Retaining Force Augmentation of Retaining Walls

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Abstract

Concrete blocks retaining walls are commonly used for landscaping projects in which the retaining force strength of the structure is of paramount importance in preserving the integrity of the project and safety of humans and property. The effect of augmenting the retaining force strength of concrete block retaining walls was investigated using interlocking and interlocking with a horizontal steel re-bar and compared with regular concrete block walls. The average maximum retaining force for regular, interlocking and interlocking with horizontal rebar walls was 16862 N, 24546 N, and 80855 N at wall deflection of 12.2 mm, 13.3 mm and 50.7 mm, respectively. The average maximum retaining force of the interlocking and the interlocking with horizontal re-bar walls increased by 45.6 % and 379.5 %, respectively, when compared to regular concrete block walls. The inclusion of a horizontal steel re-bar in the interlocking design showed an increase of 229.4 % in the retaining force strength. The wall sections without the horizontal re-bar failed abruptly beyond the maximum retaining force for both the regular and interlocking blocks. The interlocking concrete block design and the inclusion of a horizontal steel re-bar both significantly augmented the retaining force strength of concrete block retaining walls.

Keywords: Retaining wall; Concrete block; Retaining force; Horizontal re-bar.

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1. Introduction

In areas of landscaping where the ground elevation exceeds the angle of repose of the soil retaining walls are constructed to resist the lateral pressure of soil and keep it in place [1]. There are different designs of retaining walls suited for respective applications [2]. Concrete block retaining walls are ideal for controlling small scale erosion, to level a hard-to-mow slope, build an embankment to add a planting bed, or to level an ideal patio area. However, the most important consideration in proper design and installation of retaining walls is to ensure that the wall counteract the tendency of the retained material to move downslope due to gravity since the downslope movement of the retained material creates lateral earth pressure behind the wall [3]. The magnitude of this pressure depends on the angle of internal friction, the cohesive strength of the retained material, as well as the direction and magnitude of movement the retaining structure undergoes [4]. Concrete blocks are one of the fastest and simplest material available for small scale retaining wall construction and offer a different option than poured concrete [2]. They are frequently used in foundations and walls, easy to install, durable, reasonably priced and available in a variety of colors and textures [5]. Retaining walls constructed from standard blocks are generally the same as freestanding block walls; however, since the retaining wall has a horizontal force to resist it must be stronger than freestanding walls [6]. The conventional concrete blocks has a square edge, 2 hollow cells in each block and the outer dimensions are 16 inches long, 8 or 6 inches deep and 8 inches high, though there are other variations available [7]. Concrete block retaining walls are constructed by first laying a foundation base with vertical rebar for interlocking the block layers [8]. During wall construction the block layers are typically stacked staggered to contribute to the stability and the vertical rebar accommodated within the hollow core. At intervals of three block layers high poured concrete are used to fill the hollow cells to reinforce the strength of the retaining wall [9]. The strength is mainly due to the block staggering, vertical rebar and concrete filled cores.

In this study, an interlocking concrete block design that do not require mortar between consecutive horizontal blocks was used to construct a retaining wall section. The horizontal retaining wall force was tested and compared to a conventional block retaining wall section under similar test conditions.

Some blocks are designed with interlocking features that do not require the use of mortar and the interlocking feature also add some strength and stability to the wall [10]. In this study two interlocking block designs were used to construct experimental retaining wall sections and tested for horizontal retaining force strength. One design accommodated vertical rebar within the concrete filled cores and the other design accommodated a vertical rebar and a horizontal rebar across the top of each block layer and concrete filled cores.

2. Test Specimen Preparation

Three specimens each of three different retaining wall sections were constructed for comparative horizontal retaining force strength testing.

The first set of test specimens were constructed using the commonly available regular retaining wall concrete blocks. The dimensions of the blocks are 152 mm x 203 mm x 406 mm and the design has two hollow cores as shown in Figure 1.

