Surcharging as a method of road embankment construction on organic soils

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Abstract: Road embankments in urban areas are very often located in difficult and problematic soil conditions. The problematic soils consist of soft plasticity clays and organic or calcareous soils. These soils can be characterized as highly deformable with a low initial shear strength and an insufficient bearing capacity. Under the load of the road embankment the problematic soils show a large deformation both vertically and horizontally. The settlements often appear quickly but may also continue for a long time due to creep. The low shear strength often causes stability problems and consequently the load has to be placed in stages, or alternatively, the soil must be improved through a prior treatment. The choice of a construction method has to be based on the soil type, its initial properties and the height of the embankment. In this paper a method of surcharging in the embankment construction on soft soils is presented. Using this method it is possible to eliminate the primary consolidation settlement and to compensate the secondary compression. The application of the precompression technique will be presented on the basis of tests embankments constructed on organic subsoil. The calculations of the settlement will be made using the nonlinear stress-strain characteristics obtained from the laboratory tests. The results of field investigations show that most horizontal movements in subsoil under embankment appear during loading. Therefore, the calculation of settlement course may be done by a one-dimensional consolidation theory using a nonlinear constitute soil model.

Résumé: Dans cet article on a parlé la notion des faibles sols, precisement des sols organiques dont la caractéristique est de faibles résistance au cisaillemnt et de grande compressibilité. A cause de sa caractéristique physique et sa structure ces sols montrent de grand tassements pandent la longue terme. La plupart de ramblais sont construits sous la route et egalement la meme chose pour les autres constructions, par example dans l'hydrotechnique que pendant l'exploitation ne peut pas deformée. Donc il est nécessaire d'appliquer les téchniques de constructions de remblai ce qui permet d'obtenir relativement court le tassement des sols et d'une maniére sûr et sans panne pandent le travail technique. Entre les differntes methodes de constructions de remblai sur le faibles sols il devrait etre d'utuliser le technique de construction par etape.

Keywords: Embankments, settlement, loading, consolidation, organic materials.

INTRODUCTION

Construction of embankments on a soft organic subsoil needs a proper prediction and assessment of settlements influenced by loading. Under a load caused by a road embankment, problematic soils, such as organic soils, show large deformations. The settlements usually appear rather quickly but may also continue for a long time due to secondary compression.

Secondary compression often consists of creep processes which can cause the subsoil to reinforce but may also lead to a failure of the subsoil and the loading structure. Consequently, the load sometimes has to be placed in stages or, alternatively, the soil must be improved through prior treatment (Wolski *et al*. 1988). The choice of the construction method has to be connected with the type of soil, its initial properties and the height of the embankment.

It is necessary to use a technique of build embankments which allows them to reach a safe amount of settlement in a short time. In this case, surcharging is proposed as a method of road embankment construction.

SURCHARGING - ONE OF THE ROAD EMBANKMENT CONSTRUCTION METHODS FOR ORGANIC SOILS

Construction of structures such as buildings, tanks, walls, and embankments on soft organic soils raises several concerns that relate to a bearing capacity failure and excessive or differential settlement. Preloading, staged construction, surcharging, soil improvement and replacement are some of the techniques commonly used to address these concerns. When settlements after the end of the embankment construction have to be minimised, surcharging is used (Sas at al. 2005). This is a temporary preloading with a load in excess of the permanent fill.

The staged loading method is the one which gives safe construction movements during the exploration time. Additionally, the surcharging assures the stability of the road embankment and subsoil and also gives target and equal settlements in a shorter time (Figure 1). The staged construction occurs with background consolidation and rise of the strength parameters. It gives the possibility of predicting the layer height and deformations. As a result, the surcharging method gives the possibility of building high road embankments without having to use, for example,

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reinforced constructions such as vertical drains. Because of the fact that the secondary compression is spread in time and can also appear in the period of embankment exploitation, the surcharging is especially recommended to balance the settlements.

