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Function of Construction Waste as A Replacement Material for Stones in Stone Column

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Abstract

Sustainability is an important aspect of the civil engineering domain and mainly focuses on the reduction of carbon footprints. One of the major contributors to carbon footprint is construction and demolition (C&D) waste, which increases with urbanisation. With an increase in awareness of recycling, the usage of C&D waste is used as a replacement material for stones in a stone column. The stone column is a conventional ground improvement technique used to stabilise the soil by improving its strength and settlement behaviour. The C&D waste of M30-graded crushed concrete and the brick is considered and used as a replacement material to make columns of two consistencies (0.4 and 0.6). The other waste material of C&D waste is removed and crushed to a size of 5 mm and used as a column material. A load-penetration study is conducted in California Bearing ratio (CBR) mould by developing a column in the center of the mould with 100% of conventional aggregate, crushed concrete and bricks which is compared with the virgin clay. Due to the interlocking behaviour of the column materials, the initial behaviour of the load-penetration behaviour follows the same pattern. With an increase in load intensity, the load bearing of crushed concrete is similar under higher consistency. As the water retention of brick is more for lower consistency, the load bored by 100% crushed brick is the same as that of stone aggregate. There is almost 4 times increase in the strength of composite ground compared with virgin clay. Making the zero-value material more useful by creating a circular economy.

1. Introduction

The rapid growth in technology and the construction industry leads to altering the existing structure or demolishing and reconstructing the existing building. The construction demolition waste (C&D) generated in this process increases rapidly and tends to increase up to 2.2 billion tonnes globally by 2025 which is much higher than the municipal waste generated [1]. Fig. 1 shows the data provided by the World bank about the C&D waste generated across the globe [2]. This waste includes wood, metal, plaster, asphalt, bricks, tiles, ceramics, steel etc.; all these materials are dumped in the landfill (almost 150 million tonnes annually). Out of all the C&D waste, concrete has the longest durability period: which is the major source of carbon emission and steel can be recycled and used in multiple ways.

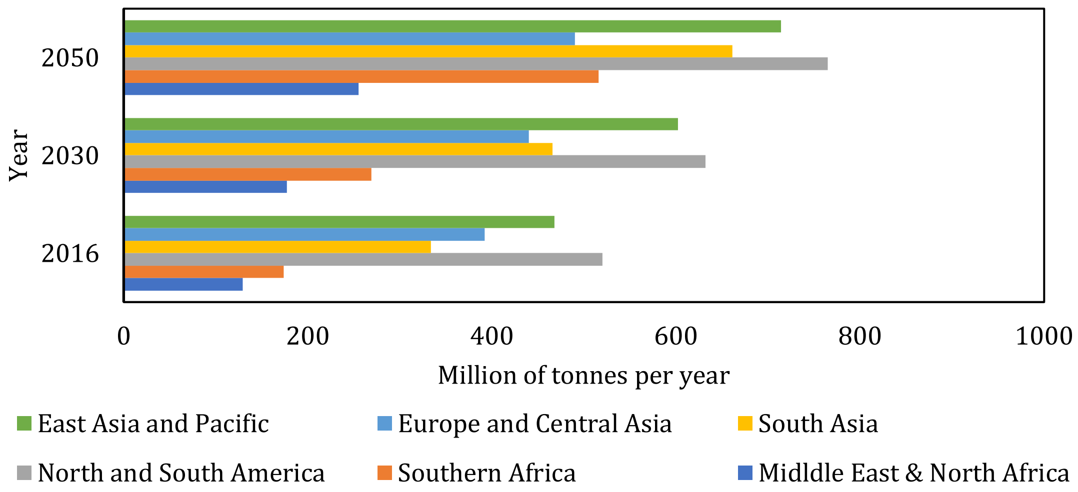


Fig. 1 *C&D waste generated*

The waste material from construction waste has potential benefits while recycling [3]. The ceramic waste when powdered and mixed as a replacement for cement in concrete, initially it functioned as a filler material and later helps in pozzolanic reaction [4]. When the used tile is converted into aggregate with a maximum percentage of replacement up to 10% reduces the cost of construction and also reduces the dumping issues [5] and beyond 10% of replacement the problem of bonding arises.

