ABSTRACT

This article considers the alternative of the reinforcement of ground basements of historical monuments in the Central Asia with reduced impact geotechnics. Reduced impact geotechnics are job practices which do not interfere with the existing basement structure of buildings and minimize the impact on a ground base, which may degrade the basement condition during the works. To the reduced impact geotechnics the authors refer high-pressure directional injection method and foundation perimeter reinforcement. Reinforcement of a ground foundation by high-pressure directional injecting consists in pressurized feeding of a cement-sand mortar into a ground foundation which increases structural strength of the ground. After the cement-sand mortar is hardened, tough incompressible inclusion form and helps to reinforce the ground. As a result, the foundation becomes geocomposite, obtains better load-bearing capacity and lower deformability. Injection works may be performed both with simple tools like a plaster pump and another common equipment. Perimeter reinforcement consists in introducing separate vertical reinforcing members or a number of hard inclusions into the ground along a perimeter of a shallow basement. As a result, a certain kind of a die block is formed in a foundation and ground condition under the basement head towards compressive. Reinforcing members may be formed by injection of a movable composite. The landmarks of such technologies are the possibility if working in constrained environment (basement of buildings, compact planning), low equipment cost, technological simplicity, low prime cost and high reliability of works.

Keywords: reinforcement ground base, high-pressure directional injection method, outline reinforcing, impact geotechnics, Central Asia historical monuments

1 INTRODUCTION

In the practice of geotechnical construction, tasks to reinforce ground base and foundation often arise, which require closer attention to safety of standard operating procedures and provision of building preservation. This is due to the poor condition of overground structures and foundations of buildings, lack of space in indoor premises (small area, low-height basement, etc.), cramped conditions of the surrounding urban areas, specific soil conditions and so on. Such facilities in full measure include a large number of architectural and historical monuments of Central Asia. Taking into account their historical value and all of the aforesaid, strengthening of the foundations and ground base of such buildings is desirable to carry out with special – “gentle” geotechnologies, which exclude intervention (usually capable of causing redundant strain and damage) in the existing building structures. In this case, one of the most important requirements is to minimize post-maintenance settlement of buildings, which can worsen their technical condition.

“Gentle” geotechnologies should include standard operating procedures without direct physical effects on the foundations of amplified buildings, which inevitably occur, for example, while underlaying the piles under foundations, increasing the bottom of shallow foundations and so on. This condition, according to the authors, is satisfied with: strengthening of foundation soil through directional injecting of moving cement-sand mixture and contour reinforcement of foundation ground base with rigid vertical elements (piles that do not match with the body of the amplified foundations) (Nuzhdin & Nuzhdin 2012b).

2 ABOUT CENTRAL ASIA HISTORICAL MONUMENTS

Historical monuments of Uzbekistan (especially mosques and madrasas) are usually rectangular buildings, fenced in a wall with a high portal entrance (gate) and a courtyard bordered by two or four vaulted iwans.
and bypass one-story or two-story hudzhras performed in the form of galleries. On the opposite side from the entrance, there is a main building opened with a large archway into the yard. In the corners of the walls, there are often two or three-unit minarets (Khasanov & Holmurodov 2003).

Fig. 1. The mausoleum of Burkhaniddin Sagardji in Samarkand (XIV century).

Buildings usually have one or two floors, exterior bearing walls and dome-shaped roof, made of flat rectangular bricks. Most of the buildings, except the minarets, are characterized by relatively small loads transmitted to the foundation. Foundations are typically made strip and shallow with a width of the bottom 0.9 ... 1.2 m. The width of the foundations for the pillars in the crestal area of the building can reach 3.0 ... 4.0 m. The foundation bottom depth is determined by the design requirements and changes from 1.5 ... 2.0 m to 3.0 ... 4.0 m from the ground (Khasanov & Khasanov 2006).

Fig. 2. The plinth of the building and strip foundations of the mausoleum of Burkhaniddin Sagardji.

Fig. 3. An example of the building foundations built in the XIV century in the city of Bukhara.

Anthropogenic layer is characterized by considerable heterogeneity of composition: the presence of soil layers of diverse consistencies with different deformation properties, inclusions of crushed bricks, sludge and rubble, the presence of voids, cavities and so on.

