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Dynamic analysis of high-rise residential structures through the cone method

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Abstract: In this article, to analyze the behavior of surface foundations based on reinforced soil, a simple physical method based on material resistance called (cone method) has been used. Which is used as an alternative to the exact solution methods that are based on the three-dimensional elastodynamic theory. The purpose of this research is to introduce a simple physical method and analytical tool to analyze the surface foundation based on geocell-reinforced soil. With the cone method, it is possible to examine the effects of layered soil. Obtaining the dynamic stiffness of the foundation based on reinforced soil using the cone method for the vertical degree of freedom and also investigating the effect of various parameters related to geocell reinforcement on the dynamic stiffness of the surface foundation are the goals of this research. In general, the longer the geocell cushion has, the smaller the holes, and the higher the modulus of elasticity, the better the results. By increasing the number of geocell layers, the amount of spring stiffness coefficient and damping coefficient and as a result the dynamic stiffness coefficient increases. On the other hand, the closer the geocell is placed to the soil surface, the higher the stiffness of the spring and the lower the damping coefficient. In general, among these two parameters related to dynamic stiffness, the role of the damping coefficient has been more prominent and decisive in the investigation of foundations based on reinforced soil. One of the most obvious characteristics of geosynthetic materials in the soil, regardless of the greater hardness it gives to the soil, is the damping percentage of its constituent materials.
Keywords: *Cone model, Physical method, Reinforced soil, Surface foundation, Wave propagation.*

1. Introduction

If the soil environment is heterogeneous and has different layers with different characteristics, the analysis will be complex and expensive. Considering non-homogeneous soil as homogeneous soil or using average properties for layered soils may result in an unrealistic solution. Shear and expansion waves are created by the propagation of forces in each of the soil layers with different amplitudes. The reflection of waves at common boundaries in layered soils and the reduction in amplitude for the transmission wave towards the far field is a phenomenon that complicates the problem. It will be very difficult to give the effect of these phenomena for the complete behavioral analysis of wave propagation in unlimited environments.

Because of these problems, these methods can only be used in important projects with critical conditions. For everyday problems, the physical modeling method can be used to study soil without boundaries. Among the merits of this method is its simple application and presentation of a comprehensible physical view of the problem. The cone method is one of the physical modeling methods that takes into account the salient features and is based on the experience gained from detailed analysis (Aghazadeh et al., 2019). For more than 20 years, modeling based on the strength-

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of-materials approach using conical bars and beams, called cones, has only been used for surface foundations resting on homogeneous half-spaces. There was a soil reagent, but today it is possible to model based on the same assumptions for more complex applications.

For example, changes in soil properties can be modeled with depth, and the structure can have any number of horizontal layers (ibid, 2019). This method provides the possibility of soil analysis with planar and three-dimensional reinforcements due to the efficiency and flexibility it provides to change the characteristics of soil layers. In this research, the cone method has been introduced and developed as a simple and physical method for the analysis of surface foundations based on geocell-reinforced soil. The reason for using geocell as a reinforcement is its three-dimensional nature and its mattress property, which improves the characteristics of the soil bed more than other reinforcements (Bahuguna & Firoj, 2022).

2. Theoretical

Introducing the basics of the cone model. Unlike structural engineering, geotechnical engineering is another field of civil engineering where modeling is important, but the material resistance method is not widely used. There are two main reasons for this; first, in structural engineering, load-bearing elements that must be analyzed tend to have a dominant direction to determine the axes and cross-sectional characteristics of bars and beams (Carranza et al., 2024). While in geotechnical engineering there are three-dimensional materials of soil and rock. Therefore, the selection of axes and especially the characteristics of the cross-section, which must be able to express all the necessary characteristics determined by the deformation behavior, is more difficult in geotechnical engineering than in structural engineering (Norouzian, M. M., 2024).

Second, until recently, the development status of this method was extremely limited, even more than 10 years ago, only for surface foundations located on the homogeneous half-space representing the soil, it possible to model with the material resistance method using There were conical rods and beams, which are called cones in the following. Since soil characteristics in a real construction site change with depth, this approach was only of academic importance. Seismic vibrations can be processed using this type of modeling without introducing new assumptions. Therefore, cone models can be used for foundation modeling in a dynamic soil-structure interaction analysis (Sarabi, M., et al., 2023). Cone models for low and medium frequency ranges are important for device vibrations and earthquakes and for very high-frequency limits that occur in shock loads. They also work well for other static state constraints (Mohasseb et al., 2020).

Presenting the method of analysis using conical mass. The dynamic stiffness coefficients of a disc on the surface of a single layer on a half-space can be obtained using cone models. This concept can be extended to the case of an environment with horizontal layering including several layers on a homogeneous half-space (Sarabi et al., 2023- a). This makes it possible to estimate, based on the cones, the dynamic stiffness coefficients for each degree of freedom for a surface foundation in a layered half-space soil. The cone mass for each layer is a part of the soil located in an incomplete cone between two interfaces. According to Figure (1), the formation of the conical mass for the surface disc starts from the surface and continues downward to infinity (Norouzian, M. M., 2024).

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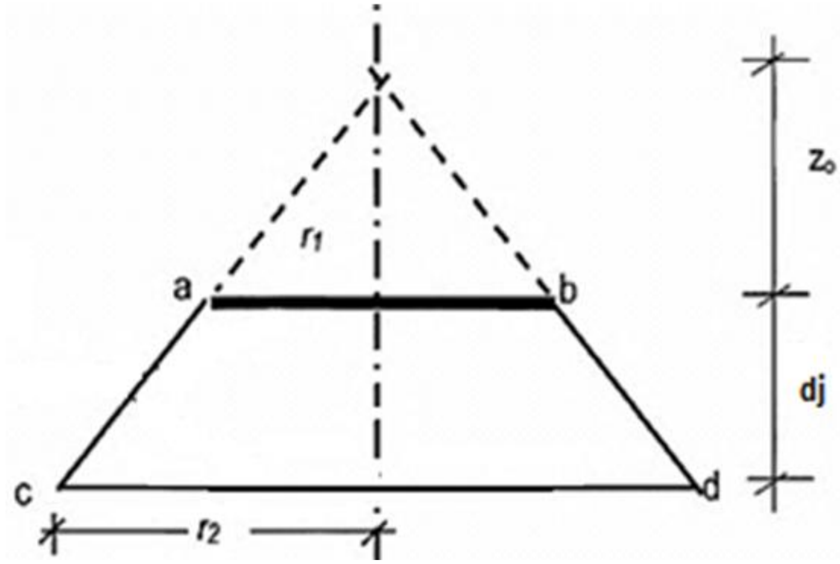

Figure 1.
The soil layer between the two interfaces is an incomplete cone.
Source: Li et al., 2024.

Figure 2 shows an environment with horizontal layers where the characteristics of each layer are different in depth. In this figure, n-1 layers with their characteristics are located on a homogeneous half-space with an index. Each node represents the interface between two layers, which is numbered from 1 in the free surface to above the bottom half-space surface (Li et al., 2024). The vertical degree of freedom considered in this research is shown in Figure 2. However, this method can be used for other degrees of freedom (horizontal, torsional, and rotational) completely independently of each other (Aghazadeh et al., 2017). According to the figure, the thickness of the jam layer (the thickness of the incomplete cone in each layer) is indicated by DJ. Also, the radius of the incomplete cone at the joint surfaces of the conical mass can be determined according to the following relationship using the geometry of the problem:

