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Numerical Analysis of Compaction Load Impact on Lateral Wall Deformation in Geosynthetic Reinforced Structures

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Abstract

Geosynthetic Reinforced Structures (GRS) have emerged as versatile engineering solutions, offering a range of applications including reinforced retaining structures and bridge abutments. Their ability to reinforce, separate, and stabilize soil layers has proven effective in constructing steep slopes, enhancing foundation soil properties, and minimizing the differential settlement issues often encountered at the transition between bridge decks and approach slabs. In GRS technology, geotextiles or geogrids with approved specifications are strategically placed within layers of backfill material. The frictional interaction between geotextiles and the interlocking of geogrid apertures with the backfill soil imbue the structure with tensile strength. The mechanism of GRS technology involves the development of apparent cohesion, increased apparent confining pressure, and the suppression of soil dilatancy behavior as recent studies have revealed. Previous research efforts have explored various aspects of GRS behavior, including reinforcement spacing, stiffness, the stiffness of backfill soil, compaction effects, and facing rigidity's impact on bearing capacity, wall deformation, and reinforcement strain development. Furthermore, researchers have also delved into the seismic behavior of GRS structures under various parameters. However, limited attention has been directed towards comprehensively understanding the influence of compaction loads on lateral wall deformation during the serviceability stage. In this study, a numerical model was validated using Finite Element Method (FEM) 2D simulations. The research model aims to elucidate the effect of compaction loads on lateral wall deformation during the serviceability stage. Employing a plain strain model, this study simulates different levels of backfill compaction within retained soil. The research findings indicate that, during the static surcharging of GRS walls, structures subjected to higher compaction loads exhibit significantly reduced lateral deformation compared to those subjected to lower compaction loads. This research contributes valuable insights into optimizing the design and construction of GRS structures, particularly in addressing lateral wall deformation concerns during serviceability, ultimately enhancing their overall performance and reliability in various engineering applications.

Keywords

Backfill Compaction,Compaction Induced Stress, Geosynthetic Reinforced Structures, Lateral Deformation

1. Introduction

In the realm of Geosynthetic Reinforced Structures (GRS), a multitude of studies have been conducted to unravel the intricate web of factors influencing system performance. These investigations have spanned the realms of backfill material properties, the nature of reinforcing structures, the characteristics of facing elements, and the properties of foundation soils. Researchers have employed diverse methodologies, including prototype testing, full-scale experimentation, analytical modeling, and numerical simulations, all in pursuit of a deeper understanding of GRS system behavior. A relatively limited number of studies have focused on a critical aspect—namely, the impact of backfill compaction during Post Construction Surcharging (PCS) phases. This research addresses this knowledge gap by delving into the nuanced effects of modeling compaction efforts and loads on EOC (End of Construction) and PCS. Through a systematic examination of these parameters, we aim to elucidate their role in shaping the performance of GRS systems, contributing valuable insights to the field of geotechnical engineering. By advancing our comprehension of how compaction practices influence the behavior of GRS structures, we aspire to enhance the design, construction, and overall efficacy of these versatile engineering solutions.

To establish the effective parameters in GRS walls, numerous experimental and numerical investigations have been conducted recently [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]. Nevertheless, despite these in-depth examinations, the impact of compaction has only seldom been taken into account. [4] provides the effect of compaction induced stress on behavior of geosynthetic-reinforced soil walls and concluded that compaction of backfill soil may represent kind of pre-stressing of reinforcement and pre-consolidation of the backfill soil. However, the effect of compaction load on the serviceability stage has been rarely considered. [11] conducted a series of full-scale testing and developed a finite difference based numerical method in which author applied 8kN uniformly distributed load on each stage of construction. The author mentioned compaction load has significant effect on horizontal earth load at the toe at the end of construction in GRS walls. GRS walls has been used as the structure to support the roadway and during construction of road pavement, application of roller on the surface of the GRS walls affect the horizontal wall deformation of GRS walls which is rarely studied. So, in this study effect of compaction load on serviceability behavior of GRS walls for static condition has been considered.

