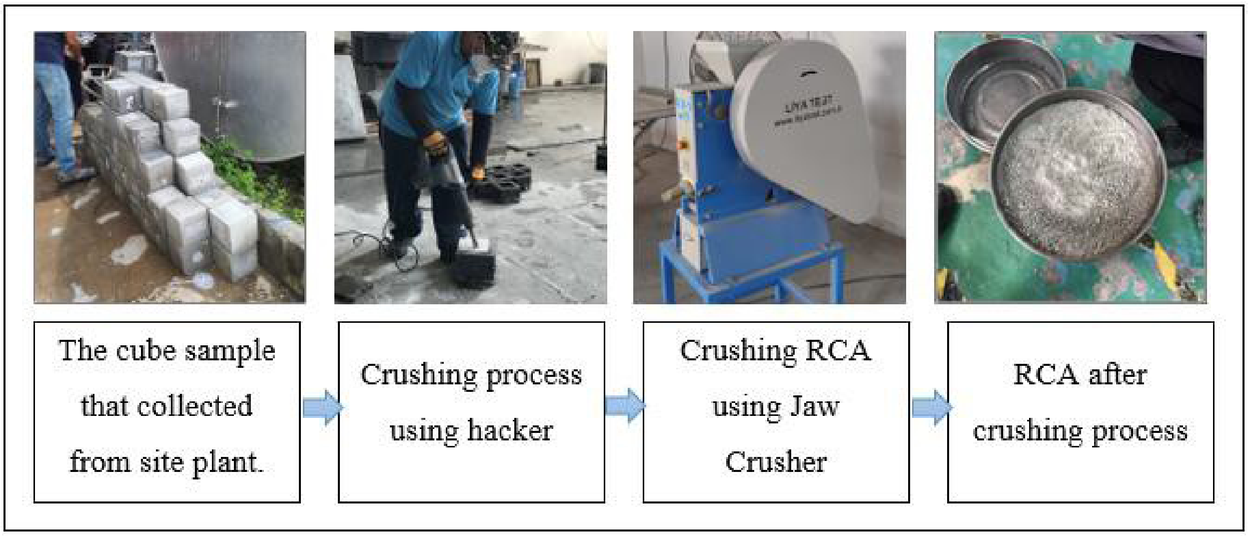

FIGURE 1. Processes of crushing concrete cube.

A precast concrete structure, as opposed to a cast-in-place reinforced concrete (RC) structure, is made up of individual elements combined with various sorts of connections, including dapped ends, which have previously been seen applied to beam-column connection interfaces. This research aims to evaluate the structural performance of horizontal reinforced dapped precast wall panel connections. Uniformly Distributed Load (UDL) tests will be used to determine the structural performance. Furthermore, natural aggregates in the concrete mortar mixture will be replaced with 50% recycled concrete aggregate. To achieve the above goals, the following objectives are outlined to propose new a vertical wall-to-wall connection for precast wall panels to increase the overall quality of the IBS wall and to evaluate the structural performance of a newly designed vertical wall-to-wall connection under Uniformly Distributed Load (UDL).

METHODOLOGY

MORTAR MIX DESIGN

Mortar is not as durable as concrete and is rarely used as the only building material. Rather, it is the "glue" that keeps bricks, concrete blocks, stone, and other construction materials together. Mortar mix design involves a preparation procedure in which a mixture of components produces the required strength and durability for mortar construction. Cement (OPC), sand, and RCA are all included in the mortar mix in the ratios of 2:2:1 and water.

RECYCLED CONCRETE AGGREGATE (RCA)

RCA was obtained by crushing the concrete aggregates cubes in the Heavy Structural Laboratory, UiTM Kampus Permatang Pauh, Pulau Pinang. The size of the waste concrete cube is 150 mm x 150 mm x 150 mm. The RCA was manually crushed using a hammer and hacker, then with a jaw crusher set to a maximum size of 5 mm, the RCA was further crushed. The final RCA product will then be sieved to a maximum size of 5 mm. These processes are shown in Figure 1.

