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Modified composite material developed on the basis of no-fines asphalt concrete

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Abstract. Being a composite material, asphalt concrete is widely used in hydraulic engineering and road construction. The paper proves one of asphalt concrete modification, which includes first creating a skeleton of no-fines concrete and then its washing-down with bituminous materials by a hot procedure, can be successfully used in hydraulic structures Modified composite material based on no-fines asphalt concrete has a harder skeleton because of links from cement stone and has a technological advantage, as through the proposed technology it allows to reduce the cost of filling porous spaces. This technology allows to conclude that concrete aggregate with size fractions of 120 mm or less and frost resistance of 50 cycles and less can be recommended for fastening of slopes.

1 Introduction

The use of composite materials in construction allows to build constructions with pre-projected specified properties. Concrete and asphalt concrete as its type [1-5] can be named among the most common composite materials. In asphalt concrete bituminous materials perform the fiction of a binder. In hydraulic engineering and road construction asphalt concrete became widely spread and is often used as a protective coating.

Asphalt concrete quality is affected by the selection of its optimal composition and primarily depends on the quality of the larger aggregate, and the availability of silt particles, their size, shape and roundness [1]. Thus, a large number of requirements to raw materials, leads to an increase in the number of operations, in financial costs and in construction time.

In addition, sometimes there might not be enough necessary materials on a certain construction site. That leads in its turn to the use of transported expensive materials.

In hydraulic engineering, the size (or fineness) of construction stone to be used in coast protecting structures at major watercourses such as the Volga, ranges from 300 to 600 mm [6]. Shipping companies often refuse to transfer such materials because road transport with carrying capacity of more than 25 tons cannot be used on public roads, and the distance from the quarry to the construction site can be rather long and does not allow to use equipment outside the quarry. Often loading in dump trucks at the quarry is carried out with an increasing share of overburden to reduce shock loads in the process of unloading the

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stone material out of a bucket excavator. Sometimes it requires special loading nodes for reloading by use of lower-capacity hydraulic excavators. These extra actions increases selling price of stone materials. Railway and water transport also require special actions when performing loading operations. Thus a possible "transport" dimension of materials does not exceed 250 mm and the optimal value involves the use of stone materials of 80-120 mm fineness.

These restrictions resulted in the use of more expensive construction solutions compared to rubblework, i.e. mesh structures, monolithic steel-concrete and concrete slabs, concrete oversize (tetrapods, tetrahedrons, stars, cubes, etc.), concrete-filled mates, polymer concrete, asphalt concrete [7-10].

2 Materials and Methods

Asphalt concrete is a traditional material for bank protection. However, it has a number of shortcomings related to its reliability in the case of ageing of bituminous binder and using large filler fractions of 120 mm or less.

To protect asphalt concrete from destruction, we propose a new technology that provides first making a skeleton of no-fines concrete and then washing-down with bituminous materials by a hot procedure. This material is shown on Figure 1.

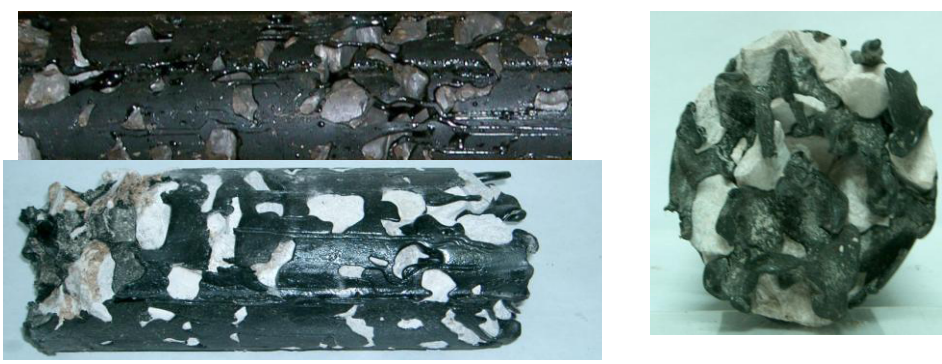

Fig. 1. Sample view

Besides, this technology has the advantage when compared to traditional concrete plates because higher demands to the preparation of the foundation (variations in the horizon should not exceed 2-3 cm for every 5 meters of a slope) are put forward when laying prefabricated monolithic plates. The use of this technology makes it possible to abandon the increased requirements to the preparation of a foundation. Hollows under the plates can be filled with bitumen in the process of filling the porous space, its excess expenditure not more than 6%.

