Earth Pressures under Rotational Movement Mode for Red Soil Backfill partially replaced with Building Derived Materials

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Abstract. The variation of earth pressures plays a crucial role in the construction of retaining walls. The present study proposes a sustainable and eco-friendly usage of Building Derived Materials (BDM) mixed with red soil as a backfill for these retaining walls. An attempt is made to examine the variation of magnitude of at-rest earth pressure, with reference to various possible wall movements, necessary to mobilize passive earth pressures on the wall. Small scale laboratory model tests are conducted on a cantilever rigid retaining wall with different red soil – BDM blends as backfill. The BDM content is varied from 0 – 30% by weight of red soil. The retaining wall is rotated about its base with the help of a hydraulic jack. The earth pressures are measured with earth pressure cells fixed at different heights of the wall. The width of the backfill is varied at 0.35L, 0.5L and 0.65L to assess its effect on the variation of earth pressures, L being the base length of the retaining wall. The experimental results indicate that the earth pressures are not increased significantly by the inclusion of BDM to red soil, which suggests that BDM can be used as an effective light – weight backfill. The optimum pressure is obtained on mixing 20% BDM with red soil. It is observed that since the wall is made to rotate about its base, the earth pressure is greater near the top of the wall and decreased non-linearly with depth, in contrast to classical earth pressure theories. The results of the tests also demonstrate that the failure surfaces are limited by the width of the backfill.

Keywords: Retaining Wall, Earth Pressure, Building Derived Materials (BDM), Laboratory Model

1 Introduction

Infrastructure is the second important sector, contributing to nation GDP, after agriculture in developing countries like India. Infrastructure sector comprises of construction of new airports, bridges, roadways and housing. Retaining structures play a vital role in construction of bridges and road network elements. The variation of earth pressures on these walls plays a crucial role in the construction of retaining walls. Hence it is pre-requisite to estimate lateral earth pressures subjected by soil on these structures. Lightweight backfills tend to reduce earth pressures, which in turn reduces possibility of failure. Nowadays materials like Ground Granulated Blast furnance Slag (GGBS), flyash, geofoam, shredded tire chips are emerging as light-weighted backfills. Lee *et al.*,[1] conducted research on rubber sand and found that at-rest and active earth pressures are reduced by its inclusions in backfill. Aspect ratio of rubber tire chips is an important parameter as it can alter earth pressures [2]. Coulomb's equations predict earth pressure accurately when wall is moving away from backfill [3]. Compaction of granular material leads to greater earth pressures whereas in case of cohesive soils, earth pressures are function of undrained strength

[4]. Lateral earth pressures vary non – linearly with height in contrast with theoretical value when backfill is arranged in layers in gabion walls [5]. Minor movements occurred when backfill is reinforced with geosynthetics compared to non – reinforced backfill [6]. Rankine’s or Coulomb’s theory underestimates earth pressures generated when subjected to pull out tests on reinforced backfill [7]. To estimate earth pressures and to conduct parametric studies, model retaining walls are developed with specified boundary conditions. Moving pluviator is used to arrange sand samples in retaining wall to achieve field conditions [8]. Surcharge load alters earth pressure variation in backfill, air bags are placed over backfill for uniform load distribution [9]. Flyash in combination with 30% cohesive soil can be used as backfill as it can bear surcharge loads up to 33 kPa [10]. Replacing backfill with Recycled Concrete Aggregates (RCA) partially improved seismic performance of retaining structure [11]. Construction and Demolition Waste (CDW) contains concrete, brick, glass, plastic, wood. Out of which, concrete and brick part forms Building Derived Materials (BDM) is inert material and occupies more land space.

