Foundation improvement for a building on loess soil

Remise en état des fondations d'un bâtiment sur le sol de loessde

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ABSTRACT

A high school two store building made of bricks, about 200 years old, suffered from settlement caused by increase of water content in loess soil, as a result of leakage of sewage system. Soil improvement with use of jet-grouting was designed and applied as a measure of foundation improvement and suppression of further settlement and fissuring of the building. Grouting was executed on outer and inner foundations, in the region affected by settlement, to the depth of 12 m under surface. In order to assure most suitable grouting technique a trial piles of jet-grouting were executed, aside from the object, using different pressures, direction of jet and time of jet action in place. With the pressure of 400 bar columns of 55 cm in diameter were obtained and it was accepted as a good result having in mind distance and spacing of boreholes under foundation. During execution of soil improvement measurement of soil deformation with depth and measurement of cracks in walls was performed, as well as topographic measurement of points on building. Before start of jet –grouting tunnels under building were filled with special concrete through the borehole from the surface. Comprehensive measurement of soil deformations, settlement and cracks on the building was performed before, during and after remediation work. Movements of the building ceased some time after the work was done, indicating that remediation work was successful.

RÉSUMÉ

L'ancien bâtiment de lycée à deux étages, bâti deux siècles auparavant, a été endommagé par tassement causé par l'augmentation du contenu d'eau dans le lœss, résultant de la fuite d'eau du système d'égouts. L'assainissement du terrain à l'aide d'injection par jet a été étudié et appliqué afin de remettre en état les fondations et d'arrêter le tassement et la fissuration du bâtiment. Les travaux d'injection ont été faits aux fondations extérieures et intérieures, dans la zone affectée par le tassement, jusqu'à une profondeur de 12 m au-dessous de la surface du terrain. Afin de définir une technique optimale d'injection, les injections d'essai ont été faites en-dehors du chantier en utilisant plusieurs pressions, directions de jet, et temps de injection. Les colonnes de 55 cm de diamètre ont été obtenues en utilisant une pression de 400 bars, ce qui a été accepté comme favorable compte tenu de la distance et de l'écartement des trous de forage au-dessous des fondations. Au cours de l'assainissement du terrain, la déformation du sol en fonction de la profondeur a été mesurée, le degré de fissuration des murs a été défini, et le relevé topographique des points sur le bâtiment a été fait. Avant le commencement des travaux d'injection par jet, les tunnels sous le bâtiment ont été remplis d'un béton spécial à partir des trous de forage réalisés depuis la surface du terrain. Le mesurage détaillé des déformations du sol, du tassement et de la fissuration du bâtiment, a été fait avant, au cours, et après les travaux d'assainissement.

Keywords : settlement, soil, improvement, jet-grouting, monitoring

1 INTRODUCTION

A high school building in Vukovar, reconstructed after the war destruction, and situated on the elevated loess terrain near the Danube river, was suffering from the decline of the bearing capacity of the foundation soil and excessive settlements followed by the formation of cracks within the structure and its facade. Denivelation of the surrounding terrain on the south-east side of the object was partly protected by the retaining wall and during the construction of the remaining wall segments local landslides appeared, which however, had no significant influence on the building. It turned out that poorly reconstructed rainfall collecting system caused the wetting of the foundation soil composed mostly of loess. Upon cracks emerging exploratory works were performed in order to determine the tendency of an increase in movements and soil properties in the zone of the biggest cracks and settlements. Based on the results of exploration works, remediation measures were derived and jet-grouting method of soil improvement had been selected. The success of remediation works was followed by extensive observation of the object and foundation soil. Wider Vukovar area is known for numerous loess tunnels which were once used as wine cellars. The tunnels under the building caused the increase in deformation of the foundation soil so that the two of them had to be filled with concrete.

Figure 1. Vukovar High-school.

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2 SCOPE OF THE PROBLEM

Few years after the war reconstruction (1998), some cracks had been noticed on the building. In the period between 2002-2006 the cracking progressed, regarding both the number and width of cracks throughout the object. The structure was built of massive masonry and was sensitive to settlement. In the early phase of cracking, the settlements of the object was recognized as a main cause for crack formations. There was a concern for a student's safety. The extensive exploratory works, observations and geotechnical measurements on the object and its surroundings were conducted in order to determine the exact cause of the problems. Intention was to identify the regions affected by yielding and to suggest remediation methods. The cracks and their tendency to change in width were constantly monitored so that in case of a sudden crack development the object could be closed for public use. The cracks developed on the facade and within the object are shown in the Figure 2 and Figure 3.

