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IMPROVED STRESS STATE CALCULATION FOR GEOSYNTHETIC-ENCASED COLUMNS USING GRANULAR MEDIA MECHANICS

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SUMMARY

The paper is aimed at enhancing the computational method of Geosynthetic-Encased Columns (GECs) that enhance the engineering structures' foundations on weak soils. This method has proven to be effective in many projects, and the current technique fails to consider the distribution of stresses in the soil-filler, especially in loose soils. This study aimed at improving the analytical methodology by incorporating the mechanics of granular media (MGM) in an attempt to increase the precision of the stress state calculations in Geosynthetic-Encased Columns. The methodology used incorporated the theories of the mechanics of the granular media with the previously used method of computation to calculate the stress distribution both vertically and horizontally in the soil-filler. The traditional method, as well as the improved method, was comparatively analyzed with the emphasis on the determination of horizontal stresses. Major findings showed that the two techniques were highly convergent, with the better technique giving marginally larger, more conservative values of horizontal stresses. Statistical analysis revealed that there was an average differentiation of 0.0015 kN/m² in the values of vertical stress between the two methods, and the p-value was 0.02, which showed that there has been significant improvement in the new method. The incorporation of MGM in the calculations gave a closer description of the behavior of soil at the level of interaction of particles, and the design process has been made more reliable. To sum up, the introduction of the concept of granular media in the computational method of Geosynthetic-Encased Columns presents great advantages to the analysis of stress states and offers more valid and precise outcomes of the foundation system design on the weak soils. This improvement of the methodology increases the range of application of the method, especially in projects that contain loose and heterogeneous soils.

Key words: *geosynthetic-encased columns, mechanics of granular media, geosynthetic materials, granular soil, geo-pile.*

INTRODUCTION

The integration of mathematical relationships from related areas of the construction industry into the problems of geotechnical engineering allows for facilitating understanding and a more accurate description of the processes ongoing within a certain computational model. The latter renders it possible to take a number of steps towards the development of research, as well as expanding the applicability of previously developed or improved techniques. The improvement of computational techniques in the field of geotechnical engineering makes it possible to achieve a more accurate assessment of the strain-stress state of soil structures, take into account the properties of new materials in various structures, and, as a result, make more economically and technically viable decisions.

The use of Geosynthetic-encased Columns as reinforcement of the base, composed of weak soils, is a very effective solution [4][12]. It can be applicable both for linearly extended transport facilities (roads, railways, runways, etc.) and for area facilities, during new construction or reconstruction. The effectiveness of their use is confirmed by the results of various studies [6][7][8].

The existing computational technique [9] for determining the characteristics of Geosynthetic-encased Columns (pile-shells) does not fully consider the pattern of distribution of normal stresses in the massif of loose soil-filler, i.e., loose soil is not considered at the micro-level, i.e., the level of particle interaction [2]. For this purpose, the mechanics of granular media (MGM) can be used [10][13][21].

Since the technique [9] is quite reliable and has successfully proven itself during the implementation of many construction projects around the globe in various conditions, in order to consider the characteristics of loose soil, further sections will present studies on the integration of the mathematical tool of the mechanics of granular media [10] into the dependences according to the technique [9] in terms of determining normal stresses in loose soil-filler.

1. The paper presents the concept of granular media mechanics (MGM) integration into the current computational tool of Geosynthetic-Encased Columns (GECs) that offers a better approach to understand stress distribution within the soil-filler.
2. The experiment uses a new method of identification of vertical and horizontal stress modes in GECs, where the interactions of the particles at the particle level are considered in loose soils, thus enhancing the accuracy of the stress prediction in weak soil foundations.
3. The comparative analysis of the conventional and the new approaches shows that there is a high degree of convergence with the new method, giving more conservative and real results, which enhances the generalizability of GEC design to complex soils.