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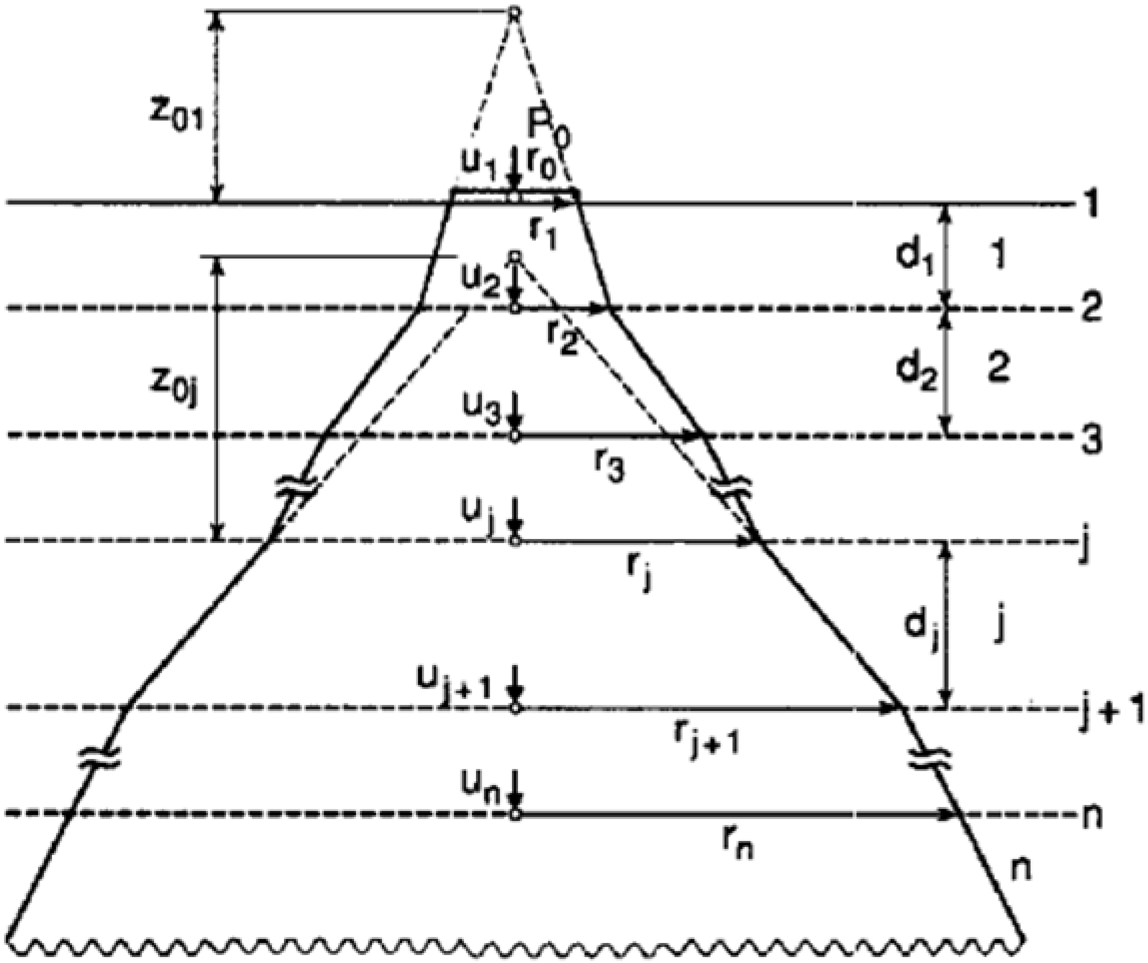

Figure 2.
Conical mass consisting of incomplete cones for a soil environment with horizontal layering under vertical loading.
Source: Li et al., 2024.

$$r_{j+1} = \frac{z_{0_j} + d_j}{z_{0_j}} r_j \tag{1}$$

If the radius of the surface disc located on the soil is r0, the incomplete cone of the first layer is formed with the upper radius r1, which is equal to the radius of the surface disc. In general, the apparent proportions of the incomplete cones of each layer change depending on the Poisson's ratio ν in the depth, as a result of which a conical mass consisting of incomplete cones is obtained, whose slope varies linearly (Samami et al., 2024). Now, if the Poisson's ratio is constant in the depth, the conical mass will not have a discontinuity in the slope. Also, the elastic half-space under the soil layers can be modeled as a single incomplete cone and entered into the calculations (Karimimansoob et al., 2024- a), (Figure 3).

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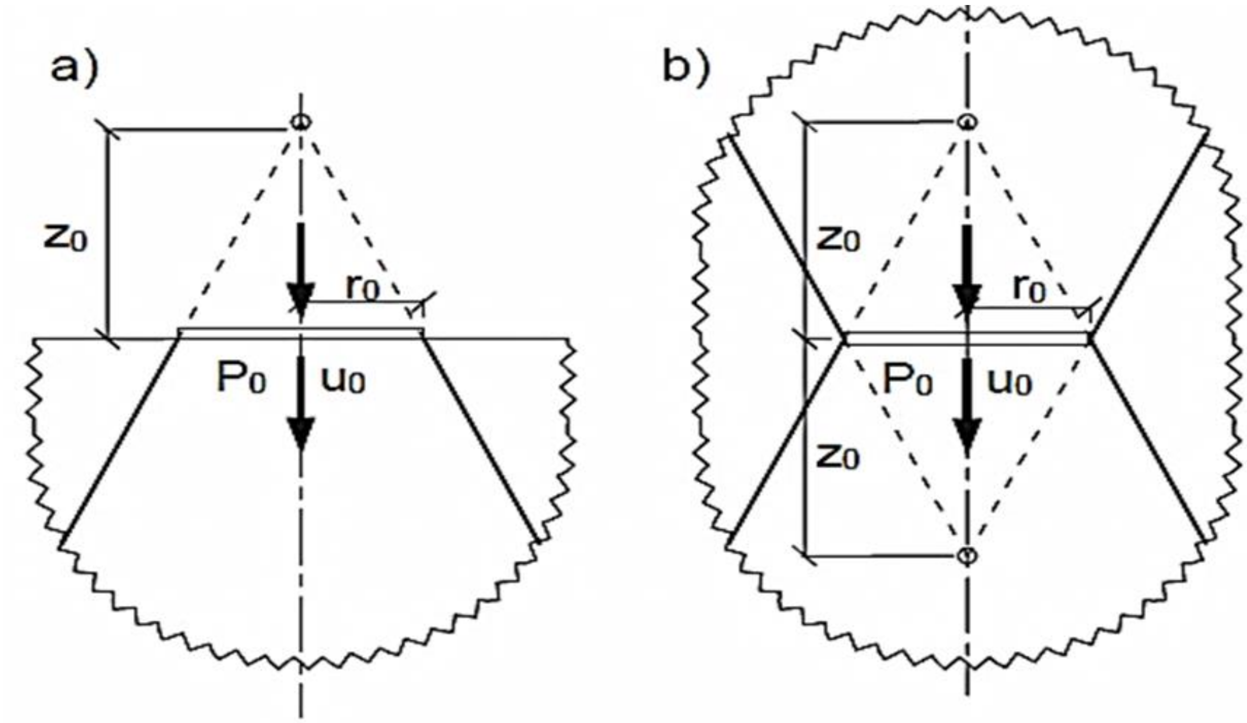

Figure 3.
Modeling of the lower half-space. a) Single imperfect cone for elastic half-space modeling; b) Two types of primary cones, ascending waves and descending waves.
Source: Li et al., 2024.

The accurate analysis of this situation leads to the solution of a completely complex three-dimensional elastodynamic problem. Instead, working with a one-dimensional two-cone model leads to approximate solutions with very high accuracy (Dizaji et al., 2023).

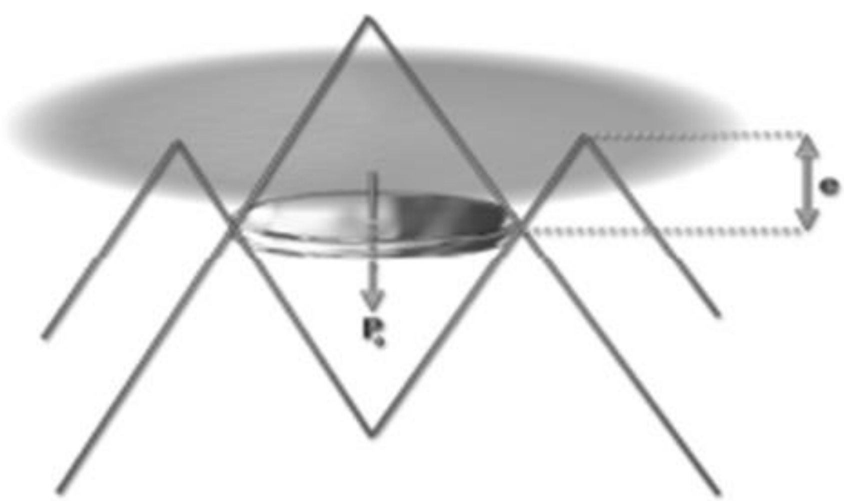

Figure 4.
The disk was placed in the depth of a half-space.
Source: Li et al., 2024.

