Methods for producing laboratory samples of soils reinforced with inorganic binders

Nadezhda Slobodchikova

1 Irkutsk National Research Technical University, Department of Jurisprudence, 83 Lermontov street, 664074, Irkutsk, Russia

Abstract The article discusses the methods for producing laboratory samples of soils reinforced with inorganic binders. In the Russian Federation, production of laboratory samples of reinforced soils is regulated by SS 23558-94 “Road and airfield construction mixtures of black stone, gravel-sand and soils reinforced with inorganic binders. Technical conditions (with amendments No 1, 2) and SS “Public roads. Soils reinforced with inorganic binders. Specifications”. These documents describe two approaches to sample production: the impact method and the static load method. The article studies the application of these methods in the laboratory conditions. It was found that the impact method has a number of drawbacks that distort physical and mechanical characteristics of reinforced soils. It was found that the static load method is the most accurate and less labor intensive. The use of cylindric forms for producing samples of reinforced soil simplifies the production process and improves geometric characteristics of the samples.

1. Introduction

The use of soils reinforced with inorganic binders in road construction can significantly reduce the cost of pavement construction. The high-quality material can be produced by pre-selecting the composition of the reinforced soil in the laboratory [1–9]. To select the composition of reinforced soil, it is necessary to produce laboratory samples.

In the Russian Federation, selection of the composition of soils reinforced with inorganic binders and production of laboratory samples of reinforced soils are regulated by

• PNS “Public roads. Soils reinforced with inorganic binders. Specifications» [10];
• ST 23558-94 Road and airfield construction mixtures of black stone, gravel-sand and soils reinforced with inorganic binders. Technical conditions (with amendments No 1, 2) [11].

These documents describe two sample production methods: the impact method and the static load method. Practical implementation of these methods generates contradictions and difficulties [12].

2. Materials and methods

Impact method applied by the Road Union Research Institute. According to SS 23558-94, selection of the composition and production of samples are based on the maximum density and optimum moisture content of the reinforced soil in accordance with SS 22733 with the following amendments: to prepare and test samples of mixtures with a maximum grain size of 20 mm, a large tool of the RURI is used.

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Three portions of the mixture are poured into the form and rodded 25 times with a metal rod 12 mm in diameter. After laying the entire mixture, it is compacted with 120 beats of 2.5 kg in weight falling from the height of 30 cm [11].

According to the results of numerous laboratory tests, it was established that maximum density of the soil and reinforced soil have the same values of optimum humidity (Fig. 1, 2).

![Figure 1](image1.png)

**Figure 1.** The dependence of density of dry soil on moisture.

![Figure 2](image2.png)

**Figure 2.** The dependence of density of dry soil reinforced with a 6% cement addition on moisture.

The sample production method described in SS 22733 and SS 22733-2016 “Soils. Method of laboratory determination of maximum density (as amended)” [13] applied for soils reinforced with inorganic binders has several disadvantages:

- The standard compaction method developed by RURI is used for soils with a maximum particle size of 20 mm which limits its use for soils containing particles of more than 20 mm;
- Preparation of a soil sample includes moistening and keeping it at a room temperature for at least 2 hours for non-cohesive soils and 12 hours for cohesive soils. In testing the soil moisture is increasing. The number of consecutive tests is 5. When adding water, the non-cohesive soil stands for at least 15 minutes, and the cohesive soil stands for at least 30 minutes. On average, the testing time is 4–5 hours for non-cohesive soils and 15–16 hours for...
cohesive soils. The setting time is from 45 minutes to 10 hours [14]. The setting period ends 3-4 hours after mixing.

- The use of a nozzle generates a difference in density by the mass of the sample;
- The grooves formed after stripping the sample surface due to precipitation of large particles are manually filled with soil from the remaining part of the sample and leveled with a knife, which also distorts the density data;
- Samples have irregularities which distort the results of compression testing samples;
- In the Standard Seal Instrument, the tamper diameter corresponds to the internal diameter of the instrument. This causes crushability of large particles.

SS 23558-94 provides recommendations for preparation and testing of mixture samples with a maximum grain size of up to 5 mm. A small device developed by the RURI is used. The mixture is poured into the form, rodded 25 times with a metal rod, compacted with 20 beats of a 2.5-kg weight falling from the height of 20 cm.

This method is not correct because:

- Reduction of the number of beats decreases density;
- The use of a nozzle generates a difference in density by the mass of the sample;
- Samples have irregularities which distort the physicomelchanical characteristics of reinforced soils;
- In the Standard Seal Instrument developed by the RURI, the tamper diameter corresponds to the internal diameter of the instrument. This causes crushability of large particles;
- The value of optimum moisture is larger than the amount of water required for mixing inorganic binder in the soil mixture. It reduces strength and frost resistance of reinforced soils.

Consequently, sample production using the standard compaction method developed by the RURI does not ensure high homogeneity of the results, and is extremely labor-consuming.

**Sample production using the PNS method.** Clause 7.1. of the PNS “Public roads. Soils reinforced with inorganic binders. Specifications” regulates determination of maximum density and optimum humidity in accordance with the PNS “Public roads. Soils. Determination of optimal humidity and maximum density using the Proctor method” [15]. This standard is a modified ASTM D 1557-91 method [16], which is based on the use of shock loads according to the Proctor method with an increase in the compacting load mass and fall height.

The samples are prepared at optimum humidity determined with a binder added to the soil. A compacting hammer weighing 4.5 kg is used. The number of compaction layers is 5, the number of strokes per layer is 25.