1.1 Mechanics of Geosynthetic Reinforced Soil Structure

Soil exhibits a notable disparity in its mechanical behavior, being weak in tension while relatively strong in compression and shear compared to tension. To rectify this inherent weakness in tensile strength, reinforcement materials are introduced, imparting robust tensile resistance to the soil mass. The incorporation of reinforcement initiates a bond between the soil and these reinforcing elements, yielding a cascade of beneficial effects. This bonding mechanism serves to restrain lateral deformation, bolster confinement, enhance the overall stiffness and strength of the soil mass, and mitigate the tendency of the soil to undergo dilation. The symbiotic relationship between the soil mass and the reinforcement materials enables the strains developed within the soil mass to be transferred to the reinforcements, endowing the soil with newfound tensile strength. This intricate interplay between soil and reinforcement engenders a more robust and stable geotechnical system, ultimately expanding the repertoire of engineering solutions available for a variety of applications.

The introduction of a reinforced layer was observed to significantly impact the principal stress at failure, concurrently manifesting as an apparent cohesion effect, as documented by [14]. Furthermore, this investigation provided evidence that the ϕ values, representing the internal friction angle of the soil, remained constant, assuming no slippage occurred at the interface between the soil and reinforcement layers. The concept of an augmented apparent confining pressure provides an alternative perspective on the functioning of reinforced soil. According to this theoretical framework, an increase in the confining pressure results in an enhanced axial strength of the reinforced soil. Essentially, reinforcement serves as a preventative measure against soil expansion. Through the mechanism of friction at the interface between the soil and reinforcement, tensions within the soil mass induce tensile strain and elongation of the reinforcement elements. The stretched geosynthetics form a containment structure that effectively inhibits soil expansion [15].

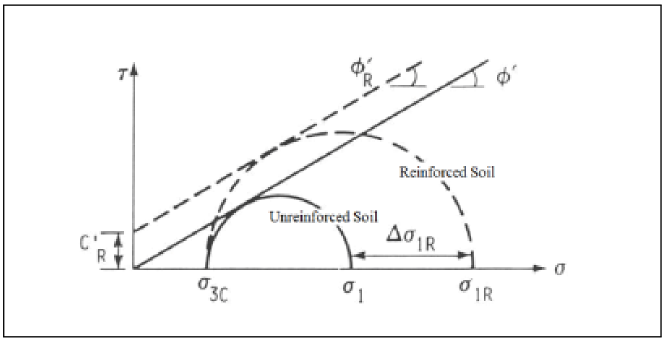

Figure 1: Concept of Apparent Cohesion due to the presence of Reinforcement [12]

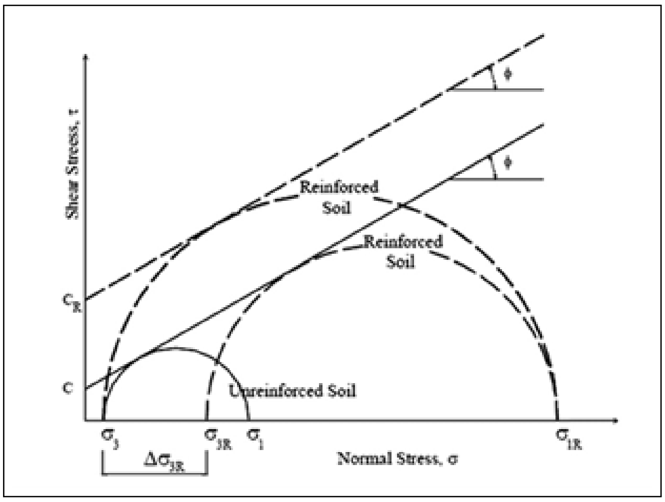

Figure 2: Concepts of apparent cohesion and apparent confining pressure of a soil-geosynthetic composite [13]

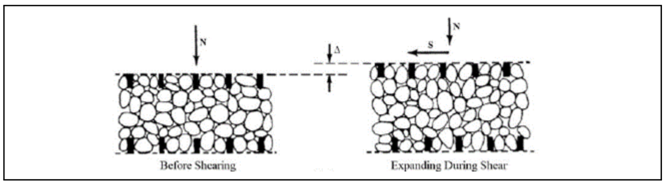

Figure 3: Schematic Diagrams of Volume Change Behavior of Compacted unreinforced Granular Soil [15]

