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Numerical Analysis on the Reinforced Earth Walls Back-filled with Coal Gangue

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Abstract. With the growing impetus to utilising solid waste in civil engineering works, there is a need to identify alternatives to natural earth materials like soils. In this context, in the present study, numerical analysis was performed to ascertain the feasibility of utilising coal gangue as a fill material in reinforced earth wall construction, which is a solid waste generated during the mineral processing phase of coal mining. The coal gangue procured from Kakatiya coal mines (Bhupalpally, Telangana State) was characterised for its geotechnical properties prior to numerical analysis. Further, for the numerical analysis plaxis 2D software application was utilised. From the consolidated drained tri-axial test results, it was inferred that coal gangue has favorable geotechnical engineering properties to facilitate its application as a fill material. Further, from the numerical analysis, it was noticed that the maximum displacement occurs at the top surface of the reinforced earth wall and the deformations reduced with the increase in fines content of coal gangue. Further, correlations were drawn between factor of safety and mode of failure of the coal gangue based reinforced earth wall.

Keywords: Coal Gangue; Mining Waste; Reinforced Earth wall;

1 Introduction

Recently there has been expanding consumption of energy which created a demand for energy sources coal is one among them, resulting in coal mining, associated with the coal waste, which is disposed of in the surrounding areas of coal mining. At present, there is a demand for addressing these problems associated with the disposal and associated environmental impact of coal wastes. Among coal wastes, coal gangue which is solid waste generated during the mineral processing of coal mining is the largest which amounts to 10% of total coal produced [1-3]. In line with natural granular materials (gravel and sand), recent studies on coal gangue by Ashfaq et al. [4] have proven the feasibility of using coal gangue as a substitute for natural material as backfill. In the past studies, it has been noted that embankments with coal gangue have become unstable due to rainfall [5]. Earlier studies have also examined the issue of leaching and environmental impacts of coal gangue utilization [1-2]. The current status of coal gangue research is limited to laboratory experimental study. But there is a lack in modeled examining of laboratory experimental results. In this context, this study mainly focuses on the study and understanding of the geotechnical properties of the coal gangue [CG], followed by the numerical analysis on stability of Reinforced Earth wall.

Numerical modeling of reinforced earth wall is carried out in finite element method software PLAXIS 2D. the parametric studies are carried out to understand the stability and its associated parameters.

Study of engineering properties such as physical properties and geotechnical properties of coal gangue.

- Effect of reinforcement length on the stability of the reinforced earth wall.
- Influence of vertical spacing of reinforcement on the stability of the reinforced earth wall.
- Modeling and stability analysis of reinforced earth retaining wall in the software PLAXIS 2D.

2 Materials and methodology

The coal gangue is investigated in this study and categorized as poorly graded sand (SP) based on the unified classification system (UCS) and is presented in Fig. 1.The physical and geotechnical properties of coal gangue with the test methodology (standard) adopted are presented in Table 1. From results presented in Table 1, it can be noted that the unit weight of the coal gangue was found to be lower than any conventional material which leads to the lower backfill pressure on the retaining structures. Well compacted coal gangue can have a maximum dry density of 1740kg/m^3 and frictional angle of 39° which is comparable with the natural granular backfill material. parametric study was conducted using finite element method software PLAXIS 2D. The boundary condition of the model was, the lower boundary of the structure was considered as fixed in both vertical and horizontal directions, and the side boundaries were fixed in a horizontal direction only. The foundation soil mass was considered as the still and boundary resistance was not assigned whose depth was considered as 5m from the ground level. The structure has a facing element as modular blocks, whose dimensions are 50cm wide and 25cm height. In the analysis reinforcement lengths were chosen as 4.5m, 6m, 9m, and 13.5m.corresponds to the value of L/H value of 0.5, 0.67, 1.0, and 1.5 respectively. The spacing of the reinforcement was kept as 0.5m and 1.0m. The similar model on reinforced earth wall by Guler et al [6] was validated prior to its extension to coal gangue as fill material.

