Improvement of Structures of Spatial Reinforcement Modules

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Abstract. The topic of the article is the introduction of new materials and technologies into road construction, the goal is to improve the design of spatial reinforcement modules for use in road construction with the possibility of reducing manual labor during their installation during the construction of the roadway or complete mechanization of the process. The tasks solved in the article are to improve the spatial reinforcement modules for the construction of the roadway based on the analysis of factors affecting the strength and time characteristics of its service. Factors affecting the strength and time characteristics of the service of the spatial reinforcement module, the main materials and technologies used for the construction of the roadway in different countries of the world were analyzed. The model of calculation of strength of the spatial reinforcement module and versions of its design are proposed. It is concluded that the proposed module increases stiffness of reinforcing elements when creating roads and filtering and draining abilities of road layers, reduces specific load on the road bed and vibration on it and road-surrounding soils, time and cost of construction, provides strength of the structure when changing the terrain of the road surface and mechanizes the simultaneous manufacturing and installation of the module directly on the working section of the road.

1. Introduction

The introduction of new materials and technologies in road construction is relevant throughout the world. This is due not only to the growth of the road network, constantly growing requirements for their quality, but also to an increase in requirements for environmental protection measures, an increase in areas for construction with difficult geological conditions, a complication of the climatic situation in nature and a constant increase in competition in the construction business. Therefore, the search and analysis of new developments in the field of technologies and the use of new building structures, including cheaper and more technological materials, is very important. The latter is important for the business due to the need to increase the speed of construction, while meeting the growing requirements for the quality and durability of roads and not increasing the cost of their construction and maintaining their performance.

One of the promising directions that increase the strength and time characteristics of roads is the use of reinforcing structures in road construction. Over the past decade, polymer reinforcing structures have been increasingly used in road construction. Modern polymers are not only more corrosion resistant than metals, but also have similar strength characteristics. In addition, they are more...
technological both in the creation of reinforcing structures and in their installation in the road bed. At the same time, not only primary, but also secondary raw materials can be used as materials, after appropriate processing of industrial and household waste.

2. Literary review

The quality of road pavement is one of the main factors of traffic safety, and the increase in the life of road pavements is one of the strategic tasks of road science. During operation, various damage to the road bed inevitably occurs, such as cracks of different origins, for example, reflected, temperature, power, technological, etc., as well as rutting, potholes, pits, etc. The main influence on the work of road pavements and directly on the processes of crack formation, rutting, pits, potholes is exerted by transport loads, a complex of weather and climatic conditions and non-compliance with technological processes when laying all layers of road pavement. There is a considerable amount of research that analyzes the possible causes of road bed destruction. At the same time, road surface damage comes from the complex influence of external and internal factors [1, 2].

One of the main reasons for the destruction (formation of cracks and rutting) of the road bed is deflection associated with insufficient stiffness of the underlying surface. Standard layers of sand and crushed stone evenly distribute pressure, but are not able to withstand heavy loads. This problem helps to solve the reinforcement of the layer of the underlying surface. This method increases the cost of construction. However, from the point of view of improving the operability and transport and operational characteristics, reinforcement is more appropriate than obtaining one-time savings [3, 4].

Analysis of literature data shows that in the USA and in Western Europe, where concrete is most often used as a pavement, steel reinforcement is most often used in laying the base [5]. At present, this method, although it is very expensive, helps to solve problems of improvement of operability and transportation and performance characteristics, but does not solve problems of durability due to corrosion of metal and its high cost [6].

In recent decades, due to the emergence of different grades of asphalt concrete and the development of the production of new reinforcing materials from polymers, as well as taking into account the variety of their properties and manufacturing technologies, various types of geosynthetics and composite reinforcement began to be used in strengthening road surfaces both separately and in combinations. These are different types of geotextiles, geogrids, geolattices. In their production, various types of polymers are used: polyester, polyamide, polypropylene, polyethylene, polyvinyl alcohol, etc. Glass, basalt, carbon and aramid fibers are used for making composites. The manufacturing technology uses gluing, stitching, fusing, weaving, knitting, etc. [7, 8].

3. Problem statement

In view of the ever-increasing requirements for the quality of roads, the construction time, the cost with an increase for the construction of roads of territories with difficult geological and climatic conditions, as well as, despite the huge variety of reinforcing materials offered to the construction market, problems with road destruction remain. Road science requires research and development in the field of new structures of reinforcing elements and high-quality materials, reinforcement technologies and equipment that provide mechanization/automation and increase labor productivity in the construction of road surfaces and have great prospects [9].

