ANALYSIS OF DESIGN FEATURES OF FLEXIBLE PAVEMENTS ON FEDERAL HIGHWAYS IN RUSSIA

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Abstract. Nowadays the pavements of highways in Russia work under difficult conditions of constantly growing traffic volume. The current method for flexible pavements design has a number of serious disadvantages. It does not take into complete account the best practices in design and the actual operating conditions for highways. In a number of cases, this leads to the design of inefficient structures of pavements with a short service life.

On a number of federal roads, there are observed rutting and premature wear out of road surface in the first years of the operation. Drainage sand layers and shallow drainage drains are quickly working out. Geosynthetic materials are sometimes used unreasonably. The design life of pavements does not comply with the current standards. In Russia the effective road construction materials are not yet completely used up, as well as local materials reinforced with astringents. The actual experience in operating various road structures with the identification of the most optimal solutions is still poorly considered, except for certain regions.

Thus, an urgent need has arisen to develop standard designs of pavements for various natural and climatic conditions in Russia ensuring pavements' efficient operation. It is necessary to analyze the existing pavement designs on the federal highways under various road building climatic zones to develop the standard pavement designs.
Keywords: flexible pavements, typical constructions of pavements.

Introduction. The distance of federal highways in Russia is more than 50 thousand km with the total length of the road network in Russian of about 1 million 600 thousand km. Whereas about 45% of freight traffic falls on federal highways. When increasing the standard terms of pavement coatings service, it is necessary to improve the quality of design solutions in order to take into account all advanced modern methods of pavement design and calculation. In this regard, in Russia, there has been a shift from an individual design of pavement (carried out by design bureaus) to standard solutions that exclude errors and inaccuracies of a different nature, including those caused by the insufficiently high competence of project executors. The development of the catalogue of standard designs of flexible pavements of federal highways is currently conducted on the basis of a detailed study of the most modern structures built in the last ten years under various road-building climatic zones of Russia.

The efficiency of this approach has been proved by the practice of Austria, Belgium, Germany, Italy, France, the USA, China and other countries [1, 3, 4, 5, 6, 11], where standard designs for pavements have been developed for various conditions. It should be noted that in the Russian Federation the typical catalogue solutions have been used for a number of years in Moscow [8] at designing toll roads [9].

Methods. The basis of the research method and the development of recommendations for the construction of flexible pavements is the analysis of statistical data on the design features of the most durable flexible pavements of federal highways. Information on modern designs of flexible pavements of federal highways of Russia was presented by 22 Federal Highway Administrations. The statistical sample covered 43 federal highways of the country. The total number of surveyed sites was 213, and the total number of pavement designs - 219. The distribution of road sections by category is given in Table. 1.

Table 1. Characteristics of federal highway sections of various categories

Road category	A number of sections under consideration				
	Number of sections	**Percentage of the total number**	**Length, km**	**Percentage of the total length**	**Reduced statistical weight**
I	71	32,4	770,3	30,31	0,77

II	64	29,2	452,5	17,81	0,86
III	70	32,0	1204,8	47,42	0,78
IV	14	6,4	112,8	4,44	3,90
Total	219	100	2540,4	100	-

Since the number of road sections of different categories is not equal and in order to ensure an objective evaluation of the distribution of the analyzed characteristics of pavements among road categories, their reduced statistical weight is given (see Table 1). The amount of this reduced statistical weight should be multiplied by the number of cases for a road of this category, and then set the distribution of the examined characteristics of pavements. This approach is used only to assess the distribution of the characteristics of pavements between the categories of highways. The territory of the Russian Federation is divided into five road-building climatic zones, numbered from I to V [13]. Most of them are divided into sub-zones according to the nature of the climatic conditions. The sections of the federal highways included in the analysis cover almost all the subzones of road-building climatic zoning (Table 2).

Table 2. Correspondence of sections of federal highways to their location on the map of road-building climatic zoning

Road-building climatic zones and subzones	Road sections length, km
I_2	29,7
I_3	911,4
II_1	177,3
II_2	555,9
II_3	17,0
II_4	17,0
III_1	451,7
IV	224,6
V	155,8
Total	2540,4

Results

The study examined the construction of flexible pavements with a surface course of asphalt. In addition, most of the construction of pavements include the asphalt binder course, as well as asphalt base course (usually the upper base course) - Figure 1.

