Bending Behaviour of Post-tensioned Interlocking Block Masonry Wall

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Abstract. Interlocking soil blocks are one of modern techniques of house construction due to its durability. The use of these blocks fits suitably within the production cost and environmental quality as an alternative to fired bricks. This paper reports the result investigation done on walls made using interlocking soil blocks. Three types of walls with different combination of reinforcements were tested. The performance is assessed in terms of cracking patterns, failure modes and load-deflection characteristic. Results show that the ductility of all walls are good and wall with post-tensioned bars performed the best. The post tensioned walls are able to deflect up to 42% without any failure compare to non pre stressed wall. The walls with combination of reinforcement and post –tensioned systems are more ductile compare to walls with reinforcement only. It is concluded, post-tensioned wall developed using interlocking soil blocks can be used in reinforced and post-tensioned masonry application instead of conventional brick masonry.

1 Introduction

Production of building blocks over the years has give good performance and benefits to the construction industries. The demand for residential houses has increased year by year in order to accommodate the rising population in developing countries [1]. Interlocking blocks was invented as an alternative to conventional masonry bricks in wall for low-rise buildings. Interlocking soil cement blocks (ISCB) become a new trends in construction industry since it is a low cost material with only required non skilled labor. Unreinforced masonry walls are prone to failure when subjected to overstress which caused by out-of-plane load for example seismic load, high wind pressure and in-plane loads in order to overcome the failure, post tensioning of structural masonry has been study by other researcher and it is reported that the used of post-tensioning has increase the flexural and the shear capacity. Interlocking-block masonry results in relatively high efficiency factors in axial compression and eccentric-to-axial capacity ratio when compared with mortar bedded masonry. Unlike conventional masonry, the flexural capacity of interlocking-block

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masonry normal to the bed joint is higher than that parallel to the bed joint. A better interlocking mechanism of channel-shaped interlocking blocks, as compared to I-shaped blocks, leads to a relatively higher flexural capacity of the former [2]. Soil-cement blocks are used for the load bearing masonry and the quality was influence by the initial moisture content of the block and block characteristics (strength, cement content, and surface characteristics). Major findings are initial moisture content of the block at the time of construction affects bond strength and use of partially saturated blocks is better than dry or fully saturated blocks; as the cement content of the block increases, its strength increases, and surface pore size decreases leading to higher bond strength irrespective of the type of mortar [3]. By increasing the cement content, the density, the stability of the material is greatly enhanced and becomes more acceptable for use in humid areas [4]. Strength testing of soil cement specimens should be undertaken in a saturated condition, as the inherent strength of dry clay content may provide a misleading impression of compressive resistance. Due to the inherent variability of the main constituent material strength values should be specified in terms of 95% characteristic rather than average values. Although the test can prove conservative, adopting a one sixth relationship between modulus of rupture and compressive strength provides the basis for rapid and inexpensive field assessment. Although limited, much of the work undertaken on stabilised soil blocks to date has concentrated on the properties of the individual units. Further work is required to consider the suitability of mortars for construction and the properties of stabilised block masonry under compressive and lateral loading [5].

2 Material and method

2.1 Material

The material used in this experiment is interlocking blocks consists of 40% sand, 42% soil, 13% with 5% of water. The interlocking blocks weight per unit is 5 kg with dimension of 250 mm x 100 mm x 125 mm for full blocks as shown in Figure 1 and 125 mm x 100 mm x 125 mm for half blocks. Compressive strength of the blocks has been tested accordance to ASTM C140. Mechanical properties of interlocking block is illustrated in Table 1.

Table 1. Mechanical properties of interlocking block

Masonry compressive strength	10MPa
Masonry tensile strength	0.014 MPa
Steel bar max load strength	41.7 kN
Steel bar grade	460 MPa
Reinforced bar size	10 mm
Steel bar allowable elongation	0.05%

2.2 Test method

Three types of walls made up of interlocking bricks were constructed namely T1, T2 and T3. The wall dimensions are of 375 mm length x 1500 mm height x 125 mm width. Details dimension of the wall as shown in Fig. 2.

