Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-1925

FEM analysis of road embankment on consolidating subsoil influenced by mining deformation

Analyse MEF du remblai de chaussée construit sur un sol consolidé sous l'influence des déformations minierés

K. Sternik
Department of Geotechnics, Silesian University of Technology, Gliwice, Poland

ABSTRACT
During construction of motorway's embankment geodetic monitoring was performed to investigate subsidence of embankment's ground as well as mining deformations occurring in surrounding area. Back analysis of these measurements, making use of finite element method, allowed for determination of ground's parameters and evaluation of time of settlement termination. The time of ground's consolidation determines the starting moment of pavement's construction.

RÉSUMÉ
La controle géodésique du tassement de sol ainsi que l'influence des déformations minierés a été conduite pendant la construction du remblai de l'autoroute. En profitant des résultats de cette controle dans l'analyse en arrière (« back analysis ») avec la méthode des élements finis, on a déterminé les paramètres du remblai de sol et on a évalué le temps finissant du tassement. Le temps de la consolidation détermine le début de la constitution de revêtement.

1 INTRODUCTION

In the area of Upper Silesia there is a construction of A-4 motorway. The motorway lies through regions of active mining exploitation of several mines. Part of the motorway is built on an embankment of height reaching 16 m.

The moment when a road pavement may be performed is determined by termination of ground's settlement under embankment's weight. The process of settlement is time-dependent and results from changes of effective stresses and dissipation of excessive pore pressures both during embankment's construction and after that when the height (and therefore the weight) of an embankment is constant – consolidation phase. The process of consolidation is influenced by effects connected with ground softening caused by underground mining activities. So, besides well-known decrease of stiffness of soils during straining soil enforced softening additionally influences properties.

In these circumstances, predicting the starting moment of road pavement construction is extremely difficult task considering the need of accounting for variability of parameters determining strength, stiffness and permeability of soils used in embankment's structure and underlying its base. Besides, accumulation of different influences on ground subsidence at the same time produces difficulties with their separation.

The paper presents a method of prediction of consolidation time after which settlement of the surface of a ground under embankment's weight stabilizes. The method is based on the back analysis of geodetic measurements results. The monitoring considered the height of the embankment under construction as well as the subsidence of the ground surface under embankment and in its neighbourhood influenced only by mining deformations. Such prediction was performed by modelling "embankment – ground" system with finite element method.

Modifying values of some arbitrary chosen parameters of the ground and obtaining good agreement of the computed ground settlement with measurement results during embankment rising and during consolidation phase at its constant height allowed for evaluation of the consolidation time. The details of the assumed computational procedure are presented below.

2 SHORT DESCRIPTION OF THE EMBANKMENT

The motorway design assumes performance of two roadways, each with tree lanes. Each roadway will be 11.25 m in width. The roadways will be separated with a strip of land of 5.0 m in width. Emergency lanes, ground shoulders, technological lanes or plant lanes will be located outside of the roadways according to localization. The width of embankment crown will vary but not less than 32 m.

The grade of embankment slopes for the time of initial settlement designed as 1:1.47 and ultimately 1:1.5. Motorway embankment is constructed from weathered sandstone mixed with clayey sand.

3 CHARACTERISTICS OF EMBANKMENT'S SUBSOIL

In the considered section motorway's subsoil consists mainly of clays layered with fine-grained sands. The thickness of deformable subsoil is 20 – 25 m. Rock layer has been found underneath clay. Ground water has been found in layers of sand. Its table stabilized on the level 1.0 to .1.5 m below the ground surface.

4 MONITORING OF EMBANKMENT SUBSIDENCE

Motorway embankment under construction was geodetically monitored. Embankment height and ground surface subsidence caused by embankment weight were periodically measured. Subsidence of the ground surface beyond the influence of embankment weight following from underground mining activities was also measured at the same time. The whole monitoring was performed under supervision of academic staff from Silesian Technical University in Gliwice.

Mining subsidence of the ground surface was measured at points located along the motorway on both its sides at a distance of 50 m to 80 m from its centre line. Investigation of embankment subsidence was performed with taking advantage of specially designed bench marks located in the central section of the embankment (Bzówka & Gryczmański, 2004).

