

Studying the impact of geosynthetic materials on the strain-stress state of soil structures applicable to the mechanics of granular media

Sura A. Saadoon¹, Safaa Hamdan², Ali A. Al-Robay³

¹Department of Roads and Transport Engineering, Al-Qadisiyah University

²Civil engineering, Al-Muthanna University

³Department of Civil Engineering, Al-Qadisiyah University

ABSTRACT

In the modern construction industry, a solution being successfully proven is the use of geosynthetic materials, applied as semi-holders, to increase the reliability and stability of soil structures. In connection therewith, solving the issues of expanding the range of methods and approaches to predicting the behavior of such structures under the activity of surface loads is a relevant task, since this is a vital factor in evaluating the designing arrangements made, including the use of geosynthetic materials. The aim of the studies according to this paper is to expand the pertinence of the mechanics of granular media (MGM) in order to assess the reliability of decisions made in the design of soil structures from pitifully durable soils, supported with geosynthetic materials, by comparing the obtained values with the results of full-scale tests and the values obtained by the limited component strategy. For this purpose, the paper presents a comparative analysis for the results of determining vertical stresses under the bridge reinforced with geosynthetic materials and its displacement, obtained by the mechanics of granular media and the limited component strategy. The results of laboratory tests, performed in a soil tray, were taken as verification data. The actual values of vertical stresses were determined using soil pressure sensors, and the values of displacement were determined using the movement indicator of the clockwork installed on the deflection meter of a die unit. An approach to determining displacement of a reinforced bridge using the mechanics of granular media was presented for the first time. The newly presented approach to determining displacement of an bridge, reinforced at the base with geosynthetic materials, allows us to conclude on its reliability, which significantly expands the applicability of the MGM as an alternative to the use of the limited component strategy. The aftereffects of contrasting the upsides of vertical anxieties under the bridge reinforced with geosynthetic materials and its displacement, utilizing the Plaxis programming bundle and the MGM dependencies, counting when contrasted and the consequences of lab tests, are presented. Based on the results obtained, a general conclusion was made on the possibility to use the MGM dependencies in deciding the example of the pressure dispersion and the values of displacement of reinforced bridges under the action of surface loads. The paper also discloses the promising directions of research in this area of geotechnical engineering.

Keywords: Mechanics of granular media, geosynthetic materials, weakly cohesive soils, superposition principle, Plaxis, limited component strategy

Corresponding Author:

Sura A. Saadoon
Department of Roads and Transport Engineering
Al-Qadisiyah University, Iraq
E-mail: sura.saadoon@qu.edu.iq

1. Introduction

Improving the safety and reliability of engineering solutions made in the design of soil structures is one of the main tasks of geotechnical engineering. One of these important tasks is to predict the behavior under the action of surface load, for example, of bridges with semi-holders of geosynthetic materials formed at the base to improve the strength and deformation characteristics of the structure as a whole. To date, the best-known tool for assessing the strain-stress state is the limited component strategy carried out by means of the Plaxis programming bundle.

The mechanics of granular media (MGM), with a somewhat extraordinary numerical device, can be utilized as an elective strategy for evaluating the strain-stress condition of a bank supported with geosynthetic materials. In the MGM, in view of a far-reaching approach, a probabilistic-reenactment model of the dissemination of ordinary and unrelated burdens in a granular medium massif is introduced [1]. The issues of deciding, for instance, the upsides of removal of supported dikes are settled in the MGM dependent on the example of

dispersion of all pressure segments in the mass of the bank, just as at its base. For this situation, one of the fundamental properties of this model is the coefficient of dissemination limit ν , which portrays the properties of the free-soil massif structure.

An important aspect in determining the strain-stress state of a granular medium is the method or structural history of such a soil massif. In [2], it is noted that a granular medium does not have a constant density, since the latter depends on the arrangement of particles relative to each other and on the interacting forces in between. The use of geosynthetic materials in various solutions in the construction of bridges enables to somehow reduce the significance of the last statement. This issue will be also discussed in this paper.

2. Material and methods

In September 2020, inside a structure of an examination work pointed toward contemplating the impact of high-strength woven geosynthetic materials on the strain-stress state of reinforced soil of the bridge and weak base, in September 2020, the tests were performed in a 4x2x2m soil tray (Figure 1). The temperature during the trial ranged from +18 to +20 °C.