From the past research works, it can be observed that limited studies are reported on reusing of Building Derived Material (BDM) in retaining wall applications. This research is focused on using Building Derived Material (BDM) admixed with locally available soil as a backfill component. This will help to reduce the cost related to disposal of waste materials, as well as reduce carbon footprint, thereby making the process eco-friendly and sustainable. In the present study, an attempt is made to examine the variation of magnitude of at-rest earth pres-sure, with reference to various possible wall movements, necessary to mobilize passive earth pressures on the wall. Small scale laboratory model tests are con-ducted on a cantilever rigid retaining wall with different red soil – BDM blends as backfill.

2 Materials Used

In the present study, the red soil is collected from Jawahar nagar area, Medchal district, Telangana. It comprises of 1% gravel, 52% sand and 47% silt and clay, appears reddish brown in color. From grain size distribution (Fig. 1) and plasticity characteristics, it is classified as silty sand (SM). Construction and Demolition Waste (CDW) contains concrete, brick, tile, glass, wood and plastic out of which concrete and brick are separated. Building Derived Material (BDM) is obtained by breaking CDW into small particles. BDM is classified as poorly graded gravel (GP) by Unified Soil Classification System. Particles ranging 2.36 – 10 mm are utilized in this study as larger particles (>10 mm) tend to break and loose its strength prior to loading. The index properties of red soil and BDM are presented in Table 1. There are 38.2% gravel, 61.6% sand and 0.2% silt and clay-sized particles present in BDM. Cu and Cc of BDM are found to be 18.4 and 0.87. According to Rahman et al. [13, 14], the shape parameters of heavyweight material are 78.83 and 2.97. It is also stated that for a lightweight material, gravel, sand and finer fractions should be less than 40 %, 70%, and 3% respectively, whereas, for heavyweight material, the values are 47.9%, 42.2% and 9.9% respectively [15, 16]. From the above analysis, BDM can be classified as lightweight material.

From consolidated undrained triaxial tests, the cohesion and angle of internal friction of red soil are obtained as 9.5 kN/m^2 and 20° respectively. BDM is admixed with red soil (R) in different proportions ranging from 5 – 30% of total weight and their shear strength parameters are presented in Table 2. A constant relative density of 40% is maintained throughout. Red soil admixed with 20% BDM (R20) is the optimum blend as it exhibited more strength than other proportions [13].

Table 1. Index Properties of Red soil and BDM

Property	Red soil	BDM
Coefficient of Uniformity (C_u)	2.5	18.4
Coefficient of Curvature (C_c)	0.11	0.87
D_{10}	0.017	0.4
D_{30}	0.023	1
D_{60}	0.4	5
Specific Gravity(G)	2.62	--
Liquid Limit (LL)	39	--
Plastic Limit (PL)	29	--
Plasticity Index (PI)	10	--
USCS Classification	SM	GP

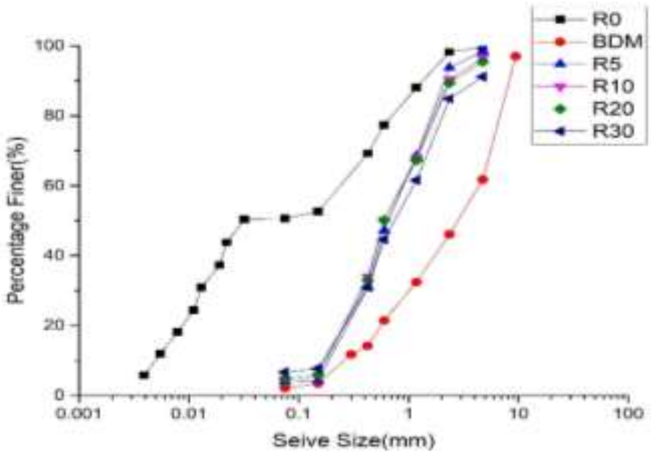

Fig. 1. Grain Size Distribution for Red soil and Red soil – BDM blend

Table 2. Shear strength properties Red soil - BDM blend [17]

Proportion	Cohesion (kN/m^2)	Angle of internal friction (^{0})
R0	9.5	20
R5	7	26.5
R10	10	23.02
R20	28	38.65
R30	18	33