Table 1. Geotechnical properties of coal gangue

Property	Test Method	Value
Liquid Limit (%)	ASTM D4318-17e1 [7]	28
Plastic Limit (%)	ASTM D4318-17e1	NP
Plasticity Index (%)	ASTM D4318-17e1	NP
pH	ASTM D4972-19 [8]	7.24
USCS Classification*	ASTM D2487-17e1 [9]	SP
Specific Gravity	ASTM D854-14 [10]	2.57
Optimum Moisture Content (%)	ASTM D698–12e2 [11]	17
Maximum Dry Density (kN/m^3)	ASTM D698–12e2 [11]	21
Cohesion	ASTM D2850 [12]	Nil
Angle of internal Friction(φ)	ASTM D2850 [12]	39°

3 Results and Discussion

Based on the physical and engineering properties of coal gangue presented in Table 1. It was observed that it is classified as poorly graded sand (SP) based on the UCS soil classification system. The unit weight of the coal gangue was found to lower than any conventional material which leads to the lower backfill pressure on the retaining structures. Well compacted coal gangue can have a maximum dry density of 1740kg/m3, and shear strength parameters of 39° and little cohesion which is comparable with the natural granular backfill material. The higher values of shear strength parameters support the bulk utilization of coal gangue as a backfill material for any geotechnical applications. The coal gangue compaction can be easily performed using conventional compaction machinery.

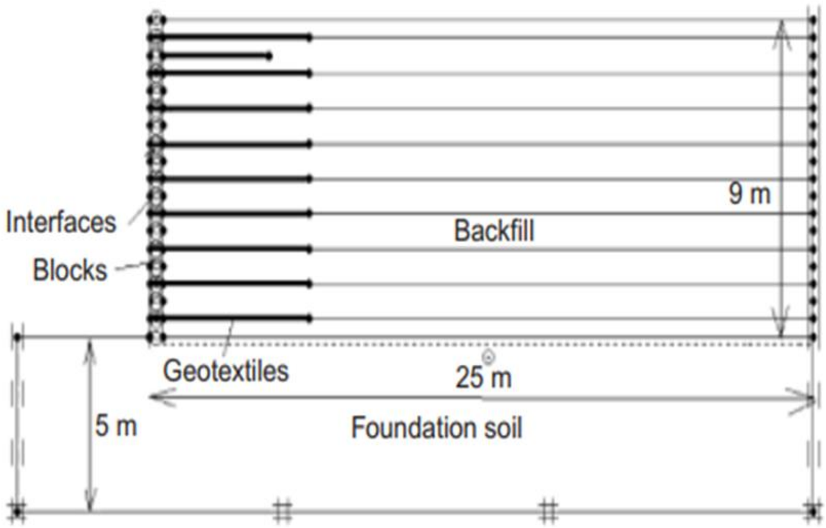

Fig 1. Geometric representation of reinforced earth wall

The numerical analysis was carried out for the reinforced earth wall, dimensions and other details are shown in Fig 1, with the backfill as the coal gangue. The results of the analysis consist of the deformed mesh, incremental strain concentration, and failure plain and Factor of the safety of each combination were compared and analyzed, which are shown below.The model combination C1 represents the reinforced earth wall with the reinforcement spaced at 1m, and of length, 4.5m gives the ratio L/H=0.5. The deformed mesh and incremental strain concentration obtained after the φ-c reduction phase is shown in Fig 2 and Fig 3 respectively. The incremental strain concentration shows that the failure plain was linear and was bilinear also at the end of the reinforcement the concentration of incremental strains was observed. The failure plain segment was extended up to the area of the bottom forth reinforcement layer. The FOS obtained for the model combination was 1.784 at the end of the step size 150.

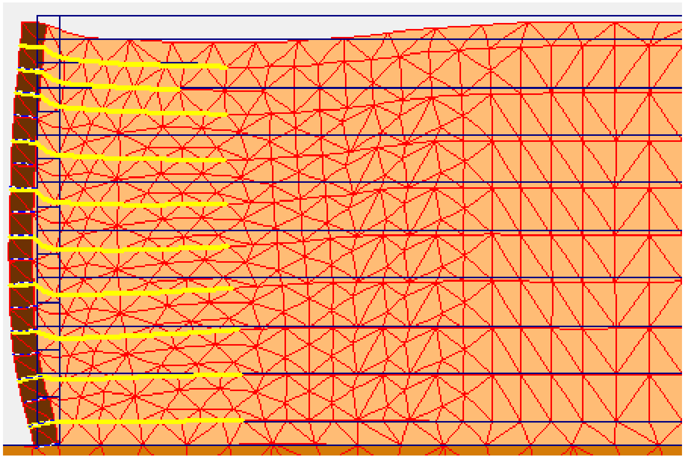

Fig. 2. Deformed mesh of model C1.