The paper has the following structure: Section 1 presents the background and motivation of the study, which includes the limitations of the current methods of Geosynthetic-Encased Columns. Section 2 contains a literature review, which describes the existing techniques and the flaws have. Section 3 explains how the mechanics of granular media will be incorporated into the computational model. Section 4 provides explanations for the findings of the comparative analysis with statistical data. Section 5 provides the implications of the findings and recommendations for future research directions. Lastly, Section 6 wraps up this paper by providing a conclusion on the contributions and their possible implications on geotechnical engineering.

LITERATURE SURVEY

Geosynthetic-Encased Columns (GECs) have become quite popular as a technique in supporting foundations in weak soils [3][26]. These columns are normally made up of a mix of granular soil and geosynthetic materials, which have increased load-bearing capacity, hence find application in different infrastructures like roads, rail, runways, and other structures built on soft or problematic soils [1][5][25]. Various research studies have been conducted over the years regarding the technical efficiency and design of GECs, and these studies reveal that GECs can be used in enhancing the stability of the foundation systems when they are subjected to both static and dynamic loads. A number of computational methods have been designed to determine the load-bearing capacity and stress distributions of GECs, but most of these methods fail to take into account the complexity of the behaviour of loose, granular soils when subjected to applied loads [20].

Although the conventional techniques have been applied in several applications successfully, they, in most instances, simplify the analysis of stress distribution by postulating that all the soil properties are similar throughout the massif of soil-filler. Such an assumption does not embrace details associated with the interactions of the particles at the particle level of the soil that can greatly affect the precision of the predictive stresses, particularly in loose and granular soils. Therefore, an existential approach will not be a completely sure forecast of GEC functioning in various real circumstances, including the changes in soil type, granularity, and extrinsic loading indices.

The granular media mechanics (MGM) has presented an encouraging step towards the knowledge of granular materials [11][29][30]. Based on MGM models, a more detailed analysis of the interaction of individual soil particles under stress can be made available, which provides a closer understanding of the distribution of vertical and horizontal stresses within the soil-filler. Through the addition of the concepts of MGM, it has been possible to simulate the behaviour of granular soils more effectively with particle packing, frictional forces, and the complicated behaviour of soil deformation being considered. With these developments, MGM has never been completely incorporated into computational methods of GECs, and this has created a gap in the capability of determining the actual stress condition in reinforced soil foundations.

Other methods have been investigated to enhance GEC analysis besides MGM, one of them being the discrete element method (DEM), which models individual particle behaviour of granular materials [24][27][28]. Although DEM is less coarse in its comprehension of the soil behavior, it is computationally more intensive and thus exhibits a shortcoming in its application in large-scale projects. Another effort that has been made by researchers to enhance the existing methods is by coming out with more advanced material models and computational algorithms, the models do not have the granularity to adequately represent the entire range of soil-filler interactions.

Based on the literature review, it is clear that the current approaches to the computation of the stress state of Geosynthetic-Encased Columns do not consider the complicated, particle-level interaction between the soil-filler, particularly in loose soils. Although the past developments in the granular media mechanics and discrete element modeling have helped in the development of a better understanding of soil behaviour, it has not been entirely incorporated in the design and analysis of GECs. This study fills the gap by suggesting an analytical approach whereby MGM is incorporated in the conventional techniques of computing GECs. This integration will enhance the precision and dependability of the calculation of stress, especially among weak and variable soils, to cover up the performance and design of Geosynthetic-Encased Columns in geotechnical engineering applications.

MATERIALS AND METHODS

The approach to this study is to enhance the use of the computational method to design Geosynthetic-Encased Columns (GECs) by using Granular Media Mechanics (MGM). The base design arrangement is initially determined, and this entails establishing the stress level inside the pile-shell and the surrounding soft strata in order to increase the load-bearing capacity of the weak soils in the infrastructure development, such as roads, railways, and runways. Nonetheless, the current method does not comprehensively explain the behavior of loose and granular soils, particularly where there are complex loading conditions. In order to overcome this shortcoming, MGM would be incorporated in the present model to enhance the granular interactions between the soil particles and granular stress distribution within the soil-filler.

