Analysis of numerical model parameters for dry-mixed soil-cement composite with high content of organic matter

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Abstract. Numerical modelling of geotechnical issues requires basic subgrade parameters which need to be introduced into the program. The best way of collecting such information is to commission a series of tests. Defining the parameters of the material gained when admixtures are introduced into existing soil becomes problematic. Basic strength parameters can be found from trial batches of quasi-concrete composite, however they do not ensure the full spectrum of necessary data. Numerical programs often require more parameters from the user and these data are dependent on the strength hypothesis assumed. In this situation, one of possible solution is to run a inverse analysis. The paper provides exemplary procedure of iterative determination of cohesion, internal friction angle and Poisson’s ratio for a soil-cement sample obtained in dry mixing procedure. The original soil contained relatively high content of organic parts in dry mass. The analysis was made for hypothesis of Coulomb-Mohr and Drucker-Prager. The conclusions drawn from performed studies give some recommendations, but, due to possible soil heterogeneity, emphasise the need for further studies.

1. Introduction – scope of the work

Deep Soil Mixing is one of the constantly developing soil improvement technologies. Composite materials may be achieved by mixing natural soil with cement grout or dry cement binder. In Poland, some scientific studies on the parameters of soil-cement composites were developed in PhD thesis of Leśniewska [1]. Many articles and conference papers were published since than, describing various possible fields of application of composites [2], perspectives of week (organic) soil stabilization [3] and mostly the application of DSM for large infrastructural projects [4,5].

As the concerns about methodology of cement-soil composite testing and its adequacy to the on-site conditions were risen, many contributions refer to that subject [6-8]. Series of Research and Development (R&D) programs were curried out together by Wrocław University of Science and Technology and the company Menard Polska [9,10].

Meanwhile, various aspects of soil-cement composite composition were examined [11,12], e.g. the application of fly ashes [13-15], problems with organic parts content in mineral soil in works of Nowak and Prokopowicz [16-19]. The actual paper deals with exemplary reverse process (inverse analysis) for the proper determining of cement-soil material parameters. Some preliminary attempts were already published by Jendrysik [20-22] and summarized in work [23]. The need for this development was addressed in work [24].

For the purpose of the current study, composite material was achieved in laboratory conditions by so-called dry mixing. Despite of cautious mixing, the material structure was of non-uniform nature. As the binder sets, a skeleton is created as a load carrying part. Unbound soil particles act as a force
damper, so that the material is resistant to shrinkage. Some problems may be caused by organic parts in the soil. Because of acids (acetate, tannic, humic acids [3, 6-8]) occurring there, recorded were cases when cement did not bind with soil so strengthening ensures no positive results. For this sake, in in-situ conditions, it is important to run control during mixing process and after completing the subgrade improvement. The material which has been obtained has always hardly predictable parameters.

One of ways to evaluate the properties of such material is to make trial samples and try to derive some information from their testing. This would not resolve the problem ultimately as numerical programs intended for modelling geotechnical issues require more data to be introduced by the user. The purpose of the current paper is to propose the path to determine the parameter by reverse analysis and numerical modelling. The basis is a selected laboratory sample being a part of research project having been conducted at Wrocław University of Science and Technology.

2. Preparation of dry-mixed soil-cement composites
All the samples were mixed, poured to 15×15×15 cm forms (figure 1) and stored in laboratory conditions. Constant temperature and humidity was provided.

![Figure 1. Bags with soil and forms with soil-cement composite.](image)

Detailed information about cement amount in samples, time of testing and testing procedure was described in former author’s works [20-22].

3. Basic aspects of laboratory test
Laboratory tests were run to prepare 145 samples of soil-cement material. The soil was taken at Oława Town. Out of these 145 samples which had various content of concrete, organic matter and natural moisture, one representative sample was selected which was analysed. It contained 6.21% of organic matter and its natural humidity was 50.71%. The CEM III/32.5 N cement content was 166 kg/m3. The batch of concrete was laid down in four layers in a standard mould with dimensions of 15×15×15 cm. Following 28 days, the sample subjected to destruction in single-axis compression testing machine. From the data obtained the stress-strain relationship was drawn in figure 1. The material tested reached strength of 0.2 MPa.

Due to uneven surface of the sample, the single-axis compression machine matched the soil-cement block during the first phase of operation. As a result, a non-elastic form of the diagram exists at the beginning of the stress-strain path. It is so called a bedding error. For this reason, the elasticity modulus was determined at the point of 50% of sample strength – it was found to be 14.63 MPa. For modelling purposes, the figure 2 was modified.
4. Description of numerical model

Attempts were made in the numerical model to capture, as far as possible, the nature of the diagram for the sample obtained in laboratory test. The model was developed using student version of the ZSoil 2018 program (non-commercial version). A cube with dimensions of 15×15×15 cm was modelled. The cube was divided into smaller elements – each edge was divided to 11 parts. All three degrees of freedom of nodes were blocked at top and bottom surfaces (figure 3). The piston of machine travelled in uniform movement, hence knowing the duration of test and sample strain, linear displacement of top supports versus time was modelled which represented the sample compression process (figure 4).

![Figure 3. Numerical model](image)

![Figure 4. Deformed mesh after compression](image)

**Table 1. Parameters for Coulomb - Mohr criterion**

| Parameter | Initial value | Final value |
|-----------|---------------|-------------|
| c         | 28 kPa        | 38 kPa      |
| \( \phi \) | 24°           | 34°         |
| v         | 0.10          | 0.49        |

**Table 2. Parameters for Drucker – Prager criterion**

| Parameter | Initial value | Final value |
|-----------|---------------|-------------|
| c         | 53 kPa        | 63 kPa      |
| \( \phi \) | 46°           | 56°         |
| v         | 0.10          | 0.49        |
The material was modelled according to two hypotheses: Coulomb-Mohr (table 1) and Drucker-Prager (table 2). These hypotheses were selected because the first one is the basic and best known and is the base for other ones, including Coulomb-Mohr version. They are based on the same material parameters, hence they can be compared with each other. In both cases, the internal friction angle, cohesion and Poisson’s ratio were changed in ten iterations (figures 5-10).
This operation was run by changing one parameter while the other two were kept constant. Initial values for the Coulomb-Mohr model were: \( c = 33 \text{ kPa}, \Phi = 29^\circ, \nu = 0.3 \), while those for Drucker-Prager were: \( c = 58 \text{ kPa}, \Phi = 51^\circ, \nu = 0.3 \). The variation ranges of particular values were shown in tables (table 1, table 2).

5. Summary and conclusions
The procedure of numerical modelling revealed the essence of selecting the proper strength hypothesis. As shown in the above example, in no case the numerical model has been exactly fitted to the laboratory sample. The reason is that analysis has been made for ideal elastic and plastic hypotheses while examined material behaviour is different. It includes a specific “gain effect” which could not be obtained in hypotheses selected.

Calibration of the numerical model might prove necessary for soil-cement material only. While comparing the results, one can notice a big impact of cohesion and angle of internal friction in case of Coulomb-Mohr case. As concerns the proper selection of Poisson’s ratio, much more attention should be paid when using the Drucker-Prager hypothesis. It should be emphasized that much worse parameters were used for the first criterion than those for the second one. Hence, the Coulomb-Mohr hypothesis is more conservative, so it can be safer in many cases.

The analysis carried out may be only used as an upper estimation of soil-cement parameters. Material used to prepare laboratory samples has been very well crumbled and mixed which is not possible at field conditions. Additionally, a homogenous material was assumed in the numerical model. Each parameter was varied separately. Analysis should also include cases when all values are changed at the same time.

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