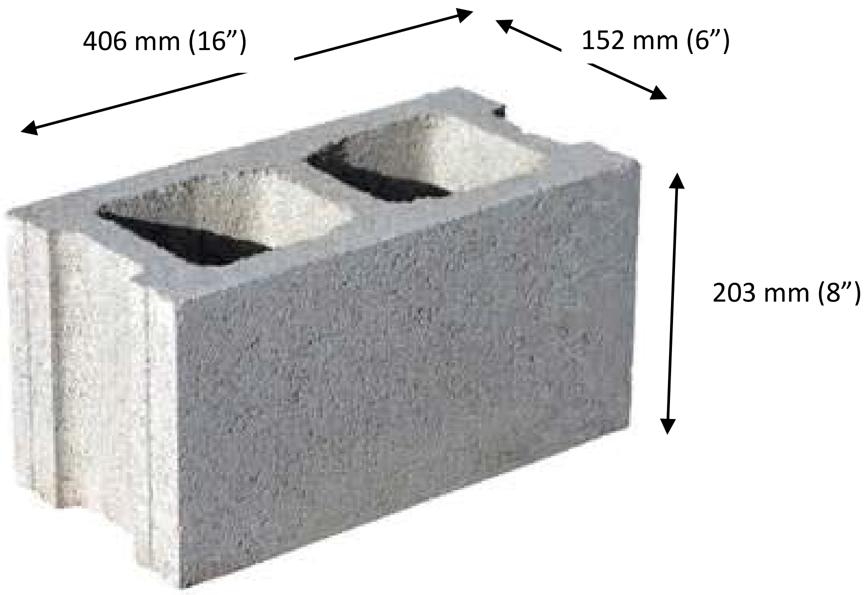

Figure 1: Regular concrete block

The retaining wall section constructed was 3 m wide and 2 m high. The wall section was constructed in the conventional manner with the blocks in each layer placed adjacent to each other with mortar between for holding the blocks in place. The hollow core was placed vertical to allow for filling with concrete. The next layer was placed staggered on top of the lower layer with mortar between the layers and between the adjacent blocks for stability, to accommodate for alignment adjustment, and holding the blocks in place. Vertical 13 mm diameter steel re-bars were placed in the center of alternate hollow core and the cores were filled with concrete every three layers high. Figure 2 shows a completed wall test section with regular concrete retaining wall blocks with vertical re-bars and concrete filled cores.

Figure 2: Completed wall test section with regular concrete retaining wall blocks

The second set of test specimens was constructed using the interlocking design retaining wall concrete blocks. The dimensions of the blocks are 152 mm x 203 mm x 406 mm and the design has two hollow cores as shown in Figure 3.

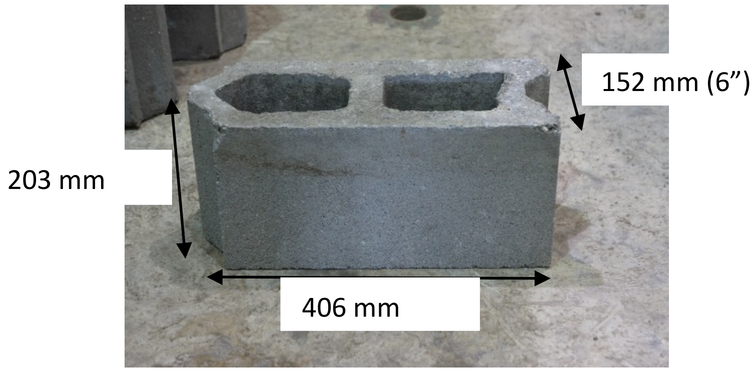

Figure 3: Interlocking concrete block

The retaining wall section of size 3 m wide and 2 m high was constructed in a similar manner with the blocks in each layer placed adjacent to each other with mortar between for holding the blocks in place. The hollow core was placed vertical to allow for filling with concrete. The next layer was placed staggered on top of the lower layer with mortar between the layers and between the adjacent blocks for stability, to accommodate for alignment adjustment, and holding the blocks in place. Vertical 13 mm diameter steel re-bars were placed in the centre of alternate hollow core and the cores were filled with concrete every three layer high.

