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EXPANSIVE CLAYS IN TRACK SUBGRADE IN DEEP CUT (SECTION TŘEBOVICE – RUDOLTICE, CZECH REPUBLIC)

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ABSTRACT
Track section Třebovice – Rudoltice on the border between Bohemia and Moravia and European watershed is one of the most complicated sections in Czech Republic. Main difficulties in that area result from expansive clays with high plasticity. Swelling of these clays caused destruction of the Třebovice tunnel built in 1842. This tunnel was restored after great difficulties in 1932.
Modernisation of railway track in that area was solved by re-alignment of existing tracks. Crossing the soils with the worst mechanical properties (highly plastic expansive clays) was designed as cut-and-cover double-track tunnel protected by diaphragm walls with invert.
Contractor that won the tender suggested solution with open cut and proclaimed significant reduction of costs. Geotechnical hazards of this alternative were discussed in paper in Railway Engineering 2003.
Expansive clays occurring at the bottom of this cut (depth of 12 m) represent the most significant geotechnical hazard. We had a short time to analyse behaviour of these expansive clays, to find out any relationships and to define and make trial tests of their treatment.
Expansive clays in that area are represented by marine Miocene highly plastic clays (CV, CE) that are stiff to firm (unconfined shear strength is 200-300 kPa.). Linear swelling achieves values up to 25 % (median is 5 %); the maximum value of swelling pressure was 276 kPa (median is 111 kPa.).
It is mainly organic matter dispersed within clays that causes swelling of them. The organic matter content is 4-7 %, maximally 12 %. Influence of mineralogical composition of clays on their swelling behaviour has not been proven.
Due to time shortage only two methods of expansive clays treatment were tested. In both cases we considered mixing of clay in situ with a binding agent and in one case we added also granular aggregates. By comparing linear swelling and swelling pressures of untreated and treated samples we obtained the best result for treatment of clay by lime (5 %), cement (7 %) and gravel fraction 0-4 mm (10 %). In case of treatment only by lime (8%) and cement (7 %), linear swelling was higher than in treatment by the first mixture.
CBR values of treated materials increased from 6-8 % to 25-30 %. Similarly shear strength parameters changed (effective cohesion increased from 5 kPa to 40 kPa).
Based on our laboratory study, the treatment of expansive clays on the bottom of the deep cut and in track subgrade was proposed.

KEYWORDS: expansive clays, Miocene, swelling, Třebovice-Rudoltice, geotechnical hazard, mineral composition, organic matter

1. INTRODUCTION

Track section Třebovice – Rudoltice on the border between Bohemia and Moravia in the place of European watershed is one of the most complicated sections in Czech Republic. Main complications in that area arise from expansive clays with high plasticity. Swelling of these clays caused destruction of the Třebovice tunnel built in 1842-1845.

The Třebovice double-track tunnel was built in 1842-1845. Constructors in that time had no experiences with tunnelling in expansive plastic clays. Therefore Negrelli, main designer of railways in Austria, proposed to build open cut instead of a tunnel or to build cut-and-cover tunnel. Austrian railways did not accept these proposals and the first tunnel in Bohemia was built by German coring method. Tunnel was finished in 1845 after great difficulties arising from highly plastic expansive clays and water coming from both saturated sand lenses inside the clay mass and saturated sand layers above clays. Expected costs (188000 guldens) increased more than six times over 1 mil. guldens. Swelling of these clays caused destruction of the lining and tunnel was closed in 1866.

In 1866 a new track was built that followed the surface, however, with worse track gradient (9.5 ‰). That was the reason for reconstruction of the closed tunnel. Tunnel was restored after great difficulties in 1932 (advance in digging per round was only 5-30 mm). New lining from granite blocks was placed to the old one from sandstone. Restored tunnel has been operated since that time as one-track (Borovský, 1994).