Figure 2. Crackings in facade.

Figure 3. Crackings in one of the classrooms.

The purpose of the exploration works was to determine soil properties of the foundation soil and to direct the remediation measures. Exploratory borings, in-situ testing (flat dilatometer) and laboratory investigation works were conducted. Disposition of boreholes, inclinometers and deformeter holes were presented in the Figure 4. The foundation soil is composed of clay layers in the upper part and loess layers beneath them (the soil profile is shown in the Figure 5). Special consideration was given to loess wetting (caused by precipitation water due to a poor rainfall collecting system around the object). The soil profile with the moisture change, observed in the period between the first noticed cracks and time of remediation, has been made. Also the modulus of vertical deformation change with depth has been obtained and then used as the basis for the analysis and modelling of the remediation works. Figure 5 shows the soil profile, and in the Figure 6 the increase of moisture content with depth as a result of precipitation water coming from the conduit system is presented.

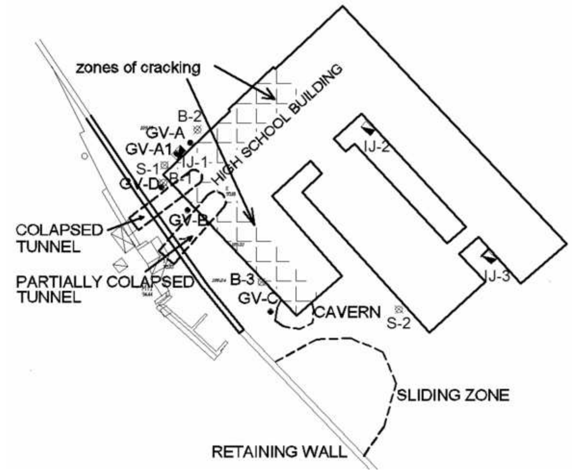

Figure 4. Dispositon of boreholes, inclinometer and deformeter holes, along the area of the building (boreholes: B-1, B-2, B-3, S-1, S-2, IJ-1, IJ-2, IJ-3, deformeters: GV-A, GV-B, GV-D, inclinometers: GV-C, GV-D).

The exploration works have revealed the zone of increased moisture content in the soil right beneath the foundation, to the depth between 9 – 11 meters. This fact provoked collapse of the loess structure, which has been confirmed by the oedometer tests. Wetting and softening of the foundation soil did not affect the whole object equally, and the most affected area was the south-eastern part of the object under which there were tunnels (Figure 4, shaded area).

The tunnel vaults under the building (see the cross-section presented in the Figure 7) made of loess became wet because the tunnel served as a drain for the excess water in the soil. Gradually they started to collapse causing the additional soil settlement under the structure. It was therefore decided to fill the tunnels with concrete.

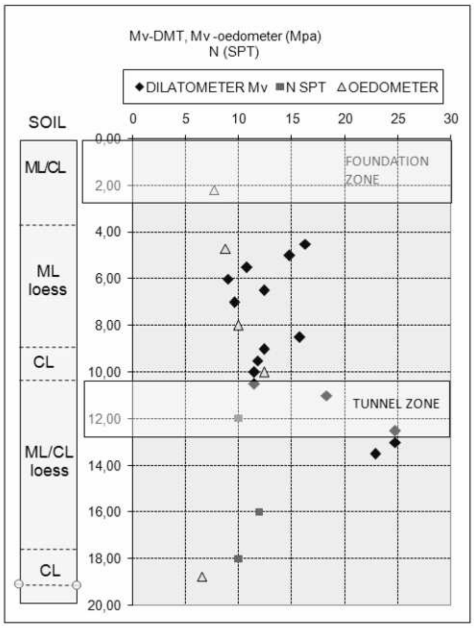

Figure 5. Soil profile and modulus of vertical deformation.

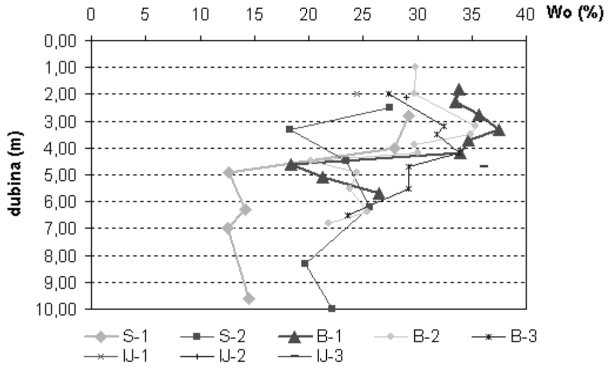

Figure 6. Moisture content versus depth for boreholes B-1, B-2 and B-3 from year 2006. and S-1, S-2 I S-3, IJ-1, IJ-2, IJ-3 from year 1998 (position - see Figure 4).