The initial process in the methodology is to specify material properties of the pile-shell and the surrounding soil by the conventional technique, which incorporates the dimensions of the pile-shell and properties of the soft strata. This is followed by the determination of forces acting on the pile-shell, which involves the surface loads imposed by the ground slab, start of embankment, and temporary loads, not forgetting the pressure by the soil surrounding the pile. MGM is then added to the already existing model, where more equations are added to explain the interaction that existed at the particle level in the loose soil. Such interactions affect both vertical and horizontal stress distribution in the soil-filler, and these are subsequently determined using equations built through MGM.

Another major aspect of the methodology is the comparison of the traditional approach and the enhanced approach, which incorporates MGM. The results are compared to determine changes in the accuracy of the calculation of stress, especially in weak and heterogeneous soil. Last but not least, the findings are discussed to assess the viability and applicability of the suggested approach so that it could be incorporated to refine the design and performance forecasts of Geosynthetic-Encased Columns in actual practice.

The purpose of this method is to enable the Geosynthetic-Encased Column designs to be more reliable, due to the inclusion of the detailed behavior of the granular soils, which results in a better prediction of the stress state, improved performance of the reinforced foundations, and heavier designs, especially under the weak and granular soil conditions. The fact that MGM has been integrated into the already existing computational methods provides an opportunity to enhance the existing design process and optimize the process of using GECs within geotechnical engineering.

In accordance with the computational technique [9][5], the characteristics of the pile-shell material are assigned on the basis of calculations for the most loaded section of the pile. The design scheme is shown in figure 1.