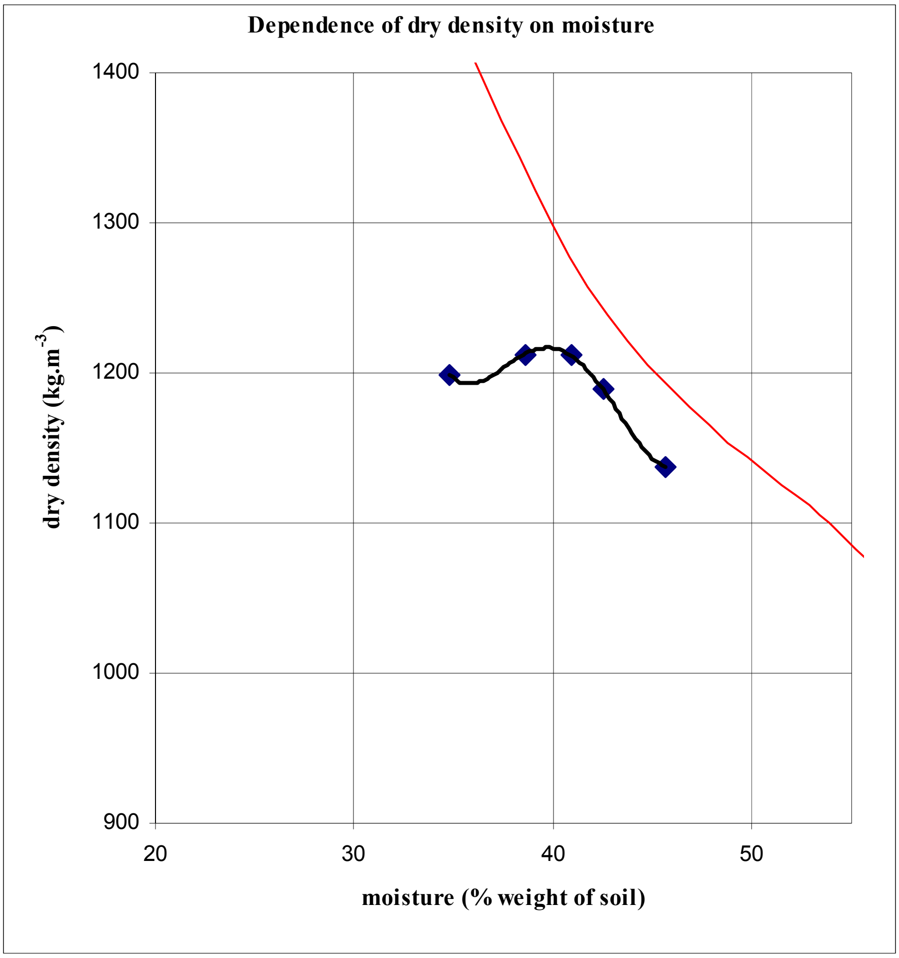

Fig. 2 Proctor Standard test (Miocene clays, borehole J205, depth 9.4-10.6 m).

Modernisation of railway track in that area was solved by re-alignment of existing tracks. Crossing through the soils with the worst mechanical properties (highly plastic expansive clays) was designed as double-track tunnel built by diaphragm walls with invert. However, contractor in tender proposal suggested to build an open cut and proclaimed significant reduction of costs (approx. 10 MEUR). This solution was accepted by investor and now is under preparation.

2. GEOTECHNICAL HAZARDS OF THE OPEN CUT SOLUTION

Geotechnical hazards of the open cut were discussed in paper presented in Railway Engineering 2003 (Kresta, 2003b). Geotechnical hazards of the open cut are seen to be as follows.

Expansive Miocene clays

Expansive Miocene clays are found out on the designed subgrade or below it. They cause technical problems in existing tunnel. Mechanical properties of these clays decrease by climatic influences (mainly at long and intensive rain precipitation). In addition it is necessary to take into account influx of water from overlying sands. Mechanical properties and swelling of these clays are discussed in sections 3 and 4.

Saturated Quaternary sands

Saturated sands overlying the Miocene clays will negatively influence mechanical properties of clays during construction. Underground water level changes will influence slope stability of lower parts of cut from long-term point of view. Technical measures have to be accompanied by a drainage system on the bottom and top of cut to protect lower parts of the cut.

Removing of significant amount of material without subsequent compensation

Removing of material from cut will result in great deficit of normal stress and it can cause long-term stability problems (decrease of effective stress, generation of high negative pore pressures, shear stress concentration at the toe of the slope may generate formation of plastic zones and fissures in underlying clays with subsequent back saturation of them). These phenomena may result in slope and track deformation.

