1. INTRODUCTION

The application of numerical methods for the solution of complex geotechnical engineering problems is more firmly established in engineering practice. Increasingly, more computationally-based studies are being carried out for the solution of real life problems than ever before. Procedures for designing and constructing reinforced soil (RS) structures are being evaluated to develop improved techniques. Special emphasis is placed on using RS technology to build roads, bridge piers and overpasses on weak subsoil. The concept of RS is not new, but now people are reinforcing soil using different techniques and methods, so new and applicable mathematical and numerical models should be adopted for general use. One of these methods is the realization of gravel columns in geosynthetic sleeves. Generally, in applying gravel columns to the subsoil we accelerate the process of consolidation, which not only increases the carrying capacity, but also strengthens and stabilizes the ground and reduces settlement of the subsoil as well.

Computational science involves the use of computers in a scientific investigation by combining and supplementing the area of theoretical and experimental aspects with conventional research approaches. In light of the title of the paper, the first question to be dealt with should be what is understood by model and modelling. Indeed, a model is an artificial form that reflects and reproduces important characteristics, relationships and functions of a real-life object or phenomenon, while modelling comprises all of the activities involved in building a model. The real-life object and its model must share certain features and functions. Any theoretical investigation aiming to understand the behaviour of such a ground medium under internal and external influences demands a mind-model complete with a set of formulae describing its properties, assumptions and simplifications, all of which together could constitute a mathematical or computational model.

J. GASZYŃSKI, M. GWÓŹDŹ-LASOŃ

NUMERICAL MODEL OF SUBSOIL REINFORCED BY GRAVEL COLUMNS IN GEOSYNTHETIC SLEEVES

ABSTRACT

The paper considers the issue of ground-medium reinforcement. Based on generally accepted principles, the authors present numerical modelling patterns of subsoil reinforced by gravel-columns in geosynthetic sleeves. The paper compares the outcome of numerical simulations with the measured load capacity of gravel columns located along a motorway bypass of Cracow, Poland.

The paper constitutes an attempt to summarise and generalise earlier research, which involved FEM numeric procedures and the Z_Soil package (which offers an attractive alternative to traditional approaches to geotechnical problems) and utilised an elastic-plastic model of a ground medium, not only with the Drucker-Prager criterion, but the Cap model as well. Both of these models are very convenient from the point of view of numerical efficiency.
2. PROBLEM SPECIFICATION AND ASSUMPTIONS

In this study, the behaviour of gravel columns installed in a regular array over an extensive area situated under the speedway of Cracow’s South Ring Road near Wieliczka was tested. The motorway design assumes the performance of two roadways, each with two lanes. Each roadway will be about 8.00 m in width. The roadways will be separated by a strip of land of about 7.00 m in width. Emergency lanes, ground shoulders, technical lanes or median lanes will be located outside the roadways according to their locality (Fig. 1). Any model’s development begins with defining the problem by adopting a research objective, problem scope and the accuracy expected. This project is aimed at developing numeric models of a reinforced ground foundation reflecting the specific gravel column technologies applied. (Fig. 1.)

A number of computational models of a gravel column reinforcing this ground were proposed for this representative cross-section. At first, an axis-symmetric system, consisting of one gravel column with the ground medium was analyzed; subsequently a two-dimensional model was adopted and considered as a row of columns and then as a grid. The following numeric simulations assumed the ground and the reinforcing gravel columns as an elastic-plastic model, applying the Drucker-Prager and Cap.

3. CHARACTERISTICS OF THE REINFORCED SUBSOIL

The values of the parameters necessary for analysis have been assumed as typical of soils in the ground of the region considered. These parameters are: $\gamma$ - unit weight, $c$ – cohesion, $\phi$ - friction angle, $\nu$ - Poisson’s ratio, $e$ – voids ratio and some cap parameters $\lambda$, $P_{co}$, $R$. The values of the parameters applied in the FEM analyses are given in Table 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>$\gamma$ (kN/m$^3$)</th>
<th>$c$ (kPa)</th>
<th>$\phi$ (°)</th>
<th>$\nu$ (-)</th>
<th>$E$ (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsoil (S)</td>
<td>18</td>
<td>17</td>
<td>17</td>
<td>0.30</td>
<td>20.000</td>
</tr>
<tr>
<td>Gravel Column (GC)</td>
<td>22</td>
<td>3</td>
<td>40</td>
<td>0.20</td>
<td>120.000</td>
</tr>
<tr>
<td>Weak Layer (WL)</td>
<td>14</td>
<td>10</td>
<td>5</td>
<td>0.32</td>
<td>15.000</td>
</tr>
<tr>
<td>Embankment</td>
<td>20</td>
<td>65</td>
<td>65</td>
<td>0.20</td>
<td>80.000</td>
</tr>
</tbody>
</table>

