Geotechnical support for building construction in the changed basic design considerations of the superstructure

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ABSTRACT

The paper presents a system for safe construction assessment of a building with a developed substructure and with a crucially changed superstructure under the conditions of the completed substructure. The specific feature of construction is to ensure the continuity of the superstructure erection followed by the increased loads on the foundation until it is strengthened. The paper proposes a verification system for monitoring data and calculated values of settlements and deformations of the foundation slab which ensure the operational safety using the "traffic light" method.

Keywords: geotechnical monitoring, observation method, geotechnical calculations, soil foundation, ultimate strains, foundation strengthening

1 INTRODUCTION

Large buildings, especially embedded ones which are erected in agglomerative, built-up, historical areas have a number of features which complicate their construction. These features are as follows: utility lines, proximity to the surrounding buildings and transport corridors, architectural features and restrictions, etc. The situation becomes more complicated when the concept of construction changes with the substructure being partially or fully completed. The situation becomes even more problematic when execution of construction work must be adapted to the business plan for construction and commissioning of commercial facilities.

2 DESCRIPTION OF THE BUILDING

The authors faced a similar problem when the multifunctional complex with a two-level substructure was being erected in the historical center of Tyumen, Russia (Fig. 1).

In 2008, the concept of construction implied erection of two high-rise buildings: 78 and 105 meters in height with a total two-level substructure of 7m in height. The foundations were composed of bored piles of 800 mm in diameter, 24.7 meters in length and spacing from 1.8m to 3.0m, which rested on strong solid loams.

Fig.1 General view of the complex

After pit digging and pile installation, the architectural concept of the complex was radically changed. Instead of two high-rise blocks of the superstructure, three lower blocks (9, 8 and 7 floors) were erected; they were joined by an underground two-storey stylobate (Fig. 2). In here, the new buildings did not fit into the boundaries of the existing pile field, and gross design errors had been made in foundation engineering. First, additional piles were not provided for the new blocks. Second, the entire building was being erected on a single foundation slab installed on pile fields excluding expansion joints and free settlement of the individual blocks was not possible.

In 2016, when the foundation and the stylobate were completed, building site works were suspended due to lack of funding. In 2018, the works were renewed.

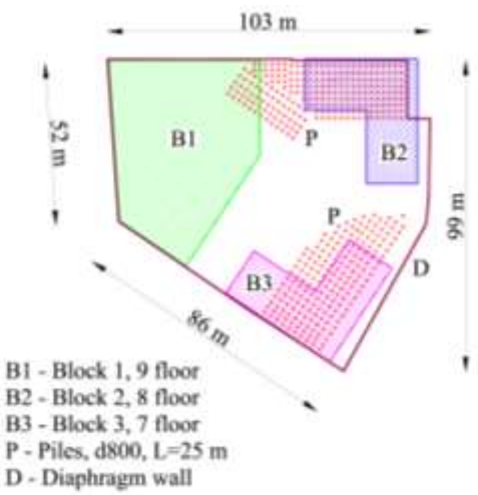

Fig.2 Schematic illustration of the blocks

The geological section of the construction site from the foundation foot to a depth of 10.8–15 m is represented by a layer of loose water-saturated clay soils with poor strength and deformation characteristics. Then, up to a depth of 22.4-25 m, the lithology is mainly represented by fine sands of average density which are underlain by solid loams.

3 SCIENTIFIC AND TECHNICAL SUPPORT OF THE RENEWED CONSTRUCTION

The first stage of the scientific and technical support for construction embraced the following tasks: comprehensive technical surveys of the stylobate and geotechnical monitoring of the blocks and the adjacent buildings; geotechnical examination of the blocks to ensure the possible use of the foundations for the new concept of construction; identification of possible risks in the continuation of construction and development of two fundamental options for substructure strengthening.

A detailed numerical model (FE analysis) of the building was performed in the STARK ES software package for geotechnical examination of the blocks during construction and operation. Interaction of the blocks with the soil foundation was modeled in the MIDAS GTS NX software package, taking into account the stages of construction and operation (Fig. 3).

