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MODELLING THE RIGID AIRFIELD STRUCTURE OPERATION WITH A REINFORCEMENT LAYER OF MODIFIED CONCRETE

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Abstract

The purpose of this article is to present the results of the study of the operational suitability of the existing induced airfield coating by experimental and theoretical methods. Based on the analysis of the results of the research, it was determined that the material that provides performance characteristics, namely: crack resistance, tensile strength, impact strength, abrasion resistance - is a modified concrete, i.e. concrete with additives that have a positive effect on the structure and operational properties. This paper presents the results of studies of the reinforcement layer made of concrete with the introduction of the most common modifiers of polymeric substance (polymer-cement RCC - Polymer Cement Concrete) and basalt chopped fiber - fiber (basalt fiber concrete FRC - Fiber Reinforced Basalt concrete).

Keywords: airfield, concrete, fiber, physico-mechanical properties

1. Introduction

Operation of monolithic concrete aerodrome pavement in the conditions of action of weather-climatic factors and considerable loadings from modern types leads to wear of a surface, formation of defects in the form of various types of cracks, chipped edges of plates, sinks, potholes, etc. As a result, the bearing capacity and durability of the aerodrome structure as a whole is reduced.

In modern conditions, increasing the level of operation of aircraft, especially heavily loaded, the issue of ensuring the proper condition of aerodrome structures becomes relevant.

Elimination of defects of aerodrome pavements is most often carried out by arrangement of a layer from concrete or asphalt concrete that promotes improvement of roughness of a surface and a little strengthens a design - increases its bearing capacity.

But when arranging layers of such materials, the stresses from the action of aircraft remain significant, the probability of cracks in the lower zone of the plate (on the border with the artificial base) also does not decrease.

2. Analysis of the research and publications

Based on the analysis of literature sources and research results, it was determined that the material that provides crack resistance, tensile strength, toughness, abrasion resistance - is a modified concrete, a concrete with the introduction of additives that positively affect the structure and performance. This paper presents the results of studies of the reinforcement layer made of concrete with the introduction of the most common modifiers of the polymeric substance (concrete polimer-cement PCC – Polimer Cement Concrete) and basalt chopped fiber - fiber (basalt fiber concrete FRC – Fiber Reinforced Basalt concrete).

In polymer-cement composites (PCC) the polymerization process occurs before or in parallel with the hydration of the cement, which provides resistance to dynamic loading, high compressive, flexural and tensile strength, sufficient adhesion to the lower layer and water resistance.

Strength of fiber concrete (FRBC) due to the combined interaction of basalt fiber and cement matrix, as a result of which they are equally subject to Hooke's law, ie the strength of concrete at a given deformation is determined by the volume of components and their modulus of elasticity. The ratio of modulus of elasticity $E_f/E_b>1$ ($280*10^3$MPa/$4,2*10^3$ MPa>1), that is FRBC will be characterized by high crack resistance, compressive and tensile strength, impact strength and wear resistance.

3. Research part

The following materials were used for preparation of concrete mixes:

- Basalt fiber obtained from basalt coarse fiber d 5-8 mm, length 8 mm;
- Portlandcement PC 400;
- Plasticizing additive from Stachem.

Physico-mechanical properties of concrete were determined by testing samples - cubes measuring 10x10x10 cm and prism samples measuring 10x10x40 cm, at the age of 28 days after curing under normal conditions according to current regulations.

Physico-mechanical properties of concretes accepted for research are given in table 1.

Table 1

Physico-mechanical properties of modified concrete

Indexes	Concrete warehouses		
	Polimercement concrete (PCC)	Fiber-concrete (FRBC)	Concrete (traditional)
Compressive strength, MPa, at the age of 28 days	67,5	72,4	46,8
Tensile strength in bending, MPa, at the age of 28 days	8,56	9,21	6,54
Modulus of elasticity, MPa - in compression - tensile when bending	 $0,9*10^4$ $0,3*10^4$	 $2,6*10^4$ $0,5*10^4$	 $3,12*10^4$ $0,1*10^4$
Poisson's ratio	0,12	0,14	0,15
Density, кg/m^3	2350	2680	2420

Analyzing the data in table 1 it is seen that basalt fiber concrete has higher strength, and especially tensile strength in bending than traditional concrete, which indicates the presence of chemical interaction between the neoplasms of the plasticizer and fiber and aggregates. Increased values of the modulus of elasticity of fiber concrete causes higher stresses that will occur in the concrete slab when applying the load.

Thus, the proposed types of concrete can be used to arrange a layer of reinforcement that will ensure its high strength properties and deformation resistance.

