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RESEARCH NOTE

Structural and Functional Analysis of an Industrial, Flexible, and Demountable Wall Panel System

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ABSTRACT

Building waste is a critical issue in current construction. Innovative design strategies are required to reduce the depletion of valuable materials and resources through providing flexible and versatile structures. This study focuses on the development of an industrial, flexible, and demountable wall panel construction system. The panel system consists of concrete blocks with steel connectors that can be simply assembled and disassembled onsite. This work experimentally investigates the structural response of panels under compressive load. After testing the stability and load-bearing capacity of the designed panels, the construction stage of the walls indicated satisfactory performance with predictable behavior within the installation process. During the experiment, displacement and strain were determined using linear variable differential transducers and strain gauges. Careful visual examination was also performed to observe the formation of cracks in panels. Although the architectural panels were not designed to resist the structural load, results in terms of load-deflection, strain distribution, and crack patterns signify that the panels' response to the compressive load is satisfactory.

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1. INTRODUCTION

In current construction, sustainable criteria are commonly considered during the early stages of a building's life; however, sustainable maintenance and demolition are often neglected [1]. To support the sustainable criteria, design concepts must be introduced that consider the building as part of the environment, enabling it to supply nourishment for other new products even after the functional life of the building [2]. Industrialized building systems (IBS) have emerged worldwide as a solution to improve construction image and performance [3, 4]. The method facilitates cost saving and quality improvement through construction standardization and reduced labor intensity. In addition, IBS offers minimal wastage, fewer site materials, and a cleaner environment. Although industrialization improves construction performance, certain issues persist, such as the designer's lack of awareness of the client needs, higher initial construction cost, inflexible design, an extended amount of time required for initial design development, limited space on the site, leakage problems, minimal contractor experience, and monotony in aesthetic issues [5-9]. As a result, IBS is often misinterpreted as a high-risk process that does not bring benefits to building owners.

The industry has attempted to offer more profitable and satisfying design solutions by fulfilling the parameters of affordability, comfort, and adaptability. Industrial, flexible, and demountable systems (IFD) enable simple adaptation of buildings while reducing resource depletion and construction costs [10-13].To achieve balance between the efficient use of materials, changing user demands and decreasing life cycle costs, industrially produced standardized building components are developed. IFD is a three-pronged strategy that improves the building process to achieve: (1) maximum flexibility for the users, (2) industrial production to increase quality and reduce materials, costs and time, and (3) the demountability of components that enable the separate replacement of components with various life spans, thereby extending the life of the building as a whole and decreasing waste [14]. This trend supports the key concept of sustainability, because the produced

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building is easily adapted, reprocessed, reused,or recycled [15-18].

Integrating the IFD characteristics with the application of IBS alleviates existing issues on design changeability, time management, and monotony. This research, therefore, proposes an applicable IBS system to improve adaptability in construction. The paper experimentally and theoretically investigates the strength behavior of the proposed panel system, which has been designed for low-rise residential buildings.

2. LAYOUT DESIGN

A two-storey terrace house was considered as the prototype unit. A structural system based on precast columns with concrete stabilizing walls was chosen, which was built upon an in-situ constructed basement. One of the positive effects of such a system is the flexibility it possesses. In using bearing concrete outer walls, the location of the openings must be carefully calculated for each element. Meanwhile, a system with precast columns gives the designer greater freedom to place openings in the outer walls, because only the columns are supporting the vertical loads. However, the panels between the columns can be replaced while the building is still in use, which is a difficult process with load-bearing concrete walls.

Except for the proposed panels, the other structural elements of the designed unit are selected according to the standards available in the "Modular Design Guide" and the components available in the IBS catalog booklet (Ministry of Housing and Local Government Malaysia, 2009). The constructability of the walls using the panels is an important factor that must be considered in the development of the panels. Given that the main walls in the front and rear façade are considered non-load bearing, the main requirements for the interlocking panels must include stability and the ability to distribute the weight load to the beams and columns.

The structural design of the proposed layout was analyzed using ETABS2000 (Version 9.0.4) software. The internal forces were extracted and applied for the design. The sections and structural elements were checked according to the UBC97 Code (Figure 1). Subsequently, the capacity and applied stress for each column were compared. The results indicate that the non-load bearing concrete panels can be applied in the double building following the structural capability of the beams and columns.

3. CHOICE OF PANEL CONFIGURATION

The panel system is essential to the entire concept. To achieve a flexible and adaptable panel system, a number of panel models were configured along with their interlocking mechanisms (Table 1). The major design consideration being that the panels could be assembled and disassembled easily while the air-tightness is being fulfilled. The dimensions of the panel (600 L × 100 W × 400 H) mm follow modular design rules, which require a horizontal controlling dimension of 3 M or 300 mm, and a vertical dimension of 1 M or 100 mm. Accordingly, other spaces in the house are also in conformity with modular dimensions, thereby encouraging the application of other modularly coordinated components, such as doors and windows. After a primitive analysis of the proposed designs, alternative 5 was considered as the final design choice to achieve the objectives of easy production and constructability in addition to satisfying the modular coordination requirements.

The interlocking mechanism was designed to obviate the need for formworks, thereby speeding up the construction process. Meanwhile, the monotony of appearance is another common issue in the application of prefabricated concrete panels [19]. The simplest wall configuration is a straight and right-angled wall that forms a rectangular room or yard boundary. Whenever more complex wall configurations are required, special patterns should be prepared to fit the proposed wall configuration.