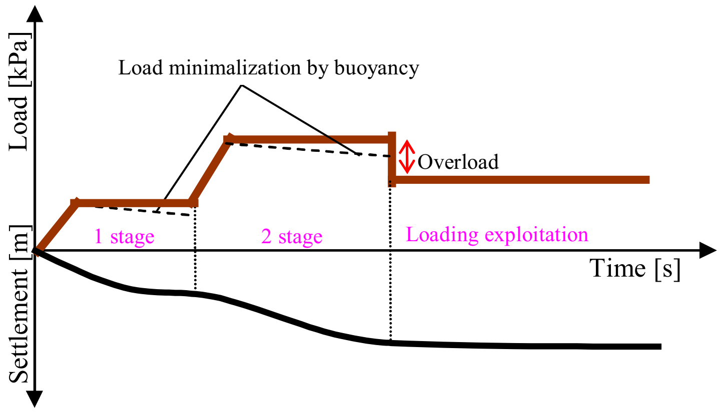

Figure1. Scheme of staged construction

To estimate preface of surcharging Ladd's scheme can be used (Figure 2).

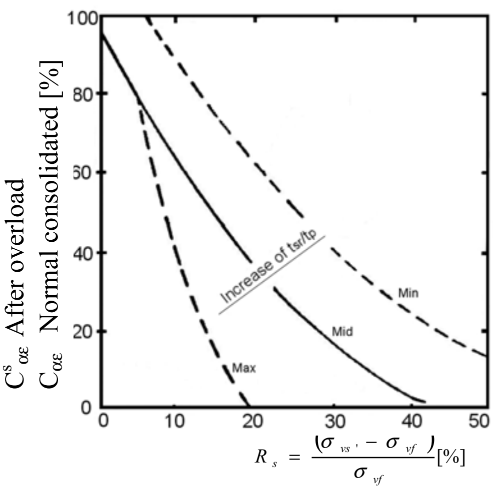

Figure 2. Reduction of secondary compression by surcharging (Ladd 1976)

For the first phase of secondary settlement the amount of surcharging can be predicted by using "max" line of reduction. The time needed to be used to remove the load t_{sr} should be similar to the time needed to finish the consolidation t_p. It means that:

$$\frac{t_{sr}}{t_p} \geq 1 \tag{1}$$

where t_{sr} is the time in seconds needed to remove the load, t_p is the time in seconds to end the consolidation.

The preliminary assumption of surcharge value can be based on the secondary behaviour of soft clays described by Larsson (1985, 1986). It was said that the secondary settlement appears when the effective, *in situ* stress is over 0.8 times the preconsolidation stress. Therefore, the surcharging should be caused by stress equal to:

$$\sigma'_{vs} = \frac{\sigma'_{vf}}{0,8} \tag{2}$$

where σ_{vs}' is the stress in kPa caused by surcharging, σ_{vf}' is the effective stress in kPa of last loading. For the most detailed analysis of surcharging the Johnson (1970) method can be used (Figure 3).

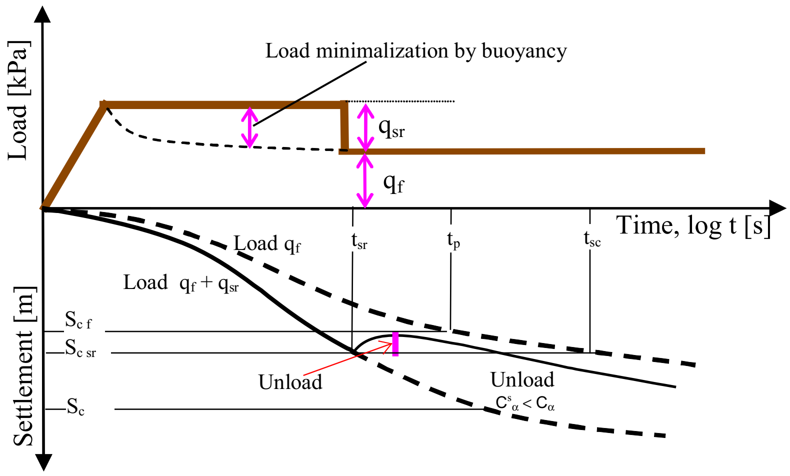

Figure 3. Compensation of the secondary settlement by temporary surcharging

Consolidation degree needed to obtain primary consolidation and requested secondary compression can be represented as:

$$U_{(f+sr)} = U_p \cdot \left(1 + \frac{C}{e} \cdot \log \frac{t_{sr}}{t_p}\right) \qquad (3)$$

where U_p is a consolidation degree under surcharging needed to obtain settlements equal to the primary consolidation, C_α is the coefficient of a secondary compression, ε is the strain in the middle of the soft soil level, caused by primary consolidation under constant loading, t_{sr} is the exploitation time in sec., t_p is the time in seconds for primary consolidation under constant loading.

The amount of surcharging can be defined considering the fact that settlements S_{csr} at the moment of unloading t_{sr} are equal to:

$$S_{csr} = U_{(f+sr)} \cdot S_{c(f+sr)} \qquad (4)$$

where S_{csr} is the total consolidation settlement under the constant loading.

In the case of roads embankments usually two or three stages are used.

DESCRIPTION OF THE TEST AREA

In order to improve the surcharging technique using staged construction an embankment trial was performed. The tested area – Antoniny site is located in north-western Poland in the Notec River valley. The soft subsoil consists mainly of peat (3.1 m depth) and calcareous soil (4.7 m depth) with a very high content of calcium carbonate. The organic soils located at the test area in Antoniny are characterized by properties presented in table 1.

Table 1. Physical properties of organic of organic soils at Antoniny site

Parameter	Symbol	Unit	Peat	Calcareous soil
Water content	w	%	310-315	105-114
Plastic limit	w_p	%	185-200	50-58
Liquid limit	w_L	%	315-320	104-112
Density of solid particles	ρ_s	kN/m^3	>15.8	>25.5
Bulk density	ρ	kN/m^3	10.8-12.2	14.1-14.3
Dry density	ρ_d	kN/m^3	2.6-3.0	6.7-6.9
Organic matter content	I_{om}	%	74-88	32-38
Degree of humification	R	%	50-70	-

The embankment was built in three stages with the last stage for surcharging according to the presented schedule (Figure 4).

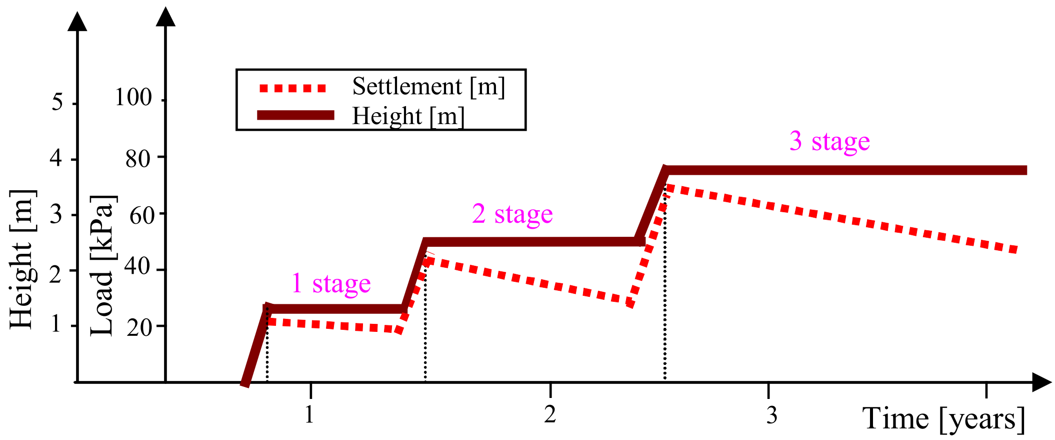

Figure 4. Schedule of stage construction on Antoniny test area

The subsoil behaviour was monitored by means of piezometers, various types of settlement gauges, and inclinometers that allowed measurement of vertical and horizontal displacements and the pore pressure (Szymanski *et al*. 2005). Observations of vertical displacements in the subsoil were performed by means of settlement gauges of 4 types: hose, plate, screw and magnetic (Figure 5).

