GEOPHYSICAL MONITORING: NEW OPPORTUNITIES TO PRESERVE ARCHITECTURAL MONUMENTS AND GREEN DESIGN IN URBAN AREAS

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ABSTRACT

A new geophysical prospecting technique developed by the author was effectively applied for these purposes in 1994–2005 within the architectural complex of the Kazan Kremlin, a UNESCO World Heritage Site.

The author has developed and successfully employed a unique gravity monitoring technique consisting in independent measurements at set points and at certain time intervals in the architectural complex of the Kazan Kremlin.

The results of the geophysical monitoring and geodetic surveys conducted in open areas and inside architectural monuments offer new opportunities in preserving ancient buildings. Because geophysical monitoring can identify the negative impact of active geological processes on foundations of buildings, mitigation measures can be taken in timely manner. However, because the Kazan Kremlin is a state historical and architectural museum reserve, another objective is to maintain its exterior and renovate its green design.

The above technology can also be used to analyze the technical condition of high-rise buildings, industrial facilities, underground railway systems and other structures, and significantly prolong their operating life.

Keywords: *geophysical prospecting, gravity monitoring, architectural monuments*

INTRODUCTION

Historical areas in modern towns are extremely intricate objects. They are studied to preserve their architectural monuments, which are often parts of large architectural complexes. Such projects inevitably require monitoring of active geological processes and their impact on buildings [2], [3], [4], [5].

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Water leakage from underground pipelines and large-volume excavations in surface building projects unbalance steady geological environments. This changes groundwater flow directions, enhances karst, suffosion and soil-slip processes, and creates weakened rock zones and sinks. As a result, the negative impact of geological processes on buildings increases and may lead to their deformation and destruction [8]. During archaeological excavations, restoration of buildings and

roadway replacement, thousands of tonnes of soil are removed from the near-surface layer with subsequent terrain changes. For this reason, mitigation works on the Kremlin hill outside of the fortress wall and within the architectural complex of the Kremlin include their mandated reinforcement and greenscaping.

METHODS AND RESULTS

In the constraint and noisy environments of modern cities, conventional geophysical prospecting methods are ineffective. Single gravity measurements require taking into consideration the effects of terrain and buildings, which is practically impossible.

The author has developed and successfully employed a unique gravity monitoring technique consisting in independent measurements at set points and at certain time intervals in the architectural complex of the Kazan Kremlin.

Because the effects of terrain and buildings are constant in repeated measurements, they do not have to be taken into consideration, while the detected local anomalous changes in physical fields caused by active geological processes can be effectively identified. These processes are tectonic movements and hydrogeological changes caused by groundwater flow. Ultimately, gravity changes detected on the Earth's surface and inside buildings can be used to identify detrimental effects of groundwater on buildings, and monitor and analyze surface movements, while enhancing the reliability of survey results [6], [7], [11].

The Kremlin hill has a relatively flat top with steep eastward, southward and westward slopes. The Kazanka River is north of the hill, and they are separated by a rock-fill dam with a traffic road. The slopes of the Kremlin hill are pronounced both inside and outside of the fortress wall. The absolute terrain elevation is 85 m at the top of the hill and 56–59 m at its foot (Fig. 1).

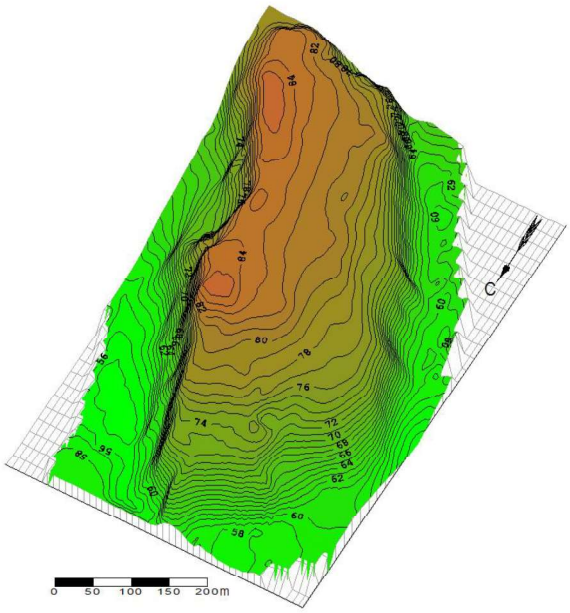

Fig. 1. Three-dimensional model of the Kremlin hill

The northern, western and eastern slopes contain a hidden irrigation system, are covered with grass turf and form the green design of the Kazan Kremlin.

Initially, the author's team conducted high-precision gravity monitoring in the northern areas of the Kremlin hill including the Suyumbeki Tower, the former Governor's Palace (now the Presidential Residence), the Tainitskaya and North-Eastern towers, and the fortress wall surrounded by the grass-turf slopes of the hill from three sides.

These measurements were made in spring and autumn, and their results were used to generate two Bouguer anomaly maps. The gravity differences were used to map the non-tidal gravity field (Fig. 2). These gravity measurements showed how the gravity field varied across the Kremlin hill. The central part of the survey area (Fig. 2) contained a local positive anomaly of more than 10 μGal caused by the natural accumulation of water and itsflow towards the northern slope of the Kremlin hill and into the underlying deposits, confirmed by subsequent gravity measurements between the spring of 1995 and the summer of 1996 (Fig. 3).

