AN INNOVATIVE APPROACH TO ROADBED RECONSTRUCTION

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ABSTRACT

The article introduces the research in the field of reconstruction and strengthening of the roadbed of railways, the method of calculation and design of dowel-lath structures, reinforcing the surface sloping parts of the subgrade, created with the author's participation. The rational dowel sizes are defined, innovative technical solutions for the roadbed for construction of the second tracks are offered, using mathematical and physical centrifugal modeling. The laboratory installation and technique of bench tests of reinforcing elements for different types of dowel structures are developed.

Keywords: railway, roadbed, dowel, innovative structure, modeling, design, bench testing, reconstruction, calculation methods, reinforcing elements.

Background.

Improving the reliability of infrastructure of rail and road transport and traffic safety through the introduction of innovative and resource-saving technical solutions – ground dowel systems in construction and reconstruction of the roadbed facilities (including those located in seismically active areas) is a promising engineering solution.

Years of research and development – production works carried out in our country and abroad have shown the effectiveness of application of reinforced ground structures and dowel-lath structures to reinforce the roadbed. Nevertheless, the analysis shows that stress state of reinforced soil is understudied, and little attention was paid to research of deformability of reinforced structures with geomaterials.

The main indicator of reliability of construction objects is the impossibility of exceeding the limit states in them under the influence of the most unfavorable combination of calculated loads over the forecast useful life [1].

In the federal regulations to assess roadbed reliability it is offered to apply the safety factor, which depends on the line category.

Stability of slopes is determined by comparing the calculated values of safety factors (sustainability) K_s with permissible safety factor (sustainability) $[K_s]$ in accordance with the requirements of SP 32–104–98. However, in the regulations degradation of properties of materials over time, environmental effects, etc. are not taken into account. There is a need to consider losses of reinforcement cross-section during operation.

For polymer reinforced elements the operating force cannot be determined by tensile fracture. It is motivated by deformations that occur after completion of construction, or loads in reinforced elements after relaxation of the material under the influence of permanent stress.

Taking into account that no material is constant, the assessment of possible changes of its characteristics in time and setting coefficients, taking into account these changes, remains acute.

To assess the operating force on the reinforced element within the design service life, it is necessary to give information on the deformation of creep.

Also the problem of estimating the vibrodinamic impact of train on the reinforced ground construction is still relevant.

Objective. *The objective of the author is to present an innovative approach to roadbed reconstruction.*

Methods. *The author uses mathematical modeling (engineering calculations), layout and geotechnical centrifugal physical modeling.*

Results.

The methodology of calculation of dowel structures

When designing strengthening of the roadbed it is necessary to distinguish the features of calculation of ground anchorages from dowels. A distinctive feature of dowels from similar retaining structures is a joint work of ground and the fastening element, in which there is no transmission of pulling load from the fastened sliding wedge and the binding of the soil mass along the entire length takes place [1].

Two main types can be distinguished among dowel ground systems:

1. reinforcing back slope / back fall;

2. fixation of back slope / back fall by dowels with lattice siding.