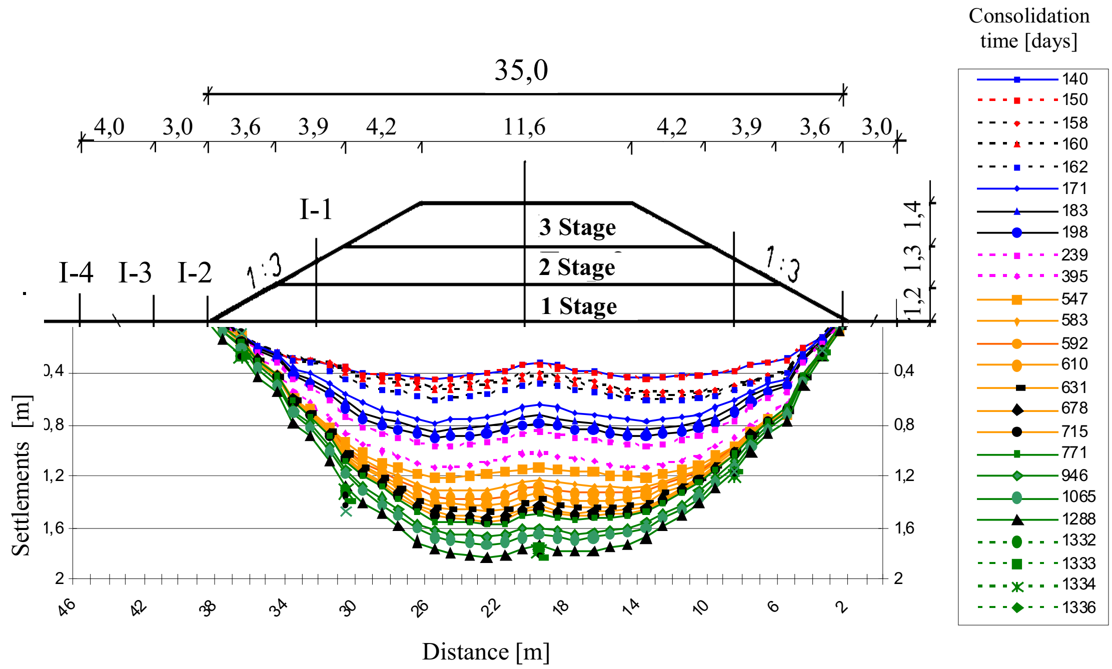

Figure 5. Vertical settlements in the organic subsoil at Antoniny site

The horizontal displacements in organic subsoil have been calculated from inclinometer readings (Figure 6).

To determine parameters for settlement calculations, some laboratory tests were performed on peat and calcareous soil samples taken from the organic subsoil. These laboratory investigations consisted of routine test, oedometer and triaxial tests as well as creep tests. Triaxial tests were performed to evaluate the deformation and strength characteristics for overconsolidated and normally consolidated stress states, which are required for estimating the displacement of organic subsoils. To determine the deformation parameters for undrained and fully drained conditions, triaxial tests were carried out. The example results obtained in laboratory tests for undrained conditions are presented in Figure 6 and for fully drained conditions are shown in Figure 7.