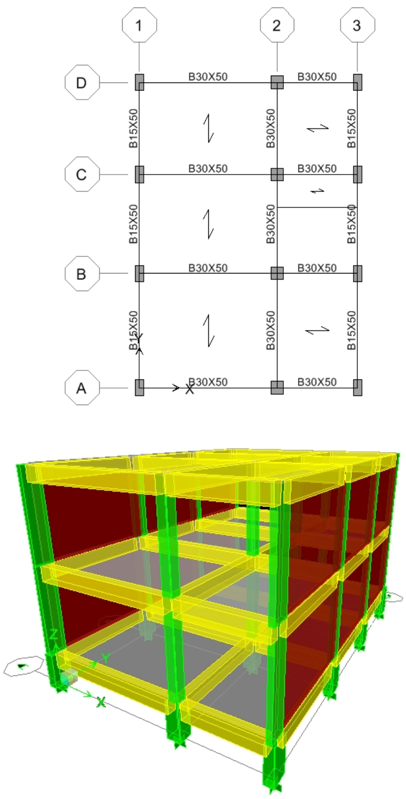


Figure 1. Frame elements section scheme in the first floor and general 3D view of the model

The application of the proposed panel block in a house can break the monotony of the wall appearance, thus improving the building's aesthetic appeal following smaller size and adjustability. Moreover, the applied mortar-less technique results in changeable elements that create the following advantages: increase of construction productivity [20, 21] as well as reduction in construction duration, labor cost [22, 23], and construction cost.

TABLE 1. Alternatives of interlocking panels, proposed in this study

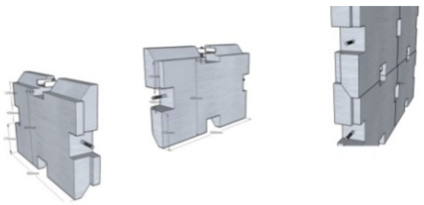
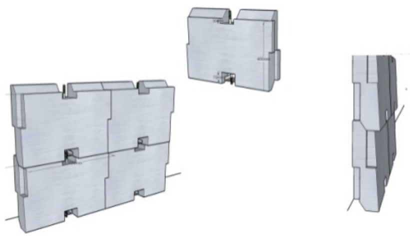
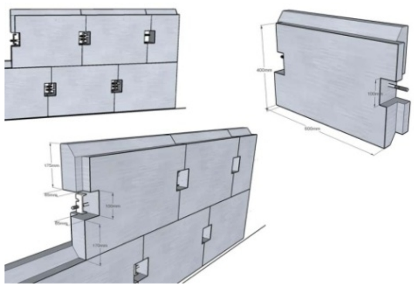
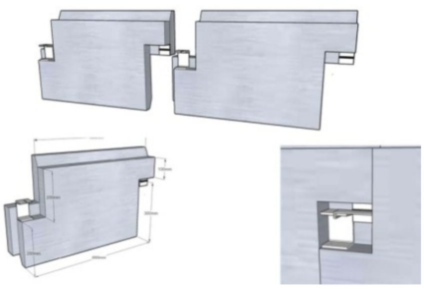
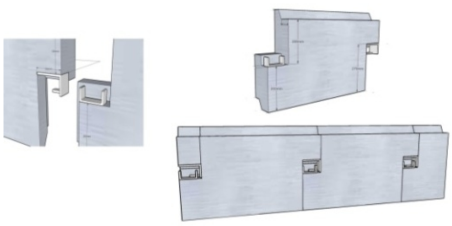
	Alternatives Dimension: (600L x 100W x 400H) mm	Advantages	Disadvantages
1		• Sufficient interlocking mechanism in four directions	• Requires complicated moulds for fabrication • Bolt and nut connections reduce the speed of installation and uninstalling process
2		• Sufficient interlocking mechanism in four directions • Slanting shape of the panel for reducing the water penetration • The interlocking mechanism replaced the connections in two sides	• Requires complicated moulds for fabrication • Bolt and nut connections reduce the speed of installation and uninstalling process
3		• Simple shape of the moulds for fabrication • The interlocking mechanism replaced the connections in two sides • Excluding the two end quarters with half panels	• Bolt and nut connections reduce the speed of installation and uninstalling process
4		• Sufficient interlocking mechanism • Simple shape of the moulds for fabrication • Easy installation process • Connections are concealed in one side of the panels' surface	• Three parts of the connection might not be easily adjusted during the installation
5		• Simple shape of the moulds • The connections are embedded inside the panels and extra connector is not required • Concealed connections • Sufficient interlocking mechanism	• Alignment of the panels have a close relation with the smoothness of the surfaces

TABLE 2. Definition of IFD characteristics for the panel system

IFD criteria	Design characteristics
Industrial	
Standardized parts	The entire layout consists of subparts that are manufactured in series. However, the small size of the panels prevents uniformity of design and introduces potential problems in component standardization.
Modular system	All the dimensions follow the modular system coordination.
Simple assembly protocol	The panels can be assembled on site via simple procedures and lightweight equipment. The installation process is less labor-intensive following the application of easy-dry connections
Able to reduce waste	The exact number of panels required for a specified design can be ascertained from the blue prints. Therefore, little waste is produced during manufacturing and onsite assembly.
Changeable	Standard components can be changed during the service life following the dry connecting system.
Increased regularity in system and materials	Few panel types are required for different installation locations in the modular house layout.
Flexible	
Freedom of design	The small and changeable parts provide free and adaptable design.
Adaptable during assembly	The panel assembly does not depend on strict planning; and changing panels does not require special skills.
Changing of layout	The modular layout can be changed with minimal disturbance to other parts of the building. The new and changing parts simply need to follow the modular design rules.
Layout freedom	There are open and free interior spaces for future modifications.
Adjustability of building parts	Bearing structure: prefab elements have limited adjustability Outer shell: dry connections allow practically adjustable installation Interior finishing: caulking and sealing is conducted before painting; it is not adjustable but weak enough to be dismantled in the future
Separation of the structural and infill elements	The non-load bearing panels are separated from structural beams and columns.
Optimal use of interior space for maximum resource application	The thickness of the panels (100 mm) provides wider space for interior optimization compared with conventional brick walls (150 mm)
Demountable	
Reusable from other buildings	The panels can be used in other modular buildings without alteration.
Dry connections	The main interfaces in the layout are the mechanical connections.
Demounting without waste	The mortar-less construction allows the future separation of the components without structural destruction.
Reuse of materials	Although reusing the building components is the best scenario for reducing waste, the concrete may also be reused as recycled concrete aggregate and recycled concrete fines, among others.
Reuse of building parts	The panels of one building can be reused in the other buildings.

4. THEORETICAL ANALYSIS

Few existing modern buildings have been deliberately designed for flexibility; thus, it is difficult to assess their flexibility over time [24]. After designing the prototype panels, theoretical analysis was applied to discuss the technical criteria for the IFD design and the productive application of the components.