Fig. 2. Wall dimension

The first type of wall, T1 has two reinforcement bars inserted into the masonry wall while the second type, T2 have three reinforcement bar inserted into the wall. For the third type of wall, T3 there are two reinforcement bar plus one post-tensioned bar within the wall. In this entire masonry unit, no mortar was used. Detail drawing of all walls were illustrate in Fig. 3.

Fig. 3. Arrangement of reinforcement and post-tensioned in each wall

Grouting were injected to wall with reinforcement bar in order to fill the space between reinforcement bar. The connection between the interlocking brick units was provided by the frogs and the hole at the opposite units. A strain gage was fixed in the tendon before the wall is constructed. A small strip area was grind at the middle of the tendon and the gage was covered with protective layer. All walls were tested horizontally by applying two concentrated line loads as shown in Fig. 4. After the walls have been set, the out of plane load applied by using the hydraulic pump on to the spreader beam. One kN load was applied gradually each time and the readings from linear variable displacement transformer (LVDT) and strain gage were taken. The load was applied in increments of 1 kN until

failure. The failure occurs when the wall has reached its ultimate load which was clearly observed by the drop of reading from the load cell.

Fig. 4. Locations of the measuring instrument and supports

3 Result and discussion

3.1 Service Load

In this experiment, wall opening load and wall deflection behaviour were observed in order to address the service load. Due to difficulty to visually detect the onset of cracking, load deflection curve were monitored in order to observe the change in force in post-tensioned bar and reinforcement bar to find the cause of cracking. Deflection of each type of wall specimen shows small scale deflection curve during the formation of crack and openings and the steel bars have been taking most of the applied loads as illustrated in Fig. 5.

Fig. 5. Load deflection curves for T1, T2 and T3

As we can observe, for T1 there was no dislocation or falling of the bricks during the testing and the wall retained its shape very well and there were no crushing of the blocks. However, the wall did manage to fail at a very low applied load of 7 kN. This is because the

reinforcement bar is allowed to bend inside the wall because there is no anchorage at the top and bottom for the reinforcement bars. Thus, the bending causes the grout covering the reinforcement bar to fail and hence reducing its strength. The ultimate capacity load for wall specimen T2 is 14 kN. After the ultimate load, the wall continues to deflect but without any increment in the load applied. The part of the wall that experiences the greatest deflection is in the middle with a maximum deflection of 31.52 mm. In general, the wall deflect together as a whole with the left and right side both experiencing almost similar deflection. As for wall specimen T3, we can clearly see that the ultimate capacity of wall T3 is 17 kN. Figure 6 indicates that the middle part of the wall experiences the highest deflection which is 43.2 mm compare to the sides which are 19.5 mm in the left side and 29.4 mm in the right side, at the ultimate load. T3 show the best result by able to sustain the highest deflection which about 45 mm. Secondly, as we can observed, T2 and T3 wall specimen are stiffer compared to T1 specimen. Meanwhile, T3 wall has the highest stiffness due to post-tensioning force. Stiffness of wall in the elastic range was not affected by the reinforcement and post tensioned steel caused increment of the flexural strength and ductile of the wall [7].

3.2 Mode of failure

Mode of failure of each wall depends on the arrangement of reinforcement and post-tensioning of the wall. Cracks and crushing locations in each wall are shown in Fig. 7,8,9. As the load increases, more deflection occurs in the opening area of the wall, and that continues until failure at ultimate load.

Fig. 7. Mode of failure of wall T1

Wall T1 experienced grout failure in the reinforcement. Initially there was a linear increment in the deflection curve. As the load reaches 3 kN, openings start to form at bricks that are in the middle of the span, in-between the applied point loads. The openings are caused by the grout surrounding the reinforcement bar giving way.

Fig. 8. Mode of failure of wall T2

Meanwhile, for wall T2, the wall failed through a combination of grout failure and blocks being pushed apart because there is no anchorage for the reinforcements, similar to wall T1.

