Stabilization of the landslides along the national roads

Problème de la stabilization d'un glissement sur les routes nationales

J. Gaszyński
Cracow University of Technology, Department of Environmental Engineering, Poland
M. Posłajko
Cracow University of Technology, Department of Environmental Engineering, Poland
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ABSTRACT
The aim of the analysis is to stabilize the landslide taking into consideration the extension of the road embankment. The Drucker - Prager elasto-plastic model in the plain state of strains was assumed for calculations. Z_Soil system was used for conducted analysis. The results regarding the stability of the embankment and the subsoil taking into account the stages of works.

RÉSUMÉ
Le but du travail consiste en analyse et une solution de question de la stabilization de sol fondation, protection de le remblai. Celles-ci problème concernent d'un glissement de le remblai sur la route Kraków-Tarnów, près Zgłobice (sur la Dunajec rivière). Une idée de la reconstruction de cette route a été etudieé aussi. La recherche contient: l'analyse d'état actuel, l'indication des causes des glissements, l'élaboration d'une méthode a'élémination d'une glissement et la protection de remblai. Pour la vérification de la validité de méthode proposée, les calculs de construction structural ont été faite par les modèles mathématiques selecteés.

Keywords: landslide protection, slope stability analysis, geotechnics

1. INTRODUCTION

Extending and modernization of the road network in Poland involves serious challenges, both during designing and contracting. Among these poblems, the geotechical ones belong to the most prominent. It is due to the character of transportation constructions which are invariably connected with subsoil. This connection is twofold: on the one hand the road object are to a great extent made from soil (road embankments, driveways, and walls from reinforced soil and on the other hand their base is (as it is the case of every construction) a subsoil.

Therefore, an important part of the geotechnical transportation works consists in problems dealing with load capacity of the subsoil and stability of the land masses used for construction of the embankments. Failing to address these problems leads to:

- excessive and unequal settlement of the road embankments due to high deformability of the subsoil or displacements of the subsoil
- the loss of stability of the slopes and creation of the landslides, leading to deformation and destruction of the road pavement.

The aim of this paper is to solve these problems, especially in case of the national road Krakow – Tarnow. This case is interesting due to the wide scope of problems, including:

- the need to stabilize the base
- the protection of the embankment slopes
- rebuilding of the road (widening from one roadway to two)

The scope of the paper is the following: analysis of the existing state and pointing to the causes of the landslides, assuming the numerical models and statistical calculations which justify the assumed model of solution.

2. PROBLEM CHARACTERIZATION

The modernization of the road network in the Malopolska region is hampered by problems related to load capacity of the subsoil and stability of the slopes. This is the case of road Krakow-Tarnow as well.

The landslides are located in the area of Zglobice near Tarnow, along the road no 4, near the Dunajec river (Figure1). The area is used for agriculture (meadows), mostly privately owned. The landslides are located near Okrężna street, on the slope of diverse north gradient. The region which contains both landslides is an area of the following: width – ca 90m and lenght - ca 200 m. The national road no 4 crosses the landslide area in the north part.

The areas of weakening are located in the body of the road embankment and in the weaker quaternary formations. The additional factors contributing to the development of the slide area in the embankment are: intensive traffic and lack of drainage alongside the road.

Taking into account the existing situation, the analysis of stability both of the existing and designed embankment along with the adequate protection of the landslide needed to be conducted in case the stability of the newly designed embankment wouldn't meed the design assumptions with the relevant safety factor.

3. GEOLOGICAL - ENGINEERING CONDITIONS

According to the documentation provided by Mineral and Energy Economy Research Institute Polish Academy of Sceinces (2001) the landslide no G079 is located at km m 497+786 km to 497+826, whereas G080 at km 497+850 to 497+880 (the data is taken from the geological-engineering

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documentation). The scale of the landslides was determined on the basis of survey and previous observation. The landslides were included in the evidence cards as MPL 0026 and MPL 0027.

Untill the start of the construction works (year 2005/2006) the intense traffic was observed on the area of the landslide. In the period preceding the start of the modernization of the road, there was a significant increase of the number of vehicles, including trucks.

Because of this degradation of the embankment and subsoil had proceeded on the existing landslide. Moreover, the additional dynamic influences related to unevenness and cracks in the pavement had appeared. Water started to fill into the cracks, leading to the change in the parameters of soils in the embankment and the subsoil outside the area previously described as landslide.

