Open Access Journal

Journal of Sustainable Research in Engineering Vol. 4 (4) 2018, 136-143

Journal homepage: http://sri.jkuat.ac.ke/ojs/index.php/sri

ISSN (Online): 2409-1243

Failure characteristics of Interlocking Stabilized Lateritic Clay Soil Block Walls

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Abstract The effect of lime (L), cow dung (CD), rice husk ash (RHA) and pozzolanic cement (PC) on the performance of interlocking clay soil block masonry panel under compressional loading was investigated. CINVA Ram type interlocking blocks were used to quantify the behavior of soil stabilizer mixture, through testing their dry compressive strength, water absorption, abrasion test and structural performance of walls. Three types of wall panels of size 900 mm long x 1200 mm high were constructed with blocks that sustained highest 28-day compressive strength: CSW1 (L-PC blend), CSW2 (PC-RHA blend) and CSW3 (CD only). The study found that, lime stabilization causes a delayed gain of compressive strength in soils with higher clay content as compared to pozzolanic cement but for lime to perform better in clay soil stabilization it should be used together with pozzolanic cement. A blend of lime and cement in clay soil results to failure of wall along its unbraced regions. This type of walls can be used under braced conditions. Walls made of blocks stabilized with PC-RHA blend failed by spalling of blocks into small debris, with the wall sustaining weak loads. However, when cow dung was used in clay soil stabilization, the walls were capable of sustaining higher compressive load and failed by compression crushing.

Keywords Abrasion resistance, Cow dung stabilization, Laterite clay soil, Wall failure mode

1. Introduction

The influence of stabilizers on the physical characteristics of interlocking clay soil blocks has been assessed by different authors [1,2] on their nature of type, content and duration of curing. It has been reported by Chukwudi and Lateef [3] that pozzolanic reaction can take place between lime and certain clay minerals in the presence of water forming an insoluble gel. Lime (L) causes a cation exchange which reduces the expansibility of the clay lattice thereby lowering its liquid limit and plasticity. A study on the effects of hydrated lime on the physical and engineering properties of clay soil by Muhmed and Wanatowski [4] found that on adding 5% lime increased the plastic and liquid limit by 23.6% and 20.6% respectively. A study by Peter and Manu [5] on strength and durability properties of cow dung stabilized earth bricks made of soil having a plasticity limit of 24% and liquid limit of 35% found that 20% of cow dung content produced blocks with dry compressive strength of 5.7MPa. On the other hand, Kwadwo and Evans [6] tested compressive strength and permeability of blocks stabilized with cow dung at 2% cement content. Their finding indicated that blocks stabilized with 2% cement and 8% cow dung attained highest compressive strength (0.95MPa), with permeability increasing with higher cow dung content. The impact of rice husk ash (RHA) has been investigated on clay soil on the compaction test, California Bearing Ratio, Atterberg tests, shear and compressive strength tests at various percentages of RHA. It has been established by Perera et al [7] that an optimum percentage of 4% of RHA leads to a strength of 3.55MPa in fired clay bricks. The strength and durability of pozzolanic cement stabilized soil blocks was found to improve by increasing cement but was impaired by clay content [8]. The presence of high clay portion in soil-cement mixture has been established by Bhattacharja and Bhatty [9] to be a disadvantage in strength gain since they tend to form a continuous matrix through the soil causing swelling and shrinkage. Therefore, best soils for pozzolanic cement stabilization have been suggested by Chukwudi and Lateef [3] to be those which have small clay content. The main challenges to clay soil interlocking blocks has been to find a treatment that will result to sufficient mechanical strength as well as low sensitivity to water attack. Despite abundance of data on physical characteristics of individual interlocking soil blocks, little is known about performance of unreinforced interlocking clay soil block walls under loading.