The main idea is to use symmetry as shown in Figure 4. Two identical double cones are considered, which are located in an infinite space at a distance from each other and are simultaneously driven by the same time histories of force. The tension waves from the lower disk move upwards and reach the middle plane at the same time as the pressure waves from the upper disk move downwards. Therefore, the stresses completely cancel each other in the middle plane of the infinite space and satisfy the stress-free boundary conditions on the surface of the earth. This condition is also established for horizontal, rotational, and torsional excitation modes.

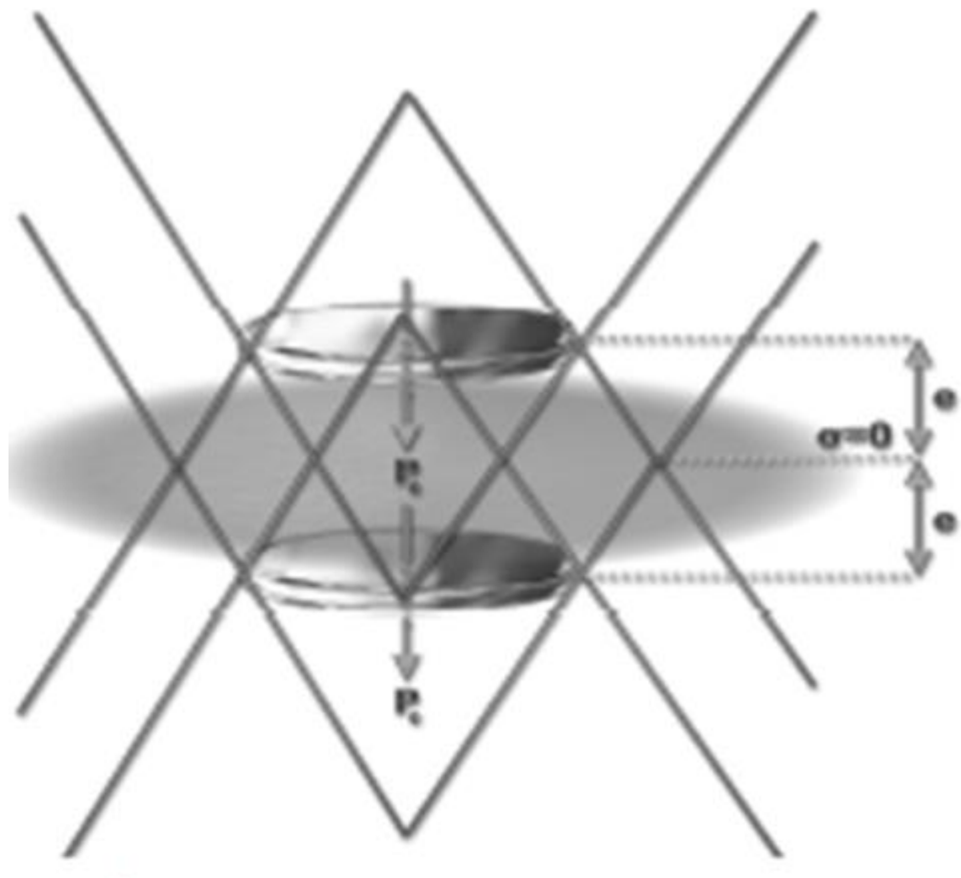

Figure 5.
Symmetry conditions for the original virtual disk and its image in the two-way cone model.
Source: Li et al., 2024.

To determine all displacement vectors (composing the column members of the dynamic smoothness matrix), programming in the MATLAB program environment has been used. Combining all the displacement vectors in one matrix will result in the dynamic smoothness matrix. Due to the symmetry and regularity of this matrix and the possibility of inverting it, by inverting the softness matrix, the dynamic stiffness matrix is obtained. In general, dynamic flexibility matrices are not symmetric (Aghazadeh et al., 2018; Tabatabaiefar, 2012). However, the asymmetry is insignificant and it can be deduced from the cross-coupling terms (Yun & Jeon, 2023). Therefore, the force-displacement relationship for the soil and foundation system can be written as follows:

$$\left[G^f(\omega)\right]_{n\times n} = [\{u(\omega)\}_1 \quad \{u(\omega)\}_2 \quad \{u(\omega)\}_3 \ \cdots \{u(\omega)\}_{nd} \quad \cdots \quad \{u(\omega)\}_n] \tag{2}$$

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$$\{P(\omega)\} = [S^f(\omega)]\{u(\omega)\} \tag{3}$$

Impedance function (dynamic stiffness coefficient) can be written as a function of static stiffness, springiness coefficient, and damping coefficient:

$$S(\omega) = K_{stat}[k(a_0) + ia_0c(a_0)] \tag{4}$$

3. Methodology

This research is based on the approximate cone method and its application is considered for the analysis of geocell-reinforced soil. The reinforcing layer is included in the calculations using an empirical composite model as an equivalent soil layer. This equivalent soil is considered based on the characteristics of soil materials and geocell material, together. Also, in this research, MATLAB software was used to model soil layers, perform repetitive operations, and perform calculations. In the first stage, using the dynamic stiffness cone model of the foundation based on a homogeneous half-space (unreinforced soil), it is obtained for each vertical degree of freedom. In the second stage of reinforced soil, the layer of soil with reinforcement is also modeled as a normal soil layer, and in this way, the surface foundation based on reinforced soil with a geocell layer is analyzed for the vertical degree of freedom. From the comparison of the obtained results, the improvement of the dynamic hardness is the result (Mohasseb et al., 2020).

In this research, the cone method has been used to analyze the behavior of surface foundations based on geocell-reinforced soil (Aydin et al., 2020). The basic assumption in this modeling is that the planes parallel to the free surface of the soil remain flat even after the load is applied and the strain on these planes remains constant; also, in cone models, unlike the exact solution, the independence of different components of movement including horizontal, vertical, rotation and twisting is established. Using this model, it is possible to model different types of surface and buried foundations with axial symmetry and arbitrary shapes by considering the equivalent radius (Mohasseb et al., 2020).

However, if the foundation does not have axial symmetry, modeling the foundation will be problematic. Like the case where the foundation is L-shaped. In this model, the foundation is assumed to be rigid and massless. The soil behavior is also assumed to be elastic in this model. The geosynthetic used for soil reinforcement is geocell, which is modeled as equivalent soil and used in the cone model with its characteristics. This research is based on the approximate cone method and its application is considered for the analysis of geocell-reinforced soil (Yun & Jeon, 2023).

The reinforcing layer is included in the calculations using an empirical composite model as an equivalent soil layer. This equivalent soil is considered based on the characteristics of soil materials and geocell material, together. Also, in this research, MATLAB software was used to model soil layers, perform repetitive operations, and perform calculations. Analysis of surface foundation located on reinforced soil using the cone method. Cone models are a fundamental step in the development of the material resistance approach for the dynamics of foundations (Carranza et al., 2024).

This method avoids the mathematical complexities caused by exact solutions, and with a physical view, it provides good conceptual clarity, simplicity in application, and the possibility of appropriate generalization, and leads to sufficient engineering accuracy. These advantages are good compensation for the lack of accuracy caused by this method compared to the accuracy obtained from the exact elastodynamic solution based on the boundary element or complex finite element method.

