Compression testing of soils by utilizing method of constant rate of loading

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Abstract. The work outlines one of the most frequently encountered methods of soil compression testing - the method of constant rate of loading (CRL). Compression tests, in fact, are laboratory tests to determine the deformation characteristics of soils. There are a large number of methods that differ in the approach to the study of soils, the duration of the test, etc. The most reliable results, which are close to those obtained in practice, are provided by the so-called method of constant rate of loading as was mentioned before. However, it also has its drawbacks - the time that is spent on researching the properties of the soil. It usually takes about two weeks. In order to optimize this method, a software product was created that relies on the developed mathematical apparatus and allows you to significantly speed up the data processing process and build a forecast regarding soil characteristics.

1. Introduction
Compression testing of soils is a very important component of geological exploration studies and their corresponding analysis, which are carried out before the building of various construction sites. Compression studies of soil samples are not an easy and very demanding job, which are usually carried out by various geological companies, since the reliability of construction structures depends on the quality of these works.

Such studies are carried out to determine the physico-mechanical parameters of the samples taken in areas where construction will take place. The obtained data are used in the calculation of the foundations on which the reliability of the building structure depends.

Examination work can be divided into the following stages:

- soil relief studies, determining the type of rock;
- determination of soil characteristics by the method of sensing;
- study of geological processes (probability of flooding, slope stability).
At the end of the survey work, an analysis and preparation of a detailed report are made, containing information on the types of soils (including their composition), on groundwater and on the possibility of flooding in the specified area [1].

Further, if the research results meet all the necessary established standards, they carry out compression tests in laboratory conditions.

Compression tests imply the process of compressing a sample of soil (extracted from a specific area on which construction is planned) without the possibility of its lateral expansion (i.e., the sample is compacted and does not collapse). This makes it possible to determine the mechanical parameters of the soil (the main parameters are structural strength, compressibility and deformation).

The main task of such laboratory studies is to simulate the load that will be transmitted to the ground located at the base of the building, taking into account the stress-strain state. The load level is formed taking into account the project of the future construction object and depends on such parameters as the area of the foundation, the number of floors, etc [2].

The desired compression characteristics are obtained using a special instrument - odometer, which excludes the possibility of lateral expansion when exposed to vertical loads. The odometer has a special working ring of a cylindrical shape, where the soil sample is placed, the mechanism of vertical load, in the form of a stamp and a water tank. Odometers generally have three methods for determining the characteristics of the soil: stepwise loading of the soil, studies with a constant rate of deformation and studies, with an estimate of the deformation by the degree of relaxation of the load.

2. Method of constant rate of loading

As mentioned earlier, there are various methods of compression testing. At the moment, the most common method of compression testing is the method of stepwise increasing load (SIL). However, despite its prevalence and ease of implementation, this method has a number of significant disadvantages - after each stage of the load, it is necessary to wait for the soil to stabilize, which significantly increases the amount of time required for the study. It should also be noted that this type of load does not always correspond to the conditions of loading the grounds of the bases arising during construction and in the subsequent operation of objects. The fact is that it is necessary to take into account the degree of load on the ground, both during construction and after its completion. The SIL method does not answer this question.

One of the alternative approach is the method of constant rate of loading (CRL), which quickly gained popularity and distribution in compression tests. This method consists in the application of an ever-increasing load on the studied soil type. It was first used by H. Aboshi et al and N. Janbu et al, K.F. Fay, C.E. Cotton [3].

The CRL method compares favorably with other methods in that it provides the most accurate and reliable results for determining the compressibility characteristics of soils (which are very close to those obtained in practice) and significantly reduces the duration of their research. Despite this, it cannot be said that at the moment the CRL method has gained sufficient popularity. This is due to the fact that the equipment and fundamental methods of its practical application have not been developed.

As part of this research, studies were carried out to determine the characteristics of soils by the CRL method, the compressibility properties of the soils under loading were studied, with a direct dependence on the CRL velocity, random and general errors of the CRL compressibility determination were established and device (odometer) with the impact of constantly increasing load.

