

Original Article

Effect of Geotextile Configuration on the Structural Performance of Mechanically Stabilized Earth Retaining Walls

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Abstract - Mechanically Stabilised Earth (MSE) walls reinforced with geotextiles are popular in geotechnical engineering because of their constructability, reliability, and cost-effectiveness. However, some geotextile characteristics, such as reinforcement length, layers, and tensile strength, remain to be addressed in design practices. This study explored these critical parameters and their effects on overall and internal stability through several comprehensive parametric analyses. One benchmark model with six geotextile layers, 5 m reinforcement length, and uniform vertical spacing was used to independently alter each parameter to evaluate sliding, overturning, bearing failure, rupture, and pullout. Lengthening the reinforcement from 3 to 5 m increased the global stability safety factor by approximately 15% and improved the pullout resistance by over 20%. Increasing the number of layers from 2 to 6 improved the rupture and pullout resistance by approximately 18%; however, the global stability changed slightly. The tensile strength variations (35–55 kN/m) affected only the rupture resistance, with no measurable impact on other failure modes. These results demonstrate that optimising the geotextile configuration based on site-specific stability requirements can lead to more efficient performance-based MSE wall designs.

Keywords - Geotextile-reinforced earth wall, Global stability, Internal stability, Mechanically Stabilised Earth (MSE) Wall, Parametric Analysis.

1. Introduction

Mechanically Stabilised Earth (MSE) systems are composite soil–structure systems in which compacted fill is reinforced with tensile inclusions to improve shear strength and stability. They are widely used in highway engineering for the construction of retaining walls and bridge abutments. These systems combine engineered fill compacted in layers with horizontal inclusions such as geotextiles, geogrids, or steel strips anchored to a facing wall to provide internal and external stability [1-3]. Though steel strips and geogrids are used around the world, the increase in synthetic polymer materials has increased the use of geosynthetics, especially for geotextiles, because of the flexibility, durability, cost-effectiveness, erosion control, and less use of other construction materials [4-8].

Numerous studies have focused on geotextiles in horizontal MSE walls. Kim et al. [9] studied hanging bag tests and geotextile tube demonstration tests to understand the behaviour of soil confined in geotextile fabrics. They indicated that the consolidation rate and dewatering

effectiveness were affected by the tube size, soil type, and geotextile mechanical properties. Alam and Siddiquee [10] conducted a related study and established that wall deformation reduction, to a certain limit, occurs with an increase in reinforcement stiffness, thus highlighting the relationship between stiffness and lateral earth pressure.

Assessing the mechanical behaviour of geotextile-reinforced systems, Lohani et al. [11, 12] executed compression tests on soil-filled geotextile bags. They analysed compacted and non-compacted conditions under unconfined vertical and shear loads. Matsushima et al. [13], Wen et al. [14], and Fan et al. [15] built on these findings by conducting model-scale experiments and stability analyses of geotextile tube-reinforced retaining walls.

Hataf and Sayadi [16] and Wang et al. [17] researched the ability of geotextile tubes to function as load distribution elements under column footings on weak soil. This work built a foundation for Sadr and Hataf's [18] research, which explored using geotextile tubes as vertical-load-bearing elements. In addition, Wang et al. [17] and Kim et al. [19]



created new soil models to analyse more thoroughly the infill materials' stress-strain behaviour. Consequently, predictions of the performance of geotextile-encased soil systems have become more reliable.

Onyekwena and Liu [20] examined the influence of primary and secondary geotextile reinforcements on the stability of unsaturated soil slopes under rapid and temporary drawdown conditions. They concluded that the use of both reinforcements stabilised the slope, as the combination weakened the shear stress concentrations at the slope face and the probability of shallow surface failures, thus enhancing the overall stability. Zaman et al. [21] investigated moisture reduction in the absence of geotextile materials, in relation to the more complex method of moisture retention and loss in silty sand with varying fines and exposure durations. They discovered that as the fines content increased, the moisture reduction capability of the geotextiles decreased. In contrast, non-wicking geotextiles impede moisture flow and trap moisture at the interface.

