Determination of the Characteristic Values and Variation Ratio for Sensitive Soils

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Abstract. In 2008, Romania adopted Eurocode 7, part II, regarding the geotechnical investigations – called SR EN1997-2/2008. However a previous standard already existed in Romania, by using the mathematical statistics in determination of the calculation values, the requirements of Eurocode can be taken into consideration. The setting of characteristics and calculations values of the geotechnical parameters was finally issued in Romania at the end of 2010 at standard NP122-2010 – “Norm regarding determination of the characteristic and calculation values of the geotechnical parameters”. This standard allows using of data already known from analysed area and setting the calculation values of geotechnical parameters. However, this possibility exist, it is not performed easy in Romania, considering that there isn’t any centralized system of information coming from the geotechnical studies performed for various objectives of private or national interests. Every company performing geotechnical studies tries to organize its own data base, but unfortunately none of them use existing centralized data. When determining the values of calculation, an important role is played by the variation ratio of the characteristic values of a geotechnical parameter. There are recommendations in the mentioned Norm, that could be taken into account, regarding the limits of the variation ratio, but these values are mentioned for Quaternary age soils only, normally consolidated, with a content of organic material < 5%. All of the difficult soils are excluded from the Norm even if they exist and affect the construction foundations on more than a half of the Romania’s surface. A type of difficult soil, extremely widespread on the Romania’s territory, is the contractile soil (with high swelling and contractions, very sensitive to the seasonal moisture variations). This type of material covers and influences the construction foundations in one over third of Romania’s territory. This work is proposing to be a step in determination of limits of the variation ratios for the contractile soils category, for the most used geotechnical parameters in the Romanian engineering practice, namely: the index of consistency and the cohesion.

1. Introduction
The swelling and highly contracting soils, called contractile or expansive soils, are those types of clayey materials, active against the water and that have the characteristic of considerably changing their volume, following the seasonal moisture variation [1]. They are spread across almost the whole surface of Romania, except for the South-Eastern Carpathians extreme area and they are split-up in two major categories (soils with an average potential of contraction-swelling (less active and active) and soils with a high potential of contraction-swelling (active and very active).

As geological age, the deposits made up by expansive materials, are Quaternary (Lower Pleistocene, Middle Pleistocene), produced as a result of intensification of the exogenous and
accumulating processes in the areas of active subsidence remained covered by water, in which lacustrine deposits have accumulated [2].

The data subjected to the research were obtained throughout years, from various geotechnical studies performed for the pavement design (high speed roads and motorways) from different areas of Romania. In order to increase the degree of confidence in the obtained results, we have only taken into consideration the data obtained from our own investigations (field investigations performed by our own teams and equipment, laboratory analyses performed in the same laboratory of the company). The investigation period develops between 2011 and 2016. Throughout these years, significant changes occurred in the Romanian legislation regarding the geotechnical investigations performed for design of the high speed roads (express ways, motorways). They also brought different approaches on the laboratory tests especially.

The previous researches performed by the authors [3] emphasized that considering the drilling through the expansive materials, a series of things should be noticed: boring by drill is not indicated, the tests of standard penetration test (SPT) are relevant when they are correlated with the materials in the status of consistency, sampling doesn’t need special requirements (but the storage conditions should be very strict), so that the sample does not lose out its natural moisture. Difficulties in the trials of determining the grain size distribution were noticed in the laboratory. Also, difficulties were noticed in performing the tests of plasticity determination (especially the plasticity upper limit). Experience of the authors emphasized also, that from the mechanic parameters point of view, most of the problems arise at determination of cohesion, in most of the cases this being influenced by the human factor [4].

Consequently, the subject of this scientific work refers to the values of the index of consistency and cohesion for the swelling and high contracting materials, to the determination and comparison of the calculation values for these two geotechnical parameters, for samples coming from different areas of Romania.

2. Determination of the calculation values
2.1. Provenance of samples
For this research, the values of consistency index and cohesion for swelling and high contracting materials were analysed. The values were determined based on samples from 5 different areas of the country (Figure 1). All the samples were collected in the period 2011 – 2016, using the same type of equipment, the laboratory tests being carried out in the same geotechnical laboratory, by means of the same laboratory equipment.

Figure 1. Expansive soils spreading and studied areas emphasizing
All the samples are of Quaternary age. Samples from maximum 4.0 m deep were taken into account. They can be influenced by the seasonal climatic changes (maximum 1.5 m) that can be opened by usual excavations (ditches, direct foundations) and represent the pavement foundation layer.