Interlocking block load bearing walls are normally made by laying block units next to each other leaving no gaps. Mortar layers are eliminated and instead the block units are interconnected through interlocking system of the blocks. The blocks are made plumb by the help of a wooden or rubber hammer to knock them gently into place. In the study on structural behavior of interlocking mortar-less Putra block wall system, Safiee [10] found that the failure of the wall was dominated by opening of dry joints, cracking and flexure deflection. Uzoegbo et al [11] have also noted that the performance of walls made by interlocking blocks is mainly influenced by the strength and deformation characteristics of the individual blocks. Sanewu et al [1] established that clay soil stabilized with 2% municipal solid waste ash leads to failure of interlocking wall by diagonal cracking and bulging of wall sides. The structural behavior problem of interlocking masonry system has been advanced to be due to lack of filler material at the block-to-block interface. Besides the problem of gradual closure of air space under load, the progressive development of strength carrying capacity as contributed by different stabilizers need to be examined. This paper presents an investigation into the effect of lime (L), cow dung (CD), RHA and pozzolanic cement (PC) on the behavior of interlocking soil block masonry panel when subjected to compressional (in-plane) loading without eccentricity effects. To quantify the behavior of soil-stabilizers mixtures, the factors of dry compressive strength, water absorption, abrasion test and interlocking wall compressive strength were investigated.

2. Materials and methods

2.1 Test materials

Clay soil was obtained from Juja sub county, Kenya. This soil type was selected since it is widely available and commonly used in making blocks. The soil was obtained at a depth 1m below the ground surface in order to avoid inclusion of organic materials. The soil was well graded with a 5.0 coefficient of uniformity and a coefficient of curvature of 12 (Fig.1). The clay soil had a liquid limit, plastic limit and plasticity index of 44.5%, 25.2% and 19.3% respectively.

Lime has been found effective in stabilizing plastic clayey soils by providing bonding between the larger particles that causes expansion of soil [12]. Commercial hydrated lime, Rhino lime, produced by Athi River Mining Company was used in this study. The lime had 94% calcium hydroxide, 72% calcium oxide, and other elements like magnesium oxide and silica.

Cow dung has been found to contain similar oxides as those of cement [13] and can be used to replace cement when used in the right proportions. The cow dung was collected from Jomo Kenyatta University of Agriculture and Technology cow sheds, either when it had been dropped from the animals or one which was not older than 5days. The cow dung was mainly collected in the morning hours before the cows were let out for grazing.

Rice husk ash (RHA) was sourced from un-controlled burning source at Mwea rice irrigation scheme, Kenya. The ash was used to replace the more expensive lime and pozzolanic cement in stabilizing clay soil.

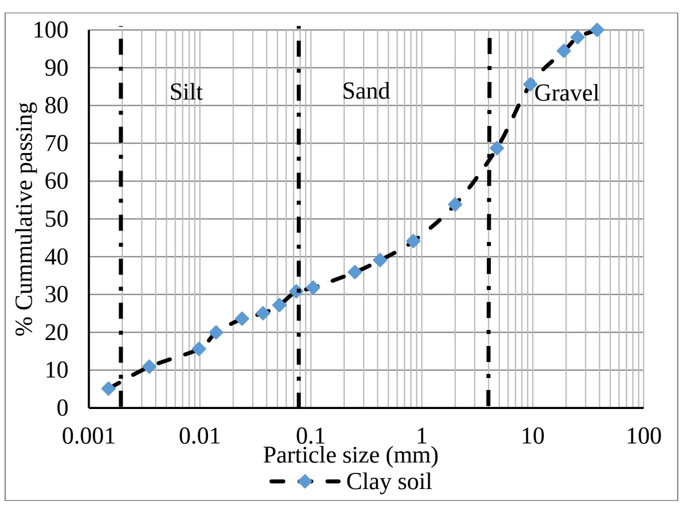


Fig. 1: Particle size distribution of clay soil

2.2 Material preparation and testing

The respective quantities of clay soil, cow dung, lime, RHA and pozzolanic cement, were proportioned and batched by weight at determined ratios of their dry weight. Interlocking blocks were molded using the CINVA-Ram press machine, producing units having dimensions 200 mm (length) x 220 mm (width) x 120 mm (height). The blocks that provided the optimum properties on curing for 28 days were used in making the wall panels. The dry compressive strength of the blocks was tested in accordance to BS EN 772-1 [14].

The blocks' water uptake ability was determined in accordance to KS 02-1070 [15]. Two sampled blocks cured for 28 days were submerged in water and left to stand for 24-hours before re-weighing them.

The abrasion test was carried out by use of a horizontal belt sander model HYS-900 having a frequency of 60 rpm. The sander utilized a sand paper belt type GXK50-P6 with a width of 180 mm. The blocks were subjected against the belt for a duration of one minute before determining their final weight.