Previous studies have examined individual factors influencing the performance of MSE walls, including reinforcement length, backfill characteristics, and tensile strength. For instance, Bilgin and Kim [22] observed that wall deformation increases with shorter reinforcement lengths, though improved soil properties can mitigate this effect. However, improper geotextile configurations in practice, such as insufficient reinforcement length or inadequate layer spacing, can lead to excessive deformation, pullout, or even local failure, compromising both safety and service life. Most prior research has investigated these parameters in isolation, emphasised numerical analyses, or overlooked a holistic evaluation of global and internal stability as required by geotechnical design standards. Consequently, there is limited understanding of how key geotextile parameters collectively influence the safety and performance of MSE walls under practical design conditions. This study addresses this gap through a comprehensive parametric assessment of the reinforcement length, number of layers, and tensile strength, focusing on their combined effects on sliding, overturning, bearing, pullout, and rupture stability mechanisms. The findings contribute practical, code-aligned insights that support the optimisation of MSE wall design beyond conventional approaches.

2. Methodology

The benchmark model of the Mechanically Stabilised Earth (MSE) wall used in this study is shown in Figure 1. The wall was 6 m tall and reinforced with horizontal geotextiles embedded in the backfill soil. Eight horizontal geotextile layers were placed at vertical intervals of 75 cm. The reinforced soil rested on a foundation soil layer that extended 4 m horizontally from the wall toe. The geotextile reinforcement in the benchmark model had an allowable

tensile strength of 45 kN/m, which was derived from the ultimate strength by applying standard reduction factors for installation damage, creep, and durability. A uniform surcharge of 10 kN/m² was applied to the backfill zone surface. This surcharge simulates the load from traffic, temporary storage, or structural loads from nearby facilities.

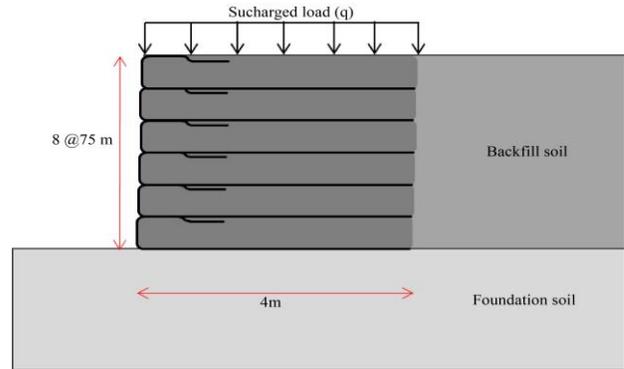


Fig. 1 Earth wall configuration

The model considers two different soil zones: foundation soil and backfill soil.

- Foundation Soil: This zone was identified as cohesive-frictional soil with a cohesion (c) of 20 kN/m², unit weight (γ) of 18 kN/m³, and an internal friction angle (ϕ) of 25°.
- Backfill Soil: The backfill is treated as a cohesionless material, commonly used in reinforced earth structures. It had zero cohesion ($c = 0$), unit weight (γ) of 19 kN/m³, and an internal friction angle (ϕ) of 35°.

This study focuses on how certain important properties of geotextiles affect the stability of mechanically stabilised earth (MSE) walls. In this study, the parameters of the length of geotextile reinforcement, the number of geotextile layers, and geotextile tensile strength were adjusted. All other parameters were maintained constant during this process. This permitted an evaluation of the effect of each on the structural performance in terms of safety, deformation behaviour, and potential failure mechanisms. To assess the stability of an MSE wall, a pair of global and internal stability parameters was used, consistent with geotechnical design practices. It is assumed that the relevant soil mass is homogeneous and isotropic and that the geotextile layers exhibit ideal tensile properties, with frictional interface interaction of soil and geotextile abstracting other soil-geotextile interactions. Time-dependent effects, such as creep and installation damage, were indirectly incorporated using the allowable tensile strength. While providing a feasible means of evaluation, these assumptions and simplifications may reduce the potential for direct application in practice in the future.

2.1. Reinforced Earth Wall Global Stability

To evaluate the global stability of the reinforced earth wall, three main external stability failure mechanisms were assessed: sliding, overturning, and bearing-capacity failure.

These evaluations were performed within the framework of static conditions and standard limit equilibrium calculations.

