

Influences of human activity on deformations of ancient structures Ichan-Kala in Khiva City

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ABSTRACT: Khiva is one of the ancient cities of the world such as Bukhara and Samarkand. Since 1997, after Khiva had 2500 anniversary, UNESCO included Khiva into the list of cities of the world heritage. Architectural complex of monuments of Ichan-Kala is a piece of work of ancient Horezm's architects XYIII-XIX century and consist of several structures such as madrasahs: Alla-Kuli han (1835), Tash-Hauli (1832), Amir-Tura (1870), Muhammad –Amin hon (1871) and others, ancient masonry city-wall (1780). Unfortunately, damage to the monuments accumulated in the course of time is inevitable. The ancient monuments are less protected from of negative factors of environment and human activity. With the purpose to find the reasons of deformation of foundation of buildings of the monument Ichan-Kala and for development of techniques for improving properties of soils hydro-geological, engineering-geological and geophysical investigations were conducted.

1 INTRODUCTION

Accordingly to archeology assessment in Khiva, this city was based in IV century on " the Great silk way " (Gulyamov, I. 1957). In XIV century is known as one of large cities of Central Asia. In XVIII century the urban structures of Khiva suffered badly and on their place in XVIII - XIX centuries new ones were erected. The destroyed structures were leveled on the areas and streets, therefore in the territory of the city the large layer of filled soils was formed. This part of Khiva, received the name of Ichan-Kala (internal fortress), became administrative, political and economic downtown of that time (Figure 1). The territory of Ichan-Kala has 26 hectares. The rather small territory of Ichan-Kala contained two palaces, more than 60 madrasahs and little mosques, a cathedral mosque, covered market, caravans - sheds and baths, apartment houses of khan's retainers, officials, clergy and whole-sale dealers. It was protected with defense city wall (Pugachenkova G.1985).

The important condition of engineering-geology research of ancient monuments for the aims of conservation and restoration is to find out the deficiency of bearing capacity that means discrepancy between existing load and real capacity of soil foundation changed under influence of engineering-geological processes (Pashkin V. 1996).

At the present time most of buildings of Ichan-Kala have deformations due to unfavorable impact of environment. For the determination of causes of deformations of foundation of buildings and for development of techniques for improving properties of soils the following investigations were conducted: analysis of influences of environmental and human made activity factors; investigations of underground water and properties of soils.



Figure 1: Plan of Ichan-Kala. 1- madrasah of Mukhammed-Amin-han; 2 – madrasah of Alla-Kuli han; 3 – palace of Tash-Hauli

2 THE INFLUENCES OF ARTIFICIAL FACTORS ON DAMAGE TO MONUMENTS

As result of conducted research it was established, that first of all the main reason of deformation of monuments of Ichan-Kala was the bearing capacity deficiency of ground foundation (filled soil) connected with moistening processes. According to these evaluations all the factors responsible for deformation were classified into natural and artificial.

To the natural factors concern:

- accumulation of moisture because of infiltration of precipitation;
- condensation of moisture under buildings and asphalt coverings;

To the artificial factors concern:

- watering of territory in a consequence of outflow from water-supply of the communications and because of a non-organized drain of water on the surface as result of absence of proper horizontal lay-out;
- filling-up of artificial drainage systems;
- restoration works without consideration of engineering - geological conditions.

Sources of accumulation of moisture are both natural, and artificial factors. They have various kind and character of influence on monuments of architecture of Ichan-Kala. For example, madrasahs Mukhammad-Amin-han is subject to numerous deformations in a consequence of accumulation of moisture from malfunction internal and external water-supply communications. Consequences of moistening of ground foundations of the monument results in non-uniform settlements of the bases, weathering of interbrick mortar as result of lixiviation of salts breaking stability of monuments (Figure 2). The similar undesirable processes and phenomena are observed on madrasahs Mukhammad-Amin-khan, Matniyaz Divan Begi, Mukhammad-Rahim-khan, Amir-Tur, complex Tash-Hauli, madrasah Alla-kuli-khan, citadel Kuni-Ark, tomb of Pahlavan Makhmud. Also the natural factor influencing on the state of monuments is the condensation of moisture appearing in the zone of aeration. As it is known from the surface of underground water table the moisture aspires upwards through capillaries.



Figure 2 : Destruction of the basement of a column as result of lixiviation of salts breaking stability of monuments (Tash-Hauli)

This moisture evaporates in superficial parts of a ground under action of temperature and there is a process of drying (Brilling, I. 1979). However in places, where the surface of ground is blocked by asphalt covering, stones, slabs there is no process of drying of ground, and there is a gradual accumulation of moisture in the zone of aeration. The occurrence of the condensed moisture is promoted by universal covering of the territory of the ensemble Ichan-Kala by asphalt, slabs, bricks and stones.