The technical requirements of IFD building design parameters have been identified by different researchers [15, 25-39]. Three main categories have been considered for analysis as: industrial properties, flexibility, and demountability criteria. It has been tried to explain the characteristics of the design components according to the presented criteria under each category. Fulfilling all the suggested criteria may not be possible, but the proposed innovative designs have attempted to improve the prominent parameters. Table 2 details the theoretical evaluation of the suggested prototype panel according to the IFD design criteria.

5. EXPERIMENTAL ANALYSIS

Experimental analysis was applied to test the alignment and load-bearing capacity of the designed prototype panel. The process of preparation and testing are described in the sections below.

5. 1. Fabrication and Casting In this study, mortar was used instead of concrete to maximize the amount of paste in the mix and avoid further complications from other variables involving different types of coarse aggregate. The materials used for the panel production were ordinary Portland cement, clean water, and fine aggregate. A few samples were taken during the casting and stored under the same conditions as the panels and tested at approximately the same time. The material properties of the mortar were tested in the laboratory. These properties are detailed in Table 3.

Steel mold inserts were utilized for casting the panels. After the designing process, these inserts were fabricated in a workshop for the following components: stretched panels, half panels, corner blocks, and first-last row panels. Each mold consisted of seven movable parts. The primary designed mold was applicable to all types of configurations. Two spacer plates were applied to divide the mold into half panels and corner blocks. Furthermore, for the first and last row panels, only one of the side frames was adopted. The parts were joined by bolts and nuts (Figure 2).

TABLE 3. Material properties

Material	Mortar	
Size of the sample	(50 ×50×50) mm	(500 ×100×100) mm
Compressive strength (N/mm^2)	28.23	
Flexural strength (MPa)		2.13

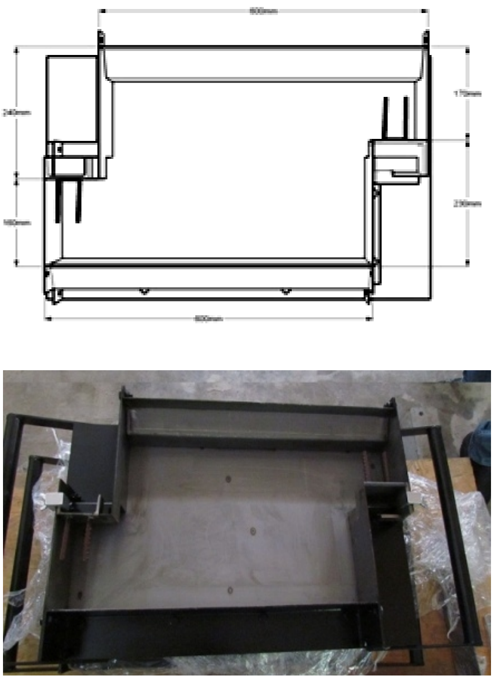


Figure 2. Main panel mould plan and perspective view

For casting the specimen, the molds were cleaned, oiled, and placed on a table with an electric vibrator. The mortar was then poured from a ready mixing rotary. After vibration, the extra material was removed from the surface of the mold, and the indentations were thoroughly filled.

5. 2. Test Setup A compression-testing machine was used to determine the compressive strength of the individual panel and two prism specimens. The test specimens consisted of a set of eight panel blocks installed in two rows. Each row contained two stretcher panels, a half panel, and a corner block. The specimen rested on steel shelves that were bolted to a pair of large steel reaction frames. The panels were tested in a vertical position with steel box supporters clamped to the steel frame. Overviews of the testing rig and specimen are presented in Figures 3 and 4, respectively. For this study, the test setup included the steps below.

1- The apparatus and impactor were checked to prevent interface while the panels were lifted.
2- End support and brackets were applied to the panels. The specimen was centered in relation to the support condition.
3- An I-beam was applied to ensure load uniformity along the specimen's length from the top.
4- A leveling ruler was used to ensure the proper leveling of the panels.
5- The strain gauges and linear variable differential transducers (LVDTs) were installed, after which the data logger was checked for recording data.

After the equipment was warmed up, the strain gauges were zeroed. The computer program that converted all the signals from the amplifiers into useful data was then activated. All the LVDTs were rechecked to ensure that they were indicating voltages near zero.