3 Methodology

The tests for generating earth pressures are carried out on an instrumented model retaining wall apparatus. The detailed diagram of the set-up is provided in Fig. 2. The retaining wall is built in a steel tank of length 1.22 m, breadth 0.92 m and height 0.92 m. Three sides and bottom base of tank are made with mild steel material of 12mm thick and one side is fitted with 25mm thick acrylic sheets. A mild steel plate of 12mm thickness and height 0.9 m is placed in the tank over a hinge. The wall can slide over the length of tank and can rotate at with the hinge facility provided. Three diaphragm type earth pressure cells (EPC) of diameter 200mm and thickness 7mm is attached flush on the backfill side of the plate at the interface of soil and wall on the front face. The plate is attached with a loading jack (L) to facilitate the rotation. This mechanically operated hydraulic jack of 150 kN capacity is used hold plate at particular position. Rotation is achieved when forces are applied with hydraulic jack on to the plate, which makes the plate move towards backfill about hinge and create the passive earth pressure conditions. The passive pressures are checked in order to check how the inclusion of BDN affect their magnitude. The wall is placed at distances of 0.65m, 0.5m and 0.35m from one end of the tank to assess the impact of different backfill lengths behind the retaining wall. A plywood sheet along with epoxied sand is placed at the bottom of the tank to create a rough surface. This simulates backfill continuity in the vertical direction. Sandpapers are pasted on the backfill side of the wall to create soil-wall friction. The interface friction angle is maintained approximately between 1/3 to 2/3rd of the friction angle of soil. An inclinometer is placed on the top of the retaining wall to measure angular rotations and the top lateral displacements are measured by LVDT placed on the side of the retaining wall.

A series of experiments are conducted on red soil and red soil admixed with different percentages of BDM. The wall is kept at rest in first case and rotated towards the backfill to generate passive earth pressure conditions in the second case. The soil is compacted at 40% relative density and the top surface of the backfill is manually levelled. The contact area of soil – pressure cell influences the earth pressures to a great extent. Before backfilling, the EPCs are calibrated to experimental conditions by dead weight calibration method [18]. Boundary conditions of experimental setup are plane strain, rigid unyielding wall with hinge at bottom; bottom base and extreme right end of tank is restrained from vertical and horizontal movements. 30 tests are performed (15 at rest, 15 passive condition) by keeping the wall at three different positions to assess the impact of variation in backfill width.

