

Study on Reinforced Earth Retaining Wall with Sustainable Backfill

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ABSTRACT

Retaining walls are vital civil engineering structures that stabilize soil, prevent erosion, and maintain grade changes. Reinforced earth (RE) walls are particularly effective because they combine compacted backfill with reinforcing elements, thereby enhancing structural integrity and load-bearing capacity. Numerical modeling software such as PLAXIS 2D is indispensable for analyzing their behavior and optimizing design. This study investigates the influence of sustainable backfill materials on RE walls, focusing on horizontal displacement of the facing, tensile forces in geogrid reinforcements, and factor of safety versus total displacement. Sand was used as a conventional backfill, while copper slag and construction demolition waste (CDW) were examined as sustainable alternatives. Results revealed significant variations in wall performance depending on the backfill type, with implications for both stability and sustainability. The findings contribute to advancing sustainable construction practices and inform engineers and policymakers in infrastructure development.

Key words: Reinforced earth wall, PLAXIS 2D, geogrid, sustainable

1.0 INTRODUCTION

Retaining walls are designed to restrain soil at unnatural slopes, creating usable surfaces and preventing erosion. They are widely applied in hillside roads, elevated and depressed roads, landscaping, canals, locks, erosion protection, flood walls, and bridge abutments. Depending on the situation, different types of retaining walls are employed, including gravity, cantilever, counterfort, sheet pile, anchored, gabion, and reinforced soil retaining walls. Each type has distinct structural principles, ranging from self-weight resistance to reinforcement with geosynthetics.

Construction of retaining walls requires careful consideration of structural integrity, material properties, environmental impact, and economic viability. Sustainable practices are increasingly emphasized, with reinforced earth retaining walls

offering resilience and reduced environmental footprint. Geogrid reinforcement, made of polymers or synthetic materials, is commonly used to improve soil stability and load-bearing capacity. Site preparation involves soil investigation, clearing, and grading, followed by engineering design that specifies geogrid type and layout. Excavation and backfilling are performed in controlled lifts, with geogrids installed in layers and attached to facing components such as modular blocks or concrete panels. Quality assurance is critical, requiring strict monitoring and testing to ensure compliance with design parameters.

1.1 REINFORCED EARTH RETAINING WALL

An RE wall is a composite structure of alternating compacted backfill and reinforcement elements fixed to a facing. The facing, often precast panels or geocells, tolerates differential movement while retaining soil. The three main components are backfill, reinforcement, and flexible facing panels.

Backfill must be properly compacted to ensure drainage and stability. Sand is widely used because of its permeability, drainage capacity, and frictional resistance, though it can be prone to erosion. Copper slag, a byproduct of smelting, offers cost-effectiveness, high shear strength, and compaction properties, though environmental impacts such as leaching must be considered. Construction demolition waste encompasses concrete, wood, metals, and plastics, and when recycled, it reduces landfill use and conserves resources. Sustainable backfill materials such as recycled concrete, crushed rock, fly ash, and slag are increasingly adopted to reduce reliance on virgin materials.

Reinforcement layers provide tensile strength, resisting lateral soil pressures. Modern reinforcements include geogrids, geotextiles, and steel meshes. Flexible facing panels made of plastics or geotextiles adapt to uneven surfaces, incorporate drainage, and are lightweight compared to stone or concrete.

1.2 PLAXIS 2D

PLAXIS 2D is a finite element program for geotechnical analysis. It models soil and structures in plane strain or axisymmetric conditions, with material properties stored in datasets for soil, plates, geogrids, and anchors. Calculations are divided into phases such as loading, consolidation, and safety factor analysis. Staged construction allows realistic simulation by activating or deactivating loads and materials. Outputs include displacements, stresses, and structural forces, enabling engineers to evaluate soil–structure interaction and optimize design.

2.0 LITERATURE SURVEY

Research emphasizes eco-friendly backfills, reinforcement techniques, and numerical modeling. Arulrajah et al. (2015) demonstrated that recycled glass reinforced with geogrids improves shear strength and sustainability. Baig and Kumar Tiwary (2019) analyzed geogrid walls in Vizianagaram, showing practical performance. Bathurst and Hatami (2001) reviewed numerical modeling, identifying strengths and limitations. Bozorgzadeh (2007) examined backfill effects on bridge abutment stiffness. Fleury et al. (2023) predicted geotextile damage under backfill drop loads, and Franco et al. (2022) showed how wall facing contributes to stability in cohesive soils. Garcia et al. (2012) confirmed tire-derived aggregates as sustainable backfill, and Khairutdinov et al. (2021) integrated geotechnology with backfills for subsoil development.

