Finite Element Analysis of Green Concrete Hollow Block (GCH block) System

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Abstract. This paper presents the finite element analysis (FEA) study of Green Concrete Hollow Block (GCH block) system. The designed system is the new approach for Malaysia construction industry to replacing the traditionally construction system. The blocks are interconnected through tongue and groove besides 20 mm protrusion provided for the self-alignment features. This study utilized explicit dynamics procedures offered in ABAQUS software to analyse the GCH block prism under axial loading. Several input parameters are taken from previous study to complete the analysis process. The simulation is conducted to analyse the structural behaviour in terms of its ultimate load, cracking patterns, deformations and also the stresses distributions. The analysis results show that the Green Concrete Hollow Block (GCH block) system is suitable to replacing the traditionally bonded masonry system.

1. Introduction

In Malaysia, the demand for affordable quality housing has increased over the years. According to The Star online newspaper [1], the demand for Malaysian housing is about 97, 500 units per year. But the annual completion rate is only at 78, 216 units per year. For the past few years, the Malaysian construction industry has seen the growth of using reinforced concrete frame structures and brick masonry as its construction system. These traditional methods have met with various problems such as its low quality, labour intensive and hence slower the construction phase [2]. Furthermore, the hike up of Malaysian housing price has also become a problem faced by low- and middle-income class. It been stated by New Straits Times online newspaper [3], that almost 73.3% from 49,452 completed house units were priced at more than RM 250,000 and its considered unaffordable for low-income group as specified by Bank Negara Malaysia.

The emergence of this problem indicates that the Malaysian construction industry need to change from the traditional method into the Industrialized Building System (IBS) method. However, the Malaysian construction industry is still 20 years behind in the adoption of the IBS system [4]. Through the recently launched Construction Industry Transformation Plan (CITP 2016-2020) [5], Malaysian government together with the Construction Industry Development Board (CIDB) will be emphasizing on a construction system which is environmentally sustainable, in line with the requirements of green construction. Hence, a study on the development of green concrete hollow block (GCH block) system as the alternative for the IBS system is needed.

According to [6], the use of structural masonry will result a cheaper and faster construction compared with traditional construction method especially for low-rise buildings. In most developed countries, masonry structure is still the important material for housing, monuments and suitable for a variety of structural applications. Masonry construction system usually consists of two components, namely, the
masonry units and the mortar unit. Typical masonry units may come up either in solid or hollow types and made up with a variety of materials such as clay bricks, blocks of stone, concrete blocks, pressed earth brick, calcium silicate bricks, soft mud bricks etc. [7]. Masonry block is also characterized by its dimensions, its mechanical, thermal and acoustic properties [8]. Meanwhile, the mortar unit sometimes being removed as the mortar joints has been proved by many past literature studies that causing delayed and have presented a significant loss of wall performance due to physical, chemical and mechanical degradation of the mortar layer [2,6,9]. These led to the innovation of the mortarless masonry construction.

A study conducted by [10] has shown that recent developments in the masonry block system, especially in Malaysia was the PUTRA block system developed by Universiti Putra Malaysia (UPM) in the year 2004. Since then, no other developments had been conducted in Malaysia on the masonry block system. Hence, this study was aiming to develop a new, efficient design of Green Concrete Hollow block (GCH block) system based on recent development of the masonry block system in Malaysia. The design is expected to be sustainable, meeting modular coordination without neglecting its structural behaviour and ease of construction method.

2. Background
According to [10], the masonry construction system has been used in Malaysia since the year of 1511 which is the A Famosa heritage building located in Malacca. The advancement of the masonry construction system in Malaysia is continued till this day whereas the latest innovation of the masonry system is the PUTRA block system developed by UPM in year of 2004 [6]. The revolution of the masonry construction system is kept on evolving to replacing the traditionally bonded masonry construction system to new masonry construction material so called interlocking loadbearing hollow block (ILHB) system. As been agreed by several researchers that the consumptions of mortar give significant effect towards the environment and also the construction process [2,6,9] the utilization of these ILHB system needs to be continued. As such, the Green Concrete Hollow Block (GCH block) system is proposed. Figure 1 shows the unit type of the design which consist of the stretcher block, half block and corner block unit. The design is following the recommendation stated by ASTM C90 and MS 1064 standard design codes. The designed also has been copyright under the title of Green Concrete Hollow Block (GCH block) system [11].

![Figure 1. Green Concrete Hollow Block (GCH block) unit [11].](image)

3. Methodology
In this study, explicit dynamic procedures were chosen for the damage analysis of quasi-brittle material such as concrete. The tested GCH block prism is idealized by homogeneous material like concrete. The GCH block prism was assembled with two stretcher block unit at the top and bottom while another two-half block unit configured at the middle course of the prism as in Figure 2.
Figure 2. Configuration of GCH block prism course in ABAQUS.