New developments service life of pavings have to allow to solve problems of reduction of costs for construction, contents and service and increases. Analysis of the literature data shows that none of the existing versions of reinforcing devices for strengthening roads allows to comprehensively eliminate the maximum number of causes leading to the destruction of the road bed, in particular, researchers indicate that the structures of reinforcing elements are not sufficiently developed and the issue of their improvement is relevant. As a result, a new approach to the design of reinforcing materials is required.
4. Theoretical model

The authors of the article propose to use for reinforcement of the upper and/or lower layers of the road bed an improved model of the power structure of the rod type, widespread in construction equipment [10-15], namely: spatial reinforcement modules (SRM) without and with preliminary stress [16]. The latter allows optimally distributing loads, improving the strength characteristics of both road and building modules, ensuring the creation of collapsible structures of the road bed, building panels and blocks, different purposes of collapsible pillars, light flat and different curvature of arched floors, etc.

The design and technology of the SRM being developed is based on the use of a three-dimensional grid, the rods of which can be made of metal, polymer or composite materials. When installed in pavement layers or in the underlying layer of the SRM, the load is transferred through the knots to the rods located both directly below the wheels and further to the next neighboring units and rods. As a result, loads "spread" along the SRM and are distributed with gradual attenuation over a large area of the corresponding section of the road bed. This reduces the specific load directly below the wheels and reduces the requirements for rigidity, both of the road bed itself and of the elements of the power structure. In addition, the property of vibration suppression reduces the negative impact on both the SRM and the earthen web, as well as the soil surrounding the road.

Give the final mathematical model of calculation of strength of polypropylene SRM.

Taking in the first approximation the shape of the SRM bend in the transverse direction as sinusoidal with the maximum value f, we determine the tensile stresses arising in the SRM when exposed to the vehicle wheel:

\[ \sigma = \frac{M f E_1}{W} \leq [\sigma], \]

where \( M \) is the width of the earthen web of the road pavement; \( W = 2b^2 \) - moment of resistance of single width of polypropylene SRM; \([\sigma]\) is SRM bending strength; \( E_1 \) is modulus of elasticity of soil, \( E_2 \) is modulus of elasticity of polypropylene, \( d \) is height of polypropylene SRM, \( b \) is single width of polypropylene SRM; \( l = \frac{4 k b}{\sqrt{E_1}} \) is the length of the bending wave, where \( k \) is the soil stiffness factor (the amount of force that must be applied to 1 m\(^2\) of the surface of the soil base so that its sediment is 1 m).

5. Results of experimental studies

The upper and lower elements of the improved SRM (Fig. 1) are made of straight reinforcement bars (1-4) of round or square sections and wave-shaped elements (5) installed in the middle part of the module.
a-d) - assembly options: 1, 2 - upper rods located along and across the ridges; 3 shows lower rods arranged along the ridges; 4 shows lower rods arranged along the ridges; 5 shows a wave-like element; 6 - upper ridge; 7 - lower ridge; 8 - slot in rod 2; 9 - slot in rod 1; 10 - slot in rod 1; 11 - thrust element; 12 - reinforcement retainer; 13 - plastic polymer.

Upper and lower elements are made by crossing horizontal reinforcement bars (1-4) to form a grid consisting of squares. Inclined reinforcing bars of wave shape (5) are obtained by bending straight reinforcing bars with appearance of ridges in places of bending (6, 7). During assembly of all SRM elements, a structure is formed consisting of conjugated cells in the form of regular, oppositely oriented vertices, tetrahedral pyramids and node elements located at the intersection of their edges. Axes of horizontal reinforcement bars coincide with axes of base ribs, and axes of rectilinear sections of wave-like elements coincide with axes of inclined ribs corresponding to regular tetrahedral pyramids.

Knot elements are formed during assembly by intersection of respective horizontally arranged rods (1-4) and ridges (6, 7) of wave-like elements (5). There are different options for aligning these elements. For example, in the first version horizontal reinforcement bars (2) (Fig. 2a) are located between wave ridges (6). At the point of intersection of rods (1 and 2), ridges (6) are installed in the formed angle at the stop. In the second version (Fig. 2b), grooves (8 and 9) are made in rods (1 and 2) by embossing. During assembly, rod (1) rests with slot (9) on ridges (6), and rod (2) is installed with slot (8) on rod (1). In the third version (Fig. 2c), rod (1) is lowered on thrust elements (11) and rod (1) is installed on it with slot (10). Once the assemblies have been formed, at least part of them can be fastened with reinforcement fasteners (Figure 2d) or plastic polymer (13) (Figure 2e). With non-rigid attachment of the units, a certain degree of freedom remains for movements at the attachment points of the units, which reduces the occurrence of excessive bending and vibration loads due to external forces.

The SRM elements may be made of metal or composite materials based on basalt, carbon, fiberglass, polymeric materials such as ABS plastics, impact-resistant polystyrene, polypropylene, etc., or polymeric materials with reinforcing additives.

For the manufacture of reinforcing structure elements from polymers and their assembly directly on the road, at least in its rectilinear sections, the development of special equipment is necessary.