Sliding occurred when the side earth pressure exceeded the soil mass within the reinforced earth's base friction resistance. To determine the Factor of Safety against Sliding (FSS), the base friction-resisting force was balanced against the total horizontal driving forces active from the earth pressure and surcharge. This is mathematically expressed as

$$FS_S = \frac{LH\gamma \tan \phi}{0.5H^2\gamma K_a + qHK_a} \quad (1)$$

Where L is the length of the reinforcement, H is the wall height, γ is the soil unit weight, ϕ is the internal friction angle of the foundation soil, K_a is the Rankine active earth pressure coefficient, and q is the applied uniform surcharge. Rankine's classical theory [23] was adopted to carry out the baseline analysis because of its simplicity and compatibility with the study conditions. While acknowledging the model's limitations, a framework was built around Rankine's theory, with inter-reinforcement soil models as advanced provisions, nonlinear behaviours, and limitations within the soil.

The evaluation of overturning involved a comparison of the resisting moment generated by the weight of the reinforced soil mass and the overturning moments induced by the lateral earth pressure and surcharge loads. The equation for calculating the overturning safety factor (FS_O) is given by

$$FS_O = \frac{\sum M_r}{\sum M_d} = \frac{0.5\gamma HL^2}{0.5P_qH + \frac{1}{3}P_sH} \quad (2)$$

Where P_q and P_s are the horizontal forces exerted by the surcharge and soil pressure, respectively.

Bearing failure was evaluated to ensure that the vertical stress applied to the foundation soil did not exceed its ultimate bearing capacity. The safety factor against bearing capacity failure (FS_B) is defined as

$$FS_B = \frac{q_u}{\sigma_v} \quad (3)$$

Where q_u is the ultimate bearing capacity, and σ_v is the applied vertical stress, which is determined by

$$\sigma_v = \frac{W}{L-2e} \quad (4)$$

$$e = \frac{\sum M_d}{W} \geq \frac{L}{6} \quad (5)$$

Where W is the total weight of the reinforced mass, and e is the eccentricity of the resultant force. Condition $e \leq L/6$ was maintained to avoid eccentric loading beyond the middle third of the foundation's base.

2.2. Reinforced Earth Wall Internal Stability

An internal stability assessment is important to ensure that the geotextile reinforcement layers in the MSE wall can handle the induced tensile forces without failure.

Two main internal failure mechanisms were examined: geotextile rupture and pullout failure. The failure modes were examined for each reinforcement layer along the wall height.

Rupture occurs when the tensile force in the reinforcement exceeds its allowable tensile strength. The safety factor against rupture (FS_r) was calculated as

$$FS_r = \frac{T_a}{K_a\sigma_v S_v} \quad (6)$$

Where T_a represents the allowable tensile strength of the geotextile, S_v is the vertical spacing between reinforcement layers, and σ_v is the vertical stress at the reinforcement layer.

Pullout failure occurs when the length of the mattress in the geotextile passive zone is insufficient to generate sufficient friction resistance to avoid slippage of the surrounding soil. The safety factor against pullout (FS_p) is given by

$$FS_p = \frac{2\mu\sigma_v L_p}{K_a\sigma_v S_v} \quad (7)$$

Where μ is the interface friction coefficient between the soil and geotextile, σ_v is the vertical stress applied to the reinforcement, S_v is the vertical spacing between the reinforcement layers, and L_p is the length of the reinforcement embedded in the passive zone, which is estimated using the following empirical expression:

$$L_p = L - \tan\left(45^\circ - \frac{\phi}{2}\right)(H - z) \quad (8)$$

Where L is the total length of the reinforcement and z is the vertical depth of the reinforcement layer measured from the top of the wall. This provides the length of the reinforcement beyond the potential failure surface that is frictionally anchored.

3. Results and Discussion

This section discusses the outcomes of an extensible examination of the effect of fundamental geotextile features on the stability of Mechanically Stabilised Earth (MSE) walls, incorporating an analysis of the global and internal stability and their respective parameters.

