Pedotransfer function for calculating the potential of volume changes in soils

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Abstract. The volume changes in the soils are manifested both by the formation of cracks and by the vertical movement of the soil surface. Both of these could be generally negative for engineering constructions. The Coefficient of Linear Extensibility (COLE) is used to quantify volume changes. In this work a pedotransfer function was designed to calculate the COLE potential. Calculation is based on the texture of the soil. This function was designed on the basis of 169 samples of soil samples taken at 11 locations in the East Slovak lowland.

1. Introduction

Volume changes of soil are caused by clay minerals. These minerals can change their volume when they are wetting (soil is swelling) or drying (soil is shrinking). The more content of clay minerals, the more significant volume changes. Content of clay minerals in soil is close related to the content of particles with diameter < 0.002 mm. Therefore, when soil texture is known, it is possible to predict a potential of volume changes of soil. Volume change of soil is three-dimensional process, which in vertical direction results in vertical movement of terrain and in horizontal direction results in creation of soil cracks. Both, vertical movement and cracks can affect engineering constructions (buildings, pavements, pipelines etc.) almost in negative way. The principle and mechanism of soil’s volume changes is relatively well described in literature [1-11].

Most of present research in soil physics is oriented to mathematical methods used for obtaining hydrophysical characteristics of soil from data, which can be easily measured (in most cases from the particle size distribution of soil). Outputs are called “pedotransfer functions” (PTF), which are useful for calculation hydrophysical characteristics of soils. This paper presents PTF for computing potential of volume changes of soils from soil texture. Potential of soil’s volume changes is expressed in form of Coefficient Of Linear Extensibility (COLE).

2. Materials and methods

2.1. Sample collection and preparation

The soil sampling site was situated in the East Slovak Lowland (ESL) (figure 1). This lowland is characterized by the high textural diversity of its soils. This is caused by complicated tectonic development of this area. The soils of ESL are mostly agricultural used. For soil sampling were selected 11 localities of ESL. Together, 169 undisturbed soil samples were taken into the Kopecky cylinders with a volume of 100 cm\textsuperscript{3}. At the same time, disturbed soil samples were also taken from
each site for grain analysis. The parameters of sampling sites are listed in Table 1. All undisturbed soil samples were saturated by water in the laboratory to reach the full water capacity.

![Map of the study area (Eastern Slovakian Lowland).](image)

**Figure 1.** Map of the study area (Eastern Slovakian Lowland).

| Locality      | Coordinates                  | Sampling depth [m] | No. of samples |
|---------------|------------------------------|-------------------|---------------|
| Michalovce    | N48° 44,255’ E21° 56,664’    | 0 – 0.8           | 24            |
| Milhostov     | N48° 40,185’ E21° 44,248’    | 0 – 1.6           | 32            |
| Přibeník      | N48° 23,688’ E21° 59,547’    | 0 – 1.0           | 6             |
| Senné         | N48° 39,802’ E22° 02,892’    | 0 – 0.8           | 42            |
| Sírnik        | N48° 30,538’ E21° 48,830’    | 0 – 0.8           | 12            |
| Somotor 1     | N48° 23,748’ E21° 48,471’    | 0 – 0.8           | 23            |
| Somotor 2     | N48° 23,173’ E21° 48,237’    | 0 – 1.0           | 2             |
| Veľký Horeš   | N48° 22,540’ E21° 53,907’    | 0 – 1.0           | 6             |
| Veľký Kamenec | N48° 21,048’ E21° 48,877’    | 0 – 1.0           | 4             |
| Vysoká nad Uhom | N48° 36,796’ E22° 06,898’ | 0 – 0.6           | 16            |
| Zatín         | N48° 28,725’ E21° 54,918’    | 0 – 1.0           | 2             |
| **Σ**         |                              | **169**           |               |

### 2.2. Laboratory measurements

The soil texture analysis was determined from disturbed soil samples by hydrometer method. According to the grain size analysis, the soils were classified according to the USDA classification (sand: 2–0.05 mm, silt: 0.05–0.002 mm and clay: <0.002 mm). The undisturbed soil samples were weighed after saturation and then dried in a laboratory dryer at 105 °C to a constant weight. After drying, the volumes of the cylinders were measured. Volume measurements consisted in measuring the height and diameter of the cylinder by a caliper. Each dimension was measured 2x (in perpendicular directions). From the average values of heights and diameters were calculated volumes of the soil samples.