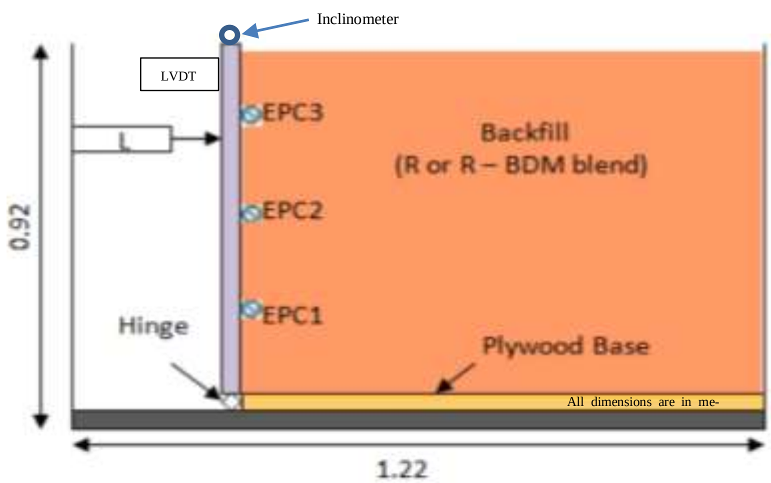

Fig. 2. Schematic view of model retaining wall set-up

4 Results and Discussions

The earth pressure distribution for red soil – BDM blend at at-rest and passive conditions are shown in Figures 3(a-e) and 4(a-e) respectively. It can be observed from the figures that the earth pressures are increasing non – linearly with height of the wall in at- rest case; whereas in passive case, the top EPC exhibits more earth pressure compared to middle and bottom cells. When the backfill is in at-rest case with only red soil and no BDM, the maximum pressure (8.5 kPa) is observed at the bottom cell for wall position at 0.5 m. As the wall position is altered from 0.65m to 0.35m, the bottom pressure (P_{Bottom}) decreases significantly compared to the top and middle (P_{top} & P_{Middle}) ones. When BDM is added to red soil from 0 – 30%, P_{Bottom} is increased from 5 kPa to 10 kPa at wall position of 0.65m. In at-rest case, earth pressures are in the range of 1.5 – 10 kPa; while in passive case, earth pressures fall in between 10 – 70 kPa. In passive case, the top earth pressure cell (P_{top}) exhibits the highest pressure in the range of 30 – 40 kPa. As the backfill width is altered, P_{top} value decreases. It may be observed that for narrow backfill (0.35m), it is difficult to develop the full failure surface and hence it exhibits less pressure compared to the other two positions of the retaining wall. The obtained experimental values are compared with theoretical values from Jaky's theory for normally consolidated soils (at – rest condition) and Coulomb's earth pressure theory (passive case)

$$P_o = (1-\sin\varphi)\,\gamma z \quad (1)$$

$$P_p = \frac{\gamma H^2}{2} \cdot \frac{sin^2(\alpha-\emptyset)}{sin^2(\alpha).\sin(\alpha+\delta)[1-\sqrt{\frac{\sin(\emptyset+\delta).\sin(\emptyset+\beta)}{\sin(\alpha+\beta).\sin(\alpha+\delta)}}]^2} \quad (2)$$

Where, P_0 = at-rest earth pressure, P_p=passive earth pressure, α is the angle of inclination of front face of the retaining wall with vertical, β is the angle of inclination of top of backfill.

The interaction between red soil and retaining wall is made rough and tests are conducted in dry state. Interface tests conducted on sandpaper and red soil yielded an interface friction angle between them delta (δ) as 13.2°. The back of the retaining wall is considered to be vertical (alpha = 90°) and the backfill horizontal (beta = 0°). From the results, it is clearly observed that the experimental findings vary significantly with the theoretical values. The backfill is assumed to be homogenous where vertical and lateral pressures remain constant. But in this case the backfill soil is mixed with BDM particles resulting it to be non – homogenous. This resulted in uneven distribution of earth pressures along the height of wall. Strength mobilization of backfill depends on density and angle of internal friction. From triaxial tests, it is noticed that angle of internal friction increases with addition of BDM. In passive state, the strength exhibited by soil due to its arrangement is dominated by wall weight and horizontal pressure acting on it. Thus, full soil strength is mobilized in this condition in all directions. Pressure envelops are developed along the height of wall, assuming zero earth pressures at top of backfill, assuming no surcharge is acting on the backfill.

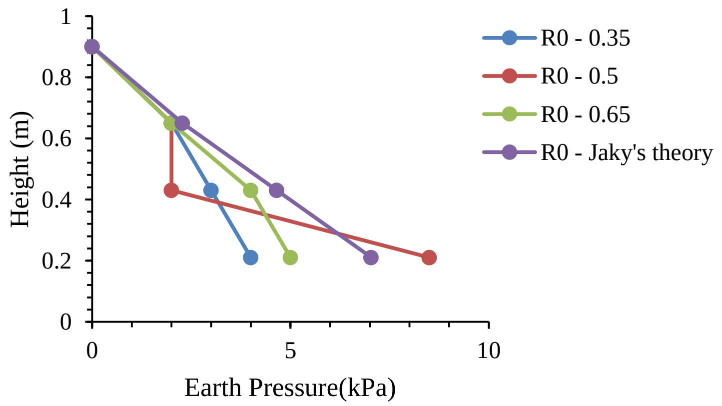

Fig. 3. (a) Variation of earth pressure with wall height for Red soil – 0% BDM at K_0 condition