Three types of wall panels (two specimens of each) of size 900 mm (length) x 1200 mm (height) were prepared in accordance to BS EN 1052-1[16]: CSW1 (L-C blend)), CSW2 (PC-RHA blend) and CSW3 (CD only). The walls were constructed with blocks that sustained the highest 28-day compressive strength. The optimum stabilizer blend ratios used in making the walls were: CSW1 was 5%C1%L, CSW2 was 1%C5%RHA and CSW3 10%CD. The blocks were dry stacked utilizing the block interlocking system to make the walls. The wall compressive strength was tested perpendicular to the bed joints without the effects of eccentricity. Vertical load displacement was determined at mid length using linear variable displacement transducers (LVDT). The compressive strength of the wall panel was calculated by considering a net contact area of 45% of the gross area as recommended by BS 5628-1[17].

3. Results and discussion

3.1 Effect of stabilizers on clay block properties

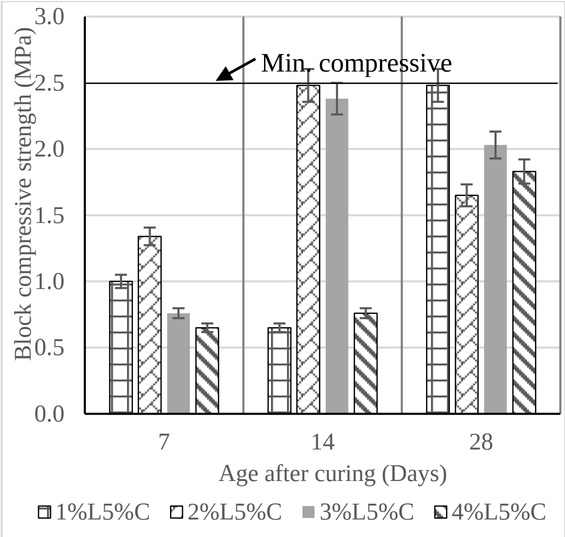
3.1.1 Compressive strength of interlocking stabilized clay soil blocks

On average, stabilized clay soil blocks with 5% lime had higher gain in compressive strength over the curing period (Fig. 2). This observation was consistent with findings of Muhmed and Wanatowski [4] who in their investigation found that stabilizing active clay soils with lime reduced their plasticity index and increased the liquid limit and plastic limit. Blocks stabilized with constant amount of 5% lime with cement added incrementally had higher compressive strengths as compared to blocks where lime was incrementally added (Fig. 2a and 2b).

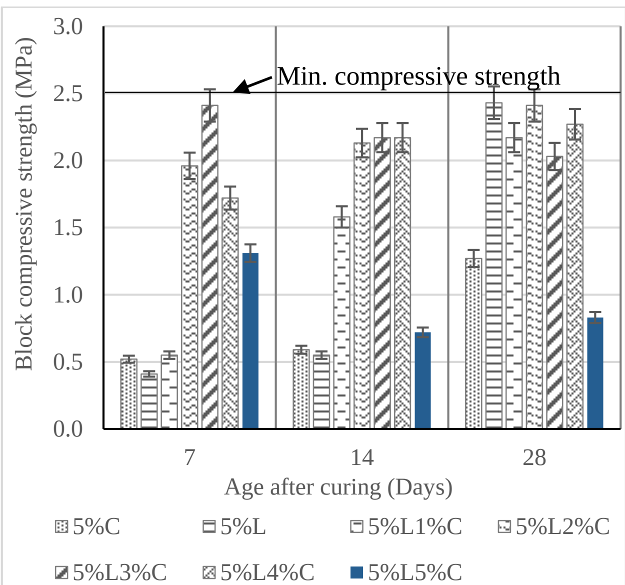
It is clear from these results that lime stabilization causes a delayed gain of compressive strength in soils having higher proportions of silty particles as compared to pozzolanic cement. This phenomenon can be attributed to pozzolanic cement hydration which produces a cementing colloidal gel that binds the clay, silt and sand particles causing them to set and harden over a short time [9]. This process initiates a pozzolanic reaction between calcium oxide liberated during the hydration of cement and the clay. However due to high amounts of clay particles present in clay soil, they tend to form a continuous matrix through the soil causing swelling and shrinkage. It is worth noting therefore, higher compressive strengths on early curing days are not achieved in clay soil blocks stabilized with pozzolanic cement.