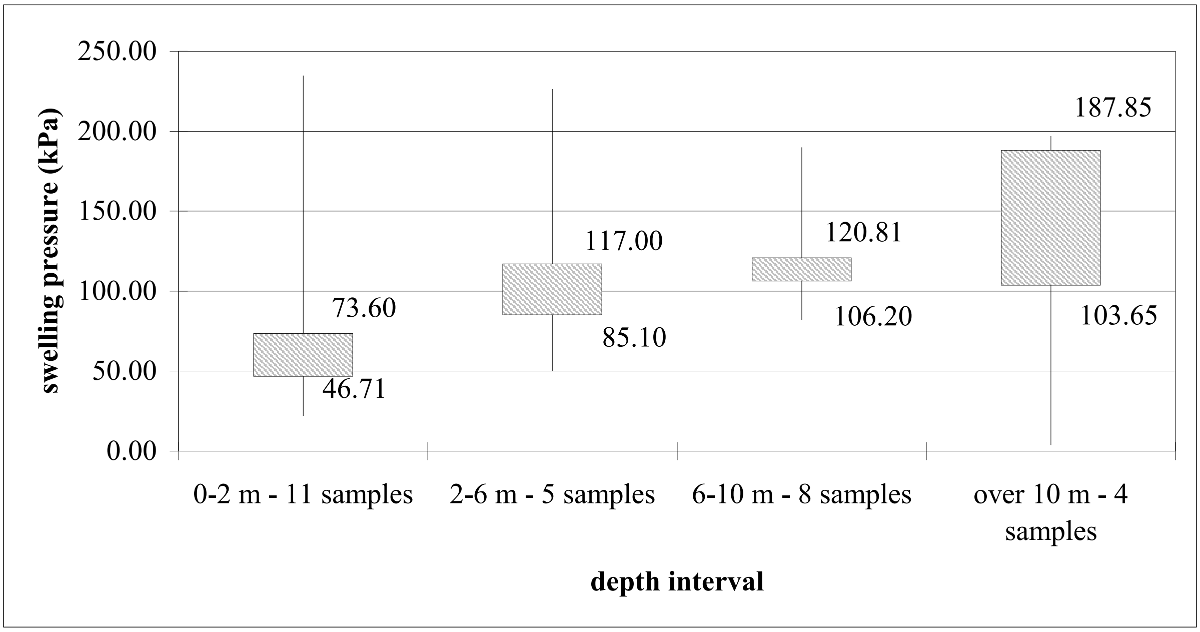

Fig. 4 Robust analysis – dependence of swelling pressure on the depth of samples (distance from Quaternary – Miocene boundary)

Cut crossing with existing tunnel in the overburden

Crossing of the cut with existing tunnel represents a significant geotechnical hazard. Its tunnel lining is situated approx. 4 m below track level. According to the geotechnical survey of existing lining under crossing point (Pavlík, 1998) no cavities beyond the lining have been found. However, possibility of their occurrence is not excluded regarding to the frequency of cavities in other parts of the tunnel. Heterogeneity in the tunnel surroundings will complicate construction.

3. EXPANSIVE MIOCENE CLAYS

Expansive clays occurring at the bottom of this cut (depth of 12 m) represent the most significant geotechnical hazard. There was a short time to analyse behaviour of these expansive clays, to find out any relationships and to define and make trial tests of their treatment.

Expansive clays in that area are represented by marine Miocene highly plastic clays (CV, CE) that are stiff to very stiff (unconfined shear strength is 200-300 kPa.). In section of km 7.400-7.800 Miocene clays contain significant content of organic matter (4-7 %), maximally 12 %) (see Fig. 1). The deeper parts of borehole soils were classified as carbonaceous clays and claystones, sometimes as clayey coal.

Presence of organic matter influenced also the results of Proctor Standard tests. Values of dry density reached only ρ_{dmax} = 1220 kg.m^{-3} and optimum moisture w_{opt}=40 % (see Fig. 2). Value of dry density is lower than requirements of Czech Standards (1500 kg.m^{-3}) and these cannot be deposited in embankments without treatment.

The surface of Miocene sediments is modelled by several depressions representing probably old streambeds (see Fig. 3). In section of km 8.000-8.100 Miocene soils were removed due to fossil landslide that is apparent morphologically on the surface. At the end of the re-alignment (km 8.150-8.250) Miocene clays reduce their thickness. Cretaceous rocks (marls, mudstones and limestones) were found out in boreholes. The total thickness of Miocene clays in the middle part of the open cut is more than 80 m.

Values of effective angle of internal friction vary from 12.30-26.50°(median from 13 samples was 17.70°), effective cohesion was 0-49 kPa (median from 13 samples was 22 kPa). Clays are impermeable with coefficient of permeability k_f= n.10^{-11} m.s^{-1}.