But the efficiency of the reinforcement layer is due not only to the properties of the materials from which it is arranged, but also from the optimal thickness, which together provides resistance to force, temperature, moisture and shrinkage.

The choice of the thickness of the reinforcement layer was made taking into account the technological capabilities of the layer on the existing coating and the effect of deformation on the stress state of the aerodrome structure. Thus, the choice of layer thickness within 3 cm, 5 cm and 8 cm was justified by the following conditions:

- thickness of 3 cm - the minimum at which there is no shift of a layer concerning a concrete covering, at dynamic loadings from wheels of the chassis of PS (protective layer);

- thickness of 5 cm - due to the size (depth, width) of the defects of the concrete surface;

- thickness 8 cm - maximum, due to the need to increase the bearing capacity of the aerodrome structure (reinforcement layer).

To compare the characteristics, tests of a concrete slab 22 cm thick without a reinforcement layer were performed.

The amount of adhesion (m) of the arranged layer to the existing coating was taken $m \le 2,65$ MPa. The load was a six-wheeled support of the aircraft with a diameter of 0.68 m. The effective pressure in the pneumatics of the wheels of the aircraft is 1.25 MPa.

Modeling of the layer thickness was performed with the determination of the slab deflection, normal and tangential stresses in the slab concrete and the reinforcement layer.

The stress-strain state (VAT) of an aerodrome coating with a bearing layer lying on an elastic Winkler base is determined on the basis of the provision that the prints from the tires do not move horizontally and the forces from the aircraft support are evenly distributed on the aircraft wheels.

Due to the complexity of the actual operation of aerodrome coatings, the basis of the analytical model of this process is a three-layer model (base, existing coating, reinforcement layer) implemented in the universal calculation complex "Matlab".

The research was carried out under the condition that the Poisson's ratio of the arranged layer is less than the concrete of the slab $\mu_{pec}<\mu_{conc}$, $\mu_{FRBC}<\mu_{conc}$. The scheme of research is shown in table 2.

Table 2

The order of the experiment

Construction of an aerodrome plate	Cases are considered		
	I	II	III
	$\mu_{FRBC}>\mu_{conc}$ $\mu_{PCC}>\mu_{conc}$	$\mu_{FRBC}<\mu_{conc}$ $\mu_{PCC}<\mu_{conc}$	$\mu_{бет}$
Concrete 22 cm Polimerconcrete 3 cm	🟦	🟦	
Concrete 22 cm Polimerconcrete 5 cm	🟦	🟦	
Concrete 22 cm Polimerconcrete 8 cm	🟦	🟦	
Concrete 25 cm			🟦
Concrete 27 cm			🟦
Concrete 30 cm			🟦

The scheme of division of an aerodrome plate on sections is shown in Fig. 1.

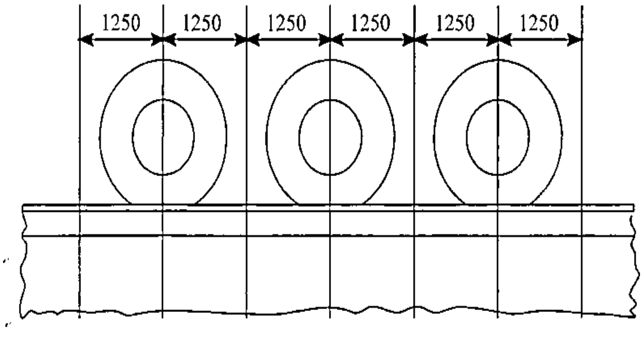


Fig.1. Scheme of the breakdown of the aerodrome plate in sections

The calculations of the stress-strain state of the coating slab with a layer of RCC and FRBC with a thickness of 3 cm showed that in I and II cases the values of normal stresses in the lower part of concrete are greater than the normative characteristics of concrete strength by 17% RCC and 14% FRBC, i.e. in sections II and VI in the lower zone of the plate may crack, the thickness of the layer is insufficient.

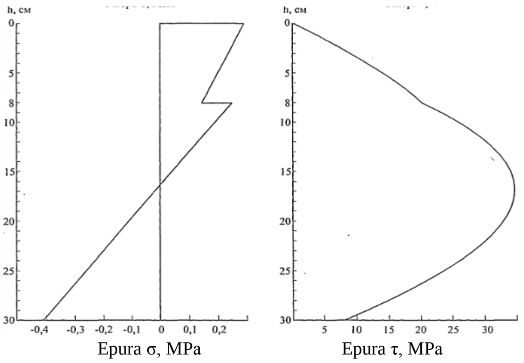
When the thickness of the RCC and FRBC layer is 5 cm in I and II cases, the load from the multi-wheel support is redistributed by the RCC layer and then transferred to the concrete, with tangential stresses reaching a maximum value at a depth of 10.5 cm. degrees, and the tangential stresses reach a maximum value at a depth of 12 cm, but the possibility of crack formation in the lower zone of concrete is very large and especially in the II and IV sections, ie the layer thickness of 5 cm is insufficient.

