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Evaluation on Crack Pattern of Concrete Masonry Wall Column

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ABSTRACT

In recent years, concrete masonry unit (CMU) structures have been widely used in rural areas of Malaysia. However, it was found to have a poor performance of masonry wall-column regarding to the failure and crack behaviour. This research work presents the investigation and study on the cracking behaviour of concrete masonry wall-column structure. The results from this study will provide a significant understanding of the crack and failure of local in-filled reinforced CMU wall-column. The experimental work involved investigating the failure and crack pattern of CMU wall-column under axial loads performance. The experimental outcomes outlined that reinforced CMU wall-column under axial loading it failed usually due to the cracking caused by a breakdown of the bond between the masonry blocks and the mortar. Therefore, cracking is not due to the tensile failure of the units themselves or of the mortar itself.

Keywords: Concrete Masonry Unit (CMU); wall-column; crack behaviour; axial forces

INTRODUCTION

In Malaysia, there are not many engineers capable in using and designing masonry structures. This results the progress of Masonry's work very slowly and rare. Malaysian engineers are only able to adopt the British Standard practice code in designing the material and strength to be used but may not be suitable for use in Malaysia. There has been a large array of improvements achieved in the last few years. Concrete masonry walls and columns are common structural members that typically resist compressive loads, with several members being required to resist combined axial load and out-of-plane bending due to direct out-of-plane loads or an eccentricity of the axial compressive load.

There is a lot of data regarding CMU from other country especially from British to cater the needs of the construction industry. However, there is none locally manufactured data of CMU and workmanships. Thus, it is important to know the strength of locally manufactured and constructed CMU element with local workmanship. A long time ago, only sand and mortar were used to make up the concrete unit and tie it on top of each other. The masonry today deserves to be rediscovered by the latest technologies of engineering, such as fire protection, heat resistance, and sound insulation (Hendry 2001). In Malaysia, for residential houses, masonry is an essential content. Modern construction in Malaysia uses a load bearing and non-load bearing wall as a masonry structure. Although there are a lot of buildings made of reinforced concrete in Malaysia, the use of masonry is not negligible. In terms of design and construction aspects, a lot of research was established on a masonry structure.

In the other hand, the emphasis of codes of practice and the specifications of these technical elements are increasing, and the relentless rise in demands of optimize the safety of the building users are increasingly important. Extensive studies in many countries have contributed to the creation of a more comprehensive design code, but in recent years Masonry has been used almost exclusively for low and medium-sized buildings and for coating of steel and concrete buildings, and potential for high-rise building have not been fully explored. From the point of view of the construction, the availability of skilled labour required, the construction time and the construction work phases with the number of construction plans will also be an important consideration.

In Masonry's study, there are many lacks experimental evidence to use and calibrate empirical models of their mechanical and material properties. To provide a structural designer with valuable knowledge that can be used to achieve the exact numerical model, additional experimental data on the properties of materials and stone infill wall mechanics built from various types of materials needed. The design approach described in this study assumes that horizontal joints produce preferential weakness lines along which the deformation of the masonry infill concentrates, in the form of relative slipping between the joints and columns bounded by sub-portions of masonry, shielding masonry from crushing and shear failure.

This study enhances understanding the basic and advanced of concrete masonry unit (CMU) especially load bearing wall under lateral loading. The study will benefit by well explained concept, figures and graphs contain in this research. Besides that, the study will stimulate an interest in designing the CMU wall and provide an acceptable data for local construction method and workmanship. It also provides guidance for solving or eliminating a frequently encountered design problem such as the factor that affecting lateral loading in masonry wall. Those factors which are the effect of mortar joint, axial loading and crack behaviour of masonry wall is considered. The methods presented the compressive and shear strength on structural members and compare it with design standard that can be used as a guide for local construction technique. Furthermore, this study gives advantages to new reader in understanding the concept of masonry unit as a guide in designing the masonry structure.

