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Experimental investigation of long interlocking brick column subjected to eccentric load

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Abstract. The Industrialized Building System (IBS) is referred as advanced construction technique which involved the prefabrication of construction components in controlled environment and then installed on site. It promotes faster, neater, safer, easier and cheaper construction works in future. Interlocking Brick (Blockwork System) is one of the IBS which has not commonly known in Malaysia. The key objectives of this research are to investigate the compressive strength of long interlocking brick column with cement mortar and SikaGrout®-215 filler under concentric and eccentric load, in addition to study its failure mechanism and compare the experimental result with existing design code. Four number of 2.3-meter height column was built by using interlocking brick with Y12 steel bar and different filler and performed compressive strength test and the result is compare with the existing design code which is Eurocode 2 and BS 8110. From the research, Interlocking brick column with cement mortar filler had lower compressive strength capacity compare to column with SikaGrout®-215 under concentric and eccentric load. In term of failure mechanism, the column samples were failed by sudden crushing of interlocking brick. For column sample with grout, the percentage of difference of BS 8110 and Eurocode 2 modified equation compare to the experimental result is 10.20% and 12.56% respectively under concentric load. Moreover, for column sample with mortar infill, the percentage of difference is 67.16% for BS 8110 and 73.23% for Eurocode 2. For eccentric load, Eurocode 2 did not provide reasonable agreement where the percentage difference is range from 66.40% to 482.47%. The optimum design of interlocking brick column in this study is the column sample with SikaGrout®-215 as it has higher compressive strength compare to Type M cement mortar.

1. Introduction

IBS is a pre-fabricated system at which structural components are manufactured in factory, transported and assembled on-site. Undoubtedly, it offers innovative and sustainability in term of reduced materials, labor, and wastage, speed up construction time and improve quality by construction standardization. In order to increase the application of IBS to cope for current construction challenges, further researches and studies shall be always performed to increase the technical knowledge and confident level of Malaysia construction industry in adopting the new technology.

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1.1 Problem Statement
The usage of IBS in construction projects in Malaysia is far below the targeted although the usage of IBS increased steadily and gradually, the usage is still low and there is a lot of improvement to be done to promote it usage. This can infer that the application of interlocking brick in construction industry Malaysia is low as compared to conventional construction method. Construction industry in Malaysia afraid to change to new innovative method because they are lack of experience, technical knowledge, and confident in new technology such as interlocking masonry. There is no specific code or standard guideline to design dry stack masonry system. Eurocode 6 has been used to design masonry unit with mortar but not applicable for interlocking brick. Besides, Eurocode 2 were used to design concrete structure only. Further researches and studies on the structural properties and failure mechanism of IBS,s system should be increased to improve the understanding of construction industry regard the IBS. In this research, the compressive strength and failure mechanism of load bearing interlocking brick column is investigated.

1.2 Objectives
The objectives of this study are:
1. To investigate the compressive strength of long interlocking brick column with different type of filler under concentric and eccentric load.
2. To study the failure mechanism of interlocking brick column with different type of filler under concentric and eccentric load.
3. To compare the experimental result with existing design code and propose an optimum design by select a suitable type of filler.

1.3 Scope of Study
This research is carried out to study the structural behavior and failure mechanism of interlocking brick column system under concentric and eccentric load so that the IBS blockwork system can be implemented in residential building construction. Four number of 2.3-meter height column was built by using interlocking, Y12 steel bar, type M cement mortar, and SikaGrout®-215. The column is tested under concentric and eccentric load until it fails. The ultimate axial capacity of interlocking brick column is investigated in this research and an optimum design is proposed. The experimental result will be compared with theoretical calculation modified from Eurocode 2 and BS 8110.

2. Literature Review
Industrialized Building System (IBS) is a construction process that use standardized building components which manufactured in controlled environment either in a factory or on-site, then transported or assembled into a structure at construction site [1]. IBS survey conducted in 2003 indicated that only 15 percent of construction projects in Malaysia had implemented IBS method, and IBS roadmap's mid-term review in 2007 stated that only 10 percent of complete projects involved IBS in 2006 which far below the targeted of 50 percent [2]. The application of IBS in Malaysia construction industry is low because of; early failure of closed fabrication system; low cost of unskilled foreign labor; high capital investment; lack of expertise and knowledge in IBS; necessity of on-site specialized skills for assembly of components and lack of special equipment and machinery.