Here, the boundary between two soil layers or the boundary between two soil layers or the soil layer and the geocell layer (which is equated as a soil layer) using virtual hard disks of the model is made. It should be noted that the extension of the cone method to foundations based on reinforced soil is the innovation of this article. When the surface foundation is loaded, the loading effects are transferred to the underlying soil. The impact of the loading level can be shown by using a cone, which is called a cone mass in this research. This conical mass is formed independently for each of the soil layers to include these effects until the end, which is the propagation of the displacement wave in the elastic half-space.

The displacement of each of the disks is determined using approximation by Green's function, which is a simplified (one-dimensional) form of the boundary element method. Finally, by using the principle of the sum of forces, the flexibility matrix of the soil at the place of the discs can be determined (Norouzian & Sarabi, 2023). Then, using conventional matrix operations, the force-displacement relationship can be determined for the surface foundation placed on reinforced soil on the elastic half-space. The basic approach to solving this problem is based on the approach of material resistance for foundations using Green's function approximation in a double-sided cone.

In general, to provide the dynamic stiffness coefficient of the foundation in a layered environment for each layer, the dynamic stiffness matrix is calculated based on the cones. By superimposing the dynamic stiffness coefficients for the lower half-space and the dynamic stiffness matrix of all layers, the dynamic stiffness matrix for the soil layer field is obtained. The assumptions governing the problem are as follows:

Soil has elastic behavior.

- The cross-section of the foundation is circular.
- The surface foundation is assumed to be massless and rigid.

Based on this, the surrounding soil can be made up of any number of layers, and the non-homogeneous soil in which the shear modulus changes with depth can also be modeled and investigated.

4. Findings

In this part, the results of the cone modeling method, as a simple and approximate physical method, for a circular foundation located on a relatively large construction with known geometry and specifications, are compared with the results of a precise numerical method. According to Figure (6), the building consists of two layers located on a flexible half-space. In which the waves - similar to a building with a homogeneous half-space - propagate towards infinity. The shear modulus decreases with depth, which can correspond to the condition of a typical embankment.

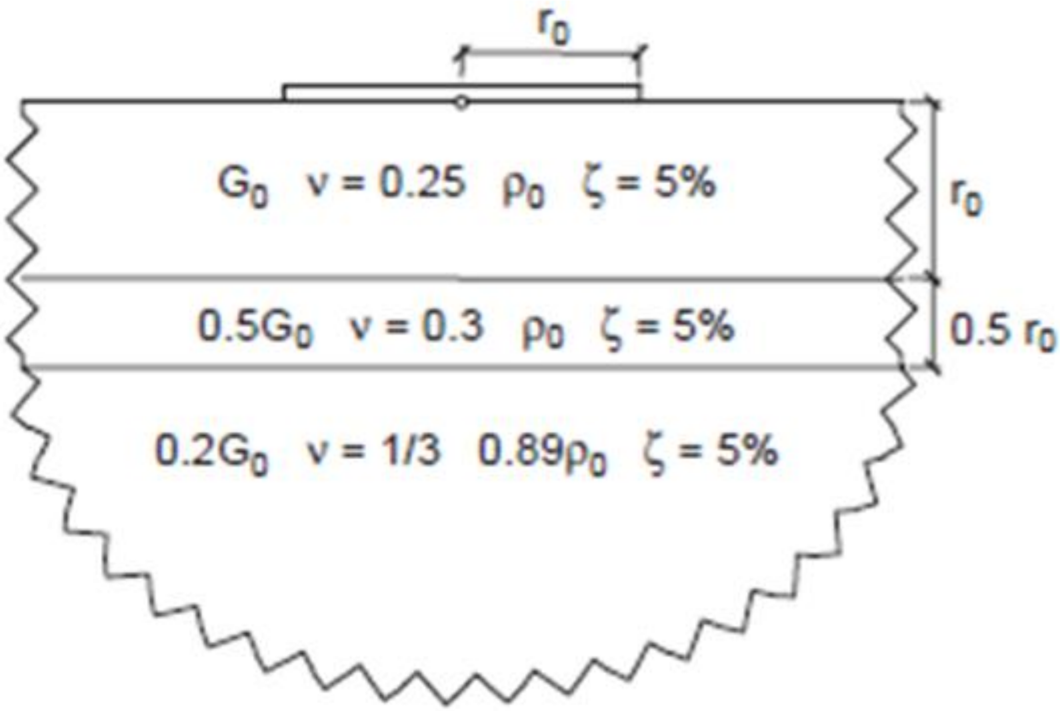

Figure 6.
Disk located on two layers placed on a flexible half-space.
Source: Khudainazarov et al., 2021.

The results obtained from the cone method are compared with the results obtained from the thin layer method, according to the vertical degree of freedom. Figure 6 shows the dimensionless spring coefficient k(a0), the dimensionless damping coefficient c(a0), and the magnitude of the stiffness coefficient, respectively. Dynamic is dimensionless in terms of frequency:

$$\sqrt{k^2(a_0) + a_0^2 c^2(a_0)}$$

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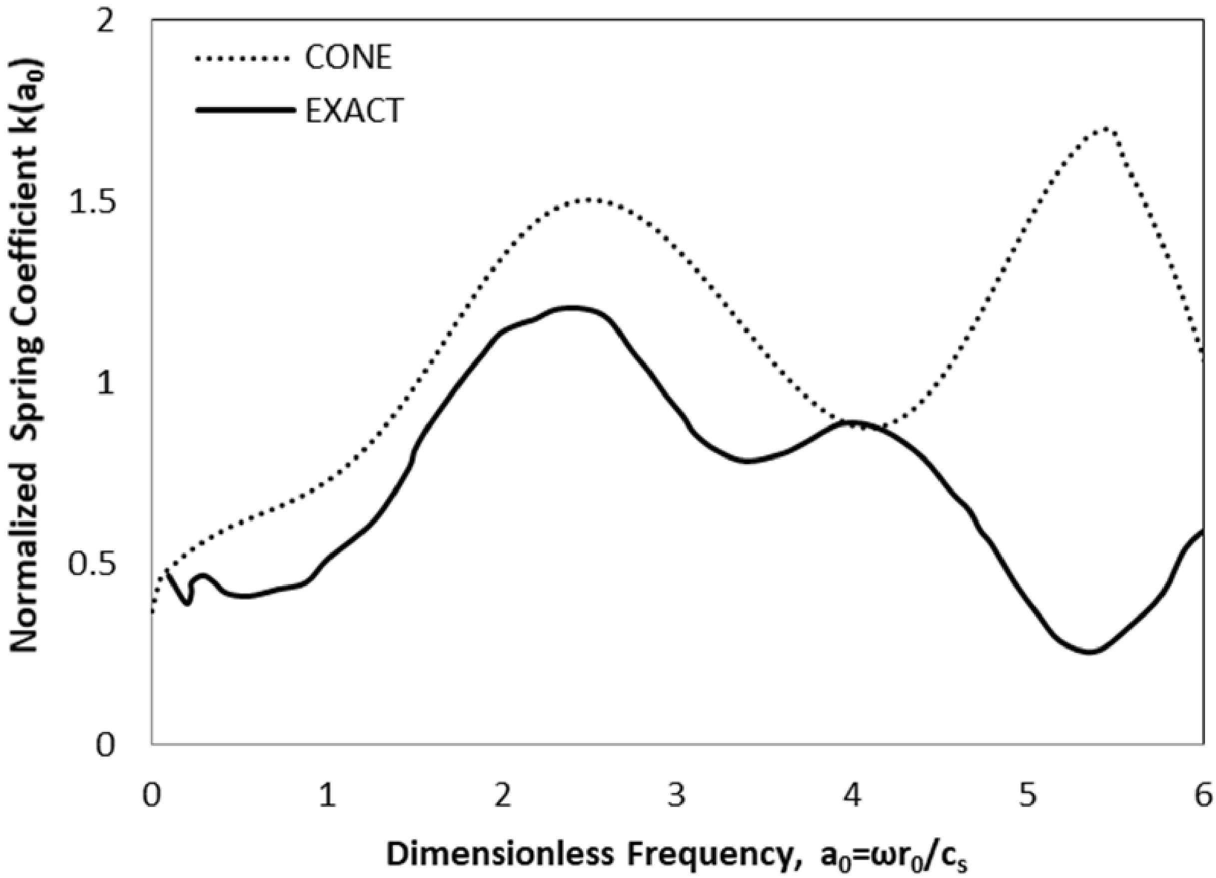

Figure 7.
The stiffness coefficient of a disc spring located on two layers located on a flexible half-space for the vertical degree of freedom.
Source: Khudainazarov et al., 2021.

