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USE OF STRENGTHENING CEMENTATION WHEN CIVIL STRUCTURES ON KARSTED TERRITORIES CONSTRUCTION

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ABSTRACT

The paper describes measures on strengthening cementation of karsted territories both when erection of new houses and in failure situations. The result of strengthening cementation is water resistant strong base preventing development of karst-suffosion processes.

At present, the civil engineering in city Ufa undergoes great increase. All favourable for construction sites have been already developed, that's why more and more often the construction is carried out on sites with the complicated engineering-geological conditions. About 50% of such sites are karsted territories and the problem of their development is extremely actual not only for Ufa city but for Bashkortostan Republic as a whole.

Any construction as a rule provokes disturbance of the natural geology-hydrogeological development due to technogenuous leakage of service lines of different kind and elevation of ground water level in urban conditions. Such disturbance lead to activization of dangerous geological processes that provoke bases and foundations refusals, especially on karsted territories (Abdrakhmanov, 2002).

The Russian codes permit construction on such sites on conditions of keeping to karst protection measures to prevent the activization of karst-suffosion process.

The paper describes the experience of construction on a karsted site with the karst protection. A subject of construction is a 14-storey, 2-section building. Each section is 20 x 40 m in plan, 36 m height with a basememt of 2.5 m height. The walls of the building are brick, the foundation is a reinforced concrete raft.

The soil of the site is the complicated stratification of rock and semirock soil, such as gypsum, limestone, marl, argillite and aleurolite being in different extent of weathering. Such rocks as carbonate and sulfate rocks are cavernous and with great extent of jointing. Ratio of porosity for these rocks is within 5 and 10%. A network of small and average size cracks of subvertical direction is observed in rocks. The clay variety is of dense structure with the subhorizontal small cracks. The ratio of karsting evaluated on samples is within 3.6 and 21.3%, the same ratio but accrding to boring results is 6.7%.

The site is situated in conditions of development of carbonate -suffosion karst. According to the class of karst stability, the site applies to the III-d class, i.e. insufficiently stable, and by extent of karst danger it applies to zones "A" and "B" (Instruction, 1996).

At the depth of 60 m the underground water is not revealed. The section is fully drained and represents a zone of vertically-descending filtration of thawing, rain and technogenuous water.

The hydrogeological investigations carried out at site allowed to evaluate the filtration ratio and the specific water saturation of section rocks (table 1).

As table 1 shows, the specific water saturation of the soil mass of the building base changes within 0.1 and 10.3 l/min m^2. The averaged filtration ratio for the whole section is 5.8 m/day. It should be noted that the rocks of the upper part of soil mass to the depth of 20 m are characterized with the largest jointing.

Table 1. Specific water saturation of soil mass for each interval of hydrogeological investigation

Interval, m	Specific water saturation q, l/min m^2, hole number				
	6	7	8	9	q_{av}
0 – 5	4,1	2,8	7,1	0,1	3,5
5 – 10	4,9	3,5	4,0	2,9	3,8
10 – 15	4,3	0,8	7,6	0,7	3,4
15 – 20	0,8	10,3	9,6	0,7	5,4
20 – 25	0,9	0,9	2,5	0,4	1,2

To make the base soil of the building under construction more stable, it is advisable to carry out the strengthening cementation at site.

The aim of the strengthening cementation is to decrease the rock permeability in order to prevent the activity of karst-suffosion processes, to increase soil strength, to prevent karst deformations in the cementation zone.

Based on materials of the engineering-geological explorations and laboratory formulation grading, a project was worked out for the strengthening cementation of a building base to the depth of 15 m below the foundation raft base.

The cement solution with the water- cement ratio of 1 (the density of cement solution is 1.5 g/cm^3) was used as the injection solution. Portlandcement used, was of the grouting mark PTTs -50 of Republic Bashkortostan production.
To improve the karsted rock of the building base, 52 injection holes were arranged by a 5 x 5 m grid. 5 m height holes were drilled at the three levels of injection. The general depth of cementation was 15 m with the radius of cement solution spread of 2.5 m.

The works were carried out according to the following technology:

- 160mm diameter holes were drilled with the unit URB-2A-2 to the depth of 1 m up to a foundation base mark. A 146 mm diameter borehole casing was mounted, then a hydraulic plug was fit, and then the discompacted space between the soil and the casing was cemented. In two days the holes were drilled to a mark of a bottom of a 5 m depth zone being cemented. The injection holes were drilled in two steps: by the grid 10 x 10 m and 5 x 5 m
- The cement mortar with the density of 1.5 g/cm^3 was prepared in mortar mixer with the proportion accuracy 5%. Then it was injected into soil in amount of 10 m^3 with the injection pressure 0.5 MPa. In a day after the injection finishing the drilling was carried out for the second zone of injection, etc.
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After the job finishing, the holes were filled with cement mortar. The general cement discharge for the strengthening cementation was 1175 t. In the process of cementation the geotechnical monitoring of the job was carried out with the data logging.

After the strengthening cementation, completion the water permeability of the cemented soil and its physical and mechanical properties were controlled.

The hydraulic test of the cemented soil mass (table 2) showed the water saturation of the soil mass to decrease 17.5 times. The average filtration ratio of the soil mass after the cementation was 0.6 m/day.