Figure 3. Individual panel testing

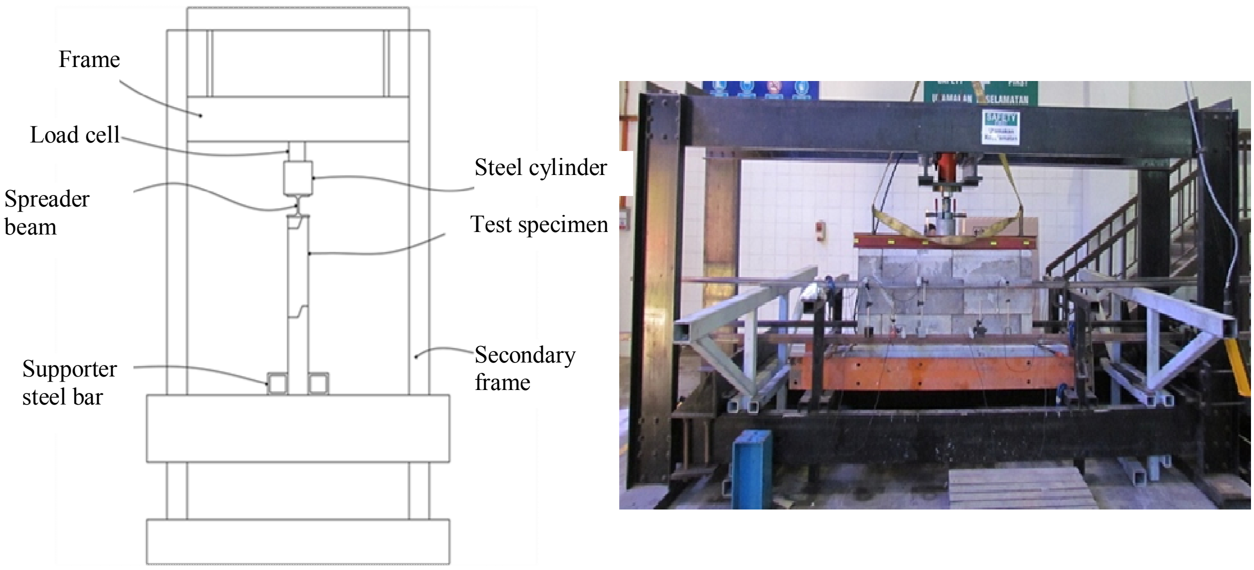
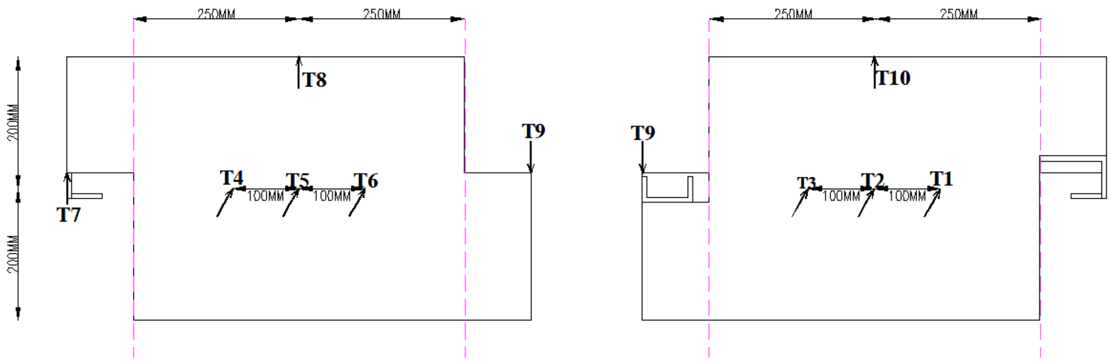
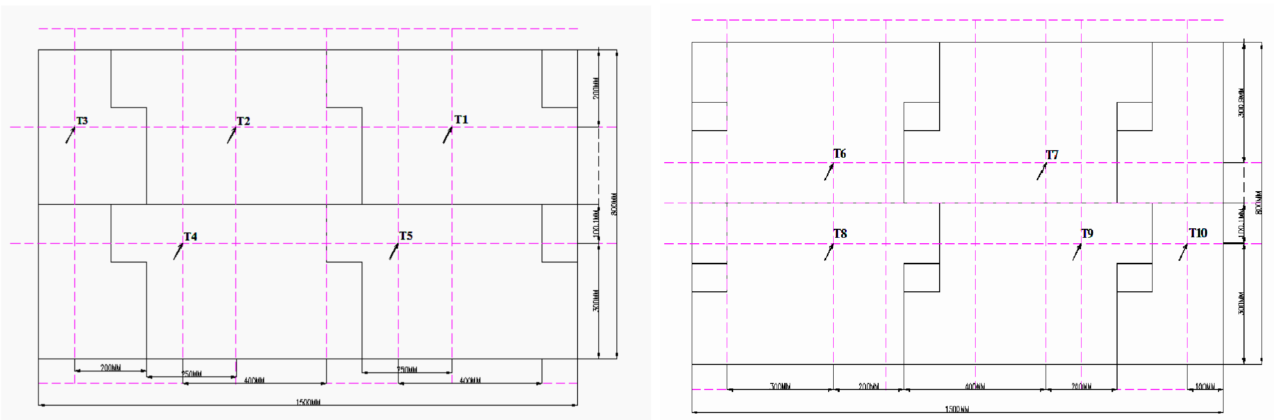


Figure 4. Specimen and testing frame sketch and lab photo



(a) Exterior facade (b) Interior facade

Figure 5. Location of LVDTs on the surface of the individual panel



(a) Exterior facade (b) Interior facade

Figure 6. Location of LVDTs on the surface of the specimen

Next, a pilot test was conducted to ascertain the testing condition and the specimen's workability. The specimen was at the same condition as the main test. The overall test results were satisfactory except for the improper and inadequate alignment of some test panels. This problem was rectified for the main experimental test, from which more reasonable results were obtained.

5. 3. Measurements Digital measurement devices were placed onto all panels of the specimen to obtain the thickness parallel, plane perpendicular, and loading parallel displacements in addition to the strains. The devices were placed in locations where they were expected to measure higher stress and displacements, such as near the connections, mid-points, and interlocking edges.

Displacements were measured by five LVDTs on either side. Figure 5 shows the location of the LVDTs for individual panel testing. LVDTs 1 to 4 measured the load parallel deflection in critical points, and LVDTs 5 to 10 measured the plane perpendicular deflection at the mid-height of the panel. The locations of the transducers for the main test are detailed in Figure 6. The small arrows represent LVDT measurements in relation to a fixed point. LVDTs 1 to 3 were positioned at the mid-height of the panels; LVDTs 4, 5, 8, 9, and 10 were 100 mm from the top; and LVDTs 6 and 7 were placed 100 mm from the bottom.

The strains were measured with strain gauges glued onto the precast panels. A total of 10 electrical strain gauges (ESG) were used in each specimen for strain measurement. The strain gauges were placed near the interlocking areas and at mid-height of the panels. The strain gauges were 30 mm in length.

Next, the specimen was placed in the loading frame in the correct position. The instruments were checked and properly adjusted before applying the load. The load was applied from the top as uniform pressure; no axial load was applied. A small load of approximately 1 kN was first applied to ensure the operation of all the instruments. Then, the load was gradually increased. The structural behavior of the specimen was carefully observed during the load application. During the test, displacements and strains were automatically recorded by a Data Logger UCAM-20PC connected to a computer. The crack pattern was also noted, and cracks were marked on the surface of the specimen, indicating the corresponding load.

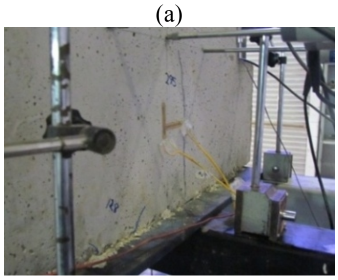
6. STRUCTURAL RESPONSE

The structural behavior of the panels was observed by measuring the surface strains and displacements. For improved understanding of each panel's performance, the results of the test were analyzed in terms of cracking patterns, load-stress curves, and load displacement profiles.

