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THE THREE-DIMENSIONAL ANALYSIS OF THE BEARING CAPACITY OF THE SQUARE FOOTING LOCATED IN GEOMATERIALS WITH A LAYERED MICROSTRUCTURE

1. Introduction

In many geomaterial soils a specific type of microstructure can be recognized: usually two constituents are present in the form of thin, periodically repeating layers. This specific pattern is an effect of the decomposition and consolidation in different, but periodically repeating conditions. This type of microstructure can be found in both: soil and rock masses. Varved clays and sedimentary rocks, like sandstones and schists are some of its most typical examples. All these materials are widely known as strongly anisotropic in both elastic and inelastic range.

Sedimentary rocks and varved clays can be found in Poland in many locations and in a number of cases they serve as the base for engineering structures. To safely and economically design a structure located in such a material, the designer needs to take into account the strength anisotropy of the ground. As a result, the process of design usually needs to employ numerical calculations and a formulation of the boundary-value problem which incorporates the anisotropic strength criterion for ground.

The identified anisotropic strength criterion for layered geomaterials has been presented in work [3] and its application for particular problems of structure design can be found in works [3, 4]. It has been shown that the identified criterion is in very good agreement with the three-dimensional macroscopic strength results obtained for a layered microstructure with constituents governed by the Drucker-Prager criterion. Nevertheless the applications presented for the numerical model have been formulated for a plane strain state and solved using the FLAC 2D program. An appropriate boundary-value problem has been then modeled and solved in two-dimensional space.

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. It is obvious that in many cases the process of the design of a three-dimensional structure needs to employ a full three-dimensional analysis and then the anisotropy of the ground needs to be analyzed in three dimensions. In the present work, an example of the three--dimensional analysis of the structure located in layered geomaterials has been performed utilizing the identified criterion.

2. Failure function in three dimensions

In the work [3] an anisotropic failure criterion for the geomaterials has been presented. The criterion is a conjunction of two different models: Jaeger[1] critical plane inclusions described by equation:

$$|\tau| + \frac{3 \cdot a_c \cdot \sigma_n - k_c}{\sqrt{1 - 12 \cdot a_c^2}} \leq 0 \tag{1}$$

are immersed in matrix ruled by anisotropic Pariseau [5] criterion:

$$A_{ij} + \sqrt{\sigma_{ij} \cdot A_{ijkl} \cdot \sigma_{kl}} - 1 \leq 0 \tag{2}$$

The inequalities shown in (1) and (2) τ, σ_n denote the tangential and normal component of the stress vector on critical plane, σ_{ij} is the stress tensor, k_c, a_c are strength parameters for critical plane, and A_{ij}, A_{ijkl} are anisotropic strength tensors for matrix. The method use for the identification of all parameters of both parts of the criterion has been thoroughly described in the cited work. All parameters of the criterion have been identified as a function of the strength parameters and the geometry of the microstructure. Since the Pariseau criterion is expressed by tensor measurements only and critical plane inclusions are parallel to the stratification plane of the modeled material, the criterion can be easily rotated in three-dimensional space.

In the third work [3] the influence of orientation of load on the shape of the macroscopic failure function of microstructure has also been shown. This failure function has been obtained by the homogenization technique for the two-constituent layered microstructure with the strength of both constituents ruled by the Drucker-Prager criterion. The shape of failure function has been presented in three-dimensional principal stress space in the form of a cross-section on the octahedral plane obtained for different values of confining pressure and different values of orientation parameters. The layered microstructure has a transversally isotropic properties, so only two material directions can be distinguished. Therefore, the unambiguous definition of orientation of the load tensor to material directions requires only two parameters. The angles α and β chosen as orientation parameters are shown on figure 1.

The identified criterion has been verified against the failure function of the microstructure. The comparison of criterion and microstructure strength results have been presented in [3] for wide rage of orientations in both the "in plane" and "out of plane" load cases. In all of the presented situations for the criterion it is in a very good agreement with the strength of the microstructure. It therefore appears that the use of the criterion in analyzing the three-dimensional problem is possible and reasonable. Despite these opportunities a material model with this criterion has only been applied only for solving two-dimensional problems [3–4].

