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Optimization of EFDB «Mikrodur» Composition with Complex Fillers of Natural and Technogenic Origin

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ABSTRACT

This paper represents the potential technological solutions to reduce the takeoff of the high-priced Mikrodur®, to reduce the production cost of especially finely-dispersed binders (EFDB) and to raise its practical effectiveness and availability while stabilizing the building and structure foundations replacing the part of binder materials by fine fillers of various origin, including of technogenic, without degradation of physical and mechanical, structural or other characteristics of soil-concrete.

KEYWORDS

ARTICLE HISTORY

Finely-dispersed binder, fine filler, subsiding soils, injection strengthening, subsidence, viscosity

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Introduction

In Russia as well as in all parts of the world the loessial subsiding soils cover the best part of the territory and rest in the areas of intensive real estate development (Krutov, 2007).

The loess rocks occupy 34% of the area on the territory of CIS countries. The large part of Ukraine (up to 80%) and the South of the European part of Russia are covered with loess rocks. The large areas of Central Asia, Kazakhstan, East, South and West Siberia are cover with loess rocks too. Quiet frequently one can meet loesses in the North Caucasus, Belarus, Volga region, Yakutia and other regions. Figure 1. shows the map of the loess rocks distribution on the territory of CIS (Sergeeva, Larionova & Komissarova, 1986a; 1986b).

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Due to the wide-spread occurrence of loess soils the problem with their subsidence in the foundations of engineering structures becomes highly relevant. The reason for this is that upon wetting of loess the subsidence and soil strength drastic degradation occur that usually contribute to complete or partial decay of buildings and structures because of foundation failure and its settlement (Krutov, 2007).

The provision of strength and reliable maintenance of buildings and structures on subsiding soils can be achieved by application of appropriate principles and methods of construction based on the consideration of the peculiarities of soil formation, composition, structure and characteristics, and the known behavior of occurrence of additional subsidences (Krutov, 2007; Grigoryan, 2007).



Figure 1. Distribution map of loess rocks in the territory of CIS:1 – loesses and loess rocks of a high degree of thickness (more than 10 m), experiencing the subsidence under gravity; 2 – loess rocks and thick loesses (more than 5 m), experiencing the considerable subsiding deformations under super loads; 3 – medium thickness loess rocks (5 – 10 m), experiencing the minor subsiding deformations under super loads; 4 – loess rocks of sporadic distribution (3 – 5 M), non-subsiding; 5 – variable thickness loess rocks of sporadic and island distribution, nonhomogeneous by subsidence; 6 – loesslike and covering clay rocks of sporadic and island distribution, thin thickness, non-subsiding; 7 – frozen covering silty-clayed rocks experiencing the thermal subsidence due to defrosting.

When constructing on loess subsiding soils it is necessary to consider the possibility of their wetting and to take measures to prevent the deformation of engineering structures since the subsidence and soil strength drastic degradation occur upon loess wetting. It leads to the foundation failure, its intensive settlement and even to the extrusion of the saturated loess soil from under the foundation, that typically ends with complete or partial decay of buildings and structures (Sergeeva et al., 1986a; 1986b).

According to the specialists, the most effective method to eliminate the reasons causing the soil deformation of building and structure foundations is an artificial soil stabilization (Badeev, 2005).

Methodological framework

There are various methods of artificial soil stabilization depending on the stabilization technology, chemical processes emerging in the soil upon solution injection and on the behavior of soil properties (fig.2) (Arsan, 2005).

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The experience of Russian and foreign scientists shows that the most effective method to prevent the non-uniform settlements and further deformation of buildings and structures is an injection-based soil stabilization of foundation bases.

The injection-based soil stabilization means such methods of improvement when by solution injection the additional bindings are created between the soil particles providing the gain in the soil strength, reduction of their compressibility and sensitivity to ambient environment (Abukhanov, 2007).



Figure 2. Available methods of soil stabilization

The injection stabilization of subsiding soils ensures the increasing of soil bearing capacity, water resistance, longevity and strength. The great contribution to the development of theory and practice of this subject has been made by R. Perianez (2005), G.V. Nesvetaev (2008), I.F. Efremov (1971), I.V. Kozlova (2006), Y.V. Astafjev (2006), O.G. Kryzhanovskaya (2005), A.V. Volzhensky (1986), T. Mori et al., (2003); M.S. Saduakasov, I.V. Kolesnikov & V.A. Yugay (2006), V.G. Klimenko et al. (2005) and many others.