IBS blockwork system is one of the building system in IBS technique. Blockwork system with standardized properties, controlled quality and aesthetic in appearance have made the construction easier, faster, neater and safer. On the other hand, interlocking brick are believed to have the potential to overcome the construction problems such as high construction cost, material wastage, delay, environmental impact, large number of labor required, and energy consumption [3]. Construction using interlocking brick is two times faster than using conventional method and it provide superior levels of performance in harsh environment compare to concrete and conventional brick [4].

The interlocking brick is widely used in the construction of building due to its high flexibility, it can be used to construct load bearing wall, column, beam and other structural or non-structural member.

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Dry stack masonry system is economical and time saving as it eliminates the need of mortar layer because the interlocking brick are made with unique protruding part and recess part which can fit to each other and aligned automatically in horizontal and vertical direction. The brick can be laid without mortar layer can save up a considerable amount of cement. Nonetheless, mortar-free system allow movement at the interlocking face to facilitate the dissipation of energy when seismic event or earthquake occur [5]. In order to study the structural behavior and the compressive strength capacity of interlocking brick column, experimental test of compressive strength test was performed on the column and analytic study was carried out.

Column is a vertical structural element that is been designed to resist load from roof, slab, and beam down to the foundation. It is a member in structural engineering which subjected to axial compressive load and may have to resist bending moment due to eccentricity of loads. Column are normally made by reinforced concrete and steel. Column are divided into two categories which is braced and unbraced columns and another category is slender and non-slender column. [6]. In this research, 2.3-meter height column sample was built according to the concept of reinforced concrete column by introduced four Y12 rebar into the cavities of square interlocking brick column and reinforced by mortar infill. Compressive strength test was performed on the column to represent the axial load acted by the structural component of real building and Eurocode 2 and BS 8110 was used to determine the design axial resistance of the column sample.

3. Methodology

The main objective of the research is to study compressive strength and failure mechanism of interlocking brick column subjected to concentric and eccentric loading using compression machine. In addition, the result obtained from the experiment was compare to the modified Eurocode and BS 8110 equation. This research methodology consisted of 3 key activities:

1. Preparation of interlocking brick column sample.
2. Material test on cement mortar, grout, Y12 reinforcement, interlocking brick
3. Compressive strength test on column sample
4. Analytic Study.

3.1 Column Sample Preparation

The brick use in this study is provided by Oasis Gallant Sdn Bhd which have dimension of 250mm x 125mm x 100mm as shown in Figure 1. Two type of filler is used in this study which is type M cement mortar and SikaGrout®-215, cement mortar was prepared in accordance to ASTM C270 [7] while SikaGrout®-215 was prepared according to it product sheet. Column sample was constructed by placing 2 wall brick together to form a 250 x 250 mm square, followed by stacking 2 wall brick on top. The height of a wall brick is 100 mm which means that a total of 23 layers of interlocking brick was to stacked up to 2.3-meter height. The column is casted in 2 stages to ensure the filler to fully occupy the cavities of interlocking brick, first stage is stacking the interlocking brick up to 1 m height. Leveling ruler is use to ensure the column is aligned vertically. After that, four number of 1.3-meter-long Y12 reinforcement is insert into the cavities of the interlocking brick. Next, the filler is pour into the cavities until full and the column is left for 24 hours before proceed to stage 2 by stacking of another 1.3 m height column above it. The column sample was casted in the Fire Testing Laboratory, Universiti Teknologi Malaysia and cured for 28 days to ensure the design strength of mortar and grout is achieved.