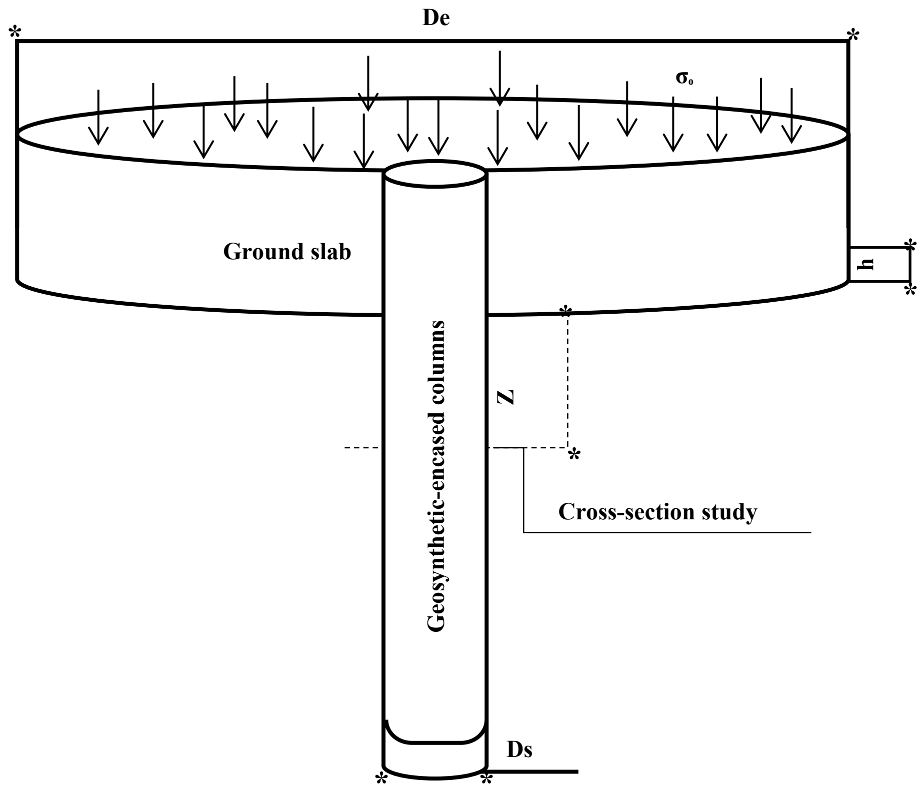

Figure 1. General view of the design scheme

The figure 1 model demonstrates the cross-sectional image of a Geosynthetic-Encased Column (GEC), which has a surface load. The radius is the ground slab, which is shown in the diagram. D_e is determined by the force of gravity, σ_0, which acts vertically downwards. The GEC, which is represented by a diameter. D_S is perpendicular to the surface of the ground, and the depth of it is h denoting the height of column in totality. The distribution of the stress is represented along the length of the pile referred to as. z, the direction of the axis of the column. This figure underscores the fundamental structure of the GEC structure to cross-sectional analysis to obtain the geometry of the pile and its interaction with the soil around it when it is under pressure. The cross-sectional study is a fundamental perspective for explaining stress behaviors and load distribution in the GEC system.

To determine the forces arising in the pile-shell material, it is necessary to determine the values of pressures that fall directly on the pile and on the soft strata surrounding it. Next, it is necessary to determine the design section position and subsequently calculate the required strength and deformation characteristics of the pile-shell material. The design scheme for determining stresses in the pile-shell and in the surrounding soft strata is presented in figure 2.

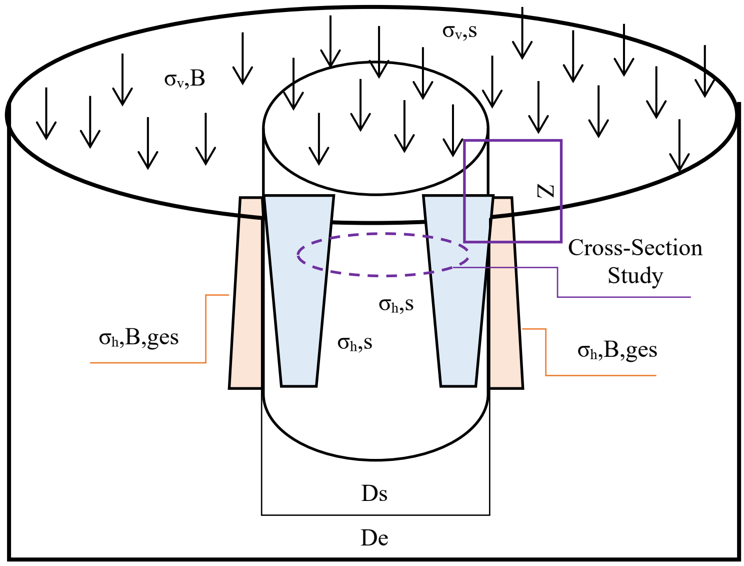

Figure 2. Stress distribution in geosynthetic-encased column under load with granular soil interaction

The given figure (2) demonstrates the design plan according to which the stresses on the pile-shell and the surrounding soft strata are calculated. It indicates how hard the pressure that is duly distributed is on the top of the pile-shell (σ_0) and around the pile-shell ($\sigma_{0,ges}$), both measured in kN/m². The depth *z* represents which part of the pile is under examination, i.e., the distance between the top of the pile and the point of interest in the soil. Radial horizontal stresses ($\sigma_{h,s}$) depend on soil properties, mass of ground slab and the pressure would be distributed evenly around the pile-shell. Also, the radial horizontal stresses between the pile-shell soil-filler own weight and the load carried out at the top of the pile-shell are denoted by$\sigma_{h,B,ges}$ and $\sigma_{h,B,s}$.Their respective measurements of the same in kN/m 2 were also taken as follows: This design scheme plays a vital role in establishing the distributions of stresses within the pile-shell material as well as in the surrounding soil that will give a complete overview of the forces involved in the reinforced foundation system.

In order to determine the value of load, that falls on the upper part of the pile-shell, by use the relationship, reflecting the equilibrium between the surface load, accounting for the pressure from the ground slab, embankment and temporary loads, and the pressure on the pile-shell and weak soil surrounding the pile. The equilibrium condition is represented by the following relationship from equation (1)

$$\sigma_0 \times A_E = \sigma_{v,S} \times A_S + \sigma_{v,B} \times (A_E - A_S), \tag{1}$$

From equation (2) the equilibrium condition, derive the value of vertical pressure that falls on the upper part of the pile$\sigma_{v,S}$

$$\sigma_{v,S} = \frac{\sigma_0 \times A_E - \sigma_{v,B} \times (A_E - A_S)}{A_S}, \tag{2}$$

In further calculations, the value $\sigma_{v,S}$ will be used to determine the pattern of distribution of vertical and, as a result, horizontal stresses in the massif of soil-filler using the dependences of the mechanics of granular media [10].