3.0 METHODOLOGY

The design and stability of the reinforced earth retaining wall with geogrid were analyzed using PLAXIS 2D. A new project was initiated in the input program, and the plane strain model was selected with fifteen-node triangular elements. Coordinates were created by defining boreholes within the soil boundary, and values were assigned through project properties. For the backfill soil, sustainable materials such as sand, construction demolition waste, and copper slag were used. The Mohr–Coulomb model was adopted with parameters including cohesion, unit weight, Poisson's ratio, Young's modulus, and dilatancy angle. The foundation soil was modeled as jointed rock with non-porous drainage conditions, and its parameters included stiffness, Young's modulus, Poisson's ratio, unit weight, and dilatancy angle. Concrete

panels were defined with isotropic properties, assigning axial stiffness, modulus, Poisson's ratio, diameter, and width. Bearing pads and foundation blocks were similarly modeled with isotropic properties, assigning stiffness and geometric values.

The structural model was created by defining soil polygons and plates, with bearing pads and concrete panels attached to plates and set as foundation blocks. Geogrid layers were introduced in the geometry, with material properties such as Young's modulus, axial stiffness, Poisson's ratio, and width specified. Mesh generation was performed using medium mesh, and the mesh was viewed at selected points for analysis. Staged construction was defined across forty-one phases, activating soil clusters, geogrids, and panels step by step. In the final stage, external line loads were applied, and the calculation type was selected to determine the factor of safety. The completion of calculations provided outputs including displacements, wall height, and safety factors. Plastic analysis was conducted to assess material behavior under loads and environmental conditions, predicting weaknesses and ensuring safe design. The Curve Manager tool was used to define stress-strain relationships for soil and rock, enabling accurate representation of material behavior. Finally, node points were added to refine the analysis and ensure precision in evaluating the reinforced earth retaining wall.

4.0 RESULTS AND DISCUSSIONS

4.1 General

This section presents the findings from the analysis of geogrid-reinforced earth retaining walls using different backfill materials. The performance of sand, copper slag, and construction demolition waste (CDW) was compared in terms of displacement, tensile forces in geogrids, and factor of safety. The details of the backfill materials and foundation soil are shown in **Table 4.1**, which summarizes the material models, unit weights, cohesion, friction angles, and other parameters used in the analysis.

4.2 Analysis of Geogrid Reinforced Earth Retaining Wall

The dataset prepared for the analysis included sand, copper slag, and CDW modeled with the Mohr-Coulomb material model, while the foundation soil was represented as jointed rock. As shown in **Table 4.1**, sand had a unit weight of 16 kN/m³ above the phreatic level and 18 kN/m³ below, copper slag had 20 kN/m³ in both conditions, and CDW had 19 kN/m³. Cohesion values were 5 kN/m² for sand, 10 kN/m² for copper slag, and 40 kN/m² for CDW, while the friction angles were 36°, 30°, and 80° respectively. These differences in parameters directly influenced the wall's stability and deformation.

The input plates, including concrete panels, bearing pads, and foundation blocks, were modeled as isotropic materials. Their properties are detailed in **Table 4.2**, which shows axial stiffness, Young's modulus, Poisson's ratio, and geometric dimensions. The geogrid properties are presented in **Table 4.3**, with axial stiffness values EA1 and EA2 of 1632 N/m, a Young's modulus of 1.00×10^5 kN/m³, and a width of 0.3 m. Mesh generation was carried out using medium refinement, ensuring accuracy in capturing soil-structure interaction. The reinforced earth retaining wall model is illustrated in **Fig.4.1**.

4.2.1. Staged Construction

The construction was simulated in multiple phases to represent realistic field conditions. Plates, soil layers, geogrids, and line loads were activated or deactivated sequentially, with interfaces between geogrids and panels engaged at appropriate stages. The staged construction extended through forty-one phases, with external line loads applied in the final stages. Factor of safety values were calculated at phases 8, 15, 26, 36, and 41 to assess stability at different stages of construction. The retaining wall model during staged construction is shown in **Fig.4.2**.

4.2.2 Effect of Type of Backfill on Horizontal Displacement of the Facing

The type of backfill material significantly influenced the horizontal displacement of the wall facing. The displacement values for sand, copper slag, and CDW at different wall heights are presented in **Table 4.4**. At the base of the wall, displacements were relatively small, with values of 0.9 m for sand and copper slag and 0.5 m for CDW. As the wall height increased, displacements rose steadily. At 2 m height, sand showed a displacement of 5.6 m, copper slag 6.03 m, and CDW 4.8 m. At 4 m height, the displacements reached 9.1 m for sand, 9.7 m for copper slag, and 8 m for CDW. The displacement trends are illustrated in **Fig.4.3**.

The graph demonstrates that displacement increases with wall height for all backfills. Copper slag produced the highest displacement values, followed closely by sand, while CDW consistently showed lower displacement. This indicates that CDW provides better lateral stability compared to sand and copper slag. For example, at 2 m height, CDW displacement was nearly 1 m less than sand and 1.2 m less than copper slag. These results highlight the importance of selecting backfill materials with favorable drainage and frictional properties to minimize wall deformation.