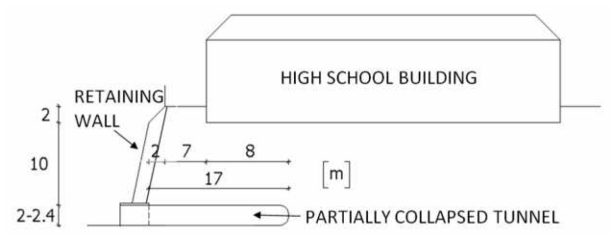

Figure 7. Schematic cross-section of highschool building with position of collapsed tunnels.

3 REMEDIATON WORKS

Based on the analysis of foundation soil and structure behaviour it was concluded that it was necessary to extensively remediate the foundation soil and to improve the structure foundations. It was also needed to transmit the structure load into greater depths in the improved soil, which was achieved by jet-grouting under the structure foundation forming columns in the appropriate disposition. The tunnels under the structure, discovered during exploration works (plan view Fig 4. and cross-section Fig 7.) started collapsing, due to loss of strength in wetted loess in which they were made. This fact significantly influenced the planned remediation and was carefully studied. Before the foundation remediation, the tunnels were first vaulted (at places where they were accessible) and filled with specially prepared concrete, poured from the surface through the borehole.

Jet-grouting was the key procedure in the foundation remediation. The area of softened soil was improved by jet-grouting with columns of 60 cm in diameter, to the depth of 6 or 9 meters under the foundation (the foundation depth was cca 2m under the ground surface). The plan view arrangement of jet grouting columns can be seen in the Figure 8. The typical jet-grouted column cross-section for foundation underpinning is shown in the Figure 10. Since the soil in the remediation zone was composed of loess, which is water sensitive, compressed air was used in the jet-grouting preparation procedure (soil cutting). Water was used only to a minimal needed amount in the grout mixture. In order to assure most suitable grouting technique a trial columns of jet-grouting were executed, aside from the object, using different pressures, direction of jet and time of jet action in place. Three different methods were tested and six test columns were made, the two for each grouting procedure. Each method was evaluated by testing the strength of the column core, by means of soil improvement rate determined with SASW method (before and after the test field was made) and on the basis of the achieved column diameter. The method of jet-grouting with cutting the soil by horizontal air jet, jet-grouting under the pressure of 400 bar, and with slow grouting vertical movement was chosen. The diameter of piles obtained by this procedure was 55-60 cm which met the design requirements.

During the jet-grouting at the corner of the object, just under the object foundation, (the closest corner to the previous local landslide), a cavern of 50-60 m^3 was found, which was then filled with concrete. A raw of grouted columns was placed between the structure and the hill-slope, to ensure the effectiveness of pressure transfer in the grouting zone under the object. Since the basement of the object was partly situated in the remediation zone, it was particularly difficult to carry out the jet-grouting under the basement walls due to their inaccessibility and lack of manoeuvring space. Thus the jet-grouting in the basement zone was accomplished according to the design solution using a small drilling machine.

The settlements in the Figure 10 show the increase in the phase of strengthening of the jet-grouted columns and taking load structure, but with the smaller increase than before the remediation. After the grouted columns had strengthened and, after a new static foundation system was formed, the settlements started to slow down until they finally stabilized.

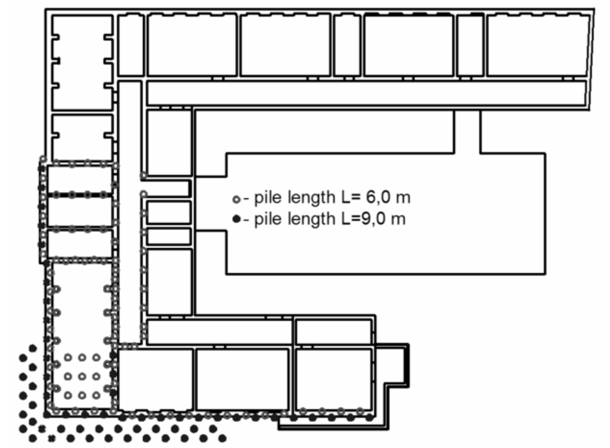

Figure 8. Dispositon of piles under footings.

