Study of the stability of soil slopes and downhills with the use of fiberglass dowels

A K Ryabukhin*, V A Lesnoy, D Y Kalashaov
Kuban State Agrarian University, 13, Kalinina Str., Krasnodar, 350044, Russia

E-mail: ryabukhin@geoproekt.net

Abstract. This article presents the findings of a study of applicability of fiberglass dowels for reinforcement of soil slopes and downhills in geological conditions of the Greater Sochi. Within the framework of the performed surveys, the analysis of the data array on engineering-geological conditions has been executed, physical- and mechanical properties of soil properties for the Greater Sochi have been defined. According to the results of mathematical modeling in the software complex PLAXIS, applicability of using fiberglass dowels and its scope of application has been determined. Economic efficiency in comparison with the widely-used soil dowels Titanium has been herein estimated. According to the survey findings multiple landslide areas with surficial character of formation, which currently do not threaten the safety of human life, are identified. However, lack of timely measures on fixation of the above said slope areas may lead to the development of global deformations.

Introduction

Normally, at the initial phase of the landslide development we can observe occurrence of the erosion scouring, small cracks and then their development up to crack stretching, forming of sagging deformations and shaping of disruption sidewalls on the landslide. Finally, the landslide loose appears and displacement of the landslide solid is formed. When no measures are taken to fix the slope stability in its initial phase, it may lead to the collapse of slopes and downhills, which jeopardizes the safety of human activities.

Now it is possible to fix the slopes and downhills with metal dowels Titan, GeoIzol, GeoBrug, etc. However, their application is expensive. An alternative solution may be the application of the composite rebars.

As you know, the dowelled constructions operate in tension. Analysis of experimental studies shows that fiberglass dowel is able to take significant tensile forces, and its production is much cheaper than of a metal one. Hence, it is advisable to make a kind of survey of applicability of fiberglass dowels for fixation of soil slopes and downhills.

Analysis of regulatory sources to determine the strength properties of fiberglass dowels

According to the analysis of the documents, the most extensive information is obtained for the fiberglass composite rebars ASK. Below there are given the strength properties of fiberglass dowel and brief comments to the normative documents.
The cross-sectional area of composite rebars is presented according to the Technical Conditions 2296-016-20994511-2009. The deformation modulus is \( E = 45 \, 000 \, \text{MPa} \). Elongation is not defined, which is unacceptable by designing the dowel fastening. The related figures are presented in Table 1.

**Table 1. Basic parameters under the Technical Conditions 2296-016-20994511-2009**

| Diameter \( d \), [mm] | 16   | 18   | 20   | 22   | 26   | 28   | 30   |
|------------------------|------|------|------|------|------|------|------|
| Crosssection area \( A \), [mm\(^2\)] | 201  | 254  | 314  | 380  | 491  | 615  | 706  |
| Elastic modulus \( E \), [MPa]      | At least 45000 |      |      |      |      |      |      |
| Elongation at break, [%] |     |     |     |     |      |      |      |

The fulness of index numbers relating to the Technical Conditions 2296-016-20994511-2009 is given more precise in the document [1]. It contains an index of elongation at break, which is 3.0 % of the tested pattern length.

However, according to [2], at determining the elastic modulus \( E \) of the composite rebars, the diameter of the tested patterns is taken into account, and it is not clear how come at \( d = 22 \div 30 \, \text{mm} \) the elastic modulus is reduced by 400 MPa up to a value of 45 600 MPa (Table 2). All while, the cross-sectional areas almost match the Technical Conditions 2296-016-20994511-2009. In this document the cross-sectional area is determined according to the formula:

\[
A = \frac{\pi d^2}{4}
\]

where \( d \) – diameter of dowel, mm.

**Table 2. Basic parameters under [2]**

| Diameter \( d \), [mm] | 16   | 18   | 20   | 22   | 26   | 28   | 30   |
|------------------------|------|------|------|------|------|------|------|
| Crosssection area \( A \), [mm\(^2\)] | 201  | 255  | 315  | 380  | 491  | 616  | 710  |
| Elastic modulus \( E \), [MPa]      | At least 46 000 | At least 45 600 |      |      |      |      |      |
| Elongation at break, [%] |     |     |     |     |      |      | At least 3.0 |

According to [1], the cross-sectional area of composite rebars is significantly lower than the one given in the above said documents (Tables 1, 2). The modulus of deformation differs by about 25000 MPa despite the fact that the dowel elongation is 2.2 %. The related figures are presented in Table 3.