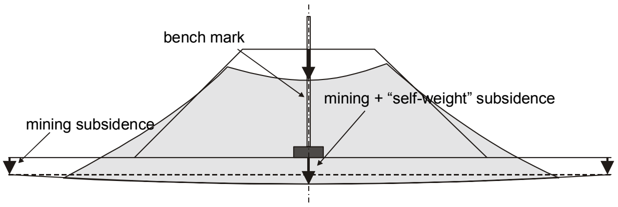

Fig. 1.Deformed embankment and interpretation of subsidence

The bench mark consists of a square reinforced concrete slab of 0.7 m in length and 180 kg in mass and a steel rod fixed in it vertically. The slab lies on the ground in the embankment centre line. The rod consists of 1.0 m sections. As the embankment height increased new sections were joined to a bench mark, so the top of the rod always stayed above the embankment crown.

Knowing the length of the rod the embankment height was precisely measured as well as the subsidence of the ground surface under the embankment. This subsidence is a result of embankment mass acting on the ground, ground softening induced by mining activity and mining subsidence itself. These influences should be separated to perform precise predictions.

Separation of the first two influences is difficult and requires measurements of porosity changes and application of appropriate soil model which takes into account strain hardening/softening following from changes of porosity to interpret influence of these changes (Gryczmański, 1998). To simplify further analysis, it has been assumed that reasons of subsidence under embankment weight will not be considered. Mining subsidence is only separated from the rest of settlement according to the scheme given below.

The subsidence of the ground caused by mining exploitation was measured usually at least at four points near a bench mark beyond the embankment base. Mining subsidence under embankment's centre may be linearly interpolated from these points. Thus, the subsidence caused by embankment weight is the difference between the settlement of a concrete slab and interpolated mining subsidence (Fig. 1).

5 RESULTS OF MONITORING

Prediction of time needed for stabilization of ground subsidence will be presented for embankment of 8.12 m in height. Construction of the embankment was started in March 2003. Observations of embankment rising together with subsoil subsidence were made between May 2003 and may 2004.

The results of monitoring (after interpolation to the centre of the embankment's base) are given in Table 1 and depicted in Fig. 2. It should be noted that due to the lack of data between March and May 2003 the state of earthworks in May has been assumed as the starting stage for further analyses. At that time embankment's height was 1.4 m, whereas mining deformations in the area did not occur. For these reasons subsidence of zero value has been assumed in May 2003 and increments of displacements from this stage on have been considered in numerical analyses.

Table 1. Monitoring results

Month	Height (m)	Mining subsidence (cm)	Mining and "self-weight" subsidence (cm)	Separated "self-weight" subsidence (cm)
May 2003	1.4	0.0	0.0	0.0
Aug 2003	6.22	0.97	4.10	3.13
Nov 2003	7.95	2.57	16.10	13.53
Feb 2004	7.96	5.71	19.80	14.09
May 2004	8.10	7.11	22.40	15.29

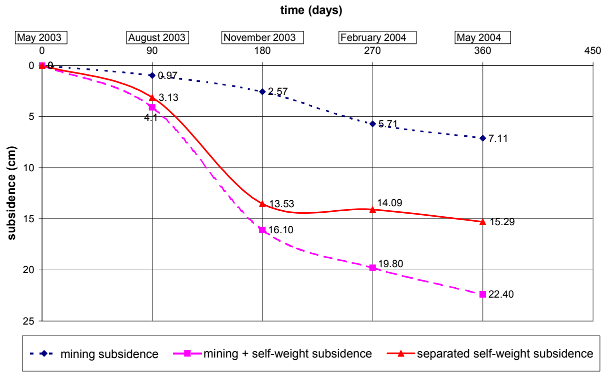

Fig. 2. Monitoring results

6 NUMERICAL ANALYSIS

6.1 *Assumptions*

For prediction of settlement stabilization time FEM model has been created depicted in Fig. 3.

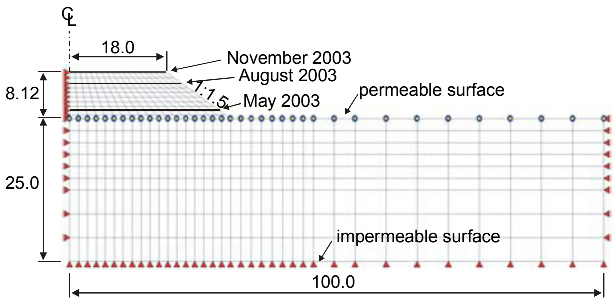

Fig. 3. FEM model used in predictions

The embankment's crown is 36 m in width and slope grade is 1:1.5. Due to the symmetry of the system considered in plane strain only a half of an embankment has been modelled. In this case a rocky base is at depth of 25 m.