Figure 1: Interlocking brick by Oasis Gallant Sdn Bhd

3.2 Material Properties Test

Material property test involve compressive test of cement mortar, interlocking brick, SikaGrout®-215, and tensile test of Y12 steel bar. Type M cement mortar with cement to sand ratio of 1: 3 was prepared and the expected strength of the mortar is 17.2 N/mm2 at 28 days. Another filler which is SikaGrout®-215 was prepared by mixing 4 liters of water to a pack of 25kg grout and the expected strength stated in the product sheet at 28 days is 65N/mm2. In addition, the expected tensile strength of Y12 steel bar is 460N/mm2. The objective of carry out the material property test is to ensure that all the material used in this study are able to achieve the minimum required strength specified in the design standard. The values obtained from the experimental test could be used in the analytic study later.

3.3 Column Test Experiment

Compressive strength test is conducted after 28 days to investigate the compressive strength and failure mechanism of interlocking brick column under concentric and eccentric load. This test provides a guideline to propose an optimum design of interlocking brick column based on the result obtained. Four number of column of 2.3-meter height was built by using interlocking brick with reinforcement and filler and tested to study the failure mechanism. Two specimens with mortar and grout was tested under concentric load and another 2 specimens was tested under eccentric with 62.5 mm eccentricity which is a quarter of it width. The arrangement of the interlocking brick and it infill is shown in Figure 2 and the experiment set up for eccentric load is shown in Figure 3. Overhead crane is used to lift the column to the compression machine, the top and bottom of the specimen is covered by a steel plate to ensure uniform pressure is transmitted to the specimen. For eccentric load, a 130mm steel plate is placed on top of the specimen to provide an eccentricity of load at 62.5mm. Apart from that, the specimens are loaded at 0.05mm/s [8] until it fails and the maximum load sustained is recorded.