**Table 3. Basic parameters under [1]**

| Diameter \( d \), [mm] | 16   | 18   | 20   | 22   | 26   | 28   | 30   |
|------------------------|------|------|------|------|------|------|------|
| Crosssection area \( A \), [mm\(^2\)] | 123  | 154  | 201  | 254  | 380  | 452  | 530  |
| Elastic modulus \( E \), [MPa]      |     |     |     |     | At least 70 000 |      |      |
| Elongation at break, [%] |     |     |     |     |      | At least 2.2 |      |

According to [3], it can be noted that the cross-sectional area of composite rebars is not given at all, while the elastic modulus \( E \) of the fiberglass dowel does not differ and is at least \( E = 55 \, 000 \, \text{MPa} \) (Table 4).

**Table 4. Basic parameters of fiberglass dowel under [3]**

| Diameter \( d \), [mm] | 16   | 18   | 20   | 22   | 26   | 28   | 30   |
|------------------------|------|------|------|------|------|------|------|
| Crosssection area \( A \), [mm\(^2\)] | -    | -    | -    | -    | -    | -    | -    |
| Elastic modulus \( E \), [MPa]      |     |     |     |     | At least 55 000 |      |      |
| Elongation at break, [%] |     |     |     |     |      | At least 2.2 |      |

According to the code of rules 295.1325800.2017, the elastic modulus \( E \) of fiberglass dowel is assumed to be \( E = 50 \, 000 \, \text{MPa} \), while the normative document does not specify such the important parameters for calculation as the relative elongation at break or the cross-sectional area of composite
rebars. At analysing the most elaborated company's code [4], it is notable that the document determines the scope of application of composite rebars. However, the specific strength properties of composites required for design are not presented, and neither full-scale, nor mathematical confirmation of the composite rebar applicability is performed.

Thus, based on the results of a comparative analysis of the strength properties of fiberglass dowel, in accordance with various regulatory and methodological documents, it should be noted that this material can be used in the structures working on tension, for example, at fixation of soil slopes and downhills with dowels.

It is also notable that in [4] there are presented recommendations for application of composite rebars for dowelled fixation.

In practice, fiberglass rebars were not used for dowelled fixation of slopes and downhills, therefore, for approval of its applicability it is required to perform:
- mathematical modeling in view of various geological conditions;
- full-scale testing after implementation of mathematical modeling.

Taking into consideration the results of the analytical review of studies, as well as the regulatory documents, the strength properties of the most popular fiberglass composite rebars are here preliminarily determined (Table 5). The cross-sectional area $A$ is adopted according to [1]. The modulus of elasticity $E$ is determined according to the code of rules 295.1325800.2017. Elongation at break is at least 2.2\%.

According to the said parameters, the stiffness and bearing capacity of composite rebars are here determined.

Table 5. Generalized parameters of fiberglass dowel ASK

| Diameter $d$, [mm] | 16 | 18 | 20 | 22 | 26 | 28 | 30 |
|--------------------|----|----|----|----|----|----|----|
| Crosssection area $A$, [mm$^2$] | 123 | 154 | 201 | 254 | 380 | 452 | 530 |
| Elastic modulus $E$, [MPa] | At least 50 000 |
| Elongation at break, [%] | At least 2.2 |

In order to determine the final strength properties of fiberglass dowel, taking into account some specific production technology, each manufacturer is recommended to do his own tests. So, in near future it is planned to test fiberglass dowel of LLC RIO-RITA production in the laboratories of the Kuban State Agrarian University. The related control patterns have been now prepared. Tests of composite rebars made by LLC RIO-RITA shall be carried out, and the results shall be reported at the conference.

Analysis of geological conditions within the Greater Sochi area

As part of this study, the analysis of the geological conditions of the Greater Sochi area is done with regard to the results of the previous surveys. It is required to establish the boundary values of the strength properties of soils for their application within the framework of mathematical modeling and for available use of composite rebars to ensure the resistance of slopes and downhills.

On the basis of geographical location and fullness of information of engineering and geological properties of the Greater Sochi, it is divided into four target areas:
- № 1 – geological conditions in the road area of Makopse village – Nadzhigo aul, and Ashe railway station — Lygotkh aul;
- № 2 – geological conditions in the road area of Lazarevskoye village– Tkhagapsh aul, and Tkhagapsh aul – Marino village;
- № 3 – geological conditions in the road area of Loo village – Verkhnearmyanskoye Loo village, and Uchdere village – Upper Uchdere village;
- № 4 – geological conditions in the road area of Dagomys village – Solokhaul aul, and Dagomys village – Baranovka village.
In the course of determining the strength properties of soils within the boundaries of target areas, the reports of engineering and geological surveys are analyzed. Volumes of numerical indicators are presented in Table 6.