4.2.3 Impact of Type of Backfill on Tensile Force in Geogrid

The tensile force in geogrids was also affected by the type of backfill. The values are shown in **Table 4.5**, which presents tensile forces for sand, copper slag, and CDW at different wall heights. At the base, sand induced a tensile force of 1.9 kN/m², copper slag 1.2 kN/m², and CDW 1.5 kN/m². As the wall height increased, tensile forces rose. At 2 m height, sand produced 4.9 kN/m², copper slag 4.8 kN/m², and CDW 4.2 kN/m². At 3.5 m height, sand and copper slag reached 6.4 kN/m², while CDW dropped to 3.1 kN/m². At 4 m height, tensile forces decreased sharply, with sand at 1.6 kN/m², copper slag at 0.6 kN/m², and CDW at 1.6 kN/m². The variations are depicted in **Fig.4.4**.

The graph indicates that tensile forces generally increase with wall height but vary depending on backfill type. CDW generated the highest tensile forces at intermediate heights, followed by copper slag and sand. The angular particles in CDW and copper slag likely enhanced interlocking with geogrids, increasing frictional resistance and tensile forces. Sand, with its smoother particles, produced lower tensile forces. These findings suggest that sustainable backfills such as CDW and copper slag can improve geogrid performance compared to conventional sand.

4.2.4 Factor of Safety versus Displacement

The factor of safety was evaluated against displacement for each backfill type. The results are shown in **Figures 4.5a, 4.5b, and 4.5c** for CDW, copper slag, and sand respectively. The factor of safety values were consistently above the acceptable limit of 1.3 to 1.5, with values of 1.60, 2.20, 2.60, and 2.90 recorded at different stages. CDW exhibited stable performance with moderate displacement and satisfactory safety factors. Copper slag showed higher displacement but also maintained safety factors above the limit. Sand displayed the highest displacement values but still achieved acceptable safety margins. These results confirm that all three backfills can be used safely in reinforced earth retaining walls, though CDW offers the best balance between displacement control and tensile force distribution.

Table 4.1: Backfill Materials

Parameter	Name	Sand	Copper Slag	Construction Demolition Waste	Foundation Soil	Units
General						
Material model	-	Mohr Columb	Mohr Columb	Mohr Columb	Jointed Rock	-
Type of material behaviour	-	Drained	Drained	Drained	Non-Porous	-
soil unit weight above phreatic level	γ_{unsat}	16	20	19	25	kN/m ³
soil unit weight below phreatic level	γ_{sat}	18	20	19	25	kN/m ³
Initial void ratio	e_{int}	0.5	0.5	0.5	0.5	-

Parameters						
Young's Modulus	E'	100.0e ³	60.0e ³	50.0e ³	60.00e ³	kN/m ³
Poisson's ratio	V	0.3	0.3	0.3	0.3	-
Cohesion	C _{ref}	5	10	40	5	kN/m ²
Friction angle	ϕ	36	30	80	36	0
Dilatancy angle	ψ	6	6	6	6	0
Interfaces						
Thermal resistance	-	Manual	Manual	Manual	Automatic	
Interface strength	R	0.7	0.7	0.7	0	-
Initial						
K ₀ determination		Automatic	Automatic	Automatic	Manual	

Table 4.2: Input Plates

Parameters	Concrete panel	Bearing pad	Foundation Block	Units
Properties	Isotropic	Isotropic	Isotropic	-
Value of axial stiffness	6.00E+06	2.50E+04	1.75E+07	N/m
Young Modulus	1.10E+04	6.00E+03	364.05	kN/m ³
Diameter	-0.1483	0.5	0.5	mm
Width	38	38	38	m
Poisson's Ratio	0.15	0.4	0.1	-

Table 4.3: Geogrid

Identification	Geogrid	units
properties		
EA1	1632	N/m
EA2	1632	N/m
Youngs Modulus	1.00E+05	kN/m ³
Width	0.3	m