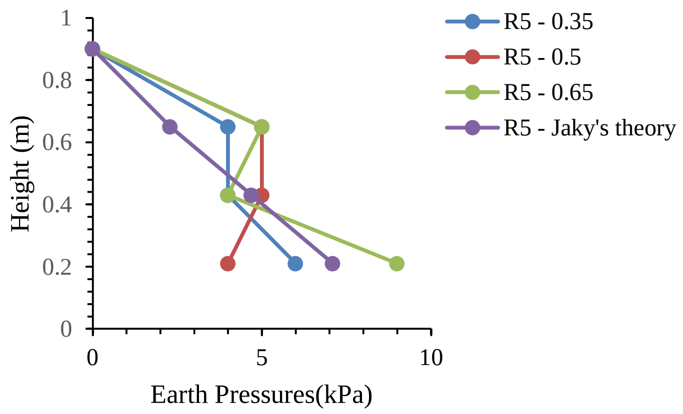

Fig. 3. (b)Variation of earth pressure with wall height for Red soil – 5% BDM at K_0 condition

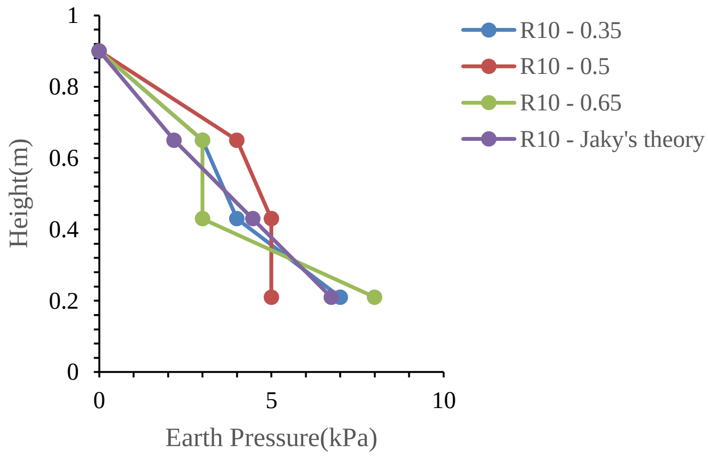

Fig. 3. (c)Variation of earth pressure with wall height for Red soil – 10% BDM at K_0 condition

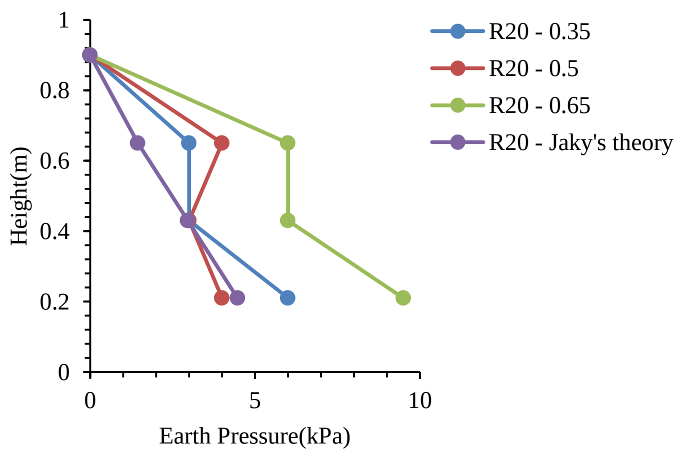

Fig. 3. (d)Variation of earth pressure with wall height for Red soil – 20% BDM at K_0 condition