In recent years the great attention is given to methods of soil stabilization by solution injections based on especially finely-dispersed binders (EFDB). The technology of German scientists should be particularly noted. It is based on application of highly efficient mineral binder Mikrodur® obtained by air separation of the dust upon grinding of plain cements marked under «600» (Abukhanov, 2009; Bazhenov, 2012; Panchenko & Kharchenko, 2005).

EFDB Mikrodur[®] is a mineral hydraulic binder characterized by especially fine, continually and smoothly varying granulometric as well as by explicit and steady chemico-mineralogical composition to be used for injection-based stabilization of soils, cement and masonry constructions.

EFDB Mikrodur® mostly consists of ordinary cement raw material such as for instance, Portland cement clinker, blast furnace cinder, set-modifying admixtures and mineral additives. So that, Mikrodur® is a mineral product which depending on various water to cement ratios, as like regular cements, becomes solid during hydration reaction (Bazhenov, 2012).

The mineral composition of Mikrodur® is manufactured with different branded markings (tabl. 1) that allows ensuring the soil and structure stabilization with the view of various requirements: durability and impervious properties of strengthened massifs, resistance to various aggressive actions, solidification at below zero temperatures in the case of liquid water, setting time, rate of strength gain etc. (Bazhenov, 2012; Panchenko & Kharchenko, 2005; Grigoryan, 2007):

Grain fineness of Mikrodur®	Bi	randed marl	king (type) of Mikro	odur®
d ₉₅ [µм]	R	Р	E-Plus	Rock
TunS: d ₉₅ ≥ 24	R-S	P-S	S-E-Plus	S-Rock
TunF: d ₉₅ ≥ 16	R-F	P-F	F-E-Plus	F-Rock
Tun U: $d_{95} \ge 9,5$	R-U	P-U	U-E-Plus	F-Rock
Tun X: d ₉₅ ≥ 6,5	R-X	P-X	X-E-Plus	X -Rock

Table 1. Classification of EFDB Mikrodur®

The application of EFDB allows combining the effectiveness of injection-based technologies and ensuring the high strength and longevity of stabilization, allows creating massifs of large sizes and appeared to be an ecological and safety material.

EFDB Mikrodur® allows applying the injection not only as the method of soil stabilization and gain in the bearing capacity, but also as the method of soil transformation into structural elements of buildings ensuring the gain of the bearing capacity of building foundations and its elements due to increasing of its sizes in width and depth of occurrence. The injected cement-bound soil massifs can function as supporting foundation bearers for piles, excavation shoring, wall in trench, impervious screens etc.

Thus, with the due consideration of geotechnical conditions and developing pace of construction in Chechen Republic and Russia, the study and improvement of available methods of soil stabilization as well as the development of new injection formulations with the usage of domestic raw materials becomes the issues of importance for present-day construction and engineering-geological practice.

The improvement of method of injection-based soil stabilization of building and structure foundations by applying the suspensions based on domestic finely-dispersed raw material will ensure the reduction in expenditure, labor inputs and worktime, will also allow enhancing the forecast of the quality of the soils stabilized and its effective usage to solve the complex geotechnical problems.

Results and Discussions

In the light of the foregoing, in order to optimize the composition of EFDB Mikrodur® with complex use of fillers of various origin we performed experimental researches in the laboratory of CRDC «Modern building materials and technology» of GSOTU named after acad. M.D. Millionschikov on selection of alternative among

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domestic raw materials to reduce the takeoff of the high-priced Mikrodur®, and to reduce its production cost and increase its availability. Mikrodur® type R-U-E-Plus was used in researches.

The use of especially fine filler of low-grade raw material in the form of microsilica, cement kiln dust, very fine and thin sands laid down in our country by the dozen (Zaurbekov, Murtazaev & Uspanova, 2011; Gairabekov et al., 2015; Murtazaev et al., 2015a; 2015b) will allow solving not only the issues on reduction of production cost of the end product, but also the issues on ecological situation in the region.