Figure 1. General perspective on the dirt plate

A diagram of the tested bridge constructed on a frail base, just as the area of a dirt pressing factor sensor, is appeared in figure 2.

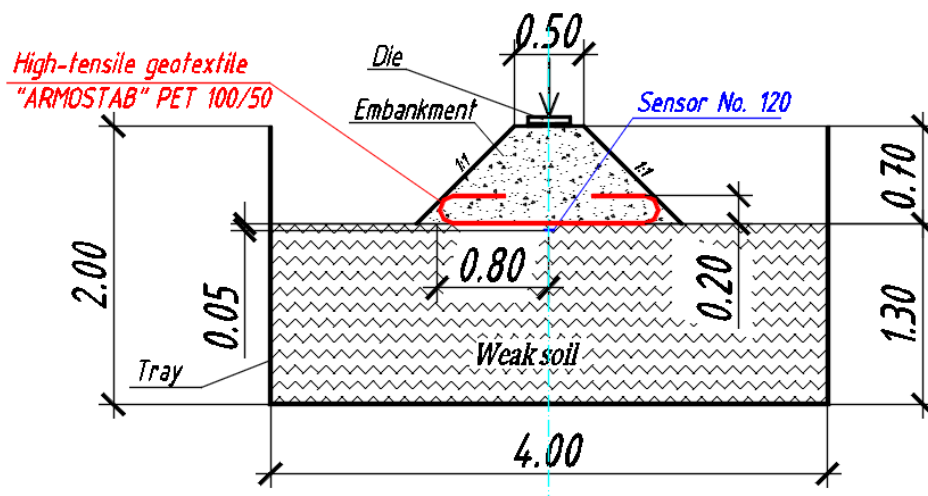


Figure 2. General perspective on the bank built on a feeble base

This exploration work manages the accompanying sorts of soils:

- fine sand for dike development ($h = 0.7\text{m}$);
- heavy soil, liquid plastic, exceptionally deformable for modeling a "weak" base ($h = 1.3\text{m}$).

General view of the tested bridge design is shown in Figure 3.

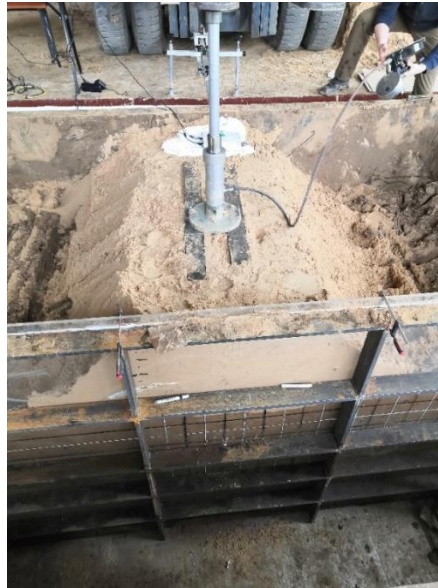


Figure 3. General perspective on the bank built on a "weak" base

To decide the anxieties, soil pressure sensors of the KDE-1MPA sort and the strain-check station ZET 017-T8 were utilized. A high-strength woven geosynthetic fabric made of polyester (polyester threads), brand ARMOSTAB PET 100/50, by "MIAKOM SPb", LLC, was used as a reinforcing material. The process of forming a reinforced soil holder is shown in figure 4.



Figure 4. Formation of a reinforced soil holder at the base of the bridge on a "weak" base

The surface burden was sent from a pass on, mounted on two steel plates having measurements of 0.1x1.2x0.02m (Figure 5). The distance between the plates was 0.1 m. The step of load application was 0.05 MPa with a time delay until complete stabilization of the die. The test results are shown in figures 10 and 11.