4. NUMERICAL ANALYSIS

The meshes shown in Fig. 2 were generated with elements, the dimensions of which are mostly 30 x 30 cm, and then the compressed mesh was spread on 60 x 90 cm elements. The ground foundation in question included one 3.60 m thick weak layer, 4.50 m below the surface. On the top of these meshes, a 0.90 m thick road embankment was erected using a geogrid on a geosynthetic mattress, Fig. 3.

The footing and flank column parameters are accordingly different for the horizontal and vertical sliding lines. Characteristic parameters were adapted as intermediate between the layer soil and gravel columns and are equal to 2/3rds of the cohesion and friction angles. The geosynthetic will be simulated with a no-compression membrane element.
Figure 2. The accepted meshes for FEM.

Figure 3. Road embankment made of special aggregate in geogrids on a geosynthetic mattress and two-dimensional model with a row of columns and then as a grid.
The model is built of four material zones representing the subsoil, weak layers, embankment and gravel columns. These materials are homogeneous and isotropic, described by parameters of average global values. Considering the process of consolidation (Lewis & Schrefler, 1998), the bottom surface has been assumed as impermeable. Drained conditions have been assumed on the ground surface, applying appropriate water boundary conditions. In the consolidation analysis, the subsoil was fully saturated. The behaviour of all the materials during loading has been described at first by an elastic, perfectly plastic model with Drucker-Prager yield criterion and the non-associated flow rule with a dilatancy angle equal to 0. The second model was made by assuming the Cap model. The axis-symmetric system was analysed, consisting of a gravel column with the ground medium. As a result of this numerical simulation, we receive a radius of the co-operating zone gravel column – subsoil (1.30 m ÷1.60 m), depending on the load capacity of the entire configuration (Fig. 4).

The computation shows that the column construction technology is an important factor in the development of a numerical model. It has a considerable impact on the end results of numerical testing to determine the ground load capacity and deformation process analysis.

The numerical model of the reinforcement soil with the gravel column in a geosynthetic sleeve were tested. There is a different technology for making this kind of reinforcement: first we must make a hole in the ground (protection by a steel pipe), then put the geosynthetic sleeve into the subsoil and finally fill it with gravel – this is a very short explanation of this method. This engineering process allows us to model this kind of soil reinforcement not only without modelling the interlayer, but also in this case, we do not have to take the elastic recovery parameter into consideration, as well.

The contact elements between the subsoil 1 geosynthetic 1 columns have been introduced at the edge of the material boundary of a much greater stiffness and the soil (Fig. 5). In the proposed model we assume an elastic plastic medium by the Drucker-Prager and Cap models, which is very convenient from the point of view of numerical and technological efficiency.

By building those kinds of gravel columns into the subsoil, we accelerate the process of consolidation (Fig. 6). The moment when a road pavement may be constructed is determined by the termination of the RS’s settlement. The process of settlement is time-dependent and results from changes in the effective stresses and dissipation of any excessive pore pressures. The motorway bypass of Cracow, is still geodetically monitored.

5. RESULTS OF THE ANALYSES

The theoretical instigation, simulation and empirical experiment are closely related and, none of these cognitive methods should be applied separately. A simulation, i.e., an analytical or numerical solving of model equations, can generate full and credible results.
Figure 5. A numerical model in Z_SOIL_PC for the subsoil reinforced by gravel columns in a geosynthetic sleeve. From the top – embankment elements – sliding line – membrane elements – sliding line – subsoil and columns elements.

Figure 6. Vectors of fluid velocities in the consolidating soil.
only if it is theoretically and empirically verified. In order to arrive at the best possible model of the actual system, further testing is necessary to determine the impact of the various assumptions and simplifications adopted at the end result of the investigation, which should be followed by a selection of a computational model that is both as simple as possible and provides results that are closest to real life. The values of the settlement (deformation) and carrying capacity of the RS for the accepted models and monitoring results are different, but by no more than 15%.

REFERENCES