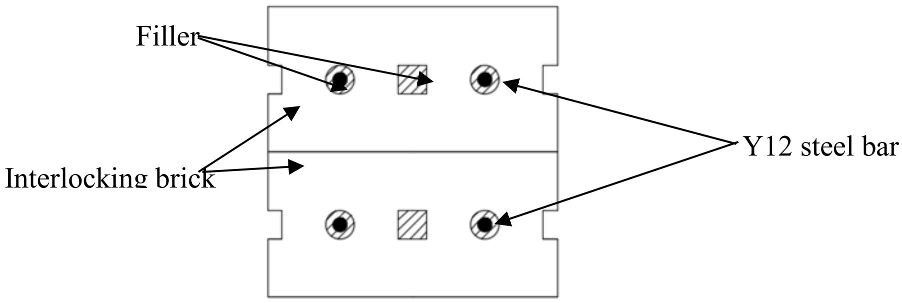

Figure 2: Arrangement of interlocking brick and filler

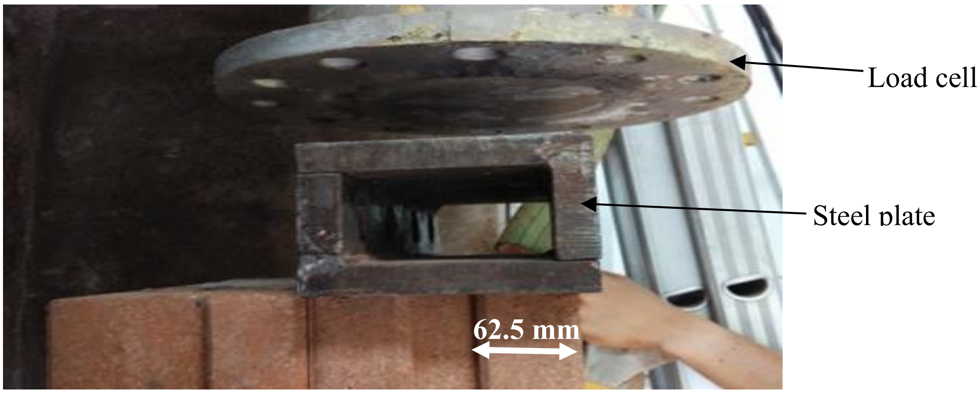

Figure 3: Eccentricity test set up

3.4 Analytic Study

Data and result obtained from the column test was extracted from the computer program and load stroke curve was plotted. Load stroke curve shows the relationship between load and stroke where the load increased until maximum and started to decreases after the maximum load reached indicates that the column sample was failed. The failure mechanism of column sample under concentric and eccentric load was observed and recorded. The maximum load attained from the load stroke curve was compared with the result from theoretical calculation using standard design code BS 8110 and Eurocode 2 because currently no standard design code is available to design interlocking masonry. Modification was done on the BS 8110 and Eurocode 2 design axial resistance equation to predict the result of the experiment subjected to concentric load. For eccentric load, Eurocode 2 column design chart is used in order to obtained the design axial resistance of the interlocking brick column. BS 8110 design code is not adopted for eccentric load in this study because the minimum fck value is 25N/mm^2 and minum value for d_2/h is 0.75 which is far bigger than the d_2/h and f_{ck} value of this study which is 0.2 and 4N/mm^2 respectively.

BS 8110 : $N_{Rd} = 0.35f_{cu}A_c + 0.67f_{yk}A_s$ (1)

Eurocode 2 : $N_{Rd} = 0.567f_{cd}A_c + 0.87f_{yd}A_s$ (2)

A_sf_{yk} / bhf_{ck} (3)

M_{Ed} / bh^2f_{ck} (4)

N / bhf_{ck} (5)

4. Results And Discussion

The results of material properties and experimental compressive test on column sample until it fails was obtained as shown in Table 1 and Table 2 respectively. The failure mechanism of column specimen is shown in Figure 4. No cracks are observed for specimen with grout but specimen with mortar cracked before failure is achieved. Generally, all column specimen was failed by sudden crushing of interlocking brick at maximum load. Sudden crushing of interlocking brick at mid height of column is observed under concentric load and sudden crushing at the top part of the column is observed under eccentric load. The load stroke curve for all the specimens are shown in Figure 5 and Figure 6.

Table 1: Materials Properties

Specimen	Compressive/ Tensile Strength (N/mm^2)			Mean Value (N/mm^2)	Design Value (N/mm^2)
	1	2	3		
SikaGrout-215	60.41	66.75	70.59	65.92	65.00
Mortar Type M	21.84	20.22	21.29	21.12	17.20

Interlocking Brick	5.86	4.34	4.30	4.32	-
Y12 Steel Bar	615	613	611	613	460

Table 2: Experimental result for column subjected to concentric and eccentric load

Type of load	Specimen	Maximum Load, kN	Maximum Stroke, mm
Concentric	SG1	385.00	22.22
	CM1	94.55	20.26
Eccentric	SG2	135.82	8.30
	CM2	50.44	13.68