Figure 5. General perspective on the loading device

2.1 Computer simulation of laboratory tests

PC reenactment of the test cycle was performed through the Plaxis 2d programming bundle. The underlying information and parameters taken for the model were as follows (table 1)

Table 1. Starting information for PC reproduction by means of the Plaxis 2d programming bundle

Parameter name	Measuring unit	Value
Weak soil (base)		
Material model	-	Mohr-Columb
Drainage type	-	Undrained (B)
γ_{unsat}	kN / m^3	18
γ_{sat}	kN / m^3	18
E'	kN / m^2	141
ν'	-	0.30
$s_{u,ref}$	kN / m^2	6.0
Bridge soil		
Material model	-	Mohr-Columb
Drainage type	-	Drained
γ_{unsat}	kN / m^3	18
γ_{sat}	kN / m^3	18
E'	kN / m^2	80 000
ν'	-	0.30
c'_{ref}	kN / m^2	6.0
ϕ'	$^{\circ}$	40.0
Load during the first step	kPa	8.84
Load during the second step	kPa	17.68
Reinforcing material (geotextile polyester fabric)		
EA	kN/m	900

The results of computer simulation are presented in figures 6-8 and summarized in tables 2 and 3.

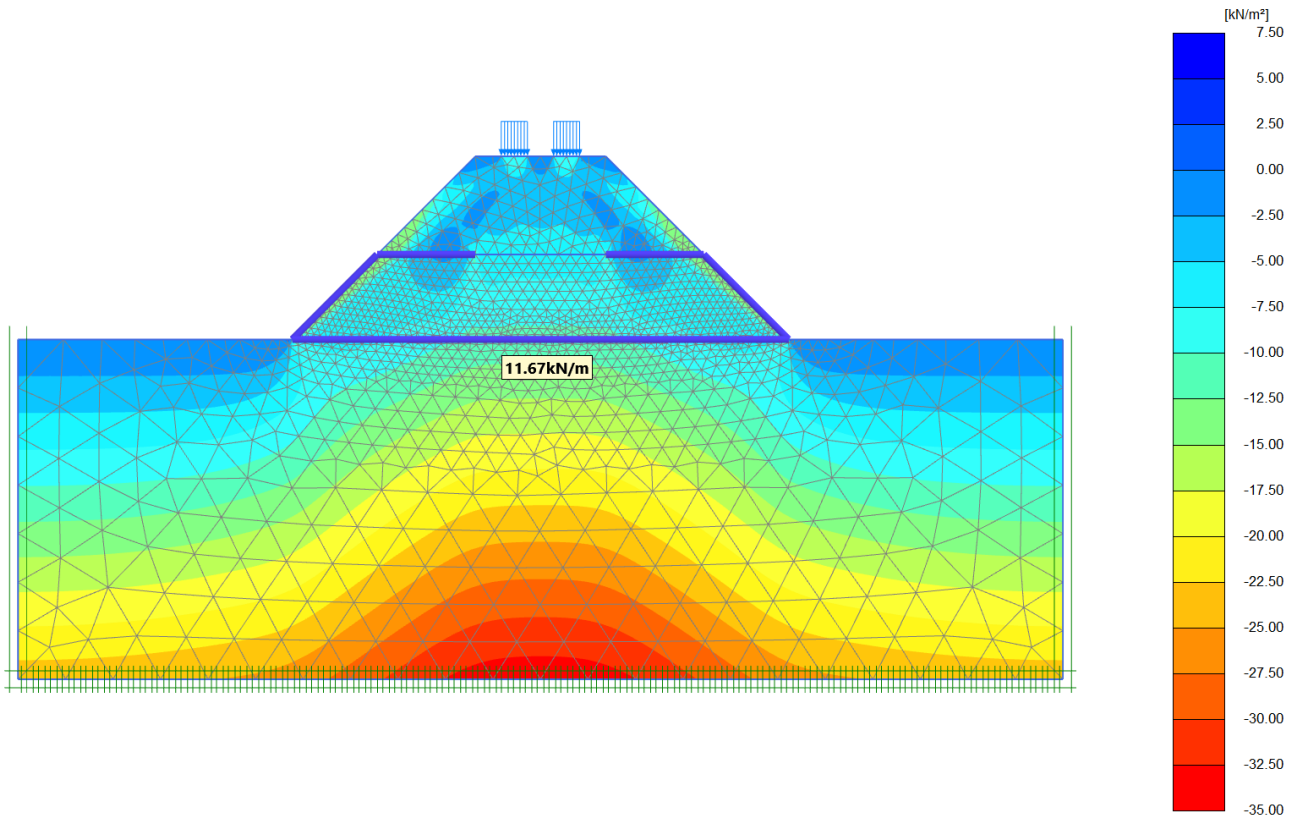


Figure 6. Vertical anxieties at a surface heap of 17.68 kPa

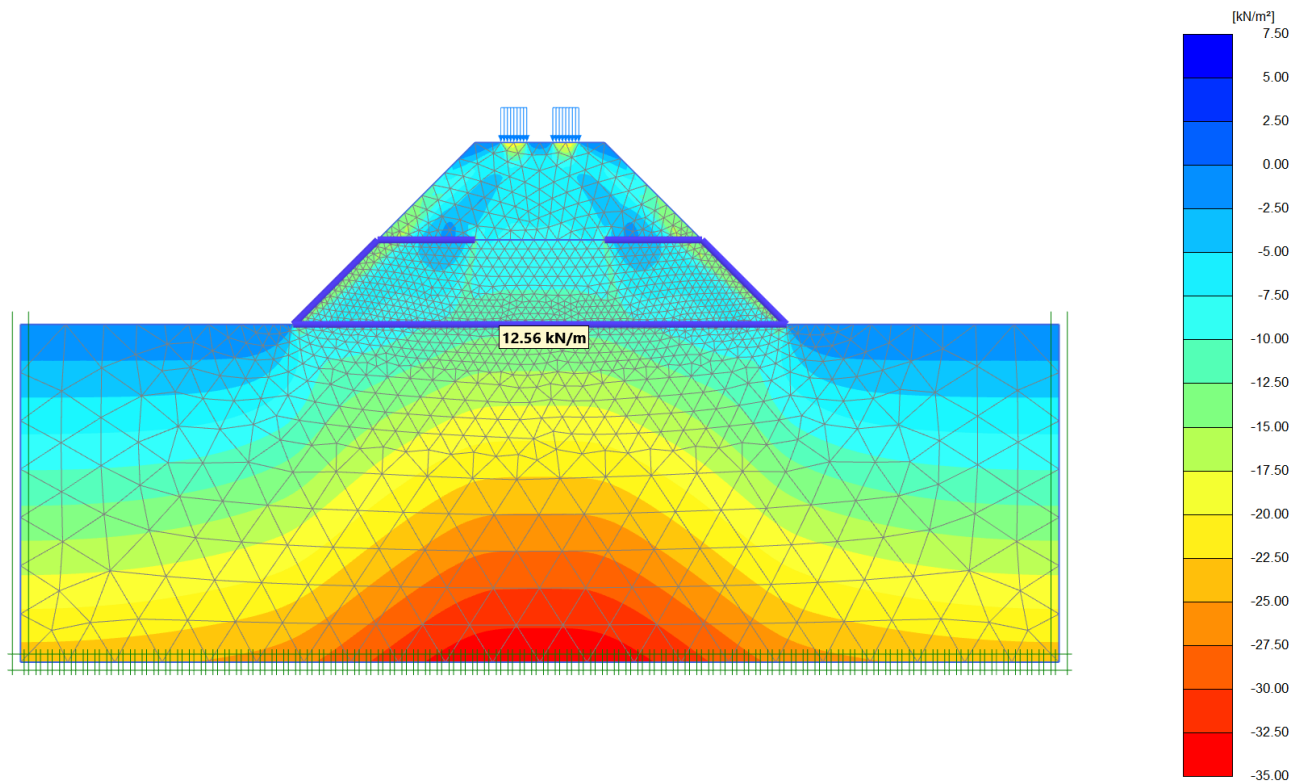
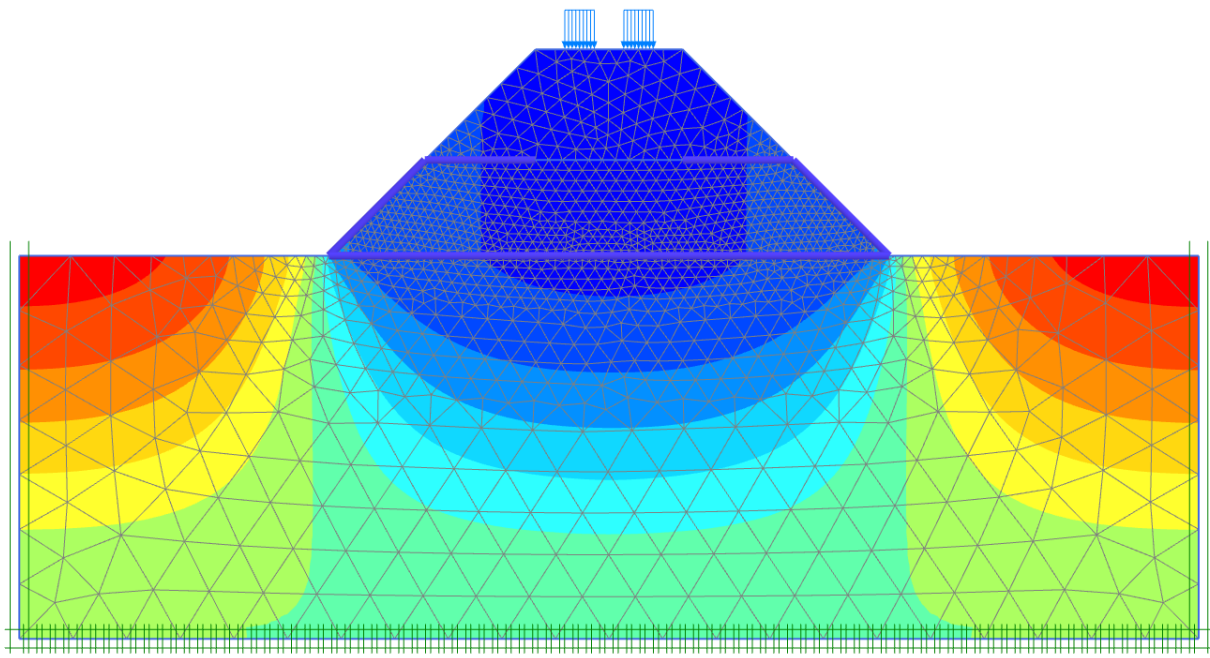