SAND

Sand, which is fine aggregate, is one of the most important materials used in mortar preparation. Fine aggregate was supplied from the Faculty of Civil Engineering, UiTM Pulau Pinang's Structural Heavy Laboratory. The sand was collected and passed through a sieve with a maximum size of 4.75 mm. The sand was air-dried for 24 hours at room temperature. For 1.25×10^{-4} m^3 of 12 sample cubes, 1.5324 kg of sand were used and 183.858 kg for 0.03 m^3 of 6 sample walls.

ORDINARY PORTLAND CEMENT (OPC)

As a binder, OPC was the most commonly utilised material in this study. In this study, OPC was the type of cement utilised. The OPC percentages used in the samples are fixed throughout all samples, according to the mix design. For this study, 0.5746 kg of cement were used for 1.25×10^{-4} m^3 of 12 sample cubes and 68.947 kg for 0.03 m^3 of 6 sample walls.

WATER

Water is very important in concrete mixing if it is not sufficient, the mixture will be difficult to mix and will result in excessive voids in the concrete when it hardens. However, the mortar should not contain too much water and should be flexible and easy to use. Moreover, it will require less time for the mortar to compact and fill all the voids during casting. Previous trial mix of water-cement ratio 0.5 with 1% superplastisizer recorded zero workability. Hence this study will utilize a ratio of 0.75 with 1% SP. Since the water-cement ratio in this study was 0.75, 0.431 kg of water was used for 1.25×10^{-4} m^3 of 12 sample cubes and 52.71 kg for 0.03 m^3 of 6 sample walls.

SUPERPLASTISIZER (SP)

SP are high-range water reducers that are utilised in the preparation of high concrete. SP can cut water content by up to 30% while maintaining workability. Sika® ViscoCrete®-2192 as in Figure 2, a chloride-free superplasticizer that is suitable for all kinds of Portland cement, including Sulphate Resistant Cement (SRC), was used in this laboratory experiment. SP utilised in this study is 1% of the cement weight, with 5.746×10^{-3} kg of SP used for 1.25×10^{-4} m^3 of 12 sample cubes and 0.6894 kg used for 0.03 m3 of 6 sample walls.

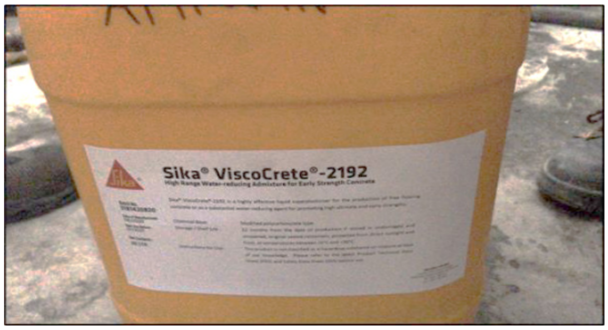

FIGURE 2. Sika® ViscoCrete®-2192

PREPARATION OF CONNECTION

The connection was used to join the wall-to-wall panel either on-site or at the manufacturer. Dapped connections were proposed as a new connection design for this study. However, horizontal light reinforcement was placed on the vertical wall-to-wall connection of the precast wall panel to strengthen the connection. R8 must be installed overhanging the top support from 1' x 2' timber placed on top of the mould. To make the dapped section, Styrofoam was cut into the size of 1000 mm x 300 mm x 100 mm and placed into the formwork before pouring the mortar to make the shape of the connection as shown in Figure 3.