The tensile strength, compressive strength and flexural strength are affected when using the brick waste[6]. The crushed brick didn't showcase any improvement in the properties of the concrete, whereas considering it as a waste and a landfill material it can be used in a lesser quantity [7].

As the quantity of concrete waste generated is more than the other material in C&D, it was explored as a replacement material by various authors in concrete, mortar, subgrade material and also as a soil stabiliser.

The concrete with recycled concrete aggregate with internal curing improves the strength of the concrete [8]. Depending on the aggregate size, the elastic modulus of the composite increases to a maximum of 6% when the size increases from 7 to 12 mm[9]. But the major problem is the high porosity [10] as shown in Fig. 2. This can be rectified by using fibres as a tertiary additive. When the debris of the C&D waste is analysed properly towards its chemical composition so that the recycled material will not cause any further pollution[11]. When using the C&D in mortar, the water required is more than the conventional material but the water holding capacity is better and improves the workability properties[8], [12].

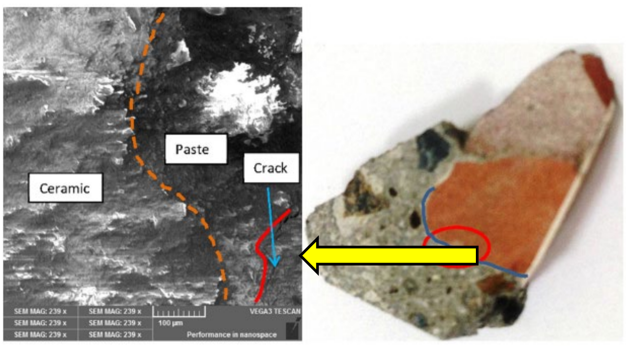


Fig. 2 *SEM images of C&D in concrete*

Crushing the C&D waste to a finer size to the size of clay and silt in a stabilised block increases the strength and acts as a potential replacement [13]. This C&D waste can also be used in subgrade under cyclic loading as a potential replacement material [14], [15].

Considering all these facts, the C&D waste is used in the soil as a replacement or a soil stabiliser. The change in Atterberg's limit trend reduces the possibility of cracks formation in the foundation when a maximum of 24 % is replaced and also the angle of internal friction increases [16]. When the C&D waste along with glass waste is used as a replacement material, the unit weight of the soil increases with a maximum replacement of glass waste as 5% and the compressive strength increases with an increase in the curing period to a maximum limit [17]. The compressive and flexural strength increases with an increase in the percentage of C&D waste along with polypropylene fibre, which makes the soil sample fail in brittle mode [18]. This makes the C&D waste in black cotton soil a potential stabiliser to increase its unit weight and strength and make it a recyclable material so that it will not be one of the stockpile materials dumped in the landfill [19].

The C&D waste can also be used as a replacement material for stones in the stone column[20] which is witnessed through the load intensity ratio; the ratio increases by 2.8 times when compared with the conventional stone[21]. In a floating stone column, the bearing of the soil increases minimum by 2 times that of the soil medium[22]. The brick waste as column material is weak and tends to expand in larger depth which makes it more suitable to take a larger surcharge load. Also, it reveals hydrostatic pressure generated excessively and also acts as a vertical drain which is the main function of stone column. The main advantage of having C&D as a replacement material for stones is that the maximum total settlement occurred during the construction itself[23]. Also, the permeability characteristics of the brick debris material are better than the concrete debris and conventional stone columns [24].

Considering the environmental aspect, the C&D waste should be properly disposed in order to avoid CO2 emission. Hence a laboratory study is proposed to study the replacement behaviour of C&D waste.; which includes concrete and brick waste. This is further compared with the pure clay and soil stabilised with stone column studied in this paper.

2. Methodology

2.1 Clay and Material Properties

The testing was done in CBR mould (California Bearing ratio) with an inside diameter of 155 mm and height of 175 mm. The clayey soil taken for stabilisation had a liquid limit of 69%, a plastic limit of 15% [25] marking it as High Compressible clay [26]. The soil had a specific gravity of 2.7 [27]. Tests were done for two consistency 0.4 and 0.6 with a water content of 48.18 and 55.12% respectively [28].