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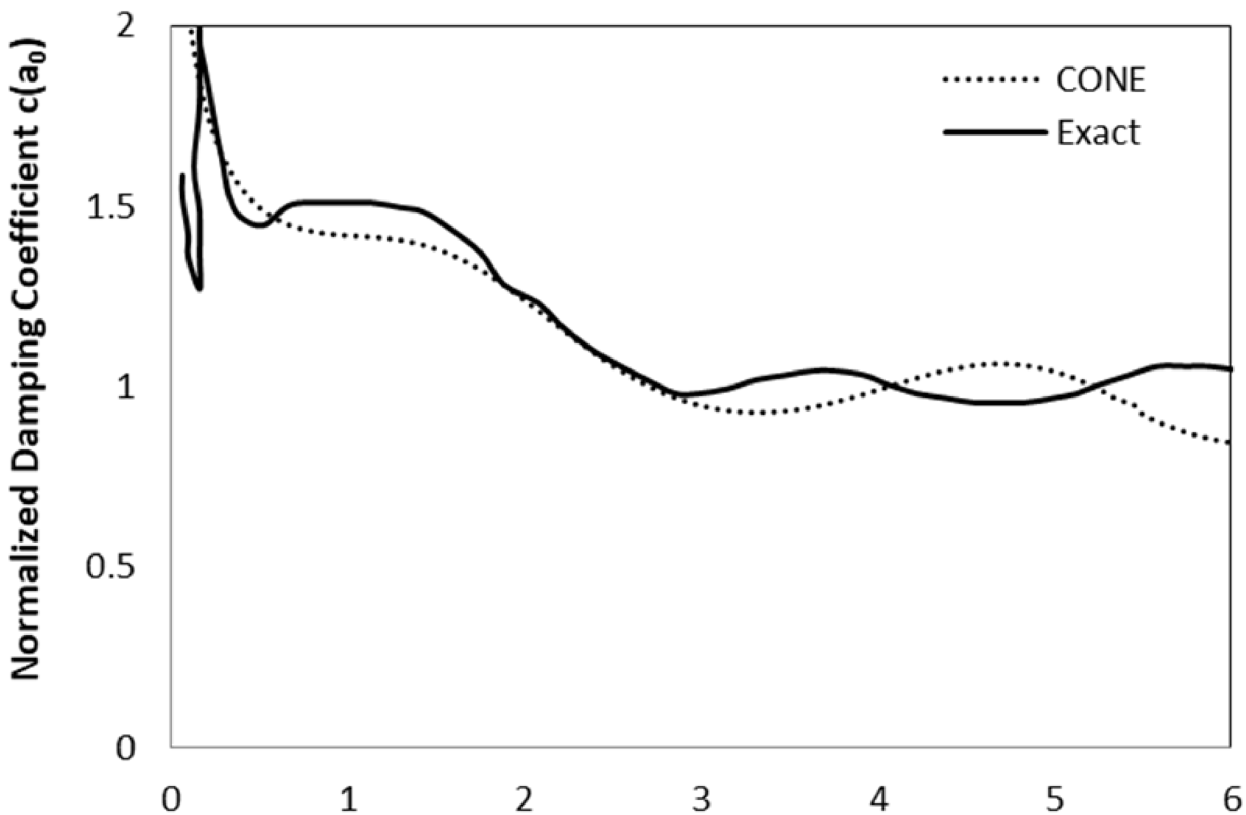

Figure 8.
The damping coefficient of the disk located on two layers located on the flexible half-space for the vertical degree of freedom
Source: Khudainazarov et al., 2021.

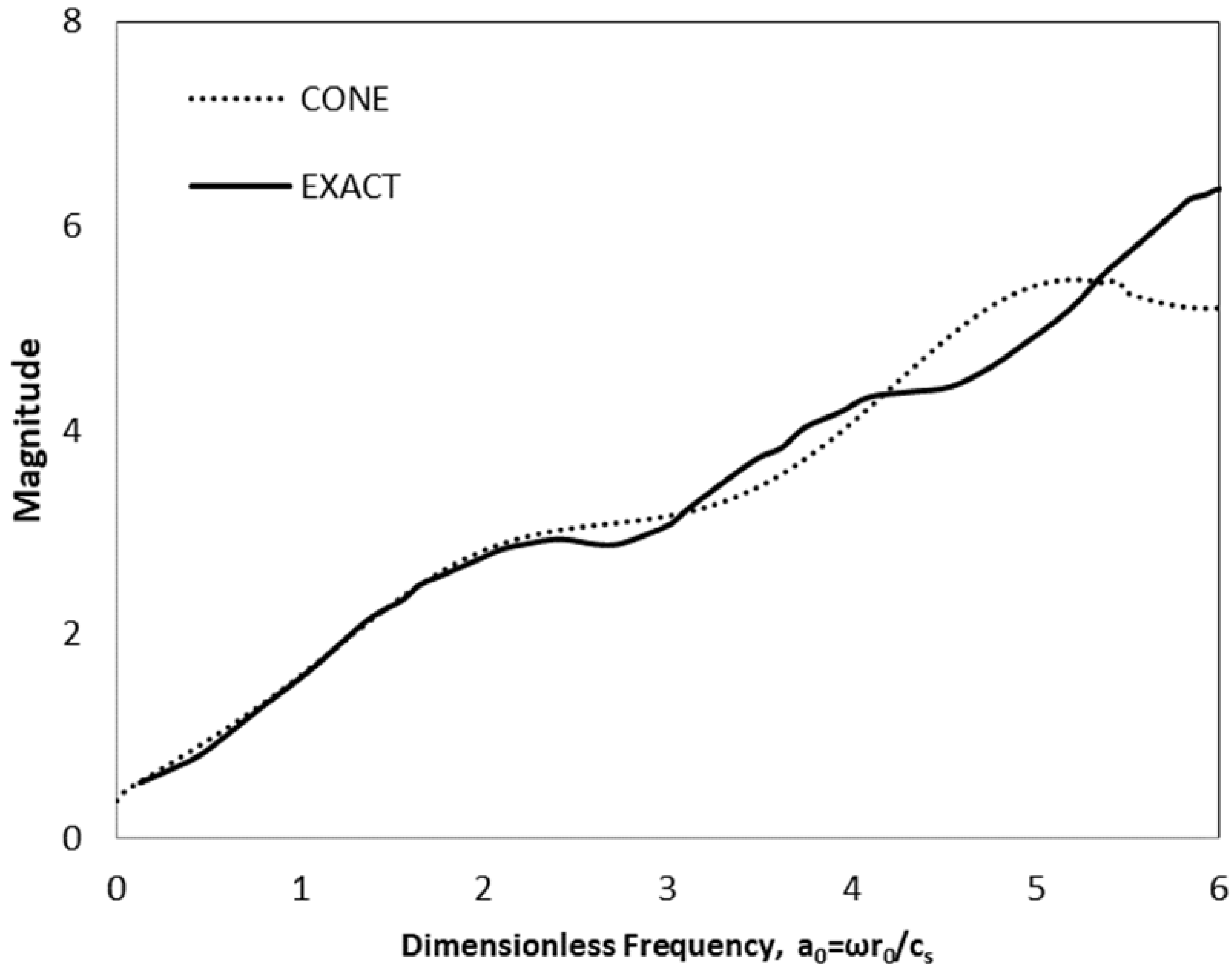

Figure 9.
Dynamic stiffness coefficients of the disk located on two layers located on a flexible half-space for the vertical degree of freedom
Source: Khudainazarov et al., 2021.