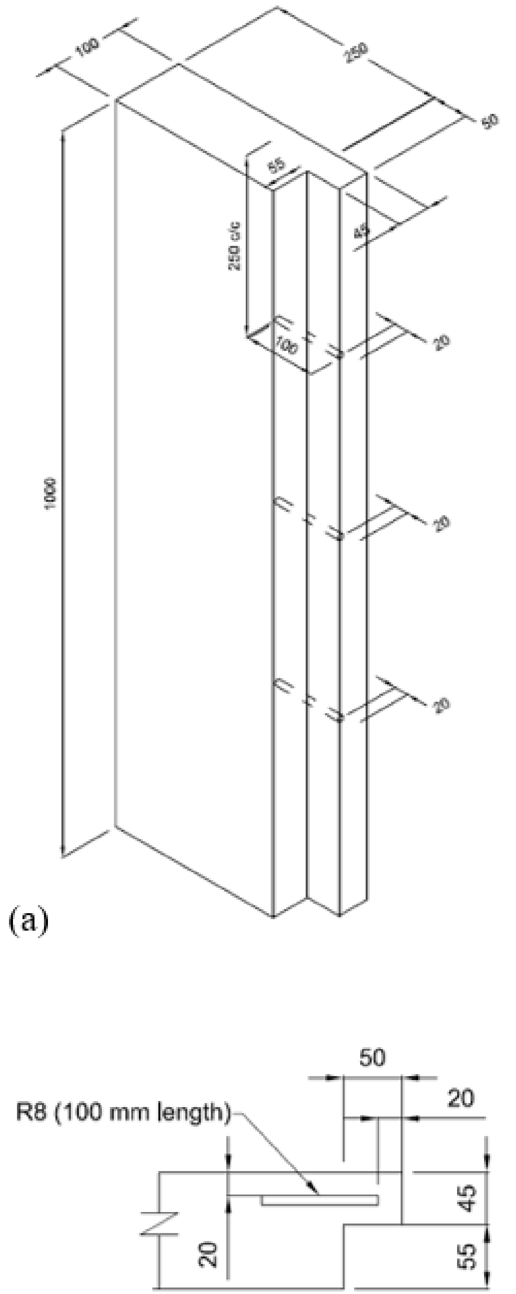

FIGURE 3. Typical view of HLRD connection for precast wall panel; (a) isometric view, (b) plan view.

MORTAR MIX

The mixing process can begin once the materials have been prepared. Since the weight of each material is very high, the materials are mixed using a concrete mixer. Instead of manually mixing the materials, concrete mixers allow users to mix huge volumes of cement, sand, or sand with water throughout a project without wasting workers' time or energy. allows them to mix materials quickly and efficiently while utilising little energy. For this research, a mortar including cement, RCA, and water was mixed in a concrete mixer.

FLOW TABLE TEST

The flow table test was conducted to identify the workability of concrete as well as the flow characteristics of the mortar mix. Before the test, dampen mould and plate of flow table apparatus shown if Figure 4. The mould was then filled with mortar mix in three layers, tamping each layer 25 times. The mould lifted vertically after tamping. After then, the table was lifted and lowered 15 times. The diameter of the mortar mix spread was observed (ASTM 2001).

FIGURE 4. Automatic Flow Table Test

CUBE SAMPLES

Twelve moulds of cube specimens with the size of 50mm x 50mm x 50mm are prepared. After the mortar has hardened, the curing process will begin. Curing is a method of achieving the required qualities of samples by keeping a sufficient moisture content and temperature for them for a period following placement and finishing. The hardened cube is placed in a water bath to cure for 3, 7, 14, and 28 days before the compression test.

WALL SAMPLES

Six wall samples with HLRD connection were casted to form three pairs of connected sample as in Figure 5 (a) and Figure 5 (b). A control sample with normal dapped without RCA replacement and R8 steel bars was also casted in the same way. It is necessary to properly maintain the moisture and temperature of the wall sample during curing to ensure and control quality. Since it is periodically wetted, the covering over vertical and sloping surfaces was properly secured as in Figure 5(b). The interval of wetting is determined by the rate of water evaporation. It ensured that the concrete surface was not allowed to dry even for a short length of time throughout the curing process. This curing process is intended to keep water in the concrete during the early hardening period, reduce water loss from the concrete's surface, and enhance concrete strength gain by raising the temperature and more moisture. On day 14, the wall samples were joined together with sika grout as a bonding agent. After being fastened to the platform, the wall continued air drying indoors for another 14 days. On the 28th, wall samples were ready for testing and were launched on the UTM for the testing phase.