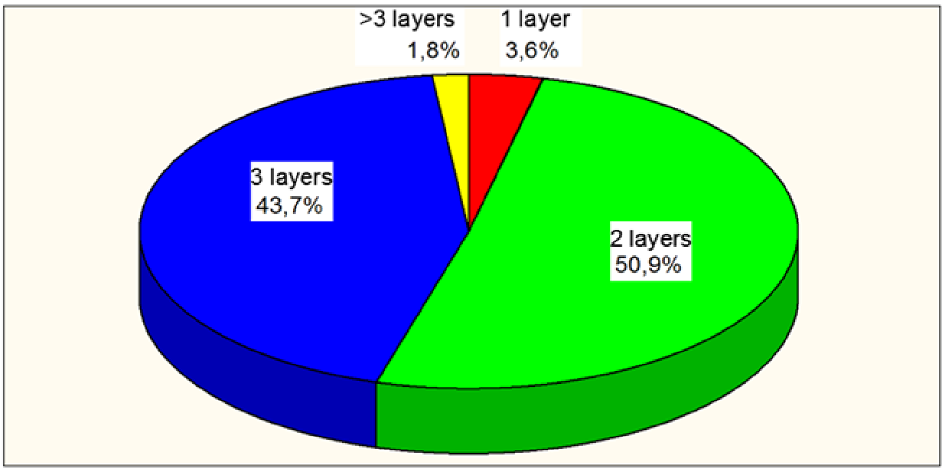


Figure 1. Distribution of flexible pavements' designs with a different number of layers of asphalt courses on federal highways

The analysis showed that a three-layer package of asphalt concrete materials was used primarily on the roads of the categories I and II. For the roads of category II, the percentage ratio between a three-layer and a two-layer package of asphalt concrete is approximately the same. For roads of the category I, the absence in the base course of asphalt is the exception to the general rule. The presented data are generally in line with international trends in the design of flexible pavements.

The results obtained allow us to recommend the number of asphalt courses in the design of pavement depending on the category of roads (Table 3). It should be noted that the surface course, in the absence of a blanket course, is considered as a wearing course and must be replaced in accordance with the norms established by the standards [7].

Table 3. Recommended number of asphalt courses in the construction of flexible pavements of federal highways

Road category	Number of concrete courses			
	1	2	3	More than 3
I	-	-/+	+	-/+
II	-	+	+	-
III	-	+	-	-
IV	-/+	+	-	-

*The "+" sign is the recommended solution, the "- / +" sign is a solution requiring a feasibility study, the "-" sign is an unfeasible solution.

Statistical analysis shows that the surface course contains the following varieties of asphalt in approximately equal proportions: stone mastic asphalt of grades SMA-20 and SMA-15, the traditional asphalt of types A and B (Figure 2). Stone mastic asphalt was most widely spread on the roads of categories I and II - 84% of design pavement (Figure 3). On roads of categories III and IV in the surface course, the dense-graded asphalt is used. The proportional ratios of SMA and dense-graded asphalt for different categories of highways are given in Table. 4.