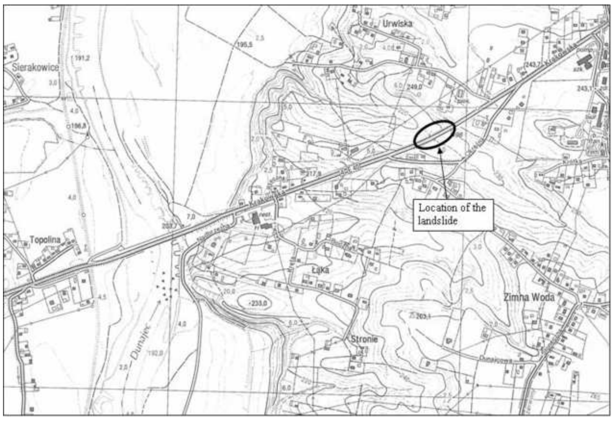

Figure 1. The location of the landslide in question (Mineral and Energy Economy Research Institute 2001).

Due to that, additional geotechnical survey was conducted, which broadened the scope of the diagnosis, among others, as far as beyond culvert in Tarnow direction. The addtional information about the subsoil and embankment was obtained. In the extended survey area there is very soft soil, at the depth of 10.8 to 12.5 m, which affects unfavourable on the stablility of the soil and load capacity of the subsoil.

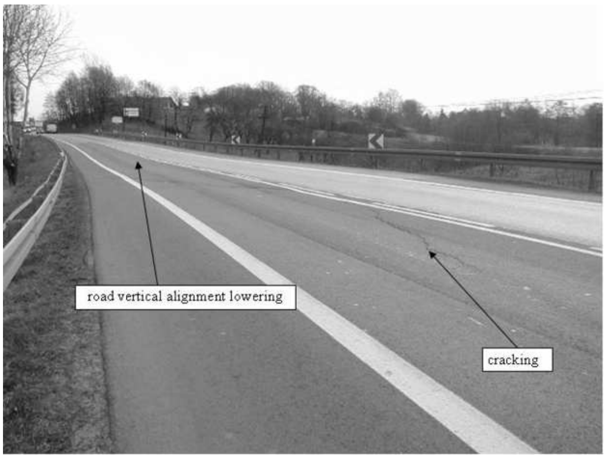

Figure 2 The view of the cracking and road vertical alignment lowering.

In addition to that, the survey confirmed the influence of the filtration of water penetrating the embankment trough the cracks in the pavement. This can be seen while analyzing the geotechnical sections, where on the one side of the road embankment soils in firm state are located, and on the opposite side (towards the water flow) the soils in very soft/soft state are located. In some places the subbase was found under the layer of asphalt of depth reaching 1.4 m (Figures 2 and 3). The thick layer of asphalt proves the constant filling in of the loosening embankment in this part of the road. Due to the new situation in the area form km 497+880 to the end of the embankment, which was confirmed by the survey, a protection of the embankment and the road subsoil was extended to the area reaching km 498+010.

4. THE CONCEPTION OF LANDSLIDE PROTECTION

Carrying out a stabilizing construction of the soil masses occurring in the subsoil under the existing embankment was involved in the protection of the landslide.

An additional problem, apart from stabilizing the landslide, was that the existing road had been a one-roadway one whereas the designed one would be a two-roadway one, with two lanes in each direction, and sidewalks on both sides, which involves widening the embankments and elevation of the road vertical alignment.

Due to the constant traffic the execution of the protection of the landslide had to be synchronized with the roadwork and the stage of the work had to be taken into account.

On the basis of the analysis of the possibility of carrying out the protection, with the ongoing traffic, the following manner of the building works was assumed:

1. Before starting work, the humus was removed from the subsoil in the southern part and the separation geosynthetics was spread out as well as the embankment as high as the level of the pile's heads
2. A row of piles was build in the south side.
3. A formation of the embankment widening the road in the south was begun in order to divert traffic into the temporary roadway at the level of existing road.
4. The piles in the northern side were built one by one.
5. After widening the embankment in the north side and building the additional temporary roadway the whole traffic was diverted into the south side. A traffic-free lane was obtained on the existing road in the north part. This lane was not subjected to load during the building of the protection of the landslide.
6. During the widening of the embankment in the north side the weak road shoulder and local soil lenses in very soft and soft state were removed (Figure. 3)..

Figure3. The local weakening of the subsoil together with the asphalt overlay and water road filtration.

7. Due to the fact, that the designed road would have the vertical aligment higher than the existing road a temporary protection of the slope of the new construction layers reaching 1.0 m was needed to be carried out. After carrying out all the work in the

northern part of the road the traffic was diverted into the newly built two-lane part of the road.