The C&D waste was obtained from our college premises with the concrete debris of M 30 grade. Bricks and concrete waste were considered as C&D waste upon demolition. The C&D waste was collected and crushed to a size of 4.75 mm to conduct the direct shear tests as per IS 2720 – part XIII [29]. The angle of internal friction of the concrete and brick waste was 40.63 and 29.12 degrees respectively.

2.2 Sample Preparation

The clay sample was pulverised, and water was mixed at its water content. It was allowed to rest for 1 day before placing the mixed sample in the mould. Before placing the clayey soil a 10 mm layer of sand in a 2 mm sieve was placed in the bottom, upon filling the mould again a 10 mm layer of sand in the top to felicitate the drainage condition at the top and bottom of the clay soils[30],[31]. To develop a column, a 30 mm inner diameter pipe was placed before filling the mould with clay soil. Once the clay was filled in the mould, pulverised bricks and concrete waste of 4.75 mm size were filled in the column. Once the column was constructed, the pipe was removed, and testing was carried out (Fig. 3).

The testing was performed in a loading frame of 10 kN by maintaining a strain rate of 1.25 mm/minute. The soaked tests were done by soaking the same sample combination for a period of 4 days in water as per Indian standard code [32]. Table 1 shows the detailed parametric study involved in the study.

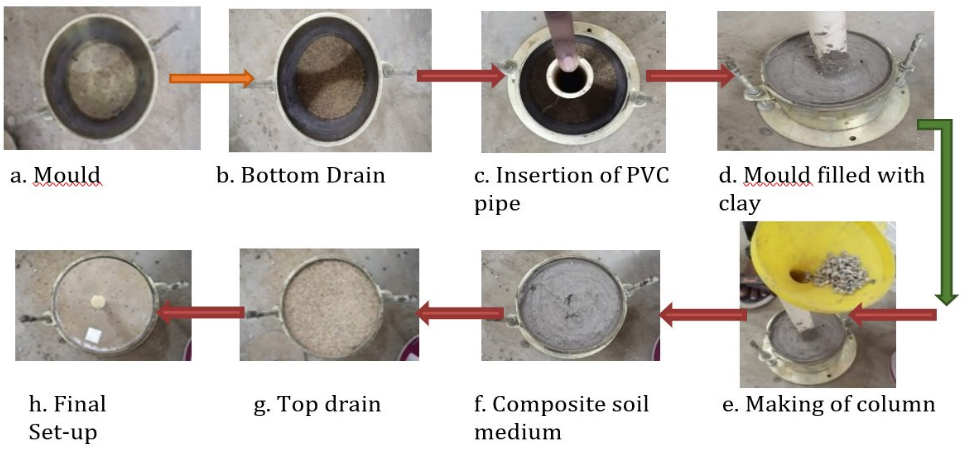


Fig. 3 *Sample preparation*

Table 1 *Parameter considered*

Consistency	Conditions	Combinations	Notations	Consistency	Conditions	Combinations	Notations
0.4	Unsoaked	Clay	C1U	0.4	Soaked	Clay	C1S
		Clay + Aggregate	C1UA			Clay + Aggregate	C1SA
		Clay + Brick	C1UB			Clay + Brick	C1SB
		Clay + Concrete	C1UC			Clay + Concrete	C1SC
0.6		Clay	C2U	0.6		Clay	C2S
		Clay + Aggregate	C2UA			Clay + Aggregate	C2SA
		Clay + Brick	C2UB			Clay + Brick	C2SB
		Clay + Concrete	C2UC			Clay + Concrete	C2SC

3. Results and Discussion

3.1 Experimental Study

The initial test was conducted for clayey samples alone. To understand the behaviour of the various materials as column material, the values were compared with the conventional column material with an angle of internal friction of 36 degrees.