Blocks with lower percentage of RHA sustained higher compressive strength which decreased with curing time (Fig. 2c). However, RHA stabilization of clay soil resulted to low 28-day compressive strength as compared to lime stabilization. Thus, replacement of lime with RHA in clay soil only resulted to soil modification rather than stabilization since the compressive strengths are very low as compared to those recommended by KS 02-1070 [15].

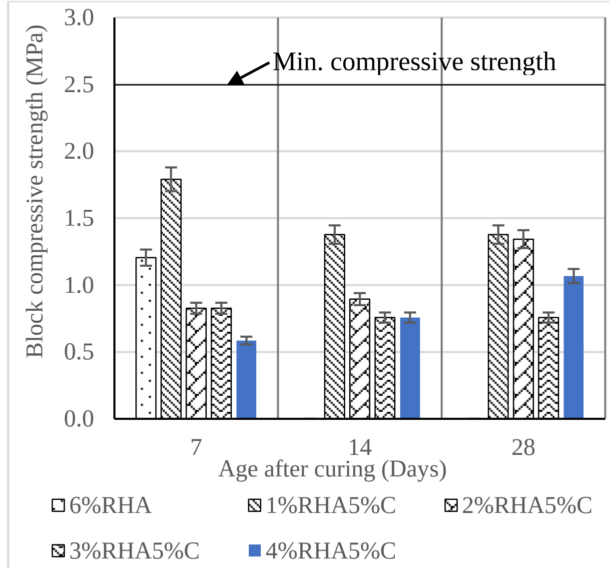
The 28-day compressive strength of 10%CD blocks expressed the highest strength (2.2MPa), though it was lower than recommended value of 2.5MPa (Fig. 2d). In compression strength testing, the blocks behaved like a sponge and they took a longer time to fail. This could be attributed to the physico-mechanical properties of cow dung which makes the soil to have voids leading to high accommodation of compression deflection.



(a) Clay soil + Cement + varying lime

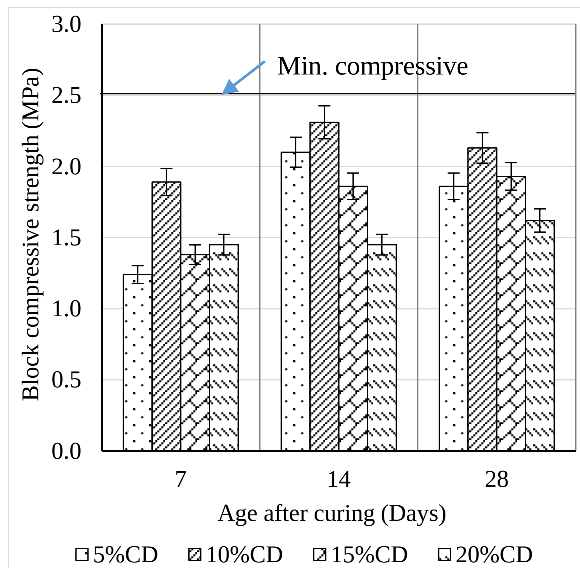


(b) Clay soil + Lime + varying cement



(c) Clay soil + Cement + RHA

(d)



(e) Clay soil + Cow dung

Fig. 2: Compressive strength of stabilized lateritic clay blocks

3.1.2 Water absorption by clay soil blocks

The water absorption by clay soil blocks increased with cow dung content but reduced on stabilizing with cement and lime (Fig. 3). The high absorptivity by cow dung stabilized blocks could be attributed to voids introduced by fibrous nature of cow dung. There was also no measurement obtained in most of RHA stabilized clay soil blocks. The blocks disintegrated in water due to the high porosity introduced in the blocks by RHA. Fibers increase water absorption as the absorbent nature of fibers creates pathways through soil blocks, thereby allowing more water absorption. A similar observation was made by Kwadwo and Evans [6] in their investigation on the improvement of earth bocks for low income communities in Ghana.