As can be seen, there is some deviation in the high-frequency range for the spring coefficient k(a0) and for the damping coefficient c(a0), there is a slight deviation in the low-frequency range. These deviations are removed to a great extent in the calculation of the magnitude of the dynamic stiffness coefficient (the third part of the Figure). Therefore, according to Figure 9, the cone method can be used as an efficient, acceptable, and sufficient engineering accuracy method in engineering calculations (Sarabi et al., 2023- b).

Unarmored soil condition. In this part, first, the soil bed on which the surface foundation is placed is modeled using the cone method for the vertical degree of freedom mode. The unreinforced soil bed, which is schematically shown in Figure 10, consists of a layer of dense sandy soil with a known thickness of d=2m placed on a homogeneous semi-infinite environment (Ghadarjani et al., 2013- b).

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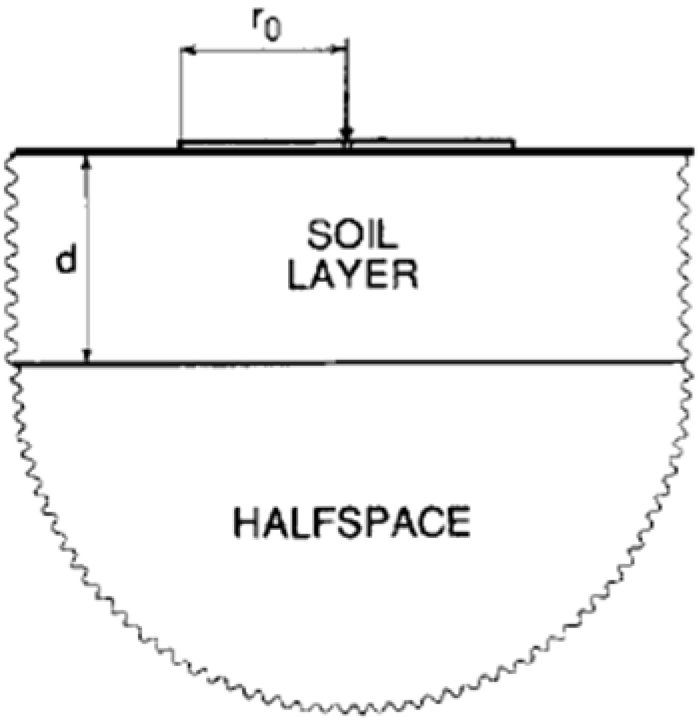

Figure 10.
Unreinforced soil bed with geocell.
Source: Tabatabaiefar, 2012.

The characteristics of soil materials used in the analysis are considered according to Table (1). In this table, ρ is the symbol of volumetric mass, Poisson's ratio, ξ is the damping percentage of soil materials and E is the modulus of elasticity of the soil. In this study, the surface of the foundation is circular and has a rigid behavior. It is also assumed that the foundation is massless and the behavior of the soil is elastic. In this analysis, the surface foundation radius is considered to be one meter (Ghourchi, M. et al., 2018).

Table 1.
Characteristics of the soil bed under the surface foundation.

E	ξ	ν	ρ	Soil type	parameter
MPa	-	-	kg/m3	-	unit
52	5	0.30	1900	dense sand	The soil layer is 2 meters thick
20	5	0.33	1600	loose sand	Homogeneous semi-infinite medium

It should be noted that for this soil bed, the maximum volume mass of 32000 kg/m and the minimum volume mass of 31500 kg/m have been assumed, based on which the relative density of the half-space soil is equal to 25%Dr and the relative density of the soil located on the half-space is equal to 85%= Dr is considered (Aghazadeh et al., 2019).

5. Results

Now, if the problem is compared for both reinforced and unreinforced soil conditions, Figures 9, 10, and 11 will be obtained, which respectively represent the dimensionless coefficients of the spring stiffness the damping coefficient, and the magnitude of the dynamic stiffness in terms of the dimensionless are frequency a0.

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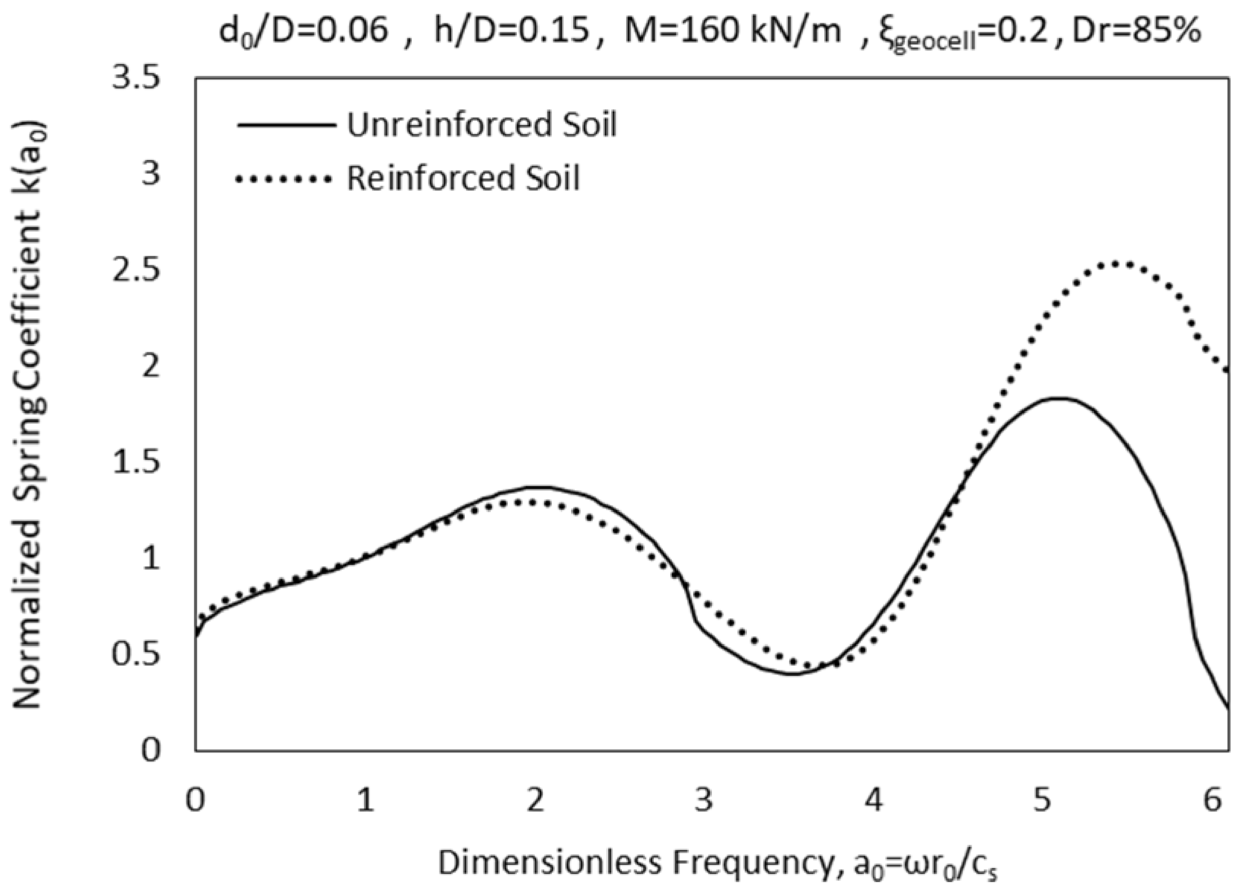

Figure 11.
Comparison of the spring coefficient obtained by the cone method for unreinforced soil and reinforced soil.
Source: Khudainazarov et al., 2021.