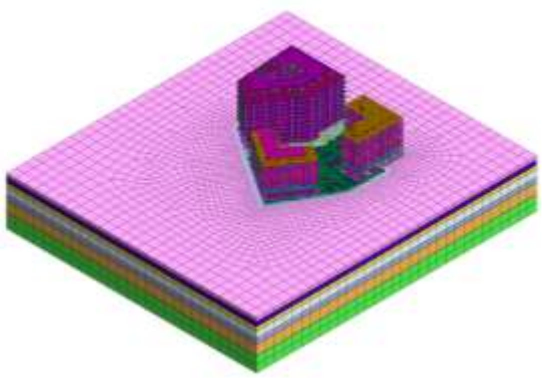

Fig.3 General view of the complex

The first stage resulted in the expected excess values of absolute settlements and their relative difference (Fig. 4) and the weak zones of the foundation slab due to the extremely uneven stiffness of the soil under the various zones of the foundation (Fig. 5)

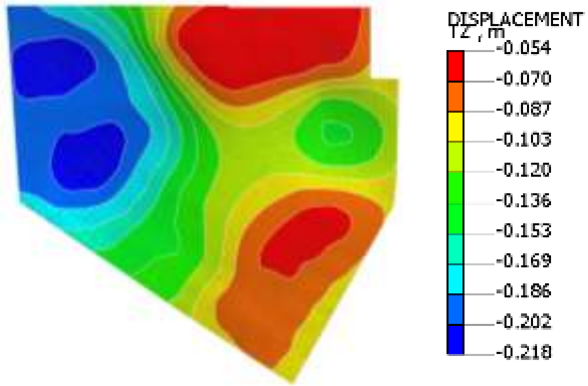

Fig.4 Settlement of the foundation foot at design loads

The second stage of the scientific and technical support for construction under the conditions of continuous growth of loads on the foundation embraced the following tasks: determination of the safe degree of soil bed loading prior to reinforcement; development of a project for strengthening the substructure with injection piles based on the numerical simulation results and the data of static testing of injection piles (FE analysis).

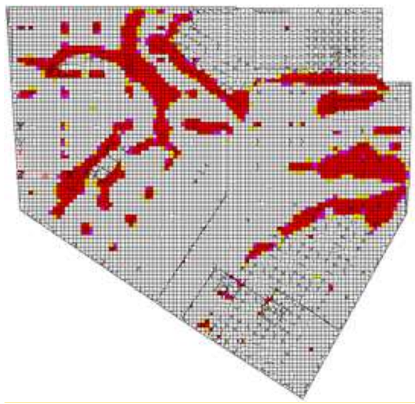

Fig.5 Zones of possible destruction of the foundation slab

The staged calculation of the framework excluding application of operational loads showed that the expected deformations of the soil bed exceeded the standard values. FE analysis does not take into account soil bed consolidation; therefore, the settlements measured during construction are usually much less than the expected values in a stabilized state.

In agreement with the building owner, it was decided to continue construction of the framework and monitor the actual settlements of the building. Foundation strengthening prior to application of the operational load was a prerequisite for continuation of construction (Katzenbach and Leppla 2016, Katzenbach and Leppla 2017). The building owner insisted on continuation of construction; otherwise, this led to non-compliance with construction time and financial charges.

The following restrictions were the conditions for assigning limit values for checkpoint settlements on the foundation slab (Fig. 6) verified by the data of continuous geotechnical monitoring: 1) settlements from the condition of ensuring strength and crack resistance of the foundation slab; 2) intensity of the settlement growth in construction of blocks per floor; 3) relative difference in settlements between individual points.

A reflex system of geotechnical support is based on the principle of "traffic light", when three geotechnical risk levels are assigned to the assessment criteria (settlement, differential settlement, deformation of the foundation slab): green, yellow and red. If the checkpoint settlements are in the “green” zone, then the framework is erected as the standard procedure; in the “yellow” zone the state of the building is being monitored intensively and it is possible to change the construction staging; the “red” zone means that foundation loading must be stopped until it is strengthened.