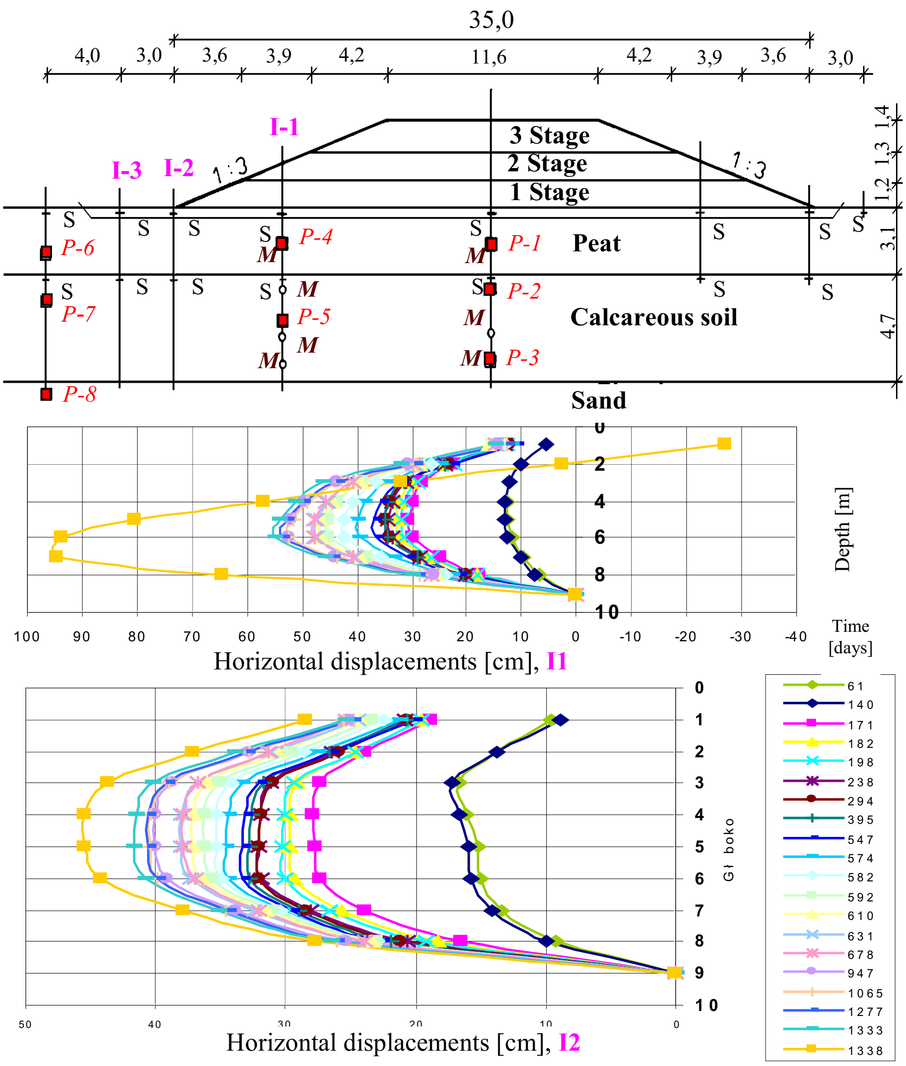

Figure 6. Horizontal displacements at Antoniny site

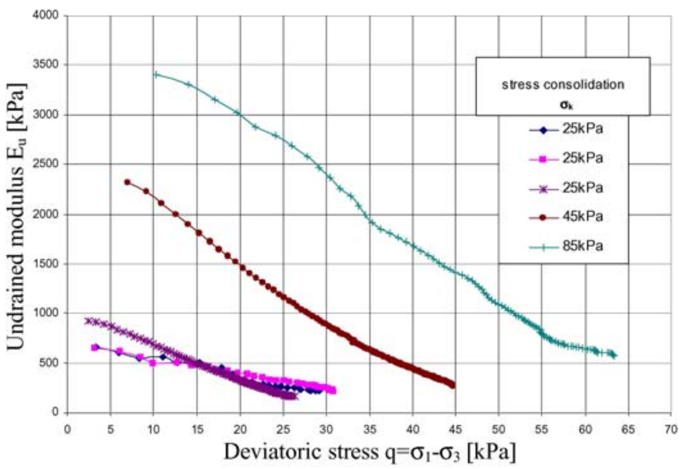

Figure 7. Variability of undrained modulus Eu obtained in triaxial tests CU for calcareous soil