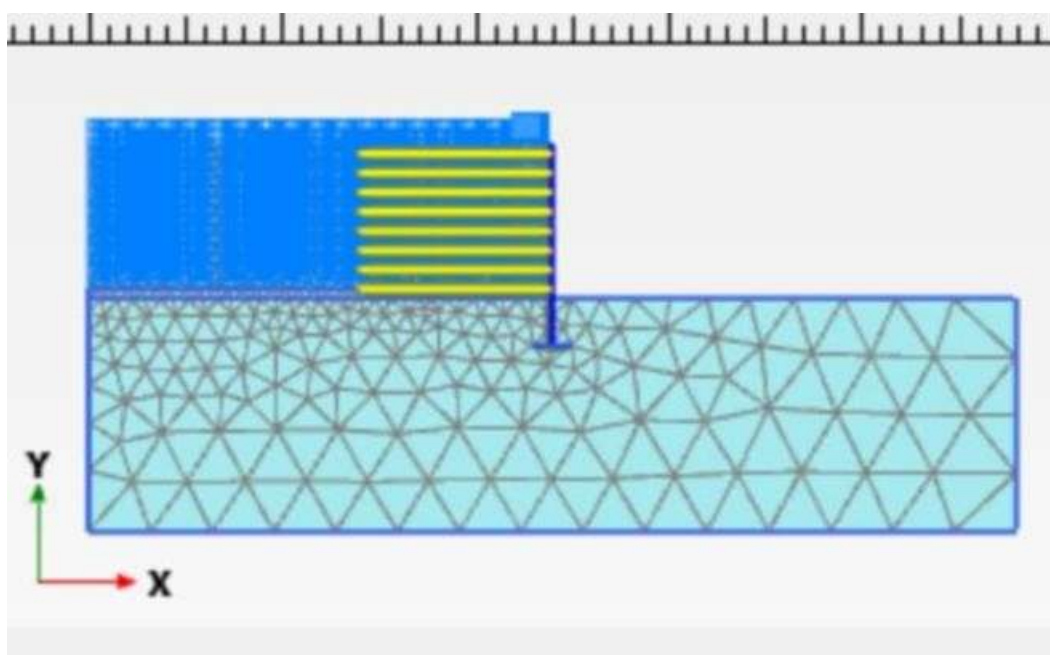


Fig. 4.1: Reinforced Earth Retaining Wall

4.2.5 CREATE A STAGED CONSTRUCTION

Phase-1

- Activate plate-1.
- Activate plate-4 and its negative interface.
- Activate soil-2.
- Activate positive interface of plate-1.
- Hide line loads - first.

Phase-2

- Activate line load 1 and 2.

Phase-3

- Activate geogrid-1. Deactivate its negative interface.

Phase-4

- Activate soil layer-3.
- Deactivate line load 1,2.
- Activate positive interface concrete panel.
- Activate negative interface of geogrid.

Phase-5

- Activate load 3,4 for the 2nd soil layer.

Phase-6

- Activate soil-4.
- Deactivate line load 3,4.
- Activate interface of concrete panel.

Phase-7

- Activate line load 5,6.

Phase-8

- Activate geogrid-2.
- Deactivate its negative interface.

Phase-9

- Activate soil layer-5.
- Deactivate line load -5,6.
- Activate positive interface of concrete panel.
- Activate negative interface of geogrid.

Phase-10

- Activate line load-5,6.

Phase-11

- Activate soil layer-6.
- Deactivate line load-7,8.
- Activate interface of the concrete panel.

Phase-12:

- Activate line load-9,10.

Phase-13:

- Activate geogrid-3.
- Deactivate its negative interface.

Phase-14:

- Activate soil layer-7.
- Deactivate line load-9,10.
- Activate the positive interface of the concrete panel and negative interface of geogrid.

Phase-15:

- Activate line load-11,12 for the fourth layer.

Phase-16:

- Activate soil layer-8.
- Deactivate line load-11,12.
- Activate interface on the concrete panel.

Phase-17:

- Activate line load-13,14.

Phase-18:

- Activate geogrid-4.
- Deactivate its negative interface.

Phase-19:

- Activate bearing pad, i.e., plate-2.

Phase-20

- Activate soil layer-9.
- Deactivate line load-13,14.
- Activate positive interface concrete panel.
- Activate negative interface geogrid.

Phase-21

- Activate line load-15,16.

Phase-22

- Activate soil layer-10.
- Deactivate line load-15,16.
- Activate positive interface of the concrete panel.

Phase-23

- Activate line load-17,18.

Phase-24

- Activate geogrid-5.
- Deactivate its positive interface.

Phase-25

- Activate soil layer-10.
- Deactivate line load-17,18.
- Activate the positive interface of the concrete panel (plate-3).
- Activate negative interface of geogrid.

Phase-26

- Activate line load-19,20.

Phase-27

- Activate soil layer-12.
- Deactivate line load-19,20.
- Activate the positive interface of the concrete panel.

Phase-28

- Activate line load-21,22.

Phase-29

- Activate geogrid-6.
- Deactivate its negative interface.

Phase-30

- Activate soil layer-13.
- Deactivate line load-21,22.
- Activate positive interface of plate-3.
- Activate negative interface of geogrid.

Phase-31

- Activate line load-23,24.

Phase-32

- Activate soil layer-14.
- Deactivate line load-23,24.
- Activate positive interface of the concrete panel.

Phase-33

- Activate line load-25,26.

Phase-34

- Activate geogrid-7.
- Deactivate its negative interface.

Phase-35

- Activate soil layer-15.
- Deactivate line load-25,26.
- Activate positive interface of plate-3.
- Activate negative interface of geogrid-7.