REINFORCED MASONRY WALL-COLUMN

Reinforced masonry can be utilized to conquer this constraint in structures in seismic regions and for the most part where non-load bearing panels are subjected to substantial wind load which is critical in windy area or for high-rise building where the wind is getting stronger when the building gets higher (Hendry 2001). Masonry wall development has various focal points the first is the way that a solitary component can satisfy a few capacities including structure, fire security, thermal and sound protection, climate insurance and sub-division of space. Another advantage position identifies with the strength of the materials which, with suitable determination, might be relied upon to stay serviceable for a long time, if not hundreds of years, with moderately maintenance.

Conventional masonry works are especially defenseless to in-plane shear activities because of their low rigidity. Hence, with a specific end goal to anticipate appropriately the masonry shear limit, it is important to recognize to start with the in all probability failure components, considering the information of the included materials. Avoiding both in-plane and out-plane collapse mechanism, the reinforcement should be added to masonry works. Some reinforcing strategies were proposed which are, (a) injection of grout in cases when at least the external leaves of the walls appeared in good conditions, (b) injections and jacketing with a reinforced cement rendering when also the bond between the stones of the external leaves were missing, (c) partial reconstruction of the walls in the worst cases (Corradi et al. 2008). However, the repaired masonry structures failure, partial and total collapse showed improperly implement technique. Poor workmanship are the major cause of the failure and absence of information of the masonry itself lead to this problem.

According to Corradi et al. (2008) the aims of the deep repointing are: (i) to supplant the damaged mortar on the wall surface to a profundity of 70–80 mm in order to adequately bond in-plane the stones, (ii) to bind the wall externally as a supplement to injection, (iii) to give a superior penetration of the grout while keeping away from spillage to the outside. In order to use these techniques, it is important to have proper investigation to know the qualities of the masonry to be repaired and of its parts (mortar, stone, bricks) before choosing. A reasonable examination on location and in research center was passed on out through: (i) accurate geometrical survey of the masonry morphology (number of leaves in the section, dimension of the leaves, type of connection between the leaves), (ii) characterization of the stones and of the mortars, (iii) survey of the physical and mechanical decay, (iv) crack pattern survey.

In order to understand more about masonry, a set of tests (compression, shear-compression and diagonal tests) had been carried out on site which is to determine the shear stiffness and strength. The panels have been cut when the test was carried out from the load-bearing walls. Diamond wires which is special cutting technique were used to stay away from significant damages to the panels.

MASONRY WALL-COLUMN REINFORCED BY CFRP UNDER IN-PLANE LOADING

The conservation of the architectural legacy is one of the obligations designated to structural engineering and given the geometric multifaceted nature of the structures included, the inconstancy of materials utilized and the loading history of similar structures, this goal might be done knowing the conduct of notable unreinforced (HURM) and reinforced (HRM) masonry walls under in-plane loading (Capozucca 2011). The arrangement of resistance in shear depends on upon the geometry of masonry panels, their farthest point conditions, the greatness of the vertical loads and, at long last, on the qualities of the interface bond between bricks or stones and the mortar of HURM. The present paper depicts an exploratory research conveyed out to research the conduct of HURM and HRM walls fortified utilizing Fiber Reinforced Polymers (FRPs) until failure. Cracking stages, strain conveyance and deflection under augmenting cyclic shear loading were recorded amid trial in-plane tests.

New reinforcing advancements composite materials, for example, FRPs appear to speak to a legitimate arrangement in masonry building rehabilitation. These are a class of materials having the potential which is comprise in high quality strands embedded in a resin matrix to altogether enhance the masonry reaction of building in seismic territories activity. In any case, fibers are solid toward them yet for the most part weak along the side and it also shows no ductility and stress-strain behaviour is direct flexible up to the failure. Regularly, externally fortified FRP strips are utilized as a method for reinforcing shear masonry walls by expanding tensile limit with regards to supporting consolidated pressure and shear activity set-off amid earthquakes (Capozucca 2011).