In recent decades, geological engineering conditions of a large number of areas in Uzbekistan undergo significant changes. Intensive development of irrigation, laying of ramming and non-ramming lines in historical parts of the cities, shielding the surface areas with asphalt covering and other factors contribute to a substantial increase of humidity in the foundation’s aeration zone and the rise of the groundwater level.

This process has a particularly negative impact on the building of historic districts of old towns. For example, in the old part of the city of Samarkand (founded more than three and a half thousand years ago), the cultural layer capacity can reach 4.0 to 9.0 meters or more.

The rise of the groundwater level causes essential deformations of the foundation soil, resulting in additional differential settlements of foundations of buildings and structures erected four hundred or more years ago. Moreover, wetting of inhomogeneous anthropogenic layer causes the most unpleasant consequences.

Currently, many of the historic buildings of Central
Asia are in poor condition and subject to reconstruction and restoration. Repair works should be (and, in many cases – must be) carried out after eliminating the possibility of further deterioration of the technical state by stabilizing the foundation soil deformation and strengthening of foundations.

Fig. 4. The formation of cracks in the walls of the Tim Abdullah Khan of the Sheibanids dynasty mausoleum (1577).

3 TECHNOLOGY OF HIGH-PRESSURE DIRECTIONAL INJECTING METHOD AND PERIMETER REINFORCEMENT

Described in this article strengthening technology of shallow foundations by high-pressure directional injection of moving cement-sand mixtures is developed on the basis of the Office of Scientific Research, planning review and implementation of the Novosibirsk State University of Architecture and Civil Engineering (the principal is Professor L.V. Nuzhdin) under the supervision of M.L. Nuzhdin (Nuzhdin 2003a, 2003b). The principle of high-pressure directional injection of the ground base is patented in Russia and has patents of the Russian Federation under number 2259446 (2005) and number 2259447 (2005).

The following strengthening technology of shallow foundations with contour reinforcement was developed under the guidance of Professor L.V. Nuzhdin. Employees of the Novosibirsk State University of Architecture and Civil Engineering, OJSC “Stroyizyskaniya”, Siberian State Transport University, LLC “Novosibirsk engineering center” and SPEC Company “O&F” were involved in its various experimental and theoretical research and implementation of results into building practice (Nuzhdin et al. 2002, 2003a).

Fig. 5. Scheme of vertically oriented injection bodies.

Approbation of technologies, testing on practice grounds of Central Asia and improvement of parameters under the regional soil conditions of Uzbekistan are performed by LLC “Geofundamentproject” under the guidance of Professor A.Z. Khasanov from the Samar-kand State Institute of Architecture and Civil Engineering (Khasanov et al. 2010).

3.1 High-pressure directional injection method

The essence of the high-pressure directional injection method is about simultaneous supply of moving cement-sand mixture into foundation soil through a few injectors. This is performed under pressure greater than the structural strength of the soil (usually in the range from 3 to 10 MPa depending on the soil conditions). Because of discharge, continuity of the soil mass is disturbed, and cracks are formed therein. They are filled with mortar, in the base of which, after hardening, solid injectable bodies are formed.

High-pressure directional injection technology provides location of injectors in a certain geometric order. Simultaneous intrusion of mortar through three or more injectors located in terms of a straight line, creates a flat vertically oriented injectable body in the soil mass. Intrusion of mortar through the injectors, disposed at the vertices of an imaginary triangle, creates a horizontally oriented disk-shaped body (Nuzhdin 2004, Nuzhdin & Nuzhdin 2012a).

There are three phases of mortar intrusion during the injectable works. Phase I – increase of the applied pressure and its subsequent sharp decline corresponds to the process of soil mass discontinuity and crack formation. Phase II - established “working” pressure corresponds to the process of filling the resulting crack with mortar and the formation of an injection body. Phase III – subsequent monotonous increase of injection pressure indicates the formation of injection body and the beginning of the “saturation” (filling) of the generated volume.

The criterion for the end of the injection is a gradual increase in the applied pressure by 40-50% in relation to the worker. If this does not happen, in practice, a certain amount of injected mortar is accepted as a criterion for the end of the injection.

According to the developed technology, shallow
foundations strengthening is carried out in two stages. The first stage is the formation of vertically-oriented injecting bodies – “walls” on both sides of the strip foundation or on all sides of the post foundation. This is achieved by simultaneous mixture supply through the groups of injectors of three or more pieces, disposed along the edges of the foundation. Artificially created locally reinforced areas of the foundation function as reinforcing elements that contribute, to a large extent, a decrease in the specific pressure on weak soils located in the active part of the foundation. In addition, the shape of the reinforced area is able to create similarity of compression conditions under the foundation bottom, which has a positive impact on stabilizing of foundation deformations.

