

Geotechnical Monitoring of a Tunnel in the Kiscelli Clay in Budapest

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ABSTRACT The ventilation tunnel of the Bocskai station of the metro line 4 in Budapest is 76.86 m long, 9.1 m wide and 7.62 m high, with the cross section of 55.52 m². The primary lining is 250 mm sprayed concrete with double reinforcements. This article is about the measurements of displacements and earth pressures and the issues after the measurements. If the results are evaluated, some new information are obtained about the tunnelling in the Kiscelli" clay.

Displacement measurements: During the construction, the vertical and horizontal displacements were read twice a day, every morning and every afternoon. The displacement cross sections were every 5 m, and at the beginning, close to the wall, they were in the 3 m, 5 m, and 8 m cross sections. Two cross sections were chosen: one of them, 0+08, has the smallest construction time, and the other, 0+65, has the longest construction time. The smallest time is 42 h and 30 min and the longest is 414 h and 10 min.

Earth pressure measurements: Earth pressure cells were built in the 0+43 cross section. The radial cells measure the earth pressure between the concrete lining and earth. The tangential cells measure the pressure in the lining.

1 GENERAL DATA

1.1 General Information

The ventilation tunnel at the Bocskai Station of the metro line 4 in Budapest is 76.85 m long, generally 9.1 wide and 7.62 m high. The cross section area is 55.52 m². The primary lining is SCL (Sprayed Concrete Lining), 250 mm thick, with double reinforcement.

The general construction company of this SCL tunnel was Swietelsky Építő Ltd. The designer was Mott MacDonald Magyarország Ltd as subcontractor for Főmterv Zrt. The Magyar Alagútépítő és Bányászati Ltd (Hungarian Tunnel Constructor and Mining Ltd) was the actual construction company as

a subcontractor. The geotechnical site manager was Geovil Ltd, responsible for the in-situ measurements of the displacements during construction and their evaluation. The installation of the earth pressure cells, and the measuring of the radial and tangential stresses and their processing and evaluation were a very special exercise.

1.2 Geology, Geotechnical Information

The geotechnical and hydrogeological environment of the tunnel was investigated by Geo Pannon Ltd.

According to their study, the uppermost layer to a depth of 4 to 5 m below the ground surface is made up of loose pleistocene

deposits underlain by a mid-oligocene formation of clay marl known as Kiscell clay. The upper zone of the clay stratum in a thickness of 1.4 to 2.8 m is expanded, fractured and weathered, and below this an expanded, cracked zone of 4 to 5 m thick is found. With increasing depths, cracking and effect of expansion gradually diminish and eventually a sound stratum exhibiting the original even texture is encountered, this is the Kiscell clay, familiar to and rated high by geotechnical engineers as providing very favorable environment for tunnel construction.

As the construction of the tunnel was progressing, continuous advance investigations were made of the soil/rock conditions around and ahead of the cross section of the tunnel. Based on this, it was ascertained that at no place intruded the excavated profile into the expanded, fractured, weathered zone, while the vault may have reached the cracked zone, the lower portion of the cross section was invariably constructed in sound Kiscell clay.

1.3 Construction Technology

This ventilation tunnel of the Bocskai Station was constructed by mining technology with shotcrete lining, as the primary lining.

The construction technology is summarized as follows.

The mining consisted of five stages:

1. The top heading was opened and the primary lining of the top heading was constructed.
2. The bench was opened and the primary lining of the bench was constructed.
3. The vault was opened and the primary lining was lined with shotcrete.
4. The bench was opened+ primary lining
5. The invert was opened + primary lining, closure of the ring.

Each stage was 2 m long. During the construction, the displacements of the structure were checked.

The suggested geotechnical measurements were determined by the CEN-European Committee for Standardization: European Standard ENV 1997, Geotechnical Design

Part 1, General Rules. Of which one of them is highlighted, which states "...the properties of the tunnel structure have to be certified by perpetual back analysis and monitoring".

2 DISPLACEMENT MEASUREMENTS

During the construction, readings were taken twice a day by optical surveying instrument at 5 observational points located in the primary lining. The vertical and horizontal displacements of the points were read.

