

Reinforcement on Landslides Areas



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Abstract

Slopes and landslides are one of the most common and most dangerous geological threats in Poland and beyond. They cause losses and destruction not only in infrastructure but also in the environment. They are a huge threat to people and their functioning in the environment. The presented document is aimed at presenting concepts and solutions for landslide protection and slope stabilization at existing damaged road sections. The main design task of this work is to restore to full technical efficiency the analyzed body of the existing poviata road No. 1475S Żywiec - Rychwałd in Żywiec at 0 + 405km to 0 + 455km by stabilizing an active landslide in the entire known range of its occurrence and ensuring safety for road users.

Calculation was made by the GEO5 program, the Slope Stability module, and Wall analysis. Firstly, the soils layers were averaged and defined. The object was included in the third geotechnical category in complex soil conditions. Then, soil parameters were assigned and modeled by geology. Finally, loads and groundwater levels were defined, and results were obtained. The shape of the slope was then given and calculations were made. It uses Bishop, Fellinius, Spencer, Janbu, and Morgenstern-Price methods for stability analysis. The calculations are mainly based on Eurocode 2, 3, and 7 and the technical design, in this case, is called the Tessin Wall.

Keywords: Slope; Landslide; Protection; Engineering; Construction; Pike; Soil; Eurocode 7

Introduction

Slopes and landslides are some of the most common and most dangerous geological threats in Poland and beyond. They cause losses and damage not only in infrastructure but also in the environment. They are a huge threat to people and their functioning in the environment [1].

In the vast majority of cases, the essence of the issue of stability of slopes is in the excess of soil shear strength over shear forces. The factors that have the greatest impact on the unfavorable arrangement of these values relative to each other are, among others, a large variety of soil layers, groundwater level, or slope [2]. Geotechnical assessment of phenomena in the ground depends on estimating the degree of cooperation between the building and the ground [3,4].

Both concepts, landslides, and escarpments function in close dependence and one phenomenon does not exist without the other. In Poland, the area most vulnerable to landslide phenomena is the south-eastern part of the country, especially the Carpathian regions. In addition, landslides often occur in the coastal area as well as in the Kielce and Masuria Voivodeships.

Theoretical Background

Methods of strengthening and reinforcement for slopes

There is a lot of methods and ideas for the most effective and long-term protection for slopes in the literature. The implementation of appropriate types of finishing and rehabilitation works or suitable constructions reduces to minimum activities related to the removal of erosive damage. Even a completely statically secured slope is exposed to soil erosion, which leads to the formation of dangerous landslides.

Methods of strengthening for slopes

The first way may be geogrotechnical protection of slopes. This method is based on securing slopes with chopped straw and a mixture of grass mixed with water, which, when unfolded on the slope, combine to form a whole, which gives them protective properties for the slope Table 1.

Another important activity for strengthening slopes is planting and compacting so that the vegetation receives 60 - 80% of rainwater.

Table 1: List of plots in the landslide area.

No.	Number of Plots	Owner, Address	Comments
1	1713/2	State Treasury, Kraśnińskiego 13 Street, Żywiec	dr
2	1733/1	Commune of Żywiec, Kraśnińskiego 13 Street, Żywiec	dr
3	1734	Żywiec Powiat, Kraśnińskiego 13 Street, Żywiec	RIIIb, ŁIII, ŁIV, PsIV, LsIV
4	1735	Regional Water Management Board in Krakow, Management Board of the Soła and Skawa basin with headquarters in Żywiec	Wp
5	1741	Żywiec Powiat, Kraśnińskiego 13 Street, Żywiec	LsV

The fermentation process of sewage sludge and composts for strengthening slopes and slopes in the humus process should be the increasingly preferred method of securing slopes by modern

engineers and designers, because this method is based on the use of renewable raw materials Figure 1.