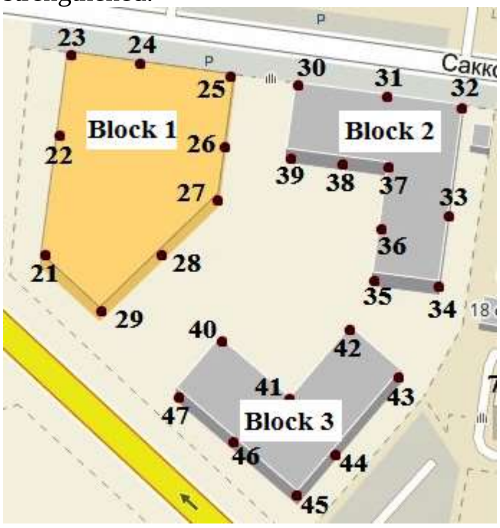

Fig.6 Geotechnical Monitoring Checkpoints

To determine the criteria for separating risk zones was challenging as for geotechnical engineering. The practice of construction on weak water-saturated clays shows (Vasenin 2013) that on completion of construction and prior to setting the building into operation about 30% of the final settlement is realized. Erection of the framework prior to foundation strengthening takes several months, i.e. a significant part of the expected settlement simply cannot be realized due to lack of time for the process of filtration consolidation. Thus, the criteria for the safe settlement (“green zone”) were taken as follows: 30% of safe settlements resulted from the strength analysis of the foundation slab, 30% of the calculated settlement growth from loading at each stage equal to erection of one floor of the framework and 20% of the relative values of differential settlements in accordance with the Building Norms (Table 1)

Table 1. Geotechnical risk criteria.

Absolute settlements of foundation slab footing S	Intensity of settlement growth during the 1st stage of construction	Relative differential settlements ΔS/L in accordance with the Building Norms 22.13330
Green (normal). Continuation of construction works and observations excluding modifications.		
≤ 0.3**S*	≤0.3*Δ*S*	≤0.2**[ΔS/L]ᵤ*
Yellow (greater attention). The state of the building is monitored intensively. Possible changes of technological parameters for construction works and strengthening of the soil bed excluding changes of the design solutions.		
*0.3-0.5*S*	*0.3-0.5*ΔS*	*0.2-0.3*[ΔS/L]u*
Red (the greatest attention) Construction works are stopped. Analysis of the geotechnical situation. Changes of the design solutions. Technological corrections of construction works.		
*> 0.5*ΔS*	*> 0.5*ΔS*	*> 0.3*[ΔS/L]u*

The matrix of permissible differential settlements in block 1 is given as an example (Fig.7). If the current differential settlements do not exceed the permissible values, then erection of the framework is allowed to be continued.

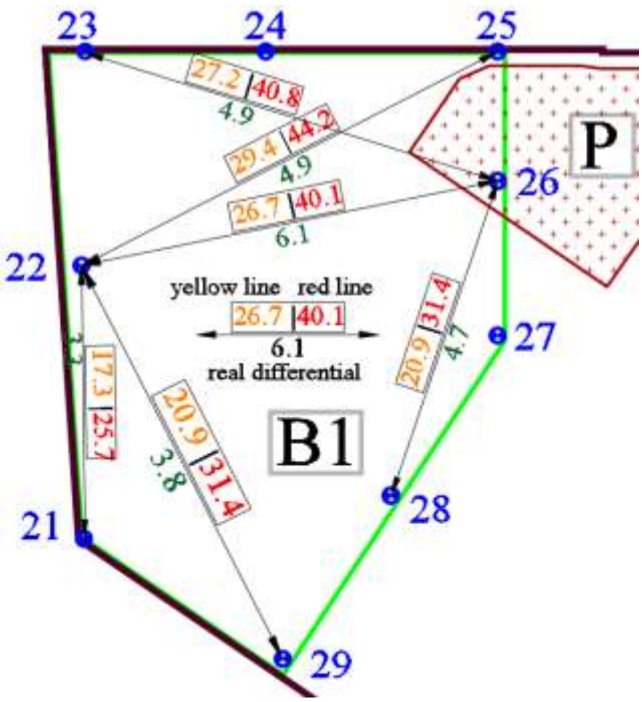

Fig.7 Differential settlement in block 1, mm

The developed automated digital platform makes it possible to monitor the state of the building after each cycle of geotechnical monitoring; each checkpoint of monitoring is assigned its own level of geotechnical risk and instructions are given for construction works to be continued on the basis of the developed criteria.

When the fourth floor is erected, the differential settlements are within the permissible limit values and the construction works can be continued.

4 CONCLUSION

The concept of building construction, which is changed after the substructure is completed, usually requires significant restrictions on renewal and continuation of building site woks. The situation is even more complicated if it is necessary to make changes in the substructure if construction procedure is renewed and foundation loading constantly increases. In here, it is necessary to use the “observation” method based on verification of the results of geotechnical calculations and high-precision leveling data along with the rapid development of the project for strengthening the foundation foot. As for the building considered in the paper, on the one part, the building site works were continuously carried out; on the other part, the structural safety of members and elements was ensured and reliability of the complex as a whole.

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