To make no-fines concrete we recommend using the following materials:

– gravel mark 400-600;

– cement – M400-D20 with discharge of 150 kg/m^3;

– water W/TS = 0.45.

When using gravel of 20-40 fineness, the authors defined strength of no-fines concrete during laboratory tests. Its average strength is 45-50 kg/m^3. The researchers also studied changes in frost resistance and demonstrated that there was an increase in the number of cycles 10-15 on average.

3 Results

For the implementation of the proposed technology it is required to standardize the temperature of bituminous mixture according to the composition of bitumen, aggregate size and thickness of the bind. Temperature selection is conducted by function (1) received as a result of laboratory and field studies:

$$h = d \cdot \left(\ln \frac{Ga}{B \cdot \Delta K} \right) \cdot A \cdot m, \tag{1}$$

where d is an effective diameter of the particle of porous medium,
GA - Galileo criterion - is defined by function (2)

$$Ga = \frac{\mathrm{Re}^2}{Fr} = \frac{g \cdot d^3}{v^2} \tag{2}$$

$\Delta K = \frac{K_n}{K_z}$ – the ratio of the temperature at the beginning of Kn supply to the temperature of the fluid hanging Kz (for water is equal to 273 k, for bitumen – 373 K); m – coefficient of porosity, defined empirically 0.35-0.45, A and B are correction coefficient found by the least squares method based on the results of the pilot data processing.

The values of the coefficients A and B depend on the permanent indicators of porous medium d and m and are defined by the equations (3) and (4).

$$A = \text{-}0.39 \cdot \frac{m}{d} + 13.2 \tag{3}$$

$$B = 2460 \cdot \frac{d}{m} \text{-} 60 \cdot \tag{4}$$

Taking into consideration that we recommended to use stone with 100 mm fineness. According to the calculation methodology we made technological calculations of the temperature of laying, which are presented in Tables 1 and 2.

Table 1. The relationship between Galileo criterion, aggregate fineness and bitumen mark

Bitumen mark	Aggregate fineness	Technological delivery temperature, °C					
		120	140	160	180	200	220
BN-IIU	0.02-0.08	8390	30175	108530	390343	1403922	5049402
	0.02-0.1	14498	52143	187540	674512	2425977	8725366
	0.04-0.1	23022	82801	297806	1071100	3852362	13855558
	0.08-1.0	48930	175983	632946	2276479	8187673	29448110
BND 60/90	0.02-0.08	3372	13137	51185	199428	777010	3027380
	0.02-0.1	5827	22701	88448	344611	1342673	5231313
	0.04-0.1	9252	36049	140453	547230	2132115	8307131
	0.08-1.0	19664	76617	298513	1163064	4531521	17655681
BN-III	0.02-0.08	3285	13322	54022	219070	888374	3602534
	0.02-0.1	5677	23020	93350	378553	1535110	6225178
	0.04-0.1	9014	36555	148237	601129	2437698	9885352
	0.08-1.0	19159	77692	315057	1277618	5180996	21009976
BND 40/60	0.02-0.08	1626	7144	31383	137863	605626	2660483
	0.02-0.1	2810	12345	54230	238228	1046522	4597315
	0.04-0.1	4462	19603	86115	378297	1661839	7300366
	0.08-1.0	9484	41663	183025	804019	3532013	15515939
BN-IIIU	0.02-0.08	2112	8227	32055	124891	486598	1895880
	0.02-0.1	3649	14216	55390	215811	840841	3276080
	0.04-0.1	5794	22575	87958	342700	1335225	5202294
	0.08-1.0	12315	47981	186942	728362	2837840	11056771