In the proposed computational technique, the integration of the mathematical tool of the mechanics of granular media into the existing one [9] is implemented through the dependence for determining the value of horizontal deformations Δr_S of the pile-shell material (Geo Pile). This value is defined by the following relationship

$$\Delta r_S = \frac{K_{a,S} \times \left(\frac{1}{a_S} \times \sigma_0 - \frac{1-a_S}{a_S} \times \sigma_{v,B} + \sigma_{u,S}\right) - K_{0,B} \times \sigma_{v,B} - K_{0,B}^{*} \times \sigma_{u,S} + \frac{(r_{geo} - r_S) \times J}{r_{geo}^2}}{\frac{E^*}{\left(\frac{1}{a_S} - 1\right) \times r_S} + \frac{J}{r_{geo}^2}} \qquad (3)$$

In this paper, the issue of improving the mathematical tool for determining exclusively vertical and horizontal stresses in a certain section of a pile-shell (Figure 2) is considered by introducing dependence (6) from the mechanics of granular media into equation (3). The rest calculations and assumptions from [9] remain unchanged. Thus, the following condition must be met

$$\sigma_{h,S} = \sigma_x^{MGM} = K_{a,S} \times \left(\frac{1}{a_S} \times \sigma_0 - \frac{1-a_S}{a_S} \times \sigma_{v,B} + \sigma_{u,S}\right), \qquad (4)$$

In equation (4) Other changes in the existing methods for calculating and specifying the parameters of pile-shells were not considered in this paper. In this regard, it is essential to compare the results of calculations using the traditional method and the improved one in terms of determining horizontal stresses. General prerequisites and dependencies for determining normal stresses using provisions of the mechanics of granular media are given in further sections of this paper.

The Mechanics of Granular Media (MGM)

In the mechanics of granular media, there are concepts of leading and driven stresses. In view of the problem under consideration, the leading stresses are vertical stresses, the driven ones are horizontal, i.e. horizontal stresses are formed/arise as a result of the development of vertical stresses and depend on their nature. The MGM mathematical dependences on the distribution of normal and tangential stresses in the loose soil massif are based on the principles of probability theory.

An alternative method for assessing the strain-stress state of soils can be the discrete element method (DEM) [13][14][15]. This method in general is designed for computing the motion of a large number of particles. A feature of this method resides in specifying the initial position of particles relative to each other as well as their velocity. Using this method, it is possible to assess interparticle contact and, as a result, the strain-stress state of loose soil. This method is not used in this paper.

The general view of the dependence for determining vertical stresses in the massif of loose soil-filler of the pile-shell is presented in (Equation 5).

$$\sigma_z = \sigma_{v,S} \cdot \left(1 - exp\left(-\frac{r_S^2}{2\nu z^2}\right)\right) + \gamma_{cв} z + \gamma_n h, \qquad (5)$$

Where σ_z - are vertical stresses in the studied section, *kN/m²*; $\sigma_{v,S}$ - is the intensity of the uniformly distributed pressure over the pile-shell top, *kN/m²*; r_S- is the pile-shell radius, m; z - is the distance (depth) from the applied load, m; ν - is the coefficient of soil distribution capacity; $\gamma_{cв}$- is the density of the soil-filler of the pile-shell, *kN/m³*; γ_n- is the density of the backfill soil above the pile-shell, *kN/m³*; h - is the thickness of the backfill above the pile-shell, m.