8. Then the elevation of the south side of the road to the parameters assumeed in the project was carried out.

5. NUMERICAL MODEL

The numerical model (Fig. 4, 5 & 6) was assumed on the basis of the geological-engineering sections (CHEMKOP-LABORGEO 2005). The following factors were included in the calculations:

- Carrying out the widening of the existing embankment

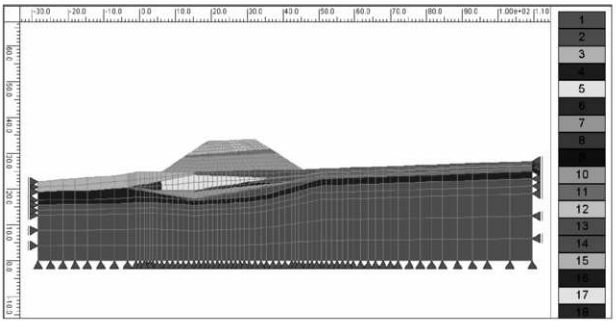

Figure 4. The numerical model elements grid – the existing embankment.

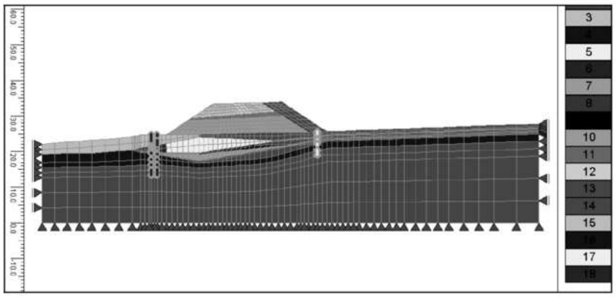

Figure 5. The numerical model elements grid – the embankment being built.

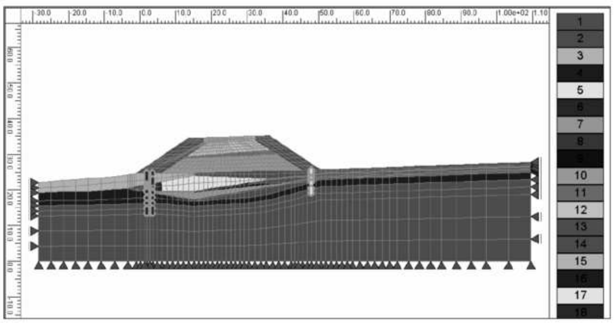

Figure 6. The numerical model elements grid – the designed embankment.

- Carrying out the elevation of the existing embankment
- The influence of the the stages of the work
- The influence of the designed protection

Material within the subsoil zone was assumed to be isotropic based on Drucker – Prager elasto – plastic yield criterion, Gryczmański (1995), Lambe, Whitman (1969). Elastic properties of material were characterized by modulus of elasticity (E) and Poisson's ratio (ν), while the plastic ones by cohesion (c) and internal friction angle (ϕ), Zienkiewicz ((1998).

Yield surface in Drucker – Prager model assuming associated flow rule in the plain state of strains can be presented in the form:

$$F(\sigma) = a_{\phi} \cdot I_1 + \sqrt{J_2} - k = 0 \qquad (1)$$

$$a_{\phi} = \frac{tg\phi}{\sqrt{9 + 12 \cdot (tg\phi)^2}} \qquad (2)$$

$$k = \frac{3 \cdot c}{\sqrt{9 + 12 \cdot (tg\phi)^2}} \qquad (3)$$

where:

$$\begin{aligned} I_1 &= \sigma_{ii} \\ J_2 &= \tfrac{1}{2} s_{ij} \cdot s_{ij} \\ s_{ij} &= \sigma_{ij} - \tfrac{1}{3} \cdot I_1 \cdot \delta_{ij} \end{aligned} \qquad (4)$$

I_1 – the first invariant of stress tensor, J_2 – the second deviatoric stress invariant, aϕ, k – material constants determined from equations (2), (3) as a function of c and ϕ from Coulomb- Mohr model.

In order to build geometrical model, there were used quadrilateral finite elements [5] based on the EAS method for incompressible and subjected to loosening mediums, which in turn were implemented into Z-Soil system (1998). The protection of the landslide was modelled by the bar elements

The road embankment was loaded with self- weight and live load caused by the traffic. The protection of the landslide was modelled by the bar elements. The steps of calculation were chosen to model the main steps in the carrying out the new embankment.

On the basis of Mineral and Energy Economy Research Institute (2001) and CHEMKOP-LABORGEO (2005) the values of the parameters for the respective material zones were assumed.

6. THE NUMERICAL CALCULATIONS AND THEIR ANALYSIS

The first step of the calculations involved the analysis of the stability of the existing embankment – the situation after creation of damage to the pavement, local landslides and new geometry. The stability factor for this conditions was determined 1.1 (Figure 7).