Figure 7. Vertical anxieties at a surface heap of 35.35 kPa



Total displacements u_y (scaled up 5.00 times)

Maximum value = 0.01125 m (Element 1519 at Node 136)

Minimum value = -0.01058 m (Element 74 at Node 22242)

Figure 8. Vertical deformation of the reinforced bridge at a surface burden of 35.35 kPa

2.2 Mechanics of granular media (MGM)

In various sources [3,4,5,12], a high convergence with the experimental data of the results for deciding the ordinary and extraneous burdens utilizing the MGM is noticed.

In works [5,6] introduced interestingly are conditions dependent on the superposition guideline, which make it conceivable to decide the example of the circulation of stresses actuated by a limitless number of surface burdens, including those of various nature and greatness.

General perspective on the reliance for deciding the upward burdens in the free-soil massif is introduced in (1).

$$\sigma_{z,0\delta\theta\theta} = \sigma_{z,1} + \sigma_{z,2} + \dots + \sigma_{z,n} + \sigma_{ce}, \quad (1)$$

$$\sigma_{z,i} = \frac{p}{2} \left(\Phi \left(\frac{x - \xi_i + b}{z\sqrt{2\nu}} \right) - \Phi \left(\frac{x - \xi_i - b}{z\sqrt{2\nu}} \right) \right), \quad (2)$$

Where, p is the force of the consistently dispersed pressing factor, kN/m^2 ; b is a large portion of the applied burden's width, m ; z is the distance (profundity) from the applied burden, m ; ν is the coefficient of soil appropriation limit; Φ is the fundamental of blunders; ξ_i is the abscissa of burden focuses; n is the quantity of applied surface pressing factors; σ_{ce} are stresses from the own load of the dirt (connect), kN/m^2 .

To determine the stresses under the reinforced part of the bridge using the MGM dependencies, the assumption made is that the reinforcing material makes it possible to achieve a more stable structure of the bridge soil, i.e. $\nu = const$. This statement is also presented in [7,11]. Proceeding from the above, it can be said that when studying the strain-stress state of a point located below the reinforcing material, the pattern of the stress distribution within the reinforced bridge does not matter. The latter is true when ensuring the stability and reliability of such an bridge as a whole. Thus, to determine the stresses under the reinforced bridge from its own weight, a dependence that allows determining the stresses from the parabolic load was used. This is due to the uniform deformation of the lower part of the reinforced bridge during testing and the formation of a curved surface in the form of a parabola under the bridge (Figure 9), which transmits stresses to the underlying soil layer. This statement was considered earlier in [8,10].