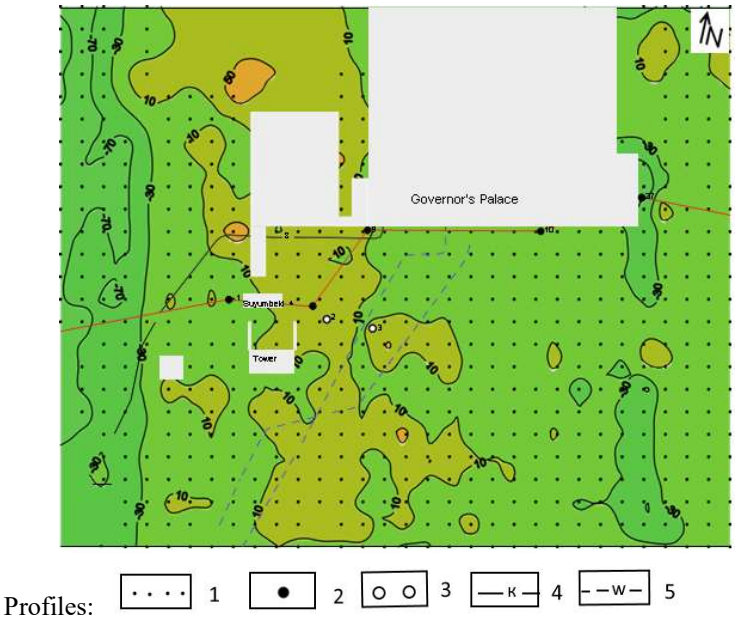

Fig. 2. Non-tidal changes of gravity on the territory of the Suumbeki Tower and Governor Palace, spring–fall 1995.

1 – gravimetric observation points; 2 – wells; 3 – wells drilled in 1999; 4 – sewerage; 5 – water supply pipeline

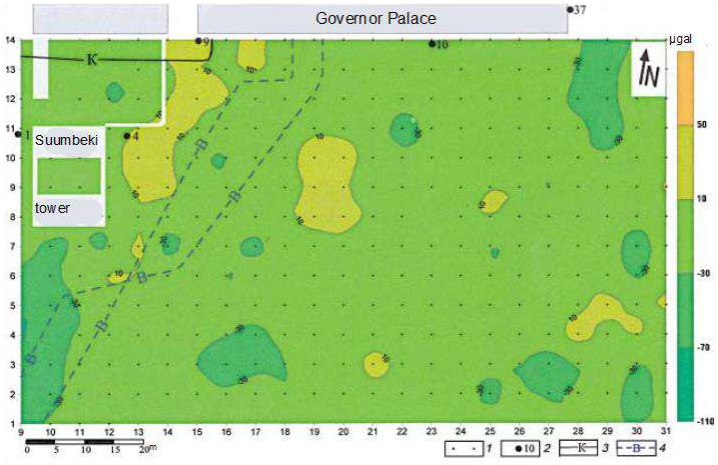

Fig. 3. Non-tidal changes of gravity on the territory of the Suumbeki Tower and Governor Palace, spring 1995–summer 1996:

1 – gravimetric observation points; 2 – wells; 3 – sewerage; 4 – water supply pipelines

The effect of recent tectonic movements on the architectural monuments of the Kazan Kremlin was studied by high-precision gravimetric and geodetic surveys outside of the fortress wall over three years, from 2000 to 2002. Stationary pads for gravity measurements and bench marks for the geodetic survey were set in advance. Gravity measurements at these pads and bench marks, as well as the determination of their altitudes and coordinates, were performed in separate cycles.

The obtained gravity data were used to map the gravity field and analyse its increasein the north-western direction from the Spasskaya tower to the Tainitskaya tower, where a relative gravity increase was estimated at 17 μGal. According to repeated measurements of 2000□2002, a maximum local gravity decrease of 0.08 mGal/yr was detected at the Tainitskaya tower.

Repeated geodetic measurements detected terrain changes in the north-western direction from the Spasskaya tower to the Tainitskaya tower, with an abrupt subsidence at its base of 11 mm/yr. Since the foundation of the town of Kazan about one thousand years ago, the north-western slope of the Kremlin hill and the Tainitskaya and North-Eastern towers have subsided by about 10 m (Figs. 4 and 5) [1], [9].

Fig. 4. Tainitskaya Tower of the Kazan Kremlin (2004)

Fig. 5. Northeastern Tower of the Kazan Kremlin, 2006

Such fast subsidence of the northern slope of the hill is indirectly evidenced by pictures, etchings and other graphics showing Kazan of the 16th–18th centuries with all buildings of the Kremlin being at the top of the hill [6], [7], [10].

CONCLUSION

Thus, this geophysical monitoring method developed by the author is the first technique ever to study the technical condition of buildings in urban areas.

The results of the geophysical monitoring and geodetic surveys conducted in open areas and inside architectural monuments offer new opportunities in preserving ancient buildings. Because geophysical monitoring can identify the negative impact of active geological processes on foundations of buildings, mitigation measures can be taken in timely manner. However, because the Kazan Kremlin is a state historical and architectural museum reserve, another objective is to maintain its exterior and renovate its green design.

The above technology can also be used to analyse the technical condition of high-rise buildings, industrial facilities, underground railway systems and other structures, and significantly prolong their operating life.

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