Phase-36

- Activate line load-27,28.

Phase-37

- Activate soil layer-16.
- Deactivate line load-27,28.
- Activate positive interface of the concrete panel.

Phase-38

- Activate line load-29,30.

Phase-39

- Activate geogrid-8.

Phase-40

- Activate soil layer-17.
- Deactivate line load-29,30.
- Activate positive interface of plate-3.

- Activate negative interface of geogrid-8.

Phase-41

- Activate line load-31,32.
- Activate soil layer-17.
- Deactivate line load-31,32.
- Activate positive interface of plate-3.

Phase-42

- Factor of safety at phase-41

Phase-43

- Factor of safety at phase-36

Phase-44

- Factor of safety at phase-26

Phase-45

- Factor of safety at phase-15

Phase-46

- Factor of safety at phase-8

4.2.6 CREATE NODE

- Two points to be add.
- Node-1.
- Node-3226.

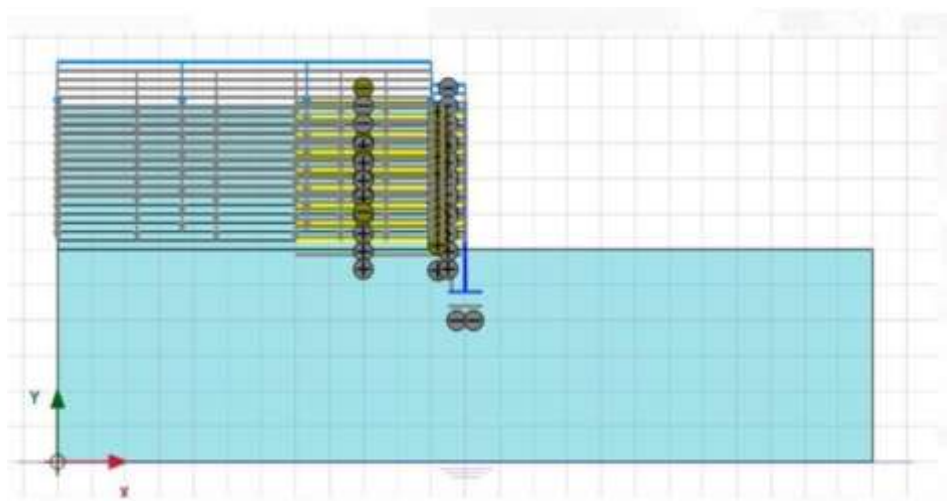


Fig. 4.2: Retaining Wall

Table 4.4: Effect of Type of Backfill on Horizontal Displacement of the Facing

Height of the Wall(m)	Horizontal displacement of the facing(m)		
	Sand	Copper Slag	Construction Demolition Waste
0	0.9	0.9	0.5
0.5	1.2	1.3	0.7
1	2.6	1.7	0.9
1.5	4.6	4.9	3.9
2	5.6	6.03	4.8
2.6	6.4	6.8	5.8
3	7.3	7.7	6.8
3.8	8.6	9.1	7.8
4	9.1	9.7	8

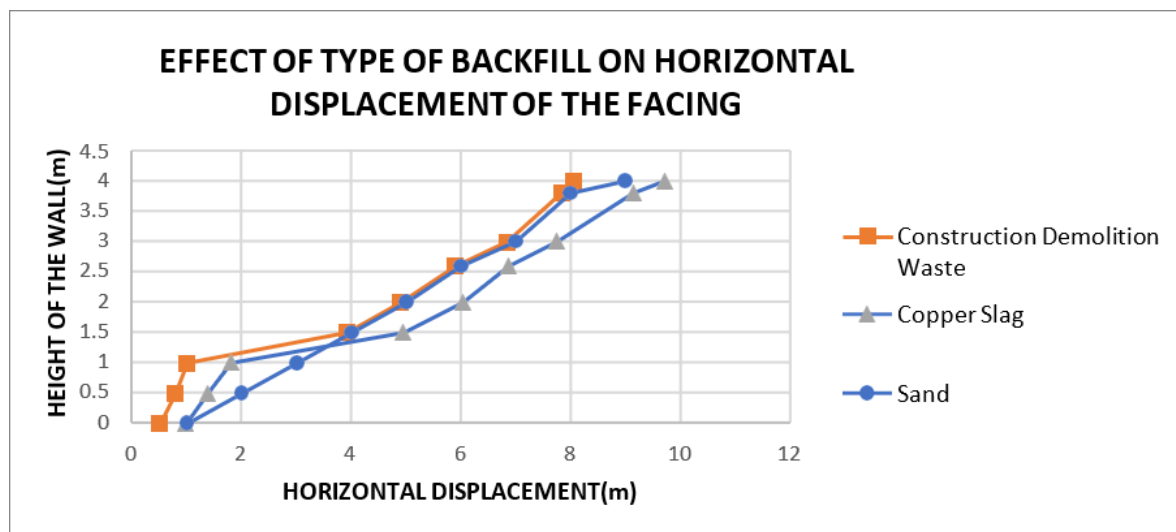

Fig.4.3: Effect of Type of Backfill on Horizontal Displacement of the Facing.

