Landslide hazard assessment in city under construction
Innopolis (Russia)

A Latypov¹, N Zharkova² and I Nuriyev³

¹, ², ³ Vernadsky Institute of Geochemistry and Analytical Chemistry of the Russian Academy of Sciences, Moscow, Russia Kremlevskaya str. 4/5, Kazan (Volga region) Federal University, Kazan, Russia

E-mail: ² kazannad@rambler.ru

Abstract. The paper reflects the main results of exploring the landslide hazard threatening Innopolis city, precisely field and laboratory studies, assessment of the slope stability. A regional short-term landslide hazard forecast was performed using a digital model of geological medium and the method of engineering-geological analogy: an engineering-geological zoning was conducted; data from standard areas, the critical values of surface slopes were calculated for the identified types of soils and different types of humidity; the obtained data were extrapolated, verified and corrected. On the basis of the forecast, development of a landslide monitoring network is proved.

1. Introduction
The estuary area of the Sviyaga river (located in Verkhneuslonsky District of Republic of Tatarstan) is currently under active development: since 2005 there has been created and constantly reconstructed a unique ski sports complex (SSC) "Kazan", and in summer of 2012 there has began the construction of new city - IT-center with extensive business infrastructure (industrial parks, research centers, etc.) called Innopolis.

Despite good location of Innopolis and SSC (proximity to Kazan city and M-7 highway), the investigated area is characterized by highly complex engineering and geological conditions. The presence of a thick layer of clay soil (of natural and technogenic origin), complex hydrogeological conditions, as well as the large ruggedness of terrain (the Sviyaga river slopes and numerous gullies and ravines systems) stipulate the development of landslide processes.

In 2012, under a contract with the Ministry of Ecology and Natural Resources of the Republic of Tatarstan, Kazan (Volga) Federal University performed the integrated assessment of landslide hazard [1], which was of particular urgency in terms of ensuring safe operation conditions on the territory of city "Innopolis" under construction and "Kazan" ski sports complex.

2. Results and discussion
Main stages of the work are as follows:

Collection, consolidation and analysis of published fond materials. As part of the work, there has been studied different sources of information of previous years, such as the reports of the regional search works, hydrogeological reports on groundwater reserves assessment, geological, hydrogeological and engineering-geological surveys, geological maps of Quaternary sediments, and
etc. Taking into account the fact that the territory of Innopolis city is undeveloped, there are no any reports of detailed engineering-geological investigations. The area of SSC "Kazan" is the only exception as there are 46 reports on engineering surveys (performed by SUE RT "Tatinvestgrazhdanproekt" in the period from 2002 to 2008).

Interpretation of aerial and satellite materials. This kind of work was carried out by the employees of the State Unitary Enterprise "NPO Geocenter RT" using Erdas Imagine, ArcGIS, MapInfo softwares. Despite the presence of a large number of satellite imageries of the study area, the images of required quality were taken only in 2005, 2011 and 2013, thus engineering and geological interpretation was carried out only during this period. The total square of the study area is 21 km². Thus, the comparative analysis of landslide dynamics within the study area was conducted for the period of 2005-2013.

Visual inspection of the area to assess the conditions of landslide activation. The visual inspection was carried out along the elements of erosion and hydrographic network (the slopes of the Sviyaga river and Morkvashka creek, slopes of numerous gullies and ravines), because gravitational processes are tend to develop in such areas. 10 observation points were planned at 1 km of the route within the slopes of the terraces, river banks and erosion systems, and 4 points of observation were chosen within the watersheds, gentle slopes, as well as at the adjacent territory.

A passport was developed for each landslide area. It includes geological and geomorphological description of the slope (height, steepness, shape, exposure, genesis), the nature of landslide bodies’ boundaries, the type and subtype of landslides, their age, the phase of sliding process, type of sliding surface. In addition, geometric parameters of landslide bodies (width, length, rupture surface, amplitude of displacement) were measured, and the main reasons for landslide were identified.

