Settlement of an art relic church caused by the construction of the Metro line

Tassement d'une église historique du à la construction du métro

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ABSTRACT

The church of Kalvin square is found in the center of the Hungarian capital, Budapest. The subsoil layers are very changeable, the groundwater is 4-6 m deep from the surface. Next to the art relic building a 90 m long and 27.5 m wide underground station is being constructed from the surface by cut-and-cover method using diaphragm wall excavation technology.
Some effects had to be analyzed which can cause the settlement of the church.

a) the stability of the nearby diaphragm ditch.
b) deviation of the diaphragm wall's direction from the vertical.
c) Settlement depression caused by the construction of the nearby connecting line tunnels
d) Dynamic effects.

The foundation and the surface structure of the church were strengthened before the beginning of the underground construction. To measure the settlements during the construction there was settled a modern automatic monitoring system, which gives automatic report if the settlement reaches a predetermined value.

RÉSUMÉ

L'église à la place Kalvin est située au centre du capital hongrois, Budapest. Les couches de sous-sol sont très variables, la nappe phréatique est dans une profondeur de 4-6 m. Très proche de l'église une station souterraine (longueur 90 m, largeur 27,5 m) est construite par la méthode de « cut-and-cover » employé une technologie d'excavation des parois de diaphragme.
Quelques effets étaient analysés pouvant causer les tassements de l'église

- la stabilité du fossé proche de diaphragme
- déviation de direction des parois diaphragme du vertical
- dépression du tassement causée par la construction des tunnels proches de la ligne de connexion
- effets dynamiques

Les fondations et la structure en surface de l'église étaient fortifiées avant les constructions souterraines. Pour la mesure des tassements pendant la construction un monitoring system moderne était placé, donnant des indications automatiques quand le tassement atteint une valeur prédéterminée.

1 INTRODUCTION

The reformed church of Budapest on the Kalvin square is found in the center of the Hungarian capital. The subsoil layers are very changeable, the groundwater is 4-6 m deep from the surface. Next to the art relic building a 90 m long and 27.5 m wide underground station is being constructed from the surface by cut-and-cover method using diaphragm wall excavation technology.

The platform is 22.2 m deep from the surface. The distance between the corner of the church and the corner of the diaphragm wall will be 1.5 m. and 6.0 m from the end diphragm wall of the station to which connect the two 5.8m diameter line tunnel constructed with shields.

The foundation level of the domed building, which wall was made of dressed stone and brick, is 4.4 – 4.5 m deep under the surface. Cracks on the wall had already been seen before the underground construction. The structure of the church is in bad condition and sensitive to settlements.

To measure the settlements during the construction there was settled a modern automatic monitoring system, which gives automatic report if the settlement reaches a predetermined value.

The foundation and the surface structure of the church were strengthened before the beginning of the underground construction.

2 SUBSOIL AND GROUNWATER CONDITIONS

The surroudings of the valued church was former the floodplain of the Danube river, and a longish neck of land, like a little island was here. The boundary of the former little island from the east side was a swampy, morass area, from the west side was bordered with the floodplain of the river. At higher water levels the island were flooded. By all of the floods more and more silty sand and river drift were deposited, until the regulation of the river. Above this a fill layer is found until the surface level.

According to the geology the upper layer is organic silty sand fill until 2,0-4,0 meter deep. That is followed by yellow fine sand, and yellowish-grey gravelly sand, sandy gravel layers. The substratum of this layers can be found between 12,5 – 15,5 meter.

Under this layers the upper tertiary period layer is found a low plasticity, sandy clay, the thickness of the layer is c.ca 8,0 meter. Following this layers from 23,5 meter deep we can find sand, sandy silt and sandy clay layers until 28,0 m deep from the surface. Below that until the bottom of the drillings (41 meter) silty sand and sand layers were found.

The latter deep layers have only indirect effects on the church. This effect depends on the stability of the construction

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of the diaphragm walls, which will be made in 1,5 meter distance from the north-west corner and from the western column of the building.

The level of the groundwater can be found at 4,0 – 6,0 meter depth, and it is flowing in the pleistocene layers.

The former experience of the metro construction shows that in this area the groundwater is not under pressure. The estimated maximal groundwater level is in 3,4 meter deep under the surface level.

3 STRUCTURE OF THE CHURCH

The longitudinal ground plan church, which was built between 1816 and 1830 in neoclassical style (Photo 1.) was made of craved stone and brick wall, in front and at the rear with annular vault and cupola on pendentives (18m span). The construction of the metro station is a danger for the entrance portal (Photo 2).