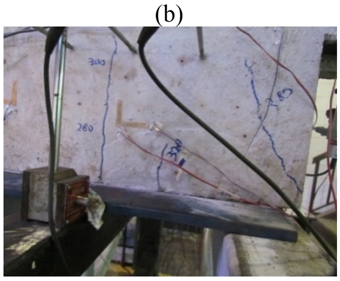
6. 1. Individual Panel

- **Cracking Characteristics** The loading process has resulted in distributed primary cracks on the panel. The first crack patterns were observed at 128kN in the base areas of the panel under compression. As loading continued, vertical cracks appeared at the bottom edges of the panel and extended toward the mid-height of the panel. Displacement up to 8.93 mm and compression of 285 kN resulted in diagonal cracks propagating from corners and continued to the top area (Figure 7).
- **Stress Distribution** The stress numbers refer to the amount of measured deformation in the external face of the specimen. Two types of stress were identified: compressive stress (negative value) and tensile stress (positive value). The results showed that the areas near the loading point were experiencing higher compressive stress (5.4 MPa) while, in the corners of the panel higher tensile stress were recorded (6.4 MPa). The first crack appeared while the recorded stress was 5.0MPa.

(a)



(b)



(c)

Figure 7. Progression of cracking during the individual panel test

- **Load-Displacement Behaviour** The deformation response exhibited by a structure under load is usually known as its structural behaviour. Plane perpendicular and load parallel deflections were measured during the individual panel test. The results illustrated that, the highest deflection (9.14 mm) was recorded by LVDT8 parallel to the compressive load. Besides, higher plane perpendicular deflections were recorded in the mid-height of the panel by LVDTs 5 and 2 and had a range between 0.03 to 3.98 mm.

6. 2. Pilot Test

- **Cracking Characteristics** During the test, each specimen was allowed to settle into the test setup and the wall was elastically deforming. Thus, no part of the specimen was yielding or failing, and the displacements were linear to the applied load. Under increased displacements, diagonal cracks from middle to the upper corners of the panel began to form. The first crack patterns were observed in the corner half panel of the first row at a load of 65 kN. These cracks were accompanied by vertical cracks from the top towards the mid-height of the panels (Figures 8 a and b). As loading continued, vertical splitting cracks appeared near the base of the panels under compression and extended toward the height of the panels (Figure 8c). With increased displacements of up to 2.62 mm and compressive force of up to 200 kN, the vertical cracks widened and a part of the specimen broke off from the half panel in the first row (Figure 8d).
- **Stress Distribution** These stresses were measured at the surface of the panels and at the connections. We observed that the stresses at the corners of the panels (i.e., the interlocking areas) were higher. In addition to resisting the load, the connections were primarily undergoing compressive stress instead of tensile stress.

Figure 9 shows the principal stresses over the sections at a load of 200 kN. This occurred immediately before the test was stopped. The highest stress at this point was 1.176 MP, which was recorded in strain gauge 8 located near the connection in the second row. In general, the first row registered higher stresses. However, all the measured stresses of the members during the test were below the elastic limit (0.45fc′) (ACI318M-08 2007).

- **Load-Displacement Behavior** In general, the panels exhibited a symmetric load-displacement relation for loading in the positive (front) and negative (back) directions until toe crushing occurred at one end at a load of 140 kN. Figure 10 shows the highest displacements which were recorded by LVDT 3 and 7.They were located in the first row at the top of the broken half panel. The deflections for the panels from this stage until 200 kN ranged from 0.07 to 2.62 mm.

The results revealed that the panels in the first row had higher displacements compared with the second row, which resulted in increased cracks in the panels. In general, the panels of the specimen for the pilot test did not have adequate alignment due to insufficient vibration during the casting process of the panels. This led to the unsmooth corners at the top and bottom of the panels. As a result, the interlocking mechanism did not work very well. This inconsistency was corrected for the main specimen. However, the deflection limits for the non-load-bearing precast wall panels following ACI 533R-93 were limited to 0.75 in (19 mm) [40]. Therefore, the pilot test specimen still satisfied the deflection limit. Approaching the 200 kN load, increased broken parts were observed in the specimen; thus, we decided to terminate the experiment at this point.

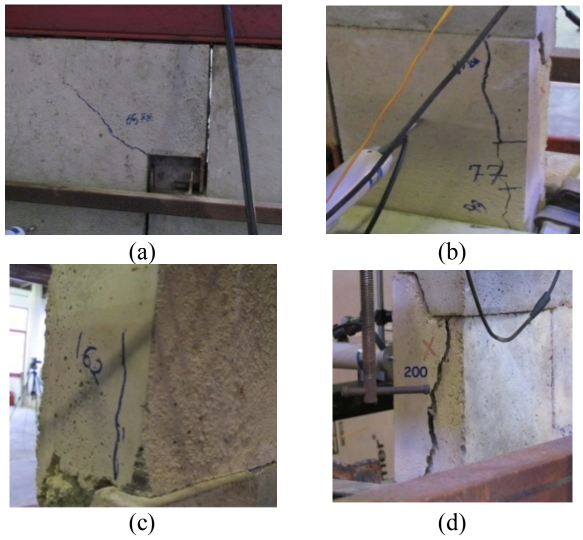


Figure 8. Progression of cracks during the pilot test

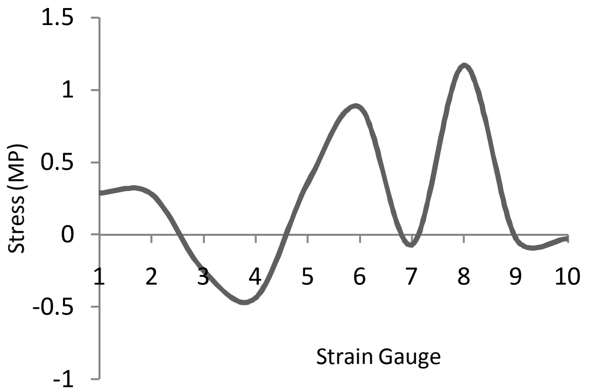


Figure 9. Recorded stress on the surfaces of the pilot test specimen at the load of 200 kN