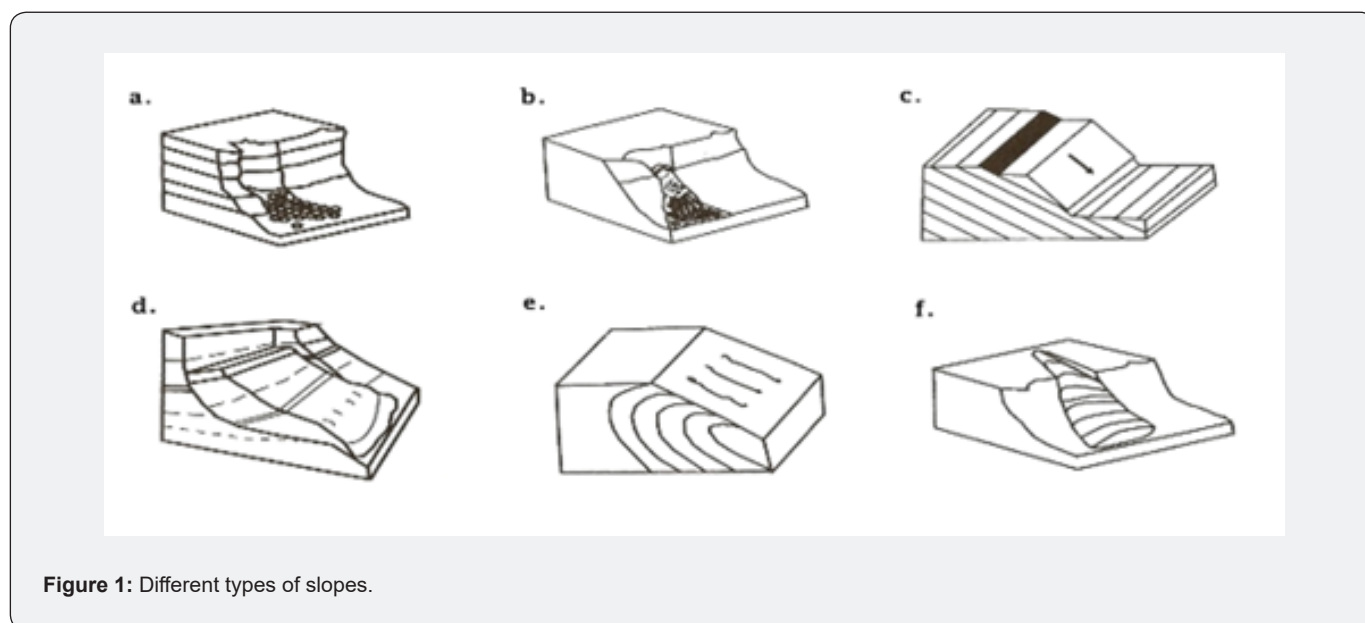


Figure 1: Different types of slopes.

A common way to protect slopes and slopes is also the use of geotextiles and shading nets, at least 5 cm thick, which not only protects the slope from erosion, but also allows you to continue work at any time of the year [5-7].

Gabions are another popular solution for securing landslides and slopes. It is a system of meshes made of galvanized wires with a diameter of 2 - 3.5mm, which is filled with large aggregate and shaped in any way. Thanks to this structure, the bearing can freely drain and not plasticize the soil, and the gabions themselves are a great stabilizing load [8].

The Pneusol method is also popular in Poland and it is based on the use of worn tires from retaining wall structures [9].

Methods of reinforcement for slopes

The main method of strengthening slopes according to Eurocode are three types of retaining structures. The first method of securing slopes by Eurocode 7 concerns the use of massive (gravitational) retaining walls, which usually define several geotechnical parameters (γ , ϕ , c). The second type is walls recessed in the ground, e.g., sheet piling, mainly made of steel, reinforced concrete, or wood, which are often fixed with anchors or struts to the ground. The last type of retaining structure is a wall with a complex structure and it can fix the first and the second one method together [10].

It is also worth mentioning other methods of reinforcement, e.g., pinning, filter buttresses, concrete injections into the ground,

drainage wells, the Tessin Wall technology, pikes, and micro spikes [3,4,6].