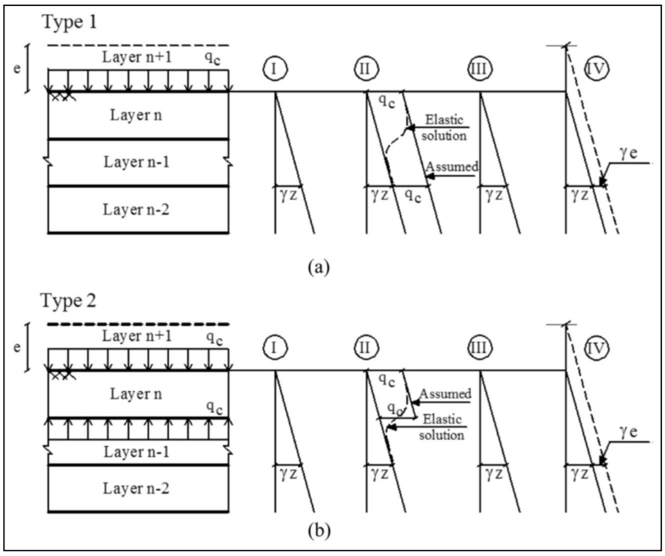

Figure 4: Modelling of compaction [16]

1.2 Compaction Induced Stress

When a soil mass is subjected to an additional vertical load, the vertical and horizontal stresses in the soil mass generally increase, and if the additional vertical load is removed, the increase in vertical stress will diminish to a very small value or zero, but the increase in horizontal stress might only diminish slightly, and the net increase in horizontal stress that remains in the soil mass is commonly referred to as the "lock-in" lateral stress, which is defined as the "Compaction-Induced Stress" (CIS), due to fill compaction during the construction of GRS mass. [6].

[16] conducted modeling of compaction-induced stresses using two methods: Type I, a uniform vertical stress applied to the top of each backfill soil as the wall was modeled from the bottom of each soil layer; type II, a uniform vertical stress applied to the top and bottom of each backfill soil as the wall

Table 1: Material Parameters of Backfill Soil [7]

Parameters	Symbol	Unit	Value
Material Model	-	-	Hardening Soil Model
Unit Weight of backfill soil	γ_s	kN/m^3	16.8
Cohesion	c	kN/m^2	5
Internal friction angle	ϕ	Degree	44
Dilatancy angle	Ψ	Degree	11
Reference secant stiffness from drained triaxial test	E_{50}^{ref}	kN/m^2	56667
Exponential Power	m	-	0.5
Unloading / reloading Poisson's ratio	ν_{ur}	-	0.2
Coefficient of earth pressure at rest	K_0^{nc}	-	0.3035
Failure ratio	Rf	-	0.9
Interface between reinforcement and backfill	R_{inter}	-	0.67

was modeled from the bottom of each soil layer. They found that Type I overestimates the performance characteristics, and results from Type II satisfy the experimental results [16].

Table 2: Material Properties of modular block

Parameters	Symbol	Unit	Value
Material Model	-	-	Linear Elastic
Unit Weight of modular block	γ_b	kN/m^3	21.8
Modulus of Elasticity of modular block	E	kN/m^2	100000
Poisson's ratio	ν	-	0.15

2. Methodology

2.1 General

A geosynthetic reinforced wall was chosen to study the effect of compaction-induced stress, and the numerical modeling of the wall was based according to [3]. The parameters for the numerical analysis was adopted from [7]. The horizontal toe reaction, and the horizontal wall displacement were chosen as validation criteria. The geometric and material properties were adopted from the [3] and [7]. A small cohesion value was assigned to the backfill to consider the cohesiveness property of backfill due to the presence of moisture during the experimental model [11]. The angle of internal friction of the backfill was adopted from plane-strain tests as suggested by [11].

The detailed properties used in the numerical model is shown in Table 1 and 2.

For the modelling of geogrid, the material model was adopted as linear elastic with tensile stiffness, EA = 97 kN/m^2, as suggested by [7].