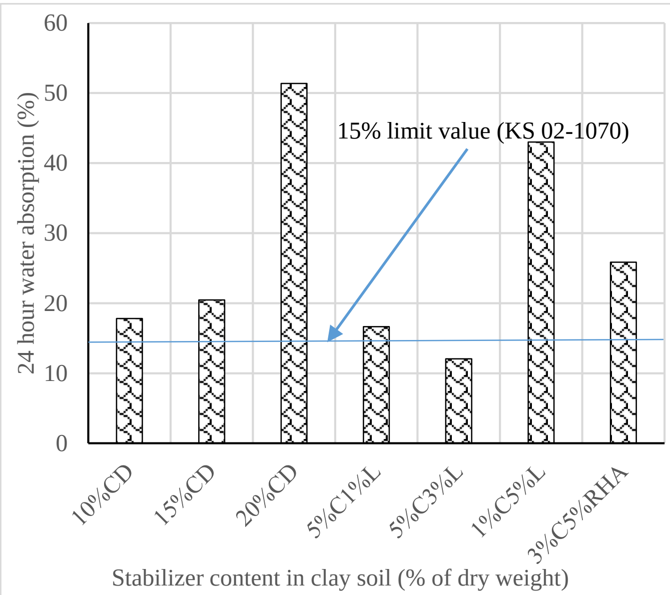


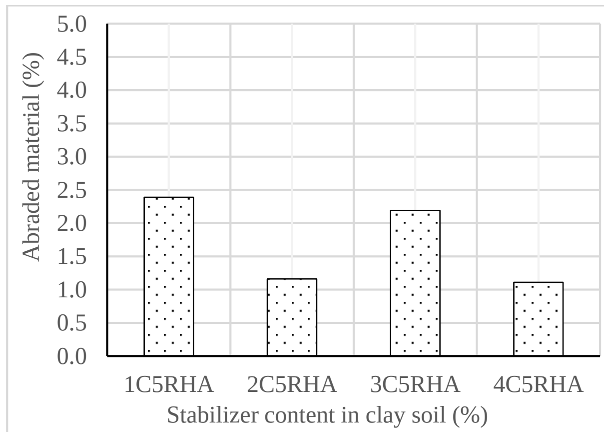
Fig. 3: Water absorption by stabilized clay soil blocks

Addition of 3% lime to clay soil at specified 5% cement reduced the water absorption by the blocks to a lowest value of 12.06% (Fig. 3). The decrease has been explained by Musa [18] to be as a result of formulation of cementitious compounds by calcium from lime which fills the soil voids thereby obstructing the flow of water. These findings were also consistent with the findings of Guettala et al [19] who found that increase in lime content from 5% to 12% decreased the water absorption capacity of clay blocks. However, there was an increase in water absorption beyond 3% lime dosage level resulting to fully disintegration of blocks in water. This therefore indicates that for lime to perform better in clay soil stabilization it should be used together with other stabilizers.

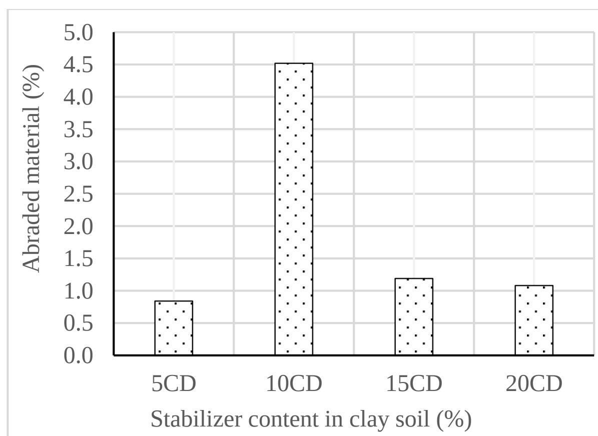
3.1.3 Abrasion resistance of stabilized clay soil blocks

The performance of clay soils blocks in abrasion was better on adding cow dung than lime and RHA in presence of cement (Fig. 4). Cow dung has fibrous characteristic that may have imparted greater cohesion of clay particles. However, abrasion resistance decreased with increase in cow dung content. The high concentration of fibers has been found by Ismail and Yaacob [20] to cause them to bunch together and lose cohesion with the soil leading to breaking up of the soil matrix. This can cause weakening of the soil mixture thus increase in abraded material.