The monument building with a shallow foundation and no cellar was damaged during the II. World War. Later the construction of the pedestrian subway in front of the church caused significant horizontal and vertical displacement and cracks on the building (Photo 3).

The foundation base level of the rubble stone wall of the church is 4,4 - 4,5 m deep in the silty fine sand layer, which tend to be a drift sand. The facing main walls were reinforced with steel rim 10 years ago. The average static state of the tower is suitable. The building itself is in an extremely subsidence state.

Photo 1.

Photo 2.

Photo 3.

4 THE PREDICTED DISPLACEMENTOF THE CHURCH CAUSED BY THE CONSTRUCTION OF THE METRO LINE

In the introduction mentoined the platform levels of the metro station are in 22,2 m deep. The structure of the station will be built with diaphragm walls, after that the slabs will be built with open cut. The thickness of the diaphragm walls are 1,25 meter, and the foundation level is at -36,1 meter.

Constructing an excavition it is unavoidable the changes of the stresses in the soil structure and the develope of deformations, which cause a surface settlements. Making simplifications, we can say that the distance of the effect of the excavation which cause surface settlements, horizontal displacements and possibly structure damages is double the depth of the excavation, or rather the width of the zone within the monitoring systems must be installed.

Such five effects had to be analyzed which can cause the settlement of the church.

a) the stability of the nearby diaphragm wall filled with bentonite slurry; the danger the drifting of sand and gravely sand soils
b) deviation of the diaphragm wall's direction from the vertical which surround the area of the station; settlement of the church caused by the movement of the diaphragm wall
c) Settlement depression caused by the construction of the nearby connecting line tunnels
d) Dynamic effect when the line tunnels reach and break through the 125 cm thick diaphragm wall.
e) the effect of the construction of the NATM tunnels for ventilation in front of the station and between the stations

The biggest risk to our church comes from the stablitity problems of the nearby diaphragm panels which are filled with bentonite slurry. By the excavation of the panels the fine sand sandy silt, and silty sand layers have to be cut across, which is very dangerous for drifting, so they can easy flow into the panels. This facts have to take into consideration by the design of the width of the panels. The constructor has to make allowance for the consistence, the viscosity and the stability of the bentonite slurry.

We have made a stability calculations for a 2,8 meter width panel, where the unit weight of the slurry was 11 kN/m^3. The factor of safety for the damage of the diaphragm panels were 1,23-1,30. The calculations were made with Plaxis v8.6, where the settlement of the church, caused by the construction of the diaphragm wall, arise to 4-6 mm.

The building settlement caused by the vertical inclination of the diaphragm wall can be predicted to 1-11 mm. This can be derived the 6-9 mm horizontal displacements of the soil behind the panels.

It must be taken into consideration that the construction of the metro lines has effects on the surface settlements, too. It is notorious that the soil structure surrounding of the closed method tunnels is yielding, the relations of the stresses are changing, there will be movement until the surface level. The north-western corner of the church is only 6 meters far from the connection spot of the rightside metro line. Above the closed method tunnel arise a ground surface settlement. The shape of the settlement can be approached by a Gauss-curve, or with a very similar curve. This area of the surface settlements give us the vertical settlements. From this results with kinematic and elasticity theories can be calculated the angle change, the inflexion, and the horizontal displacement.

According to the calculations the predicted surface settlement from the tunel construction near the north-western corner will be 16 mm.

By the connection of the metro line tunnels, the dynamic effect of the diaphragm wall at break through, will cause 1-2 mm surplus settlement.

Before the construction of the station will be made a connection gallery between the two lines, which cause 3-4 mm settlement by the nearby corner of the church.

Before the beginning of the construction the building contractor made a jet-grouting reinforcing at the square side of the church. The upper side of the church were also reinforced.

In this time, until 2009 february, the a,) b.) and d.) effects caused deformations on the church and the measured settlement is 19 mm, which is coresspond with the predicted settlements (Figure 1 and 2).