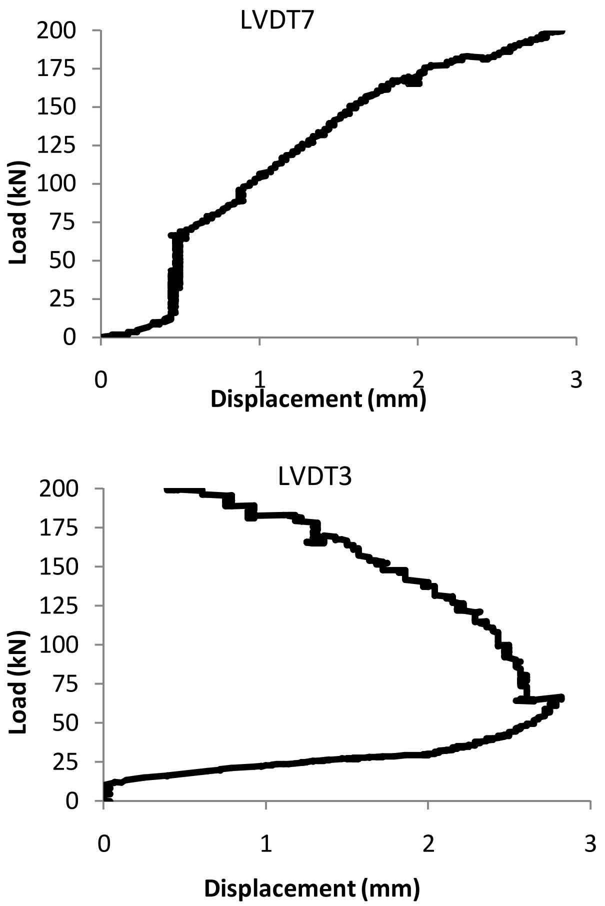


Figure 10. Displacements of the pilot tested specimen in different load

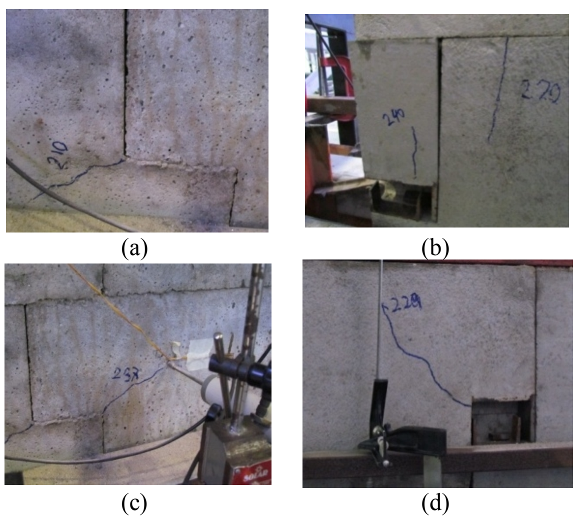


Figure 11. Crack patterns in the main test specimen

6. 3. Main Test The prototype panels behaved in a linear elastic manner up to a load of 210 kN and a mid-span lateral deflection of 2.61 mm. The first crack was observed at this point. The panel was loaded up to a maximum load of 250 kN and a lateral deflection of 2.64 mm. At this point, slight buckling was observed in the main frame of the testing machine. The buckling increased with the increase in applied load; therefore, the test was terminated at this point.

- **Cracking Characteristics** Under increased displacement, diagonal cracks were clearly visible, starting from the middle corners to the upper corners of the panels. Displacement up to 2.6 mm and compression of 230 kN resulted in extended diagonal cracks up to the top part, which was also accompanied by vertical cracks toward the mid-height of the panels (Figures 11 a and b). As loading continued, vertical cracks typically appeared at the top and bottom edges of the panels starting from the interlocking areas. In general, in the exterior face of the specimen (without the connections), the cracks were primarily diagonal, beginning from the middle corners to the upper corners of the panels (Figure11 c). However, the crack patterns in the interior face revealed that the cracks propagated from the top region around the connections and then followed vertical or diagonal directions (Figure 11 d).