4. SWELLING OF MIOCENE CLAYS

Linear swelling of Miocene clays achieves values up to 25 % (median from 45 samples was 5 %); the maximum value of swelling pressure was 276 kPa (median from 28 samples was 111 kPa.). Robust statistic analysis was used to identify any dependence of linear swelling and swelling pressures on the depth of sampling. The depth was taken as the distance of sample from the boundary between Quaternary and Miocene soils. Results are presented in Fig. 4 and Fig. 5 by box-and-whiskers diagrams.

In case of linear swelling no significant dependence on the distance of samples from the Quaternary – Miocene boundary was proven. Values

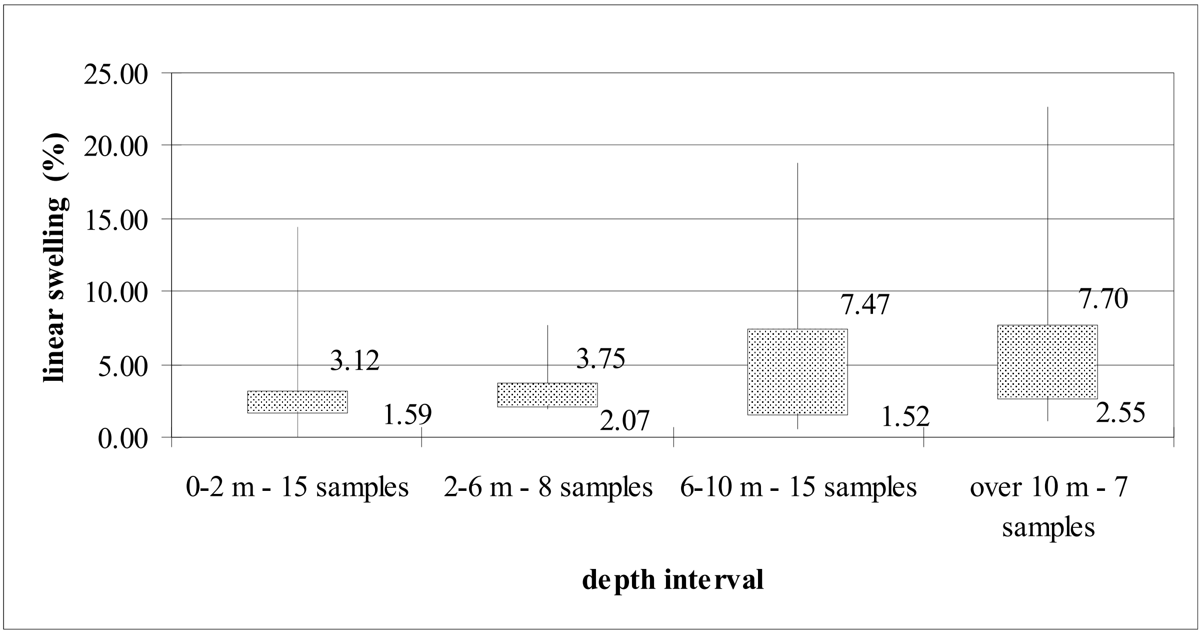

Fig. 5 Robust analysis – dependence of linear swelling on the depth of samples (distance from Quaternary – Miocene boundary)