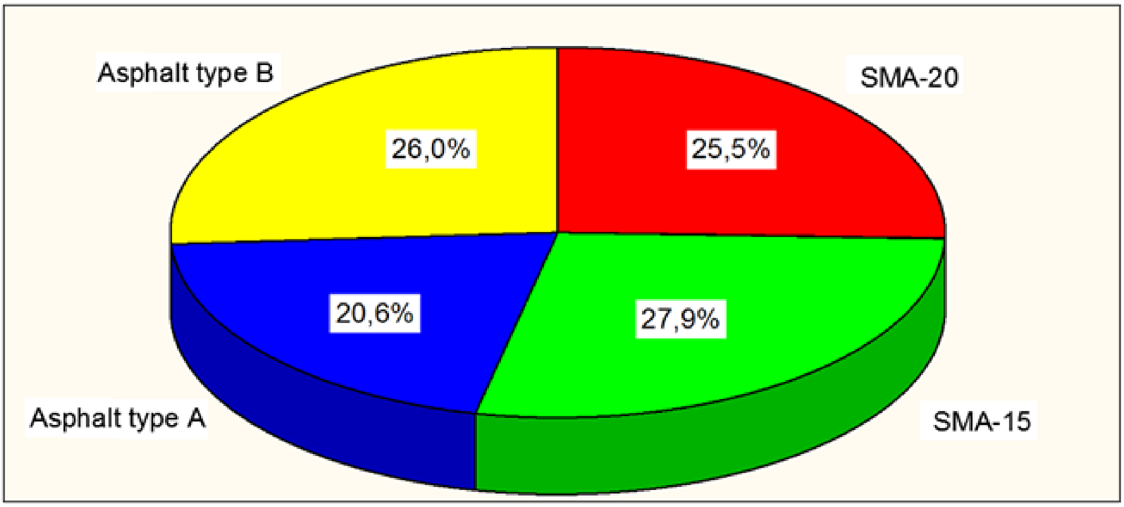


Figure 2. Application of different types of asphalt in the surface course on federal highways

Figure 3. Application of stone mastic asphalt in various categories of federal highways

Table 4. Application of various types of asphalt in the surface course of flexible pavements covering of federal highways

Road category	Type of asphalt	
	SMA-20 and SMA-15	**Dense-graded asphalt of types A and B**
I	80.3	19.7
II	66.7	33.3
III	28.2	71.8
IV	0	100

*The "+" sign is the recommended solution, the sign "- / +" - the decision requiring a feasibility study, the "-" sign is an unfeasible solution.
**The dense-graded asphalt of type A is recommended to be assigned for IV and V road-building climatic zones, type B - for I, II and III road-building climatic zones.

One of the ways to ensure the normative design life of pavements and coatings is the maintenance and periodic restoration of wearing courses and blanket courses. In the Russian Federation, a blanket course is understood as a layer of up to 4 cm thick, designed to protect the underlying course of asphalt pavement from the direct impact of the wheels of road transport and a complex of weather and climate factors. The blanket course is not taken into account when calculating the pavement design and is subject to periodic restoration during maintenance. According to this definition, in the practice of operating federal highways, blanket courses, including thin-layer coatings, do not yet find a wide application (Figure 4). The potential of the blanket courses to ensure the required design life of pavements and coatings is not common. Flexible pavements are traditionally designed with a surface course that acts as a wearing course [7].

