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Structural perfomance of cold-formed wall frame under combined gravity and lateral loading

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Abstract. Light steel framing is generally based on the use of standard C or Z shaped steel sections produced by cold rolling from strip steel, which is normally refers to cold formed steel sections. Light steel framing is already well established in residential construction in North America, Australia and Japan. Cold formed steel sections are widely used in many sectors of construction, including mezzanine floors, industrial buildings, commercial buildings and hotels and are gaining greater acceptance in the residential sector. In Malaysia, cold formed steel sections are frequently use in roofing systems such as roof trusses and purlins. The light steel framing system has yet to be practiced in Malaysia. There is a need to investigate the economic aspects of the light steel framing system in our local industry, conduct comprehensive testing and parametric studies to create the guidance and procedures of the analysis and design of such building. This paper presents a lightweight system for wall panels made of cold-formed steel sections. Three wall panel samples are tested experimentally under combined gravity and lateral loading to investigate the performance of the panel in terms of strength, stiffness and ductility. The results from the experiments show the wall panel using back-to-back and box arrangement able to increase the lateral stiffness and strength as compared to single section wall panel. The increment of strength can goes up to 39% under combined gravity and lateral loading while for lateral stiffness the increment can goes up to 83%. The performance of the panel can be applied to the light steel structure that can materialize the new residential building mode of low cost, high efficiency and large scale. The significance of this study is to reduce the use of labour by introducing pre-fabricated panel section, which is environmentally friendly and reduce congestion on site, and able to reduce overall construction cost by using precast construction with higher strength and stiffness capacity.

1. Introduction

For the past few decades, application of cold-formed steel in construction sector has becoming more prevalent as cold-formed steel offers a wide variety of advantages like cost effectiveness, lightweight, high strength-to-weight ratio, high quality, long design life, high efficiency in fabrication, speedy construction, able to recycle and re-use, and produce less waste materials. Despite all these advantages offered by cold-formed steel, the application of cold-formed steel in Malaysia still limited to roofing system. To cope with current and future development of cold-formed steel, intensive study should be done to ensure safe, economical and high quality of cold-formed steel application in Malaysia construction industry. Progressive development of cold-formed steel application in construction industry of Malaysia is inevitable due to its mass advantages. Design in cold-formed steel structure should be reliable, safe and appropriate for the intended function. Effect of lateral loadings from winds could be significant for low-rise buildings especially those made of cold formed steel as it is lightweight and less stable as compared to structures made of hot rolled steel sections. Therefore, it is important to study the behaviour of cold formed steel frame subjected to lateral loading and the effects of using various wall stud configuration. Gad et al. [1] has conducted a study on lateral performance of cold-formed steel-framed domestic building. The failure of the frames when subjected to earthquake stimulated force is governed by the failure of the strap braces instead of type of connections between framing members. DaBreo et al. [2] studied the effect of steel sheathed cold-formed steel framed walls when subjected to lateral and gravity loading. It was concluded that the use of closely spaced sheathing panel fasteners and thicker panels leads to a higher shear resistance. Doaa Bondok et al. [3] conducted a study on static resistance function of cold-formed steel stud walls. He predicted the energy absorption capacity of steel walls varied greatly with connection type and strength. He presented an analytical model to analyses the response of steel stud walls under blast loads by assuming that buckling and connection failure is prevented through properly designed bracings and improved connection. As result, this study showed that using oriented strand board (OSB) sheathing generally helped stabilize the stud behavior in the softening zone and increase the ultimate load. Ye et al. [4] has conducted a research on behavior of cold-formed steel wall stud with sheathing subjected to compression. This research conducted axial compression test on 16 cold formed steel walls to study the effects of sheathing types, sheathing layers, and stud spacing on the static mechanic behavior of the wall studs. Flexural-torsional buckling accompanied by local distortion and local buckling at the ends of the steel studs were observed in the experiments. On top of that, types of sheathing may influence the ultimate capacity of the wall stud. Most of the previous research studies [5], [6], [7] and [8] focused on testing of cold-formed wall frames with sheathing either on one or both sides of the frames or without sheathing, sheathing type, studs spacing and screw spacing. From the study [6], the results showed that, the increase in axial load capacity of cold-formed steel wall frames varies based on the sheathing types and material properties. The attachment of boards to the side of the wall can increase the axial strength of the wall by as much as 91% when comparing the case of no sheathing (Bare-Bare) to that of oriented strand board on both sides (OSB-OSB). The screw spacing used at exterior framing members influence the load capacity of wall panel. Between the cases of 15cm and 30cm screw spacing, the increase in load capacity of wall panels was between 37% and 85% with decrease of screw spacing depending on type and thickness of sheathing panel. Test results indicated that the beneficial effect of increasing sheathing panel thickness from 11mm to 18mm where 18mm thickness remained very limited in terms of the load capacity of wall panels. This study aims to investigate the structural behavior of lightweight modular wall panel (as shown in Fig.1) subjected to lateral loading only and both lateral and gravity loading.