Table 4.5: Impact of Type of Backfill on Tensile Force in Geogrid

Height of the Wall	Tensile force in geogrid(kN/m ²)		
	Sand	Copper Slag	Construction Demolition Waste
0	1.9	1.2	1.5
0.5	2.2	1.9	1.8
1	3.2	2.6	2.9

1.5	4.6	3	3
2	4.9	4.8	4.2
2.6	5.9	5.6	4.5
3.5	6.4	6.4	3.1
4	1.6	0.6	1.6

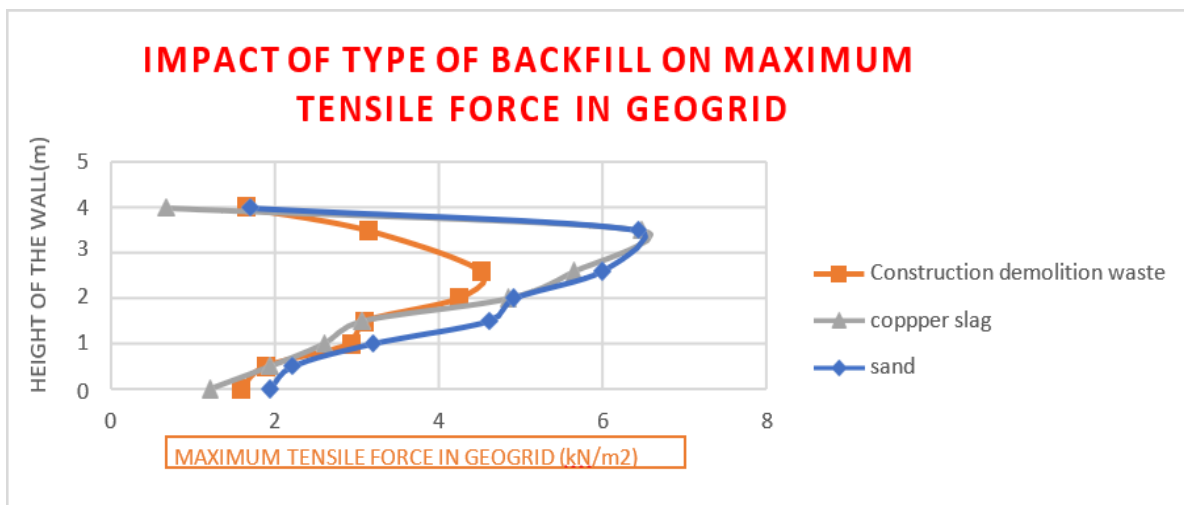


Fig 4.4: Impact of Type of Backfill on Maximum Tensile Force in Geogrid

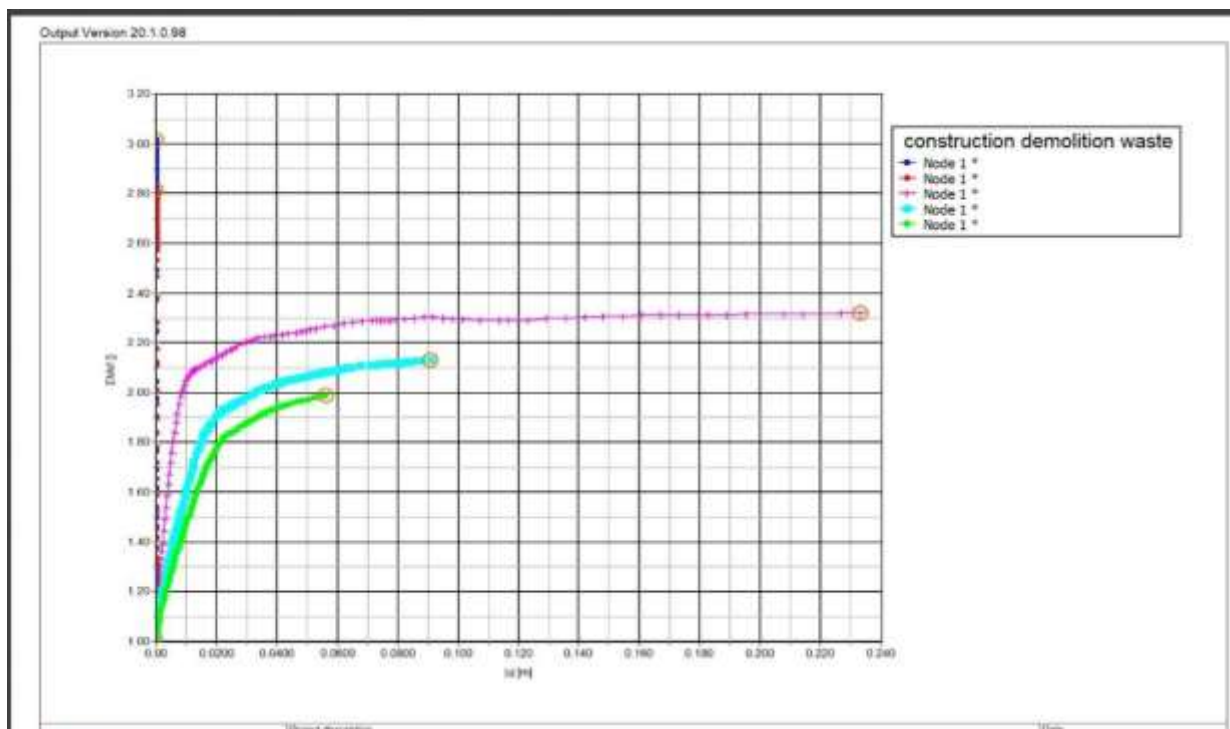


Fig 4.5 a: Factor of Safety Versus Displacement - CDW

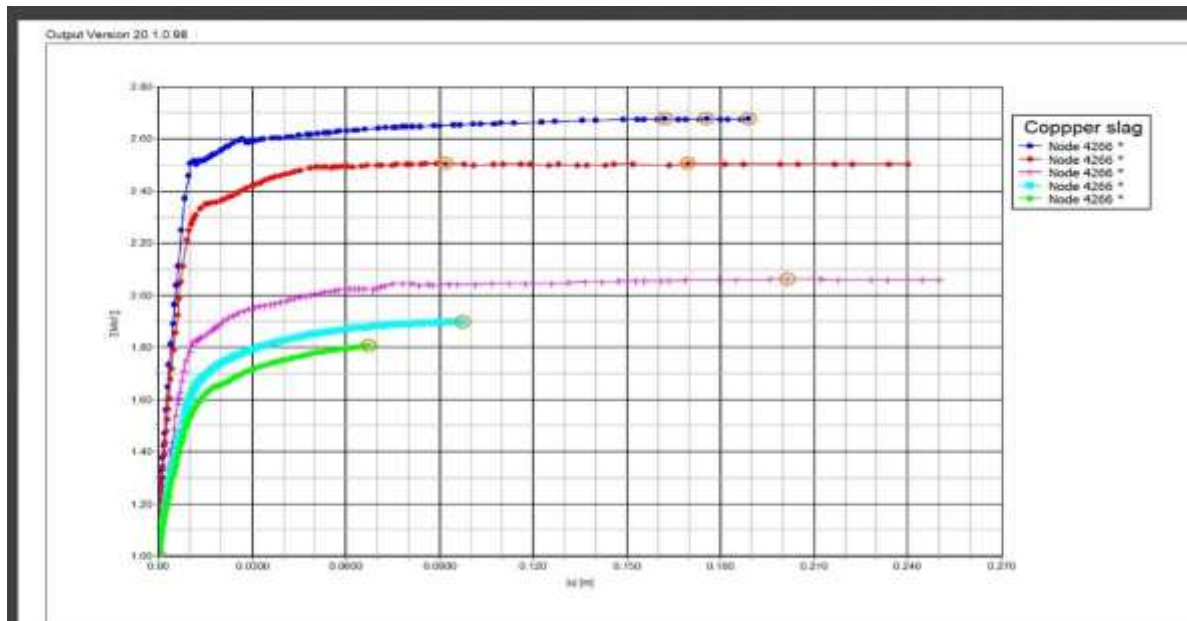


Fig 4.5 b Factor of Safety Versus Total Displacement – Copper Slag

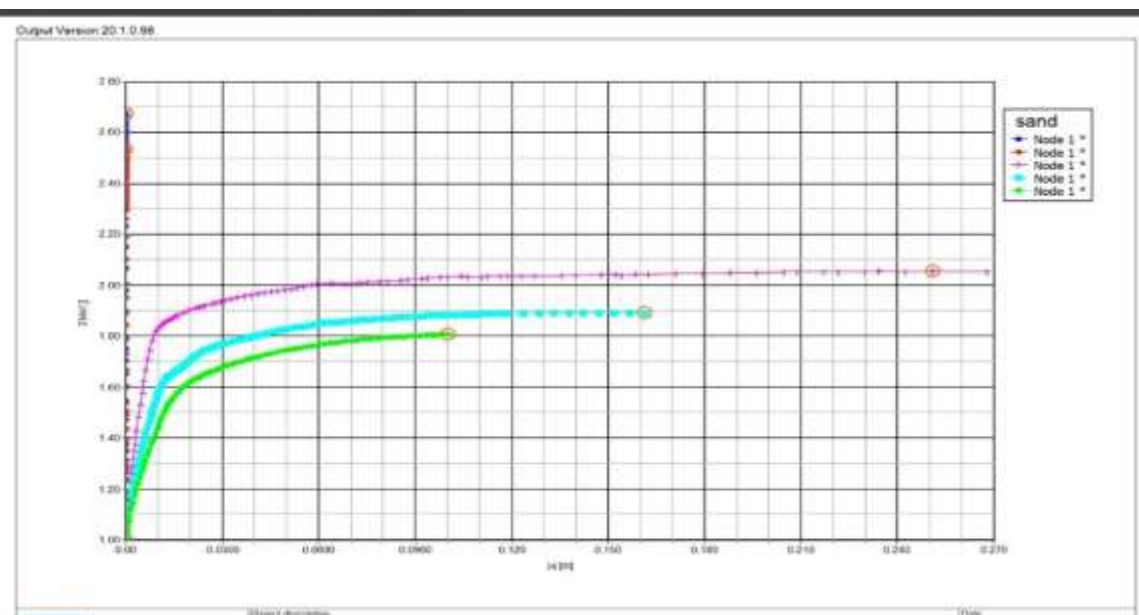


Fig 4.5 c: Factor of Safety Versus Total Displacement - Sand

5.0 SUMMARY

Reinforced earth (RE) walls are innovative retaining walls that use compacted backfill material reinforced with elements like geogrids. To analyze their behavior and optimize design, engineers use software like PLAXIS 2D. This study investigates how sustainable backfill materials (slag, and construction demolition waste) comparable to sand affect RE wall performance. It focuses on the horizontal movement of the facing wall and the maximum tension in the geogrid reinforcements. The research examines how these backfill materials influence the factor of safety against total displacement of the wall.

6.0 CONCLUSIONS

This study provided an insight into the potential of two sustainable materials for backfill.