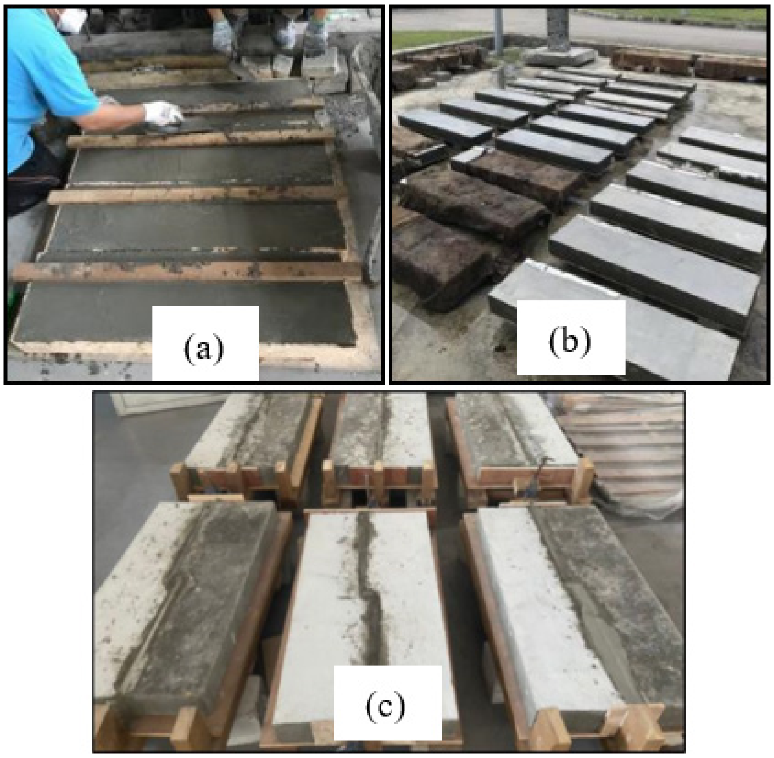

FIGURE 5. Wall samples. (a) Casting, (b) Curing, (c) Grouting for connection

COMPRESSION TEST OF CUBE SAMPLES

Following the completion of the curing process, the sample cubes are removed from the curing tank and dried in the sun or with a fan. The cubes were subjected to a compression strength test to assess characteristics such as product type and mortar quality. These samples were examined using a compression machine 3, 7, 14, and 28 days after curing. The compressive strength test was conducted at the Faculty of Civil Engineering (FKA), UiTM Kampus Permatang Pauh, Pulau Pinang.

UNIFORMLY DISTRIBUTED LOADING (UDL) COMPRESSION TEST

Uniformly Distributed Load (UDL) testing on walls is conducted using a Universal Testing Machine in accordance with BS EN 13523-7:2001. The acquisition system and power supply were linked for the initial readings once the wall was set on the measuring platform. The testing machine had undergone calibration and was being used in displacement control mode with constant displacement rates of 0.1 mm/min. In order to measure the deflection, Linear Variable Deflection Transformer (LVDT) were placed at LV1 and LV2 located 240 mm and 490 mm from the top, and strain gauges labeled as SG1 and SG2 that measure force or strain were glued to the specimen at 250 mm and 500 mm also from the top of the wall. White paint was used to paint the wall's front, and a grid was drawn to assist in measuring the deformation. Readied sample was shown in Figure 6.