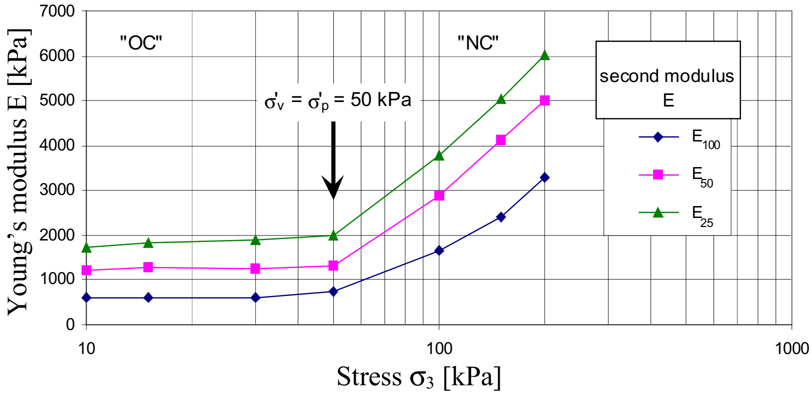

Figure 8. Relationship between Young's modulus E and effective stress component σ'_3 obtained in triaxial tests CD for peat

The results of the oedometer tests indicated that organic soils are overconsolidated with preconsolidation pressure σ'_p around 15 kPa for peat and around 22 kPa for calcareous soil (Lechowicz *et al.* 1987, Lechowicz 1992, Szymanski 1991).

During the first stage of the stage construction the effective vertical stress still remained below the initial preconsolidation pressure but in the second and third stages the effective vertical stresses were higher than the initial preconsolidation pressure (Figure 9).

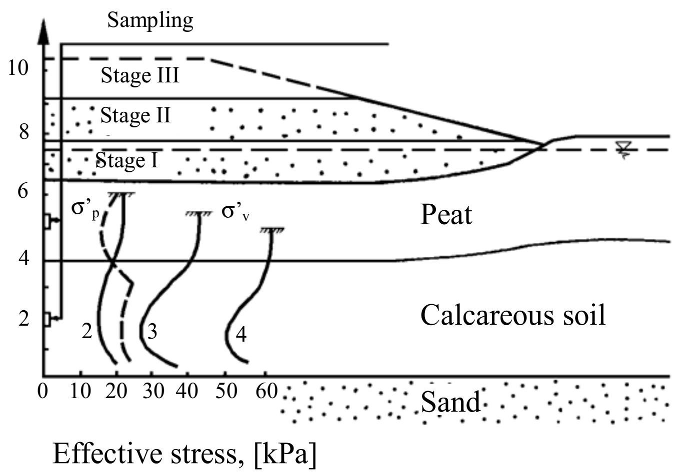

Figure 9. Sampling location with effective stress conditions during a stage construction

The results obtained from the laboratory tests have been used to elaborate the strain – stress and time relationships used for settlement calculation.

CALCULATION OF THE SETTLEMENTS

In general, the consolidation processes consist of two stages (Candler & Chartress 1988):

- Primary settlement (immediate and consolidation)
- Secondary and tertiary settlement (creep)

The primary settlements (immediate and consolidation phase) have been calculated using the relationship between the modulus E_u for undrained conditions versus the deviatoric stress q and consolidation stress σ_c obtained from the laboratory tests in the following form:

$$Eu = \beta_0 \cdot q^{\beta_1} \cdot \sigma_c^{\beta_2} \quad (5)$$

where E_u is the undrained modulus in kPa, β_0, β_1, β_2 are the empirical coefficients, q is the deviatoric stress in kPa, σ_c is the consolidation stress in kPa.

The analysis of the test results gives the following values of empirical coefficients to Eq. 5 for peat: β_0=17.5, β_1=–0.86, β_2=1.70 and for calcareous soil β_0=3.51, β_1=–0.78, β_2=2.11.

The relationship between the Young's modulus E for fully drained conditions versus effective stress components σ'_1 and σ'_3, for peat are given by:

$$E = \alpha_0 \bullet \sigma_1^{\alpha_1} \bullet \sigma_3^{\alpha_2} \qquad (6)$$

where E is Young's modulus for fully drained conditions in kPa, σ'_1 is the majority effective stress in kPa, σ'_3 is the minority effective stress in kPa and where α_0, α_1, α_2 are the empirical coefficients.