The analysis of stability for the next steps simulating the construction of the new embankment indicated lowering of the stability factor to the values indicating the loss of stability or insufficient safety margin, comparing to the norms.

The cause of the situation described were unfavorable geotechnical conditions in the subsoil and road embankment. The solution proposed consisted in putting construction elements reinforcing the embankment to the subsoil. The elements in question were piles situated in a grid of 2,5 m x 2,5 m do 3,0 m x 3,0 m. The numerical analysis was conducted for the next steps and the stability factor was determined. In the intermediate steps, due to the temporary character of the works, the stability factor was assumed to equal form 1.2 to 1.3 (Figure 8) .

After conducting the calculations according to the steps from 3., the stability factor obtained equals 1.5 (Figure 9).

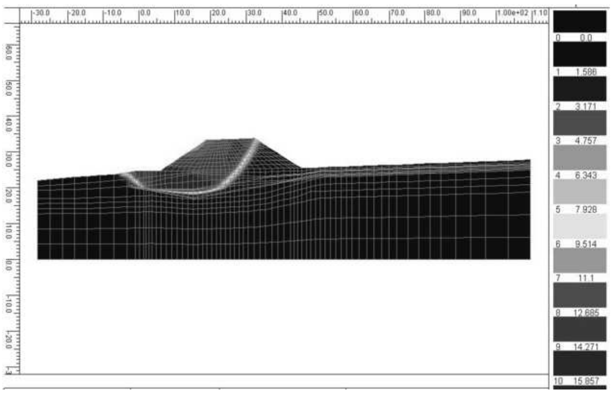

Figure 7. The image of the displacements at the moment of the stability loss before the beginning of construction obtained by the reduction method c – tgϕ. Stability factor FS=1.1.

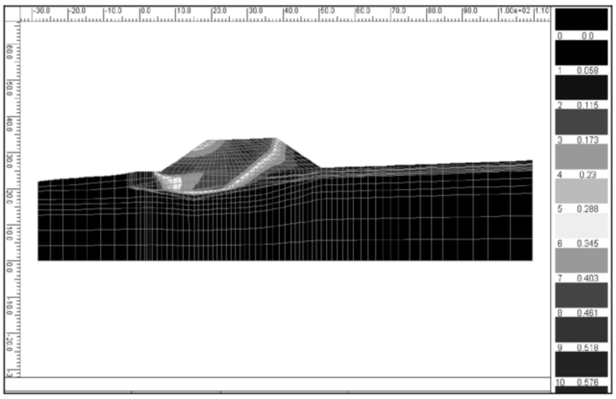

Figure 8. The image of displacements at the moment of stability loss at the intermediate step of construction obtained by reduction method c – tgϕ. Stability factor FS=1.3.

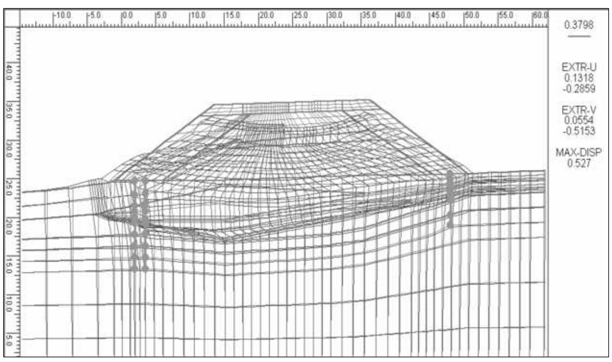

Figure 9. The image of the displacements at the moment of the stability loss before the beginning of construction obtained by the reduction method c – tgϕ. The stability factor FS=1.5.

7. SUMMARY AND CONCLUSION

250 piles of total length 2820 m were used for protection. Piles of length from 6,0 m to 18,0 m and diameter 0,60 to 0,80 were made, depending on the hight of the embankment, which varies from 2 m to 10 m.

The analysis leads to the conclusion that during the designing and construction of the engineering objects on the existing landslides the current and designed state as well as the intermediate steps need to be taken into account. A precise geotechnical – engineering information, including real values used for calculation is also crucial. These values have a significant impact on the level of complexity of the landslide protections.

Pic. 10 The view of road after stabilization of the landslide

Moreover, the inaccurate information leads to increase in the cost of construction or, conversely, to over-dimensions of the protecting construction. It should be born in mind, however, that in fact the building process is a complex one, and it is difficult to foresee the exact time of the works, their order and technological breaks.

The big variation of the subsoil parameters in the base of the landslide in question caused increase in the area of probable slide areas and their range, which was included in the geological-engineering documentation.

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