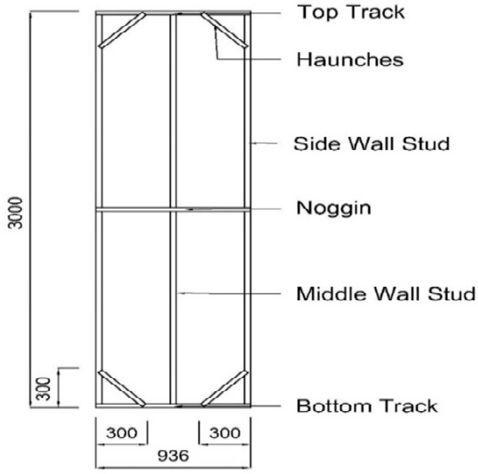

FIGURE 1. Typical assembly of wall panel

2. Experimental Program

This study will look into the effect of gravity load to the lateral resistance of wall panel and the effects of using different wall stud configuration. The research work comprises of a series of full-scale testing on lightweight wall panel system with 3 types of wall stud configuration, namely single lipped C arrangement (Type 1), double back-to-back arrangement (Type 2) and double box arrangement (Type 3) as shown in Fig.2. The key focus of this study is to investigate the structural behavior of wall frames in terms of failure mode, initial stiffness, and resistance to lateral loading. The details of each specimen type is presented in Table 1.

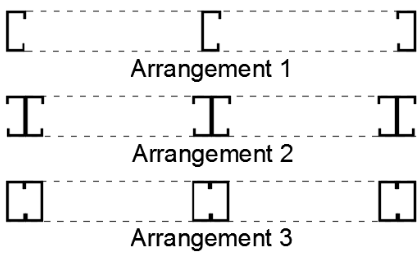

Figure 2. Types of arrangement of wall panel

TABLE 1. Details of test specimens

Specimen Type	No. of specimen	Height (mm)	Width (mm)	No. of wall stud	Wall stud size
Type 1	2			3	
Type 2	2	3000	900	6	76 x 34 x 1.15BMT
Type 3	2			6	

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There are two phase of experiments been conducted in this study, where phase 1 test only apply lateral loading to the wall frame while phase 2 test apply both gravity and lateral loading to the wall frame. The setup for both phases 1 and 2 tests are similar, where the bottom track is mounted to the test frame rigidly to prevent movement in any direction. Lateral bracing is provided to restrain the sample from out-of-plane buckling. For phase 1 test, the lateral load is applied to the top track of the sample with an increment of 0.1kN/s. The sample was further loaded until there was a significant deformation on test sample can be observed. This procedure continues testing until the specimen has reached its failure condition. For phase 2 test, the specimens are first loaded with gravity load on top of the top track and then lateral loading is applied gradually to the specimen similar to phase 1 test. The gravity load is fixed at 1kN as it is calculated as 50% of lateral resistance of the wall panel. Typical setup of test program is illustrated in Fig.3.

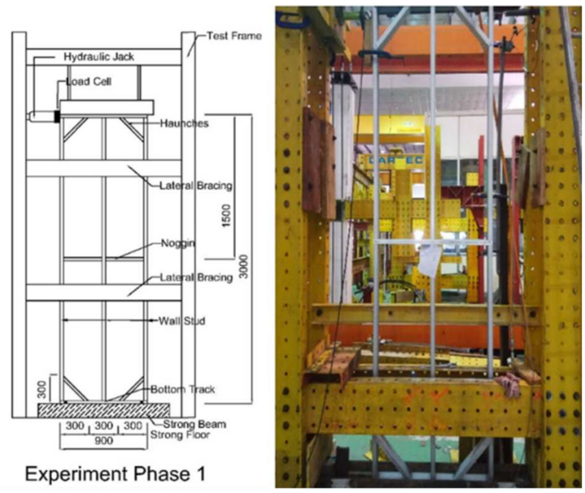

Figure 3. Types setup of wall panel test

3. Result and Discussion

3.1. Test Failure Observation

For phase 1 test, all test specimens didn't achieve ultimate load capacity as the lateral movement is too large and exceeded the capability of the measuring equipment. Deformation was observed on haunches located at the top right and bottom left of the wall panel. This is due to both haunches are subjected to compressive forces and has buckled before reaching the failure of wall stud members. Figure 4 shows the failure on haunches observed in the experiment.