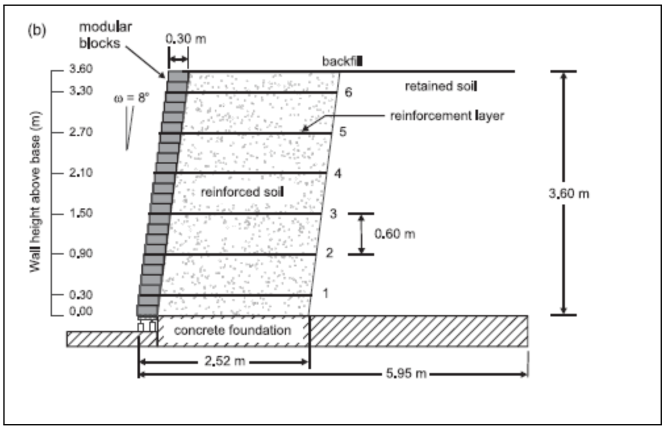

Figure 5: Schematic Diagram of the full-scale model [11]

2.2 Construction Stage

Stage Construction procedure was employed for modeling the construction of the wall. Each stage involves the placement of the 0.15 cm soil layer. [3] recommended using an 8kPa distributed load at every lift to simulate the backfill compaction. However, the type 2 method of simulating backfill compaction (Figure 4) suggested by [16] was employed. To study the effect of compaction load, three backfill compaction loads:8kPa, and 32kPa were applied in the post construction stage (surcharging age).

2.3 Boundary and Toe conditions

For horizontal, restraint boundary was employed to right side of model. The bottom boundary was fixed in vertical direction. To model the load ring located at the model's left side, a horizontal fixed-end anchor with axial stiffness suggested by [3] was placed at the toe of the model.

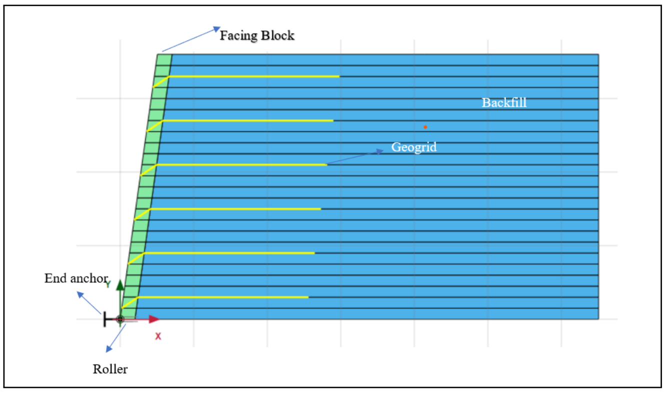

Figure 6: Finite Element Model Developed

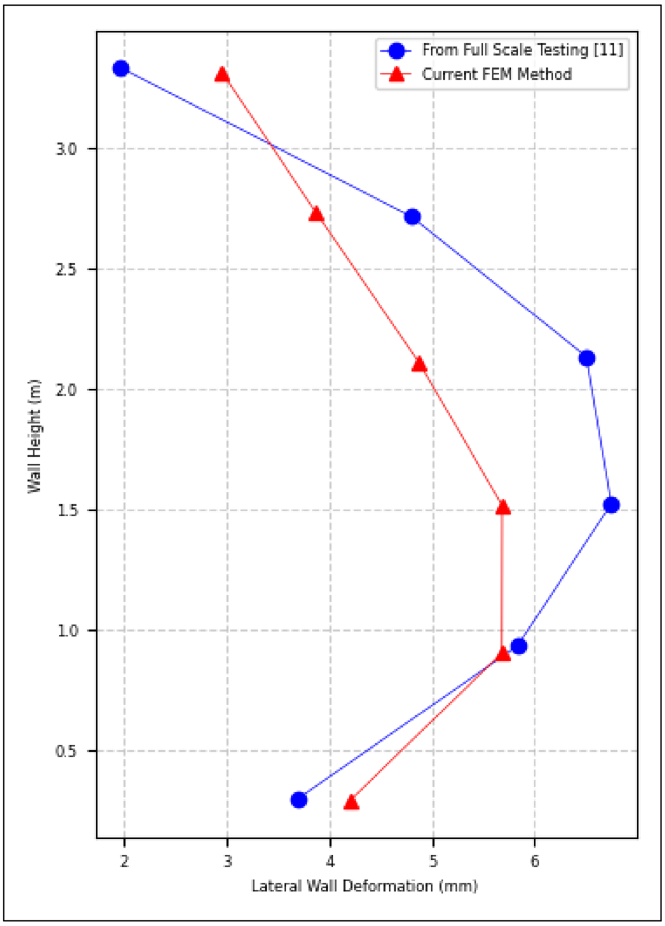

Figure 7: Comparision of Horizontal Wall Displacement

3. Result and Discussion

3.1 Validation

In Figure, we present a comprehensive comparison of horizontal toe reactions for three distinct studies. Notably, the present investigation exhibits a noteworthy correlation with the finite difference method, as initially formulated by [11]. However, it is essential to highlight a contrasting perspective by [11] who posits that the horizontal wall deformation derived from the experimental model does not represent an accurate result. This juxtaposition of horizontal wall deformation findings is visually depicted in Figure 7, 8 for a clearer understanding.