The model combination C2 represents the REW with the reinforcement length 6m, spacing 1m gives the ratio L/H=0.67. The deformed mesh after the φ-c reduction phase is represented in Figure 4. The incremental strain concentration plot was drawn after the completion of the φ-c reduction phase and the same is represented in Figure 5. The failure plane was bilinear and the first segment was within the bottom three layers of the reinforcement, which implies that the increase in the reinforcement length flatters the failure plane. The second segment of the failure plain was away from the reinforced area, the incremental strain concentration was observed at the end of the reinforcement layer. The FOS of the model combination was observed to be 2.4 at the end of 137.

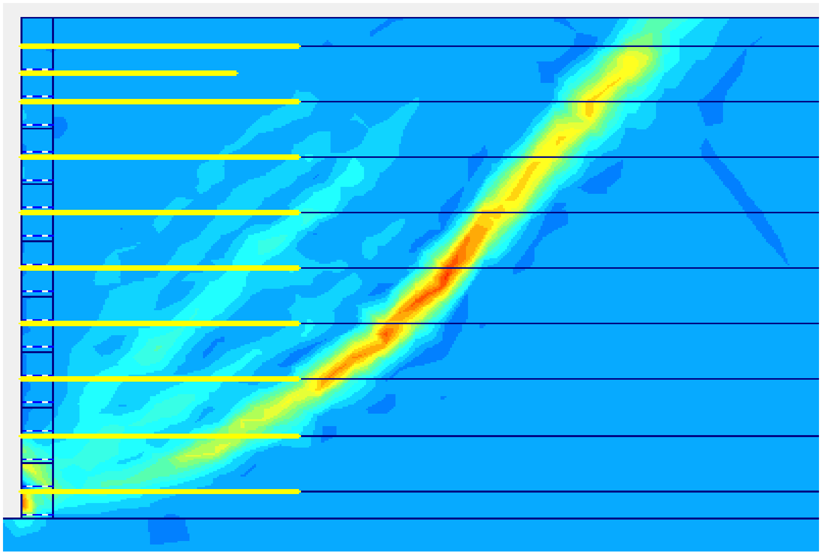

Fig. 3. Incremental strain concentration of model C1

3.1 Effect of reinforcement vertical spacing

In the model combination, C1 with L/H ratio of 0.5 the incremental strain concentration was bilinear. Moreover, the initial failure plain was within the reinforcement zone and the second segment was extended in unreinforced soil zone. For the vertical spacing of 1.0m in model C2, the initial failure segment was extended up to the bottom four layers of the reinforcement, whereas for 0.5m vertical spacing the initial failure plain was found to be within the bottom two reinforcement. The flattening of initial failure plain with decreasing reinforcement spacing which can be attributed to the drastic decrease in the deformation. Further, the FOS of the structure increases drastically with the increased number of reinforcement layers acing was observed for the other combinations with different reinforcement lengths.