- The performance of copper slag and CDW was compared with that of the conventional material (sand) backfill application. To investigate the suitability of the materials, a finite- element analysis was carried out on MSE wall with plaxis-2D.
- The model RE wall and analysis will help in understanding failures before construction is taken up. The contribution of reinforcement in improving stability is significant. There is an improvement of 1.60 to 2.60 in factor of safety with reinforcement.
- The factor of safety of the RE wall found out using PLAXIS and generally the required factor of safety ranges between 1.3-1.5.

7.0 REFERENCES

- Arulrajah, A., Horpibulsuk, S., Maghoolpilehrood, F., Samingthong, W., Du, Y. J., & Shen, S. L. (2015). Evaluation of interface shear strength properties of geogrid reinforced foamed recycled glass using a large-scale direct shear testing apparatus. *Advances in Materials Science and Engineering*, 2015. <https://doi.org/10.1155/2015/235424>
- Baig, A. A., & Kumar Tiwary, A. (2019). Behavior & Stability Analysis of Geogrid Reinforced Earthwall: A Case Study in Vizianagaram (A.P). *International Journal of Civil Engineering and Technology*, 10(4).
- Bathurst, R. J., & Hatami, K. (2001). Review of numerical modeling of geosynthetic reinforced soil walls. *10th International Conference of the International Association for Computer Methods and Advances in Geomechanics*.