In this regard, we have studied the properties of the filler of various origin: domestic very fine and thin sands, cement kiln dust, calcareous rock, volcanic ash and microsilica to create the complex finely-dispersed binder (CTDB) based on EFDB Mikrodur® and finely-dispersed domestic raw material (tabl. 2).

Table 2 shows that the density of researchable materials vary within the range 2,2 - 3,1 g/cm3, and its specific surface falls within the range 5000-14000 cm2/g.

No.	Applied material*	Powder density, ρ, g/sm ³	Specific surface, SSS, cm²/g	Milling time, min
1	Cement kiln dust (Chiri-Yurt, ChR)	3,1	12100	-
2	Limestone (Shatoysky district, ChR)	2,62	8600	40
3	Sand (Vedeno, ChR)	2,6	5000	30
4	Sand (Chervlennaya, ChR)	2,65	5000	30
5	Sand (Tolstoy-Yurt, ChR)	2,55	5850	30
6	Volcanic ash (Nalchik)	2,60	6800	30
7	Microsilica (Novokuznetsk)	2,20	12150	-
8	Microsilica (Chelyabinsk)	2,25	12400	-
9	Mikrodur® R- U-E-Plus	2,90	14600	_
-				

Table 2. Properties of applied materials for CTDB

The main indicators of CFDB suspension applicability are:

- Viscosity – it is a ratio of liquid sample passage through the orifice (shear rate) to the amount of force (liquid weight) prompting the liquid to flow (shear stress). So, the viscosity indexes determined by means of Marsh Funnel Viscometer and standard cup (fig. 3) are measured in seconds for one quart and show the time (in seconds) required for outflow of one quart (0,946l) of liquid sample through the funnel having the size-defined inlet orifice of 4,7 mm.

- Sedimentation (water separation), it is a process whereby the suspended matters are separated from the water under the action of gravity and settled to the container or reservoir bottom (fig. 4) (Panchenko & Kharchenko, 2005; Kharchenko & Bazhenov, 2012).

The time of complete water separation is characterized from the beginning of experiment to the end of water separation process. As a rule, the water separation for the period of 60 min should not exceed 10%.

Coefficient of water separation is calculated by formula, %:

$$\kappa_{\rm B} = \frac{V_1 - V_2}{V_1} \cdot 100 \tag{1}$$

where V_1 - suspension initial volume, sm³;

 V_2 - volume of the settled suspension in the meantime, sm³.

The water separation is determined as arithmetical mean value of two concurrent determinations, provided that the difference in results should not exceed 1 %.

The rate of suspension sedimentation. The standard sedimentation (ΔH) of suspension for 60 min at the temperature of suspension 10 °C is calculated by empirical formula:

$$\Delta_{\rm H} = \left(1 - \frac{2,14}{{\rm B/B} + 0,34}\right) \cdot 100\% \tag{2}$$

where B/B - water/binder ratio of suspension.

The actual suspension sedimentation for 60 min should not exceed the standard one > 5%.







Figure 4. Sedimentation analysis of CFDB suspension

Table 3 presents the indexes of suspension viscosity with the use of domestic raw material at B/B=4, which are valuated by the rate of suspension outflow on the device «Marsh Funnel and standard cup»; and presents the data of water separation of these suspensions determined by means of graduated cylinder with the capacity of 500 ml according to GOST 310.6-85 (1986).

It should be noted that this article presents the results of sedimentation analysis for only finely-dispersed materials without the use of EFDB «Mikrodur®». Such results are important to perform further researches on selection of mix formulation of the saturated especially finely-dispersed binders of Mikrodur® type with materials close to it by viscosity indexes and water separation.

Table 3. The indexes of viscosity and sedimentation of raw materials

No.	Material	Viscosity, sec	Viscosity, Sedimentation as time goes in min., % sec							
			15	30	45	60	75	90	120	150
1	Cement kiln dust	14,0	10,8	18,8	22,8	27,2	34,0	34,4	35,2	35,2
2	Lime stone	14,5	17,4	24,6	32,8	37,4	43,0	45,4	46,4	46,4
3	Sand (Vedenskiy)	15,0	32,4	55,2	62,8	64,8	66,4	67,6	67,6	67,6
4	Sand (Chervleniy)	14,5	61,2	70,6	70,4	72,0	72,4	73,2	73,2	73,2
5	Sand (Tolstoy- Yurt.)	15,0	42,0	57,2	59,6	61,6	63,2	64,4	64,4	64,4
6	Volcanic ash	14,5	58,8	63,6	65,6	68,2	69,6	70,0	70,0	70,0
7	Microsilica (Novokuznetsk)	15,5	12,0	21,2	29,4	30,2	32,8	35,2	37,2	38,0
8	Microsilica (Chelyabinsk)	16,0	4,0	7,2	9,6	13,6	16,0	18,8	25,2	25,6