Worthy of note, that according to the up-to-date designer conception, the displacement measurement is more practicable for the displacement of the primary lining or the checking of the structure than the convergence.

The displacement measurements were carried out as follows:

- 5 observation points had to be fixed into the primary lining,
- the first reading was to be made within 6 hours after the completion of the primary lining ring,
- the reading frequency rate can be seen in Table 1:

Table 1. The reading frequency rate

Tunnel Lining Convergence	
0<d<30	Daily
30<d<72	Twice weekly
72<d	Weekly
d- is a distance in meters of the monitoring array from the tunnel face (m)	

The limiting values of the displacements were accorded by the designer (Mott MacDonald Magyarország Ltd) and summarized in Table 2.

Table 2. The limiting values of the displacements

	dh	dv	Trigger	Action	Danger	Trigger	Action	Danger
CP1	dv	10	20	40	12	25	50	
CP2 and 3	dv	10	20	40	12	25	50	
	dh	10	20	40	12	25	50	
CP4 and 5	dh	10	20	40	12	25	50	

dh: horizontal displacement; dv: vertical displacement; CP1, CP2, CP3, CP4, CP5: the observation points located in the primary lining.

The displacement measurements were designed to be spaced generally at 5 m intervals. But in the first 10 m they actually were at the 3th, 5th, 8th m because that was the area of the outbreak of the tunnel across the diaphragm wall. Beyond this 10 m, the measurements were at each 5 m. The observation points in the SCL primary lining are shown in Figure 1.

If the results of these displacement measurements are analyzed, it is possible to draw some conclusions.

In the established practice, the displacements of the structure are analyzed at 5 points per cross section.

Hereinafter, the displacements of the points CP1 (point of the top heading), CP2, CP3 (points of the bench), CP4, CP5 (points of the invert) are presented.

The cross sections 0+08 and the 0+65 are chosen because the construction time at 0+08 was the longest, 414 hours 10 minutes, and at 0+65 it was the shortest, 42 hours 30 minutes. Let us consider the displacements in these two cross sections side by side (Figs. 2-5):

We can see that the construction time influences the displacements of the points CP1, CP2 and CP3 points, but at the invert it does not influence the displacement of CP4 and CP5.

The danger tendencies of the displacement of the prop can be presented by the rate of the displacement. If the rate is growing, the prop/structure will have to sustain more and more strain. If the rate is toning down, the stability will be able to set in. Hereinafter we can see a usual displacement-rate diagram.

The change with time in the rate of displacement can be assessed from Figure 5. The movements of the points were first relatively fast after completion of the construction. After the first month the rate of the movement of the points slowed down practically to zero, i.e., the tunnel and the ground environment got into a stable, new equilibrium after 1 month.

In the two cross sections:

0+08:

- start of the construction: 18.12.2006,

- the construction time: 414 hours 10 minutes,

- the date of reaching equilibrium: 24.01.2007,

- elapsed time: 37 days.

0+65:

- start of the construction: 03.02.2007,

- the construction time: 42 hours 30 minutes,

- the date of reaching equilibrium: 13.02.2007.

- elapsed time: 10days.

It is observable by these two examples what relationship exists between the construction time and the time of reaching equilibrium. Fast construction time can help equilibrium to be reached fast and the movement of the structure to tone down.

3 THE EARTH PRESSURE CELLS USED IN THE KISCELLI CLAY

The Glöttzl earth pressure cells were installed in the cross section 0+43. The installation of the pressure cells was helped by a few days of study tour at the Glöttzl Company.

The radial cells can show the stresses between the SCL and the clay. The tangential cells can show the stresses in the structure. Figure 6 shows the installation scheme of each cell.

In the cross section 0+43 there are six radial and two tangential cells. The location of the cells is shown in Figure 7.

The readings were taken twice daily. By the continuous reading we can get a complete image of how the stresses were transposed onto the prop and what magnitude of the stress was in the SCL.

Finally, Figure 7 shows the distribution of stresses around the primary lining. The state of stress is very interesting, because it appears to be "quasi hydrostatic".