The third set of test specimens were constructed using the interlocking design retaining wall concrete blocks with the space that accommodated a horizontal re-bar. The dimensions of the blocks are 152 mm x 203 mm x 406 mm and the design has two hollow cores as shown in Figure 4.

Figure 4: Interlocking design concrete blocks with the space to accommodate a horizontal re-bar

The retaining wall section of size 3 m wide and 2 m high was constructed in a similar manner with the blocks in each layer placed adjacent to each other with mortar between for holding the blocks in place. The hollow core was placed vertical to allow for filling with concrete. The next layer was placed staggered on top of the lower layer with mortar between the layers and between the adjacent blocks for stability, to accommodate for alignment adjustment, and holding the blocks in place. Horizontal 13 mm diameter steel re-bar was placed between each layer of blocks and vertical steel re-bar of 13 mm diameter was placed in the centre of alternate hollow core and the cores were filled with concrete every three layers high.

During the core filling process the concrete was prodded with an 18mm diameter steel rod to ensure proper and complete filling of the cores. Each test wall section was constructed on top of a smooth 18mm thick steel plate to simulate a free standing wall section and allowed to cure for seven days before testing.

3. Test Procedure

Horizontal-retaining-force tests were conducted on the cured test specimens. The apparatus used to apply the horizontal force was the 793 Series MTS Actuator. This linear actuator measured simultaneously the horizontal force (N) (± 0.1N) and the respective horizontal wall displacement (mm) (± 0.01 mm). Once the test started the apparatus was automatically controlled by a computer that recorded the force and corresponding horizontal displacement data at one second intervals. Each test proceeded until the wall failed. The retaining wall sections were 'simply-supported' vertically at both ends. The distance between the vertical restraining bars was 2 m. The base of the walls rested freely on a smooth 18mm thick steel plate to simulate a free standing wall section. To simulate the force exerted from the backfill material a centrally placed horizontal force was applied to the wall section. Figure 5 shows a schematic of the test set-up.

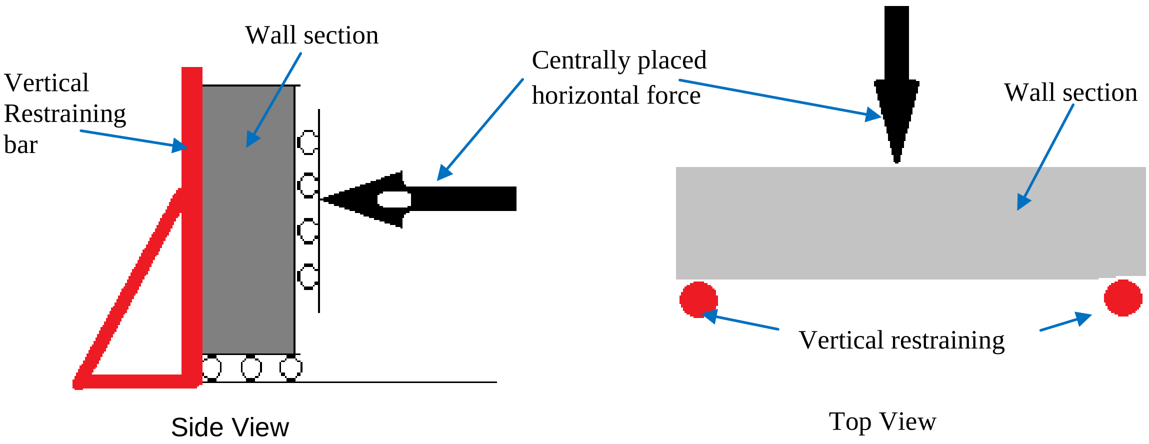

Figure 5: Schematic of wall section test set-up

4. Experimental Test Results

The cured specimens simulating a free standing retaining wall sections, simply-supported vertically at both ends, were tested to determine the horizontal retaining force. The specimens were subjected to a centrally located horizontal force using the 793 Series MTS Actuator apparatus and the variation of horizontal force with horizontal wall displacement was recorded automatically by the computer at one second intervals until the wall section failed. The test results for the three wall sections constructed with the regular concrete blocks with 13 mm diameter vertical rebar in the core filled with concrete are shown below in Figure 6. The maximum retaining force for the respective test specimens were 17150 N, 15600 N, and 17835 N at wall displacements of 10.5 mm, 12.2 mm, and 13.8 mm, respectively.