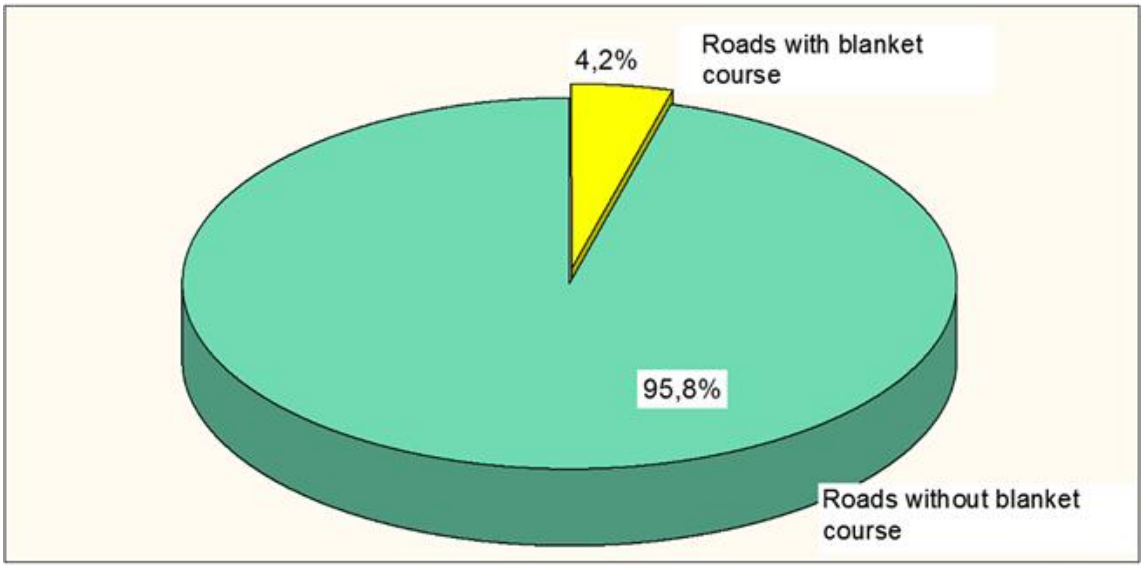
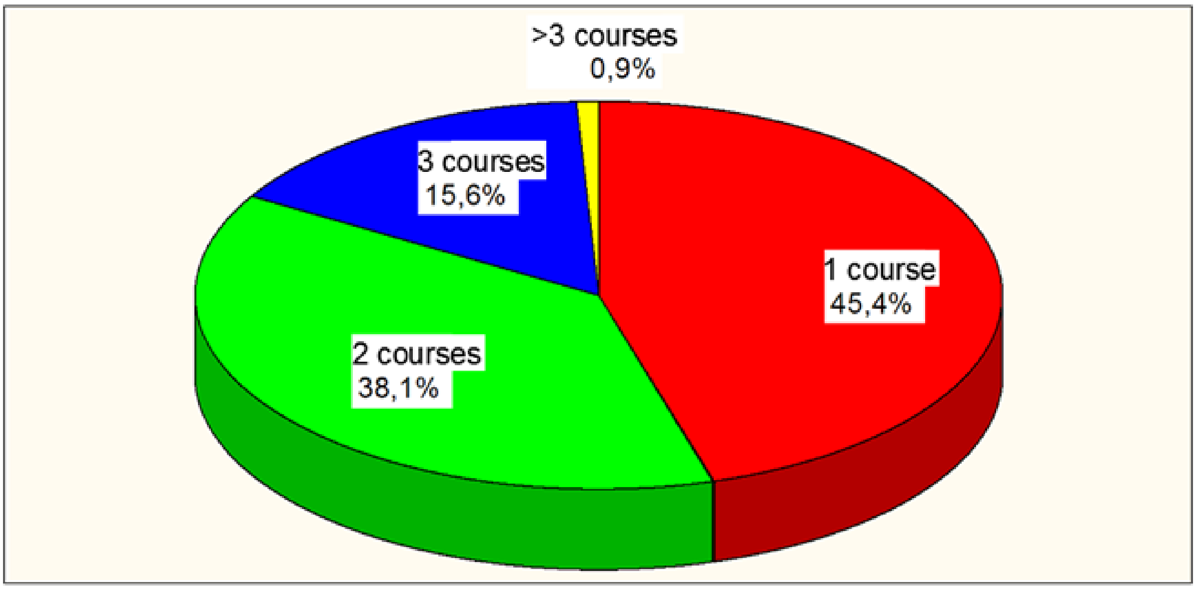


Figure 4. Application of blanket courses in the construction of flexible pavements of federal highways

The design of flexible pavements on federal highways includes a different number of base courses. The single-layer and two-layer pavement bases are the most common (83.5%) - Figure 5. From the point of view of stable pavement work, an increase in the number of layers leads to a deterioration of homogeneity of the road structure in strength and is caused by the accumulation of errors during construction, which inevitably appears during the operation of road construction machines. As shown by the theoretical studies performed at the MADI Department of roads



construction and maintenance, even with the accumulation of errors in the thicknesses of pavement courses within the limits of norms, the heterogeneity in the overall elastic modulus of pavement over the surface area will be unacceptably high [2].

Figure 5. Distribution of flexible pavement structures with different number of base courses on federal highways

The results obtained allow us to recommend, depending on the category of roads, the appropriate number of road base courses (Table 6).

Table 6. Recommended number of base courses in constructions of flexible pavements of highways

Road category	**Number of foundation base courses**			
	1	**2**	**3**	**More than 3**
I	-	+	-/+	-
II	-	+	-	-
III	+	-/+	-	-
IV	+	-	-	-

* The "+" sign is the recommended solution, the "- / +" sign is a solution requiring a feasibility study, the "-" sign is an unfeasible solution.

Base courses arranged according to different technologies, from construction aggregates of diverse origin are most often used in the construction of flexible pavements. From loose aggregates, both base courses and subbase courses are arranged. The relative number of constructions of road clothes with loose aggregates as at least one of the base courses in pavement is 77%. In other cases, the base courses are represented by bonded aggregates.

The part of stone-gravel-sand mixtures and their varieties is almost half of all cases of using loose aggregates (Figure 6).