Figure 5. displays the recordings of the process progress for the suspension water separation with the use of domestic raw material depending on time passed from the experiment start. The volume of the EFDB settled paste has been measured every 15 min during 1,5 hour and every 30 min at further observations. The moment of the first reading of the EFDB paste volume is taken as the experiment starts. If the last two readings coincide, the further observations should be stopped and the cylinder should be emptied.



Figure 5.The sedimentation analysis of suspensions with the use of domestic raw materials: 1 - Cement kiln dust – CD; 2 – Lime stone - carbonate flour, CF; 3 - Sand (Vedeno) - S_V; 4 - Sand (Chervlenaya) – S_{CH}; 5 - Sand (Tolstoy-Yurt) – S_T; - Volcanic ash – VA; 7 - Microsilica (Novokuznetsk) - Microsilica_N; 8 - Microsilica (Chelyabinsk) – Microsilica_{CH}.

The results tabulated above show that the closest by its indicators to Mikrodur® are microsilica and cement kiln dust which can be used for its reduction in the injected water suspensions. At this, it is possible to use other materials if the CFDB suspension formulation selected properly.

That way, with the consideration of the data obtained, we selected the suspension formulations based on CFDB (Mikrodur® + filler) at B/B = 4, while keeping the suspension steadiness and the viscosity required.

Tables 4-11 below presents the indexes of viscosity and sedimentation of solutions based on CFDB with different ratio of Mikrodur® and finely-dispersed domestic raw materials: 20/80, 30/70, 40/60, 50/50.

Table 4. The indexes of viscosity and sedimentation of CFDB compositions with the filler of cement kiln dust (CD)

No.	Microsilica/C	Viscosity,		Sed	iment	ation a	as time g	goes in r	nin., %	
beaker	D ratio, %	sec	15	30	45	60	75	90	120	150
1	20/80	29	8	22	36	49	54,5	56	57	57,5
2	30/70	30	0	12	16	22	28	31	32	33
3	40/60	33	0	0,5	11	14	16	16,5	17	17,5
4	50/50	35	0	0	8	12	13	14,5	15,5	16

Table. 5. The indexes of viscosity and sedimentation of CFDB compositions with the filler of carbonate flour (CF)

No.	Microsilica/CF	Viscosity,		Sedim	nentati	on as ti	me ge	oes in n	nin., %	
beaker	ration, %	sec	15	30	45	60	75	90	120	150
1	20/80	30	18	36	44	57	59	59,5	60	61
2	30/70	31	0	12	26	34	38	41,5	42	42
3	40/60	34	0	1	11	18	25	28	35	37
4	50/50	36	0	0,5	10	15,5	18	26	28	31

Table. 6. The indexes of viscosity and sedimentation of CFDB compositions with the filler of Vedeno sand (S_V)

No.	Microsilica/S _v	Viscosity,		Sedime	entatior	n as ti	me go	oes in n	nin., %	
beaker	ration, %	sec	15	30	45	60	75	90	120	150
1	20/80	31	24	38	45	60	61	61,5	62	62
2	30/70	32	10	25	62	37	44	46	48	49
3	40/60	35	1	11	19	28	37	39	40	41
4	50/50	37	0	2	10	18	19	24	27	30

Table. 7. The indexes of viscosity and sedimentation of CFDB compositions with the filler of Chervlenaya sand (S_{CH})

No.	Microsilica/S _{CH}	Viscosity,		Sedimentation as time goes in min., $\%$									
Deaker	ration, %	sec	15	30	45	60	75	90	120	150			
1	20/80	31	21	44	48	54	56	56,5	56,5	57			
2	30/70	33	0	22	31	34	35	36	36,5	37			
3	40/60	36	0	0	5,5	11	13,5	17	23	29			
4	50/50	37	0	0	1,5	4	8	14	19	22			