![Fig. 6. The typical diagram of injection pressure value and mixture’s volume.](image)

Also formed “walls” prevent the uncontrolled spread of the mortar during works at the second phase, which is especially important in the strengthening of the foundation containing heterogeneous anthropogenic layer of high power, with the inclusion of voids, construction debris, organics and so on. Since voids and weak non-compacted layers of soil are preferably filled while anthropogenic layer injecting, which causes form violation of the injectable body and the uncontrolled spread of the mortar beyond the injection zone.

The works of the second phase are performed for total stabilization of foundation settlements, especially in order to partially eliminate any deformations. They consist in intrusion of mortar into the soil under the foundation bottom between the “walls” and its seal until excessive pressurization contributing to the slight “rise” of the building. According to field observations, a real rise of rather heavily loaded foundations can be achieved with the mortar intrusion into the soil. Therefore, this process should be carefully monitored.

While works at phase II, under the foundation bottom, horizontally oriented bodies are formed, which is carried out by the supply of the moving cement-sand (sometimes with the addition of lime to increase plasticity) mortar through a group of three injectors arranged at the corners of an imaginary equilateral triangle. Single injectors produce mortar intrusion as well.

Mortar intrusion into soil can be conducted in one or more injection depth horizons. Appointment of the number and location of the high-rise injecting horizons is carried out depending on the geotechnical conditions of the site and checked according to the results of monitoring the sinking rate of injectors into the ground - a kind of “dynamic probing” (Nuzhdin & Nuzhdin 2010, 2011, 2013).

![Fig. 7. The chart of foundation soil strengthening of strip foundation which is typical for architectural monuments of Central Asia.](image)

### 3.2 Perimeter reinforcement

Strengthening of shallow foundations with contour reinforcement is to perform separate vertical reinforcing members - piles around the perimeter at a certain distance from the edges that do not match with the body of the foundation. This leads to the formation of “screens” that prevent horizontal displacement of soil from under the foundation base, restricting the development of plastic strains of soil in the plan and also creating a partial similarity of operating compression conditions of the foundation. Contour reinforcement can be used to increase the bearing capacity of the soil foundation, settlement stabilization of foundations or for solving the limitation problem or exclusion of the effect of reinforced foundation of the surrounding buildings and other cases (Nuzhdin et al. 2003a, Nuzhdin & Skvortsov 2007, Nuzhdin & Teslitskiy 2008).

The contour reinforcement is defined by both the geotechnical conditions (in the presence of soft soils, underlain by the enforced support layer) and the reinforcing member bearing capacity on the ground coat.
Reinforcing members diameter is calculated on account of the material bearing capacity and the required strength of the reinforcing layer section to take bending and horizontal forces. The reinforcing members placing intervals are to be set on the account that the ground shall not break off the foundation base beyond the layer plane. With the aim of efficiency and safety improvement some special requirements can be also applied to the reinforcing members’ surface roughness for avoiding local ground distortions and to the structural measures of their interconnection against horizontal displacements.

The choice of the structure technology and material of reinforcing members to a large extent depends on the performed task. For instance, for strengthening of the subsurface foundation beds of reconstructed or dangerous buildings, as soil softening and redundant deformations are inadmissible, it is most preferable to make reinforcing members of piles driven in pierced holes or pre-bored holes, of impressed metal rolled sections or vertically aligned rigid inclusions by the high-pressure injection method of high-workability cement-and-sand mixtures.

In some cases the contour reinforcement of the foundation bed by the rigid vertical members is good to combine with the high-pressure directional injecting method.

5 CONCLUSIONS

The authors’ experimental studies and a large-scale implementation of the described “gentle” soil foundation reinforcement methods applied to reconstructed buildings and constructions in Siberia and other regions of Russia show their high efficiency and reliability. Application of these methods for reinforcement of Uzbekistan’s historical monuments foundations will make reconstruction and saving of these monuments possible. In ground conditions of Uzbekistan’s historical building this work performance is of relatively low cost and high efficiency.

At the present time the approbation of the methods described in the article has been performed on the practice grounds of Central Asia, design decisions have been made and preparatory measures for reconstruction of several buildings and constructions have been performed.

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