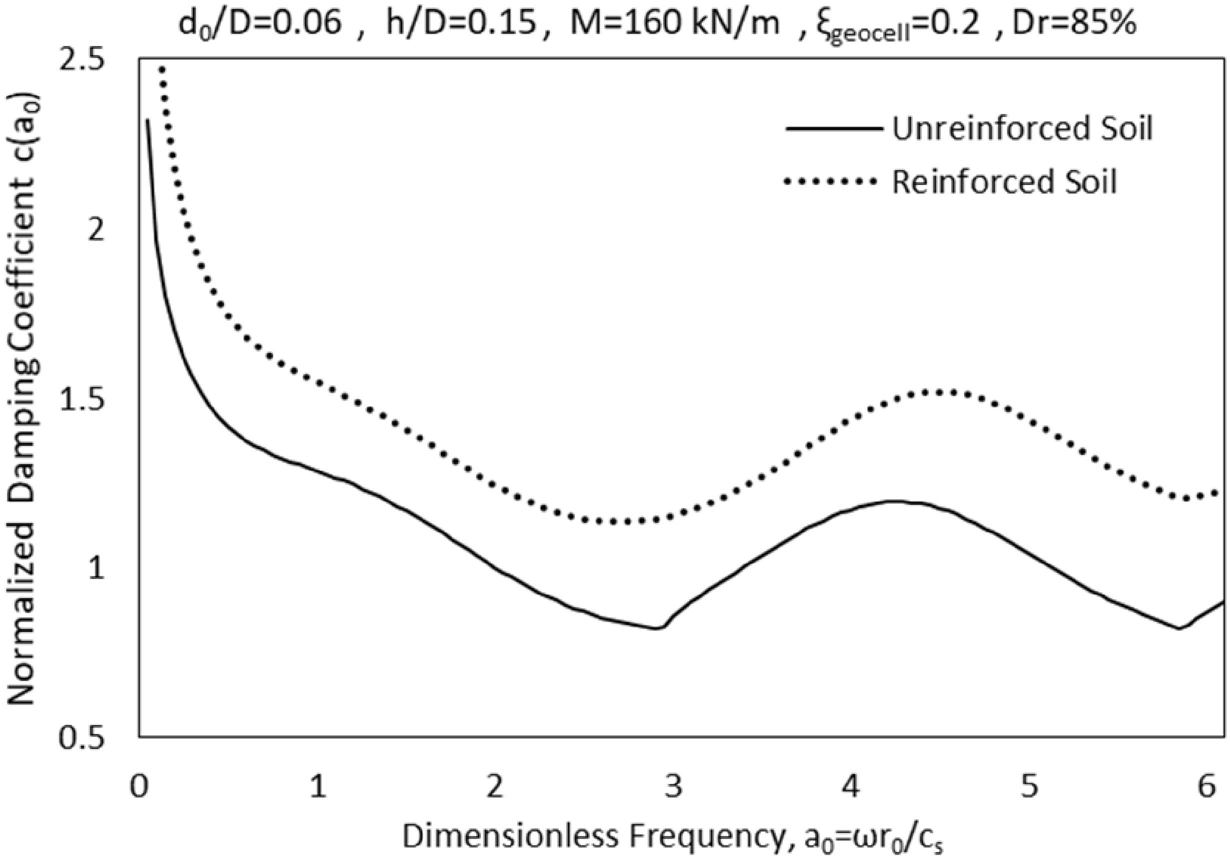

Figure 12.
Comparison of the damping coefficient obtained by the cone method for unreinforced soil and reinforced soil.
Source: Khudainazarov et al., 2021.

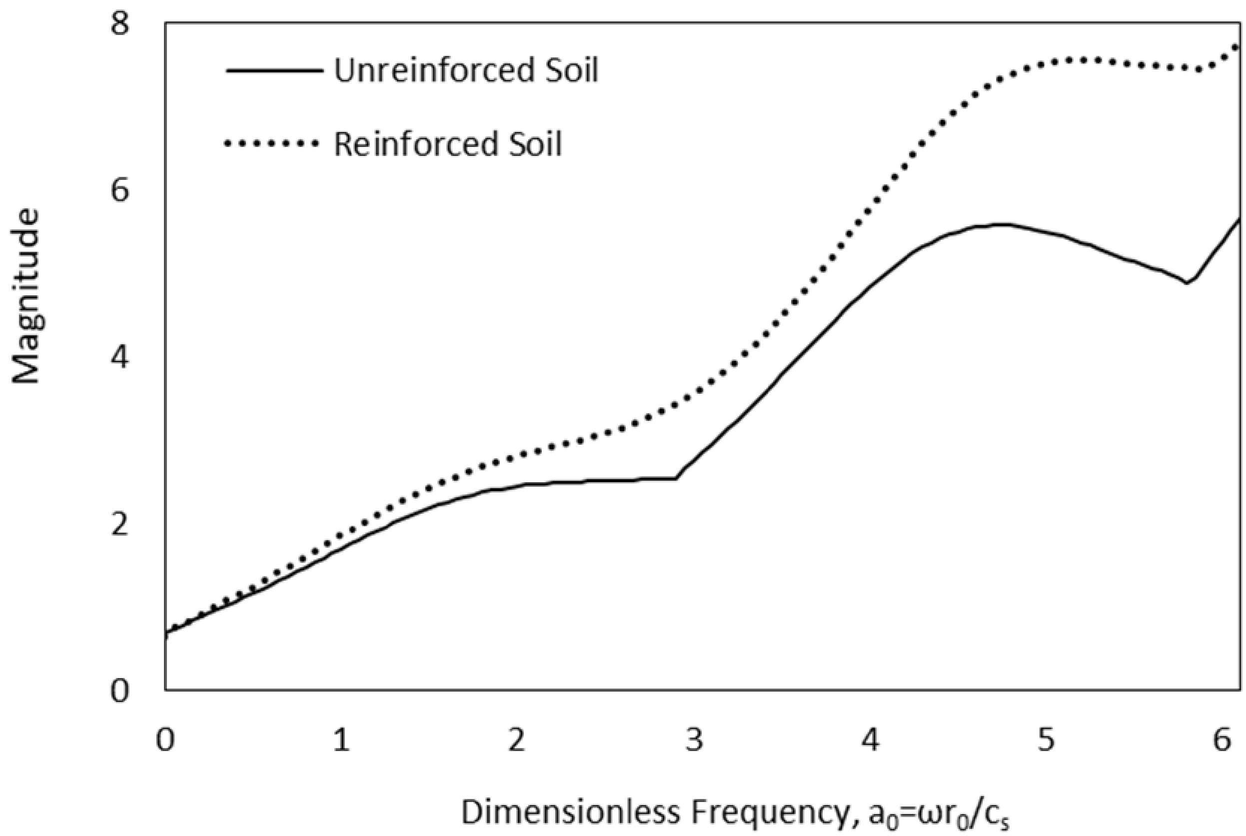

Figure 13.
Comparison of the magnitude of dynamic hardness obtained by the cone method for unreinforced soil and reinforced soil.
Source: Khudainazarov et al., 2021.

As can be seen in the graphs, in the case of reinforced soil, with increasing frequency, the amount of dynamic hardness has also increased. It should be noted that the reason for the small amount of spring stiffness changes in Figure 13, especially at low frequencies, is that the loading is in the elastic range and in this range the interaction between the reinforcement and the soil is weak. First, by using the property of propagation of waves inside the soil and based on the two-cone model, virtual disks were assumed at the joint surfaces of the layers and Green's functions were written (Aghazadeh et al., 2019).

In this way, the reflection and refraction mechanism of the incident wave from the virtual disks located on the interface and its mirror image were investigated. With the compatibility of the displacement and balance in the interface, the reflection coefficient was defined as the ratio of the reflected wave to the incident wave, and according to the change of the locations of the disks, the wave pattern in the multi-layer half-space was obtained. After that, the transfer functions were obtained and the mass of the cone was formed for each of the layers located in the unreinforced soil bed separately, and a soft matrix was written for each one (Norouzian & Gheitarani, 2024; Karimimansoob et al., 2024).

The characteristics of the conical mass are determined according to the characteristics of the materials in each layer. In each cone, the opening angle of the cone is determined according to the poising coefficient of that layer. Then, by superposing and aggregating the softness matrix of all the layers forming the soil bed, the soil bed softness matrix was obtained, and by inverting it, the dynamic stiffness matrix was obtained. Next, how to model the geocell layer as a soil layer was explained (Mirsaidov et al., 2020).