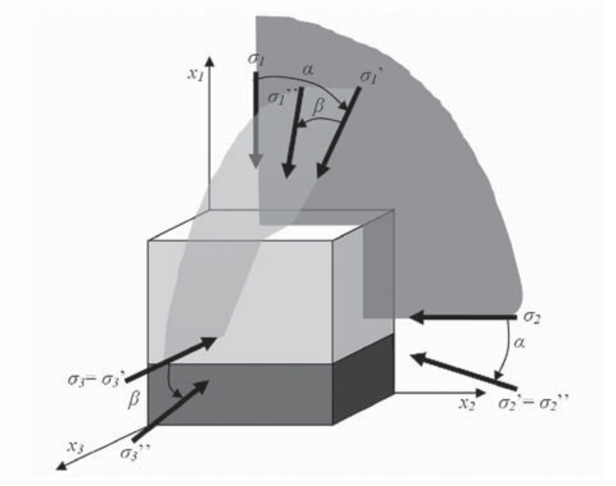

Fig. 1. Orientation parameters of load in relation to the material directions

One of the basic three-dimensional problems in geomechanics is the problem of the bearing capacity of square footing. From the start the problem needs a three-dimensional analysis but the inclusion of the anisotropy of the ground and the dependency of the solution on the spatial orientation of the stratification plane makes it much more complex. This problem has been chosen as an example of the application of the identified model in three dimensional space.

3. Bearing capacity of square footing

In order to solve the boundary-value problem in three dimensions, the above mentioned anisotropic criterion together with a method for its identification has been implemented to the FLAC 3D [1] program. A material model has been adopted in elastic-perfectly plastic with the associated flow rule. The evaluation module has been written in C++ language, as external user defined library.

The criterion has been identified using the following parameters of the two-constituent microstructure: the Drucker-Prager strength parameters of the individual layers are $a_1 = 0.15$, $c_1 = 100$ kPa and $a_2 = 0.05$, $c_2 = 20$ kP respectively and volume fraction of both constituents is equal. As before, the orientation parameters are the α and β angles. This time they orient the direction n normal to the plane of stratification in relation to the vertical direction (Fig 2.). The square footing with dimensions of 1×1 m is assumed as perfectly smooth.

A boundary value problem has been solved in the FLAC 3D [1] using a grid of 60×60×30 zones. The solution has been obtained as a displacement-driven by applying the vertical displacement

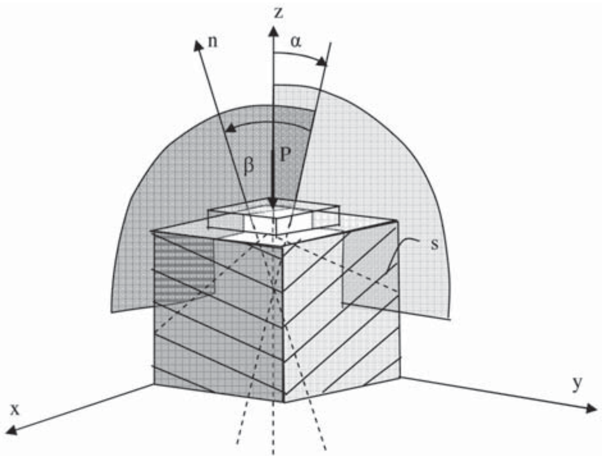

Fig. 2. Parameters α and β orienting direction n normal to critical plane family in coordinate system parallel to footing edges

velocity of the order of 10^{-5} m/time step to all of the grid nodes associated with the foundation. The admissible vertical force P applied to the foundation has been calculated as the sum of the vertical forces in these nodes. A sample graph of P against time step number is shown on figure 3.

In figure 4 examples of the plastic zones under the footing obtained for the different values of orientation parameters α and β are shown. The presented figures are in fact cross-sections through the ground material in two perpendicular directions: both sections intersect the axis of the foundation. It is easy to observe that the plastic zones are symmetric for angles α and β equal 0º or 90º

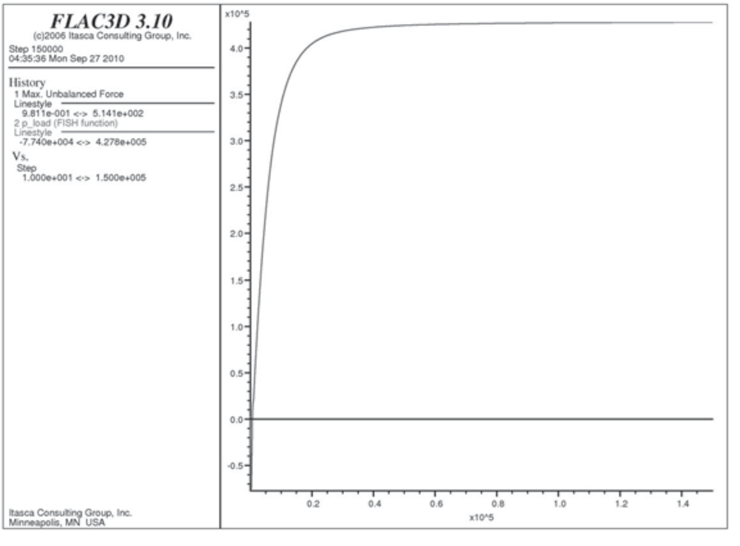

Fig. 3. Typical graph of P[N] against time step number. The graph has been obtained for $\alpha = \beta = 22.5º$

and non-symmetric for the different values of orientation angles. Since the geometry and load in the problem is symmetric, lack of symmetry in solution as well some differences in the solutions obtained for the different values of the angles illustrates the anisotropic behavior of the material.