Thus, the calculations were performed at a thickness of the reinforcement layer of 8 cm enclosed with RCC and FRBC concrete. Since the Poisson's ratio of RCC and FRBC concretes is lower in values than traditional concrete, the calculations were performed $\mu_{PCC}<\mu_{conc}$ and $\mu_{FRBC}<\mu_{conc}$ for supports and weight of aircraft more than An-22 (225t) at the constant modulus of elasticity of an artificial basis.

The research results are shown in Fig. 2-5 and in table 3.

Analysis of the monolithic rigid aerodrome coating with a reinforcement layer of RCC and FRBC concrete 8 cm thick with $\mu_{PCC}<\mu_{conc}$ and $\mu_{FRBC}<\mu_{conc}$ showed that when laying a layer with RCC, the maximum normal stresses were distributed as follows: in the upper zone of the polymer-concrete layer, the gain σ = -1.1 MPa; at the boundary of polymer concrete and concrete jump value σ = 0,4MPa; in the lower zone of concrete σ = 1.45 MPa.

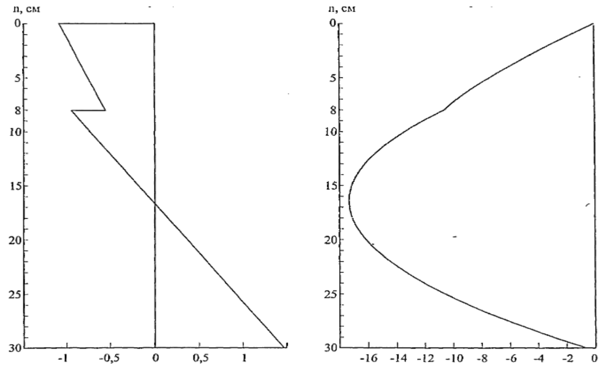
At a depth of 1 cm in the polymer concrete layer of reinforcement, the value of the maximum tangential stresses was 3.0 kPa, and at the boundary of the polymer concrete layer of reinforcement and concrete coating, the value of tangential stresses was 20.0 kPa. The maximum value of tangential stresses is reached at a depth of 8 to 12 cm in concrete, the value of normal stresses at this depth is zero. In the lower zone of concrete τ = 8.0 kPa. The total deflection of the plate was 4.3129 mm.