HURM behaviour tentatively concentrated on by utilizing walls worked as a part of scale 1/3rd and were subjected to in-plane cyclic loading. The walls were placed to in-plane cyclic loading condition shown in Figure 1. The shear damage with the diagonal cracking of the walls were strengthened by using CFRP strips bonded. It is connected by arranged both vertically and horizontally and laid out corner to corner. In order to enhance the adhesion of the CFRP strips to the wall surface, a system of steel nails and short carbon fibers were arranged and inserted into the holes and it was test subjected to cyclic loading until the walls fail. (Capozucca 2011).

FIGURE 1. Shear cracking damage of HURM wall

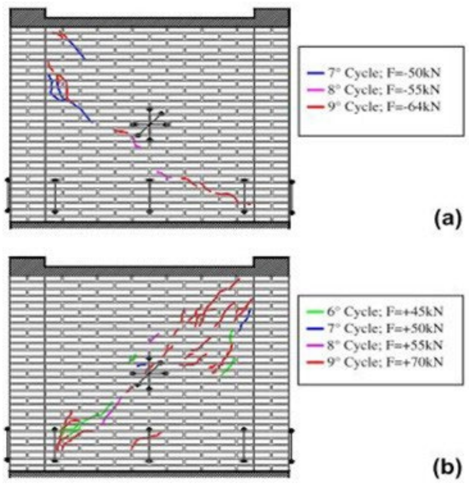

FIGURE 2. Experimental cracks on the unreinforced side of HRM wall

The reinforcing of masonry panels with composite CFRP materials presented the masonry more noteworthy resistance be that as it may, most importantly, a more prominent ability to experience abundant even developments and, thus, to disseminate vitality through the movement of adequate and across the cracking. In addition, the increase in resistance was appreciable, specifically, on account of the wall fortified with inclining strips as the delamination wonder is evaded. However, reinforcing historic masonry with CFRP requires an enhancing of obligation of the strips by embracing sufficient anchorage systems and also sticking utilizing epoxide resins.

CRACK PATTERN IN CMU WALL-COLUMN

Ernesto et al. (2018) presents axial and flexural compression strengths and deformation properties of high-strength concrete block masonry. The results show an increase of flexural compression strength of 15–29% for the hollow prisms and of 70–79% for the grouted prisms compared with their axial compression strength. Research by Alireza et al. (2019) investigate the effect of Engineered Cementitious Consequently, relative to the conventional continuous infill structure, a ductile reaction of the infill is obtained, along with decreased stiffness and power, which are sought to minimize the contact of the infill-frame (Alireza et al. 2019). This deformation mode is made possible by the unilateral existence of the relative restriction between the column and the masonry inside the plane. Composites (ECC) on the in-plane performance of a bearing unreinforced Masonry (URM) wall under quasi-static lateral loading. The results indicated an increasing in the retrofitted walls energy dissipation capacity and lateral strength. The research also stated the damage to the specimen that was intentionally cracked, the shear strength and energy dissipation capacity of the retrofitted damaged wall increased about 330% and 115%, respectively. Shady et al. (2019) was examined that at early loading stage, walls exhibited has similar crack patterns which is characterized by horizontal cracks at the first bed joint above the foundation at the front wall face followed by similar cracks at the mid height of the rear wall face. Hence, at higher displacement level, the crack started at the foundation before the wall reached its ultimate load. The crushing of this wall according to Shady et al. (2019) also started the mid-height of the front face, which was accompanied by a decrease in the wall load carrying capacity until the end of the test (Shady et al. 2019)

Good material and good level of workmanship are the main elements of solid stone construction. Organizations such as the British Brick Production Association and the British Cement and Mortar Association have pushed for the creation of new products in such a way that brick-making materials today. Referring to BS5628-3:2005 (2005) Clause 7.1.1, reinforced concrete design and prestressing should provide adequate safety margins against final limit conditions. This is achieved by ensuring that the design strength is greater than or equal to the design load. The design should be such that the usability criteria condition can be met. Consideration should be given to deflection and fracture limit conditions if appropriate, for example fatigue (5628-3:2005, 2005).