The measured facing displacements were not the actual wall deformation profiles since the instrumentation recorded the magnitude of the lateral displacement value from the time of instrument placement to the end of construction [11].

3.2 Effect of Compaction load

The numerical model developed in finite element software was used to study the effect of compaction load on horizontal wall deformation. For studying the impact on wall deformation, three different backfill compaction load were simulated using Type 2 as described by [16] and as shown in Figure 4.

The simulated numerical model was used to determine the effect of the compaction effort of backfill during the serviceability stage. Here, four different surcharge loads were applied and the effect on horizontal wall displacements was studied. Two different compaction loads, simulated using Type 2, were employed in four different surcharge loads. In all four surcharge load cases, as observed in figure 9, 10, 11 and 12, it was observed that models subjected to heavy compaction effort exhibited greater resistance to the lateral wall displacement than those subjected to light compaction. This finding suggests that compaction of the backfill material plays a crucial role in enhancing lock-in stress, subsequently augmenting the stiffness of the soil mass. This phenomenon has been corroborated by other researchers, including [6], [16], and [17]. [17] delved into the impact of compaction and reported diminished lateral wall deformation in the physical model subjected to heavy compaction during the surcharging phase, contrasting with the physical model subjected to light compaction. This observation led to the inference that backfill compaction induces a pre-consolidation state within the soil mass, thereby resulting in increased stiffness post-construction—a phenomenon well-delineated by [17].