The model is built of two material zones: representing embankment and subsoil. These materials are homogeneous and isotropic described by parameters of average global values.

Considering process of consolidation (Lewis & Schrefler, 1998) bottom surface (rock surface) has been assumed as impermeable. Drained conditions have been assumed on the ground surface applying appropriate water boundary conditions. In consolidation analysis the subsoil was fully saturated.

At the beginning of analyses in situ stresses in the ground were generated. At this stage FEM model consisted of only elements representing the subsoil.

Rising of the embankment was simulated by adding succeeding layers of finite elements representing embankment and applying gravity load. In consolidation analyses adding a new layer took five days. After the embankment had reached heights corresponding to the ones measured in reality (depicted in Fig. 3 by bold lines) consolidation periods took place. The subsoil was settling under constant load. The detailed schedule of embankment rising process is given in Table 2.

Behaviour of both materials during loading has been described by elastic – perfectly plastic model with Drucker-Prager yield criterion and the non-associated flow rule with dilatancy angle equal to 0 (Potts & Zdravković, 1999). Young modulus E and permeability coefficient k have been assumed as the leading parameters, responsible for the state of deformations and duration of subsidence of the subsoil. Values of the parameters were determined by back analysis of measured settlements of the ground surface during embankment construction and consolidation phase after its finishing.

Table 2. Schedule of embankment construction

Stage No		Time increment (days)	Total time (days)
0	In situ stress generation	0	0
I	1st layer rising	5	5
II	2nd layer rising	5	10
	Consolidation	50	60
III	3rd layer rising	5	65
IV	4th layer rising	5	70
	Consolidation	20	90
V	5th layer rising	5	95
VI	6th layer rising	5	100
	Consolidation	20	120
VII	7th layer rising	5	125
VIII	8th layer rising	5	130
	Consolidation	20	150
IX	9th layer rising	5	155
	Consolidation	40	190
X	10th layer rising	5	195
	Consolidation	405	600

Table 3. Material properties

	γ (kN/m^3)	c (kPa)	ϕ (°)	ν (-)	e (-)
Ground	20	14	14	0.3	1.0
Embankment	20	10	30	0.3	-

Values of the remaining parameters necessary for analysis have been assumed as typical for soils in the ground of considered region and utilized for embankment construction. These parameters are: γ - unit weight, c – cohesion, ϕ - friction angle, ν - Poisson's ratio, e – voids ratio. Values of the parameters applied in FEM analyses are given in Table. 3. Young modulus for the embankment is E = 60 MPa.

6.2 *Back analysis*

Back analysis of measurement results was performed in three steps In the first and second step the variable value of modulus E was initially determined for the subsoil based on subsidence measured between May and November 2003, i.e. during construction of the embankment (Table 1). In the third step, based on the consolidation analysis carried out for the whole period May 2003 – May 2004, the value of the modulus E was ultimately adjusted and the value of subsoil permeability coefficient k was determined.

Estimation of the parameter values was performed in a process of trials and errors. The estimated values were introduced to the FEM model. The value of modified determination coefficient was taken as the agreement criterion between calculated and measured subsidence in time:

$$R^2 = 1 - \frac{\sum_{i=1}^{n}\left(s_i - \hat{s}_i\right)^2}{\sum_{i=1}^{n} s_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} s_i\right)^2} \qquad (1)$$

where n is a number of measurements, s_i is calculated subsidence, $\hat{s}_i$ is measured subsidence.

The best estimation corresponds to the least deviation of R^2 from 1.

Regarding complexity of soil behaviour subjected to loading mentioned in the introduction the value of modulus E for the ground varies during embankment construction. This variability has been accounted for in the analysis in a simplified way. Namely, it has been assumed that value of the modulus varies in a stepwise manner between periods May - August 2003 and August 2003 – May 2004.

Initial estimation of the modulus value was carried out in FEM analysis with the assumption of free drainage condition (consolidation option switched off in the program). Deformation of the ground subjected to the weight of eight layers of finite elements representing embankment was considered in the first step. This load corresponds to the embankment's height found in August 2003. The initial value of E follows from matching FEM predictions to subsidence values measured between May and August 2003.

Second step consisted in restarting FEM analysis but with decreased value of E for the ground. FEM computations started from deformation, stress and strain fields determined in the previous step. Such procedure may be carried out in FEM program Z_Soil (Z_Soil Manual). Two remaining upper layers of finite elements were added to the embankment at this stage of computations.