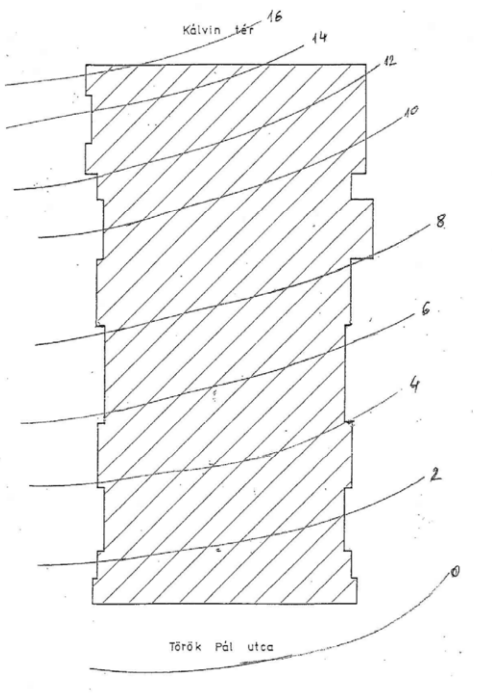

Figure 1.

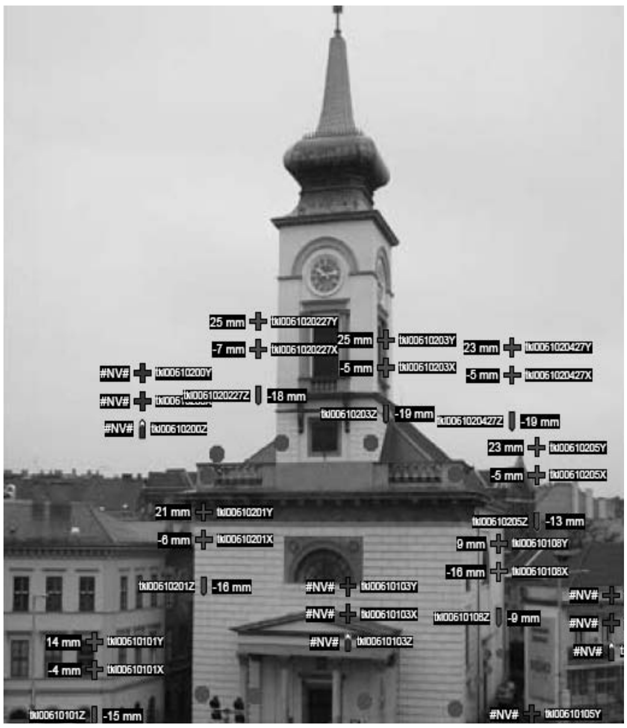

Figure 2.

5 MONITORING SYSTEM AND ALARM LEVELS

In order to conserve the church four type of monitoring systems were installed:

a) automatic survey monitoring system
b) hand optical displacement detection by geodetic instrument
c) underground monitoring system (measuring the movement of the diaphragm wall by inclinometer and extenzometer)
d) Other monitoring methods (tensiometric, building overturning etc.)

The automatic monitoring system contains the monitoring equipments and the prisms located on the church.

The fixed automatic monitoring system includes the on-line theodolite system, the prisms located on "moving" points and the reference points installed (fixed) out of the settlement zone.

Four of this kind - developed by the Sol Data and the IGN companies employed all over the world - CYCLOPS automatized, computer controlled survey system were installed.

The Cyclops operates non-stop until the construction finishing. It records the three-axis (X, Y, Z) movement. Generally it monitors 50 prisms and locates one point by measuring in 12 sec.

At those surfaces which can not be checked by automatic theodolite (side-, back, and inner main walls) hand measuring method was used.

The diaphragm-wall's deviation from vertical and the horizontal movements close to the church are measured by inclinometers and extensometers. The tilt of the tower is marked by prisms.

All of the measured data have to be sent to a special database, which is operated by such softver that allow quick and coherent utilization of the information in reference to the whole area of the construction. The reliable data recording and data communication is very important part of the monitoring systems.

After giving the measuring data to the database, or in case of excess the predetermined limit count, automatic distress signals are switched.

These distress signals if required can be siren or flash signals on the construction area. Furthermore it can be forwarded by e-mail to the site managers to their web sites or to their cellular phones

It is an important task during the construction of the metro line to give carefully the alarm levels. Usually at the urban area metro construction the required safety is doubled.

The following alarm levels were given at the church which was also accepted by the building company:

1. alarm level: warning:
   measured settlement of the building: 20mm
   measured relative rotation: 1/600
   D-wall's horizontal movement: 10mm
2. alarm level: readiness
   measured settlement: 30mm
   measured relative rotation: 1/400
   D-wall's horizontal movement: 25mm
3. alarm level: distress signal
   measured settlement: 50mm
   measured relative rotation: 1/220
   D-wall's horizontal movement: 55mm

6 SUMMARY

The monitoring system of the church of Kalvin square during metro construction is performed 4 automatized theodolites type Cyclops. The first results of continous data measurement are described in this paper.