METHODOLOGY

MATERIAL AND METHOD

Sample	Height, H (mm)	Length, L (mm)	Width, B (mm)	Stiffener Rebar	Mortar Class	Eccentricity (e = 0.2B)
190x1000x1600, Y12	1600	1000	190	Y12	M12	38
190x1000x3400, Y12	3400	1000	190	Y12	M12	38

FIGURE 3. Table of CMU wall-column samples

CMU wall-columns sample are to be constructed based on BS 5628:2005. There are 2 wall-column that constructed in this study as shown in Figure 3. Specifically, wall columns are built, and the strength of the walls is highly dependent on the quality of work and the construction process. Therefore, to get quality results, wall pillars should be built by skilled workers professionally in this sector. At the beginning of construction, the pinned wall is protected, and the beam spreader with a height of 500 mm distributes the load as shown in Figure 4. The channel is used at the very bottom of the wall, the purpose is to insert the bracket and to prevent injury during the test.

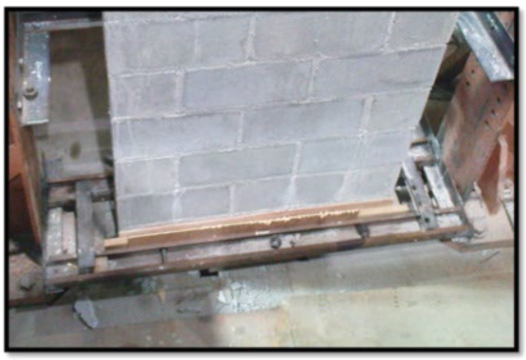

FIGURE 4. Setting out of top bracing, spreader beam and roller

SETTING OUT OF INFILLED CMU WALL-COLUMN

Ordinary Portland cement and sand was mixed in ratio of 1:3 by weight and the water cement ratio was 0.4 by weight according to BS. The sand that uses in this research should be clean, free from impurities, hard and fine aggregate that specified in BS. In this research, concrete only use for the columns and beams of the wall. The mix design of a good concrete grade is by selecting the right proportion of cement, aggregate, sand, and water. The proportion of material is important because it specified the strength and durability of concrete. For this experiment, the strength of the concrete use is grade 30MPa with the proportion of 1:3:6 (cement: course aggregate: sand) with water cement ratio 0.4.

FIGURE 5. Setting out of bottom bracing

The top brace is protected by two 100 mm x 1500 mm iron C-purlin ends. Plywood is shaped to have a smooth and wide contact area between C-purlin and the surface of the wall. Roller roles are 50 mm diameter steel rod roles. Eccentricity is controlled by changing the location of the wall of the CMU. The 12 mm diameter steel rod is used to carry both sides of the C-purlin to stabilize each other. Two sides of 100 mm x 1500 mm iron C-purlin are also protected by the bottom bracing. Stiffeners are mounted only on one side to prevent bending of C-purlin. Walls are pinned supported, and the load is distributed by spreader beam. The height of spreader beam is 500mm. Top bracing is supported by two side of iron C-purlin of 100mm x 1500mm. Plywood is placed to give soft and large area of contact between C-purlin and wall surface. Roller is roles by steel rod of 50mm diameter. Eccentricity is control by adjusting the positioning of CMU wall. Steel rod of 12mm diameter is used to brace both side of C-purlin to support each other. Bottom bracing is also supported by two side of iron C-purlin of 100mm x 1500mm. Stiffeners is placed to avoid bending of C-purlin in one side only. Channel is used at the bottom of the wall as a bracing as shown in Figure 6.

TESTING OF INFILLED CMU WALL-COLUMN

The testing of infilled CMU wall-column is conducted using 200 tones testing frame in pit. Specimen is subjected under axial load until reach ultimate load. Axial shortening is measured using Linear Variable Differential Transformer (LVDT) place under spreader beam. Figure 7 and Figure 8 shows details of CMU wall-column setting out. Lateral displacement is measured by placing LVDT at various heights. All the data is recorded using data logger. At every incremental of load, the reading of LVDT and strain gauge will be recorded until the failure of the wall. The cracking pattern and mode of failure was observed as a load increase. Before the sample can be tested, all the wiring of reading devices such as LVDT and strain gauges has been connected to the data logger. The raw data from this experiment was analysed and the result was graphically display.