The developed standard for soil investigations using the CRL method is applied to clay and sandy soils of natural origin. When carrying out tests with the CRL method, the following characteristics are used: - pressure at the end of the soil sample (having initial and final structural strength), - sample sediment (recorded, both at the beginning of the loading of the soil and at the moment of the end of loading) characterizes the plasticity of the soil. As for the pressure range, it is established considering household loads transferred to the subsoil base in the places of its occurrence. It is also necessary to take into account its water-saturated state [4].
3. Conducting a test. Algorithm for the calculation of foundation bases

To test the soil compression device must meet the following requirements:

- to have the error of constancy of the speed not exceeding 5%, with an initial pressure of 5%;
- loading range - from 1 to 1000 kPA / h; maintain ever-increasing pressure;
- determine the stabilized draft and then continue loading to final pressure;
- to register the draft of the sample at each step with an index of 0.005 mm of soil precipitation.

As an experimental sample was selected dispersive soil rock type - siltstone. This soil has a rather low rate of infiltration (water transmission), which is due to the fact that it has rather small pores (the distance between the soil particles). In this regard, it was decided to neglect the water saturation of the soil [5].

For this specimen with a height of 25 mm, there are data of compression testing by the CRL method (Figure 1) and the following indicators:

- \( p_I \) – pressure at the end of the soil sample,
- \( s_I \) – sediment sample,
- \( I \) – the number of the observation point,
- \( m \) – compressibility factor,
- \( n_f \) – is the number of observation points, where \( I = 1, \ldots, n_f \).

For prediction of deformation of specimen uses formula of compression ratios \( f \) and \( g \). They are also called filtering and consolidation ratios:

\[
( f_I = \Delta_I s / \Delta_I p, \quad g_I = \Delta_I^2 s / \Delta_I^2 p^2 )
\]

Then the cycles of changing values are highlighted \( f_I \) by changing the sign \( g_I \):

- the beginning of the cycle is the 1st positive value \( g_I > 0 \),
- The end of the cycle is the last negative value \( g_I < 0 \).

The minimum and maximum values within the \( i \)-th cycle are determined:

\[
f_{i,\min} = \min\{ f_I \}, \quad I \in i, \quad \text{and} \quad f_{i,\max} = \max\{ f_I \}, \quad I \in i.
\]

The \( p \)-lengths of cycles are calculated (\( \Delta p_{e,i} \) and \( \Delta p_{r,i} \) - the length of the descending branch and ascending, with the construction of the function \( f \), \( i \) is the number of the cycle):

\[
\Delta p_I = \Delta p_{e,i} + \Delta p_{r,i}, \quad \text{r.e.} \quad \Delta p_{r,i} = p_{e,i}^{(-)} - p_{e,i}^{(+)}.
\]

- the length of the \( e \)-part of the \( i \)-th cycle; \( p_{e,i}^{(+)} \) – the last negative sign \( g_I \) in the \( i \)-th cycle; \( p_{e,i}^{(-)} \) – the last positive sign \( g_I \) in the \( i \)-th cycle; \( p_{r,i}^{(+)} \) is the length of the \( r \)-part of the \( i \)-th cycle; \( p_{r,i}^{(-)} \) – the last positive sign \( g_I \) in the \( i \)-th cycle; \( p_{r,i}^{(-)} \) - the last negative sign \( g_I \) in the \((i-1)\) cycle. Also, \( s \)-lengths of cycles are calculated (\( \Delta s_{e,i} \) and \( \Delta s_{r,i} \) – increment of sample precipitation on the corresponding branches, \( i \) is the number of the cycle):

\[
\Delta s_I = \Delta s_{e,i} + \Delta s_{r,i}, \quad (i = 1, \ldots, n_{cy}) , \quad \text{where} \quad \Delta s_{e,i} = s_{e,i}^{(-)} - s_{e,i}^{(+)},
\]

\[
\Delta s_{r,i} = s_{r,i}^{(-)} - s_{r,i}^{(+)},
\]

\[
( 1, \ldots, n_{cy})
\]
the length of the e-part of the i-th cycle; \(s_{i}^{(-)}\) – the last negative sign \(g_{i}\) in the i-th cycle; \(s_{i}^{(+)}\) – the last positive sign \(g_{i}\) in the i-th cycle; where \(\Delta s_{i,i} = s_{i}^{(+)} - s_{i+1}^{(-)}\) – the length of r-part i-th cycle; \(s_{i+1}^{(-)}\) – the last positive sign \(g_{i}\) in the \((i-1)\)th cycle.