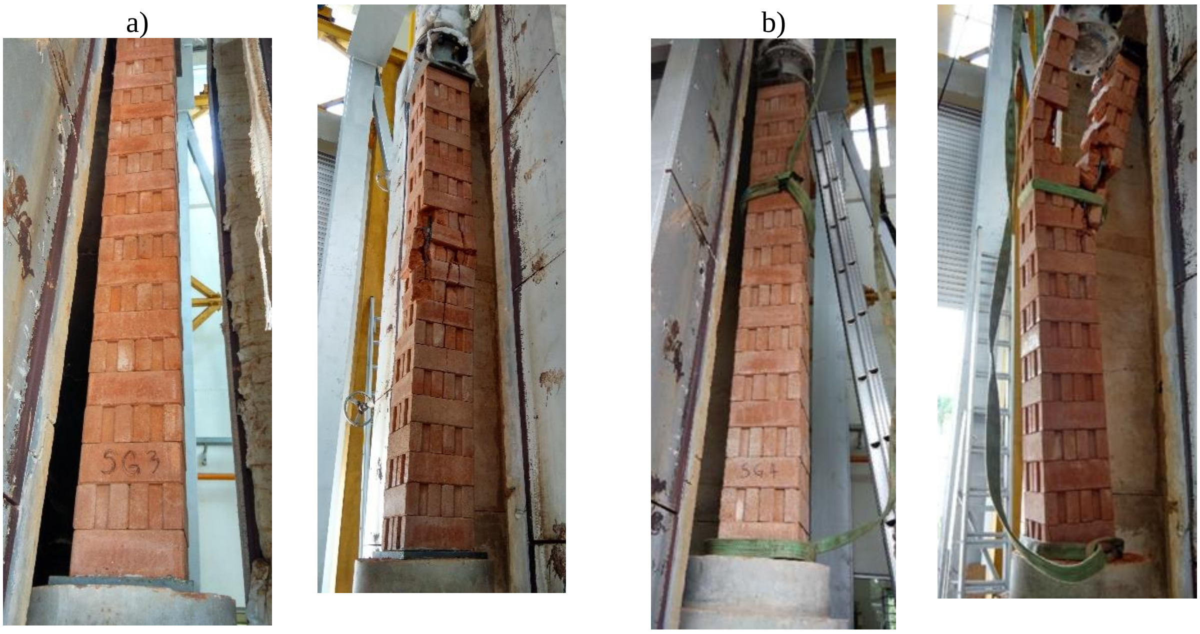

Figure 4: Failure mechanism under a) concentric load; b) eccentric load

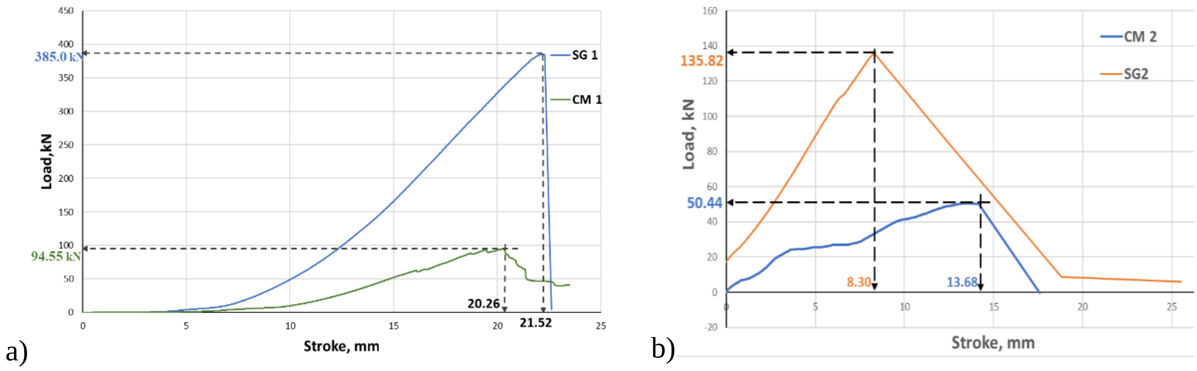

Figure 5: Load stroke curve of specimen with mortar and grout subjected to a) Concentric load; b) Eccentric load

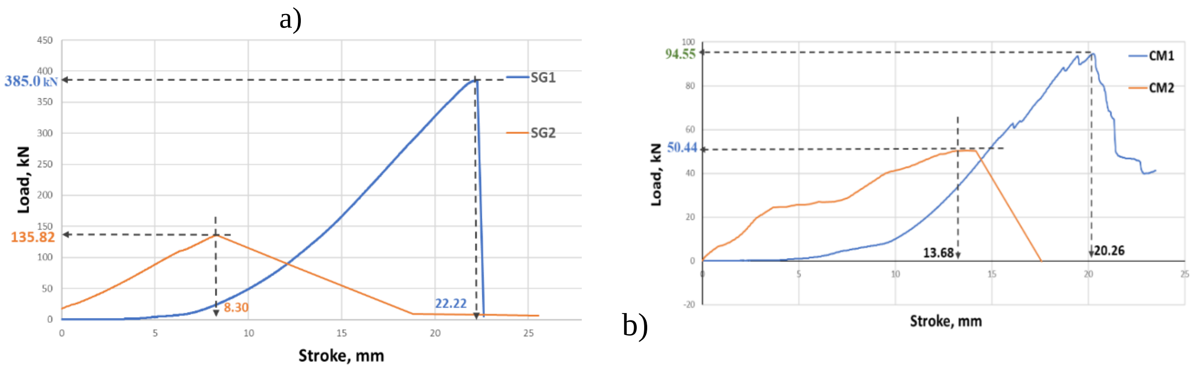

Figure 6: Load stroke curve of concentric and eccentric load for a) SikaGrout-215; b) Type M Mortar

4.1 Analytic Study

The material properties were used to calculate the axial resistance of the column sample using modified Eurocode and BS 8110 equation. The results of the column test were used to compare with the theoretical calculation. For concentric load, equation 1 and 2 is used to determine the design axial resistance of column while equation 4 to 6 is used to determine the design axial resistance of column caused by eccentric loading. The comparison of experimental result with theoretical calculation of column under concentric and eccentric loading is shown in Table 3 and Table 4 below.