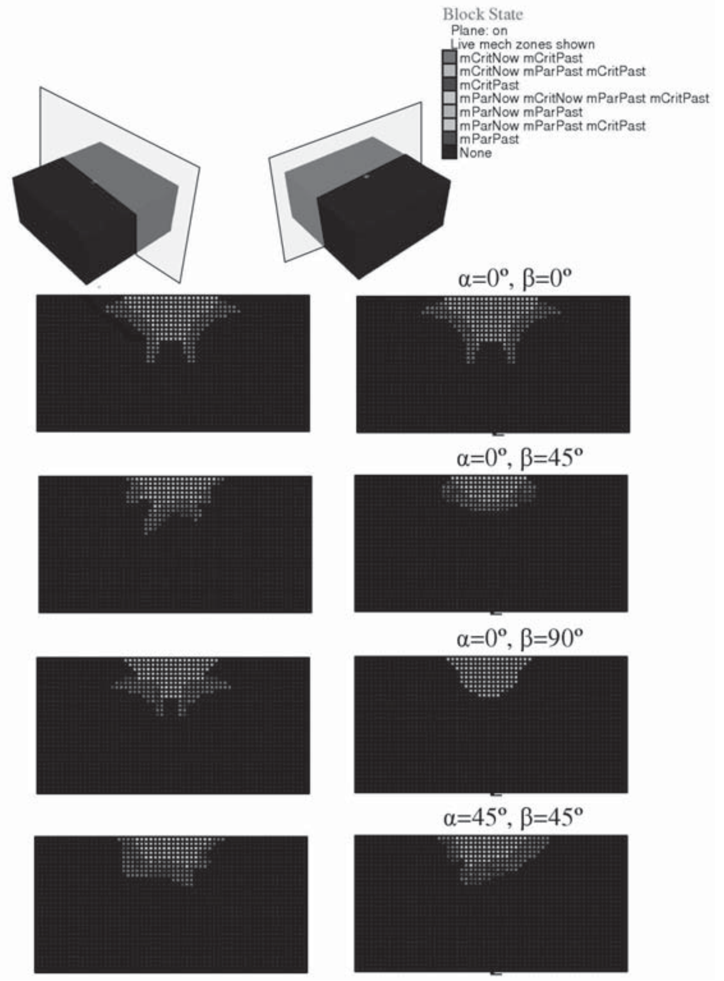

Fig. 4. Plastic zones in layered soil under footing for different value of α and β

The final effect of the analysis has been shown on figure 5. The graph presented shows the dependence of the footing bearing capacity on parameters α and β.

4. Summary

In this analysis the application of the anisotropic criterion for geomaterials with a layered microstructure to a three-dimensional problem has been presented. The problem of then

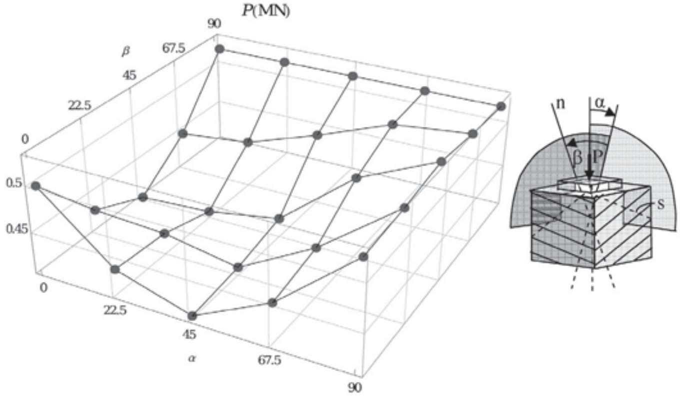

Fig. 5. The bering capacity of the square footing as a function of orientation parameters α and β

bearing capacity of a square footing located in a layered geomaterial has been analyzed and solved in the FLAC 3D program using the author's implementation of the criterion. A solution has been presented for many different spatial orientations of the stratification direction and finally presented as a function of the two orientation parameters α and β.

The function of the bearing capacity presented, relating to a square footing show strong dependence on both orientation parameters. This indicates the need to take into account the spatial anisotropy of the ground for designing three-dimensional engineering structures located in layered geomaterials.

It has been shown that the previously identified anisotropic criterion [3] seems to be very convenient in describing layered geomaterials in three dimensions. The numerical implementation of the material model to the FLAC 3D makes possible to use it for the analysis of three-dimensional boundary-value problems.

The example problem presented in the work is very simple. The author's intention has been just to show how the possibility of using of a material model in 3D can be. Implemented and used in analyzing much more complex structures. Using the module for designing real three-dimensional structures located in layered geomaterials is one of the further aim of author.

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