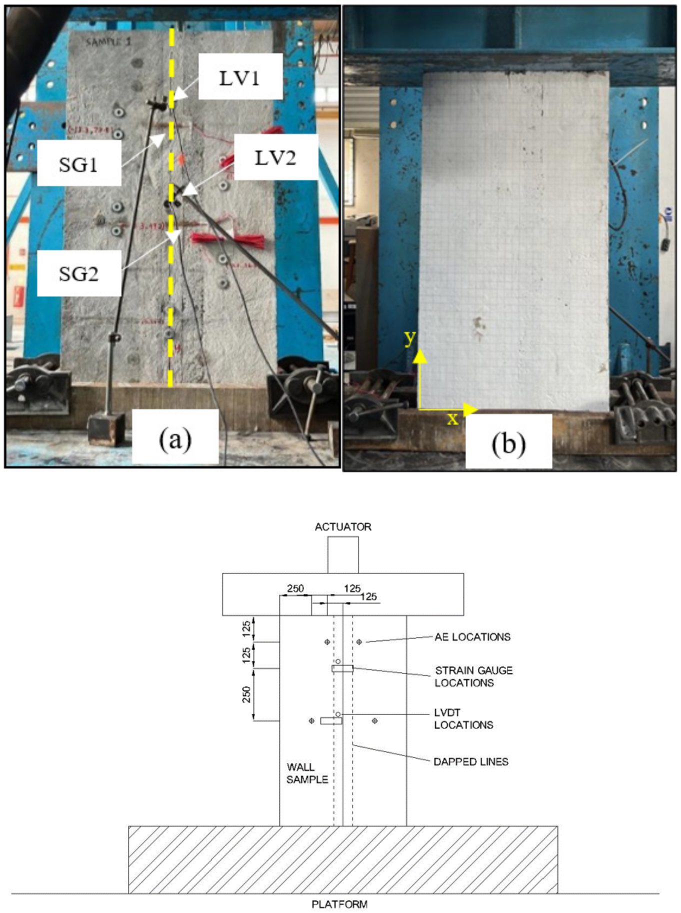

FIGURE 6. Sample Arrangement for UDL Test; (a) sensors location, (b) grid surface and X-Y axes, (c) schematic diagram of the arrangements.

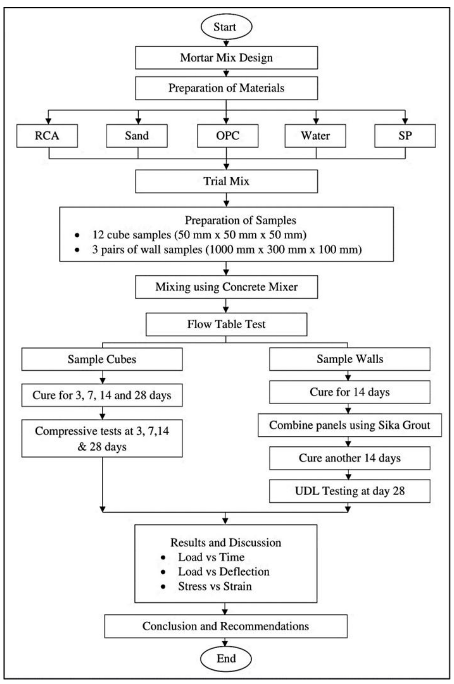

FIGURE 7. Methodology flow chart

The methodologies of this study have been summarized in flow chart shown in Figure 7.

RESULTS AND DISCUSSION

COMPRESSIVE STRENGTH OF SAMPLE CUBES AGAINST AGE (DAYS)

A compressive strength test was performed on 50mm x 50mm x 50mm cube samples that had been immersed in a water bath to cure for 3, 7, 14, and 28 days to analyse specific characteristics such as product type and mortar quality. The higher compressive strength is at 28 days which is 14.39 MPa since it is expected to reach 99% of strength by 28 days as shown in Figure 8. The compressive stress result is acceptable for mortar cubes because it is still within the typical concrete range.

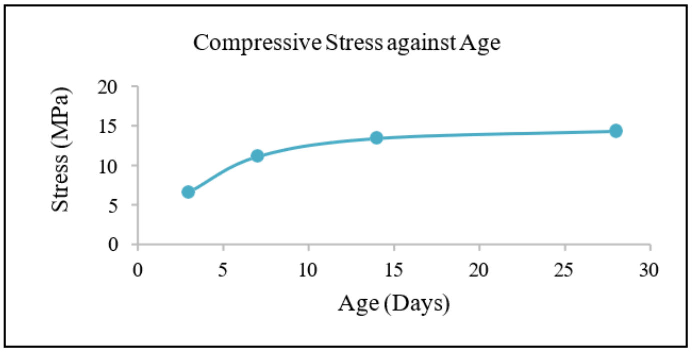

FIGURE 8. Graph of Compressive Strength versus Age (Days) of Mortar

STRESS VS. VERTICAL STRAIN ANALYSIS

The wall connection HLRD samples failed at an average of 5.4 MPa, while the control wall sample failed at 3.9 MPa as shown in Figure 9. Since the materials utilised for the wall sample were common mortar, which is a mixture of water, sand, and cement, as well as no R8 bars, it was expected that the control wall sample would break more quickly. Additionally, the wall connection HLRD sample have three horizontal reinforcement bars with a diameter of 8 mm that act as a light reinforcement for strengthening the dapped area along the X-axis of the panel. The compressive stress capacity of the wall connection HLRD sample was significantly greater than the control wall sample. Point A and B in both Figure 9 and Figure 10 indicate yield point of both control and HLRD sample respectively, which shows HLRD exhibit a plastic behaviour later compared to control sample.