Table 2. The relationship between Galileo criterion, aggregate fineness, bitumen mark and penetration depth

ln(Ga/dk×B)×A	**Multiplication d×m**					
	0.01	**0.02**	**0.03**	**0.04**	**0.05**	**0.06**
5	0.05	0.1	0.15	0.2	0.25	0.3
10	0.1	0.2	0.3	0.4	0.5	0.6
15	0.15	0.3	0.45	0.6	0.75	0.9
20	0.2	0.4	0.6	0.8	1	1.2
25	0.25	0.5	0.75	1	1.25	1.5
30	0.3	0.6	0.9	1.2	1.5	1.8
35	0.35	0.7	1.05	1.4	1.75	2.1
40	0.4	0.8	1.2	1.6	2	2.4
45	0.45	0.9	1.35	1.8	2.25	2.7
50	0.5	1	1.5	2	2.5	3
55	0.55	1.1	1.65	2.2	2.75	3.3
60	0.6	1.2	1.8	2.4	3	3.6
65	0.65	1.3	1.95	2.6	3.25	3.9
70	0.7	1.4	2.1	2.8	3.5	4.2
75	0.75	1.5	2.25	3	3.75	4.5
80	0.8	1.6	2.4	3.2	4	4.8
85	0.85	1.7	2.55	3.4	4.25	5.1
90	0.9	1.8	2.7	3.6	4.5	5.4
95	0.95	1.9	2.85	3.8	4.75	5.7
100	1	2	3	4	5	6
105	1.05	2.1	3.15	4.2	5.25	6.3
110	1.1	2.2	3.3	4.4	5.5	6.6

Basing our analysis on Tables 1 and 2, for the implementation of the proposed technology we recommend that technological temperature of use should be 170-180 °C for no-fines concrete with 80-120 mm aggregate (with a safe temperature of 220°C).

4 Discussion

The experiments demonstrated that it is not enough to use only no-fines concrete to improve freeze resistance of the composite material. Laboratory tests of polymer concrete showed that their use leads to a significant increase of frost resistance, but also leads to a 4-times increase in the cost of polymer concrete compared to no-fines concrete cost. In addition, there are higher demands to the process of polymer concrete laying connected with the time it requires to set with a binder thus making it obligatory to prepare and unload it together with large aggregates at the construction site. All this leads to an increase in the cost of works and requires the purchase of special equipment. In this regard, we propose to replace polymeric binder by the bitumen. We chose a hot filling technology directly on the site as a means to deliver bituminous materials. This technology has a number of technological and structural advantages. Firstly, washing-down with bituminous materials makes it possible to get the final product in a short time, because the asphalt quickly cools and becomes solid. To warm bituminous material up and to deliver it to the point of laying, standard equipment (like bitumen heaters used in road construction) is used. Secondly, additional processing of no-fines concrete with bitumen material will significantly increase frost resistance of the final product. It will allow the use of stone materials with frost resistance of 50 cycles and less. Thirdly, standardizing temperature and place of bituminous material delivery, it is possible to make a layer of drainage and drainage water release that will reduce the thickness of the bind and also reduce costs.

We assume that in the event of destruction of bituminous binder in asphalt concrete, its stone material will not be displaced like a wave, due to the fact that there will be cement stone binders in it, and the coast protective construction will stay until repair operations.

The use of no-fines concrete here allows to automate the process and reduce the volume of the loaded material due to prior manufacturing of plates.

Taking into account the possibility of using standard cranage, ensuring the plates sustainability for the impact of the ice field and wave loads, it is proposed to use the plates of 1.5 × 1.5 × 0.5 planned dimensions, with a weight of one plate varying within 2.02 ± 0.05 tones. Planned dimensions of asphalt plates allow to lay them out as model units.

Conclusions

The research yielded the following conclusions:

– to protect the coastal slope, we offer a new technology that involves the use of asphalt concrete together with no-fines concrete;

– the technology includes the following operations: first making a skeleton of no-fines concrete and then washing-down with bituminous materials by a hot procedure;

– advantages of the proposed technology are found, i.e. washing-down with bituminous materials makes it possible to get the final product in a short time, because the asphalt quickly cools and becomes solid. To warm bituminous material up and to deliver it to the point of laying, standard equipment (like bitumen heaters used in road construction) is used. Additional processing of no-fines concrete with bitumen material will significantly increase frost resistance of the final product. It will allow the use of stone materials with frost resistance of 50 cycles and less. Standardizing temperature and place of bituminous material delivery, it is possible to make a layer of drainage and drainage water release that will reduce the thickness of the bind and also reduce costs.

– conducted laboratory studies made it possible to develop a method of appointing technological temperature for the process of bitumen laying;

– in accordance with the methodology for no-fines concrete with 80-120 mm aggregate we found the appropriate technological temperature of use, that is 170-180 °C.

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