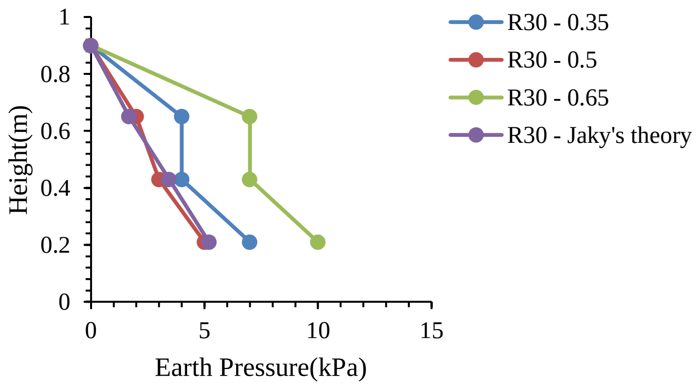

Fig. 3. (e) Variation of earth pressure with wall height for red soil – 30% BDM at K_0 condition

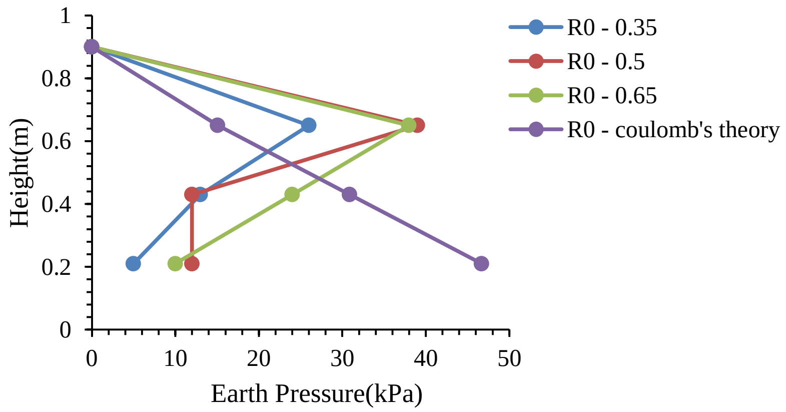

Fig. 4. (a) Variation of passive earth pressure with wall height for Red soil – 0% BDM

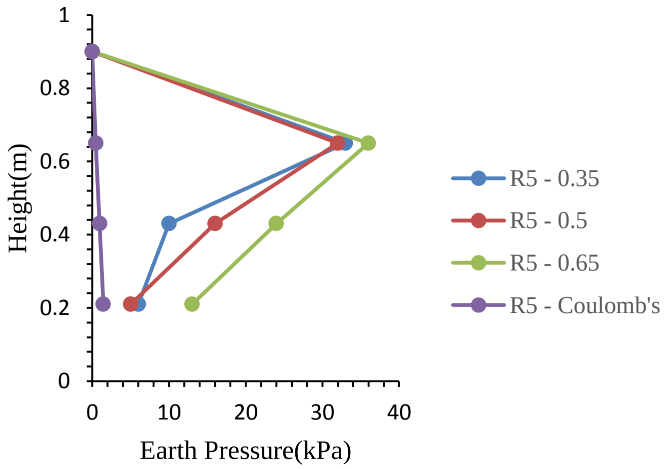

Fig. 4. (b)Variation of passive earth pressure with wall height for Red soil – 5% BDM

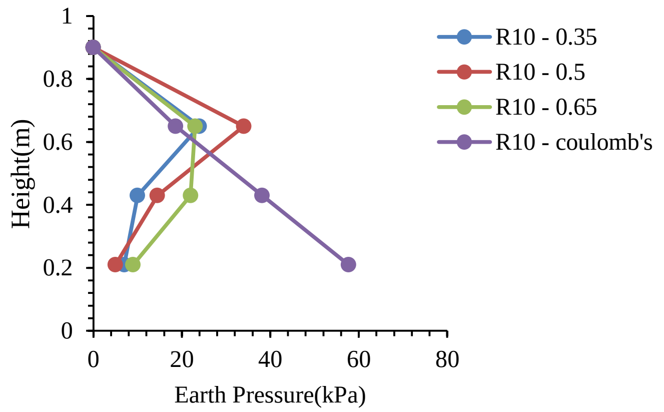

Fig. 4. (c) Variation of passive earth pressure with wall height for Red soil – 10% BDM