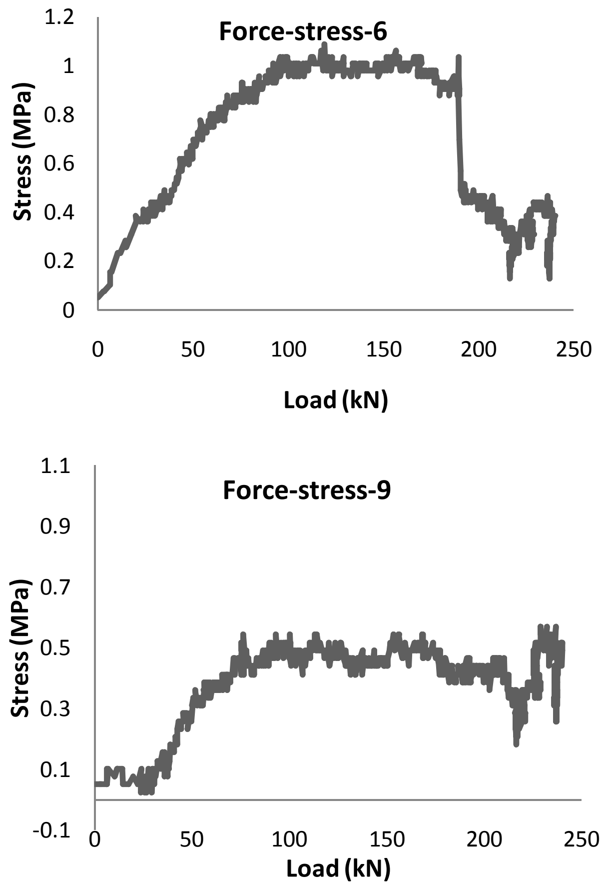
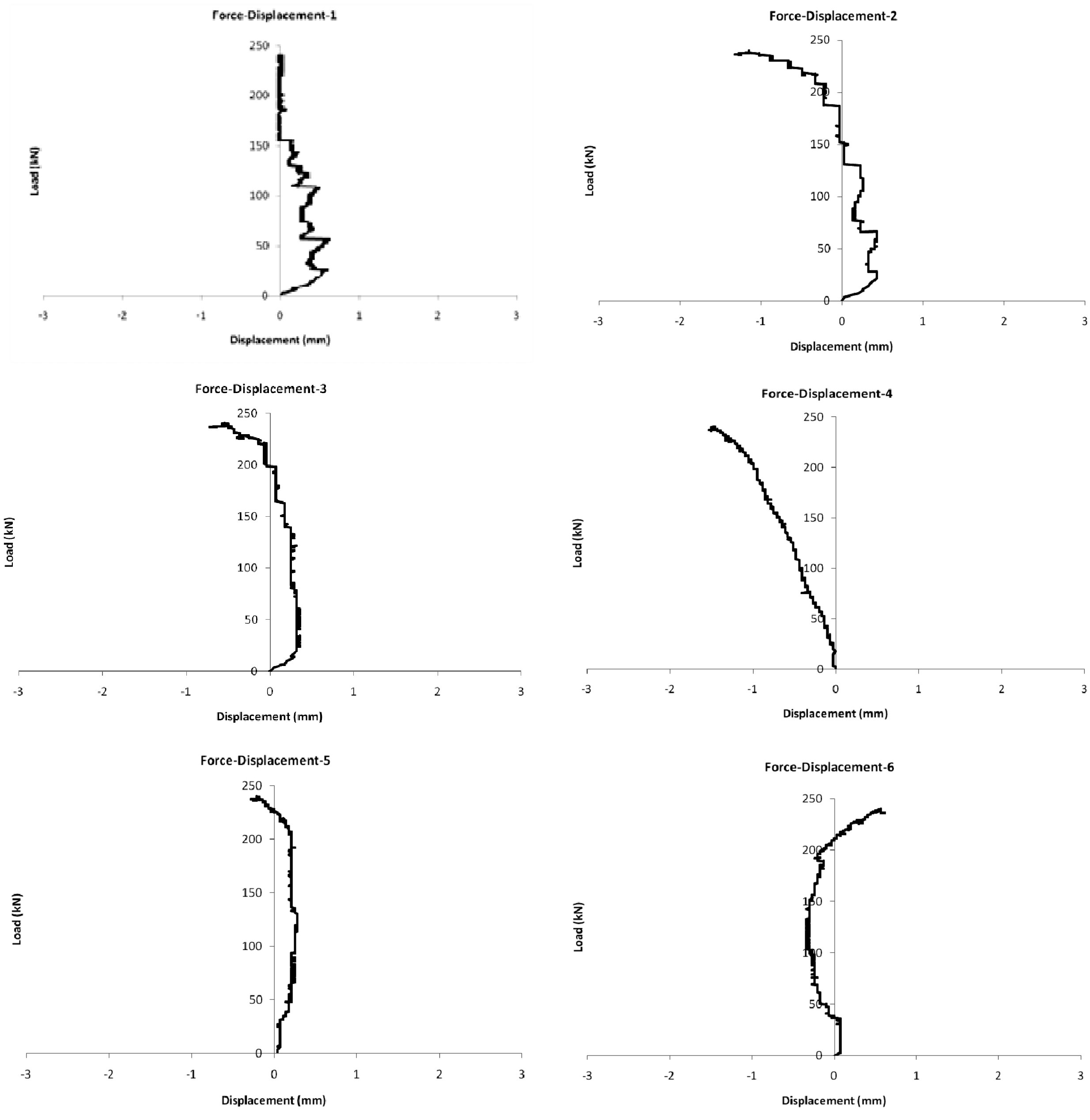


Figure 12. Load versus two higher recorded stresses in LVDTs 6 and 9

- **Stress Distribution** Results from strain measurements showed that the main recorded stress was tensile. In addition, the specimen became less compressive and indicated less tensile stress compared with the pilot test. The highest recorded compressive stress for the main test was 0.18 MPa while for that of the pilot test was 0.7 MPa. Moreover, the highest recorded tensile stress values in the main and pilot tests were 1.09 and 1.17 MPa, respectively. Gauges 1 to 4 were positioned at the mid-width of the panels, 300 mm from the corner; gauges 5 to 8 were 100 mm from the corners; and gauges 9 and 10 were on the connection of the panels. Among these, gauge 6 recorded the highest range of stress between 0.05 MPa and 1.09MPa (Figure 12). Gauge 6 was placed in the first row near the connection and on the upper corner of the panel. The second-highest stress was measured with gauge 9, located on the connector. Based on the design of the connections, this part was supposed to withstand the stress and prevent displacements in the connections. The corner gauges indicated higher strains compared with the middle gauges. However, during the panel test, the strains measured on all members fell below the elastic limit (0.45fc′) [41].