The next artificial factor regularly influencing on the state of the ground foundation of monuments is filling-up of artificial drainage systems. At the time of construction of the ensemble Ichan-Kala the artificial drainage systems were provided as ditch around defense wall and wells, reservoirs ("houses"). Until 1858 in the city there were no main communications, because there was a lake near the southern wall and there was no gate at that time. In the period from 1858 to 1867 along the southern wall of Ichan-Kala the part of the reservoir was drained and the gate appeared only by 1873. At that time the ditch and lake served as drainage network, and protective structures. During the Soviet authority, especially since 1950 a few general plans of Khiva were developed. They provide allocation Ichan-Kala as reserved zone of monuments. In this connection in 1970 - 1980 years in territory of Ichan-Kala all areas and the streets were covered with asphalt, slabs, bricks, stones, which in turn negatively influenced on moisture changes. Also in 1980 many wells were filled-up in the territory and ditch and lake located in a southern part of Ichan-Kala were liquidated, and were covered with asphalt and concrete plates. Probably, it affected very badly on increase of moisture of soils in the basis of buildings and structures in the internal part of Ichan-Kala. Therefore, as one of the basic reasons of non-uniform deformation of architectural monuments we consider filling-up of wells in courtyard of monuments and liquidation ditch around of Ichan-Kala.

3 INFLUENCE OF ENVIRONMENTAL CONDITIONS

With the purpose of finding reasons of deformations of foundation of buildings of the monument Ichan-Kala and for development of techniques for improving properties of soils hydro-geological, engineering-geological and geophysical investigations were conducted:

- investigations of regime and chemical composition of underground water;
- investigations of properties of soils; research of ground foundation conditions within the area under the structure deformation occurred.

The hydro-geological conditions of the territory of the ensemble Ichan-Kala depend on a relief and geological structure of the territory and results of man made influence. In territory of Ichan-Kala the level of underground water changes from depth 7-7.20 m (in the area of Arch) up to 2.0-2.5 m (in the area of madrasah of Shergazi-khan). On all territory underground waters related to sands, water-resisting layer are of clay is on the depth of 15-20 m. The waters are transparent, colorless, and seldom salty.

The physical state of structures depends on structure and properties of the earth bases. The bases of monuments of architecture of Ichan-Kala are filled soils and in some cases sands.

1. The first type of the earth bases is related to foundations of madrasah Alla-Kuli-khan, Mukhammed-Amin-khan, the complex Tash-Hauli (Figure 3). This type consists of filled soils (anthropogenous) with thickness from 3.2 up to 6.5 m, they include loam and sandy loam poorly condensed with inclusions of the historically usual domestic dust (fragments of brick, ceramics, bones, slag etc.). Sometimes there are layers of sand (10-15 cm) moistening from 5 up to 20 %. On the depth of 5-6 m out bricks without correct sides were found. The analysis of results of physical-mechanical properties of filled soils of this type showed, that they are various on structure and density of and they are weak and under consolidated. The wide limits of change deformation properties of filled soils are connected to inclusions, lenses and layers of sand.

Deformation properties of filled soils are characterized by values of the module of general deformation (from 6.5 up to 30 MPa), natural moisture from 7 till 18-22% and high porosity from 43.4 up to 49.5%. Investigation has shown, that the monuments located on filled soils are subject to the greatest deformation. The ancient architects foresaw such moistening, therefore in the bases one or two layers (with an interval from 1 up to 2.5 m) of "baira" made from a cane were pawned. "Baira" (bulrush intercalation) is capable evaporate a moisture vertically driven on capillary pore. At realization of restoration works for 1960-1970 "baira" was withdrawn and partially replaced with ruberoid. Such replacement complicates evaporation of moisture from the bases.



Figure 3 : Tilting of the portal of Tash-Hauli

As the second type of soils of the bases perform sands. On the investigated territory sand bedding is just under filled soils. Sands are of yellow-brown color, damp at some places water saturated (basically near to the level of underground waters). The damp sand are characterized by value of the module of deformation from 31 up to 37.8 MPa, water saturated from 20 up to 32 MPa. The researches have shown, that the bases of architectural monuments located on sand are less deformed, sometimes not deformed. It is possible to say southern walls madrasah Mukhammed-Rahim-khan, tomb of Pahlavan Makhmud, tomb of Seid Alauddin, madrasah of Shirgazi-khan to those conditions.

Accordingly to the conducted researches the scheme of structures in territory Ichan-Kala is made by degree of deformation. The zones with average and large deformation were identified. To the zone of large deformation the sites with the greatest thickness of filled soils are referred as well as places, where the water communications through walls and under the bases are carried out. To the zone with average deformation the architectural monuments, partially bedding by sandy and filled soils and partially with absence of communication systems are referred.