For organic soils from the Antoniny site the following values of empirical coefficients to Eq. 6 for peat are obtained α_0=2770, α_1=-1.95, α_2=2.16 and for calcareous soil α_0 =947, α_1 =-1.12, α_2 =1.53.

The secondary and tertiary settlement is the result of a creep of the material under the effective stress. It depends on the rheological properties of a soft soil and it is significantly time dependent in a long period (Fürstenberg *et al.* 1983). For the calculations of the secondary compression (creep settlements) the equation causing strain, mean stress and time the following relation has been used:

$$\varepsilon_s = \eta_0 \bullet p^{\eta_1} \bullet t^{\eta_2} \qquad (7)$$

where ε_s is the strain value in kPa, η_0, η_1, η_2 are the empirical coefficients, p is the mean stress in kPa, t is the time in seconds.

The obtained values of empirical coefficients to Eq. 7 for consolidated calcareous soil under σ_c=35 kPa are η_0=0.024, η_1=1.292, and η_2=0.069.

The calculations of surcharging were made using the nonlinear stress-strain characteristics obtained from laboratory tests.

PREDICTION OF SURCHARGING VALUE – VALIDATION

The derived equations (6-7) allowed calculation of the final settlements of the organic subsoil under the trial embankment. The values of the settlement of the organic subsoil obtained from the calculations are presented in Table 2. On the basis of *in situ* tests, the observed values of settlement of peat and calcareous subsoils are also presented in this table for comparison. The agreement between calculated and observed values of background settlements in the Antoniny site showed that the characteristics which describe the consolidation strains had been properly used. Therefore, to calculate the amount of surcharging which accelerates the settlements the calculated values based on the derived equations were used as they were considered to be representative.

Table 2. Calculated and observed values of background settlements

Stage	Calculated values (m)		Observed values (m)	
	Peat	Calcareous soil	Peat	Calcareous soil
I	0.29	0.29	0.27	0.24
II	0.66	0.62	0.72	0.60
III	1.04	1.10	1.06	1.03

On the bases of the calculated values of the settlement the relationships for peat and calcareous soil were obtained (Figure 10).

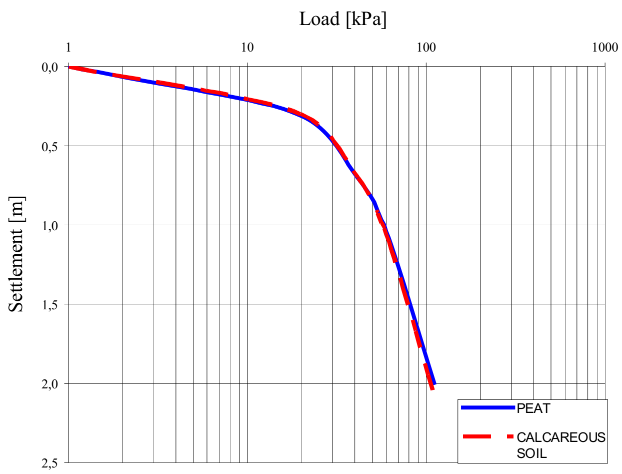

Figure 10. The calculated relationship between settlement and loading used for surcharging calculation

Using the statistical method the correlation between settlement and loading with the coefficient of determination about 95% are presented in following form:

$$S = \lambda_0 \bullet q^{\lambda_1}$$

where S is the settlement values in meters, λ are the empirical coefficients, q is the loading values in kPa.

For organic soils from the Antoniny site the following values of empirical coefficients to Eq. 8 for peat are obtained λ_0=0.0135, λ_1=1.061 and for calcareous soil λ_0 =0.0120, λ_1 =1.094.

On the bases of these equations (8 and 9), the height of the surcharging will achieve the expected settlement in shorter time and the reduced secondary deformations were also calculated. The results are presented in Table 3.