Fitting into the category of expansive soils was made depending on the grain size distribution \((A2\mu > 15 \text{ mm} - \text{percentage of clay with a diameter smaller than 0.002 mm})\), index of plasticity \((I_p > 12 \%)\), index of activity \((I_A > 0.75)\) and free swelling \((U_L > 70\%)\). Most of the results show that the materials are under an average activity, rarely being very active [1]. The following data were taken into consideration: (Table 1) ‘Figure 2’

**Table 1.** Number of values taken into account.

| Project                                | Abbreviation | Year of analysis | Index of Consistency, I<sub>c</sub> | Number of values taken into account | Cohesion (kPa)<sup>a</sup> |
|-----------------------------------------|--------------|------------------|-------------------------------------|------------------------------------|-----------------------------|
| Sibiu - Orastie Motorway                | S-O          | 2011-2012        | 79                                  | 3                                  | 14                          |
| Sebes – Turda Express Way               | S-T          | 2013             | 247                                 | 46                                 | 30                          |
| Nadlac - Arad Motorway                  | N-A          | 2013-2014        | 45                                  | 14                                 | -                           |
| Targu Mures - Ogra Motorway             | TgM-O        | 2014             | 48                                  | 11                                 | 7                           |
| Express Way between the DN69 and A1, Arad - Timisoara | DN69-A1 | 2015-2016        | 65                                  | 2                                  | 1                           |
| Total                                   |              |                  | 484                                 | 76                                 | 52                          |

<sup>a</sup>Cohesion was determined by the direct shear tests

**2.2. Determination of calculation values**

The calculation values are determined based on the characteristic values. The characteristic values of a geotechnical parameter \((X_k)\) are those values set up as a prudent estimate of the value influencing appearance of the limit status in the geotechnical structure or in the structures (constructions) co-working with them. It is mostly a prudent estimate of the average of values determined by tests or measurements in the volume of soil governing for the considered limit status, the geotechnical structure behaviour [5].

The calculation values of the geotechnical parameters \((X_d)\) are regularly set up by the Designer geotechnical structure, by relating the determined characteristic values to the partial ratio for the soil properties.

\[
X_d = \frac{X_k}{\gamma M} \tag{1}
\]

where:

\(X_k = \text{characteristic value}\)

\[
X_k = X_m \times (1 \pm k_n \times V_x) \tag{2}
\]

\(X_m = \text{arithmetic mean of the selected values}\)

\(V_x = \frac{s_x}{X_m} \tag{3}\)

\(s_x = \text{standard deviation}\)
\( k_m = \) statistical ratio of variation of the average that depends on the number of selected values and average provision level

\( \gamma_M = \) partial ratio for the soil characteristics [6].
- For drained cohesion \( \gamma_M = \gamma_c = 1.25 \)
- For undrained cohesion \( \gamma_M = \gamma_{cu} = 1.4 \)
- For the index of consistency \( Ic \) \( \gamma_M = 1 \)

![Figure 2. Sampling locations](image)

2.3. Determined characteristic values and calculation values

The characteristic and calculation values were determined for the index of consistency (Table 2) and cohesion. The values of cohesion were determined by the direct shear, tests, depending on the purpose, performed under unconsolidated-undrained conditions (UU) – Table 3, consolidated-undrained conditions (CU) – Table 4 and consolidated-drained conditions (CD) – Table 5.

| Work  | \( X_m \) | \( s' \) | min | max | \( V_s \) | \( X_k \) | \( X_d \) |
|-------|----------|--------|-----|-----|--------|--------|--------|
| S-O   | 0.83     | 0.12   | 0.42| 1.04| 0.15   | 0.79   | 0.79   |
| S-T   | 0.87     | 0.14   | 0.20| 1.21| 0.16   | 0.83   | 0.83   |
| N-A   | 0.74     | 0.11   | 0.51| 1.01| 0.15   | 0.70   | 0.70   |
| TgM-O | 0.85     | 0.11   | 0.55| 1.31| 0.13   | 0.81   | 0.81   |
| DN69-A1 | 0.91   | 0.08   | 0.55| 1.09| 0.09   | 0.89   | 0.89   |
| All works | 0.85 | 0.13   | 0.20| 1.31| 0.15   | 0.81   | 0.81   |

| Work  | \( X_m \) | \( s' \) | min | max | \( V_s \) | \( X_k \) | \( X_d \) |
|-------|----------|--------|-----|-----|--------|--------|--------|
| S-O   | 54.68    | 8.52   | 48.33| 64.36| 0.16   | 40.28  | 28.77  |
| S-T   | 57.10    | 27.76  | 14.0 | 143.6| 0.49   | 48.5   | 34.64  |
| N-A   | 28.41    | 9.41   | 18.3 | 48.6 | 0.33   | 23.7   | 16.93  |
| TgM-O | 39.49    | 19.76  | 12.0 | 75.0 | 0.50   | 28.42  | 20.3   |
| DN69-A1 | -     | -     | -   | -   | -     | -     | -     |
| All works | 48.71  | 26.8   | 12.0| 143.6| 0.54   | 40.62  | 29.01  |
Table 4. Cohesion (kPa): Statistic data, characteristic and calculation values, under consolidated–undrained conditions (c_u).