With the development of this state of stress, the static condition in the Kiscell clay tends to be transformed into a new nonstatic condition. This new condition is characterized by the formation of an active failure zone around the tunnel (Fig. 8). The Kiscell clay which is normally dry and impermeable in the

static condition, becomes wet and remoulded after the construction of the tunnel. The Kiscell clay when intact predominantly contains bonded groundwater, but with the opening of the cracks the groundwater is able to penetrate into the remoulded clay around the tunnel, so that clay particles float in water. Thus the Kiscell clay loses its original characteristics.

A "quasi hydrostatic" state of stress results because of the water and the floating clay particles. The angle of friction of the remoulded and wet Kiscell clay drops as low as $\phi=5$ to 10° . It follows from the foregoing that the coefficient of the active earth pressure (K_a) increases to ~ 1 , so the vertical and the horizontal earth pressures become virtually equal. This condition may be termed as "quasi hydraulic" state of stress. The load on the tunnel consists of the water pressure and the earth pressure reduced by buoyancy. Given this, both the vertical earth pressures and the horizontal earth pressures can be determined.

4 CONCLUSIONS

The geotechnical parameters were fair for the tunnel design, since the displacements during and after the construction were predicted reliably by the designer (Mott MacDonald Magyarország Ltd).

The tunnel was constructed in a good quality by the constructor, owing partly to the fact that the constructor possessed construction practice in similar projects.

In similar geological and geotechnical environment and with the same construction technology the movement of the point at the top heading is likely to finish by the end of the first month. The rate of displacement reduces permanently below the design value. These results can provide some good and useful information for the designer concerning the Buda site of the project.

The installation and the performance of the earth pressure cells were satisfactory. The measurement results seem to verify the designer's assumption that a "quasi hydrostatic" state of stresses is likely to develop around the tunnel.

REFERENCES

- CEN-European Committee for Standardization: European Standard ENV 1997, Geotechnical Design Part 1, General Rules
Bassett, R.H., 2007. Practical Application of settlement monitoring. *NCE Conference*, UK