- Bozorgzadeh, A. (2007). Effect of Backfill on Stiffness and Capacity of Bridge Abutments. *Ph.D. Thesis, Dept. of Structural Engineering, University of California, San Diego, La Jolla, California*.
- Fleury, M. P., Kamakura, G. K., Pitombo, C. S., Cunha, A. L. B. N., & Lins da Silva, J. (2023). Prediction of non-woven geotextiles' reduction factors for damage caused by the drop of backfill materials. *Geotextiles and Geomembranes*, 51(5). <https://doi.org/10.1016/j.geotexmem.2023.05.004>
- Franco, Y. B., Utili, S., & Da Silva, J. L. (2022). Design of reinforced cohesive soil walls accounting for wall facing contribution to stability. *Geotechnique*, 73(8). <https://doi.org/10.1680/jgeot.21.00119>
- Garcia, M., Pando, M. A., & Tempest, B. (2012). Tire derived aggregates as a sustainable recycled material for retaining wall backfills. *ICSDC 2011: Integrating Sustainability Practices in the Construction Industry - Proceedings of the International Conference on Sustainable Design and Construction 2011*. [https://doi.org/10.1061/41204\(426\)67](https://doi.org/10.1061/41204(426)67)
- Khairutdinov, A., Ubysz, A., & Adigamov, A. (2021). The concept of geotechnology with a backfill is the path of integrated development of the subsoil. *IOP Conference Series: Earth and Environmental Science*, 684(1). <https://doi.org/10.1088/1755-1315/684/1/012007>