Figure 4. Failure on wall panel haunches

For phase 2 test, the lateral resistance of all test specimens were greatly reduced as compared to those tested in phase 1 test. Similar failure modes were observed, with the buckling of haunches at the similar location in phase 1 test.

3.2. Load-Displacement Behavior

Load-displacement graphs are plotted for each test specimens. Figure 5 shows the load-displacement curves for phase 1 test and Fig.6 shows the load-displacement behavior for phase 2 test. From the load-displacement curves, type 2 arrangement shows the highest lateral resistance in both phase 1 and phase 2 test while type 1 arrangement is the lowest in lateral resistance. Phase 2 test shows a significant reduction in lateral resistance where the capacity is in the range of 0.5 to 0.7 kN. On the other hand, the specimens in phase 2 test has begun to yield with the existence of gravity loading. This may be due to the second order effects from the gravity load has speed up the failure of the wall stud. Initial stiffness of all test specimens are calculated from the load-displacement curve in the elastic region, where the slope of the curve is predicted from the best fitting linear elastic line as shown in Fig. 5 and 6.

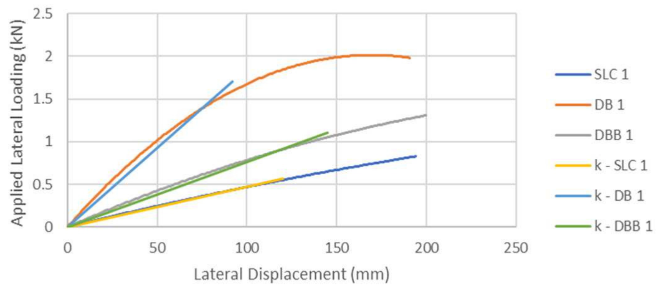

Figure 5. Load-displacement curve for phase 1 test

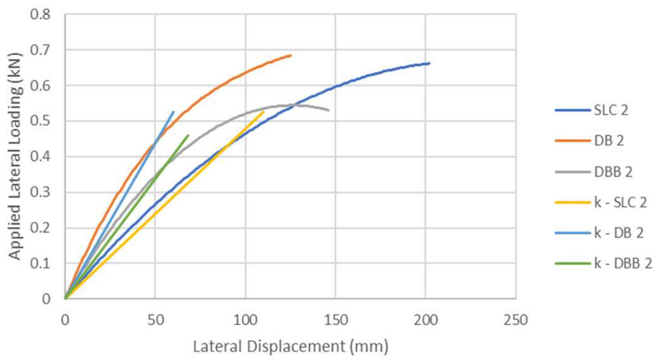

Figure 6. Load-displacement curve for phase 2 test

The summary of results for both phase 1 and phase 2 test are tabulated in Table 2. From the table, it is clearly shown that the existence of gravity load has reduced the initial stiffness and lateral load resistance of wall panel in configuration type 2 and type 3. However, there is no changes in type 1 configuration with the existence of gravity load and no failure was observed on the specimens. There is a huge reduction in type 2 configuration as the initial stiffness has dropped from 18.5kN/m to 8.8kN/m while the lateral resistance also reduced from 1.68kN to 0.64kN. This may be due to the effect of back-to-back connection on wall stud increased the lateral stability of the wall stud and prevent the wall stud from horizontal movement. In type 3 configuration, the box section was not connected to each other that the wall stud acting individually to resist the lateral loading. The increment in number of wall stud in type 2 and 3 configuration showed higher initial stiffness and lateral resistance as compared to single wall stud configuration in type 1 arrangement. Type 1 arrangement is flexible and can easily move laterally with the existence of gravity loading.

Table 2. Summary of test results.

Specimen Type	Initial stiffness (kN/m)		Failure Mode	Lateral load at 100mm displacement (kN)	
	Lateral load only	Lateral + Gravity load		Lateral load only	Lateral + Gravity load
Type 1	4.6	4.8	N.A.	0.47	0.46
Type 2	18.5	8.8	Local buckling	1.68	0.64
Type 3	7.6	6.8	Local buckling	0.78	0.52

4. Conclusion
The experimental test on modular wall panels subjected to lateral and gravity loading have been conducted successfully. Several conclusions can be drawn from this study as follow:
- The failure mode of wall panel subjected to lateral loading occurs on haunches located at the top right and bottom left of the wall panel.
- The existence of gravity loading significantly reduced the lateral resistance of wall panel in type 2 and type 3 configurations.
- Wall panel in type 2 arrangement shows the highest initial stiffness and load carrying capacity as compared to other wall stud configuration.

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