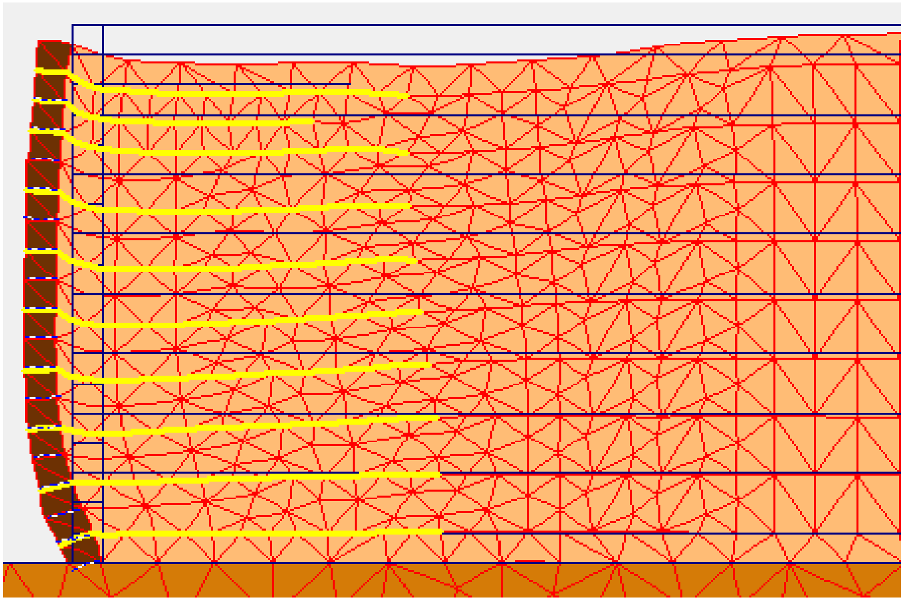

Fig .4. Deformed mesh of model C2

3.2 Effect of reinforcement length

For a better understanding of the effect of reinforcement length on the behavior of the reinforced earth wall structure the model combinations C1 and C2 were designed with the reinforcement length 4.5m and 6m respectively. The failure plain analysis was compared from the incremental strain concentration at the end of φ-c reduction phase of each combination. The failure plain was well within the reinforcement zone for the reinforcement length of 4.5m, with the increase in the reinforcement length the failure plain was discontinuous. The second segment of the failure plain was not reaching the soil surface as the reinforcement length increases. For the L/H ratio > 0.67, the mode of failure was observed to be sliding of reinforced soil block. The sliding failure plain disappears with the increase in the reinforcement length. The flexibility of the structure increases with the increase in the reinforcement length. The extreme deformation was found to be converging for the reinforcement length 13.5m for the vertical spacing of the reinforcements 0.5m and 1.0m.

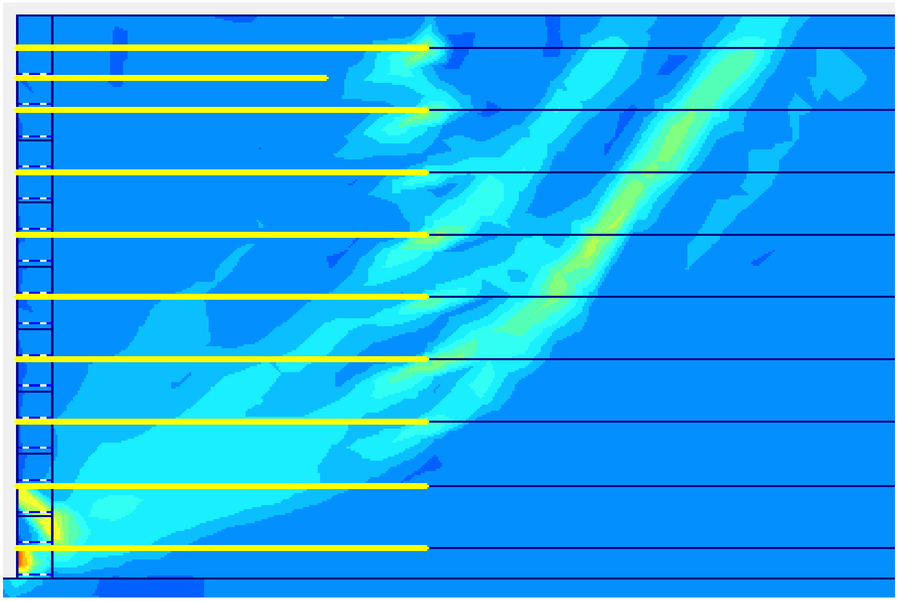

Fig. 5. Incremental strain concentration of model C2

4 Conclusions

The following conclusions were drawn from the study:

1. The mode of failure changes from internal instability to external instability which was due to sliding failure.
2. The length of reinforcement greater with L/H value greater than 1.0 has a negligible effect on the failure plane.
3. For the 1m reinforcement spacing, the displacement in the face element and reinforcements were observed to be more when compared to reinforced spacing of 0.5m.
4. The peak tensile load in the reinforcement was found to be within permissible limit and is found to be 5 to 20kN/m
5. The failure plain was examined at the end of φ-c reduction phase which shows that an increase in reinforcement density makes failure plain flatter and higher the safety (FOS) and the mode of failure changes from internal

instability to external instability and mode of failure was found to be sliding failure.

6. Reinforcement length has got a greater influence on the failure plain, with the increased L/H value (greater than 0.67) the separation of the reinforced and unreinforced soil zone can be eliminated. The length of reinforcement greater with L/H value greater than 1.0 has a negligible effect on the failure plane.
7. The flexibility of the reinforced earth wall increases with the increase in the reinforcement length, which implies that the structure gives enough warning before complete failure with visible deformation, vertical spacing has got no much difference in the extreme deformations.
8. The greater value of L/H value showed that even though the whole structure was found to be failed but the reinforced soil zone was intact. For the 1m reinforcement spacing, the displacement in the face element and reinforcements were observed to be more when compared to reinforced spacing of 0.5m.
9. The concentration was of axial load in the reinforcement decreases with the increase in the reinforcement length, it is observed that the distribution of the axial load is more uniform when the reinforcement length increases. The peak tensile load in the reinforcement was found to be within permissible limit and is found to be 5 to 20kN/m.

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