Epura σ, MPa

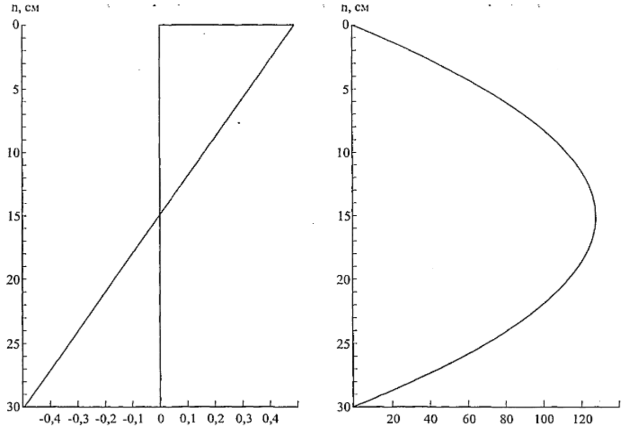
Epura τ, MPa

Fig. 2. Epura σ, Epura τ



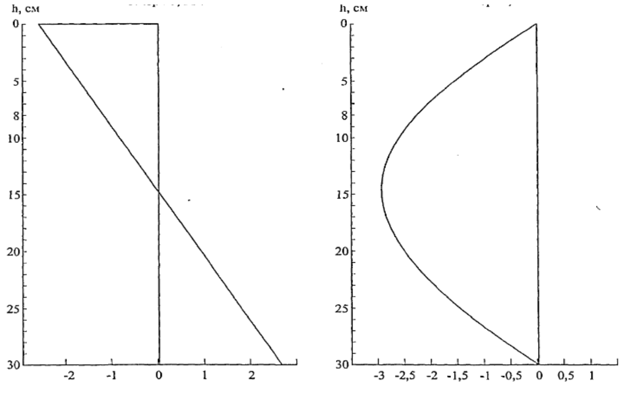
Epura σ, MPa Epura τ, MPa

Fig. 3. Epura σ, Epura τ



Epura σ, MPa Epura τ, MPa

Fig. 4. Epura σ, Epura τ



Epura σ, MPa Epura τ, MPa

Fig. 5. Epura σ, Epura τ

Analyzing the cross section at a depth of 4 cm, we find the zones of maximum normal stress in the upper zone of concrete with a value of σ = -2.7 MPa in the II and VI sections. In the lower zone of concrete, the values of normal stresses in the maximum in II and VI sections and amounted to 2.7 MPa (in cases of using a polymer-concrete reinforcement layer with a thickness of 8 cm and concrete 22 cm at $\mu_{PCC}<\mu_{бет}$ σ = 1,45 MPa). The magnitude of the tangential stresses is maximum at a depth of 12 to 16 cm in sections I and VII, and the value of normal stresses at this depth is zero. In the lower zone of concrete, the value of the maximum tangential stresses is zero. The total deflection of the plate was 3.9405 mm.

Consider the plots σ and τ in sections I and II (Figures 2.19 and 2.20). On the concrete surface (figure 4) σ = 0.48 MPa, in the lower zone of concrete the value of σ = -0.49 MPa. At a depth of 15 cm in concrete, the values of normal stresses are zero. Tangential stresses in the lower zone of concrete are zero. At a depth of 15.0 cm τ_{max} = 127.0 kPa.

On the surface of concrete (figure 5) σ = -2.7 MPa, in the lower zone of concrete σ = 2.7 MPa. At a depth of 15.0 cm in concrete, the values of normal stresses are zero. The point of transition through zero corresponds to half the thickness of the concrete slab, which indicates its optimal performance. Tangential stresses in the lower zone of concrete are zero. The maximum tangential stresses were observed in the concrete cross section at a depth of 15.0 cm and were τ_{max} = 2.9 kPa.

At a depth of 15 cm, the tangential stresses increased to the maximum value and amounted to 127.0 kPa in sections I and VII (Figures 2 and 5), ie the plate works without cracks and is strong enough.

Thus, analyzing the stress-strain state of a monolithic concrete aerodrome coating with a layer thickness of 8 cm of concrete (concrete 22 cm and a reinforced concrete layer with a thickness of 8 cm with $\mu_{FRBC}<\mu_{conc}$), we conclude that it is advisable to use as a layer of reinforcement fiberglass at a thickness of 8 cm with $\mu_{FRBC}<\mu_{conc}$, so the FBRC absorbs the load to a greater extent than the reinforced concrete layer (RCC), redistributes it and transfers it to the concrete. FBRC reduces the values of normal and tangential stresses throughout the thickness of the slab structure, concentrates the maximum tangential stresses below the center of the concrete slab, which prevents the separation of the fiber concrete layer of reinforcement.