$$\sigma^{n,0} = \sigma_{ce} \left[\left(1 - \frac{z^2 v}{b^2} \right) \operatorname{erf} \left(\frac{b}{z \sqrt{2v}} \right) + \frac{z \sqrt{2v}}{b \sqrt{\pi}} \exp \left(\frac{-b^2}{2v z^2} \right) \right] \cdot \left[\left(1 - \frac{z^2 v}{a^2} \right) \operatorname{erf} \left(\frac{a}{z \sqrt{2v}} \right) + \frac{z \sqrt{2v}}{a \sqrt{\pi}} \exp \left(\frac{-a^2}{2v z^2} \right) \right], \quad (1)$$

$$\sigma_{ce} = \gamma z, \quad (2)$$

where, $\sigma^{n,0}$ are stresses from own weight distributed along the bottom of the reinforced bridge along a parabola, kN/m^2 ; γ is the dirt thickness, kN/m^3 ; z is the test point profundity, m.



Figure 9. General perspective on the distortion of the base under the scaffold in the wake of testing

To decide the extent of the upward pressing factor under the built up connect while applying a surface burden, conditions (1 – 2) were utilized. The calculation results are presented in Figure 10.

To determine the total values of displacement, the principle of summing up the vertical deformations of the bridge and the base was used. To determine the displacement of the bridge, dependence (4) was used, and for the base – dependence (5). Herein, in the first case, the dependence was used for a uniformly distributed load, and in the second case – for accounting the pressure, from the lower part of the reinforced bridge, distributed along a parabola.

$$\sum S = S_n + S_o, \quad (3)$$

$$S_{nac} = \frac{P}{E_n} \left(h_n \Phi \left(\frac{b_{um}}{h_n \sqrt{v_n}} \right) - b_{um} \sqrt{2\pi v_n} Ei \left(\frac{-b_{um}^2}{2v_n h_n^2} \right) \right), \quad (4)$$

$$S_o = \frac{P}{E_o} \left(h_o \left(1 + \frac{h_o^2 v_o}{3b_o^2} \right) \Phi \left(\frac{b_o}{h_o \sqrt{v_o}} \right) + \frac{1}{3} b_o \sqrt{2\pi v_o} Ei \left(\frac{-b_o^2}{2v_o h_o^2} \right) + \frac{2h_o^2 \sqrt{2v_o}}{3b_o \sqrt{\pi}} \exp \left(\frac{-b_o^2}{2v_o h_o^2} \right) \right), \quad (5)$$

where, p is the power of the consistently dispersed surface pressing factor, kN/m^2 ; is the best ordinate of illustrative pressing factor, kN/m^2 ; is a large portion of the applied burden's width, m; is the thickness of the compressible soil, m; is the coefficient of soil appropriation limit; is the vital of mistakes; is the outstanding essential capacity; is the modulus of versatility of the compressible piece of the dirt, kPa.

To decide the upsides of vertical anxieties and relocation inside the extent of this examination, in light of the exploration results as indicated by [5], the worth was taken equivalent to 0.105, which relates to the worth $E = 80\text{MPa}$.

The results of determining the displacement are presented in figure 11.

3. Results

3.1 Intermediate results versus laboratory tests

Figures 10 and 11 show the consequences of looking at the real upsides of vertical burdens and relocation with the qualities got utilizing the Plaxis 2d programming bundle and the MGM.