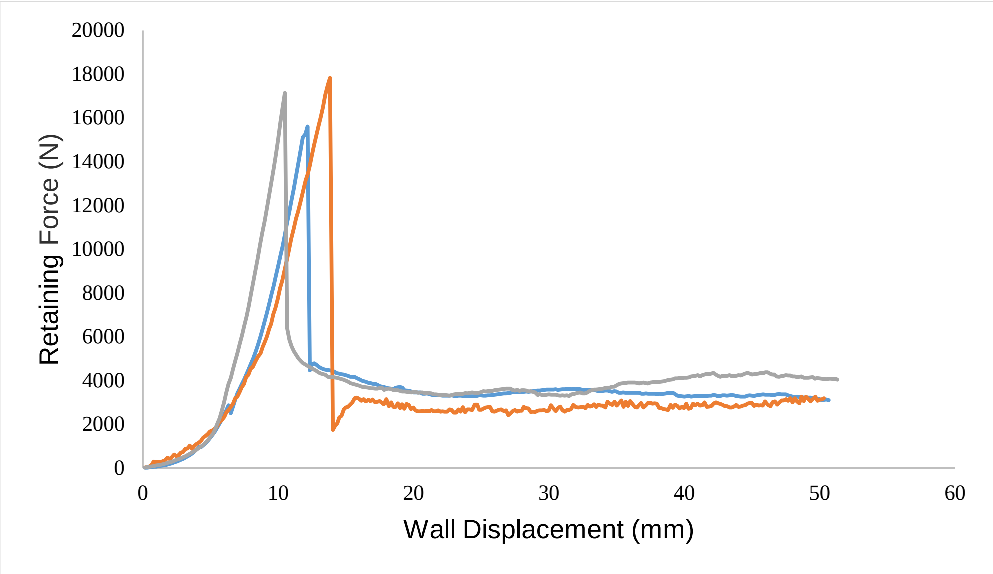

Figure 6: Retaining force vs displacement for regular concrete blocks with vertical re-bar

The test results for the three wall sections constructed with the interlocking concrete blocks with 13 mm diameter vertical rebar in the core filled with concrete are shown below in Figure 7. The maximum retaining force for the respective test specimens were 24059 N, 25942 N, and 23637 N at wall displacements of 11.8 mm, 16.5 mm, and 11.7 mm, respectively.