FIGURE 6. Setting Out of LVDT

As for the masonry wall, the compressive strength and tensile strength are the most important. Masonry is highly compressive but very weak against tensile and shear. To increase the wall-column tensile capacity, reinforcement is important to provide strength of the masonry wall. Compressive strength also increases when reinforcement is applied.

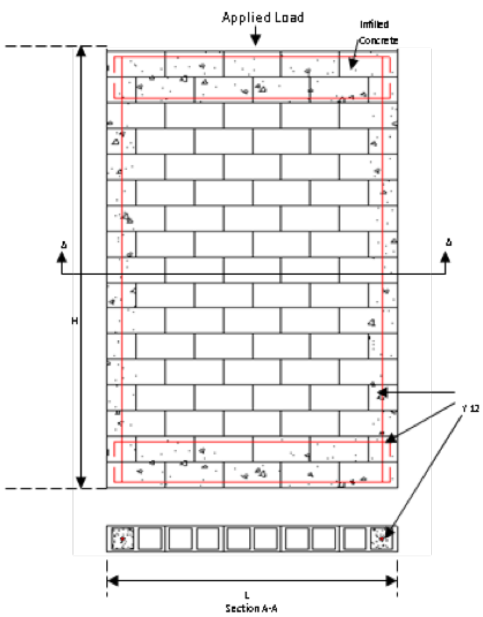

FIGURE 7. Detail of CMU wall-column

Therefore, partially reinforced masonry infill wall-column is going to be the main idea in this research. The maximum compressive strength of the mortar was also tested for 28 days. Concrete masonry infill wall-column is tested for compressive strength of 28 days.

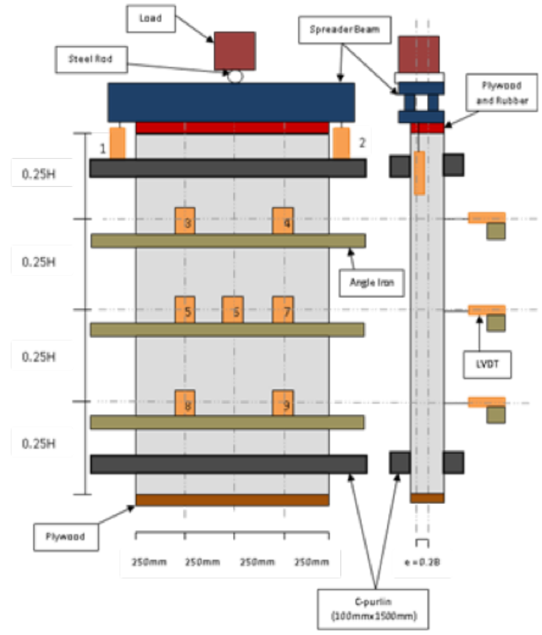

FIGURE 8. Infilled CMU Wall-Column setting out

RESULTS AND DISCUSSION

Based on the objective of the study, a result and parameter were obtained by conducted experimental work for both two masonry shear walls-column. From the analysis the behavior of load-displacement for each wall that has a different thickness of masonry unit need to be studied. The results and data analysis were carried out by analyzing the entire load and displacement graph that obtained from the experiment data output. The most important output in this study is to obtain and determine the maximum load for walls. In this study calculation on the compressive strength and compressive stress of the masonry shear wall is based on BS EN 1996-1-1:2005. Graph load displacement was plotted to find the interaction between the ratio of strength and stress of the walls.