**Table 6. Volumes of numerical indicators in territorial areas**

| №  | Title of facility     | Within boundaries of settlements | Earth bore, m. p. | Numerical indicators, pcs. |
|----|-----------------------|----------------------------------|-------------------|----------------------------|
| 1  | Target area № 1       | Makopse, Nadzhigo, Ashe, Lygotk | 947               | 716                        |
| 2  | Target area № 2       | Lazarevskoye, Tkhagapsh, Marino  | 912               | 674                        |
| 3  | Target area № 3       | Loo, Upper Loo, Uchdere, Upper Uchdere | 439              | 869                        |
| 4  | Target area № 4       | Dagomys, Solokhaul, Baranovka    | 645               | 1080                       |

The analysis of the data of engineering and geological surveys made it possible to identify the main features of the studied target areas and to determine the strength properties of soils necessary for the implementation of mathematical modeling.

Tables 7-10 provide for the summarized data on the upper and lower limits of the strength properties of soils within the target areas.

**Table 7. Area № 1. Generalized strength properties of soils**

| Parameter | UoM | EGE-1 | EGE-2 | EGE-3 | EGE-4 |
|-----------|-----|-------|-------|-------|-------|
| γ   | kH/m³ | 18.0-19.2 | 18.0-23.0 | 24.8-26.3 | 24.7-26.3 |
| E   | kPa  | –      | 29000-31000 | 10000-102000 | 10000-125000 |
| e   | kPa  | –      | 10-15   | –      | –      |
| φ   | deg. | –      | 19-25   | –      | –      |
| R   | kPa  | –      | –      | 1500-92000 | 4000-91000 |

**Table 8. Area № 2. Generalized strength properties of soils**

| Parameter | UoM | EGE-1          | EGE-2          | EGE-3            | EGE-4          |
|-----------|-----|----------------|----------------|------------------|----------------|
| γ   | kH/m³ | 18.9-20.0      | 17.7-20.4      | 24.8-26.3        | 24.7-26.3      |
| E   | kPa  | 31000-38000    | 18000-38000    | 10000-105000     | 30000-148000   |
| e   | kPa  | 7-21           | 7-34           | –                | –              |
| φ   | deg. | 24-30          | 6-24           | –                | –              |
| R   | kPa  | –              | –              | 1500-92000       | 12 800-91 800  |

**Table 9. Area № 3. Generalized strength properties of soils**
| Title | Filled soil | Clay layer, silty cobble | Clay-loam, clay layer, grus soil | Marl | Marl |
|-------|-------------|--------------------------|---------------------------------|------|------|
| $\gamma$ | kH/m$^3$ | 16.6-17.6 | 17.8-21.4 | 17.1-19.5 | 22.8-24.7 | 21.8-23.7 |
| $E$ | kPa | -- | 6800-12200 | 17300-27000 | 10000-94700 | 11000-109500 |
| $c$ | kPa | -- | 16-39 | 12-37 | - | - |
| $\varphi$ | deg. | -- | 5-21 | 5-16 | - | - |
| $R$ | kPa | -- | - | - | 9600-33000 | 25900-55000 |

Table 10. Area № 4. Generalized strength properties of soils

| Parameter | UoM | EGE-1 | EGE-2 | EGE-3 | EGE-4 | EGE-5 |
|-----------|-----|-------|-------|-------|-------|-------|
| $\gamma$ | kN/m$^3$ | 16.9-20.8 | 17.8-19.8 | 18.8-20.3 | 22.6-24.7 | 24.7-25.5 |
| $E$ | kPa | 12000-28000 | 11000-36000 | 12300-27000 | 10400-101200 | 11700-127300 |
| $c$ | kPa | 18-32 | 15-47 | 12-32 | - | - |
| $\varphi$ | deg. | 15-20 | 11-30 | 11-21 | - | - |
| $R$ | kPa | -- | - | - | 9000-31000 | 25200-45000 |

On the basis of the performed analysis of the results of engineering and geological surveys within the selected target areas, the types and forms of soils are here determined. As a rule, dispersive clay and cobble soils underlay in the upper layers. The bedrock includes rock soils such as mudstones, marls and sandstones of various strength.