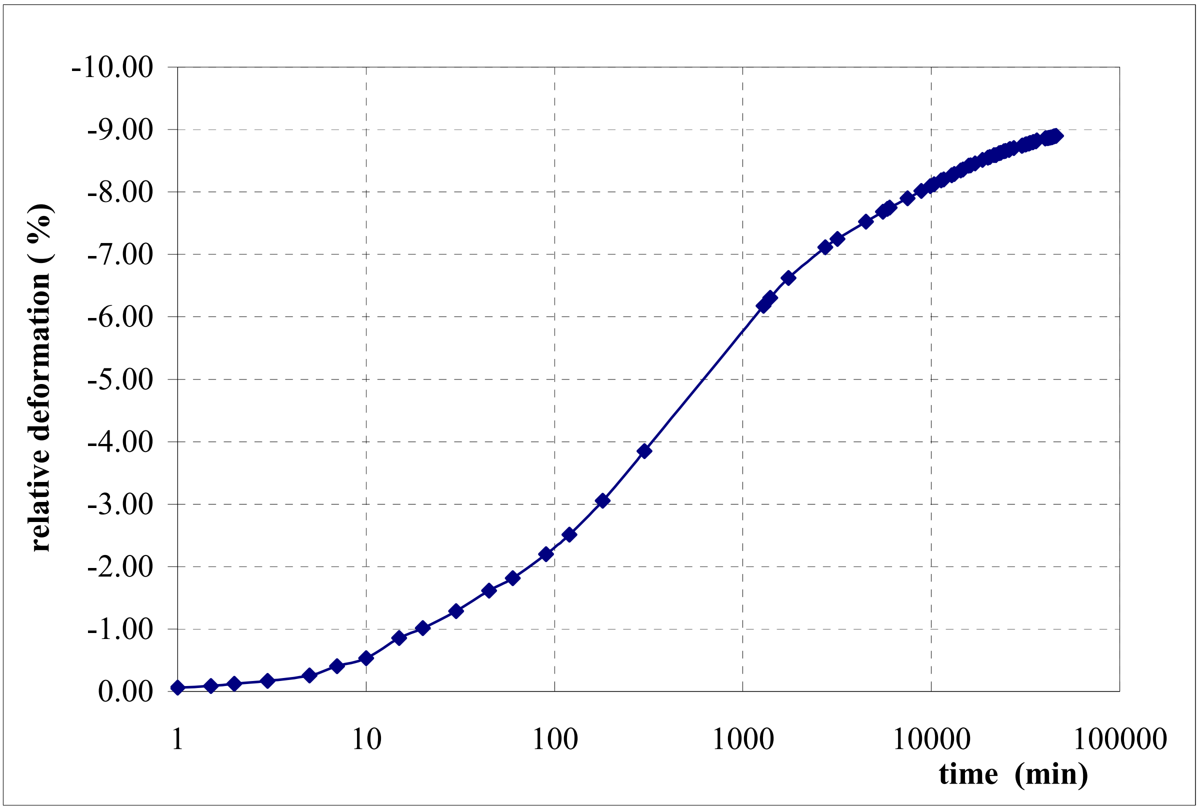

Fig. 6 Relative deformation of Miocene clays depending on time (J207, depth 11.7-11.9 m)