3.1. Effect of Reinforcement Length

In this analysis, the length of the geotextile reinforcement ranged from 3 to 5 m to assess its impact on the stability of the MSE wall. The reinforcement length often varies with the wall height to match the rupture wedge width. In this study, a constant length was used for all layers to isolate the effect of

each parameter, although the observed trends remained applicable to designs with proportional length adjustments. Changes in the safety factors against sliding, overturning, bearing capacity, rupture, and pullout are examined and discussed in the following subsection.

Figure 2 shows how the length of the geotextile reinforcement affects the stability of the MSE wall. It is clear that increasing the reinforcement length from 3 m to 5 m consistently improved both global and internal stability. This improvement was demonstrated by the increase in all safety factors, except for rupture.

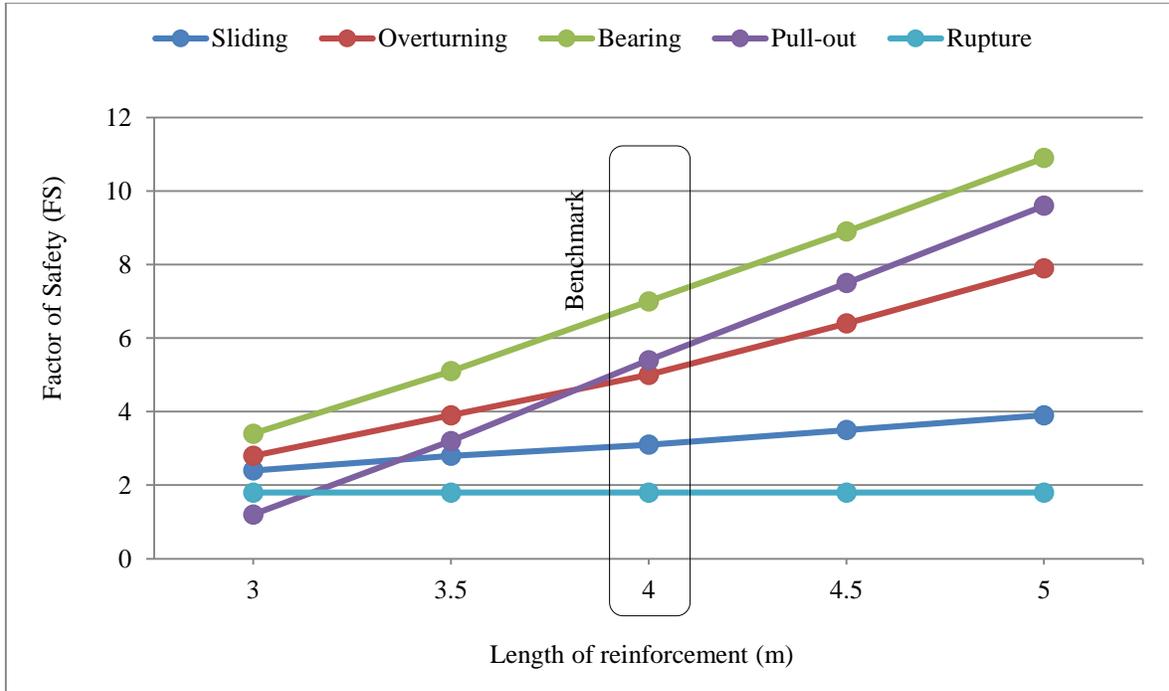


Fig. 2 Effect of geotextile reinforcement length on global and internal stability factors

For global stability, the most notable improvements were observed in the safety factor against bearing-capacity failure and overturning. This indicates that longer reinforcements offer better resistance to failures caused by rotational and vertical loads. This improvement stems from the increase in the self-weight and resisting moment of the reinforced mass, which directly enhances the stability.

However, the safety factor against sliding exhibited only slight improvements with longer reinforcement lengths. This indicates that the base friction, which controls sliding resistance, is less affected by reinforcement length than by moment and bearing behaviour.

The length of the reinforcement geotextile affected the pullout resistance and internal stability. Longer geotextile layers penetrate deeper into the passive zone and create friction along a greater length of embedment. This is a substantial improvement in preventing geotextiles from slipping in the backfill in the case of lateral load geotextile movement. Conversely, the rupture safety factor maintained the same value, irrespective of the reinforcement length. This is due to the fact that rupture is a function of the induced tensile force balanced with the tensile strength of the material, and length alone does not provide a variable.