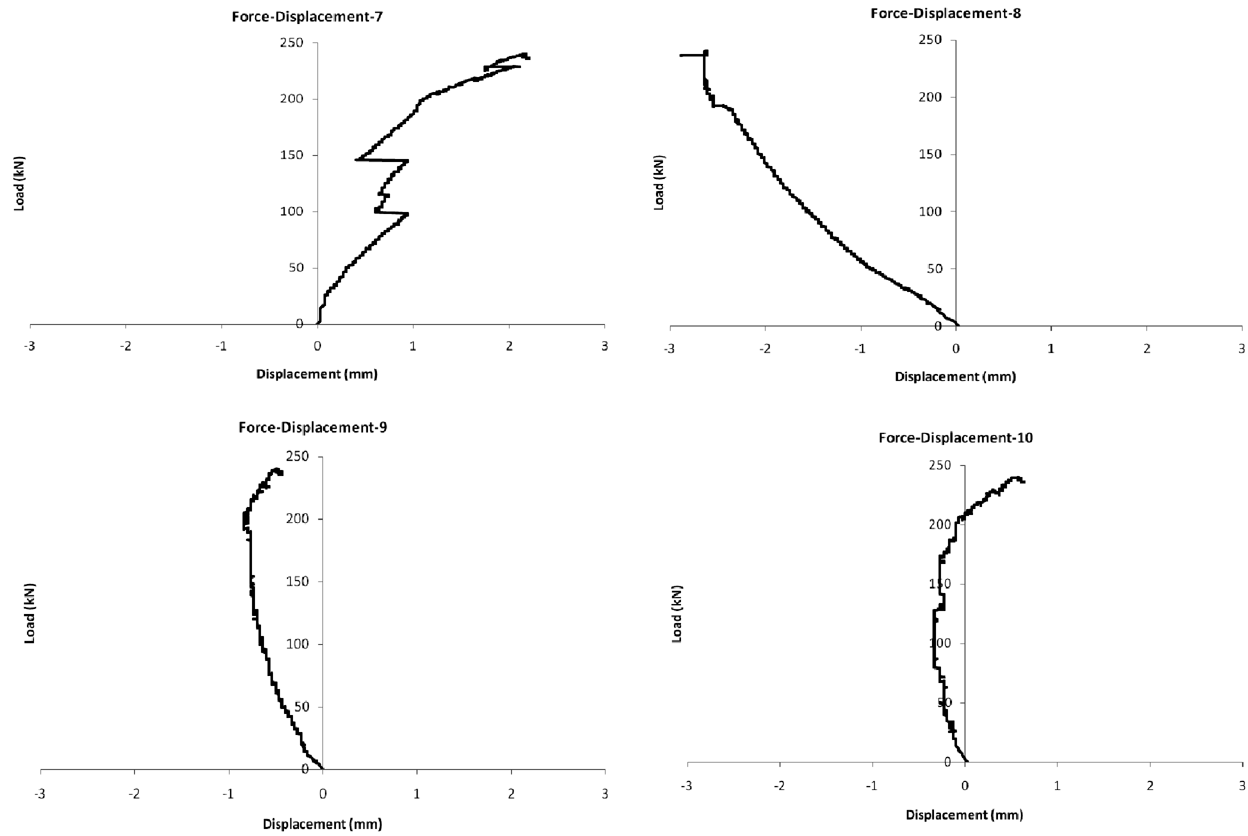


Figure 13. Load displacements record for the specimen in main test

- **Load-Displacement Behavior** The displacements recorded by the LVDTs were also determined. Figure 13 shows the load versus thickness parallel deflection of the specimen during the test. The prototype panels exhibited low displacement values, thereby indicating a high degree of composite action. The relative displacement for all specimens ranged from 0.03 mm to 2.64 mm. The maximum deflections for the panels were obtained on LVDT 7, located in the middle stretcher panel of the first row. In general, the prototype panel satisfied the deflection limits according to ACI318M-08, with a deflection of only 2.64 mm at the full load of 250 kN [41]. The behavior of the connections was not significantly different from that of the panel structure as a whole. Thus, the connections were sufficiently safe.

7. EXPECTED SERVICE LOAD

The expected service load for the specimen was calculated based on the weight of the panels. The total lateral force applied during the test was much higher than the service load. Although this was not the ultimate state, these findings indicated that the strength of the structure under lateral loads was sufficient. The weight of one row in specimen (*w*) is expressed as:

w= 23kg (half panel) + 53kg (main panel) + 53kg (main panel) + 4.2kg (corner block) = 133.2kg (1305.36N)

The weight of the 5 top rows that should be handled with two bottom rows (*w*) are given by:

$$W = 1305.36 \times 5 = 6526.8\,N.$$

Specimen area (*A*) is given by:

$$A = 1500mm \times 100mm = 150000mm^2.$$

Required pressure (*P*) resistance is:

$$P = \frac{W}{A} = 6226.8/150000 = 0.0414\,MP.$$

Applied pressure (*P*) during the test is expressed as:

$$W = 250\,kN$$
$$P = 250000/150000 = 1.6\,MP.$$

In a building made with the proposed panel system, with a ground floor and a first floor, no additional stability walls are needed, and the overall stability between the columns and beams is ensured by the system of rigid connections.

8. CONCLUSIONS

In an attempt to develop an innovative panel design, a number of criteria have been studied. Improved analytical modelling combined with experimental testing program is expected to provide insight into panel behaviour. The main features of the design are as follows:

- the applied dimensions satisfy the modular coordination requirements;
- the simple shape of the panels aid in simple production and assembly of the wall;
- the interlocking structure has been designed to efficiently withstand the load; and
- environmentally-friendly construction has been conducted in a dry and fast manner.

The stability and load-bearing capacity of the designed panels were tested via an experimental procedure. The results obtained from the compression test indicated that the interlocking panel system may be adopted in building or housing construction. However, further evaluations are required for an applicable system. Furthermore, the effects of lateral and eccentric loads, in addition to wall openings on the strength capacity of the wall, must also be investigated.

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Structural and Functional Analysis of an Industrial, Flexible, and Demountable Wall Panel System

RESEARCH NOTE

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چکیده

استفاده بیش از حد از منابع و تولید ضایعات فراوان یکی از اساسی ترین معضلات ساخت و سازهای امروز می‌باشند.در نتیجه صنعت ساختمان در تلاش است تا با طراحیهای مبتکرانه و ایجاد عناصر تطبیق پذیر و قابل تغییر موجب کاهش مصرف منابع گردد. این مقاله مراحل طراحی و ساخت یک پانل بتنی پیش ساخته وانطباق پذیر را شرح می‌دهد. پانل ها از قطعات بتنی و اتصلات فلزی تشکیل شده‌اند و به آسانی قابل اتصال و برداشت می‌باشند. ایستایی و ظرفیت باربری پانلها طی مراحل آزمایش مورد بررسی قرار گرفت. در حین تست تنش و جابجایی در نمونه ها اندازه‌گیری شد. همچنین نحوه ایجاد و تغییر شکل ترکها با دقت مشاهده و ضبط گردید.اگرچه پانلهای پیشنهادی به عنوان اجزا باربردر سازه ساختمان طراحی نگردیده‌اند، نتایج آزمایش نشان از قدرت بالای تغییرپذیری و تحمل بار نمونه‌های طراحی شده دارد.

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