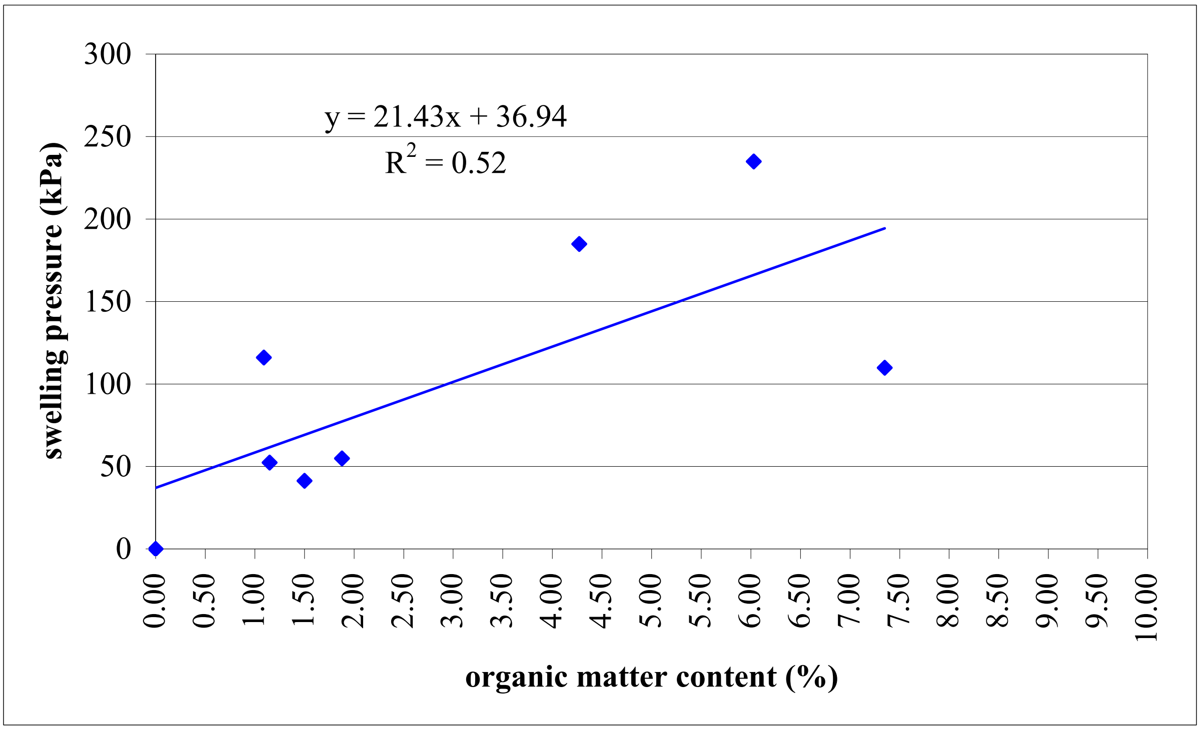

Fig. 7 Dependence of values of swelling pressure on the content of organic matter

of swelling pressure increase with distance from boundary of Quaternary sediments and Miocene clays. Correlation coefficient of linear regression is 0.57.

Swelling of clays is a long-term process as it is evident from laboratory tests of volume changes in time. Shape of all curves is similar and resembles de-consolidation curve, however stabilisation of de-formations is very slow (see Fig. 6).

It is mainly organic matter dispersed inside the clay matrix that causes swelling of them. The organic matter content is 4-7 %, maximally 12 %. Values of swelling pressure increase with increasing content of organic matter (see Fig. 7) although the correlation coefficient is only 0.52.

Influence of mineralogical composition of clays on their swelling has not been proven. Miocene clays are mainly composed of ilite–kaolinite association, occasionally with minor chlorite. Low content of non-stechiometric Fe-sulphide and carbonates is variable.

Values of swelling pressure from samples near design level of re-alignment were variable depending on organic matter content and they reached maximally 234.80 kPa (borehole J208, depth 10.70-10.90 m, km 7.750).

In FEM analysis the value of swelling pressure equal to 150 kPa was used (it corresponds to 85 % of samples taken in distance of 2 m from designed track level).

5. TREATMENT OF MIOCENE CLAYS

Due to time shortage we tested two binder and filler mixes with expansive clays only:

A – 10 % of gravel (fraction 0-4 mm), 5 % of lime and 7 % of cement

B – 8 % of lime and 7 % of cement

Results of volume changes tests are presented in Table 1. Through comparing linear swelling and swelling pressures of untreated and treated samples we obtained the best result for treatment by lime (5 %), cement (7 %) and sand-gravel fraction 0-4 mm (10 %). In case of treatment only by lime (8 %) and cement (7 %), linear swelling of clay was higher than that of the first mixture.

Figure 8 shows dependence of swelling pressure on time. It is evident that during first 24 hours of the test the values of swelling pressure of treated clays reached 60.74-95.44 % of final ones.

Comparison of mechanical parameters of treated and untreated materials was carried out for clays with 10 % of gravel, 7 % of cement and 5 % of lime.

CBR values of treated materials increase from 6-8 % to 25-30 %, which fulfil requirements of Czech Standards for materials deposited in embankments (CBR>10 %).

Similarly, treatment changed shear strength parameters (effective cohesion increase from 5 kPa to 40 kPa). In case of angle of internal friction a

Table 1 Untreated and treated Miocene clays – compared with results of linear swelling and swelling pressure

Borehole	Sample depth (m)	Treatment	Swelling (%)	Time necessary to stabilize deformations (hours)	Swelling pressure (kPa)	Time necessary to stabilize values of swelling pressure (hours)
J204A	6.70	gravel (10%) - cement (7%) - lime (5%)	1.325	92.50	181.09	123.10
J204A	6.70	cement (7%) – lime (8%)	2.410	47.50	117.08	97.40
J206A	11.70	without	6.451	189.00	54.56	22.33
J208A	10.60	without	6.433	189.00	288.91	22.33
J208A	10.80	gravel (10%) - cement (7%) - lime (5%)	0.918	0.00	220.04	89.17
J208A	12.50	without	6.919	189.00	100.48	22.33