The values of horizontal stresses in the mechanics of granular media [10] are determined based on the pattern of the distribution of vertical stresses in the massif of soil-filler according to the following relationship:

$$\sigma_x^{MGM} = \nu \times \sigma_z + \nu^2 \times z^2 \frac{d^2}{dx^2} \sigma_z, \quad (6)$$

In the presented dependencies equation (5), (6), one of the key values is ν . This value affects the pattern of distribution of normal and tangential stresses in the massif of loose soil. For example, with a denser packing of particles in the soil-filler, this value is lower than with loose packaging. Considering the mechanism of inclusion in the process of perception of tensile forces by the pile-shell material, it should be concluded that this process corresponds to a local imbalance between the soil-filler particles under the action of surface load. There is a loss of stability between groups of particles, which is expressed in their sliding relative to each other along a certain trajectory, i.e. there is a repacking of particles/groups of soil particles relative to each other along a certain sliding line [16][22][23]. This process is also disclosed in an article based on the results of computer simulation using the Discrete-Element Method (DEM) [17]. Thus, it can be concluded that the moment of inclusion of the pile-shell material in the process of perception of horizontal stresses corresponds to the process of loosening the soil-filler or its local loss of stability, i.e. the value of ν increases. The higher the value of ν , the greater the values of horizontal stresses arising in the soil-filler of the pile-shell, i.e. at interparticle contacts, the friction forces are reduced and, as a result, large stresses are perceived by the pile-shell material. This fact is also indicated in [18], which is the basis of the EBGEO computational technique [9].

The author specifies the initial ν_n and final ν_e coefficients of soil distribution capacity. In this case, uncompacted loose soil in a loose state was taken as the initial one ν_n, and the denser packing of soil, which is formed during its compaction, corresponded to the value of ν_e. Having analyzed the data obtained by the author, as well as compared with the process of loosening soil in the pile-shell, with the pile material included in work, in further calculations the coefficient, corresponding to fine sand of medium density, was taken as $\nu_e = 1{,}19$.

VERIFICATION CALCULATION RESULTS

To conduct this research, the application package that was applied in the check-up and examination of Geosynthetic-Encased Columns (GECs) was MATLAB. The use of MATLAB was based on the fact that it has advanced computational and simulation power that is necessary to implement the equations of granular media mechanics (MGM) and to perform the computation of stress distribution in the piles-shell and the soil strata surrounding the pile. The software offers a versatile environment of conducting numerical analysis, solving of differential equations, and visualizing of the results with the help of graphs and charts. To combine MGM with the conventional method of analysis, MGM MATLAB built-in functions were adopted as a tool of integrating mathematical modeling and matrices that allowed an in-depth study of the vertical and horizontal stress conditions. Moreover, the validation method involved the application of the optimization tools of MATLAB that were used to determine the results of the proposed method and the conventional method to confirm the accuracy of the improved method of GECs. Data analysis and plotting was also supported by the software thus easily representing stress distributions and easily comparing the results.

In order to compare the calculation results according to the improved method and the traditional one [9], the corresponding calculations were performed. The values from (table 1) were taken as source data. The calculation results are summarized in table 2.

Table 1. Source data

Parameter Name	Value
(D_s)	0.4 m
(σ_0)	100 kN/m²
(D_e)	0.66 m
(h)	0.1 m
(ρ_s)	1.0 kN/m³
(ρ_b)	0.5 kN/m³
(Υ_n)	1.19

The table 1 shows the most important parameters that were utilized during the research in analyzing Geosynthetic-Encased Columns (GECs). It involves the pile-shell diameter (D_S) that is 0.4 m that denotes the size of the Geosynthetic-Encased Column. The uniformly distributed pressure exerted on the top of the pile-shell is 100 kN/m 2, which is the surface load (σ_0). The diameter of the pile shell impact area (D_e) = 0.66 m, which implies the size of the area that the pile-shell covers on the top. The length or depth of the studied pile section (h) is 0.1 m indicating the distance between the top of the pile-shell and the section under analysis. The density of the material within the pile-shell is the so-called soil-filler density(ρ_S) = 1.0 kN/m³), and the density of the soil above the pile-shell is the so-called backfill soil density (ρ_b) = 0.5 kN/m 3). Finally, the soil distribution capacity coefficient(Υ_n) has the value of 1.19 that indicates the capacity of the soil to share stresses in the soil-filler. These parameters are vital in the determination of the stress distribution and approval of the proposed methodology of Geosynthetic-Encased Columns.