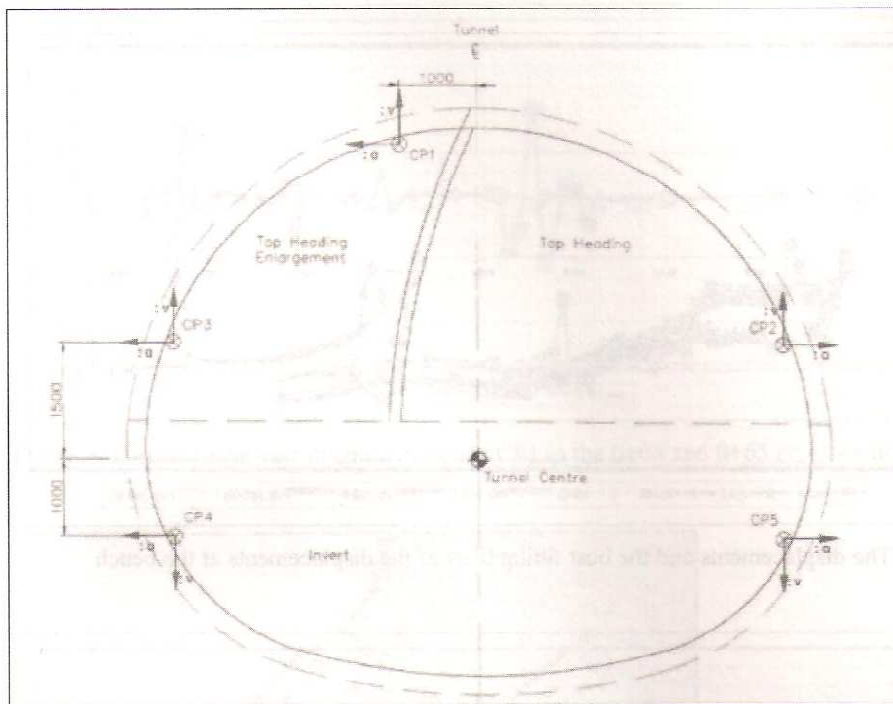


Figure 1. The observation points in the SCL primary lining

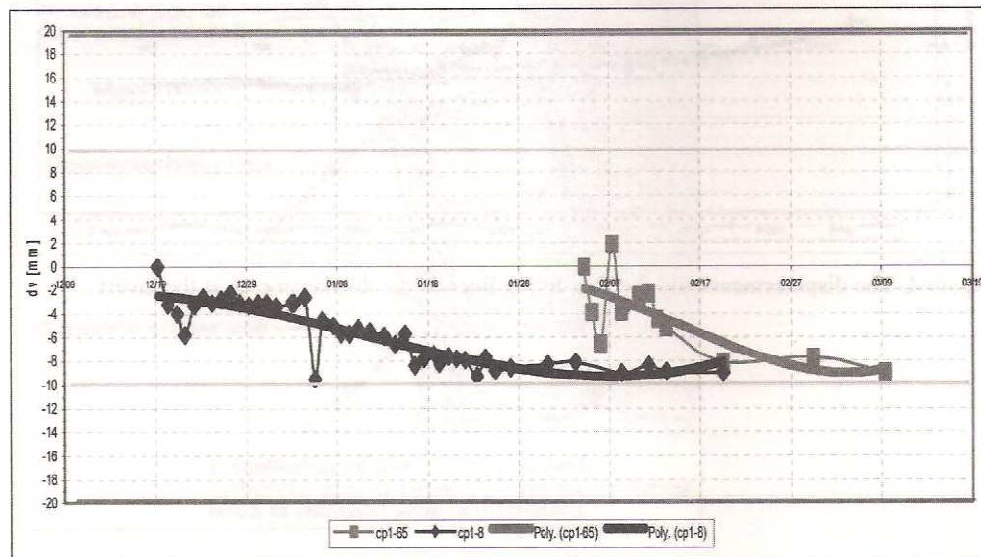


Figure 2. The displacements and the best fitting lines of the displacements at the top heading

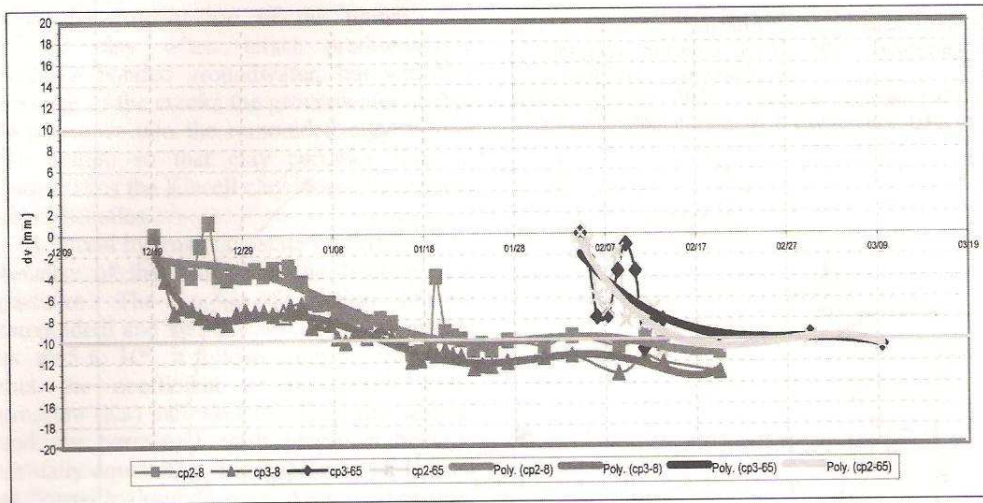


Figure 3. The displacements and the best fitting lines of the displacements at the bench