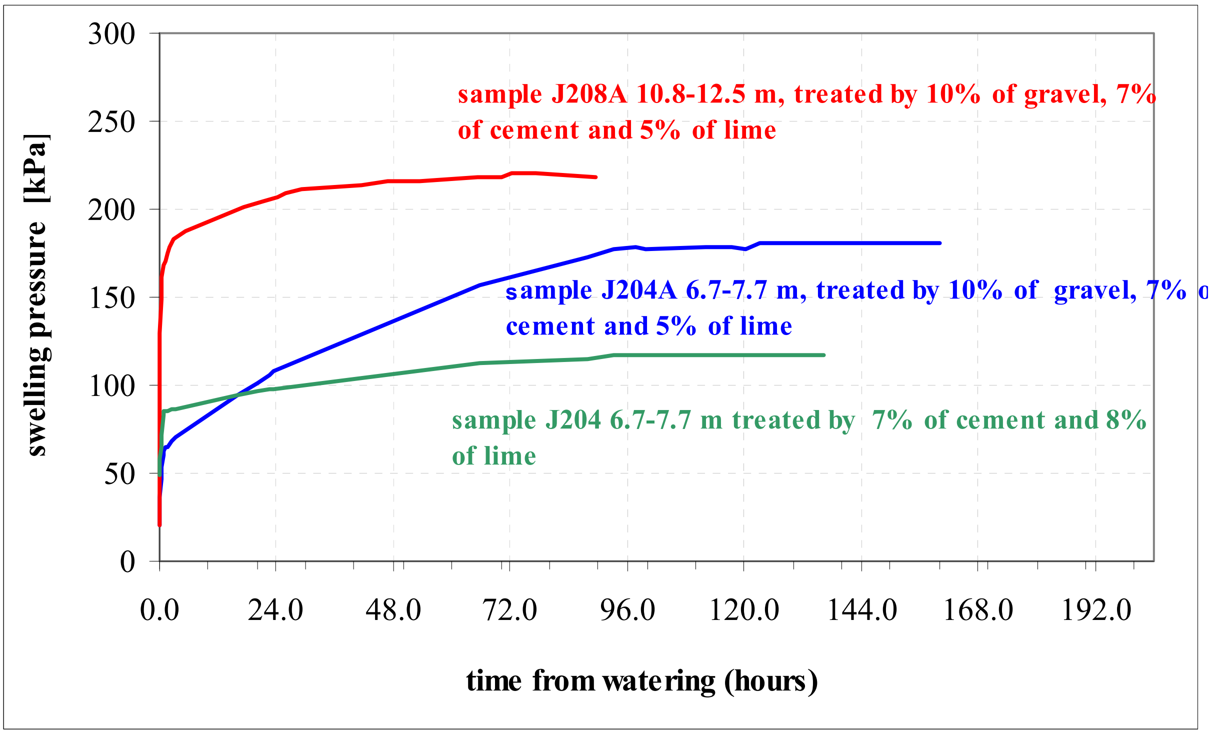

Fig. 8 Dependence of swelling pressure of treated samples of Miocene clays on time

significant increase was not observed. Values of angle of internal friction of untreated clays were ϕ_{ef} =11.1° and 16.4°, in case of treated material increased to 13.0° and 17.1°, respectively.

Following parameters of treated clays were recommended to be used as the input to numerical analysis: effective angle of internal friction ϕ_{ef} = 15° and effective cohesion c_{ef} = 30 kPa. These values should be changed, based only on sufficient number of tests.

Deformation modules of intact clays were measured between 9.25 MPa and 7.25 MPa. After treatment the deformation characteristics of remoulded clay with binder and filler decreased to 3 MPa. This fact is supposed to be a result of destruction of structural bonds in treated materials.

6. CONCLUSIONS

The results from our short-term study are summarized as follows:

1. Linear swelling of undisturbed Miocene clays achieves values up to 25 % (median is 5 %); the maximal value of swelling pressure was 276 kPa (median is 111 kPa.).
2. Mainly organic matter dispersed within clays causes the swelling. The organic matter content is 4-7 %, maximally 12 %. Influence of mineralogical composition of clays on their swelling characteristics has not been proven.
3. As far as swelling and swelling pressures of untreated and treated samples are concerned the best behaviour of the treated soil was obtained for treatment with lime (5 %), cement (7 %) and gravel fraction 0-4 mm (10 %). In case of treatment only with lime (8 %) and cement (7 %), linear swelling was higher than in treatment with the first mixture.
4. During first 24 hours of the test the swelling pressure of treated clays reached 60.74-95.44 % of final values. Approx. 50 % of volume changes are supposed to be displayed during one day after saturation of samples.
5. CBR values of treated materials increase from 6-8 % to 25-30 % which fulfil requirements of Czech Standards for materials deposited in embankments (CBR>10 %). Similarly, treatment changed shear strength parameters (effective cohesion increase from 5 kPa to 40 kPa).
6. Values of deformation modulus of treated clays are lower than in case of undisturbed soil, what is caused by destruction of structural bonds in soil during treatment.
7. Based on our study the treatment of expansive clays at the bottom of the deep cut and in track subgrade was proposed. However, many questions have remained unanswered (depth influenced by swelling, long-term influence of water on treated materials, discussion of low values of maximum dry density by Proctor Standard test).