| Work   | X_m  | s'   | min  | max  | V_x | X_k | X_d |
|--------|------|------|------|------|-----|-----|-----|
| S-O    | 37.94| 18.83| 13.0 | 80.0 | 0.50| 28.52| 20.37|
| S-T    | 45.48| 28.47| 8.0  | 110.4| 0.63| 36.66| 26.18|
| N-A    | -    | -    | -    | -    | -   | -   | -   |
| TgM-O  | 32.76| 13.73| 13.0 | 46.68| 0.42| 22.47| 16.05|
| DN69-A1| -    | -    | -    | -    | -   | -   | -   |
| All works | 45.48| 24.74| 8.0  | 110.0| 0.54| 37.82| 27.01|

Table 5. Cohesion (kPa): Statistic data, characteristic and calculation values, under consolidated–drained conditions (c_d).

| Work   | X_m  | s'   | min  | max  | V_x | X_k | X_d |
|--------|------|------|------|------|-----|-----|-----|
| S-O    | 100.57| 41.64| 33.62| 149.80| 0.41| 66.43| 53.14|
| S-T    | 76.23 | 25.14| 28.98| 116.00| 0.33| 63.41| 50.73|
| N-A    | -    | -    | -    | -    | -   | -   | -   |
| TgM-O  | 54.45 | 43.87| 16.31| 137.49| 0.81| 18.47| 14.78|
| DN69-A1| -    | -    | -    | -    | -   | -   | -   |
| All    | 76.82 | 36.3 | 16.31| 149.80| 0.47| 67.02| 53.61|

3. Results and discussions

The step constituting basis for this work is the lack of benchmarks for difficult soils from the norms of reference. The difficult soils include the swelling and high contracting soils (expansive soils). Inexistence of a data basis at a macro level leads to the situation when during the geotechnical data processing, the statistic processing is necessary for determination of the calculation values. Following determination of the calculation values for the index of consistency (figure 2 and figure 3) and for cohesion (figure 4 and figure 5) and following the statistic processing of these values, a comparison of these resulted values was possible and thus, some trends of these values were obtained.

Figure 3. Ratio of variation (V_x) for the Index of Consistency

Figure 4. Calculation values (X_d) for the Index of Consistency
Following analysis of data and statistic processing, a few important results were obtained, for the study and use in practice of the data regarding swelling and high contracting soils (expansive soils).

3.1. Results for the values of the Index of Consistency, Ic
As far as the Index of Consistency is concerned, the results have generally shown a quite small variation of the values, with standard deviations < 0.15 and variation ratios between 0.09 and 0.16. The value of the variation ratio is very close to the recommended value, $V_x = 0.15$ [5] for the Quaternary soils, considered non-difficult soils.

The calculation values of the index of consistency show a variation between 0.70 and 0.81, thus comprising the analysed soils into the category of plastic-consistent – plastic hard soils.

3.2. Results for the values of cohesion
For cohesion, the values obtained from the direct shear tests were analysed, under unconsolidated-undrained conditions (UU), consolidated-undrained conditions (CU) and consolidated-drained conditions (CD).

The values obtained for the standard deviation are in general higher than 10, and for the ratio of variation, they are between 0.16 and 0.81 (when it is about each separate work). When all of the data are analysed together, it could be easily noticed that the values of the variation ratio are between 0.47 and 0.57. The value of the indicated variation ratio, recommended by the specific standard is $V_x = 0.40$ [4].

4. Conclusions
The expansive soils cover a large part of the Romanian territory and are characterised by high volume variations, under the influence of the climatic factors.

The work pursued determination of the characteristic and calculation values for two important geotechnical characteristics: the index of consistency and cohesion. For these two parameters, the variation ratio values were set up.

In order to prepare the research accordingly, the analysed materials belong to the same geological period and are collected from depths between 0 and 4.0 m, using the same type of equipment (by the same boring methods) and analysed in the same geotechnical laboratory (by means of the same types of equipment).
The calculation values obtained for the index of consistency were between 0.70 and 0.81, the variation ratio being between 0.09 and 0.16 – very close to the recommended calculation value, \( V_x = 0.15 \).

The calculation values obtained for cohesion were between 20.3 and 34.6 kPa (unconsolidated-undrained cohesion); between 16.05 and 27.01 kPa (unconsolidated-drained cohesion) and between 14.78 and 53.61 kPa (consolidated-drained cohesion). The variation ratio values differ pretty much from the recommended value for the soils which are not from the special characteristic soil category.

Interestingly, a decrease of the calculation values in time can be noticed for cohesion, the values obtained at the level of the years 2015-2016 being little lower than the previous ones. This is not accidental. Following countless problems recorded during construction, the test laboratories increased exigency of, tests, applying numerous filters to the geotechnical parameters, the effect over time being decrease of the parameters of resistance.

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