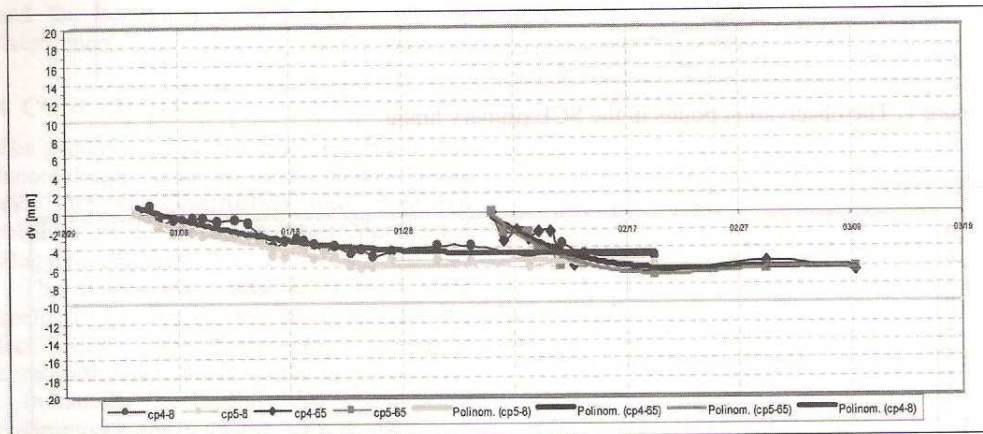


Figure 4. The displacements and the best fitting lines of the displacements at the invert

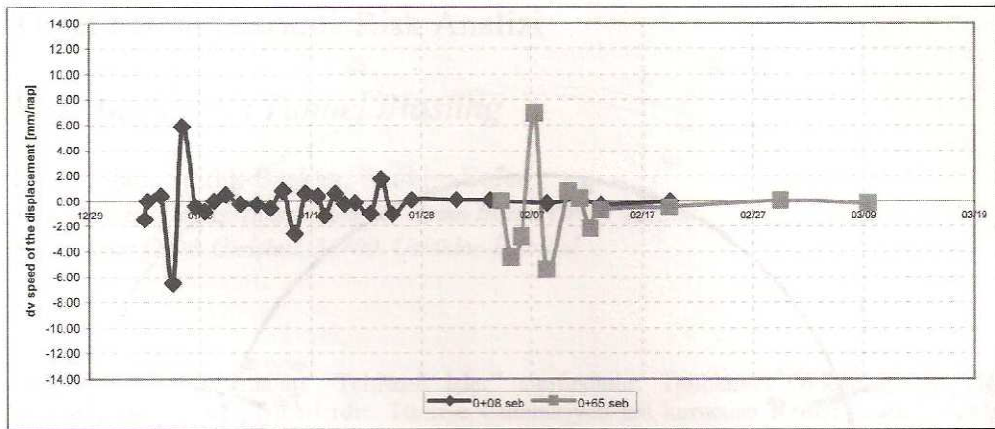


Figure 5. Displacement-rate diagram of points CP1 in the 0+08 and 0+65 cross sections