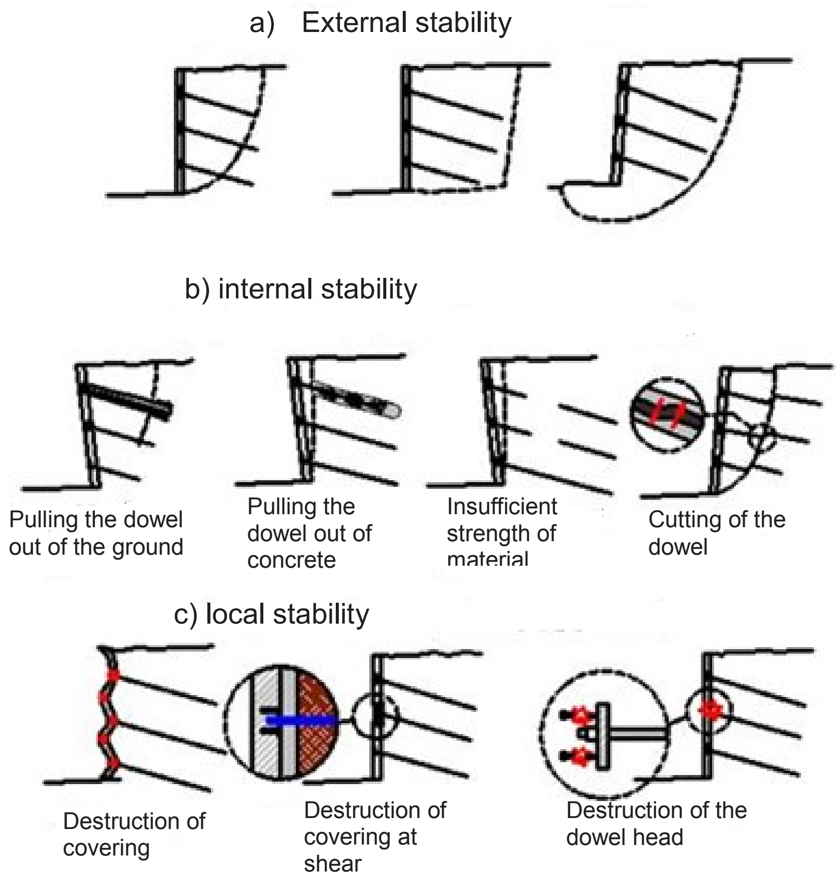
The analysis of national literature on the production of ground dowels showed that the process of selection of such parameters of dowel fastening as a step in vertical and horizontal directions, diameter, angle of slope and length of dowels must be carried out by calculating on two groups of limit states (load-bearing capacity and deformability). At the same time there is no method of calculating these parameters, and only recommended ranges of their values are given that need to be clarified, depending on ground conditions and the geometry of strengthened structures, the development of suitable values of these parameters is also appropriate. To determine the operating conditions the use of centrifugal physical modeling is advisable.

The guidance documents [1–3] present only a calculation method for the first group of limiting states, based on the conditions of stability of reinforced ground wall against the shear along the bottom and tilting over relative to the intersection point of the slope surface with the base.

According to [3, 4] dowel fastening is a geotechnical structure, designed to ensure the stability of slopes, embankment slopes and depressions, vertical and inclined walls of pits by installing in the ground array a system of reinforced elements (steel rods, tubes, composite elements, etc.). Dowels connect the ground array along its entire length, forming a self-supporting gravity retaining wall of reinforced soil.

Dowel fastening does not require the construction of a massive building envelope (piled, sheet pile, concrete and other retaining walls), it is used when natural slopes are impossible or impractical under the terms of an existing building system.

There are no schemes of possible failures of dowel fastening structures that must be considered in the calculations. Since the fastening is a reinforced ground system, the main reasons for its failure are



Pic. 1. The main reasons for the destruction of ground dowel system.

similar to those observed with reinforced ground retaining walls (Pic. 1).

And accordingly, the calculation method shall include the following steps:

– definition of the array of reinforcement parameters (number of storeys, installation step, length, slope, diameter of dowels) from the condition of ensuring joint work of dowel elements and ground (internal stability);

– checking the length of dowels from the condition of reinforced array stability for rollover and shift on the base (external stability);

– definition of characteristics of protective coating of walls (slope) and checking the step of placement of dowels from the condition of prevention of local overbreak between dowels.

We have developed a new model and calculation scheme of internal stability of a dowel fastening.

Evaluation of internal stability is tested on the basis of two types of sliding surfaces – flat and broken.

Calculation estimates the relation of forces of resistance and shear acting on the sliding surface. In addition, reliability coefficients are used, which are not taken into account in the Russian standards, but are present in the foreign techniques.

For each dowel three parameters are estimated:

– Tearing resistance;

– Resistance to pulling from the ground;

– Bearing capacity of the dowel head.