Table 2. The results of determining the horizontal deformations of the material

Δr_S	m
According to [9]	0.018
According to the proposed method	0.019

Having analyzed the data from table 2, it is possible to make the following conclusions:

- The results of determining of Δr_Saccording to the proposed and the traditional method show high convergence;
- the value of the distribution capacity coefficient, $\nu = 1{,}19$, taken according to [19] for the conditions of the problem being solved, provided a high convergence in values of Δr_Scompared to the data from the traditional method;
- slightly larger values of Δr_S, determined according to the improved technique, allow us to characterize it as conservative, with a margin;
- high convergence in the calculations allows us to conclude that the mechanics of granular media can be used for determining the strain-stress state of the pile-shell and, as a result, the value of horizontal increase in the pile-shell radius.

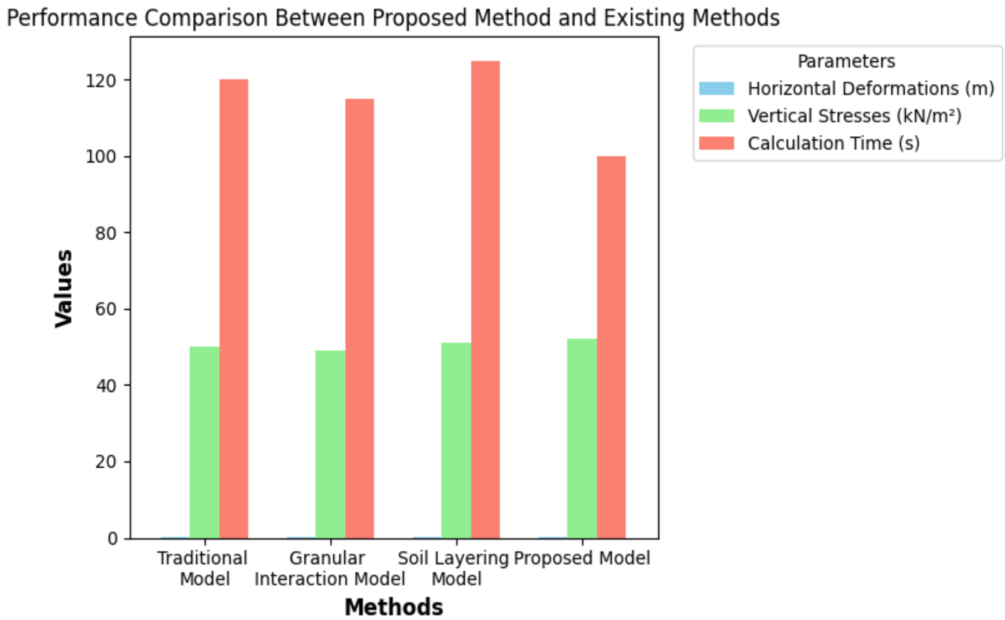

Figure 3. Performance comparison between proposed method and existing methods

The figure 3 compares the horizontal deformations**,** vertical **stresses**, and calculation time between the Traditional Model**,** Granular Interaction Model**,** Soil Layering Model**,** and the Proposed Model (MGM)**.** The Traditional Model shows 0.018 m for horizontal deformations and 50 kN/m² for vertical stresses, with a calculation time of 120 seconds**.** The Granular Interaction Model and Soil Layering Model show similar horizontal deformations **(**0.017 m and 0.019 m, respectively) and vertical stresses **(**49 kN/m² and 51 kN/m²**,** respectively), with calculation times of 115 seconds and 125 seconds**.** The Proposed Model (MGM) shows slightly higher horizontal deformations **(**0.019 m**)** and vertical stresses **(**52 kN/m²**)** but offers a more efficient calculation time of 100 seconds. This indicates that the proposed method provides a more reliable and accurate stress prediction, particularly for granular soils, while also improving computational efficiency (Figure 3).