The tests were conducted till the load–penetration graph became flat and failed (Fig. 4). At the initial stage of loading, the load taken by aggregate, brick and concrete shows a similar pattern and it is very steep. Over the increase in loading, the curve takes a turn at the yield point and the elastic stiffness value shows a similar value. The plastic zone ranges a lot and tends to show ductile behaviour.

While comparing the three materials as a stone column (concrete debris, bricks and stone aggregate), the performance of brick as a replacement material showed better behaviour due to its lesser unit weight. This ensures that the aggregate enhances the interlocking characteristics and bulge in the bottom which results in the improvement in resistance generated. However, it dilates soon and fails compared to other materials.

A load influence ratio parameter is introduced [33],[34] which is the ratio of load at 2.5 mm penetration to the standard load(1370 kg) corresponding to that penetration which is also termed as CBR value as per Indian Standard code [32]. The soil of consistency 0.6 shows better performance than that of 0.4 consistency, which is because of the lower water content. Initial study on unaltered soil shows a value of 2.29 and 4.39; this value increases when the ground is stabilised with stone columns. When the column material is of stone aggregate, the load influence ratio increases to 4.389 and 5.153 for 0.4 and 0.6 consistency of the soil. The values of C1UB and C2UB are 4.124 and 4.887 respectively; also, the value for C1UC and C2UC are 4.521 and 5.387 respectively. The value indicates that the value of CUC is more than that of the CUA, marginally: the behaviour is almost the similar.

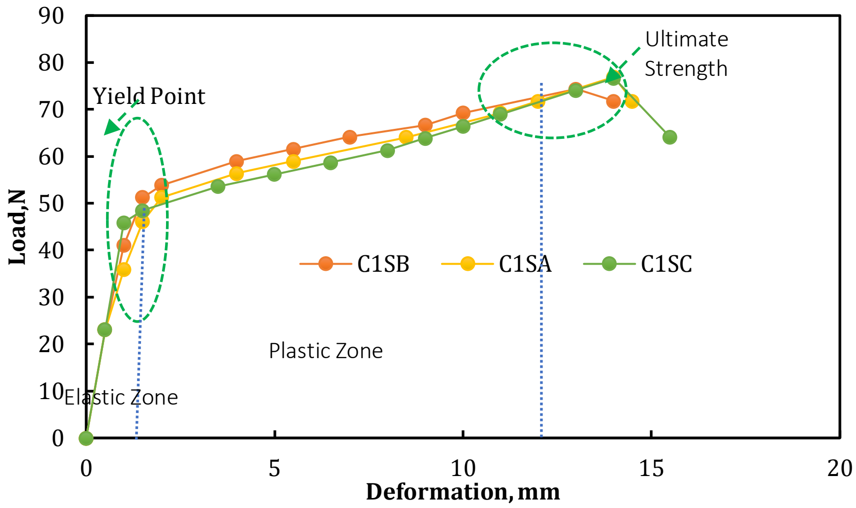
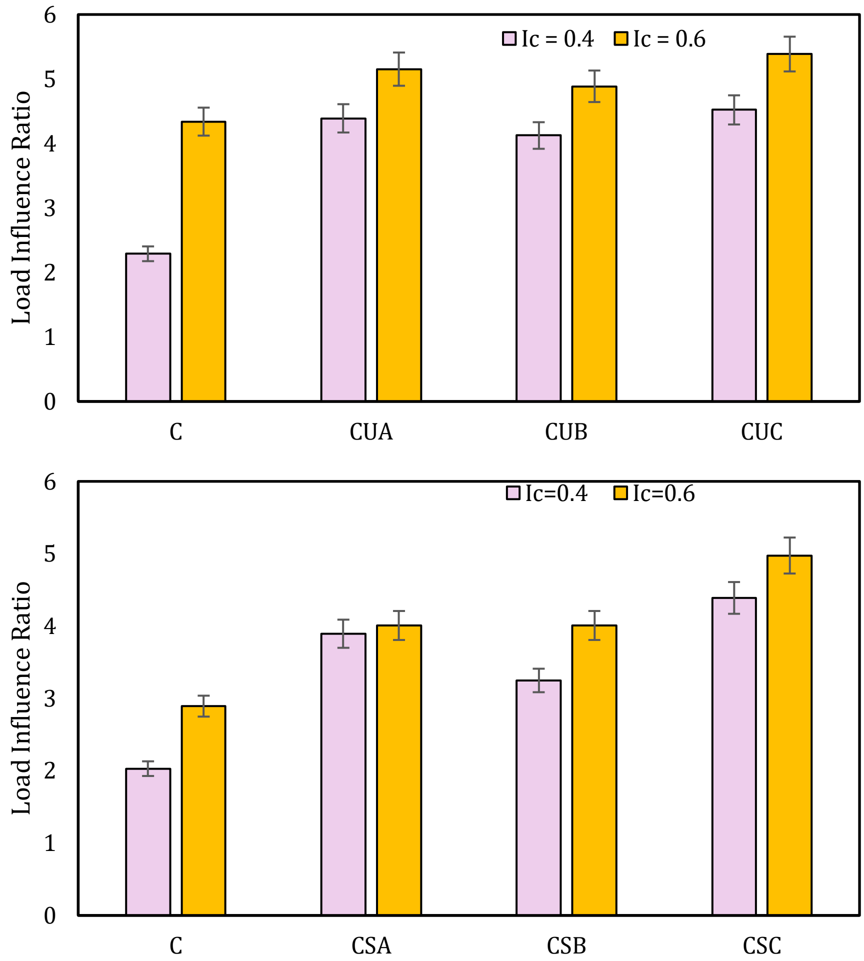