Methods for checking the stability of slopes

There are many methods in the literature for checking the stability of slopes. The most important factor determining

the choice of the calculation method is the awareness of the occurrence of the largest number of factors taken into account in the calculation algorithm. The result of calculations is usually the safety factor, the most important for the assessment of slope stability Figure 2.



Figure 2a: Views for slope.

Limit balance methods

Empirical methods for determining the stability of slopes and slopes can be divided into three sections:

- i. limit balance
- ii. stress limit state
- iii. induced friction resistance

In practice, despite many proposed methods of analysis, several of them are most often used. Usually, these methods are derived from the analysis of the limit equilibrium of forces acting parallel to the slip surface, for which the equilibrium index F is determined:

$$F = \frac{\sum U_i}{\sum Z_i}, \quad (1)$$

where:

U_i - generalized holding forces,

Z_i - generalized loading forces.

Slope stability consisting of cohesive soils should be separately tested for irrigated and dry soil [1]. In the case of irrigated soil, drainage pressure should be taken into account, while for dry soil the most important to maintain balance is the slope angle, which should be equal to or less than the angle of internal friction of the soil. In the case of cohesive soils, stability testing is a more complex calculation process.

Methods for checking the stability of slopes from cohesive soils

The initial assumption for checking statistics of cohesive soil

slopes is to assume a circular slip surface [7,11]. Such situations usually occur within layers of low strength. The essence of determining the limit equilibrium is the combination of normal stress operations along the slip surface. In practice, the most popular test method is the strip method, according to which massive settling is divided into vertical parts and determined forces occurring in it when some of the developed methods currently used in computer software for statistical calculations of the slope are available Figure 3. The first of these is the Fellenius method, which only takes into account the condition of moment balance [4,5,12]. Another often used in calculations of slope stability is the bishop method, which takes into account the two-way interaction of adjacent strips and the condition of equilibrium of moments [4,5,12], and the calculation model is carried out based on iteration. Iteration is carried out until a situation is achieved when the results for the coefficients differ from each other by less than the value assumed in advance. The third method that is equally often used is the Janbu method, which bases its assumptions on inter-band interactions, while the equilibrium condition is the sum of projections of forces on the horizontal axis [5,12]. The shape of the slip surface does not affect the value of the stability factor. The basis of this calculation methodology is the bishop equation Figure 4.

Pikes according to Eurocode 7

Nowadays, engineering objects are increasingly demanding and have to deal with difficult geotechnical conditions. Therefore, pike foundations are starting to become a more and more popular foundation method. These types of foundations transfer the load from the structure through the bottom and the side surface of the pike.

- i. Pikes should be designed based on:
- ii. results of static test loads,
- iii. analytical or empirical calculation methods,
- iv. results of dynamic tests,
- v. checking the behavior of similar pike foundations [13].

During pike dimensioning, the arrangement of layers in the soil has the greatest impact on their selection. In a situation where

a weak layer surrounds the pike's sidewall, it will be characterized by high compressibility, which will have a direct impact on the significant susceptibility of the pike to deformation and very limited shear strength, which may result in construction disasters. Therefore, the essence of designing pike foundations is to embed them in layers of strong soils, such as slate, rock. The load on the side of the pike is analyzed by dividing it separately on the pressure from the ground from the side of the loaded ground and the resistance on the opposite side. It appears with the difference of vertical stresses [9].