Our proposals will be confronted with real conditions on the site in spring and summer 2005 when construction of this section is expected to start.

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Fig. 1 Miocene clays with organic matter (J204A borehole, depth of 7.0-8.0 m)

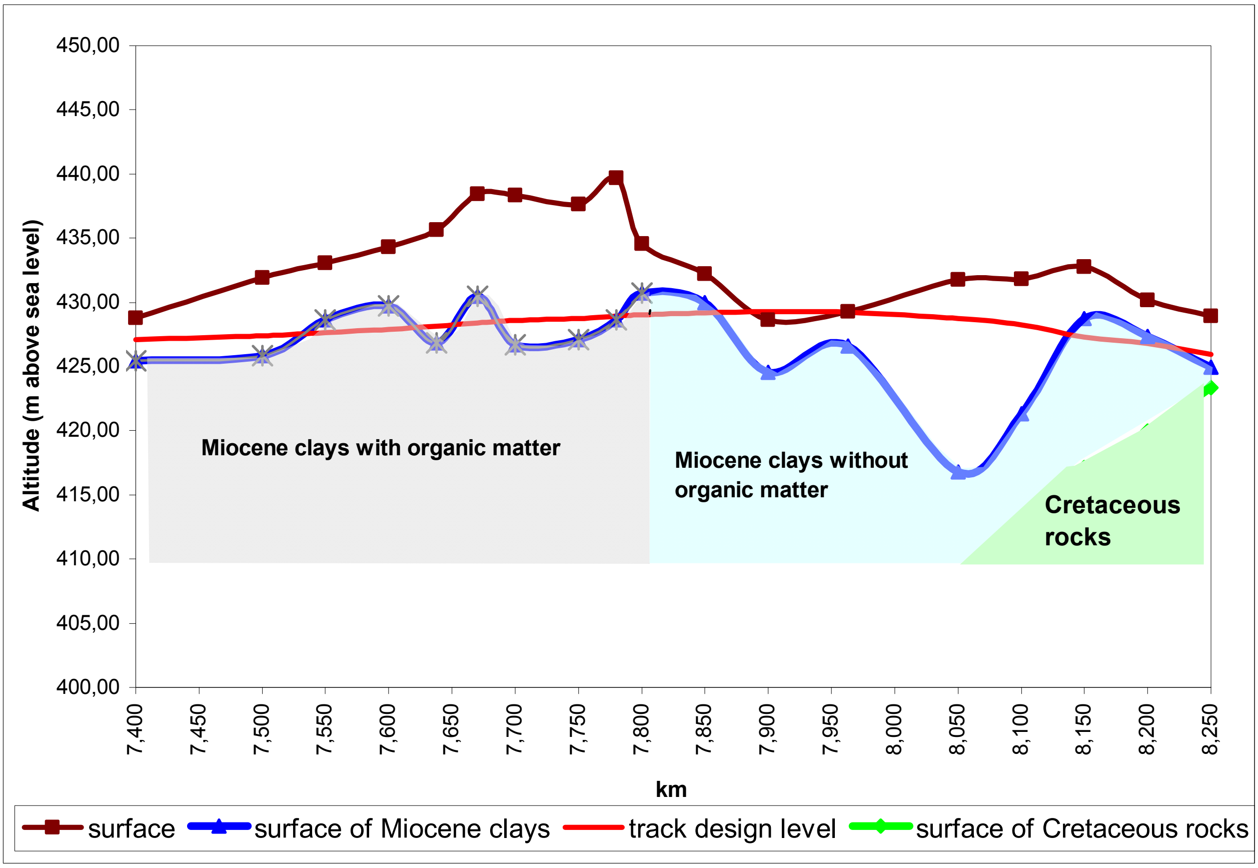

Fig. 3 Schematic longitudinal profile in the axis of designed open cut