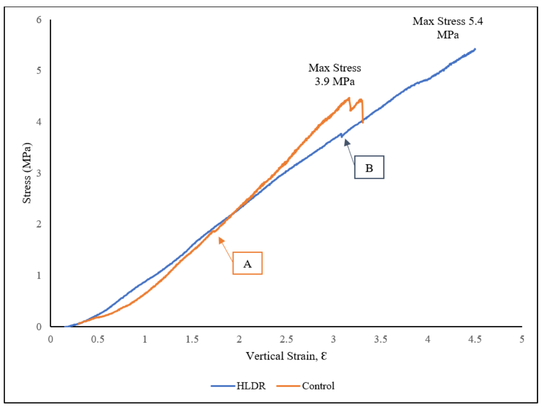

FIGURE 9. Graph of Stress Against Vertical Strain for Wall Connection HLRD and Control

LOAD VS. HORIZONTAL DEFLECTION FOR WALL SAMPLE

LVDT 1 which placed 240 mm from the top of the wall surfaces had a larger deflection than LVDT 2 which placed 490 mm from the top in the middle of the wall samples, for both types. This behaviour corresponds to the theory of effective length of structural members where one end was fixed, and the other end was free, same as the configuration used in this test setup as in Figure 6 (c). However, LVDT 1 (240 mm) and LVDT 2 (490 mm) both observed maximum horizontal deflection on the wall connection HLRD sample at 7.89 mm and 5.19 mm at 5.4 MPa, respectively as shown in Figure 11. The horizontal deflection measured by LVDTs 1 (240 mm) and 2 (490 mm) for the control wall sample was 10.26 mm and 8.77 mm, respectively, at 3.9 MPa as shown in Figure 12. This indicates that the control wall sample are having more deflection horizontally across the dapped connection interface. This was also shown in Figure 11 as stress were taken at 3.9 MPa, HLRD sample gives only 7.69 mm and 5.00 mm for LVDT 1 and LVDT 2 respectively, compared to Control which gives 10.26 mm and 8.77 mm for LVDT 1 and LVDT 2 respectively. This would occur due to the existing of light reinforcement bars along the dapped interfaces which would resist the horizontal deflection compared to control sample with no reinforcement.

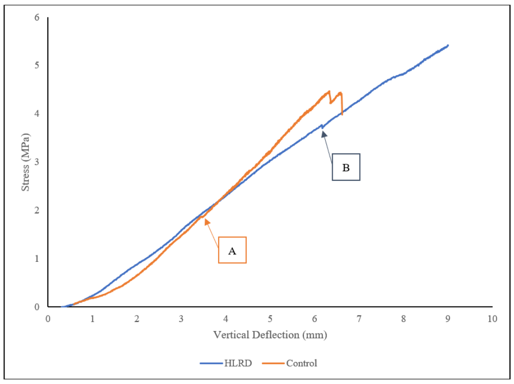

FIGURE 10. Graph of Stress Against Vertical Deflection for Wall Connection HLRD and Control

STRESS-STRAIN DIAGRAM OF SAMPLES

Strain gauges were attached to the specimen and glued at a distance of 250 mm and 500 mm from the top of the wall surfaces in order to quantify strain. The load-carrying capacity of the walls increased both at first crack and failure. SG 1, which is 250 mm from the top of the wall samples, has a higher strain value than SG 2, which is 500 mm. SG 1 was expected to have a larger strain value since the strain was measured in the grouting area that connects the two wall panels. The maximum strain value for SG 1 for the wall connection HLRD sample is 5215, SG 2 is 54 at stress 5.4 MPa, while the maximum strain value for SG 1 for the control wall panel is 181, SG 2 is 15 at stress 3.9 MPa, as shown in Figure 13 and Figure 14 respectively.