For specimen with Sikagrout-215 under concentric load, the percentage different of the design axial resistance between experimental result and theoretical calculation is small which is 10.20% for BS 8110 and 12.56% for Eurocode 2. However, the result is not satisfied for specimen with Type M cement mortar where the percentage of difference is 67.16% for BS 8110 and 73.23 for Eurocode 2. Therefore, the theoretical calculation is applicable for specimen with Sikagrout-215. The compressive capacity of specimen with mortar is far below the theoretical result might be due to partially filled of interlocking brick as the workability of cement mortar is lower than Sikagrout-215.

For specimen subjected to eccentric load, the percentage of different between the experimental result and theoretical calculation is 482.47% for Type M cement mortar and 66.40% for Sikagrout-215. The big difference between the results indicate that Eurocode 2 have overestimate the design axial resistance of interlocking brick column with Sikagrout-215 and Type M cement mortar subjected to eccentric load. Based on the result obtained from the experimental test, specimen with Sikagrout-215 as filler is the optimum design as it has stronger compressive capacity than specimen with Type M cement mortar.

Table 3: Comparison of experimental result with theoretical calculation of column under concentric load

Modified Equation	Type of filler	N_{Rd}, kN, Theoretical	N_{Rd},kN Experimental	Percentage difference, %
BS 8110 (eq. 1)	Grout	349.37	385.00	10.20%
Eurocode 2 (eq. 2)	Grout	440.29	336.66	12.56%
BS 8110 (eq. 1)	Mortar	287.93	94.55	67.16%
Eurocode 2 (eq. 2)	Mortar	353.20	94.55	73.23%

Table 4: Comparison of experimental result with theoretical calculation of column under eccentric load

Type of filler	Experimental Axial Load, kN	Eccentricity, mm	Design Moment, M_{Ed} kNm	Theoretical Axial Load, kN	Percentage Difference, %
Mortar	50.44	62.5	3.1525	293.8	482.47%
Grout	135.82	62.5	8.48875	226	66.40%

5. Conclusion

This research presents the compressive strength and failure mechanism of interlocking brick column subjected to concentric and eccentric load.

1. Based on the experimental result of column test, interlocking brick column using Sikagrout-215 have higher compressive capacity than column using Type M cement mortar. The capacity of column using Sikagrout-215 is 385kN under concentric load and 135.82kN under eccentric load. Compressive capacity of column using Type M cement mortar is 94.55kN under concentric load and 50.44kN under eccentric load.
2. All of the column failed by sudden crushing of interlocking brick. For concentric load, the column failed by sudden crushing at the mid height of the column. In addition, column failed by sudden crushing at the top part of the column is observed when eccentric load is applied.
3. For concentric load subjected to column with Sikagrout-215 filler, existing design code give the smallest percentage of different between the experimental result and theoretical calculation which is 10.20% for BS 8110 and 12.56% for Eurocode 2. For column with Type M cement mortar, the percentage different is 67.16% for BS 8110 and 73.23% for Eurocode 2 where both the design code has overestimate the compressive capacity of interlocking brick column with Type M cement mortar.
4. For eccentric load, Eurocode 2 have overestimate the design axial resistance of interlocking brick column with where the percentage of difference is 482.47% for Type M cement mortar and 66.40% for Sikagrout-215. Eurocode 2 is not suitable to be used to design interlocking brick column with Sikagrout-215 and Type M cement mortar.
5. The optimum design of the column is the interlocking brick column with Sikagrout-215 as filler as it have higher compressive capacity than Type M cement mortar.

6. Acknowledgment

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