Fig. 4 *Load- Deformation behaviour under soaked condition*

In unsoaked conditions, the load influence ratio of composite soil with stone aggregate soil increases to almost double that of the unaltered soil (Fig. 5a). When the stone column is made full of concrete aggregates after washing and drying like the process of CUA formation, the ratio is slightly or almost the same as that of CUA. The values are 2.029,3.894, 3.248 and 4.389 for C1S, C1SA, C1SB and C1SC respectively. Similarly, for C2S, C2SA, C2SB and C2SC are 2.893,4.008, 4.01 and 4.975 respectively. When comparing the same with CUA, the strength decreases compared to CUA and CUC for both the consistency, but higher than that of the virgin clay. However, the trend is the same for higher consistency soil (0.6), This ensures that the composite soil with stone column functions better in soft clay. In soaked conditions, the load influence ratio is high for CSC. The rate of increase is comparatively higher than the unsoaked condition (Fig. 5b).



(a) Unsoaked

(b) Soaked

Fig. 5 *Load influence ratio*

The behaviour of crushed concrete debris is better behaviour than crushed brick. While calculating the initial stiffness of the composite medium, which is the initial tangent of the load-deformation curve; the C2U combination shows better results. It is proved that in a composite medium under soaking conditions, the load reduces (Fig. 6) and the crushed concrete shows better results.

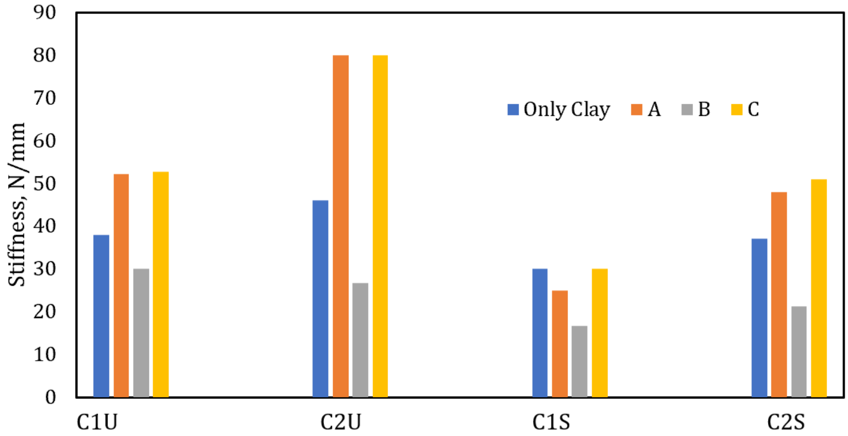


Fig. 6 *Initial stiffness*

The compression behaviour of the composite soil under soaked conditions is observed by placing a dial gauge at the top of the mould. The reading was taken every 24 hours for the 4-day soaking. The reading showcased that for the initial 24 hours, the rate of soil settling is more compared to the next 3 days and it gets constant beyond that value (Fig. 7). It is observed that the soil with lower consistency- C1 (0.4) settles more than that of C2 soil. More importantly, the settlement is immediate. When the soil has brick as a composite material it shows better results because of its water absorption capacity.