Each precipitation cycle consists of ascending and descending branches. On the descending branch of the precipitate, the stamp increases by an amount \(e_{s}\) (the speed of the precipitation decreases, reaching a value \(f_{\min.}\)), on the ascending branch, the sediment increases by an amount \(r_{s}\) (the speed of the precipitation increases, reaching a value \(f_{\max.}\)).

Using the data obtained, the functions characterizing the draft, the rate of precipitation and the acceleration of the precipitation of the sample are constructed.

### Table 1. Experimental Data.

| Point number | \(\Delta s_{i}\) | \(p\) | \(F\) | \(g\) | Cycle number | \(f_{\min.}\) | \(f_{\max.}\) | \(s_{e}\) | \(s_{i}\) |
|--------------|----------------|------|------|------|--------------|-------------|-------------|-------|-------|
| 1            | 0.005          | 2.08 | 0.00240 |      | 1            | 0.00175  | 0.00260  | 0.005 | 0.010 |
| 2            | 0.010          | 4.16 | 0.00240 | 0.000 | 2            | 0.00321  | 0.00437  | 0.005 | 0.010 |
| 3            | 0.015          | 6.08 | 0.00260 | 0.101 | 3            | 0.00332  | 0.00356  | 0.005 | 0.010 |
| 4            | 0.020          | 8.94 | 0.00175 | -0.297| 4            | 0.00343  | 0.00370  | 0.005 | 0.015 |
| 5            | 0.025          | 10.40| 0.00343 | 1.158 | 5            | 0.00300  | 0.00370  | 0.010 | 0.005 |
| 6            | 0.030          | 11.54| 0.00437 | 0.819 | 6            | 0.00356  | 0.00401  | 0.020 | 0.005 |
| 7            | 0.035          | 13.10| 0.00321 | -0.747| 7            | 0.00356  | 0.00385  | 0.005 | 0.005 |
| 8            | 0.040          | 14.56| 0.00343 | 0.157 | 8            | 0.00332  | 0.00370  | 0.015 | 0.005 |
| 9            | 0.045          | 15.96| 0.00356 | 0.091 | 9            | 0.00321  | 0.00343  | 0.005 | 0.005 |
| 10           | 0.050          | 17.47| 0.00332 | -0.163| 10           | 0.00332  | 0.00370  | 0.005 | 0.015 |

Table 1 shows only a portion of the data; a total of 183 points were recorded, which recorded data when moving the vertical odometer stamp. For all those checks, the compression ratios were calculated in a cycle [6].

### 4. Software implementation

In order to automate and speed up the data processing, a special software product was developed in the Delphi programming environment, which simplifies work with the input data, analyzes the information coming from the device and immediately builds the necessary forecast and graphs. The algorithm of the program is based on the mathematical apparatus described above [6].

At the beginning of the program, the user is prompted to enter the input parameters, in this case, the odometer reading. one can enter data directly from the keyboard, or add them by reading from a file.
When one clicks on a button, the algorithm already starts processing data and generating graphs:

**Figure 1.** Input Data.

This graph shows the structural strength of the soil for the initial and final period of loading. As can be seen from the graph, over time, after some abrupt changes in the curve, the structural strength of the sample decreases and soil destruction occurs.

**Figure 2.** Sample sedimentation rate.

Graph of precipitation acceleration looks like this:

**Figure 3.** Acceleration of the sample.
Graph 3 gives more information about how the sample will behave in the final test phase and what its final structural strength will be. With the help of data from a graph, it is also possible to find out the error of calculations (for high accuracy, it is necessary to select an interval with values of at least 6 points) [7].

5. Conclusion
The following conclusion can be made from the two graphs and calculations presented above: the absence of intervals at which consistently high structural strength indices are observed indicates that the soil structure, with a high degree of probability, was broken even before testing. In this regard, it is not recommended to make hasty and concrete conclusions. The best option would be to re-probe the terrain and select another sample to study its mechanical characteristics [8].

Based on the work done, it can be concluded that it is necessary to approach the choice of terrain for building objects very carefully. Every step is important, starting with survey work, taking into account the availability of groundwater, soil characteristics and its mechanical properties. Laboratory studies play a key role in geology and are an important final stage. Therefore, the task of automating the process of laboratory research is very relevant. Gathered graphs, which essentially model the behavior of the soil, are able to provide a quick report on the characteristics of the soil, its initial structure and further behavior under high loads. All this significantly reduces the time of soil testing and formalizes the data obtained in a convenient form [9].

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