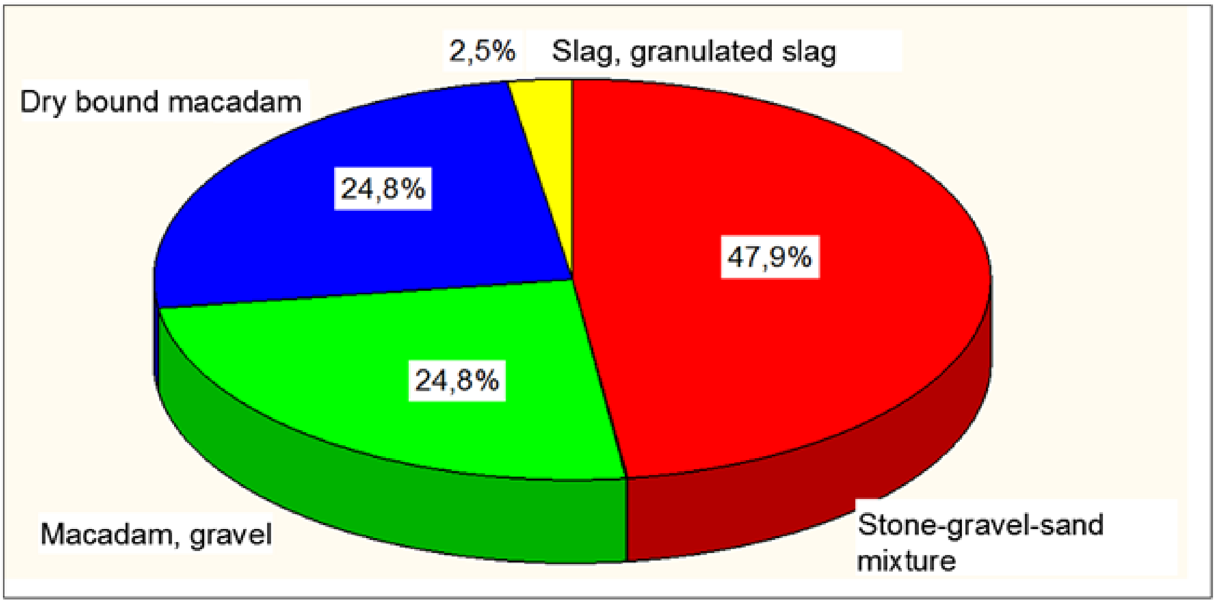


Figure 6. The use of various types of bases from loose aggregates in the construction of flexible pavements of federal highways

It is necessary to note one more positive aspect of modern designs of flexible pavements on the network of federal highways of Russia. More than 80% of the cases included in the construction the bonded base courses (Figure 7). The list of materials of such bases is quite wide: asphalt concrete, recycled asphalt concrete (including granular asphalt), bituminous aggregates, soil stabilized by various binders, rigid lean concrete.

