Creep testing on fiber reinforced sand

Vadim G. Ofrikhter i) and Ian V. Ofrikhter ii)

i) - Docent, Perm National Research Polytechnic University, 29, Komsomolskii prospect, Perm, 614990, Russia
ii) – Student, Civil Engineering Faculty, Perm National Research Polytechnic University, 29, Komsomolskii prospect, Perm, 614990, Russia

ABSTRACT

Sand reinforced with randomly oriented short polypropylene fibers (fiber reinforced sand, fibrosand, FRS) was tested to determine creep characteristics. This study is a part of research aimed at encouraging FRS application in subsoils, embankments and retaining wall constructions. Natural non-treated sand was used as a base material. Commercially available polypropylene fibers of 12 mm in length were used as reinforcement. Fiber content accounted for 0.93 %. Twin samples of FRS were put to creep tests using the two curve method. The test results were analyzed and checked with the use of ageing, hardening and hereditary creep theories. The results of a prolonged creep test on the samples under constant load were used to fit the creep parameters by the FORE method. The methodology and creep test results on FRS are given and discussed in the paper.

Keywords: fiber reinforced sand, creep behaviour

1 INTRODUCTION

Numerous tests for the determination of soil creep characteristics carried out by different researches testify that the creep curves obtained under constant and varying stepwise increasing loads differ from each other both qualitatively and by their relative position. Under the stepwise load increase the settlement, as a rule, is larger than that resulted from the same maximum load applied singly and at one step. The creep curves under maximum stepwise loading are located below the curves under maximum one-step loading. In the case of the stepwise load increase the creep curves depict the real development of a soil creep process in greater detail. For the determination of compression creep characteristics a method of two sample test is used (Meschyan, 1995). By this method two twin samples are tested, one of which is under the stepwise load increasing in time and the second one is under the constant load. The first curve (stepwise increasing load) is used for the determination of the stress – creep strain relation and stress function. The second curve (constant load) is used for the determination of creep measure parameters. By the creep measure the creep deformation under unit stress is meant. After having defined the creep measure and the stress function and assuming the similarity between the creep curves, we can plot creep curves for different values of constant stress by the relation.

Property estimation and determination of the heterogeneous soil compression creep parameters can be realized by the single-curve method (Meschyan, 1995). In this case, after the interval of load application has been assigned, one creep curve and an isochronous curve fitted with it are plotted on the basis of the averaged results of the series of samples tested by stepwise increasing load. Using these curves the stress – compression creep strain relation and the stress function are determined. The creep measure is defined by one of the curve pieces corresponding to one of the load steps.

2 TEST METHODOLOGY

When testing a specimen under stepwise increasing load it was important to determine the step interval of applied load correctly. It was no less important to form twin specimens. Specimens from fiber reinforced sand (FRS) were formed directly in the compression rings (87mm×25mm) with the layers of 12-14 mm. Each layer was compacted by a model tamper of 50 mm in diameter with a controlled tamping force of about 25 N. Five specimens were formed simultaneously. At trial formation the weight of the source material was defined. It was 240.8 g at a moisture content of 11.63 %.

In order to define the interval of the load application a series of 1-D compression experiments with five twin specimens of FRS was carried out when testing the fibrosand specimens. Four of them were tested under stepwise increasing load from 0.05MPa to 0.3MPa. Each step was equal to 0.05MPa with the retention interval of 1, 2, 3, 4 days, accordingly. Thus, the longest test with the use of the stepwise increasing load was equal to 24 days. The fifth specimen was tested at a
constant pressure of 0.3MPa for 24 days for determination of creep measure.

3 TEST RESULTS ON CREEP TESTING OF FRS

The test results on creep testing of the FRS specimens (1-D compression) are shown in Fig. 1. In accordance with the conventional technique, the experimental curved lines at different time intervals (1, 2, 3, 4 days) of load steps (50 KPa) application are given in the right part of the diagram, and the \( (\sigma - \varepsilon_{ct}) \) isochronal curves resulted from the stepwise loading are plotted in the left part. The test results show that a two-day interval of the load step application will be sufficient for FRS. Using the results of two twin specimens testing by the two curve method, the first specimen being at a constant pressure of 0.3MPa and the second one under the stepwise increasing loading with the steps of 50KPa and the retention interval of 2 days each (Fig. 2), we determine the compression creep parameters by the technique (Meschyan, 1995).

The creep curve at constant stress was approximated by the power function; the stress function was approximated by the cubic (third power polynomial).

4.1 Stress function

The approximation of isochronous curve \( \sigma - \varepsilon_{ct} \) (the left part in Fig. 2) was implemented in Excel software by adding a trend line to the empirical diagram (Fig. 3). The curve was approximated by the third power polynomial \((R^2=1)\) as follows:

\[
F\left(\sigma_{i}\right) = \varepsilon_{ct} = 1.5472 \sigma^3 - 1.1458 \sigma^2 + 0.362 \sigma \quad (1)
\]

where \(\sigma\) is stress in KPa.

4.2 Empirical creep curve at constant stress

The creep curve at constant stress \(\sigma = 0.3\)MPa was approximated in Excel software by the power function \((R^2 = 0.9797)\) (Fig. 4) as follows:

\[
\varepsilon_{ct} \left(\sigma_{i} = \text{const}\right) = 0.0357 t^{0.0244} \quad (2)
\]

where \(t\) is time in days.