4 THE CASE OF DEFORMATIONS OF ANCIENT STRUCTURES.

Madrasah of Mukhammed-Amin-khan, is located in the western part of Ichan-Kala near to the gate Atadarbaza. It was constructed in 1851-1853 on the place of former defense wall. According to historical data the defense wall by extent 70-100 m about a gate Atadarbaza was badly destroyed as a result of wars. During times of Mukhammed-Amin-khan they did not begin to restore the wall, but begun to build a large madrasah in Ichan-Kala. The rest of the wall was destroyed and leveled on the place was planned. In this connection the thickness of filled soils here changes from 3.2 up to 4.5 m. At the present time madrasah of Mukhammed-Amin-khan is reconstructed and it is used as a hotel. In the building a sewer and water network, and also heating are carried out.



Figure 4 : Cracks in the wall of caravan-saray of the complex Alla-Kuli-khan

The inspection of external and internal state of buildings shows about presence of various sizes of cracks in walls and ceilings, which were formed as a result of non-uniform settlements of various parts of madrasah. The largest crack of width up to 3-5 cm is present on the southern wall of madrasah, where it crosses the wall from above downwards. The width of the crack in the top part is greatest and in process of progress downwards it decreases. Underground waters on the depths of 6 m. Up to the level of underground waters the base is filled soils and fine sands. These soils in the natural state are characterized by increased value of strength and deformation properties, but at moistening it lose a significant part of these properties. In this connection the deformation of buildings is a direct consequence of condensation of the ground foundations at moistening. The outflow of water from the sewer network promoted washing away of salts, which served as the cementing substance of intermodular systems and losing of structural connections. This all has resulted in condensation of the ground foundations.

After construction of sewer network on the depth 1.5-2 meters the deformations of the minaret of Djuma-mosque began. Nevertheless, the construction of new hotel began.

The complex of Alla-Kuli-khan consists of the caravan-saraya, "tim" (trade places) and madrasah. Now caravan-saraya of Alla-Kuli-khan has many developed cracks (Figure 4). At the present time the caravan-saraya is used as department store with a complex of municipal systems. The ground foundations of the caravan-saraya of Alla-Kuli-khan are filled soils by capacity more than 5 m, under laid by sand. The deformation is shown as vertical cracks on northern and eastern walls. Cracks occur at the expense of non-uniform subsidence of filled soils of the bases of the northeast corner (column to the bottom diameter 1.5 m) caravan-saraya. It was found by researches, that cracks and subsidence of the basis are connected with moistening process of the filled soils (Zakirov, M. 2000).

Alla-Kuli-Khan, at the time of whose government the main building works were performed, decided to immortalize his own name by construction of madrasah and selected place for it between the tim, madrasah Khodjam-Berdy-Bay and Polvan-darvaza. The base of this madrasah consists of filled soils formed from fragments of the ancient city wall. Thickness of the filled soils is more than 5 m, underground waters are on the depth of more than 5 m. At the present time this madrasah is in a catastrophic situation because of non-uniform settlements of the grounds causing deformation of portal and facade parts of the madrasah (Figure 5).



Figure 5: Non uniform deformation of facade of the madrasah Alla-Kuli-khan

5 CONCLUSIONS

As result of conducted research it was established, that first of all the bearing capacity deficiency of ground foundation (filled soil) connected with moistening processes was the main reason of deformation of monuments of Ichan-Kala. According to these evaluations all the factors responsible for deformation were classified into natural and artificial. Analysis of these results showed that general cause of deformation of structures is moistening of ground foundations as result of man made influence. Therefore, most of prevention techniques for improving properties of ground foundations of ancient structures should include elucidation inflow water and drainage of ground foundations.

The ground foundations for the most of historical monuments of Ichan-Kala are filled soils, which in a natural - dry status are characterized by rather high values of strength and deformation properties. However, at moistening processes due to specific internal structures, they considerably lose (about 70-80 %) bearing capacity and get tendency to condensation. The

thickness of filled soils reaches 7.7 m, but in the most part of territory 4-6 m. The local moistening of the ground foundation in Ichan-Kala occurs as a result of outflow of water from a engineering-sewer and water network, unorganized drain of precipitation and accumulation of moisture in soils as a result of condensation of moisture under buildings, asphalt and other coverings.

The underground waters are on the depths from 2.5 to 7.5 m. Thus the high level of underground waters is observed on the southern part of Ichan-Kala; on the north it is lowered.

In the conclusion the following recommendations for improving properties of soils of ground foundation of structures of architectural monument of Ichan-Kala are given.

1. To organize system of a drain of superficial waters. To develop the prevention techniques for collection and removal of precipitation water, both from the internal and external areas and historical monuments and from their roofs and floors.
2. To remove all asphalt and others (brick, stone cement) covering both on the areas, and inside historical monuments. All kinds of covering (stone, brick) should be executed without application of cement and concrete.
3. To clear all filled-up wells both inside historical monuments, and on the areas.
4. To restore the drainage network around of Ichan-Kala. It is originally necessary to lay horizontal drainage on Eastern and Southern part of the external wall of Ichan-Kala. The depth of drainage network is necessary to design depending on the mark of a surface.
5. Not to use ancient structures as hotel and restaurant.
6. Not to constructed new buildings on the territory and save the Ichan-Kala as the museum for the future generation.

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