Thus, for each sliding surface a critical parameter for a dowel is determined (strength, resistance to pulling from the ground, bearing capacity of the head) (Pic. 2) is determined for each sliding surface. Bearing capacity is calculated taking into account the location of its line of intersection with the sliding surface. The dowel, which is in front of the sliding surface, is not taken into account in the calculation. If the sliding surface intersects the dowel, bearing capacity is determined by the formula

$F = \min(R_{в} \cdot x, R_{п}, R_{ог} + R_{в} \cdot y)$, (1)

where x is length of the dowel behind the sliding surface in the direction of the ground array;

y is length of the dowel opposite the sliding surface;

R_h is permissible load on the head;

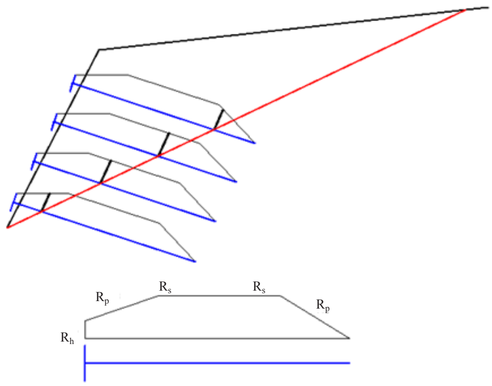
R_s is dowel strength;

R_p is resistance to pulling out.

Abroad broad experience in anchor and dowel structures to stabilize and strengthen the roadbed has been accumulated [5].

In domestic practice there is the experience in effective use of such structures to stabilize the roadbed of railways.

In July and August 2013 within the boundaries of the station Vladimir of Gorky Railway the reconstruction of the roadbed was carried out after slumping of excavation slopes, which occurred in July 2013 after a long rain [6]. The solution was discharge of water in the slope of the depression using lateral drainage slots and strengthening of slopes with anchor structures that represent two layers of reinforced concrete plates placed along the slope, with the anchors with the length of 25 m (Pic. 3) [7]. Pre-tension in anchors was not made.



Pic. 2. Distribution of tensile strength along the dowel.

In another case, specialists of MIIT carried out geotechnical calculations to assess the deformable roadbed state on the section Taezhniy – Kamarchaga of Krasnoyarsk railway and to study the possibility of its strengthening with dowel structures [8]. On the basis of materials of engineering research and project documentation calculation analysis was made to identify the causes and conditions of deformation of the double-track long exploited subgrade with the height of up to 20 m.

Strengthening of subgrades with dowel-lath structures

Long exploited subgrades, as a rule, have developed throughout the ballast tails, which were formed over time when performing repairs and routine maintenance of track, often with a high steepness of slopes, which can lead to slipouts and deformation under the influence of natural and anthropogenic factors.

Deformability of subgrades with ballast tails is largely determined by humidity conditions.

Deformation of sloping parts of subgrades, slopes and depressions may be associated with a lack of general and local stability.

The traditional way of stabilization and strengthening of such subgrades are cropping of tails, grade flattening and dumping of counter dams from draining soils. Despite reliability of these activities, they have significant drawbacks: require large amounts of scarce draining soils, allocation of a large area for the base of counter dams, extension of culverts, transfer of communication lines, duration of «windows».

On the basis of the research at MIIT at the department of Track and track facilities ways of strengthening of the roadbed of railways with reinforced ground structures have been previously created and technical guidance, recommendations,

Pic. 3. General view of the object.

technical solutions group albums, including related to anchor structures have been offered.

The alternative may be dowel-lath fastening of slopes of subgrades excavations, over-tube zone.

Dowel-lath structure is a system of protective coating or the slope by its fixing with a high-tensile metallic steel lath through support gear plate using dowels mounted with predetermined step vertically and horizontally.

The required reinforcement density is determined by calculations using finite element method.

With regard to local stability, particularly in areas with a predetermined sliding surface (subgrade with ballast tails, surface layers of depressions), experts of MIIT developed a method of designing and calculation of strengthening of the roadbed with anchor and dowel structures (Pic. 4), which provides the impact of adverse factors – including earthquakes, infiltration of precipitation and groundwater.