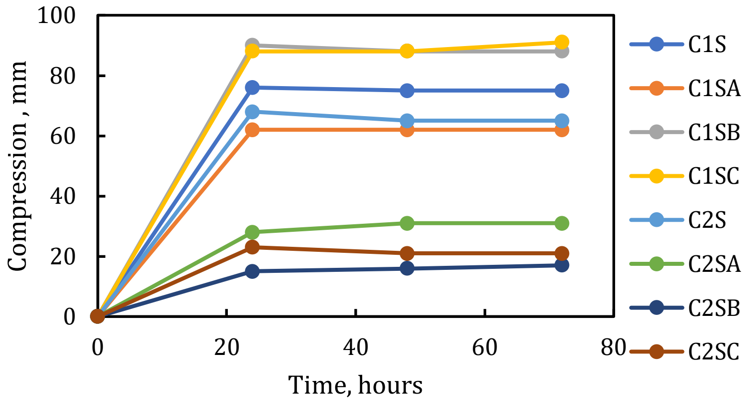


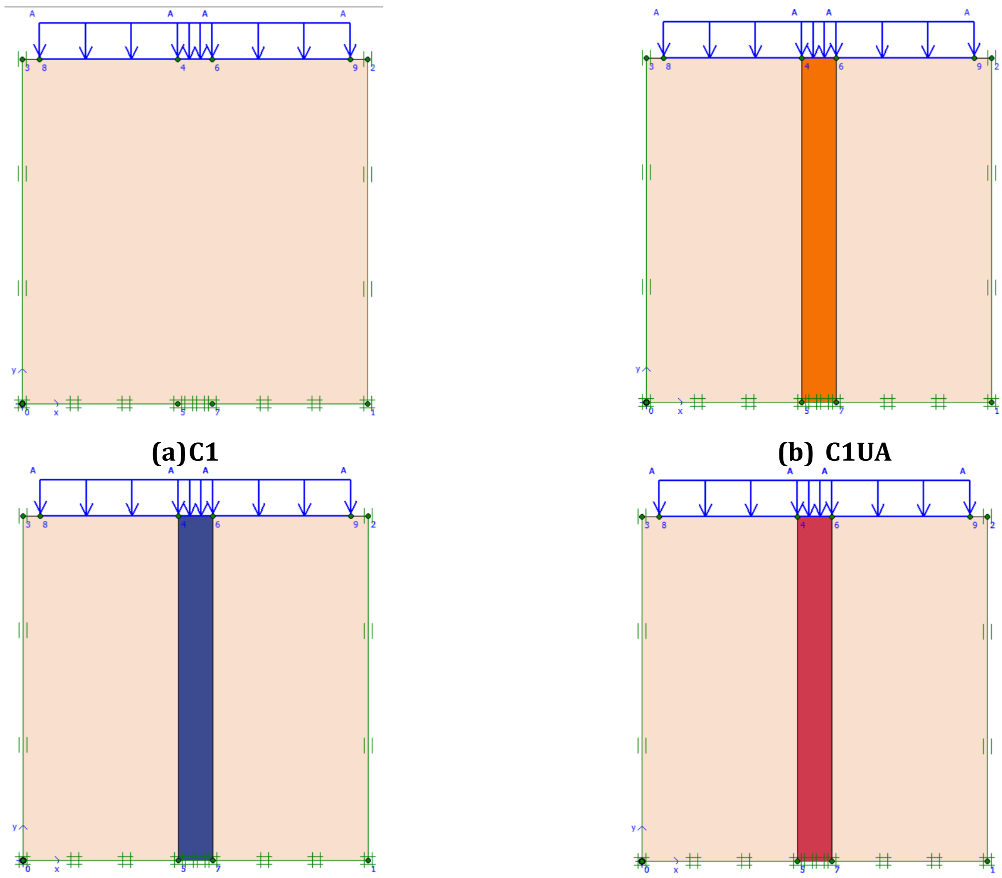
Fig. 7 *Compression reading*

3.2 Numerical Study

A soil of 1 x 1 x 1 profile with the same consistency is considered with a shear strength of 36 kPa in the study to understand the influence of a column of diameter 0.3 m [23] with varied materials as an alternative material for naturally available materials. The analysis is done using a Finite element tool and the same is validated from the previous study by the author [21]. The soil is modelled as Mohr- Coulomb model and the loading is done with a rate of 1N/mm^2. The angle of internal friction of the material is taken from the current laboratory study as 36, 40.63 and 29.12 degrees for sand, concrete debris and brick debris respectively. Initially, a model is created only with the clay soil, later it is compared with the column as shown in Fig. 8 and the properties are listed in Table 2.