The patterns concerning the effects of reinforcement length on overall and internal stability documented in this study largely align with the findings of Bilgin and Kim [22]. They observed greater wall deformations in the finite element simulations when the reinforcement lengths were decreased. The increase in deformation associated with shorter reinforcement lengths could be offset by positive soil conditions in the backfill or even the foundation, as the authors pointed out. Unlike Bilgin and Kim, this study seeks to understand stability factors without soil variability as a compensating factor. This clearly defines the effects of the reinforcement length on the available bearing, overturning, and pullout resistances, and focuses on the stability of the soil.

3.2. Effect of the Number of Layers

To evaluate the effect of reinforcement distribution on wall stability, this study varied the number of geotextile layers from 4 to 12, while keeping the vertical spacing uniform across the wall height. All configurations maintained a constant total wall height and reinforcement length to focus on the effect of vertical reinforcement density. This study examines how increasing the number of reinforcement layers improves the overall performance of MSE walls by considering both global and internal stability.

The results shown in Figure 3 indicate the effect of changing the number of geotextile layers on the stability of the MSE wall. The number of layers ranged from two to six. It is clear that adding more reinforcement layers has a limited effect on global stability but significantly affects internal stability. The safety factors against sliding, overturning, and

bearing capacity failure remained mostly the same for all configurations. This is because global stability depends mainly on the overall shape, weight, and length of the reinforcement, rather than on the number of vertical reinforcement intervals.

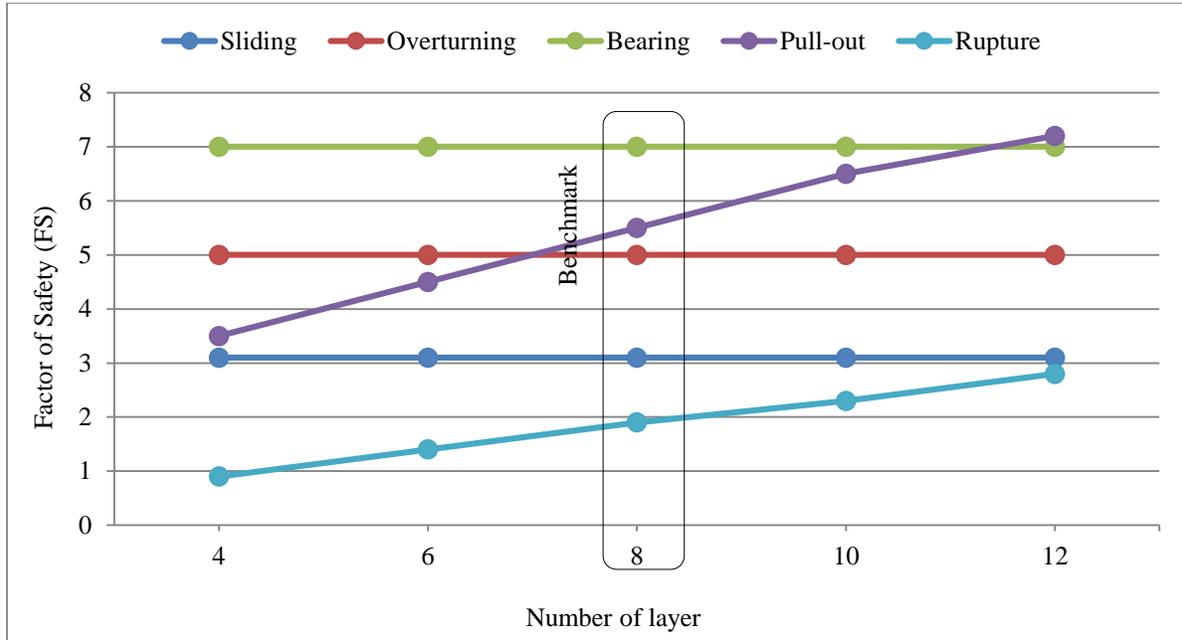


Fig. 3 Effect of the number of geotextile layers on global and internal stability factors