To convert the geocell layer into the equivalent soil and obtain the equivalent elasticity coefficient of the soil, an empirical equation is used in terms of the hardness of the unreinforced soil enclosed in the geocell cells and the tensile modulus of the geocell material. Finally, using the described method, the surface foundation located on an unreinforced soil environment and reinforced soil environment with a geocell layer was analyzed and the results were compared. As expected, the presence of the geocell layer as a reinforcement increased the spring stiffness coefficient and the damping coefficient of the subgrade soil and in general the dynamic stiffness of the soil. Of course, based on the obtained results, the influence of soil reinforcement on the stiffness of the spring was more noticeable at higher frequencies.

6. Discussion

Analysis of the behavior of surface foundations based on reinforced soil is one of the goals of this research. In this section, the analytical investigation of reinforced soil is discussed using the cone method explained in the previous chapters. The parameters whose changes have been studied in this section include the following:

- Geocell placement depth (u)
- Height of geocells (h)
- Geocell hole size (dp): The dp parameter has an indirect use in the calculations related to the modeling of the geocell layer. This means that first, by setting the area of a geocell cell (dp×Sp) and the area of a circle (d02) equal, it is necessary to obtain the corresponding equivalent diameter and then use it in the calculations.
- Damping of geocell materials (ξ)
- Hardness of geocell material (M)
- Volumetric mass of filling soil (ρ)
- Distance between geocell layers (d)
- Number of geocell layers (N)

In Table 2, the details related to the modeling of each of the above parameters, including the conditions of armament, variables, and constants, as well as the purpose of modeling are mentioned.

Table 2.
Modeling details related to the effect of different parameters.

Purpose	**Statics**	**Variables**		
Comparison with armed states	- d0/D=0.06, h/D=0.15, ξ=0.25, M=160kN/m, Dr= 85%	- u/D= 0.1, 0.2, 0.35, 0.5	**N=1, 2, 3**	**Geocell reinforced soil**
Determining the optimal depth of geocell placement	d0/D=0.06 , u/D=0.1, ξ=0.25 , M=160kN/m , Dr= 85%	h/D= 0.05, 0.1, 0.15		
Investigating the effect of geocell height	h/D=0.15 , u/D=0.1 , ξ=0.25, M=160kN/m , Dr= 85%	h/d0= 1.36, 1.88, 2.5		
Investigating the effect of geocell aspect ratio	h/D=0.15 , u/D=0.1 , d0/D=0.06 M=160kN/m , Dr= 85%	ξgeocell=0, 0.1, 0.2, 0.3		
Investigating the damping effect of geocell materials	h/D=0.15 , u/D=0.1 , ξ=0.25, d0/D=0.06 , Dr= 85%	M= 70, 160 kN/m		
Investigating the hardness effect of geocell materials	h/D=0.15 , u/D=0.1 , ξ=0.25 , d0/D=0.06 , M=160 kN/m	Dr= 65% , 85%		
Investigating the effect of filling soil compaction	h/D=0.15 , u/D=0.1, ξ=0.25 , d0/D=0.06 , M=160kN/m , Dr= 85%	d/D= 0.05, 0.1, 0.2		
Determining the proper distance between geocell layers	h/D=0.15 , d/D=0.05 , u/D=0.1 , ξ=0.25, d0/D=0.06 , M=160 kN/m, Dr= 85%	N=1, 2, 3		

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7. Conclusion

In this research, the reinforced soil was analyzed by using the principle of wave propagation in the layered soil environment and the formation of virtual discs for the joint surfaces of the layers and its analysis by two-sided cone models for vertical degrees of freedom. The results were reported as graphs for dynamic stiffness parameters. The modeling results are presented in the form of graphs of spring and damping coefficients related to the dynamic stiffness coefficient of the surface foundation. The points that can be obtained from these charts briefly include the following: In the first part, the effect of geocell layer placement depth was investigated. Based on the obtained results, the maximum amount of dynamic hardness coefficient was obtained for u/D=0.1.

From the examination of the parameters related to the thickness of the geocell layer and the size of the geocell cavity, the value of the secant modulus (hardness of the materials that make up the geocell), the damping percentage of its materials and the density of the soil filling the holes, it was concluded that The higher the thickness of the geocell layer and the modulus of elasticity and the damping percentage of its constituent materials, as well as the density of the filling soil and the smaller the size of the geocell holes, the higher the dynamic stiffness of the foundation.

Also, from the examination of the parameter of the distance between the layers of the geocell, it was concluded that the smaller the distance between the layers, the greater the improvement in dynamic stiffness. Based on this, the optimal distance between geocell layers for two geocell layers was obtained as d/D=0.05. This result was obtained by examining the effect of increasing the number of reinforcing layers.

Increasing the layers up to the middle-frequency range leads to an increase in dynamic hardness, and for higher frequencies, it results in a decrease in hardness. In general, soil reinforcement should be done in such a way as to improve the properties of unreinforced soil. In this research, three-dimensional geocell cells were considered and analyzed as reinforcement. To obtain the best characteristics for reinforced soil, various factors must be considered; among these factors, we can mention the characteristics of the geocell layer itself, the depth of placing this reinforcing layer in the soil, and the number of layers required for reinforcement.

These factors were modeled and investigated in this research using the cone method. In general, the longer the Geocell cushion has, the smaller the holes, and the higher the modulus of elasticity, the better the results. On the other hand, the closer the geocell is placed to the soil surface, the higher the stiffness of the spring and the lower the damping coefficient. Also, with the increase in the number of geocell layers, the spring stiffness coefficient and damping coefficient and as a result the dynamic stiffness coefficient increases.

The conclusions obtained include the following:

1. The optimal depth for placing the first layer of geocell was 0.1.
2. The ratio of the height to the diameter of the surface foundation was obtained as 0.15 .In general, the higher the height of the geocell, the higher the dynamic hardness.
3. The ratio of the height to the diameter of the holes obtained for the geocell, which represents the dimensional ratio, was equal to 2.5.
4. From examining the impact of geocell material's modulus of elasticity and the damping percentage of its materials, it was concluded that the increase of each increases the dynamic stiffness.
5. The dynamic stiffness coefficient increases with the increase in the density of the filling soil inside the holes. Even though depending on the density of the soil inside the holes compared to the state of unreinforced soil, the stiffness of the spring may decrease, due to the increase in the damping coefficient and the compensation of the decrease in the stiffness coefficient of the spring, we will finally see an increase in the dynamic stiffness.

6. The distance between the layers of geocell was checked for two layers of geocell and its ratio to the diameter of the foundation was found to be 0.05. In general, it was concluded that the smaller the distance between the layers, the higher the dynamic hardness. By increasing the number of reinforcing layers, the amount of dynamic hardness increases up to an intermediate frequency and decreases for higher frequencies.
7. According to the results obtained in this research, in general, among the two parameters of dynamic stiffness, i.e. spring stiffness coefficient and damping coefficient, the role of damping coefficient in the investigation of foundations based on reinforced soil is more significant and decisive. Has been more

One of the most obvious characteristics of geosynthetic materials in the soil, regardless of the greater hardness it gives to the soil, is the damping percentage of its constituent materials. Now it is assumed that if the geocell filling materials also have higher damping than the unreinforced soil, what will be the dynamic hardness and subsequently the performance of the bed soil and the surface foundation based on it, which of course, requires study and investigation in the future. It should be noted that in the cone method, because the joint surfaces of soil and geocell layers are analyzed in the form of a closed cone, it is not possible to check the optimal value of the width of the reinforcing layer and in this research it is assumed that the width of the geocell is sufficient.

Suggestions for future work. Because a part of the analysis of reinforced soil was done with the cone method in this article, in this part, suggestions for future work with the cone method are presented:

- Considering layered soil as a slope
- Considering the non-linear behavior of the soil
- Solving the problem of cone models for reinforced soil in the time domain
- The effect of water level on the foundation soil

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