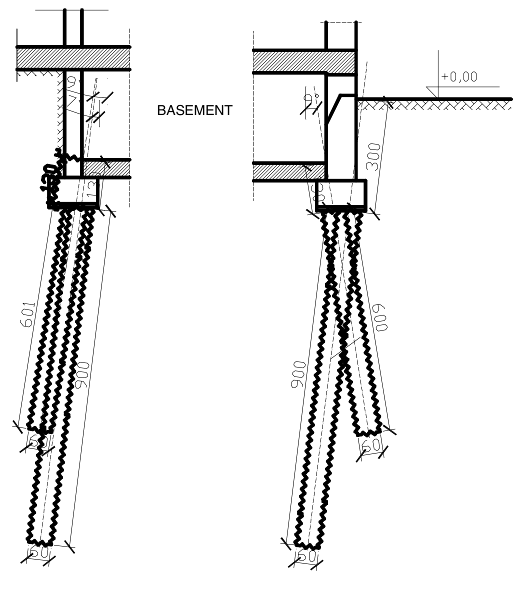

Figure 9. Tipical cross sections of foundation with pile positioning and dimensions.

4 GEOTEHNICAL MEASUREMENTS AND OBSERVATIONS

The measurement and observation system was introduced with the purpose of finding the locations of greatest movements and to monitor the efficiency of remediation measures. Points for crack width change monitoring were installed to monitor the crack changes within and on the structure facade, as well as geodetic points on the object to observe the settlement of the object. The deformeters (GV-A, GV-B, GV-D, marks - see Figure 4) were placed to the depth of 20 m, right beside the object, in order to determine the settlement of the foundation soil with depth. The inclinometers (GV-C, GV-D, Figure 4) were installed to the depth of 20 m to record the potential movements of the soil due to landslide. It turned out that during a longer period there were no significant horizontal movements which could explain the mechanism of landslide under the structure. The measurements of the crack width changes on the walls of the object served as the basis for evaluation of success of the remediation works and as an alarm for the safe use of the structure. At the same time, the growth of deformations served as an indicator for estimating the risk of possible structure collapse.

The observation system (cracks, geodetic points, sliding deformeter, inclinometer) was used for monitoring the remediation effects and for checking the state of movements a year after the remediation. After the remediation works by soil improvement all indicators measured showed the decreasing tendency, which can be seen in the Figure 10 from the settlement data obtained by a sliding deformeter .

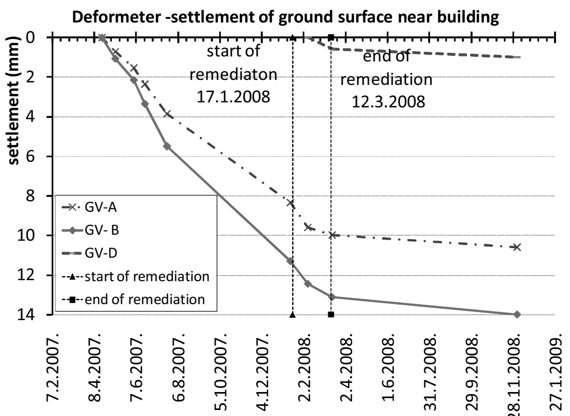

Figure 10. Deformeter measured settlements of ground surface close to building.

5 CONCLUSION

The complex problem of remediation of the structure foundation situated on the less and wetted terrain demanded an extensive soil exploration, a careful selection and control of a remediation method, as well as an extensive program of movements' measurement and observation, conducted with the three independent types of instruments. It turned out that it was necessary to fill the existing tunnels under the structure with concrete to decrease deformability of the soil under the zone of improved foundation soil. The efficiency of remediation measures was constantly monitored by observations and measurements which, very soon after the remediation work was completed, proved that the movements and settlements started to decrease. A particular unfavourable circumstance for a successful remediation appeared due to the delay of the reparation of the sewer system of some internal parts in the object which proved to be a source of additional leaking. The object was in use during the whole remediation process. The final reparation of cracking walls will be carried out after the remediation of the internal sewer system. The measurements taken by means of three independent systems (on the structure and in the foundation soil) showed the decrease of settlements and proved the efficiency of the foundation remediation in the period of one year after the remediation, enabling the control of safety and success of the remediation works.

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