Table 2 *Properties of the material*

Material	Angle of Internal friction,°	Unit Weight, kN/m³	Modulus, kPa	Poison's ratio
Aggregate	36	18.84	59.2	0.3
Concrete	40.63	24	30000	0.2
Brick	29.12	16.8	35000	0.33



(a)C1 **(b) C1UA**

(c) C1UC **(d) C1UB**

Fig. 8 *Model generated*

The displacement is measured for a uniform distributed load of 10 kN/m^2 applied over the column. It is evident that the C1 soil does not possess enough bearing and hence it slipped (Fig. 9); when the ground is stabilised with a column material, the settlement criteria vary. For the initial load, the displacement behaviour is similar for all the column materials. But when the loading increases, the pattern differs. The column with brick material shows an increase in displacement compared to the other two materials as a column medium.

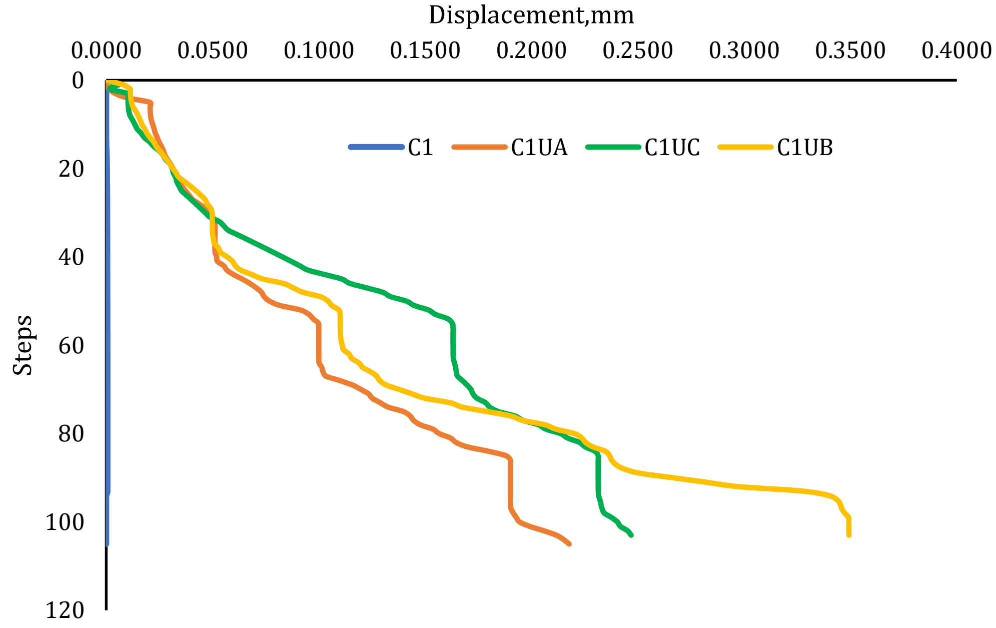
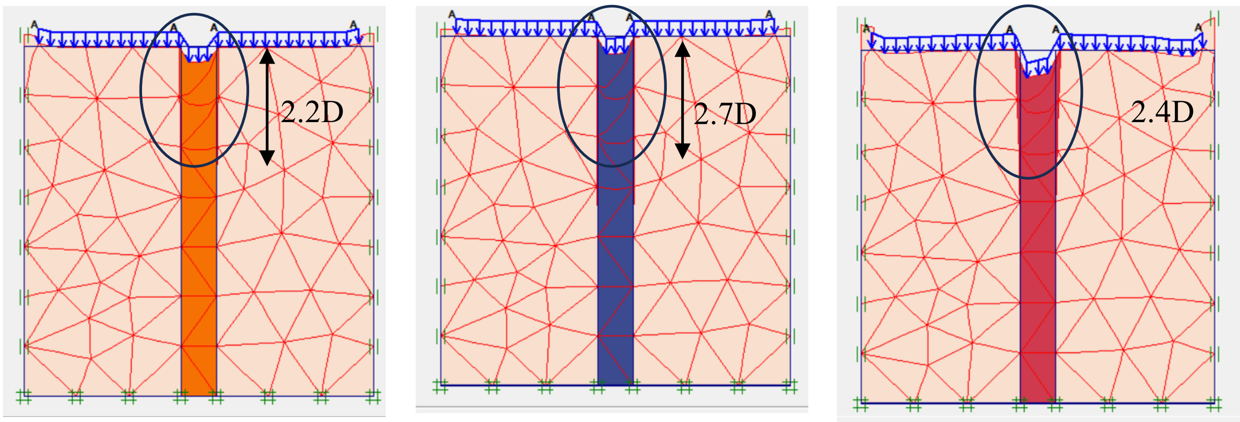