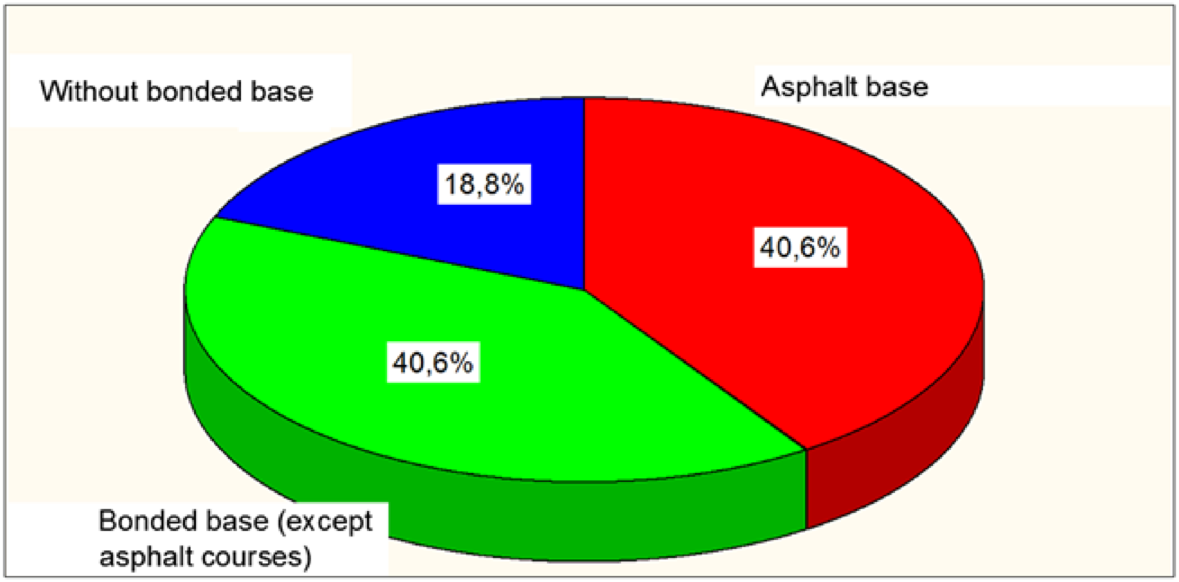


Figure 7. Application of various types of a bonded base in the construction of flexible pavements of federal highways

The fact of increasing the proportion of the construction of pavement with bonded base courses on highways of higher categories is noted. Roads of the category I in pavements construction are widely represented by asphalt base courses (usually the upper course of multilayered road base). This circumstance corresponds to the well-known model albums of flexible pavements construction [5, 6, 8, 9, 11]. At the same time, on the roads of the category IV, the bonded asphalt base courses are not arranged.

The analysis of methods of aggregates bonding is of considerable interest to scientists. Comparing the bonding by binder type shows that the cases of bonding by hydrocarbon and mineral binders have approximately equal proportions (Figure 8). Significantly less bonding is performed using combined binder materials (only 13%). The possibilities of bonding of aggregates with bitumen emulsions are not sufficiently used. The sands or stone-gravel-sand mixtures are mainly bonded by mineral binders. A good trend is to consider the almost complete abandonment of the previously popular method of strengthening by impregnation by bitumen, in which it is impossible to achieve a rational consumption of bitumen and homogeneity in strength parameters of the base course.

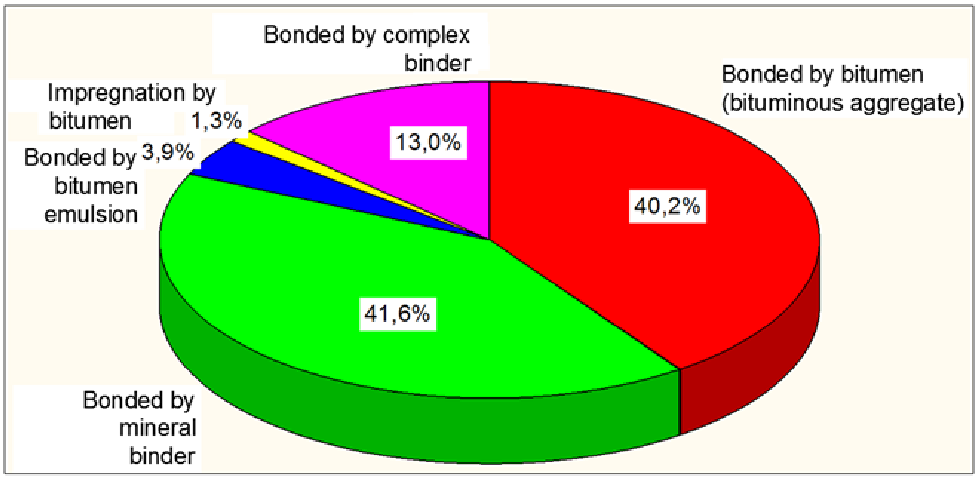


Figure 8. Distribution of flexible pavements structures on federal highways with various types of binding materials for

bonding the base courses

Stone-gravel-sand mixtures are widely used as pavements subbase of pavements of federal highways (about half of all cases) - Figure 9. They have very high filtering capacity and is subject to silting less than the sand. However, stone-gravel-sand mixtures are characterized by low frost resistance, i.e. under the influence of periodically freezing stone water in micropores, the strength of crushed stone (gravel) particles decreases. In addition, the cost of stone-gravel-sand mixtures is significantly higher than the cost of sands, other things being equal, and the technical and economic feasibility of using such mixtures is largely due to the availability of sand reserves in the region of the highway.