### 2.3. Data analysis

To quantify the volume changes of soil in this work, the coefficient COLE was used. This parameter is used to quantify the shrink – swell potential of the soil. Equation (1) was established by Grossman [12]:

\[
COLE = \sqrt[5]{\frac{V_{wet}}{V_{dry}}} - 1 \quad [-]
\]
V_{wet} means soil volume in the moist state (i.e. saturated soil sample) and V_{dry} means soil volume in the dry state (i.e. oven dried sample) and r_s is the shrinkage geometric factor. If the value of r_s factor is three, it means that soil is isotropic shrinking. In this study was assumed isotropic shrinkage of soils, so r_s factor had assumed to be three. Simple classification of soils based on COLE was introduced by Parker [13] (table 2).

| Shrink-swelling potential | COLE |
|---------------------------|------|
| Low                       | <0.03|
| Medium                    | 0.03-0.06|
| High                      | 0.06-0.09|
| Very high                 | >0.09|

By multiplying the COLE value by the thickness of the soil layer, we get the shrinkage potential of this layer expressed in the length unit (for example, if a soil layer of 100 cm has a potential of COLE 0.10, this soil layer can potentially shrink by 10 cm).

Based on measured COLE values for 169 texturally diverse soils, a PTF was designed to calculate the COLE parameter from the texture of the soil (from the clay particles (<0.002 mm)).

3. Results and discussion
The soil grain analysis results are shown in figure 2. In the examined data set, the content of the clay component ranged from min. 9.89% to max. 69.13%.

![Figure 2](image)

**Figure 2.** Distribution of soil textures of the 169 soil samples in the USDA textural triangle.

Values of V_{dry} used in relation (1) ranged from 54.5 cm$^3$ (maximum shrinkage) to 100 cm$^3$ (no shrinkage). The values of V_{wet} had a constant value of 100 cm$^3$. Calculated COLE values varied in interval from 0.00 to 0.22.

The dependence of COLE on clay content (particles <0.002 mm) based on 169 soil samples is in figure 3. Pedotransfer function was obtained in the form of polynomial function of second degree:

$$COLE = 0.00004\ (clay)^2 + 0.0006\ (clay) - 0.0056\ [-]$$  (2)
A very high level of reliability of PTF is confirmed by a high value of coefficient of determination ($r^2 = 0.937$) and relatively low value of mean-absolute error (MAE = 0.010%) (figure 4).

Figure 5 shows a comparison of obtained PTF with previously published studies [13-15]. As seen in figure 5, the previous studies expected the linear relationship between COLE values and clay content.

![Figure 3. Relationship between COLE values and clay content of the soil.](image-url)

![Figure 4. COLE values calculated vs. COLE values measured.](image-url)

![Figure 5. Obtained pedotransfer function vs. some similar functions published in world’s literature.](image-url)
This study introduces nonlinear relationship between COLE values and clay content, which seems to be more accurate. The magnitude of volume changes is null till clay content is smaller than 7%. Process of volume changes in soil starts when clay content in soil is greater than 7%.

4. Conclusions
The occurrence of volumetric changes in the soils can be a potential risk for engineering constructions. In order to determine the potential for volumetric changes, the shrink-swell potential of COLE is used. Direct determination of COLE is relatively laborious and time-consuming. Indirectly, the potential of COLE can be estimated by PTF, based on the texture of the soil. Based on 169 undisturbed soil samples from 11 locations on ESL, the PTF was submitted to calculate the COLE potential. COLE values are calculated from the clay content in the soil.

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