Fig. 9 *Displacement pattern from FEM analysis*

The bulging of the stone column happens in a soft clay layer followed by a firm stratum that has a length of 2 to 3 times the diameter of the column. The same is observed in all types of column materials (Fig. 10). The depth of the bulging occurs till a depth of 2.2, 2.7 and 2.4 D for CUA, CUC and CUB respectively. The brick debris as a replacement material shows a slight increase in building diameter.



(a) CUA **(b) CUC** **(c) CUB**

Fig. 10 *Bulging of column*

4. Conclusion

The stone column is a proven method of stabilising the soil well, the stone column dissipates the excess pore water pressure generated and makes the composite medium firmer. The failure pattern of the column with alternative materials such as bricks and concrete debris from the construction site behaves the same as that of the conventional stone aggregate. The following observations are made from the experimental and numerical study;

1. The function of the column in load ratio is better for soil with higher consistency, which is due to the confinement offered by the soil in both soaked and unsoaked conditions
2. The load penetration ratio of C1UA, C1UB and C1UC is more than 91.703,80.087 and 97.424% than the C1 under unsoaked conditions. Similarly, for C2UA, C2UB and C2UC it is more than 18.760, 12.629 and 21.153 % than the virgin clay.
3. Whereas in soaked conditions, the value of C1SA, C1SB and C1SC is more than 91.917,60.079 and 116.313% than the C1 under unsoaked conditions. Similarly, for C2SA, C2SB and C2SC it is more than 38.541,38.541 and 71.968% than the virgin clay.
4. The compression behaviour of the composite medium under soaked conditions is better for brick because of its lower strength and water absorption nature.
5. The bulging behaviour of the alternative material remains in the range of 2 to 3 times the diameter of the column.

Considering all the facts the debris material is more suitable as an alternative to stone in stone column. Compared to brick, concrete debris works well. The usage of debris as column material reduces the cost of material and reduces the pollution caused by the waste debris; this ensures a sustainable environment.

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Conflict of Interest

The authors declare no conflicts of interest in preparing this article

Authors Contribution

Sivapriya Vijayasimhan ***conceived and designed the analysis, wrote the paper***; *Sivakumar Naganathan* ***checked and analysed the data***; *Dhanushvarman J, Gokul S and Rakesh Raj M* ***performed the analysis and collected the data.***

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