In contrast to the existing methods of calculation of dowel shore are taken into account:

– Step of dowel placement in longitudinal and transverse directions;

– Different trajectories (mechanism) of possible displacement of the surface layers of the subgrade (ballast tails);

– The presence of the covering (lath);

– The impact of external factors on the behavior of the structure.

When considering the unstable areas of slopes two schemes of possible shift are taken into account:

– The trajectory of the displacement of a single plot of ground array;

– Wedge-shaped trajectory of displacement of certain unstable areas of ground array.

In assessing the balance of the selected section, taking into account the conditions of strength of Mohr-Coulomb theory the value of the holding force of dowel S with accompanying pre-tensioning force V can be represented by the calculated formula, the criterion for which is the excess of the total value of holding force over the shear, taking into account safety factors:

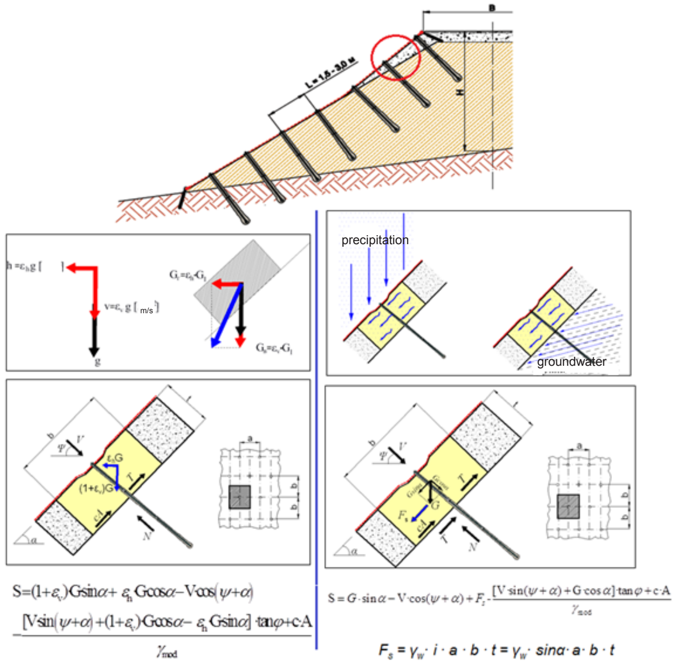
Reconstruction of the roadbed for the second tracks

In this connection, it is advisable to consider the possibility of using dowel structures not only as the primary means of strengthening, but also as an auxiliary structure in arrangement of reinforced ground walls of truncated dimensions.

An innovative technical solution is offered for strengthening of the operated roadbed of railways during its reconstruction for the second tracks by broadening of the main site, grade flattening, arrangement of reinforced ground wall with minimal development of its base and using dowel structures that reinforce the existing sloping part of the roadbed and are connected via the reinforced elements of support structures.

This solves the problem of strengthening of unstable sloping parts, increases the stability of the roadbed as a whole, reduces the amount of soil and the amount of reinforcing material in a retaining wall. In the context of the specified task, a variant is offered that allows for efficiency and increase in effectiveness of reconstruction of the roadbed in constrained conditions [9].

Based on the analysis of engineering studies and field surveys of objects, as well as the regulatory framework assessment of the subgrade was completed, the conditions and the reasons for its deformation were



Pic. 4. Calculation scheme to reinforce the roadbed of railways with anchor and dowel structures.

defined, a calculation scheme for a typical profile of a long exploited subgrade was developed. Design parameters were chosen in view of the use of modern reinforcing materials.

Used methods of research: mathematical modeling (engineering calculations), layout and geotechnical centrifugal physical modeling.

