

Geotechnical monitoring to ensure reliability of construction and operation of buildings and structures

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Abstract. To improve the reliability and durability of construction structures it is necessary to thoroughly study their behaviour during the construction process & operation and based on their behavioural analysis we can develop measures which will aid in avoiding future emergency situations. Well-timed application of geotechnical monitoring warns and minimizes the risk of deformation & destruction of the examined object as well as adjoining buildings. The necessity of conducting geotechnical monitoring should be decided during the stages of concept design or the design of new construction or reconstruction of a building structure. Geotechnical monitoring of buildings & structures includes research & analysis of «foundation soil – foundation – above-ground structures of the building» system and it consists of complex work to ensure the safety of the entire construction process as well as safe operation of buildings & structures. Its usage allows us to detect and avoid irreversible procedures occurring in the system «foundation soil – foundation – above-ground structures of the building» on time prior to the deformation of buildings & structures. This article describes special aspects of geotechnical monitoring for the deformation behaviour of operational buildings with increased level of responsibility within the influence zone of new constructions taking Vnukovo-1 airport as an example. We also study the nature of problems associated with ensuring normal operation of existing buildings, their causes, triggered by the construction work or unsatisfactory technical conditions of the observed objects. The main feature of reconstruction of the Vnukovo-1 airport was the necessity to maintain the daily-life functions of operational buildings during the construction process.

1. Main part

Well-timed application of geotechnical monitoring warns and minimizes the risk of deformation & destruction, increases the reliability and durability of building structures of the examined object as well as adjoining buildings [1]. In this article we examine aspects of geotechnical monitoring for deformation behavior of operational buildings with increased levels of responsibility. Particularly, of buildings which are within the influence zone of construction of the railway line & new airport Vnukovo-1.

The main feature of reconstruction of the Vnukovo-1 airport was the necessity to maintain the daily-life functions of operational buildings during the construction process. The buildings that enter the zone of influence of the conducted constructions are; the air-terminal complex, which handles the



passenger flow of domestic flights, office buildings, and the control tower, which not only ensures the safety of the take-off strips of the Vnukovo-1 airport, but also air traffic safety in a part of Moscow & Moscow region.

In connection with the complex transportation situation, for the convenience of connecting Vnukovo-1 airport with the city, reconstruction of the airport and the railway line was started, which connects Vnukovo-1 & Kievsky railway station in Moscow. The project of reconstruction and new construction were developed by OAO "Metrogiprotrans". The project was based on the surveys conducted by GUP "Mosgorgeotrest" and OAO "Metrogiprotrans".

A feature of the engineering-geological structure of the area was the presence of variable underground water level in the local super-moraine horizon at depths of 3.8 to 8.0m. This super-moraine horizon was located in insertions of sand interlayers in the form of lenses in cohesive soils and had a sporadic distribution.

The railway line which connects the underground terminal with the railway station «Vnukovo airport» has an above-ground and a tunnel section. The total length is 1432m. The tunnel section varies from 14,5m to 19,5m in width. The depth of the tunnel according to the project is 22m up to the exit to the surface of the ramp part. The tunnel line was built in an open cut construction with load-bearing buried wall and closed off with precast floor slabs as shown in figure 1.



Figure 1. Construction of the railway line tunnel

The roadway was constructed above the tunnel. This design solution of the construction led to cutting of the upper water-bearing horizon, which had a sporadic distribution as mentioned above.

Hydrogeological monitoring, required in this case as a constituent part of geotechnical monitoring [2] was not conducted. Accordingly, there was no hydrogeological assessment of possible changes in the hydrogeological regime of the territory in connection with construction of tunnel with such design. No special measures were taken in the design to conserve existing hydrogeological situation.

All this has led to an inevitable increase in underground water level. And as a consequence, it caused basement flooding of the adjacent operational buildings and their foundations.

Before beginning of the construction process, the buildings & structures within the influence zone of construction of the railway line, the size of which was specified by the design company, were surveyed by the employees of MGSU to determine their current technical condition.

The survey results showed that almost all of the buildings; flight control tower, old air terminal building, aircraft maintenance facility, with the exception of open type parking lot №2 were in limited

operational condition. All these buildings were intended for demolition, therefore, measures recommended by MGSU to strengthen the foundation soils and above-foundation structures of adjacent buildings were not implemented. Those building were put under Geodetic monitoring and crack-formation monitoring.

As a result of the above-mentioned monitoring for one quarter of the year, MGSU identified that due to the construction of the tunnel the actual subsidence of the flight control tower exceeded the maximum permissible value in 3 times, and subsidence of aircraft maintenance facility building exceeded this value in 9 times. The walls of the tunnel deviated from vertical by a few dozen millimeters.

The situation was recognized to be an emergency and construction works on the site were suspended. In this regard, MGSU developed relevant emergency measures which prevented collapse of the building structures of the examined buildings. An additional anchor system was installed according to our recommendations, which helped to stabilize the growing subsidence.

However, despite the relative stabilization of deformations, the crack-formation process was actively developing. The beginning of this process indicated disorder of the spatial rigidity of the buildings. In addition, twisting of vertical structures was documented.

Because of such processes (figure 2) aircraft maintenance facility building was immediately resettled and demolished.



Figure 2. Crack-formation of the aircraft maintenance facility building

However, due to the limited space availability of airport infrastructure, resettling office buildings of the flight control tower was not possible. In this regard, decision was made to strengthen the flight control tower building by using metal belts, according to special project designed by MGSU employees (figure 3).