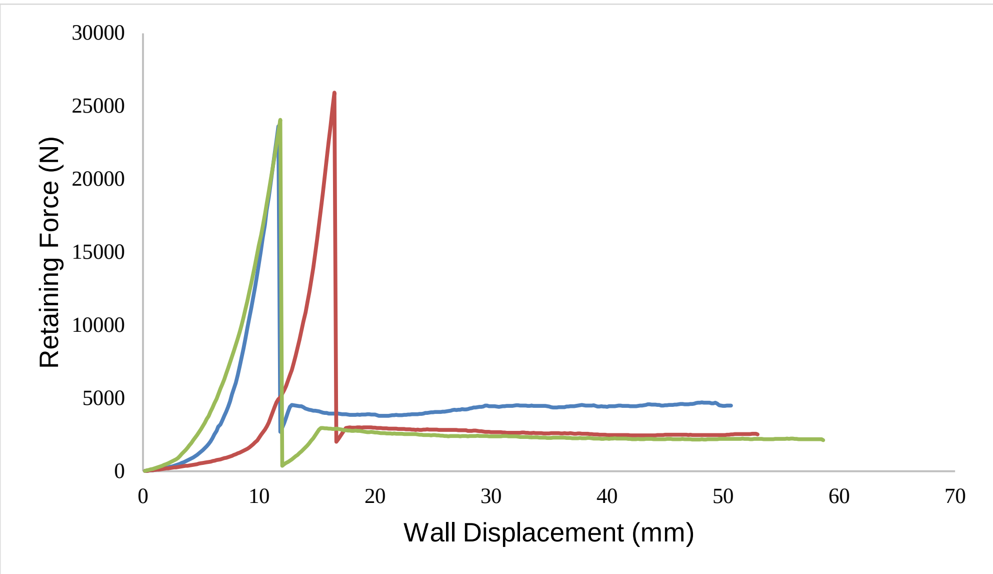

Figure 7: Retaining force vs displacement for interlocking block wall with vertical re-bar

The test results for the three wall sections constructed with the interlocking concrete blocks with 13mm diameter horizontal steel rebar between the layers and 13 mm diameter vertical rebar in the core filled with concrete are shown below in Figure 8. The maximum retaining force for the respective test specimens were 74587 N, 91857 N, and 76120 N at wall displacements of 43.2 mm, 54.5 mm, and 54.3 mm, respectively.

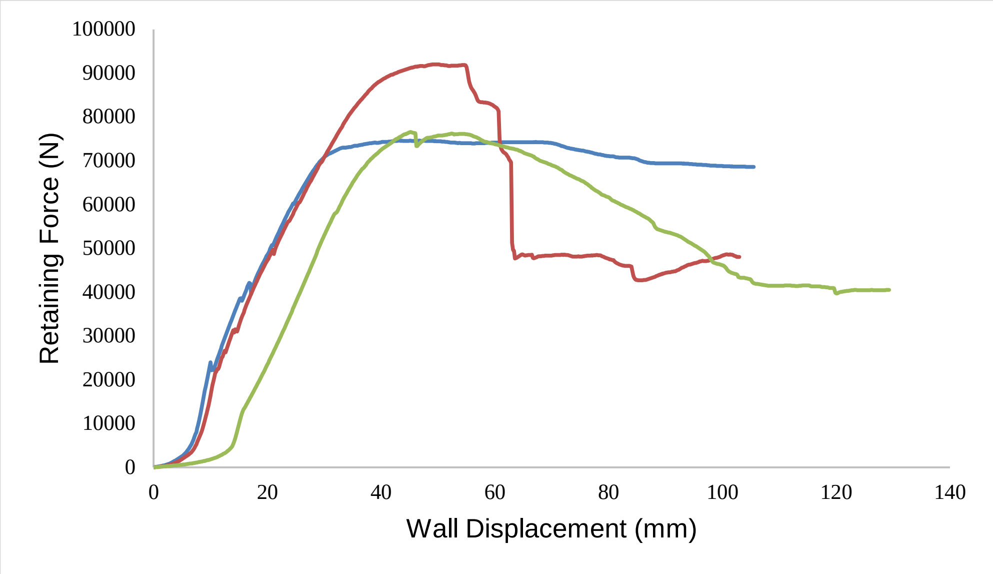

Figure 8: Retaining force vs displacement for interlocking block wall with horizontal and vertical re-bar

A graph of the average retaining wall force for the regular concrete block with concrete filled cores and vertical steel re-bars, interlocking concrete block with concrete filled cores and vertical steel re-bars and interlocking concrete blocks with concrete filled cores, vertical steel re-bars and horizontal steel re-bars is shown in Figure 9.