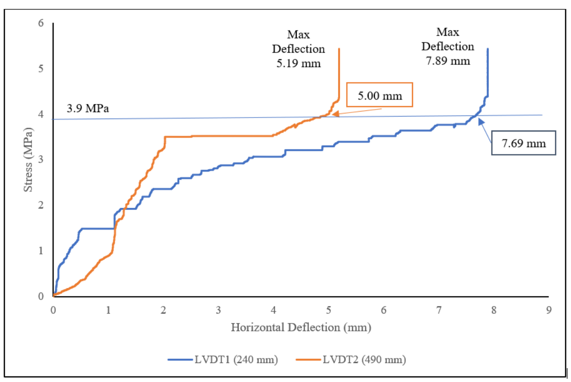

FIGURE 11. Graph of Stress Against Horizontal Deflection of HLRD Samples.

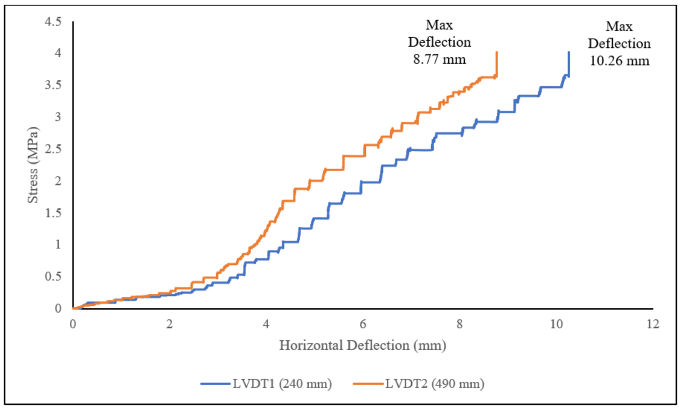

FIGURE 12. Graph of Stress Against Horizontal Deflection of Control Sample.

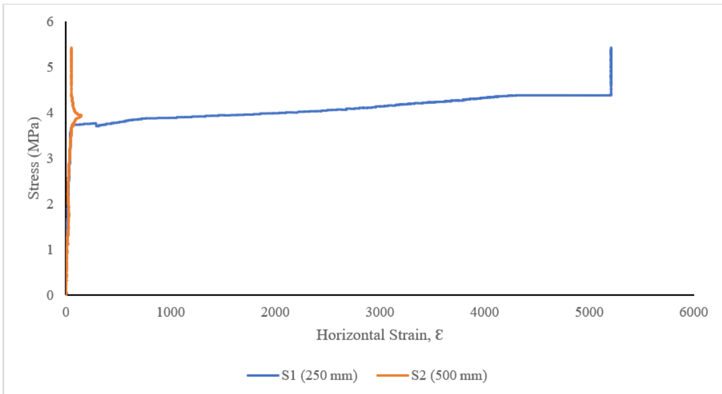

FIGURE 13. Graph of Stress-Strain for HLRD Sample

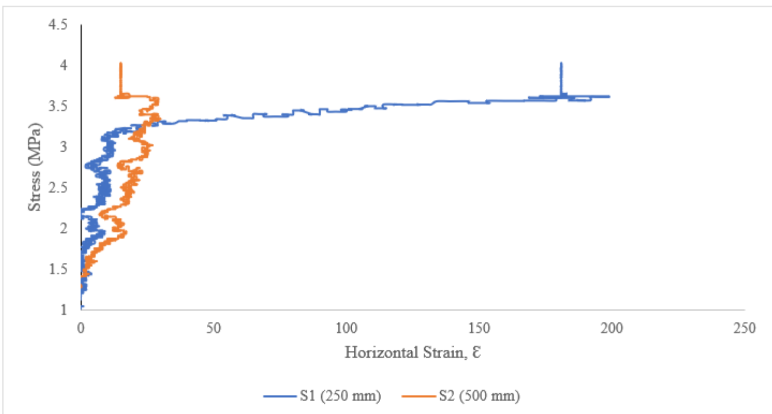

FIGURE 14. Graph of Stress-Strain for Control Sample

CRACK PATTERNS FROM VISUAL INSPECTION

According to the visual inspection, multiple vertical cracks appear on the wall samples after a load is imposed on top of the wall samples. Vertical cracks may signify the failure of structural components such as walls and hence reveal considerable strains inside the building structure. The biggest crack occurs in the middle of the wall sample, where the grouting area connects the two wall panels. The size of the crack was measured by using a crack detention microscope and it measured 0.19 mm. However, cracks also appear on another side of the wall samples which measured 0.2 mm. It was expected to appear because the area is the weakest in comparison to the others. The first crack occurred at 3680s since the load drop, and it reached failure on 5369.6s at 303.11 kN.