Figure 3. Realization of the project to strengthen the office buildings of the airport control tower in Vnukovo-1 airport

These measures were taken to restore spatial rigidity of the building and to increase reliability of its building structures. After carrying out emergency measures, the office building of the flight control tower continued to operate for two years, after which it was dismantled.

In addition to strengthening of the above-ground structures, a cut-off wall was made between the foundations of buildings and the excavation wall of the tunnel to prevent possible additional vertical deformations of adjacent buildings (figure 4.)



Figure 4. Execution of the cut-off wall between the office building foundation of the flight control tower and the excavation wall of the tunnel

As a result, based on the analysis of the results of the geotechnical monitoring conducted by MGSU, we have taken the correct emergency solutions to prevent further crack-forming and advancement of deformations in foundations. That, in turn, provided safe and reliable operation of the buildings. Implementation of emergency response activities recommended by MGSU has led to the stabilization of the situation and continuation of construction work.

After completing the railway line, construction of the new air terminal building started. The neglected influence of tunnel excavation on adjacent buildings, as well as errors in protecting buildings from the effects of construction works related to its sinking were taken into account during construction of the cofferdam of the excavation pit and excavation works on foundation pit of the new air terminal (figure 5).



Figure 5. Excavation pit of new Vnukovo-1 airport

Load-bearing buried wall was used as cofferdam of the excavation pit with a thickness of 600 mm, held in a vertical position by ground anchors in two rows in height. The length of the anchor, including its root, was 21m, and the angle of inclination is equal to 30° at the depth of the excavation of 8m.

At this stage, predictive calculations to assess the impact of construction of the air terminal on adjacent buildings were made by MGSU using PLAXIS software. The behavior of the soil appeared in accordance with the elasto-plastic Mohr-Coulomb model. The strength characteristics were taken according to the test results of OAO "Mosgorgeotrust" and OAO "Metrogiprotrans", which did not consider the influence of dynamic effects on physical & mechanical properties of soils, which could cause the development of additional subsidence. From results of these calculations it was established that the office building of the flight control tower, the flight control tower, parking lot No. 2 and hall area 2 of the conserved part of the airport complex No. 1 (AVK-1) were in the zone of influence. The old air terminal building had already been demolished by this time.

It should be noted that compared to other buildings within the area of influence of new construction and reconstruction, Parking building No. 2 underwent significant subsidence (-28mm) during the construction of the tunnel. During geotechnical monitoring by MGSU in the Parking lot No. 2, exceedance of applied loads over their designed values was noted, which indicated the shortage of load-carrying capability of building structures.

Thus, employees of MGSU developed a project to strengthen reinforced concrete structures of Parking building No. 2 with metal structures. In addition, recommendation was given to limit the linear load on the ceiling of the parking structure, prior to implementation of actions to strengthen it.

The Parking building No. 2 fell in to the influence zone of the construction of flyovers and the new air terminal. After the construction of the railway line behind the parking building, monitoring was interrupted. At the new stage of monitoring, parking building No. 2 was set to the maximum allowable value of deformation of 2 mm, which was repeatedly recorded and remained stable.

The results of calculations carried out by MGSU showed that the expected subsidence will not exceed their maximum permissible values. However, since the dynamic effect of work of the construction machinery was not taken in to account in the predicted calculations (in the absence of initial data), the project on the construction site, adjacent to the flight control tower, provided a protective slurry wall done with "jet grouting" technology, and under the building phase of the airport complex AVK-1 implementation of compensated injection of cement mortar was done. Both measures were executed.

Before start of works on excavation of the foundation pit of the air terminal, current technical state of load-bearing structures of AVK-1, including the foundations was assessed. Excavation of test pits for examination of foundations in operational buildings was not possible due to the large passenger traffic. In this regard, to determine the depth of the foundations and structural characteristics of materials, as well as contact state of Foundation-soil, we used non-destructive geophysical methods [3]. The results of these works allowed us to determine the magnitude of the additional maximum permissible deformation of AVK-1.

The above-mentioned buildings were put under geotechnical monitoring. But in this case, the monitoring program included not only of geodetic observations for deformations and crack-formations, but also visual inspection of the technical condition of load-bearing structures. In addition, further observations had been conducted for the deformation behavior of the buried wall, which is the cofferdam of the excavation pit.

Considering the importance of the conserved structures, especially the flight control tower, the "Cyclops" observing system was used [4] to improve the efficiency of obtaining data on this object, which allows receiving operative information with high frequency. However, this system can be used only under the condition of direct visibility. Therefore, geodetic monitoring of other objects was carried out in traditional ways. Thus, combined monitoring system was applied on the construction site, combining traditional methods of observations with the method of the automated system "Cyclops".

2. Conclusions

In summary, we can draw the following conclusions:

- it is necessary to consider dynamic effects during determination of soil properties in engineering-geological investigations for the most accurate estimates of the size of the influence zones of new constructions on surrounding area, as well as the most credible values of maximum permissible subsidence of buildings and structures of adjacent buildings;
- During development of underground areas, it is necessary to consider the location of water-bearing layers and in case of exposure to buildings and structures – perform hydrogeological monitoring;
- During monitoring for deformations of high-responsibility buildings directly adjacent to the construction site it is advisable to combine methods of computer control with traditional methods of observation;
- Conducting geotechnical monitoring from the initial construction phase allows to timely notice negative processes taking place in the building constructions and the foundation soil. And, if necessary, to develop actions to prevent an emergency situation to ensure their reliability and durability of structures;

- The geotechnical monitoring program must include various monitoring techniques that supplement each other and to allow for regular monitoring of the state of load-bearing structural elements in the monitored buildings to ensure their strength and reliability;

References

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