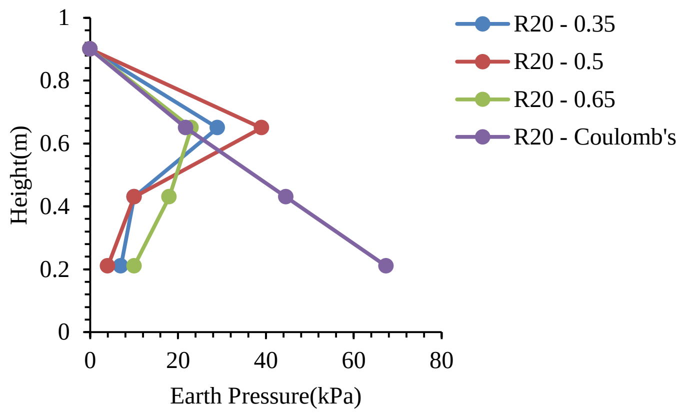

Fig. 4. (d)Variation of passive earth pressure with wall height for Red soil – 20% BDM

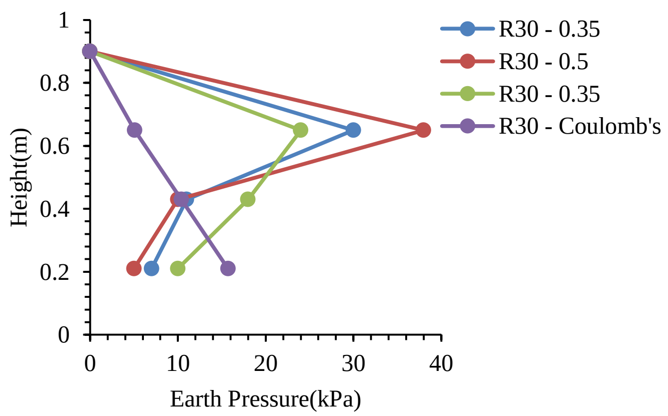

Fig. 4. (e)Variation of passive earth pressure with wall height of wall for Red soil – 30% BDM

The experimental results indicate that the earth pressures are not enhanced significantly by the inclusion of BDM to red soil, which suggests that BDM can be used as an effective light – weight backfill. The optimum pressure is obtained on mixing 20% BDM with red soil. It is observed that since the wall is made to rotate about its base, the earth pressure is greater near the top of the wall and decreased non-linearly with depth, in contrast to the classical earth pressure theories. However, the results presented in this paper are based on limited experimental findings, and more research in this direction is required, for further understanding of the behavior of retaining walls.

5 Conclusions

An accurate estimation of lateral earth pressure on retaining walls relies on a realistically defined slip surface in the backfill. This study aims to examine the at-rest and passive earth pressure in soil - BDM backfill under the rotational movement mode of the retaining wall. The present study proposes a sustainable and eco-friendly usage of Building De-rived Materials (BDM) mixed with red soil as a backfill for these retaining walls. This will help to reduce the cost related to disposal of waste materials, as well as reduce carbon footprint, thereby making the process eco-friendly and sustainable. The following conclusions can be drawn based on the findings of the present study.

- An increase in backfill width decreases the rotation of wall, thus reducing the probability of rotational failure. Hence narrow backfills are more prone to rotational failure.
- The pressure distribution is non – linear for both at – rest and passive conditions. It is observed that since the wall is made to rotate about its base, the earth pressure is greater near the top of the wall and decreased non-linearly with depth, in contrast to classical earth pressure theories. In passive case, greatest earth pressures occur at 1/3 height of wall from top which is in contrast with theoretical values.
- Shear strength mobilization is increased with addition of BDM particles to existing soils among the backfill. The experimental results indicate that the earth pressures are not enhanced significantly by the inclusion of BDM to red soil, which suggests that BDM can be used as an effective light – weight backfill. The optimum pressure is obtained on mixing 20% BDM with red soil.

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