In addition to description of the slopes and slope processes, the natural and artificial rock outcrops were documented in the course of route surveys. Particular attention was given to Quaternary sediments (usually dominant in the composition of landslide bodies) and technogenic soils: using a number of direct and indirect methods, the age and genesis of sediments were determined, the thickness (if possible) was estimated, structural and textural features were determined (grain size, the size and the number of rudaceous fraction (clay soils), the type and amount of filler, petrographic composition of the debris, the degree of roundness (for coarse clastic soils). Also, in the field conditions the degree of pore filling with water and consistency were approximately estimated in coarse-grained soils and clay, respectively. In technogenic soils, density (qualitatively) and age of the mound (when possible) were estimated [2]. Typification of ground strata was performed according to the data (Table 1).

| Table 1. Groundwater strata typification scheme. |
|-----------------------------|
| Top | A. Loam and clay | B. Loam and clay with gravel and scree | C. Loam and clay with gravel and scree >10% | D. Technogenic clay soils with gravel and scree |
|-----------------------------|
| Thickness, m | <1.5 | 1.5-4.0 | >4.0 | <1.5 | 1.5-4.0 | >4.0 | <1.5 | 1.5-4.0 | >4.0 |
| Bottom | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| P₂kz | - | - | - | - | - | - | - | - | - |
| P₂ur | - | - | - | - | - | - | - | - | - |
| P₃sd | - | - | - | - | - | - | - | - | - |
| dp Q₄ | - | - | - | - | - | - | - | - | - |
All buildings and structures located in the study area were examined on the presence of deformations, indicating the development of landslides (cracks, distortions of door and window openings, deviation from the vertical, etc.).

During the period of field surveys 14 visual inspections were conducted (364 observation points, the total length - 53 km).

**Comprehensive study of the geological structure of bedrock and landslide bodies, identification of their contours, composition, structure and physic-mechanical properties of soils in the most dynamic and dangerous areas of landslides.** Geodetic survey, including aerial photography, was carried out on landslide-prone areas. These areas were identified during the route monitoring. Then, to obtain the reference section for the most characteristic areas (landslide depressions, axial strips of large landslides, inter-landslide ridges, other large and most typical for the region forms of relief), the mine workings were carried out (wells and bore pits) to collect monoliths of soil (326 pcs.) and water samples (20 pcs.).

Further, to clarify the boundaries of landslide bodies and the engineering-geological elements, as well as position of the slip boundary and groundwater level within the study areas, the complex of geophysical surveys, including VES (using a 4-electrode setting AMNB) and geo-radar survey (GPR «ProEx, MALA GeoScienceinc) was conducted [3, 4].

Identification of physical and mechanical characteristics of soil properties and chemical analysis of water samples were performed at Institute of Geology and Petroleum Technology KFU in the Laboratory of Soil and Soil Mechanics. Deformation and strength properties of soils were determined by ASIS NPP "Geotech" in compression and shear instruments. Filtration coefficients were determined on undisturbed samples of a cylindrical shape with a diameter of 100mm, height of 65mm on Wille Geotechnik D 3325S filtration plant.

**Assessment of landslide-prone slopes stability using the latest domestic and foreign techniques.** As a result of the joint analysis of visual observations, geodetic measurements and topography, 19 measurement points were constructed on the territory of Innopolis city, 10 measurement points were constructed on the territory of SSP "Kazan" on the so-called reference stations which were selected during route surveys. On one hand, these areas are characterized as potentially landslide-prone slopes from geometric and geological point of view, and on the other hand, they are located within the boundaries or in the vicinity of projected and existing buildings.

Stability calculation was performed using GEO 5 FINE software package. As a result, the most probable sliding surface and coefficients of stability for the natural state, as well as for the predicted water saturation, were obtained for each measurement station [5].

**Implementation of short-term forecasting of landslide processes under the influence of natural and technogenic factors.** The slope stability evaluation on the standard areas and the extrapolation of the results to the entire territory (with preliminary determination of surface slopes critical value for two modes of soils moisture, Table 2) based on maps of the slopes and soil types were followed by engineering-geological zoning aimed at predicting landslide hazard using digital model of geological environment [6].

| Type of soil strata | Stability factor | \(< 1.0\) | \(1.0\div1.1\) | \(1.1\div1.2\) | \(1.2\div1.3\) | \(>1.3\) |
|--------------------|-----------------|-------------|-----------------|-----------------|-----------------|-----------------|
| \(W_n\)        | \(W_{sat}\)    | \(W_n\) | \(W_{sat}\) | \(W_n\) | \(W_{sat}\) | \(W_n\) | \(W_{sat}\) | \(W_n\) | \(W_{sat}\) |
| 21°  | 19°  | 20°  | 18°  | 19°  | 17°  | 18°  | 16°  | 16°  | 14°  |
| 39°  | 37°  | 38°  | 37°  | 37°  | 36°  | 35°  | 34°  | 32°  | 31°  |
|     | 36° | 33° | 34° | 31° | 33° | 32° | 29° | 30° | 27° |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 36° |     |     |     |     |     |     |     |     |     |
| 34° |     |     |     |     |     |     |     |     |     |
| 43° |     |     |     |     |     |     |     |     |     |
| 63° |     |     |     |     |     |     |     |     |     |
| 47° |     |     |     |     |     |     |     |     |     |
| 35° |     |     |     |     |     |     |     |     |     |
| 32° |     |     |     |     |     |     |     |     |     |
| 28° |     |     |     |     |     |     |     |     |     |
| 32° |     |     |     |     |     |     |     |     |     |

Then, subsequent verification and correction of the results obtained using data from satellite images interpretation, seasonal instrumental geodetic measurements, as well as detailed engineering-geodetic survey (using information on the stage of the landslide process) were carried out. The main result is a detailed engineering-geological map with elements of forecast (Figure 1).