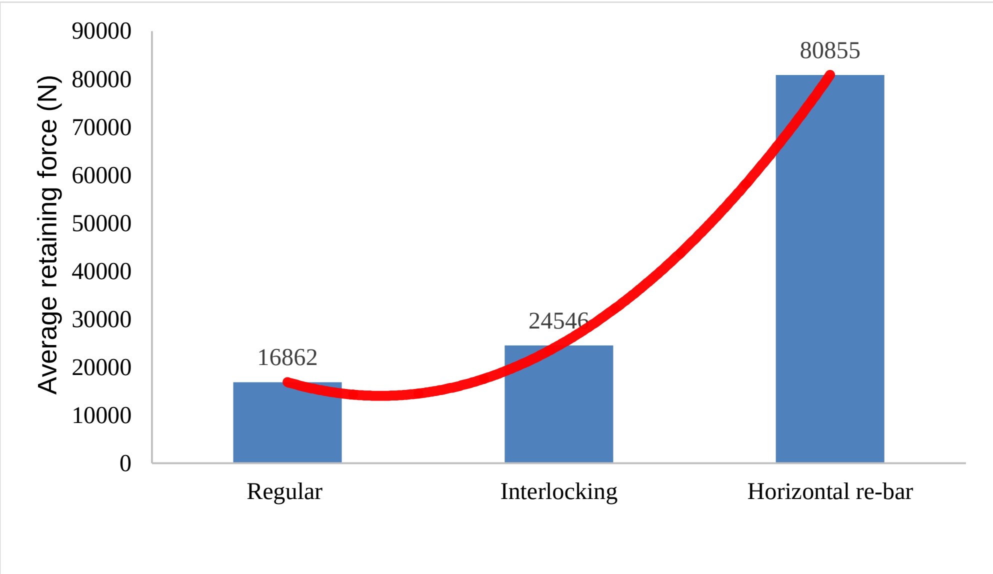

Figure 9: Average retaining force variation with different wall construction

A graph of the average wall deflection at maximum retaining force for the regular concrete block with concrete filled cores and vertical steel re-bars, interlocking concrete block with concrete filled cores and vertical steel re-bars and interlocking concrete blocks with concrete filled cores, vertical steel re-bars and horizontal steel re-bars is shown in Figure 10.

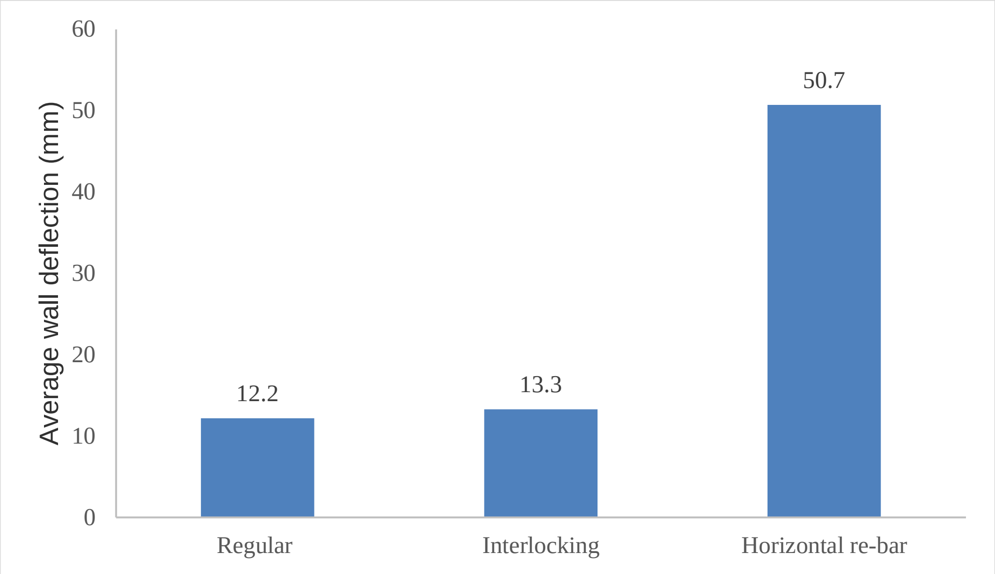

Figure 10: Average wall deflection at maximum retaining force

5. Discussion

Low cost retaining walls are commonly used worldwide as a landscaping tool to achieve desired effects in surroundings. The strength of the retaining wall is of paramount importance for ensuring safety of both humans and property. The experiments were conducted on similarly constructed retaining wall sections to determine the maximum retaining force the wall sections can withstand. Low cost methods using interlocking blocks and the addition of a horizontal steel re-bar were compared to the regular concrete block wall construction.