Subgrade was represented by exploited subgrade with advanced ballast tails. To establish quantitative indices of characteristic transverse profile the materials of analysis of geological engineering surveys on 183 cross profiles of 73 exploited subgrades were studied. The surveyed subgrades with height from 1 to 20 m were aged from 30 to 100 years old, built of local soils–clay loams and placed on a solid foundation. As an example the characteristic subgrade of clay soils 12 m in height was selected.

For the sake of saving space and materials we have developed a design, which is a reinforced ground retaining wall, mounted in the slope using dowels (anchors), embedded in the subgrade body. Dowels perform two functions in the design:

– Improving the stability of the subgrade slope;

– Holding reinforced ground retaining wall from rollover.

Since reinforced ground retaining wall is located directly at the base of the subgrade and in the bottom the length of reinforcing elements is limited by the slope, additional holding force is required for fixing a retaining wall against the shear and rollover. This additional force is created by dowels.

Calculation have tested the stability of the subgrade in construction period after strengthening of the slope with dowels. Parameters of dowels were chosen taking into account dependencies of calculated coefficients of the subgrade stability K and forces N, arising in dowels from the angle of their inclination to the horizon. Based on analysis of the graphs (Pic. 5) the angle of inclination of dowels equal to 35 degrees was adopted. Because at this angle the greatest efforts in dowels arise, the highest stability factor is achieved and the most efficient operation of the structure is provided.

Thus, the structure of strengthening of the subgrade for the second track (Pic. 6) was offered, which is recommended for use in constrained conditions in construction and reconstruction of the roadbed of railways; while strengthening the sloping parts of the roadbed without cutting, as well as the strengthening of landslide slopes. The design is processable and can be built on the field side of the railway.

According to the results of calculations and design of the subgrade, enhanced with reinforced ground wall and dowel structures, its layout was made, which was presented in the section «Ecology and rational use of land» in the exhibition of scientific and technical creativity of youth at VDNH in Moscow in 2014 and was awarded a medal [10].

In the future performance of the construction is supposed to be checked using the method of centrifugal modeling on the geotechnical centrifuge of MIIT.

Development of the installation and techniques of bench tests

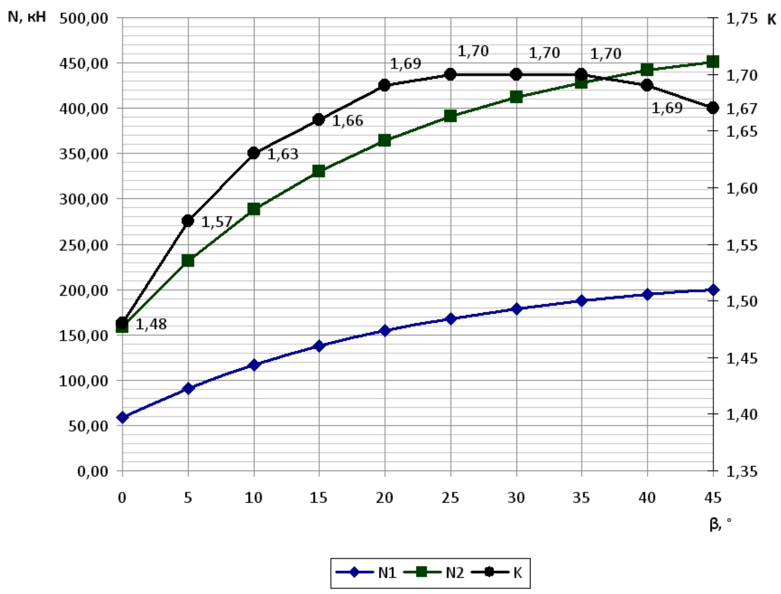
To assess the interaction parameters for different designs of dowels and ground conditions puling-out tests are conducted, taking into account various stress.

Tests for pulling-out simulate actual working conditions of the dowel in the ground.

The purpose of the tests carried out on the stand, is to study on physical models dependencies of resistance to pulling-out of a dowel fastening on the main parameters: type and soil flow index, the diameter of the dowel and its compression by the surrounding soil.