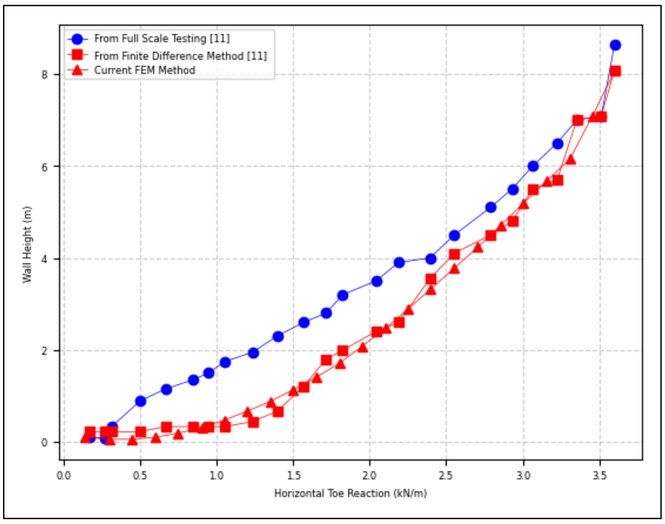

Figure 8: Comparision of Horizontal Toe Reaction

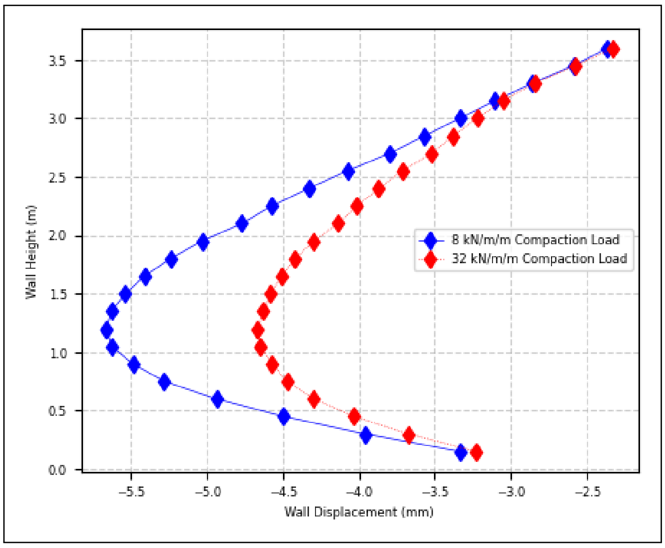

Figure 9: 8 kN/m/m surcharge load

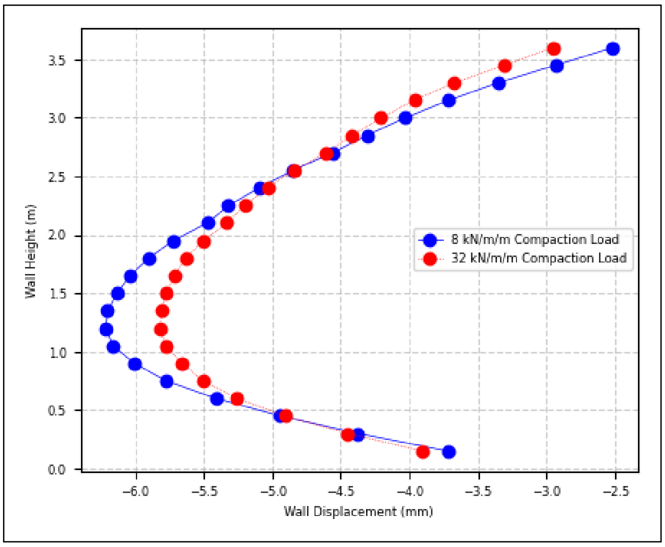

Figure 10: 16 kN/m/m surcharge load

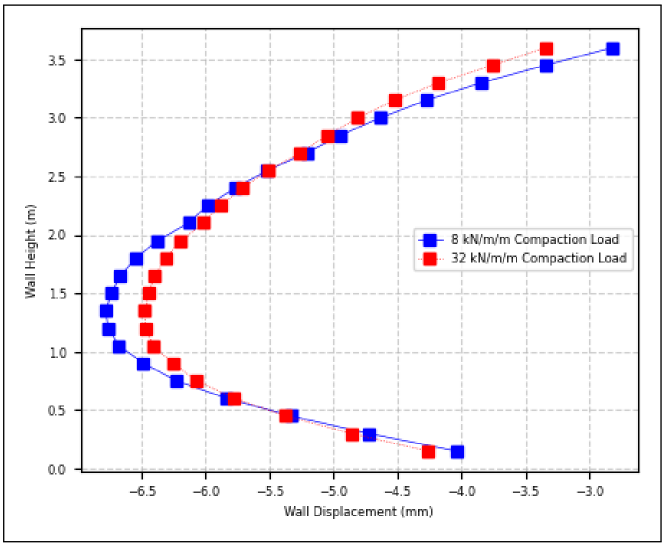

Figure 11: 20 kN/m/m surcharge load

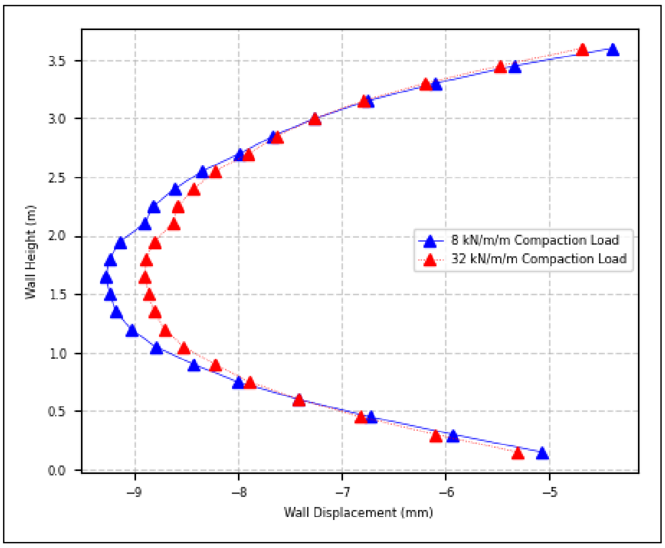

Figure 12: 32 kN/m/m surcharge load

4. Conclusion

In the realm of numerical modeling, an investigation into the influence of compaction on varying surcharge loads has revealed intriguing results. Specifically, it was observed that post-construction, geosynthetic reinforced structure models subjected to heavy compaction exhibit greater resistance to lateral wall displacement than those subjected to light compaction. The findings of this research put insights into the importance of the proper compaction effort on the construction of Geosynthetic Reinforced Structures.

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