For the regular concrete block test sections with concrete filled cores and vertical steel re-bars the average maximum retaining force was 16862 N at an average wall displacement of 12.2 mm. From the plot of the retaining force with displacement shown in Figure 6, there was a sharp drop in retaining force just beyond the maximum value for all three test specimens. This indicated that the wall section actually collapsed and failed suddenly beyond the maximum retaining force.

For the interlocking concrete block test sections with concrete filled cores and vertical steel re-bars the average maximum retaining force was 24546 N at an average wall displacement of 13.3 mm. From the plot of the retaining force with displacement shown in Figure 7, there was a sharp drop in retaining force just beyond the maximum value for all three test specimens. This indicated that the wall section actually collapsed and failed suddenly beyond the maximum retaining force. This behavior is similar to that of the regular concrete blocks, however, there was the noted increase of 45.6% in the maximum average retaining force. The average wall deflection at the point of collapse for both the regular and interlocking wall construction showed a minimal difference of 1.1 mm. This indicated that the deflection for collapse was the same for both the regular and interlocking block wall sections. The 45.6% increase in retaining force can be attributed to the horizontal interlocking between the blocks

For the interlocking concrete block test sections with concrete filled cores with vertical and horizontal steel re-bars the average maximum retaining force was 80855 N at an average wall displacement of 50.7 mm. From the plot of the retaining force with displacement shown in Figure 8, there was a gradual drop in retaining force beyond the maximum value for all three test specimens. This is in contrast to the sharp drop exhibited with the other two types of wall construction. This indicated that the wall section did not suddenly collapsed and failed beyond the maximum retaining force. There was the noted increase of 379.5% or 4.8 times in the maximum average retaining force for the horizontal re-bar wall section compared to the regular concrete block wall section. When compared to the interlocking block wall section there was an increase of 229.4% or 3.3 times in the maximum average retaining force for the horizontal re-bar wall section.

The bar-graph shown in Figure 9 indicated that there was an exponential increase in retaining force going from regular concrete blocks, interlocking concrete blocks and interlocking with horizontal re-bar wall construction. The bar graph of wall deflection at maximum retaining force with type of wall construction (Figure 10) showed that both walls without the horizontal re-bar failed at approximately the same deflection. However, the wall with the horizontal re-bar showed an increase of approximately 297.6 % or 4 times in wall deflection to reach the maximum load. The significant increase in both the maximum retaining force strength and wall deflection at maximum retaining force can be attributed to the inclusion of the horizontal re-bar.

6. Conclusion

The retaining force of commonly used concrete block retaining wall can be augmented with the use of interlocking block design and the addition of horizontal steel re-bar. The test results showed that the average maximum retaining force of the interlocking concrete block walls increased by 45.6 % when compared to the maximum retaining force of the regular concrete block walls. The inclusion of a horizontal steel re-bar in the interlocking concrete block walls showed an increase of 229.4 % in the average maximum retaining force strength. When compared to the regular concrete block walls, the walls with the horizontal re-bar indicated an average maximum retaining force strength 4.8 times higher. The wall sections without the horizontal re-bar failed abruptly beyond the maximum retaining force for both the regular and interlocking blocks. The interlocking concrete block design and the inclusion of a horizontal steel re-bar both significantly augmented the retaining force strength of concrete block retaining walls.

7. Constraints and Limitations

The physical size of the retaining wall test section was constrained by the laboratory space available for construction. Simulation of the free standing wall section to represent a section away from the foundation base of the wall was replicated by construction on a smooth steel sheet. This would have caused some resistance to the horizontal force due to friction at the base of the test specimens. Application of a uniformly distributed horizontal load on the wall was limited to the test apparatus and a centrally placed horizontal force was used.

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