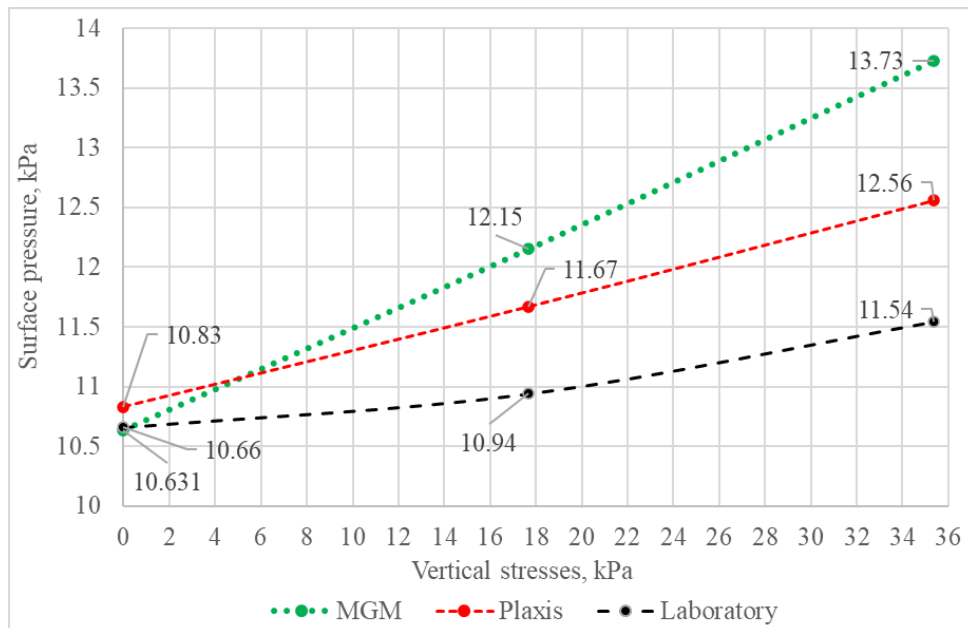


Figure 10. The results of determining vertical stresses (with the own weight of the loading equipment and steel plates taken into account)

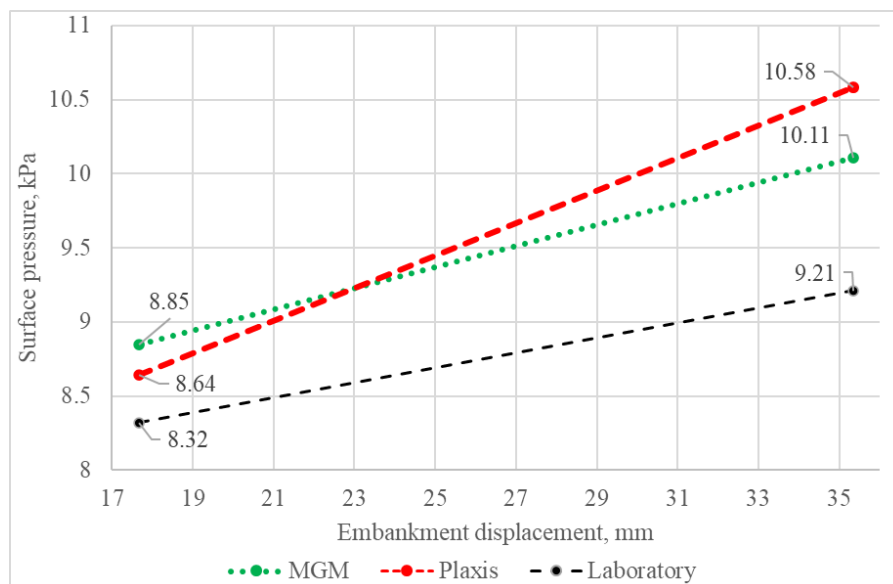


Figure 11. The results of determining the displacement (with the own weight of the loading equipment and steel plates taken into account)

Having analyzed the data from the graphs in figures 10 - 11, it is feasible to make various middle ends:

- The extents of stresses, dictated by the MGM and the outcomes, decided through the Plaxis programming bundle have slight overabundance comparative with full-scale tests. Simultaneously, the extents of stresses as per the MGM are more prominent than those dictated by the restricted segment technique;
- The worth of the coefficient of conveyance limit, acknowledged by [5] for the states of the issue being tackled, given a high assembly in the upsides of vertical anxieties with research center tests;
- The upsides of stresses dictated by the MGM at high burden esteems have a more noteworthy error in the qualities decided in the research facility.
- High combination in the relocation esteems as per the MGM with the real estimated information and the outcomes got by means of the Plaxis programming bundle make it conceivable to close on the relevance of the mechanics of granular media to survey the effect of geosynthetic materials on the strain-stress condition of soil structures.