Table. 8. The indexes of viscosity and sedimentation of CFDB compositions with the filler of Tolstoy-Yurt sand (S_T)

No.	Microsilica/ST	Viscosity,	S	edime	entati	ion as	s time	goes	in min.	,%
beaker	ration, %	sec	15	30	45	60	75	90	120	150
1	20/80	32	18	44	55	58	60	61	62	63
2	30/70	34	0	19	28	36	40	42	42,5	43
3	40/60	37	0	1	14	20	26	29	37	38
4	50/50	38	0	0	10	16	19	29	35	36

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Table 9. The indexes of viscosity and sedimentation KTDV compositions with the filler of
volcanic ash (VA)

No.	Microsilica/VA	Viscosity,	S	edime	entatio	on as	time	goes	in min.	, %
beaker	ratio, %	sec	15	30	45	60	75	90	120	150
1	20/80	30	19	43	46	47	48	49	49,5	50
2	30/70	32	0	19	28	35	38	39	40	41
3	40/60	35	0	0,5	5,5	12	17	22	25	28
4	50/50	37	0	0	0,5	8	12	15	20	23

Table. 10. The indexes of viscosity and sedimentation of CFDB compositions with the filer of Novokuznetsk microsilica (Microsilica_N)

No.	Microsilica/Microsilica _N	Viscosity,	Se	edimer	ntatio	n as t	time	goes i	in min.	.,%
Deaker	ratio, %	sec	15	30	45	60	75	90	120	150
1	20/80	32	14	23	29	36	42	45	48	52
2	30/70	34	0	16	25	28	33	39	40	40
3	40/60	37	0	0,5	9	16	21	25	27	29
4	50/50	39	0	0	0	8	12	15	19	21

Table. 11. The indexes of viscosity and sedimentation of CFDB compositions with the filler of Chelyabinsk microsilica (Microsilica_{CH})

No. beaker	Microsilica/Microsilica _{CH} ratio, %	Viscosity, sec	Sedimentation as time goes in min., $\%$							
			15	30	45	60	75	90	120	150
1	20/80	33	7	16	24	29	35	38	42	45
2	30/70	35	0	2	11	17	24	26	32	35
3	40/60	38	0	0	0	5	10	14	20	23
4	50/50	39	0	0	0	0	3	8	12	15

According to the data obtained, the viscosity indexes of CFDB solutions fall within the following ranges:

with ratio of Mikrodur®: filler 20/80 - 17-24 sec.;

with ratio of Mikrodur®: filler 30/70 - 19-26 sec.;

with ratio of Mikrodur®: filler 40/60 - 23-29 sec.;

with ratio of Mikrodur®: filler 50/50 - 25-31 sec.;

Such viscosity indexes will ensure even greater penetration ability of solutions into the soils if stabilized by injection.

The soil stabilization by injection of EFDB Mikrodur® suspension has essential features as compared to other known methods of stabilization:

- injection is performed at a low pressure in the regime of soil impregnation while keeping its natural structure;

- stabilization strength of soil masses corresponds to the strength of top-quality concretes and can reach (compressive strength) 30 MPa;

- adhesion of cement-bound massif to underground concrete and masonry structures of buildings and constructions appeared to be full-strength with cementbound massif and equals to massif resistance to tensile;

- longevity of cement-bound massifs stabilized by the injection of EFDB Mikrodur[®] suspension corresponds to the longevity of sulfate-resistant concretes;

- soil stabilization by injection of EFDB Mikrodur® suspension reduces the water filtration that is appeared to be an important factor for subsiding soils.

Conclusions

To sum it up, the application of CFDB based on Mikrodur® as compared to other alternatives allows reducing the direct costs and performance time.

The usage of the complex finely-dispersed binder based on Mikrodur® with fillers of various origin, including of technogenic, in the capacity of import-substituting materials and the selection of alternative among the domestic raw materials to reduce the takeoff of the high-priced Mikrodur®, allow without degradation of physical and mechanical, structural or other characteristics of soil-concrete to reduce the production cost of such binder and raise its practical effectiveness and availability while stabilizing the building and structure foundations.

Disclosure statement

No potential conflict of interest was reported by the authors.

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