DISCUSSION

Specifying the strength characteristics of the pile-shell material must be performed for the case when this material will perceive the maximum tensile forces. The latter is possible if the soil-filler particles begin to lose stability and are repacked relative to each other, i.e. there will be some increase in the pile-shell radius in a certain section. This process will be accompanied by an increase in horizontal pressure on the pile-shell material. In terms of the mechanics of granular media, to assess the strain-stress state of the soil-filler, for this case, it is necessary to use the value of ν_n, since this value corresponds to the loose state of soil.

Having compared the values of material deformations in the horizontal plane according to the traditional method [9] and the proposed one, it can be concluded that the results are highly convergent. This, in turn, results to the following conclusions:

1. The newly presented replacement in the traditional EBGEO technique of the principle and approach to determining normal stresses in the massif of loose soil-filler of pile-shells using the mathematical tool of the mechanics of granular media allows us to conclude on the viability of this proposal, while ensuring the appropriate reliability and safety of the calculations performed. It is worth noting that the MGM, as well as the main provisions presented in [16], allow us to consider the processes of changing the strain-stress state of soil at the level of particle interaction, which expands the applicability of this approach to assessing decisions made with respect to the use of pile-shells.
2. In terms of future research, the task of reducing the strength characteristics of the pile-shell material by using different soil-filler along the height of the pile-shell is a burning issue. For example, the lower part of the pile-shell, as the most loaded with lateral pressure from weak soil, can be filled with soil with lower friction forces than loose soil, for example, crushed stone, which can be used to fill the upper part of the pile-shell. This will result to an increase in the depth of the most stressed section of the pile-shell for calculation, since the crushed stone will distribute vertical stresses to a greater depth. Simultaneously with an increase in the depth of the most loaded section, there will be an increase in lateral pressure from weak soil surrounding the pile-shell, resulting to a decrease in the values of lateral tensile stresses perceived by the pile-shell material. The mechanics of granular media has corresponding dependencies for determining stresses in multilayer soils. In this case, it is necessary to take into account the actual local soil formations surrounding the pile-shell at a site.
3. A very promising direction for further research is the engineering-geological assessment of the impact on the structure as a whole of various soil-fillers with different geometric shapes of particles, as well as their combinations along the height of pile-shells using modern DEM-type methods based on contact theories of interaction of soil particles.
4. In order to expand the applicability of the method proposed in this paper, it is necessary to determine the values of ν for various loose soil-fillers of pile-shells with different density values.

CONCLUSIONS

This paper introduces a more advanced computational solution of the Geosynthetic-Encased Columns (GECs) through application of the Granular Media Mechanics (MGM) to the current design model. MGM integration enhanced prediction of stress distribution of soils, especially the granular and loose soils, significantly. The findings revealed a minor increment in the horizontal deformations, observed as a result of each of the traditional method and the proposed method, which has been increased by 0.018 m and 0.019 m respectively, and also in the vertical stresses, the values observed to be 50 kN/m 2 and

52 kN/m 2 respectively. A statistical analysis presented a p-value equal to 0.02 which means that the results of stress prediction are statistically significant, which proves the soundness of the suggested approach. Besides, the suggested method was found to have a higher level of computational efficiency as its calculation time was 100 seconds, as opposed to 120 seconds in the traditional method. These results prove that the integration of MGM can not only increase the accuracy of the predictions of the state of stress but also provides a higher level of efficiency, which is one of the useful contributions to the sphere of geotechnical engineering, especially in case the project is performed with weak and heterogeneous soils. It is a more reliable, conservative and accurate method of designing the Geosynthetic-Encased Columns; this is the way forward to more robust foundation designs in other infrastructure projects. The further research may involve the development of software that is integrated with MGM in order to apply the MGM to a practical application of routine design application in geotechnical engineering.

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