However, the internal stability clearly improved as the number of reinforcement layers increased. Specifically, the pullout safety factor increased steadily with an increase in the number of layers in the model. This change reflects a better distribution of tensile forces and stronger interaction between the geotextile and the surrounding soil. Similarly, the safety factor against rupture increased with the number of layers. In this case, the total tensile load was spread over more reinforcement elements, thereby reducing the stress in each layer. The observed improvement in pullout and rupture resistance with increased reinforcement layers is consistent with the conclusions of Golakiya and Lad [24], who reported that additional reinforcement layers enhance the internal stability by reducing shallow failure risks and distributing loads more effectively. The novelty of the present work lies in the explicit demonstration that the number of layers has a negligible influence on the global stability when the layer spacing is uniform, a factor that has not been emphasized in earlier studies.

3.3. Effect of Geotextile Strength

A parametric study was conducted by changing the tensile strength of the reinforcement from 35 to 55 kN/m. These values represent the typical range of geotextile products available in the market for reinforced-earth applications.

Figure 4 shows how changing the geotextile tensile strength from 35 to 55 kN/m affected the global and internal stability of the MSE wall. It is evident that variations in the tensile strength have little effect on most stability parameters. The only significant change observed was in the safety factor for rupture.

The safety factors for sliding, overturning, bearing capacity, and pullout remained the same across the different tensile strengths. This behaviour is expected because these stability modes depend on the reinforcement geometry (such as length and anchorage), soil-reinforcement interaction, and self-weight of the reinforced mass rather than the tensile strength of the geotextile itself.

The finding that tensile strength predominantly affects rupture resistance but has no measurable effect on other stability modes is in agreement with basic reinforced soil mechanics principles and supports the observations of Chalermyanont and Benson [25], who noted that reinforcement properties primarily influence tensile failure thresholds rather than external stability. The present analysis strengthens this understanding by isolating the tensile strength effects under controlled conditions, thereby providing quantitative confirmation for practical design contexts.

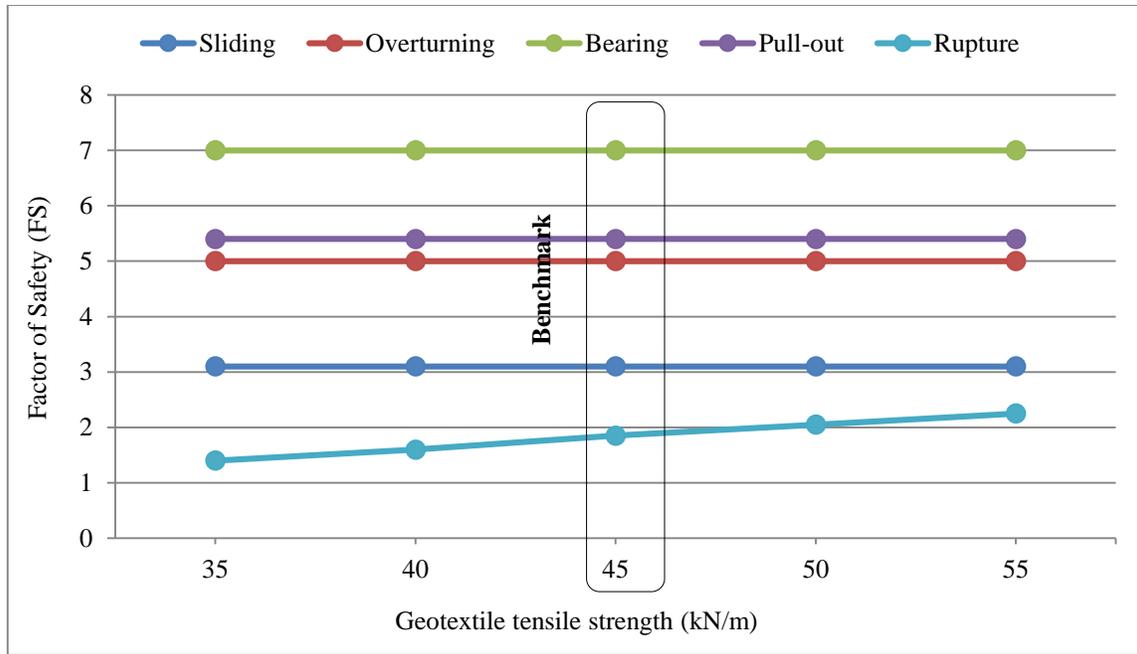


Fig. 4 Effect of geotextile tensile strength on global and internal stability factors

3.4. Design Implications

This study highlighted the importance of geotextile arrangement on the stability of Mechanically Stabilised Earth (MSE) walls. The results of this study can be used for the design and optimisation of geotextile-reinforced earth structures.