The prism was meshed using element type of 8-node linear brick with reduced integration and hourglass control (C3D8R). The individual modelled elements are properly connected to each other by using surface-to-surface contact techniques with friction coefficient of 0.603 applied on all contacted surfaces. The loading was introduced at the top surface with kinematic coupling type technique and controlled by 3 mm/min displacement. Meanwhile, the support condition is provided at the bottom surface using the same technique and fixed value of ‘0’ with no deformation or rotation. The material parameter of this study is using previous computational work data from [12]. The data which taken from the studies is the Concrete Damaged Plasticity (CDP) material model tabulated as in Table 1 below.

| Parameter of CDP model | 2000 | 32 |
|------------------------|------|----|
| Density (kg/m³)        | 2000 |    |
| Concrete elasticity    | 11   |    |
| Elastic modulus, E (Gpa)| 1.16 | 0.67 |
| Poisson ratio, ν       | 0.2  |    |
| Viscosity, µ           | 0.001|    |
| Compressive behaviour from experiment |     |    |
| Tensile behaviour from experiment |     |    |
| 16.96                  | 0.0005078 | 0 | 1.8 | 0 | 0 | 0 | 0.16667 |
| 21.24                  | 0.0013542 | 0 | 1.5 | 0.0001 | 0.44444 |
| 11                     | 0.0026122 | 0.2290909 | 0.7 | 0.0005 | 0.61111 |
| 16.96                  | 0.0055439 | 0.8681818 | 0.5 | 0.0008 | 0.72222 |
| 9.5                    | 0.0080831 | 0.7636363 | 0.2 | 0.0015 | 0.88889 |
| 5.2                    | 0.0103684 | 0.8863636 | - | - | - |
| 2.5                    | 0.0124844 | 0.9440909 | - | - | - |
| 1.23                   | -     | -   | -   | -   | -   |

The CDP material model is important in this study as it resembled the concrete failure mechanism in computational work simulation. The output data from simulation work by [12] has been validated with
previous experimental work conducted by [13] whereas the simulation is concluded that with mesh size of 6, the computational work is able to predict the experimental work results with 0.73% difference compared with the actual experimental work.

4. Result and discussion

The GCH block was configured in a prism shape with dimension of 600 mm height, 300 mm length and 150 mm width. The configuration of the prism was built by stacking the stretcher and the half block unit. The mesh size for the computational study is set to be constant at mesh size 6 and resulting about 345.254 kN of the ultimate load. The ultimate load obtain is higher than the experimental result of Putra block prism conducted by [13]. The higher ultimate load obtain is due to the internal design shape at the middle web of the GCH stretcher block unit which is larger than the Putra stretcher block unit. The capability of the design to withstand the axial load from the compressive test resulted a remarkable ultimate load with more than 10% increment of the ultimate load.

4.1. Failure modes of GCH Block prism

The failure of the GCH block prism is observed in terms of its crack pattern and the deformation behaviour. Figures 3 (a) illustrated the crack pattern occurred when the maximum load obtained. As been observed during simulation process, the higher stress occurred between the bed joint of the block unit as in Figure 3 (b). As the load increased, the crack start to initiate at the web-shell of the half block units and propagated upwards forming a vertical crack towards the shell of the upper stretcher block unit.

![Figure 3. Crack pattern of GCH block prism.](image)

Meanwhile, Figures 4 shows the deformation of GCH block prism under axial loading. The curvature of the web is visibly seen especially at the half block unit in the middle course of the prism. The deflection of the web is similar with study conducted by [14] and it was agreed that the web deflection is certainly induces tensile stress at the bottom of the webs.
4.2. Stress distribution along height

Figure 5 (a) shows the cut view of the GCH block prism across its height to show the maximum principal stress distribution inside the prism during its ultimate load. It is clearly observed that the highest tensile stress (1.60 MPa) is induced at the lower part of prism course that causing the web to fail first as in Figure 5 (b). The result is concluded that the initial failure of walls is due to the web splitting as reported by [14].

5. Conclusion

From the analysis studied, the following conclusion can be drawn:

1. The ultimate load obtained by GCH block prism is higher than the previous Putra block prism study conducted by [12] and [13].
2. The deformation of the web is almost similar with previous study that concluded the failure of the prism is initiated by the web splitting especially at the prism middle course.
3. The GCH block system dimension is satisfying the modular coordination size required by MS 1064. The internal dimensions also have been specified with a minimum dimension of 25 mm in accordance with ASTM C90.
4. The unique shape of the protrusion is introducing self-alignment features whilst the hollow features to accommodate vertical reinforcement at the desired distance.

5. The FEA studies provide relevant evidence that the Green Concrete Hollow Block (GCH block) system can be used as the alternatives in masonry construction system.

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