4. Discussion

Looking at the upsides of vertical burdens under the piece of the extension built up with geosynthetic materials, decided utilizing the Plaxis programming bundle and the MGM, it very well may be inferred that there is a high combination of the outcomes got, incorporating with the aftereffects of lab tests. This, thusly, permits us to finish up the accompanying:

1. The mechanics of granular media can be an elective technique to the restricted part methodology for deciding the example of the dissemination of vertical burdens in and under the supported free-soil massif, paying little heed to the idea of the applied surface burdens. In addition, it is worth noting that the use of reinforcing interlayers makes it possible to achieve the soil structure being more stable to surface loads, which, as a result, will improve reliability of the structure as a whole. In view of the above, it can be also concluded that in reinforced soil the value of the coefficient of distribution capacity is invariable $v=\text{const}$, since this will significantly simplify the application of the MGM to solving various geotechnical problems. But, it is also worth noting that the latter is true for the conditions wherein the strength and deformation characteristics of reinforcing materials are sufficient to ensure the stability of the structure of the reinforced soil.
2. The newly presented approach to determining displacement of an bridge, reinforced at the base with geosynthetic materials, allows us to conclude on its reliability, which significantly expands the applicability of the MGM as an alternative to the application of the limited component strategy.
3. Within the framework of future studies, of significant interest is the assessment of the strain-stress state of the bridge and the base, represented by various soils, as well as when using geosynthetic materials with different strength and deformation characteristics, including combinations thereof.
4. Taking into account in further studies the possibility of changing the structure of the reinforced soil in the process of compaction under the applied surface load in time [9].

5. Conclusions

The issues of assessing the strain-stress state of bridges reinforced with geosynthetic materials are the main ones in terms of resource saving and increasing the durability of the maintenance-free operation of the structure. The use of new approaches to assessment, computational models and theories with other tools for accounting for the features of stress distribution in a weakly cohesive medium, including reinforced geosynthetics, allows expanding the scope of geotechnical problems being solved, which ultimately is a possibility for reconsidering known solutions and searching for more rational ones.

References

- [1] I. Kandaurov, "Mechanics of granular media and its application in construction", Stroyizdat, USSR, 1988.
- [2] G. M. Ostrovsky, "Applied mechanics of heterogeneous media", SPb. Nauka, pp. 107-109, 2000.
- [3] O. I. Zayats, A. N. Nezlobin, V. G. Cheremensky, N. M. Dobrova, "Analytical methods in mechanics of granular-elastic media", Proceedings of SPIE - The International Society for Optical Engineering 3687, pp. 365-400, 1999.
- [4] O. I. Zayats, A. N. Nezlobin, V. G. Cheremensky, "To the theory of contact problems for a granular medium", Prikladnaya matematika. SPbGTU, Russia, pp. 56-64, 1992.
- [5] A. V. Moshenzhal, "Advanced design of road pavements with constructive layers from weakly cohesive soils, reinforced by geosynthetic materials", diss. ...candidate of engineering sciences; FSBEI Pacific National University, Russia, pp. 45-92, 2017.
- [6] V. Moshenzhal, "Account of Irregularity in the Stress Distribution along Wood and Concrete Sleepers from a Perspective of Granular Media Mechanics", Transportation Geotechnics and Geoecology (TGG-2017) Procedia Engineering Volume 189 St. Petersburg, pp. 637-642, 2017
- [7] V. Moshenzhal, "Theoretical substantiation of using geosynthetic materials for strengthening road pavements under conditions of travel of heavy vehicles", Transport: science, technology, management, VINITI RAS, Vol. 10, Russia, pp. 45-48, 2015.
- [8] V. "Melnikov Studying the strength and deformability of weak soils of reinforced bases", diss. ... master of engineering and building technology, SEI HVE Penza State University of Architecture and Construction, Russia, pp. 139-145, 2012.

- [9] V. Matveev, “Rheological model of a granular medium and its application to assess displacement of soil basements of surface foundations”, Part 2 monograph, Military Transport University of the Railway Troops (VTU ZhDV), Russia, pp. 96-97, 2009.
- [10] Al-Abbas, K.A., Saadoon, S., Al-Robay, A.A., Experimental Study on Using Different Shapes of Sand Cushion in Weak Soil. *Journal of Engineering and Applied Sciences* 12 (Special Issue 6): 7959-7964, 2017, ISSN: 1816-949X
- [11] Saadoon, S.A., Al-Robay, A.A., Al-Abbas, K.A. , Soil stabilizers for local roads and airport construction *Journal of Green Engineering*, 2020, 10(7), pp. 4309–4321
- [12] Ali A. Al-Robay, Sura A. Saadoon, Kadhim A. Al-Abbas, Application Of The Mechanics Of Granular Media For Solving The Problems Of Geotechnical Engineering. *Materials Today: Proceedings*, Available online 18 April 2021, <https://doi.org/10.1016/j.matpr.2021.02.723>