The PNS methods for soils reinforced with inorganic binders and SS 23558 have the following drawbacks:

- The standard is not applied to soils and mixtures of crushed stone, gravel and sand containing more than 25% of particles larger than 63 mm;
- Grooves formed after stripping the sample surface due to the loss of large particles are manually filled with soil from the remaining part of the sample and leveled with a knife. It distorts the density data.
- When parsing the form, part of the soil sticks to the walls, destroying the sample solidity and structure.

An increase in the mass of the compaction load allows for modeling compaction which is higher than that produced using the RURI method. Quality characteristics of reinforced soils are dependent on the degree of compaction. Sample production using this method is time consuming.

**Sample production using the static load method.** SS 23588-94 allows for using the pressing method. For mixtures with a maximum thickness of up to 5 mm with dimensions of 50 or 100 mm, beams of 40x40x100 mm are used; for mixtures with a maximum thickness of up to 20 mm, beams of
100x100x400 mm are used. Approximate press pressure for a mixture with a maximum thickness of up to 5 mm is 15 MPa; with a thickness of 20 mm – 20 MPa; the time under load is 3 minutes.

This method also has several disadvantages:

- It is difficult to produce sample cubes and beams, because SS 23558-94 does not provide recommendations for cube and beam forms;
- There are no requirements for sample-cubes and sample-beams;
- The method is applied to soils with a maximum particle size of less than 20 mm which limits its use to soils containing particles larger than 20 mm.

The use of static load is preferable:

- Static load ensures constant density of samples of reinforced soils and higher homogeneity of the results [17].
- The samples are smooth and have a better appearance compared to those produced using the standard compaction method.

The density of samples produced at a pressure of 15-20 MPa corresponds to the maximum density determined on the standard compaction instrument. Production of samples at a pressure of 30 MPa makes it possible to achieve a maximum density value which is not smaller than that determined by the modified Proctor method.

To eliminate these drawbacks, it is necessary to cylinder forms described in SS 12801-98 “Materials based on organic binders for road and airfield construction. Test methods” (Table 1).

Table 1. Sizes of cylindrical forms according to SS 12801 [18].

| The largest grain size of soil, mm | Size, mm | Sample area, cm² |
|-----------------------------------|----------|-----------------|
|                                   | Diameter d | Height H | Top liner height h₁ | Bottom liner height h₂ |          |
| 5                                 | 50.5      | 130      | 80            | 50           | 20  |
| 10, 15, 20                        | 71.4      | 160      | 100           | 60           | 40  |
| 40                                 | 101       | 180      | 110           | 70           | 80  |

The mass of the soil producing one sample for different types of soil is 600 - 2200 g. Cylinder samples, depending on the size of the forms, are 50.5; 71.4; 101.0 mm in height. If the cylinder samples have a height different from the specified dimensions, an adjustment of the mixture mass g is required

\[ g = g_0 \frac{h}{h_0}, \]  

where \( g_0 \) - mass of the sample, g;
\( h \) - height of the sample, mm;
\( h_0 \) - height of the testing sample, mm.

Production of a series of cylinder samples of the same size using these forms is much simpler than the use of the standard compaction instrument designed by the RURI or a modified Proctor method. The produced samples are smooth, without shells and chips, of constant height and weight. Good quality of samples reduces differences of the results of parallel tests of reinforced soils for strength, water resistance, and frost resistance, etc.

3. Conclusion

High-quality production of laboratory samples of reinforced soil is very important because it determines quality of the mixture and accuracy of the determination of physical and mechanical characteristics of the reinforced soil.

The following conclusions can be drawn:

- Production of samples by the standard compaction method does not allow for accurate results of laboratory tests of fortified soils;
• Production of samples by the standard compaction method and the modified Proctor method is laborious and time consuming;
• Production of samples by the static load method allows for high-quality and rapid production of samples.
• Cylinder forms should be used for producing samples of reinforced soils.

References

[1] Production Division Office of Geotechnical Engineering 120 South Shortridge Road Indianapolis, Indiana 46219. 13 (2008).
[2] Field Manual No. 5-410 Headquarters Department of the Army Washington, Change 1, 4. 344 (1997).
[3] G. P. Makusa. Department of Civil, Environmental and Natural resources engineering Division of Mining and Geotechnical Engineering Luleå University of Technology. 35 (2012).
[4] V.M. Bezzuk, I.L. Guryachkov, T.M. Lukanina, R.A. Agapova. 231 (1982).
[5] I.A. Ivanov, E.V. Volkova, E.I. Ivanov, D.N. Nechaev. Izvestiya vuzov. Investitsii. Stroitelstvo. Nedvizhimost. № 2 (13). 45 (2015).
[6] V.P. Podolsky, Nguyen Van Long, Nguyen Duc Shi. Scientific Bulletin of Voronezh State University of Architecture and Civil Engineering. Construction and architecture. Issue 1 (33) 102 (2014).
[7] Manual for construction of road and airfield coatings and foundations on the soils reinforced with binders according to SNR 3.06.03-85 and SNR 3.06.06-88. Moscow (1990)
[8] Highways and bridges. Construction of constructive layers of pavement on soils reinforced with binders. Review. Vol. 3. (2007)
[9] N.V. Zhukov, A.V. Shaposhnikov. Concrete and reinforced concrete. № 2. (1990)
[10] Standard “Public automobile roads. Soils reinforced with inorganic binders. Technical conditions”.
[11] State Standard 23558-94 (1994).
[12] N.A. Slobodchikova, K.V. Pluyta. Collection "Roads and Bridges", Vol. 39. 336 (2018).
[13] State Standard 22733-2016 (2016).
[14] State Standard 10178-85 (1985).
[15] Standard “Public automobile roads. Soils. Determination of optimal humidity and maximum density using the Proctor method”.
[16] ASTM D 1557-91 (1991).
[17] S.G. Fursov. Science and technology in the road. branches - № 4 (2006).
[18] State Standard 12801-98 (1998).