**Initial data and calculation results at dowelled fixation**

Within the framework of this study, a mathematical modeling under the most typical for each target area engineering and geological sections has been performed. Slopes and downhills are built with the most optimal steepness. Four target areas are combined into two due to the similarity of topographic and geological conditions (Table 11).

When determining the length of the dowel bars on slopes and downhills, several clay layers exposed to the landslide deformations were taken into consideration. To ensure the required embedding in the rock soils for the site № 1, the dowel length of 5.0 m is taken, for the site № 2 – the dowel length of 10.0 m.

Landslide slope/downhill deformations are modeled with the use of the interface of the PLAXIS calculation program, which operates as a sliding surface of landslide along the border of the dispersive and rocky soil. At that, for the sliding surface there were set some physical and mechanical properties of soils obtained in the course of the soil testing "chuck upon chuck".

Table 11. Research areas within the boundaries of the Sochi region

| № | Title of facility | Within boundaries of settlements | Earth bore, m. p. | Numerical indicators, pcs. |
|---|------------------|---------------------------------|------------------|--------------------------|
| 1 | Target area № 1 | Makopse, Nadzhigo, Ashe, Lygotkh | 1856 | 1363 |
In this paper the detailed results are presented only for the territorial zone 1. All the necessary calculations are made for the territorial zone 2 as well, those are presented in Table 13.

When modeling the resistance of a downstream side of the slope, within the territorial zone 1, in its natural state, it was found that the slope occurs to be in a state of ultimate equilibrium, and the coefficient of resistance is $k = 1.045$ (figure 1). Let us assume that during periods of large precipitation there is a probability of formation of a surface landslide body with the capacity of up to 2.5 m (along the border of dispersive and rocky soil). The results of calculation proved the landslide activity of a slope downstream side. The coefficient of resistance is $k = 0.994$.

| Target area № 2 | Lazareskoye, Tkhagapsh, Marino | Loo, Upper Loo, Uchdere, Upper Uchdere | Dagomys, Solokhaul, Baranovka | 1084 | 1949 |

In the framework of this study, we considered the fixation of slopes with metal and fiberglass dowel bars. As metal fasteners there are selected dowel bars produced by the Titan company, with the nominal size of bars 40/16 mm. As fiberglass dowels there are selected three rods of 12 mm in diameter, tightened by metal clamps with 200 mm step. In order to ensure the position of the rods exactly in the center of the borehole, there are some special spacers used, with step alongside the rod 1.0 m.

In order to evaluate the bearing capacity of the dowels on soil and material, some calculations are done according to the methods of the company's code Transstroy-023-2007 "Application of ground anchors and piles with thrust from tubicolous screwed pull-rods Titan. Bearing capacity of dowels for soils is 74.73 kN. Bearing capacity on material of the dowels Titan 40/16 is 289.64 kN, and that of the dowels ASK is 3Ø12 mm - 185.02 kH.

When enabled the dowel bars Titan 40/16 5.0 m long with step 1.0 m, the resistance of the slope downstream side in its natural state is provided as $k = 1.275$ (figure 2). This type of dowels can be applied as a permanent measure of engineering protection. At the same time, the maximum forces arising in the dowels with step of 1.0 m are $N = 1.75$ kH, which is significantly lower than the maximum permissible value of $N_{max} = 74.73$ kH.

At calculation of the data on the slope downstream side in its natural state with appliance of the dowels Titan 40/16 with step 2.0 m, the resistance is not provided. The simulation model is loaded by 20 %.
At calculation of the slope downstream side with the dowelled fixation with Titan 40/16 with step 1.0 m, with the seismicity 8 points, the resistance is ensured as $k = 1.153$ (figure 3). The bearing capacity of the dowel bars Titan 40/16 is provided as $N = 29.33 \text{ kN}$.

When the landslide is progressing, fixation of the downstream side of the slope with dowel bars Titan 40/16 with step 1.0 m can be applied only as a temporary solution, for example, within the framework of emergency response. The resistance of the downstream side is $k = 1.197$ (figure 4). Bearing capacity of the dowel bars is provided by Titan 40/16 and it makes $N = 11.49 \text{ kN}$.

When enabled, the dowels ASC 3ø12 MM 5.0 m long with step 1.0 m the resistance of the downstream side in its natural state is provided as $k = 1.276$ (figure 5). This type of dowel bars can be applied as a permanent measure of engineering protection. At the same time, the maximum forces arising
whithin the dowel bars with step 1.0 m make $N=1.75$ kH, which is significantly lower than the maximum permissible value $N_{\text{max}}=74.73$ kH.