In the third step a consolidation analysis was performed for the whole period from May 2003 to May 2004. The values of E, estimated in the previous stages, were introduced in appropriate phases of the computations. This time, the permeability coefficient k for the ground was evaluated. A small correction to the value of E for the latter phase also had to be made.

The whole procedure ended when satisfactory agreement between calculated and measured subsidence values expressed by $R^2 \approx 1$ was achieved.

6.3 *Results of analyses*

As a result of numerical analyses the following values of modulus E for the ground have been obtained:
for the period between May and August 2003 E = 67 MPa
for the period after August 2003 E = 9 MPa.
Permeability coefficient for the ground $k = 2.31 \cdot 10^{-8}$ m/s.

For the above values of parameters the value of modified determination coefficient is $R^2 = 0.9977$.

Agreement between calculated and measured subsidence of the ground surface subjected to embankment's weight during construction and afterwards is presented in Fig. 4.

Determination of subsoil properties allowed for evaluation of its consolidation time. Fig. 5 presents development of ground subsidence in time.

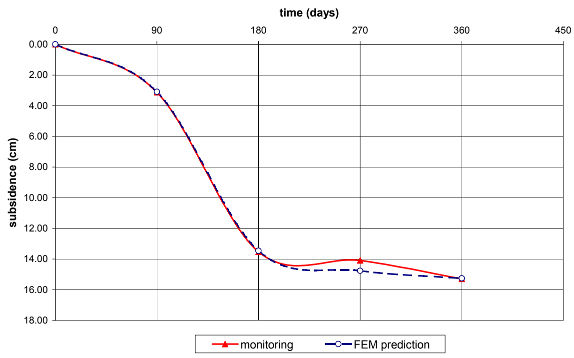

Fig. 4. Results of measurements and numerical predictions

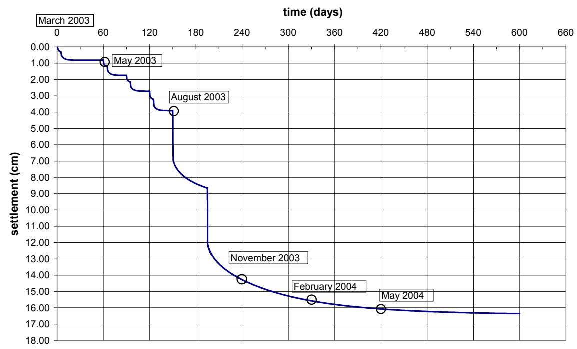

Fig. 5. Numerical predictions of ground's subsidence

Circles in Fig. 5 mark moments in time corresponding to geodetic survey. It may be concluded from the chart that increment of subsidence will not exceed 3 mm in the next six months after May 2004. Thus, the deformation of the ground caused by loading with embankment weight may be assumed as practically stabilized in May 2004. This conclusion allowed to begin performance of a road pavement in June 2004.

7 CONCLUSIONS

Predicting soil behaviour in complex loading conditions is difficult and requires application of sophisticated constitutive models incorporated into numerical procedures. Parameters of such models may not be easily identified. In addition, it may be difficult to separate factors influencing soil response to loading.

The method presented in the paper is quite simple and treats soils in a ground in a global manner. Prediction of consolidation time has been made taking advantage of a simple elasto – plastic model which is commonly available in FEM codes. Parameters responsible for developing of consolidation process (Young's modulus and permeability coefficient) have been chosen arbitrary.

In spite of assumed simplifications, predictions based on the back analysis of data collected during survey may be successful. Presented procedure is mainly of practical importance.

REFERENCES

Gryczmański, M., 1998. Influence of mining exploitation on embankments and their protection (in Polish). *Scientific Works of GIG. Conferences*. Katowice, 25: 27-38.

Gryczmański, M., Bzówka, J., 2004. Monitoring of motorway embankment settlement in mining area – methodology and interpretation (in Polish). *Proc. 2nd Problem Conf. Geotech. "Soil – structure interaction"*, Białystok – Białowieża, Vol. 1, 33-42.

Lewis, R.W., Schrefler, B.A., 1998. *A finite element method in the deformation and consolidation of porous media.* 2nd ed. New York: John Wiley & Sons Ltd.

Potts, D.M., Zdravković, L., 1999. *Finite element analysis in geotechnical engineering*. Vol. 1, Vol. 2, London: Thomas Telford Ltd.

Z-Soil Manual v. 4.2, 1998. *Soil and rock mechanics on microcomputers using plasticity theory.* Zace Services Ltd, Switzerland.