In accordance with the terrain, roads have not only rectilinear sections, but also sections of rises, descents, turns with slopes, and swampy sections may also be present. All this imposes special requirements on the design of the SRM. The rigidity of the SRM structure is related not only to the strength characteristics of the material, but also to the accuracy of the geometric dimensions of the regular pyramids, of which the structure consists. Ensuring the accuracy of dimensions along the length of the ribs of the pyramids and the observance of all angles of inclination of the ribs to each other, ensures the rigidity of the reinforcement structure. When organizing turns, slopes, rises and descents, the geometry of the pyramids, which are not only rigidly connected to each other, but also have common edges, is inevitably violated. Therefore, in the SRM, it is required to install compensating elements, as which connecting and supporting elements are used.

Taking into account road dimensions and final linear dimensions of rods, at least ends of part of horizontally arranged and/or inclined reinforcement rods are made with connecting elements providing for possibility of connection, both of individual elements of modules, and of modules themselves as support elements. To meet the required geometry of the SRM components on curved sections of the road, it is proposed to use an assembly of separate modules with the installation of support elements between them. Support elements can be made both in the form of a single part and in the form of a prefabricated structure, which compensate for most violations of the geometry of the pyramids, and provides for the organization of all necessary variations of the installation on the road in accordance with changes in the terrain.

The space between the inclined reinforcement rods of the middle element can be used to install pipes for communications, such as: telephone cables, electric cables, means for heating the road bed,
means for contactless electromagnetic power supply for electric transport, etc. Pipes are made with inspection hatches for installation or diagnostics of communications.

Requirements for SRM stiffness are increased with the presence of water-saturated and swampy soils in the route area. The reinforcement of the SRM in this case is proposed to be carried out with tension of the modules by cables through the support elements. The structure of the support elements provides tension of the modules in pairs, or simultaneously with several turnbuckles, and, if necessary, the creation of curved sections, in accordance with changes in the terrain. Cables and turnbuckles are located in tubular channels. Support elements in these cases are made with inspection hatches to provide the possibility of installation and diagnostics of cable fittings condition.

Space between inclined reinforcement rods of middle element is filled with filler, which is used, for example, sand, sand-gravel mixture, mixture of expanded clay and cement, heat-insulating and sound-insulating foams, such as pearlite or foam glass. Geotextile made of synthetic polypropylene and polyester fibers is installed on the sides, as well as on the top and bottom, in order to prevent washing out of filler from SRM, uniform distribution of load on the soil and ensure filtration of water and air in pavement layers.

6. Practical relevance and implementation results

Based on the results of SRM strength calculations, the necessary technological equipment was made and a series of experimental modules were made. To obtain the practical results of the studies, three construction sites were manufactured and commissioned, which underwent field tests over three years. The results of the experiments are shown in Table 1.

| Object Parameter | Object 1 | Object 2 | Object 3 |
|------------------|----------|----------|----------|
| Construction site| Foundation for a 2-story cottage with a garage at: Moscow Region, Chekhov District, Ivanovskoye Village | Access road, 300 m long at: Moscow region, Chekhov district, the village of Ivanovskoye. | Repair of two sections of the federal highway No. P-132 Tula - Kaluga for 56 km, with an area of 50 x 6 m |
Construction method
- Perform excavation to the depth of 10-15 cm, lay the leveling layer of sand and compact.
- Install formwork. Lay geotextile.
- Install the SRM, fill it with sand and seal it.
- Start geotextile edges on SRM and install metal mesh.
- Fill the surface with concrete 10 cm thick.
- Remove formwork.
- Plan the soil base, lay a layer of sand and compact.
- Install formwork and lay 5 cm thick layer of sand.
- Lay the geotextile.
- Install the SRM, fill it with sand and seal it.
- Start geotextile edges on SRM and install metal mesh.
- Fill the surface with concrete 5 cm thick.
- Remove formwork.
- Remove old asphalt and excavate to a depth of 10-15 cm.
- Plan the soil base, lay a layer of sand-gravel mixture and compact.
- Lay the geotextile.
- Install SRM, fill it with sand-gravel mixture and compact.
- Start edges of geotextile on SRM.
- Apply asphalt-concrete pavement.

Type of objects checked in in 2017
- During the period of operation there are no skewed structures
- During the period of operation the certificate of compliance with safety requirements was received
- Video shooting in September 2019 did not reveal cracks and the formation of deflection of sections of the road bed

7. Conclusion
1. A model for calculating the parameters of polypropylene SRM and its strength has been developed. The model takes into account the influence on the arising stresses of the height of the soil embankment and the shape of the trace of the wheel of vehicles and caterpillar vehicles.
2. The proposed improvement of SRM structures provides the solution of the following problems: 1) increasing the stiffness of reinforcing elements when creating roads and filtering and drainage capacity of road layers; 2) reduction of: a) specific load on the road bed, b) vibrations on the road bed and the surrounding soil, c) terms and cost of construction; 3) ensuring the strength of the structure when changing the terrain of the road surface; 5) mechanization of the simultaneous process of manufacturing and installation of SRM directly on the working section of the road.

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