At calculation of the data on the downstream side in its natural state, with appliance of dowels Titan 40/16 with step 2.0 m, the resistance is not provided. The simulation model is loaded by 19 %.

![Figure 5](image)

**Figure 5.** Resistance of downstream side with appliance of fiberglass dowels ASK 3Ø12 mm, step 1.0 m. $k=1.276$

At calculation of the downstream side with fiberglass dowels ASK 3Ø12 mm with step 1.0 m, given seismicity 8 points, the resistance is ensured as $N=7.93$ kH (figure 6). The bearing capacity of the dowels is provided with Titan 40/16 as $N=7.93$ kH.

![Figure 6](image)

**Figure 6.** Resistance of downstream side at fixation with fiberglass dowels ASK 3Ø12 mm, step 1.0 m, given seismicity 8 points. $k=1.152$

When the landslide is developing, fixation of the downstream side with fiberglass dowels ASK 3Ø12 mm with step 1.0 m can be applied only as a temporary solution within the framework of the emergency response. The resistance of the downstream side is $k=1.196$ (figure 7). Bearing capacity of fiberglass dowels ASK 3Ø12 mm makes $N=11.65$ kH.
Figure 7. Resistance of downstream side with fiberglass dowels ASK 3Ø12 mm step 1.0 m at landslide development. \(k = 1.196\)

Thus, in the framework of comparison and evaluation of the effectiveness of the fiberglass dowels ASK, we found that the appliance of those is allowed on the slopes and downhills within the target area 1 with the power of dispersive soils and landslide up to 2.5 m. In these conditions, there is no significant difference between the performance capability of the fiberglass dowels ASK and the metal dowels Titan. At the same time, when roughly estimated, the use of fiberglass dowels ASK is almost 3.0 times more profitable than that of Titan 40/16. That is, with the scope of work in 1000 rm. (running meters), the cost of fixation of the soil slopes will be:
- Metal dowel Titan 40/16 – 10 million rubles;
- Fiberglass dowel ASK 3Ø12 mm – 3.3 million rubles (saving 6.7 million rubles).

Summary
Within the frameworks of this study, there has been made a mathematical modeling of dowelled fixation with metal and fiberglass (ASK) rebars for the two target areas. According to the simulation results, it was found that, in the studied target areas it is possible to replace metal dowels Titan 40/16 with fiberglass dowels ASK 3Ø12 mm. The application areas for dowel bars are presented in Tables 12 and 13.

Table 12. Application range for metal dowels Titan and for fiberglass dowels ASK (site 1)

| Dowel type   | Step, m | Operation condition | Natural state | Developmet of landslide |
|--------------|---------|---------------------|---------------|-------------------------|
|              |         |                     | No seismicity | 8 point |
|              |         |                     | No seismicity | 8 point |
| Titan 40/16  | 1.0     | temporary           | +             | +       |
|              |         | permanent           | +             | +       |
| ASK 3Ø12 [mm]| temporary | +             | +             | +       |
|              | permanent | +             | +             | +       |
| Titan 40/16  | 2.0     | temporary           | -             | -       |
|              |         | permanent           | -             | -       |
| ASK 3Ø12 [mm]| temporary | -             | -             | -       |
|              | permanent | -             | -             | -       |

Table 13. Application range for metal dowels Titan and for fiberglass dowels ASK (site № 2)

| Dowel type   | Step, m | Operation condition | Natural state | Developmet of landslide |
|--------------|---------|---------------------|---------------|-------------------------|
|              |         |                     | No seismicity | 8 point |
|              |         |                     | No seismicity | 8 point |
| Titan 40/16  | 1.0     | temporary           | +             | +       |
|              |         | permanent           | +             | -       |
| ASK 3Ø12 [mm]| temporary | +             | +             | -       |
|              | permanent | +             | -             | -       |
| Titan 40/16  | 2.0     | temporary           | +             | +       |
|              |         | permanent           | +             | -       |
| ASK 3Ø12 [mm]| temporary | +             | +             | -       |
|              | permanent | +             | +             | -       |

References
[1] Technical conditions 2296-290-36554501-2010 Non-metallic composite extra-strong dowel with higher modulus of elasticity. (2010).
[2] Technical conditions 5769-001-00243240-2010 *Non-metallic composite rebars*.

[3] Technical conditions 5768-001-86901126-2011 *Polyurethane foam slab PPU TIS 70 (W)* 1000×800×50. (2010).

[4] Company's code 2.6.90-2013 *Application in transport construction of non-metallic composite rebars with periodic profile.* (2013).