As for masonry wall, the most crucial is the compressive strength and tensile strength. Masonry is extremely high in compressive but very weak against tensile and shear. To increase the tensile capacity of wall, reinforcement is required to do so. When reinforcement is added, compressive strength also increases. So, infill wall with partial reinforced is going to be the main idea in this research. The sample walls are going to be subjected to compressive strength till it is failed. The results from this study will provide a significant understanding of the strength of local in-filled reinforced CMU wall-column. There is currently no data on locally produce CMU wall and this study can provide data, specifically the compressive strength. This study can refer as part of overall local in-filled wall-column research program.

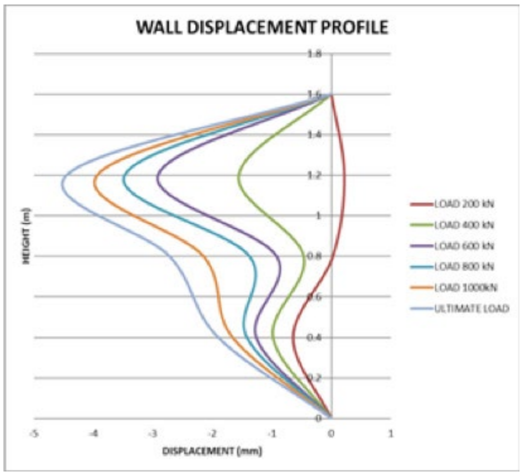

FIGURE 9. Wall Displacement Profile of CMU Wall-column

Figure 9 and Figure 10 shows the graph of wall displacement profile for both wall-column. Based on the test results that have been carried out, the 190x1000x1600 Y12 sample appears to bend more at 1200 mm from the wall soffit. This behavior proves the fact that from the top of the wall, the bending moment is stronger at 1/4 height from the top of the wall. Furthermore, LVDT are not placed at the top and bottom walls, so to achieve a lateral displacement profile, it is safe to consider as zero displacement.

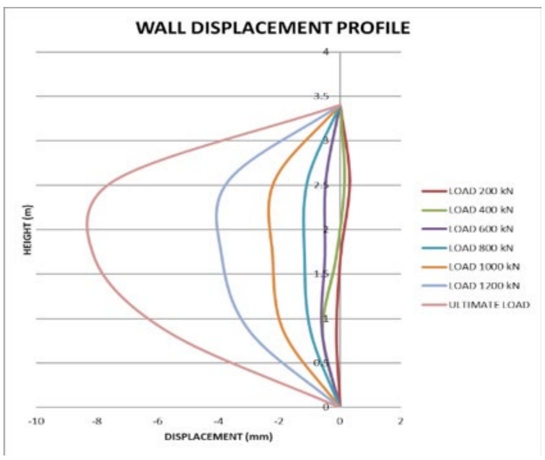

FIGURE 10. Wall Displacement Profile of sample 190x1000x3400, Y12

Sample 190x1000x3400 Y12 is known as slender wall. The findings of the analysis showed that the bending moment approaches the maximum limit at the center of the wall. At the ultimate load, the lateral displacement becomes greater than the loading of 1200kN. Thus, it can be illustrated by the fact that the wall starts to bend more faster when the ultimate load is nearly to archived. After initiate at certain loading, the cracking of the wall was observed start at the early state of the experiment. Crack also lies at the corner of the wall-column and after reach a maximum loading the diagonal crack was occur at the wall. All the cracks was lie along the mortar joint. The difference crack at the top and bottom of the CMU wall-column. From the observation of the experiments, each sample representative failure modes are presented in Figure 11 and Figure 12. The difference between the brick joint interfaces described both samples. In the top and bottom portion of the samples, some slight cracking was found, and no pure vertical cracking was observed.

FIGURE 11. Out-of-Plan Crack of Masonry Wall-Column

FIGURE 12. Crack due to tensile failure

Both walls were only subjected to pure lateral loading in this experiment. The capacity of load control for this experiment is 0.0035 mm / s. As for wall 1, it was observed that, the first crack appeared at the bottom of the wall-column connected to the foundations. While, on the first and second layers of the masonry wall, a small crack was found. In this stage, the wall starts to move due to the imperfection of the starter bar to the column reinforcement. These prevent the connection from holding the wall to move on during the experiment. The opening between mortars along the wall was measured. It is seen from the calculation that the maximum displacement took place at 190 mm from the bottom of the wall. Same as wall 1, the first crack of wall 2 also occur at the first layer of the masonry wall-column. At this stage, several horizontal cracks occurred along the mortar joint and surface of the wall-column. As a load increase more cracks appeared at the foundation of the wall-column and the crushing occurs on the surface of the wall as shown in Figure 15 and Figure 16.