First, as discussed in the previous section, global and internal stability are considerably affected by the length of the reinforcement. Defensively, the length increases the resistance to overturning, pullout, and bearing capacity failure by strengthening the anchor and the zone of stabilisation. Therefore, embedding the length beyond the failure surface is critical in designs where the foundation condition or loading is critical. Attention to detail is vital during these designs.

Second, regarding the internal stability of the structure, the number of geotextile layers positively affected the rupture and pullout safety factors. However, its effect on global stability was insignificant. Therefore, while the additional layers enhance load distribution and soil-mass interaction, the added cost and construction challenges also increase. Therefore, during construction, deterioration of overall stability is avoided by limiting the increase in the number of layers and by improving load distribution and interaction with the soil mass.

Finally, the tensile strength of geotextiles determines the rupture safety factor, and thus, the strength of the material directly impacts the prevention of reinforcement failure. However, it is vital to note that beyond a certain point, strengthening the material for tensile rupture resistance will

not improve the structural performance. Therefore, it is imperative that the designer specify the material to a reasonable rupture strength to prevent overdesign.

The findings of this study aid in the construction of performance-based design methods for MSE walls. In this case, the reinforcements are no longer used uniformly but flexibly within a prescribed range that achieves a particular stability objective. For geotechnical purposes, this is a good step towards structural and material efficiency. Furthermore, the study’s findings are in line with the stability assessment guidelines detailed in SNI 8460-2017 [26] for reinforced soil structures, which involves checks for sliding, overturning, bearing, rupture, and pullout. Therefore, before the application of project-specific conditions and partial factor design codes, the findings can be used for design optimisation within the framework of the stability prescribed by the code.

4. Conclusion

This study analysed the effects of key geotextile attributes, namely reinforcement length, number of layers, and tensile strength, on the global and internal stability of Mechanically Stabilised Earth (MSE) walls through a series of analytical parametric evaluations. A benchmark model was developed to assess the responses of different failure modes under static loading conditions. The findings demonstrate that the reinforcement length plays a dominant role in both global stability, particularly in enhancing the bearing and overturning resistance, and internal stability through improved pullout resistance. The number of geotextile layers primarily influences internal stability by increasing the resistance to rupture and pullout, while having a minimal effect on global

modes. Conversely, tensile strength affects only the rupture resistance, with a negligible impact on other failure mechanisms.

From a practical perspective, these results emphasise that a well-designed geotextile configuration can significantly enhance MSE wall performance and resource efficiency. Engineers can use the proposed relationships to optimise the reinforcement length and layer distribution to achieve stability targets while avoiding unnecessary material use. These findings align with the design frameworks in standards such as AASHTO and BS 8006, offering quantitative guidance for performance-based MSE wall design.

Despite its insights, this study was limited to static loading and idealised soil–geotextile interface conditions. Future research should incorporate seismic and time-dependent effects, non-uniform reinforcement layouts, and realistic interface behaviours validated through laboratory or field investigations. Further exploration of long-term environmental influences and sustainability aspects, including the embodied carbon and durability of geosynthetics, would broaden the applicability of these findings in modern geotechnical design practices.

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Ethical Approval

This study is analytical and involves no human or animal subjects. However, it acknowledges the environmental impact of geotextile use in the construction industry. Sustainable material selection, recyclability, and responsible disposal are encouraged to minimise waste and long-term environmental effects. The work supports responsible engineering practices aligned with sustainability principles.

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Author Contribution

RS prepared the manuscript, AS reviewed the manuscript, IGMS reviewed the manuscript, and MA reviewed the manuscript.

Data availability

Data analysis <https://zenodo.org/records/15875297>

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