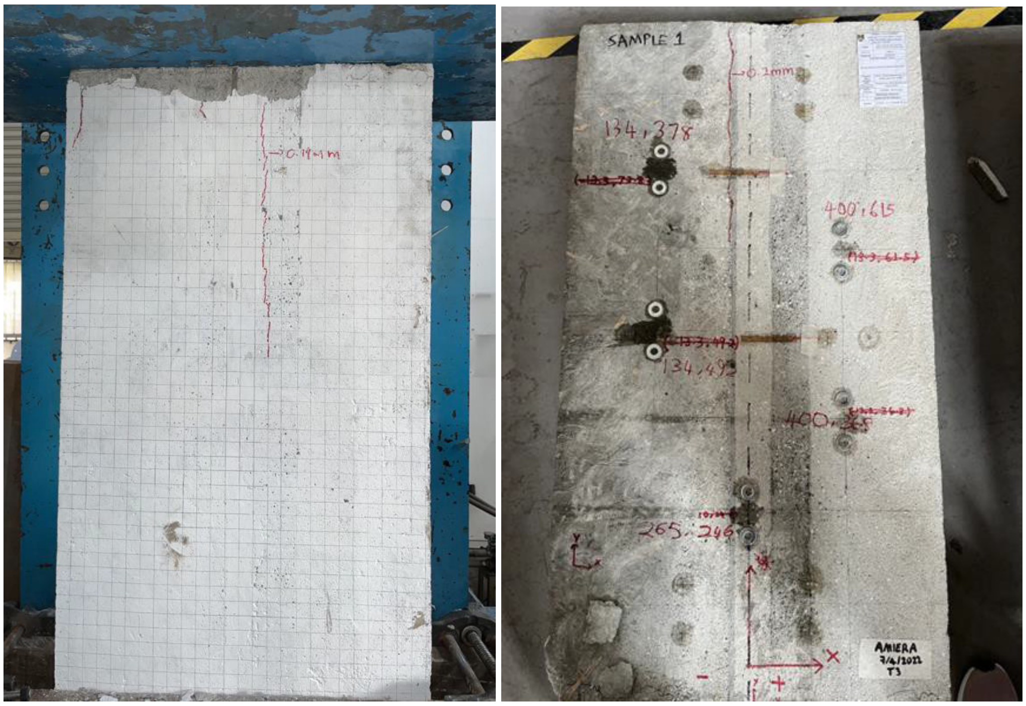

FIGURE 12. Crack Pattern Identified on the Surface of Wall Sample

CONCLUSION

To summarise the experiment performed on a wall sample to evaluate the structural performance of a newly designed vertical wall-to-wall connection under Uniformly Distributed Load (UDL) that is Horizontally Light Reinforced Dapped, the results demonstrate that the design can be used in future construction for non-load bearing internal wall in replacing the traditional brick and mortars which the latter would take more time in terms of wall construction on site. The overall behaviour of HLRD samples shows significant increment in terms of maximum compression stress capacity, as well as its capacity in resisting both vertical and horizontal deflection, when compared to control sample. It has met the acceptable condition since its performance is superior to the control wall sample. These findings will serves as fundamentals in further enhancing these types of pre-cast wall panels to be used as a non-load bearing internal walls in replacing the traditional brick and mortar and aim to have a better constructability towards IBS implementation in the construction industry, while using RCA as a more sustainable resources in reducing negative impact towards natural resources.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to Universiti Teknologi MARA, Cawangan Pulau Pinang (100-TNCPI/PRI 16/6/2 (022/2021) and Pusat Kecemerlangan Kejuruteraan dan Teknologi JKR (CREaTE) (grant no JAR 2001) for providing financial support to this research.

DECLARATION OF COMPETING INTEREST

None

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