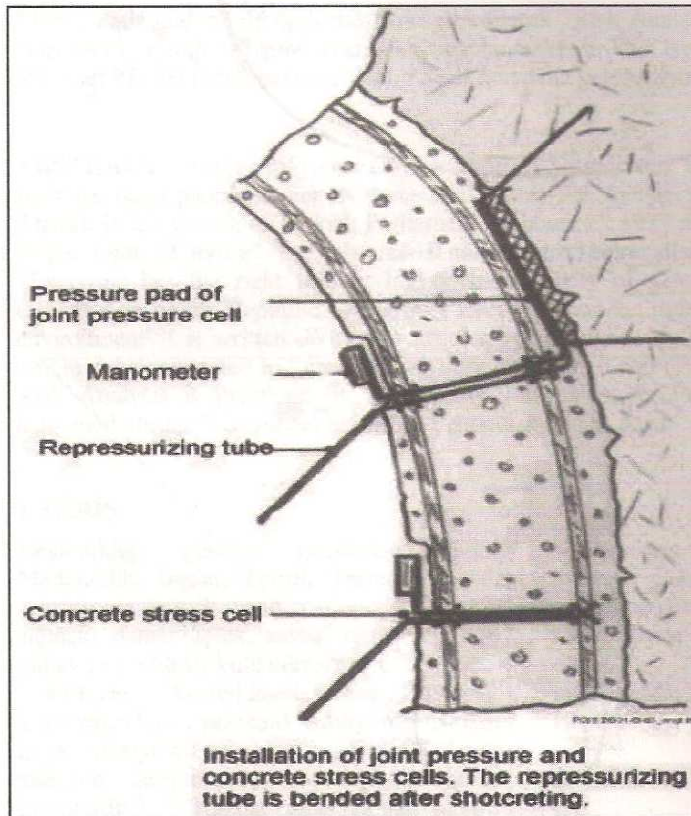


Figure 6. Installation scheme of the earth pressure cells

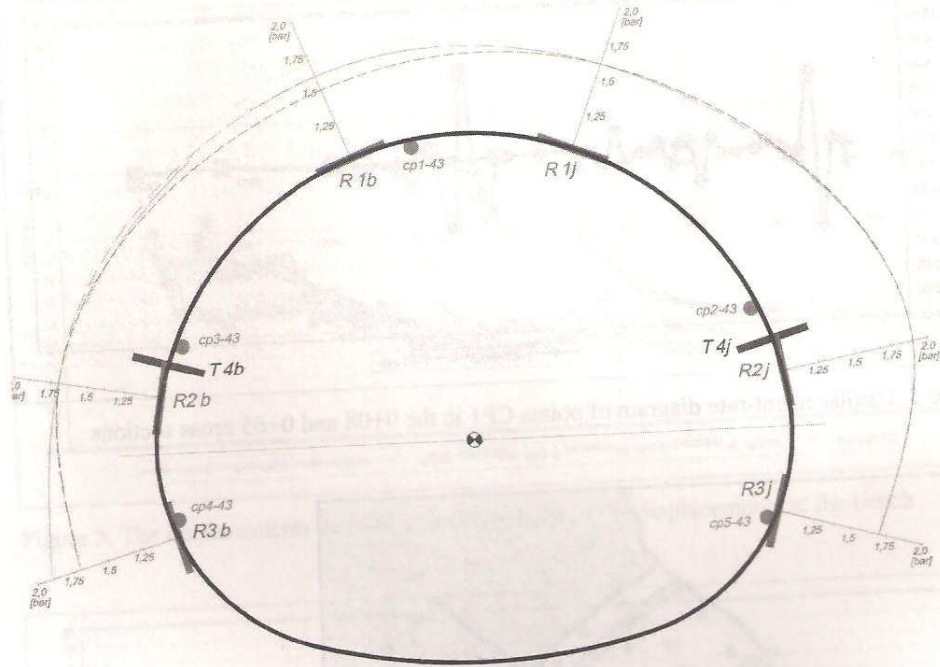


Figure 7. The earth pressure cells in the cross section 0+43

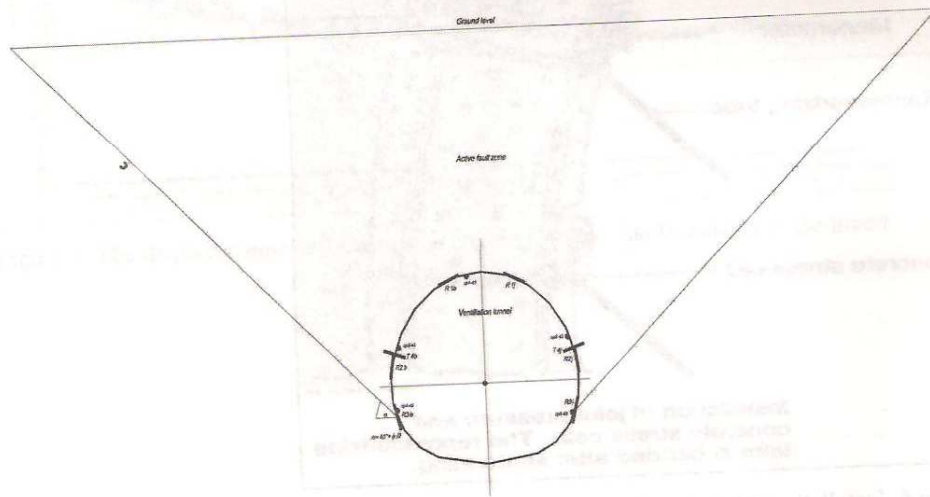


Figure 8. Active failure zone around the tunnel