The applied lateral load on the sample was induced the alternate tension and compression stress. The cracks have developed whenever the wall surface subjected to tension stress. It was discovered that a lot of cracks have propagated in the range of moderate to high stresses in the wall surface. Sample 1, CMU Wall-column with height of 3440mm, the optimum load is 1370.03 kN and for sample 2. CMU Wall-column with height of 1600mm, the optimum load is 1121.4kN. The wall failed due to local crack on masonry and cause by weakness of mortar joint. The gravity loads apply to the wall act as a gravity load (axial force) to strengthen the mortar joint of the wall. The crack was appearing at the second layer for both wall because at that layer, there is no reinforcement and concrete fill into the masonry unit (uninfill block). Furthermore, there is some error during the construction stage, where there is no starter bar that tie column and foundation. This had caused the wall to fail earlier due to local crack on masonry.

FIGURE 13. Local crushing on masonry

FIGURE 14. The inside of wall view

FIGURE 15. Failure of Wall Sample

FIGURE 16. Local crushing on masonry

CONCLUSION

This paper presents the findings of an experiment on the behaviour of concrete masonry wall-column infill under static loading. The purpose of the test was to check the effectiveness of a wall-column design solution for masonry infill that capable of solving its weakness when subjected to static loading by ensuring a potential for deformation without damage and reduced stiffness compared to conventional solid masonry infill structure. The research was conducted experimentally on both masonry walls-column under static load, and all the data and findings were carried out and discussed earlier. It can be concluded from the output obtained:

1. Masonry wall-column compressive strength is greater than ordinary wall-column compressive strength. It demonstrated that the compressive strength of the masonry wall-column was quite strong. To measure the strength of the wall-column, the combination of shear stress and tensile stress in masonry walls-column is critical.
2. The result gain from the Eurocode 6 and BS 5628 comparison concludes that the shear potential of both walls seems to have a different value. However, in way to design and construct the local CMU, it is relevant to use both codes of practise and can be applied to construction techniques in Malaysia.
3. Relationships between mortar joints of the walls represent a potential weakness in the structures that

resisting lateral forces because of their critical stress combinations that form during lateral sway in those regions.
4. In the locally of the masonry wall-column, several cracks have propagated. On the bottom of the wall and surface of the wall-column, most of the cracks have formed.

This research can be extended for the different type of CMU. The existing work is only concern with the 190mm size CMU and 1600mm and 3400mm height. Furthermore, the reduction factor of the masonry wall design from BS 5628 can be proved as manipulating the eccentricity of the wall. There are several other codes of practice that are not included in the report, such as the Australian, American, Canadian and Canadian Code of Practice. The comparison of the different codes would achieve better results. Leg placement while operating the car pedal is expected to engage with lower leg muscle activity. The finding from this study was supported with the principle of muscle loading to joint movement while coordinating the pedal. The primary muscle for pedal are numerous, however each muscle work differently based on the tasks. It consists of biomechanical movement in operating the pedal by applying different muscles and joint angle to control the pedal. In this study, the right TA is the prime mover when releasing the pedal (works in a dorsiflexion with ankle joint movement is less than 90 degrees).

In addition, different actions produce different muscle activation. In this study, pressing activity shows the lowest activation value compared to releasing action for TA muscle. Based on the study, TA muscle contracted below than 5 μV for half pressing action. It shows that during half-pressing action, the TA muscle is in the rest condition. All in all, this study shows that the TA muscle works differently according to the car pedal actions. This action influences the driver's state when operating the car pedal.

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DECLARATION OF COMPETING INTEREST

None

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