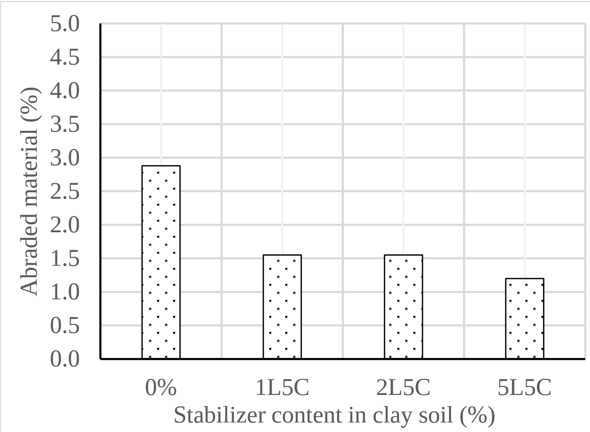
The results indicate that increase of lime in clay soil having 5% cement lead to a decrease of abraded material (Fig. 4c). The reaction of cement and water liberates calcium hydroxide which reacts with clay to form pozzolanic binder. However, if the clay content is too high the free lime from cement hydration will not be sufficient to sustain the reaction. Therefore, the addition of hydrated lime aided the pozzolanic reaction in forming insoluble colloidal gels which led to increased resistance to abrasion (Fig. 4c). Generally, abrasion resistance of clay soil blocks is well achieved with addition of lime rather than RHA to cement.



(a) Clay soil with cement and RHA



(b) Clay soil with cow dung



(c) Clay soil with cement and lime

Fig. 4: Behavior of abrasion resistance as a function of stabilizer content in clay soil blocks

3.2 Structural performance of interlocking stabilized clay soil block walls

The failure mode of CSW1 under loading (Fig. 5a) was characterized by gradual propagation of cracks in a diagonal direction on block faces. Splitting failure occurred on individual blocks as opposed to failure along the block interface. The wall failure mode was shown to be concentrated in the less restrained part of the wall (i.e. free edges and mid-height).

CSW2 failed by spalling of blocks in form of smaller debris that easily disintegrated. The blocks lacked cohesive character and easily disintegrated when the load was increased. There was presence of shear cracks on blocks at the middle courses of the wall panel that widened and spread at a fast rate on the surface (Fig. 5b).

The number of cracks formed in CSW3 were fewer with the cracks width not opening appreciably to lead to failure of the wall by cracking (Fig. 5c). This led to failure of CSW3 by compression crushing. The limited formation of cracks in CSW3 can be associated with presence of fibers from cow dung. CSW3 unit blocks bulged considerably with the wall attaining a vertical load deflection of 41.44 mm at the ultimate load. Such high deformation may be unsuitable for common structural applications and may probably result to failure of load bearing members and detachment of elements such as beams.

CSW1 attained a maximum compressive stress of 0.37MPa as compared to 2.48MPa attained by L-C blend individual blocks (being 80% higher). The load-deflection curve depicted a gradual increase in the load carrying capacity until the ultimate value (Fig. 6a). The curve does not indicate a clear point when the wall begins to yield depicting a brittle behavior of the wall.

(a) CSW1

(a) CSW2

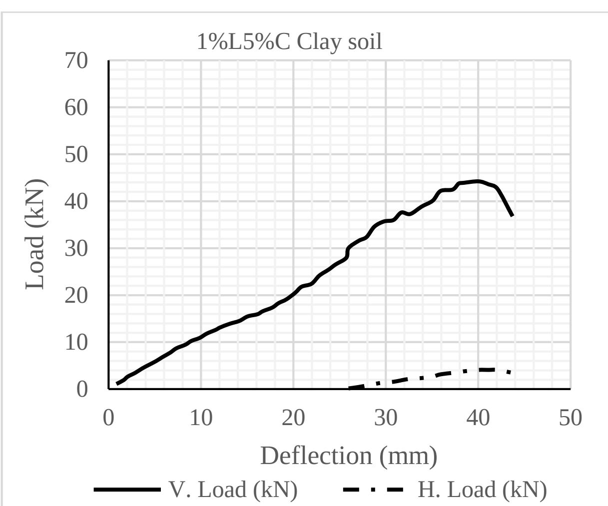
(c) CSW3

Fig. 5: Observed crack propagation and wall failure for clay soil block wall panels