Table 3. Surcharging calculation

Stage	The embankment height in stages (m)	Total embankment height (m)	Bulk density	Load (kPa)	Settlement (m)	
					Peat	Calcareous soil
I	1.2	1.2	15.0	18	0.29	0.29
II	1.3	2.5	15.5	39	0.66	0.62
III	1.4	3.9	15.4	60	1.04	1.10
				S_1	**1.99**	**2.01**
Surcharging	3.3	7.2	15.5	111.6	1.99	2.07
				S_2	**2.01**	**2.07**

The primary and secondary deformations which influences the total settlements.

$$S_1 = S_n + S_c + S_s \quad (10)$$

Therefore, to define the surcharging value the following relationship must be satisfied:

$$S_1 < S_2 \quad (11)$$

where S_2 is the settlement value of the surcharging.

Inequality (11) has been obtained both for peat and calcareous soils even for the overloading equal to 108.5 kPa. The value of surcharging is 111.6kPa, which gives the height 3.3m of an embankment built from sand with a bulk density of 15.5 kN/m^3.

As a result, these equations (8 and 9) can be used for the prediction of the value of surcharging for road embankments on organic subsoils. The height of 7.2 m is still a safe value of loading for the stability of the embankment and the subsoil. The tests done in the field showed that instability of the structure appeared at the final height of 7.95 m. The stability analyses also proved that up to this height of the embankment factor the safety is sufficient and construction in stages can be chosen.

The scheme in Figure 11 shows the observed and calculated settlements and the surcharging value.

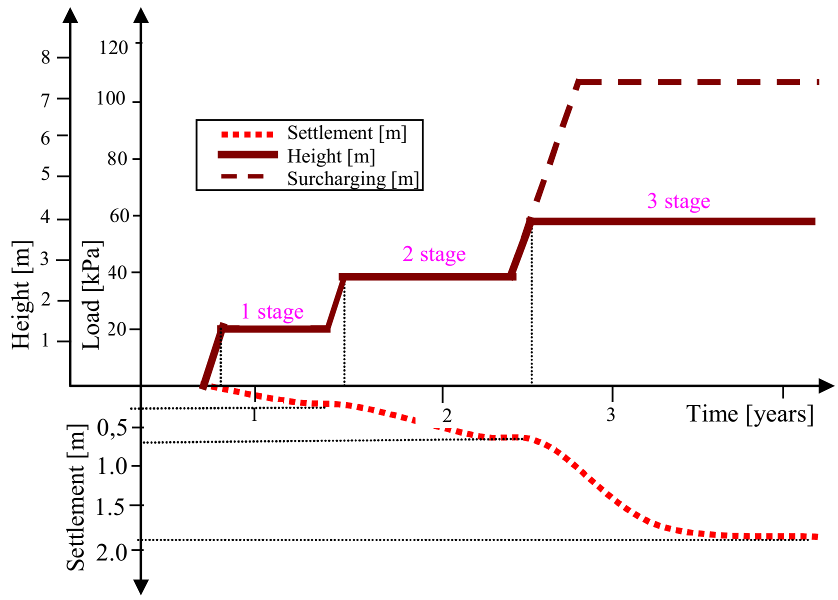

Figure 11. The observed and calculated settlements and the surcharging values

SUMMARY

The staged construction with surcharging is one of the recommended methods of road embankment construction on organic soils because it causes acceleration of consolidation and reduces long – lasting secondary settlement.

The surcharging significantly influences the acceleration of secondary settlements which receives about 20 – 30% of the total settlements which has to be considered in the settlement calculations.

The surcharging applied on highly deformable, low initial shear strength, and insufficient bearing capacity organic soils accelerate the consolidation process, reinforces the soil and also leads to the target settlements in a shorter time.

For the settlement calculations of the primary and secondary phase the following parameters should be used: undrained modulus E_u for the immediate phase (undrained conditions), Young's modulus E for the consolidation phase (drained conditions) and the relationship causing strain, means stress and time (creep settlements).

The obtained results show that in organic soils simple correlations and engineering computation can be used to predict surcharging needed to achieve a final settlement in shorter time and to reduce the secondary deformations.

The calculations presented in this paper are suitable for presented organic subsoil.

During the construction period careful monitoring of the foundation behaviour is required because of changes in the construction progress.

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