To understand the mechanism of interaction on the surface the reinforcing element-soil tests it is planned to conduct pulling-out tests. They must simulate real working conditions of the dowel in the ground.

Analysis of existing methods for calculating of the bearing capacity of dowels on the ground showed that they estimate only dowels with cement body around the metal element. However, in some cases it is expedient



Pic.5. Graph of dependence of stability coefficient K on the angle of inclination of dowels and forces in dowels N on the angle of inclination of dowels β°.

to use as dowels metallic reinforcing elements (screw fittings, pipe, metal rods) without cement shell that even with denser arrangement (smaller step in longitudinal and transverse directions) substantially reduces the time for installation and cost of the structure.

In accordance with DIN1054–2005 calculated values of resistance of different soil types on the lateral surface of the anchor / dowel are shown in Table 1.

However, the method of DIN1054–2005 provides for definition of the bearing capacity of only self-drilling anchor / dowel according to the formula:

$F_d = \varpi D l q_{sk}$, (1)

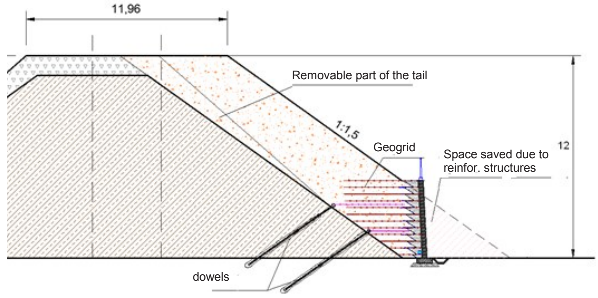
where D is diameter of anchor/dowel; l is length of anchor/dowel; q_{sk} *is resistance on the lateral surface of anchor/dowel.*

From the formula (1) it follows that it does not take into account the pressure of soil on the lateral surface of the anchor / dowel, parameters of clay and sandy soil (liquidity index, compression ratio).

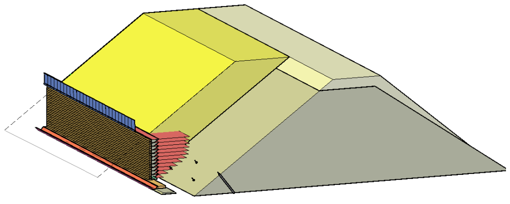
To study the impact of these factors on the bearing capacity bench for dowel models test has been developed and manufactured, as well as testing procedures.

To that end, a new installation was designed and built, which is a three-dimensional structure consisting of a metal container with dimensions 900x600 mm on the frame of the channels, the load device from exhaust jacks and pulling out power unit, through which force on the dowel is transmitted (Pic. 7). Container can be filled with sand and / or clay soils of varying consistency.

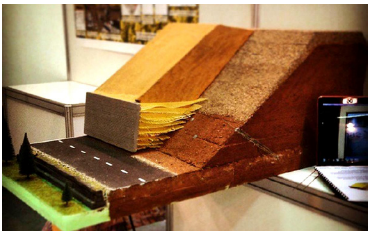
a)



b)



c)



Pic. 6. The design in three dimensions: a) cross-section of the subgrade; b) mathematical volumetric model; c) a general view of the layout.

Measuring movement of the anchor / dowel is recorded by displacement sensor; pulling out force – by dynamometer of static tensile forces, calibrated in kilonewtons; ground pressure on the dowel – by pressure sensors.

When selecting an equivalent material for plastic soils as defining characteristics, a set of values of specific adhesion c and internal friction angle is used.

To account for the structural characteristics of various reinforcing elements it is planned to test design types of dowels shown in Table 2.

Test program provides for holding four full factorial experiments of the type 2^n while varying three factors: dowel body diameter D (from 0,01 to 0,15 m), liquidity index of soil I_L (from 0 to 0,5), ground pressure p (from 100 to 300 kPa).

To account for the influence of three factors for four structural types of dowels it is necessary to conduct $(2^3) \cdot 4 = 8 \cdot 4 = 32$ experiments.

Conclusion.