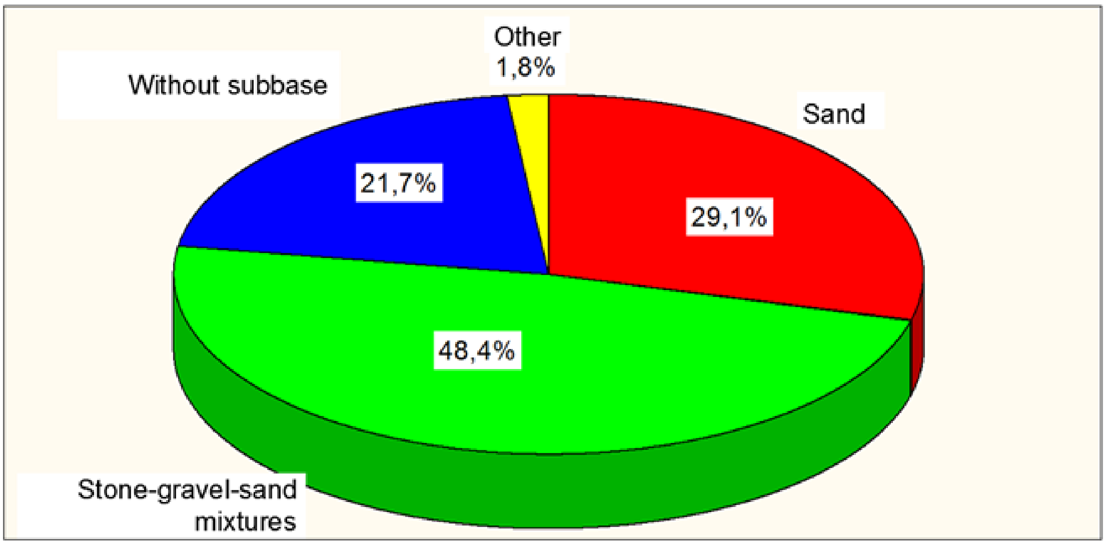


Figure 9. Distribution of flexible pavement structures on federal highways by the type of material of subbase

Discussion

The statistics show that on the roads of the category I, mostly pavements with two- and three-layer bases are used. On the roads of category II, pavements with two- and one-layered road base became widespread. For roads of categories III and IV, pavements with a one-layered road base prevail.

In addition, it should be noted that in about 20% of cases in the surface course the asphalt-concrete mixtures used are on a polymer asphalt base. The share of coverings from gravel-mastic asphalt accounts for about 90% of all cases of improvement of bitumen properties due to the introduction of polymer components into it. Although the need for introducing polymer additives in the production of crushed stone and mastic mixtures is still disputable.

Despite the fact that the possibilities of extending the service life of pavements and coatings are well known due to the reinforcement of them by geonets, reinforcement is extremely rare in the pavement structures under consideration, just 9,4% of cases. For reinforcing of asphalt courses on federal roads, geonets are used from the following materials: fiberglass, polypropylene, polyester. About 30% of the reinforcement of asphalt is made of glass fiber geonets. The most common in Russia today are geonets from polypropylene and polyester. They demonstrate quite good results in reducing cracking. Not a single case of using geonets based on polyvinyl alcohol or basalt fibers has been recorded.

It should be considered as a positive moment, the ever wider use of stone-gravel-sand mixture in the base course for the following reasons. Firstly, stone-gravel-sand mixtures allow achieving higher compaction indices, and, consequently, better homogeneity in strength and higher resistance to breaking. Secondly, the studies of the MADI Department of roads construction and maintenance [10], following the experience of specialists from Sweden, showed the erroneousness of assigning higher strength indicators in the normative document for the design of flexible pavements for layers arranged in dry bound macadam, compared with layers from stone-gravel-sand mixtures [12]. Dry bound macadam courses provide high strength only in the space of jamming of fractions. The thickness of the layers of different fractions, which are outside the jamming effect, acts as ordinary gravel and are characterized by high heterogeneity in strength. They are actively crushed and subsequently lead to large setting. Therefore, in the near future, it is necessary to completely abandon the practice of incorporating in the construction of pavement by dry bound macadam and ordinary gravel for courses in favor of stone-gravel-sand mixtures.

The presence in many regions of Russia of cement plants and a waste of fly ash makes it possible to perform bonding of base courses with mineral binders, which determines the design features of pavements in a number of regions. Among the grounds bonded by hydrocarbon binder, aggregates being processed with a binder in the facility (bituminous aggregates) are used more often. The use of bonded base courses prevents drawdowns in macadam layers and the accumulation of residual deformations in soils.