Fig. 9. Mode of failure of wall T3

Wall T3 has one post-tensioned bar in the middle which undergoes 40% of post-tensioning level which is equal to 16.4 kN, and 2 reinforcement bar at the sides with no post-tensioning force applied to it. Du/Dc ratio for all wall indicate avgood energy absorption capacity and a good margin of warning after crack and before failure occurs [8] and grouted walls exhibit a higher ability to absorb energy almost four times [9].

3.3 Ultimate limit state

The maximum out-of-plane capacity was calculated by adding the applied load to the self-weight of the wall, since the wall was tested horizontally. Ultimate limit state loads were obtained by calculating stress in the tendons using a theoretical formula. The application of interlocking blocks with post-tensioning bars created unique behaviour which by using strain compatibility equations it will not give an accurate result, instead empirical formula

were used. The wall ultimate load capacity was determined using ACI-318 [9] empirical formulas to determine the stress at ultimate in the post tensioning bar using Equation (1), (2) and (3). The formula given by ACI-318 code to find the stress inbonded tendon are:

$$f_{ps} = f_{pe} + 10,000 + \frac{f_{rc}}{100p_p} \tag{1}$$

$$M_n = 0.95 A_{ps} f_{ps} (dp - \frac{\alpha}{2}) \tag{2}$$

$$\alpha = \frac{f_{ps} A_{ps}}{0.85 f_{rm} b} \tag{3}$$

The values for f_{ps} , f_{pe} , f_{rc} in Equation (1) are in psi unit, while in Equation (2) either Mpa or psi unit. All results were standardized to unit Mpa unit. Wall stiffness for linear elastic region was calculated from the experimental results by taking the experimental deflection from central LVDTs and equating it to the deflection obtained from the formula derived from elastic analysis. Accurate deflection prediction of the post-tensioning interlocking blocks after opening is not accurate to follow from durability stand point. The calculate values byusing ACI method were general closer to the experimental values, with ratio of 1.76 to 1.95 as shown in Table 2 which indicates that the post-tensioning of interlock is feasible and can be calculated.

Table 2. Ratio between experimental and calculated ultimate load

Wall Designation	Experimental ultimate load (kN)	Calculated ultimate load (kN)	Du/Dc
T1	7	15.57	1.95
T2	14	19.2	1.76
T3	17	19.4	1.81

3.3 Ductility limit state

For flexural members, it is very important for it to be able to undergo large deformation beyond the elastic range while still keeping the moment carrying capacity. After analysing the data obtained from the strain gage inside the tendon, it was apparent that none of the forces in the tendon in the three walls reach the yield strength of the tendon. However all three walls managed to show great ductility response.

Fig. 10. Comparison between the forces in tendon of wall T1, T2 and T3

For wall T1, it was able to further deflect 10.35 mm after the formation of openings. As for wall T2 and T3, they managed to further deflect 13.6mm and 19.3mm respectively. Wall T3 which have a post-tensioning bar, was able to deflect 30 % more than wall T2 and almost 50 % more than wall T1. This clearly shows that walls with post-tensioning are more ductile than walls with just reinforcement. A ductile behaviour was clearly observed in load-deflection curves as shown in Fig. 10. Post tensioning wall carried higher portion of applied load due to the fixity of tendon inside the wall [8].

Conclusion

Based the experimental results and the analysis performed on the three wall segments presented in this paper, the following conclusions are drawn:

1. From the study of number of reinforcement in interlocking brick walls with applied load against deflection in service and ultimate load, we found out that using three reinforcements will give a result of 100 % better than just using two reinforcements. As the number of reinforcement increases, so does the out-of-plane ultimate capacity.
2. Ductility of all three walls is good but the wall with one post-tensioned bar performed the best. All the walls have a good warning system where it gave ample time before failure. Wall T3 which have a post-tensioning bar, was able to deflect 42% more than wall T2 and almost 86% more than wall T1. This clearly shows that walls with the combination of reinforcement and post-tensioning are more ductile than walls with just reinforcements.

In conclusion, post-tensioning the wall will induce the wall with a compressive force which will enable the wall to fail via compression, hence allowing the strength of the brick in compression to be fully utilised. So, it is very feasible for us to use post-tensioning in masonry especially interlocking brick walls.

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