1) The issue of increasing the reliability of infrastructure of rail and road transport and traffic safety through the introduction of innovative and resource-saving technical solutions – dowel ground systems in construction and reconstruction of the roadbed (including those located on the seismically active areas) remains acute.

Analysis of the regulatory professional literature in the design of measures for strengthening and reconstruction of the roadbed of railways shows that the degree of supply with regulatory documentation for use of reinforced ground structures is insufficient.

In the existing documentation issues of requirements for design, construction and subsequent operation of reinforced ground facilities are reflected not fully.

Basic scientific development in the field of application of reinforced ground structures during strengthening and reconstruction of the roadbed were conducted at the beginning and end of the 90s, when the choice of reinforcing materials was uniform.

Novelty of these works is the development of instructions regulating the procedure for optimal use of reinforced ground structures to stabilize and strengthen the roadbed of railway track.

The practical significance of the works is determined by the fact that the introduction of dowel ground systems allows strengthening of the roadbed under complex geological conditions: roadbed and artificial structures in the areas of erosion from the sea, on the rocky, in landslide areas, as well as in conditions of intense urban development (urban areas).

Table 1

Resistance on the lateral surface of anchor / dowel, depending on the type of soil

Type of soil	Resistance on lateral surface q_{sk}, kPa
Medium and coarse gravel	200
Sand, gravel sand	150
Clay sand, loam, clay	100

There is a positive experience of application in the areas of operation of the roadbed to reinforce high subgrades with a lack of stability.

To determine the operating conditions it is advisable to use physical centrifugal modeling. Therefore, more research is needed to assess the bearing capacity of dowel structures during their use to strengthen the roadbed.

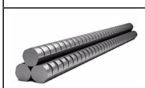
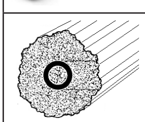
The outcome of these studies is to define the scope of rational application field of innovative technical solutions – dowel ground systems in construction and reconstruction of the roadbed facilities of transport infrastructure (using a centrifugal modeling).

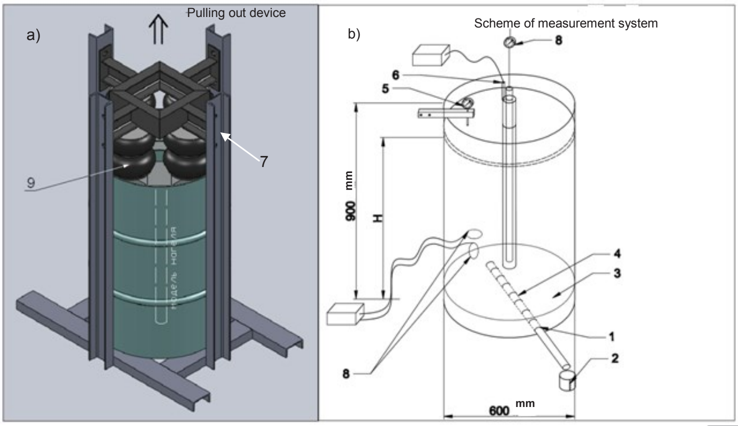
To achieve this goal it is necessary to solve the following tasks:

• perform analysis of existing methods of calculation of anchor and dowel structures;

Table 2

Structural types of dowels

	plain bar
	screwed fittings
	metal pipe
	screwed fittings with cement lining



Pic. 7. Scheme of installation and measurement system: a) general view; b) measuring system. 1 – fluid outlet opening; 2 – measuring container; 3 – drainage; 4 – perforated pipe; 5, 6 – displacement sensor; 7 – frame; 8 – pressure sensor; 9 – pneumatic jacks.

• *explore the features of the stress-strain state (SSS) of multi-row anchor (dowel) structures under various conditions;*

• *investigate the landslide pressure distribution patterns between anchors (dowels), depending on configuration of multi-storey buildings;*

• *identify the rational design solutions of multilevel anchor (dowel) structures;*

• *develop recommendations for the rational use of anchor (dowel) structures.*

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