Soil conditions in the territory of the Russian Federation are distinguished by a considerable variety. This circumstance is the reason why in some pavement designs there is no additional subbase course (see Figure 9). An example is the pavement construction on rock, pebbly, gravel or crushed rock soils. Nevertheless, the arrangement of a subbase course with the leveling regulation even in such conditions is preferable.

On clay soils, it is recommended to arrange a course of geotextile to slow the silting of the sand subbase course and to exclude its interpenetration into the subgrade soil. It is believed that the geotextile material can also contribute to the stabilization of the foundation soil under the pavement. Statistics show a relatively small number of cases of laying geotextile material between sand and the surface of subgrade on federal highways - 13% of cases. The need to use an interlayer of geotextile material requires justification in each individual case. However, the separation of cohesive and non-cohesive soil mediums in pavements is desirable.

When the base is made of crushed stone (gravel) and stone-gravel-sand mixtures, the aggregates are penetrating into the sand subbase. Observations organized by the Department of roads construction and maintenance of MADI on construction sites show that the penetration of aggregates into the sand subbase can reach 5-6 cm. This leads to a significant increase in the consumption of aggregates and a rise in the cost of work that the construction organization is forced to pay. To prevent the aggregates penetration into sand is possible by laying the geotextile interlayer on the sand subbase. However, in 16% of cases, separation of the bearing macadam and stone-gravel-sand mixtures of the base course with the underlying sand subbase was performed. In the typical construction of flexible pavements, it is advisable to provide a geotextile interlayer between the macadam and sand.

In general, the correctness of the design decisions taken, the objectivity of evaluating the initial design information, the performance of the construction of pavement and the choice of road construction materials can be judged from the results of an assessment of carriageway surface condition made on a 5-point scale (Figure 10). As follows from the histogram presented in Figure 10 The condition of the carriageway, including the operation of pavement, is at a sufficiently high level. At the same time, it is known that about 29% of the federal highway network currently does not meet regulatory requirements, primarily on the strength of pavement and the carriageway surface evenness. The data shown in Figure 10 indicate that the completed study covered areas with the most durable constructions of pavements.

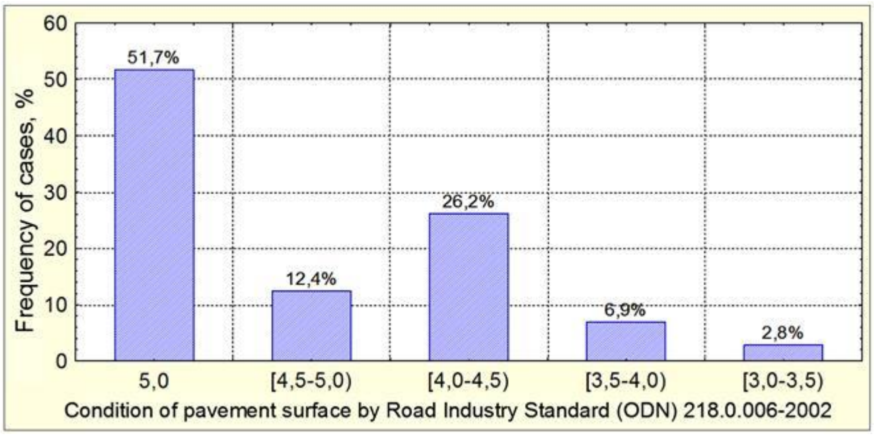


Figure 10. The condition of flexible pavements surface on federal highways

Conclusion

The results of research of the design features of flexible pavements of federal highways will serve as the basis for the development of the catalogue of typical designs of flexible pavements under various climatic conditions of operation.

1. The collection and analysis of information on the construction of flexible pavements on sections of federal highways, primarily constructed and reconstructed over the past 10 years and operated in various natural and climatic conditions under the influence of modern vehicles.
2. The analysis of the effectiveness of the use of modern and regional road construction materials for inclusion in the album of standard constructions of pavements, using of which helps to achieve money saving without reducing the reliability and durability of pavement structures.
3. Recommendations are developed for the construction of flexible pavements, depending on the category of roads and natural climatic conditions of operation.

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