4.3 Correction for deformation difference

By the end of the constant load application \(\sigma_{i} = \text{const} = 300\) KPa, the relative deformation had made up \(\varepsilon = (\sigma_{i} = \text{const}) = 0.03778\). By the end of the load step
application \( \sigma_i = 300 \) KPa when carrying out the test under stepwise increasing load, the relative deformation had made up \( \varepsilon (\sigma_i=\text{const})=0.047214 \). Correction for the difference of deformations \( \varepsilon_{\text{cor}} = \varepsilon (\sigma_i)/\varepsilon (\sigma_i=\text{const}) \) was as follows:

\[
\varepsilon_{\text{cor}} = 0.04724/0.03778 = 1.2504 \quad (3)
\]

**4.4 Creep measure determination**

The creep measure was defined taking into account the correction for deformation difference (3) from the expressions (1, 2, 3)

\[
C_c(t) = \varepsilon_{\text{ct}}(\sigma_i=\text{const}) F(\sigma_i) = 0.945 t^{0.0244} \quad (4)
\]

where \( F(\sigma_i) \) is the value of stress function (1) at 0.3 MPa

**4.5 Expression for creep deformations at constant stress**

On the basis of the creep measure (4) and stress function (1) relations the creep deformation equation at constant stress for tested fibrosand was as follows:

\[
\varepsilon_{\text{ct}}(\sigma, t) = C_c(t) \times F(\sigma) = 0.945 t^{0.0244} \left(1.5472 \sigma^3 - 1.1458 \sigma^2 + 0.362 \sigma \right) \quad (5)
\]

In accordance with the creep deformation equation (5) obtained for different values of constant stress (50, 100, ..., 300 KPa) the series of creep curves was plotted (Fig. 5).

![Fig. 5. Creep curves for different values of constant stress and curves taken from different theories](image-url)

**4.6 Method feasibility assessment**

Feasibility of the method was tested by using the description of an empirical creep curve in the well-known theories of ageing, hardening and hereditary creep (Fig. 5). The curves plotted on the basis of all those theories were in good agreement with the experiment and could be used in practice.

**4.7 Assessment of fibrosand secondary compression**

Assessment of fibrosand secondary compression was carried out by the FORE method (Handy, 2002) because the fibrosand test specimens were non-saturated and pore pressure did not dissipate. Under those conditions traditional methods (Taylor, Casagrande) did not predict secondary compression. The empirical curve resulted from testing the fibrosand specimen under the constant load of 300 KPa in the course of 24 days (576 hours or 34,560 minutes) was used for assessment purposes (Fig. 6).

On the basis of the data obtained in the course of testing the first order rate equation (FORE) for the stage of secondary compression was worked out. The equation fitting was implemented using MS Excel software. According to (Handy, 2002) a spreadsheet was tabulated, a graph was plotted and a linear approximation best-agreed with the experimental dependence was fitted. The coincidence of the experimental dependence and linear approximation was estimated using the coefficient of determination \( R^2 \).

![Fig.6. Curve resulted from the 24-day compression test of the FRS sample at a constant stress of 300KPa](image-url)

The data were taken in the interval of 10,080-33,040 minutes. On the basis of the empirical curve analysis (Fig. 6) the characteristic points were chosen and the spreadsheet was tabulated (Table 1).

**Table 1. Spreadsheet for rate equation (eu=0.7041)**

| X(t, min) | Y (e) | Yu-Y | [Yu-Y] | lg[Yu-Y] |
|-----------|-------|------|--------|----------|
| 10080     | 0.705637 | -0.001537 | 0.001537 | -2.813326 |
| 15120     | 0.705232 | -0.001132 | 0.001132 | -2.946154 |
| 15840     | 0.705232 | -0.001132 | 0.001132 | -2.946154 |
| 21600     | 0.704827 | -0.000727 | 0.000727 | -3.138466 |
| 25920     | 0.704624 | -0.000524 | 0.000524 | -3.280669 |
| 33840     | 0.704222 | -0.000322 | 0.000322 | -3.492144 |

Trial values of the void ratio had been set by the end of the secondary compression and then tested by matching the obtained “time (x) – lg |\varepsilon_{\text{cor}}-e| (y)” curve with its linear approximation (Fig. 7).

As a result, the value of the void ratio by the end of the secondary compression had been \( e_{\text{cor}}=0.7041 \left(R^2 =0.9969\right)\), for which the FORE (6) and the “rate” expression for the void ratio (7) were as follows:

\[
y = -0.00003 x - 2.5044
\]
\[
\lg (e - 0.7041) = -0.00003 t - 2.5044 \quad (6)
\]
\[
e = 10^{(-2.5044 - 0.00003 t)} + 0.7041 \quad (7)
\]

According to the realized curve construction the secondary compression had begun by the time moment being equal to 9360 min. The void ratio by the beginning of the secondary compression had amounted to 0.70574.

5 CONCLUSIONS

Fibrosand is a specific type of improved soil relating to so-called pseudo-cohesive soil. The filtration coefficient of FRS is about 1 m per day like non-cohesive soils. Under creep testing fibrosand specimens are non-saturated as a rule and pore pressure does not dissipate. Secondary compression, the term used for the creep stage of pseudo-cohesive soils, is proposed instead of secondary consolidation used in soil mechanics for natural cohesive soils. Pseudo-cohesive soil testing helps understand the distinctive features of the stress-strain state of this kind of materials. Municipal solid waste also relates to them. Application of the two-curve method ensures the correct determination of creep deformations under stepwise loading as well as the secondary compression assessment of pseudo-cohesive soils.

REFERENCES

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