Table 2. Specific water saturation of soil mass after the cementation for each interval of hydrogeological investigation

Interval, m	Specific water saturation q, l/min m^2, hole number		
	10	11	12
2 – 7	0,09	0,4	0,007
7 – 12	3,2	0,008	0,04
12 – 17	1,6	0,04	0,8
17 – 22	0,0008	1,5	0,1

The soil mass changed from the class of heavily water permeable to the class of water permeable. The cementation allowed to form a dense, closed, low permeable soil mass in a building base to the depth of 17 m.

Drilling works and laboratory test of samples and monoliths showed the soil mass after cementation to become strong and dense. All the caverns met and discompactions were filled with cement The strength of samples with caverns and fractured void filled with cement was within 2 – 8 MPa and was comparable with the strength of the mother rock (figures 1,2).

Fig. 1. Layer-flaggy structure of rocks with clear tracing of cement treatment

Fig. 2. Horizontal shear of the cement treated specimen

As a result of the strengthening cementation, the following features characterizing the karst danger have been changed:
- ratio of karsting < 0.01;
- thick of the water confining stratum 17 m;
- zones of discompaction are absent;
- velocity of the underground karst denudation of the order of 0.05 m^3/km^2 year;
- hollows are absent except partially zones of jointing;
- ratio of inner karsting 1.6%;
- time of reaching the critical hollow dimensions many time exceeds the building service life.

All these features show the site to become relatively stable without special constructive measures.

The cemented soil mass under the building foundation prevents karst holes formation and local settlements during the service life of the building.

The strengthening cementation of the karsted rocks was used when reconstruction of the failed building "K" of the University in Ufa city.

The building "K" is a many-storey reinforced concrete frame building of 35 m height and dimensions 48 x 25 m. As the building foundations, strip and post reinforced concrete foundations on the natural base are used.

The building is under operation more than 20 years. The bearing and cladding structures of the building, especially basement and staircase walls are strongly damaged. There are numerous vertical, inclined and horizontal cracks with crack growth width to 30 mm.

The foundation base is of gypsum bearing sandstone, limestone, marl, gypsum limestone and gypsum structure in a zone of vertical-descending filtration of ground water characterized with intensive karsting. In this connection, such soil mass is considered as insufficiently stable (III-d class) according to the extent of karst stability, and is referred to zone "A" according to the extent of karst danger. Carbonate rocks are cavernous and are in great extent jointing (ratio of fractured void is equal to 5 – 10%). Clay varieties are of dense structure with the subhorizontal small cracks of bedding.

By results of hydrogeological investigations, the filtration ratio of the soil mass under the foundation base was evaluated to be 3.4 m/day. The main and only reason of the staircase and adjoining bearing and cladding structures deformation is the engineering-geological and hydrogeological condition observed the last 15-20 years together with geological conditions favourable for development of the dangerous geological and engineering-geological processes, namely:

- availability of soils (gypsum soil, limestone marl) failed under the chemical and mechanical influence of the temporary underground water streams in Sheshminsky horizon;
- permeability of base soil (jointing, weathering) to moving underground water;
- formation of the temporary underground water stream at the expense of inflow from the sedimentation of the adjoining territories and seepage of atmospheric and technogenuos water. The section of the Quaternary and Permian sedimentation at site and in its vicinity is drained and represents a zone of aeration, i.e. a zone of vertical-descending atmospheric precipitation (about 360 m^3/year) and seepage of the water- bearing service lines.

Thus, within the site under investigation, carbonate and sulfate-carbonate types of karst as well as suffusion and karst-suffosion processes are developed in carbonate rock mass.

To prevent the further deformation of building "K", it is necessary to exclude the penetration of any surface and underground waters into the base; at the same time the base should be strengthened with the continuous cementation of discompacted soil under the foundation from its base to the depth of 12-15 m. This process includes:

- boring of the injection holes by 2 x 3 grid with the general number of holes at site equal to 113;
- preparing of the cement mortar using M 400 cement with W/C ratio 1, mortar density 1.5 ± 0.01 g/cm^3 with the general quantity of cement 1011 t
- injection of cement mortar by the vertical-descending scheme under the pressure 0.5 MPa with cement content 3 m^3 per one level. Altogether 4 levels by 3 m each to the depth of 12 m from the foundation base were used per injection point.

The process of strengthening cementation was accompanied with the geotechnical control. To evaluate the cementation quality, the following site works have been done – control holes boring, soil monoliths sampling, hydrogeological observations, laboratory investigations of monoliths.

It should be noted that a very qualitative cementation of soil base was under the foundations with a zone of the heaviest base deformation. Cement mortar content 3-5 times exceed the design one. The best cementation was observed in the carbonate stratum characterized as the most failed and weak part of the section.

Samples from the control holes and their test showed the high quality cementation of soil mass. The average rock strength was 3.6 MPa.

Hydrogeological investigation of the cemented soil mass showed 100 time decrease of water saturation. The average ratio of soil mass filtration after the cementation was 0.003 m/day. The class of soil mass changed from high permeable to practically impermeable. The strengthening cementation made a soil mass under the foundation dense and impermeable to a depth of 12 m.

CONCLUSION

Results of karst protection measures carried out, show that the strengthening cementation when buildings construction on karsted territories allows to change the insufficiently stable base to the relatively stable one according to a class of karst stability.

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