Development of high-priority and long-term anti-landslide measures to reduce the negative impact of landslide processes. According to the described forecast of landslide processes, high-priority (mechanical fastening of slopes with the help of massive retaining walls, sheet piling, anchoring, injection curtains, ramparts, terracing, slope flattening, removal of landslide mass) and long-term (drainage measures, planting of vegetation, reinforcement of slope surface by geosynthetic grids and frames) anti-landslide measures, aimed to reduce geological risk, were developed.

**Figure 1.** Landslide hazard forecasting map.
Table 3. Legend to the landslide hazard forecasting map (Figure 1) and the criteria of landslide displacements probability.

| Area km² (%) | Probability of displacement | Safety Factor (SF) |
|--------------|----------------------------|--------------------|
|              |                            | Natural moisture of soil | Fully water-saturated soil |
| 0.10 (0.44)  | Inevitable throughout the year | SF ≤ 1.0            |                    |
| 0.06 (0.26)  | Inevitable in spring and autumn, possible in summer | 1.0 ≤ SF < 1.1 | 1.0 ≤ SF < 1.1 |
| 0.20 (0.88)  | Inevitable in spring, possible in autumn, unlikely in summer | 1.1 ≤ SF < 1.2 | 1.1 ≤ SF < 1.2 |
| 0.48 (2.09)  | Possible in spring, unlikely in autumn, impossible in summer | 1.2 ≤ SF < 1.3 | 1.2 ≤ SF < 1.3 |
| 1.62 (0.70)  | Unlikely in spring, impossible in autumn and summer | SF ≥ 1.3 | SF ≥ 1.3 |
| 2.15 (0.94)  | Impossible under current engineering-geological conditions | SF ≥ 1.3 |                      |

Substantiation and establishment of observational network for landslide processes on the territory of Innopolis and "Kazan" ski complex. The necessity of a monitoring network is substantiated for the territory of Innopolis city. In addition, 9 observation stations were identified (including the territory of the ski complex), 10 ground frames were constructed, instrumental geodetic observations and remote methods were recommended. It was proposed to equip the observation areas with hydrogeological and directional wells, wall marks and ground reference points. The further use of satellite imagery in the infrared spectrum and SAR-monitoring was recommended.

3. Summary
Detailed maps (1: 10 000) were compiled according to the results of the study: map of factual material, engineering-geological map with elements of forecasting the development of landslide processes; large-scale maps (1: 25 000): geological and hydro-geological map, map of Quaternary sediments, map of soil types, map of landslide processes development, monitoring scheme of slope processes; the digital database of landslide and erosion processes distribution and formation conditions, containing facts of their impact on economically valuable objects.

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References
[1] Zharkova N I and Latypov A I 2013 A comprehensive assessment of landslide hazard on the territory of under construction satellite city of Kazan "Innopolis" and ski sports complex "Kazan" (FSAEI HPE “Kazan Federal University", Inv. № 2168), Territorial fund of geological information on Volga Federal District of the Russian Federation) p 298
[2] Latypov A I and Zharkova N I 2013 Landslide hazard assessment on the territory of under construction city Innopolis (Tatarstan) for the organization of geodynamic monitoring system. J. Engineering surveys 10 56-59
[3] Zharkova N and Latypov A 2014 Regularities of slope processes forming on the "Kazan" ski complex area (Russia) Int. Multidiscip. Sci. GeoConf. SGEM (Sofia: STEF92 Technology
Zharkova N I and Latypov A I 2014 Regularities of slope processes forming on the territory of "Kazan" ski complex, 2014 "Sergeev Readings. Evolution of academician Sergeev’s scientific ideas at the present stage” Annual session of the Scientific Council RAS on the problems of Environmental Geoscience, Engineering Geology and Hydrogeology (Moscow: PFUR) 269-273

Latypov A I, Zharkova N I, Nuriyev I S and Cherniychuk G A 2014 Modeling of landslide processes for prediction of landslide hazard on the territory of "Kazan" ski complex and Innopolis city Scientists notes of Kazan University, series of "Natural Sciences" 156 (Kazan: K(VR)FU press) 148-162

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