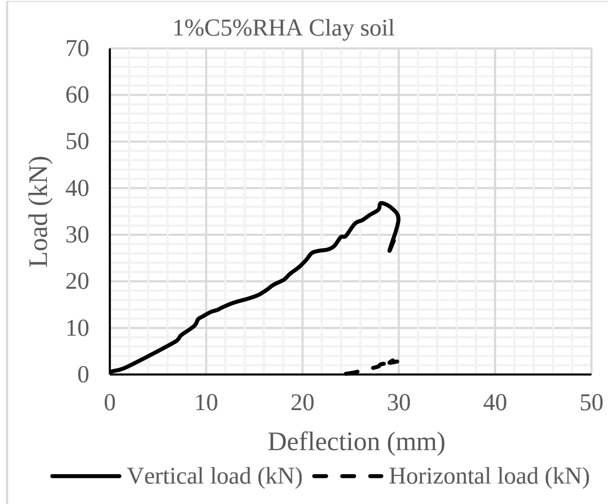
CSW2 sustained an ultimate compressive load of 35.71kN with a vertical load displacement of 29.28 mm

(Fig. 6b). Kham et al [21] has recorded that RHA has a lower density as compared to cement. This makes the quantities of RHA to be more in soil when batched by weight. This is disadvantageous in wall strength capacity since the extra RHA cannot be mobilized for pozzolanic reaction which consequently occupies space within the soil matrix reducing strength gain. This could have contributed to the low compressive strength attained by CSW2.

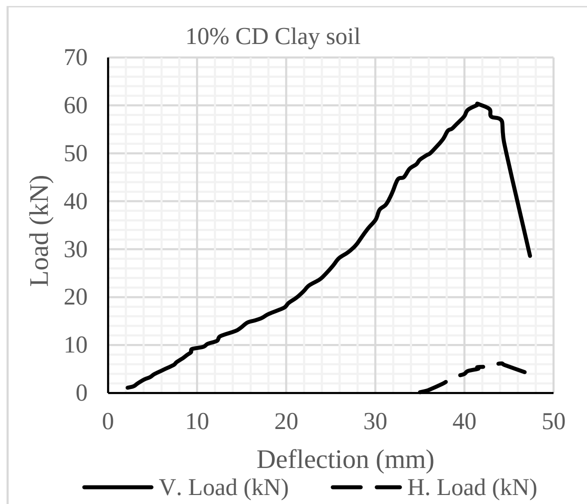
The CSW3 curve has three sections: (i) gaps closure, (ii) load uptake and (iii) wall failure. The load capacity curve for the CSW3 begun with a shallow curve until a load point of 18.80kN was achieved (Fig. 6c). This may have been contributed by closing of the interlocking joints. Beyond this point, the load curve gradient increased until the ultimate load (60.20kN) was reached. In this section the wall sustained the load to its ultimate capacity, after which it experienced failure. This observation has been justified by Quagliarini and Lenci [22] that when pressure is exerted, soil grains shift thus occupying the voids which exist within the material's matrix. As loading increases progressively, the soil grains are compacted and the material's density increases. Consequently, it gradually becomes stiffer and retains its ability to resist loading. For the case of CSW3, the wall behaved plastically allowing compressional compaction making it to sustain higher compressive load. The curves indicate that the compression capacity of the walls is affected by strength and deformation characteristics of the individual blocks.



(a) CSW1



(b) CSW2



(c) CSW3

Fig. 6: Load-deflection curve for experimental walls

4. Conclusion

The stabilizers have a positive effect on the physico-mechanical properties of individual interlocking clay soil blocks when used as blends at varying ratios. The study found that lateritic clay soil blocks stabilized with a blend of 1%L5%C performs optimally under compression loading and water absorption resistance. RHA clay soil stabilization only results to soil modification while lime stabilization causes a delayed gain of compressive strength in soils with higher silt proportions as compared to pozzolanic cement. It was noted that, for lime to perform better in clay soil stabilization it should be used together with other stabilizers, however, best abrasion resistance can be achieved with cow dung stabilization.

A blend of lime and cement in clay soil results to failure of walls in less constrained parts, therefore they can be recommended to be used under braced situations. A PC-RHA blend wall fails by spalling of blocks into small debris, with the wall sustaining weak loads. When cow dung is used in clay soil stabilization, the walls are capable of sustaining higher compressive loads and will fail by compression crushing.

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