Table 3

The results of the calculation of normal (σ) and tangential (τ) stresses

Types of aerodrome pavement material	№ step grids, cm	Values of normal normal (σ) and tangential (τ) stresses in sections													
		I		II		III		IV		V		VI		VII	
		σ MPa	τ kPa	σ MPa	τ kPa	σ MPa	τ kPa	σ MPa	τ kPa	σ MPa	τ kPa	σ MPa	τ kPa	σ MPa	τ kPa
Fiber concrete FRBC, $E_b=1,9*10^4$ MPa $\mu=0,14$	0	0,48	0	-2,3	0	0,12	0	-1,75	0	0,12	0	-2,3	0	0,48	0
	1	0,43	-10,0	-2,1	-0,4	0,105	25	-1,7	0	0,105	-25,0	-2,1	0,4	0,43	10,0
	2	0,4	-20,0	-1,9	-0,8	0,095	4	-1,5	0	0,095	-4,0	-1,9	0,8	0,4	20,0
	3	0,35	-35,0	-1,8	-1,3	0,08	7	-1,35	0	0,08	-7,0	-1,8	1,3	0,35	35,0
Polimerconcrete, $E_b=0,8*10^4$ MPa $\mu=0,12$	0	0,18	0	-0,65	0	0,3	0	-0,52	0	0,3	0	-0,65	0	0,18	0
	1	0,17	-0,8	-0,6	1,0	0,29	0,5	-0,49	0	0,29	-0,5	-0,6	-1,0	0,17	0,8
	2	0,16	-1,5	-0,55	2,0	0,27	0,8	-0,45	0	0,27	-0,8	-0,55	-2,0	0,16	1,5
	3	0,15	-2,5	-0,5	3,0	0,25	1,0	-0,42	0	0,25	-1,0	-0,5	-3,0	0,15	2,5
	4	0,14	-3,5	-0,45	3,5	0,23	1,25	-0,4	0	0,23	-1,25	-0,45	-3,5	0,14	3,5
	5	0,12	-4,5	-0,4	4,3	0,2	1,5	-0,38	0	0,2	-1,5	-0,4	-4,3	0,12	4,5
Concrete, $E_b=3,24*10^4$ MPa $\mu=0,15$	0	0,63	-35,0	-2,9	-1,3	0,14	7	-2,35	0	0,14	-7,0	-2,9	1,3	0,63	35,0
	4	0,35	-87,0	-1,9	-2,8	0,07	16	-1,4	0	0,07	-16,0	-1,9	2,8	0,35	87,0
	8	0,12	-118,0	-0,8	-3,7	0,02	22	-0,45	0	0,02	-22,0	-0,8	3,7	0,12	18,0
	12	-0,12	-119,0	0,5	-3,7	-0,04	23	0,5	0	-0,04	-23,0	0,5	3,7	-0,12	19,0
	16	-0,38	-93,0	1,7	-2,8	-0,11	17,5	1,4	0	-0,11	-17,5	1,7	2,8	-0,38	93,0
	20	-0,6	-37,0	2,8	-1,3	-0,17	7,5	2,3	0	-0,17	-7,5	2,8	1,3	-0,6	37,0
	22	-0,72	0	3,4	0	-0,21	0	2,73	0	-0,21	0	3,4	0	-0,72	0

4. Conclusions

Studies have confirmed the positive use of basalt fiber for the preparation of fiber concrete and the arrangement of a thin-layer coating to improve the properties of the existing concrete aerodrome coating.

The optimal layer thickness varies from 3 to 8 cm, depending on the functional purpose, taking into account existing technological capabilities.

Calculation of the stress-strain state of the aerodrome pavement slab shows that the reinforcement layer of fiber concrete to a greater extent reduces the action of normal and tangential stresses, evenly redistributes the load, provides no cracks in the lower zone of the slab, has a high adhesion to the concrete pavement compared with a polymer layer.

Thus, in modern conditions of aerodrome operation, increasing the intensity and weight of aircraft, it is rational to use an 8 cm thick reinforcement layer of concrete dispersed with basalt fiber (FRBC), which improves the stress-strain condition, increases the quality and durability of existing aerodrome coverage .

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Моделювання роботи жорсткої аеродромної конструкції з шаром посилення із модифікованого бетону

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Метою даної статті є представлення результатів дослідження експлуатаційної придатності існуючого наведеного покриття аеродрому експериментальними та теоретичними методами. На основі аналізу результатів проведених досліджень було визначено, що матеріалом, який забезпечує експлуатаційні характеристики, а саме: тріщиностійкість, тривкість на розтяг, ударну в'язкість, опір стиранності – є модифікований бетон, тобто бетон з введенням добавок, які позитивно впливають на структуру і експлуатаційні властивості. В даній роботі приведені результати досліджень шару посилення, улаштованого із бетону з введенням найбільш поширених модифікаторів полімерної речовини (бетон полімер-цементний PCC – Polimer Cement Concrete) та базальтового рубленого волокна – фібри (фібробетон базальтовий FRC – Fiber Reinforced Basalt concrete).

Ключові слова: аеродром, бетон, фібра, фізико-механічні характеристики

Е.В. Краюшкина

Моделирование работы жесткой аэродромной конструкции со слоем усиления из модифицированного бетона

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Целью данной статьи является представление результатов исследования эксплуатационной пригодности существующего покрытия аэродрома экспериментальными и теоретическими методами. На основе анализа результатов проведенных исследований было определено, что материалом, который обеспечивает эксплуатационные характеристики, а именно: трещиностойкость, прочность на растяжение, ударную вязкость, сопротивление истираемости – это модифицированный бетон, то есть бетон с введением добавок, которые позитивно влияют на структуру и эксплуатационные свойства. В данной работе приведены результаты исследований слоя усиления, устроенного из бетона с введением наиболее распространенных модифікаторов полимерного вещества (бетон полимер-цементный PCC – Polimer Cement Concrete) и базальтового рубленного волокна – фибры (фибробетон базальтовый FRC – Fiber Reinforced Basalt concrete).

Ключовые слова: аэродром, бетон, фибра, физико-механические характеристики

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