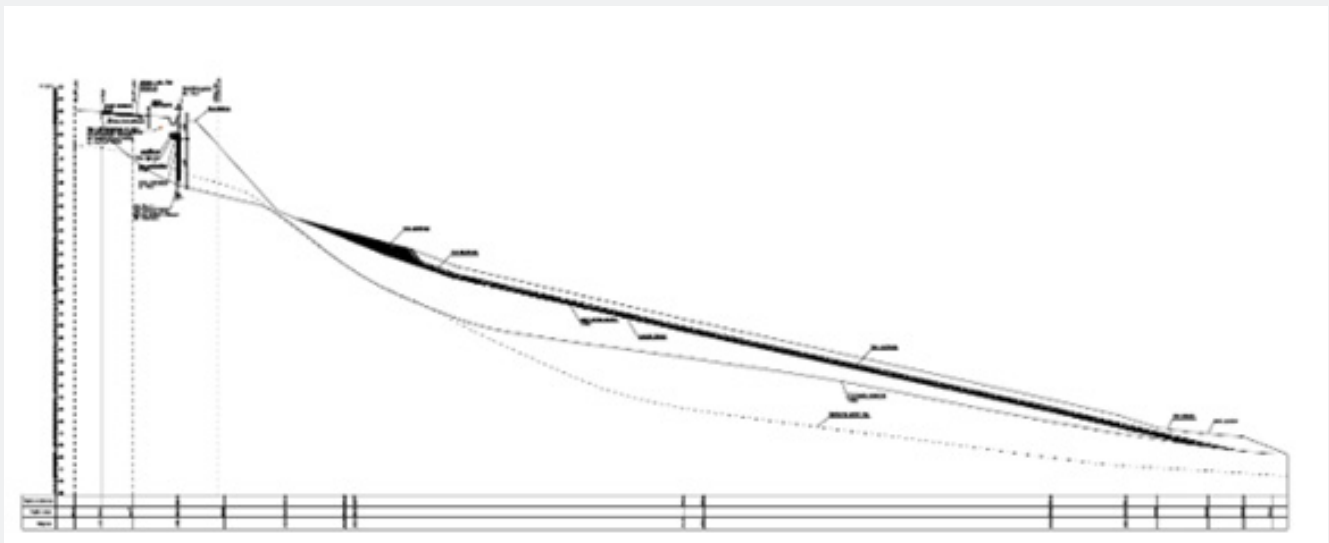


Figure 3: Transverse section.

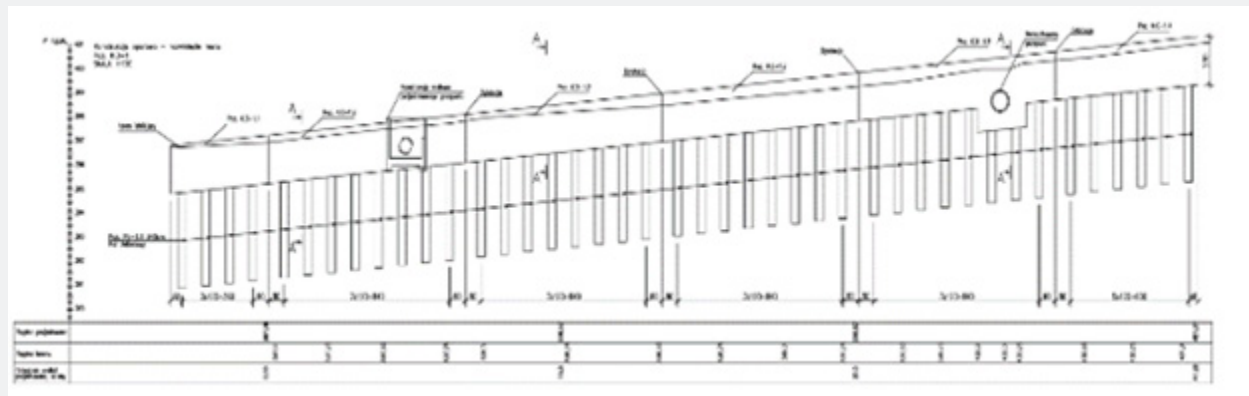


Figure 4: Retaining construction Wall expansion.

According to Eurocode 7, to demonstrate that the foundation will carry the designed interference load with a sufficient load safety margin, the following inequality must be met for all cases

and load capacity combinations [14]:

$$F_c; d \leq R_c; d \quad (2)$$

Retaining structures according to Eurocode 7

Retaining structures are engineering objects that are usually dimensioned for the transition from one ground level to another or to limit water tanks [15]. The rules and calculation procedure for retaining structures are contained in Chapter 9 Eurocode 7. It mainly contains recommendations and requirements for the correct design of retaining structures Figure 5. Annex C of Eurocode 7 sets out the methodology for calculating the limit values for soil

pressure and repulse [15]. The calculations consider primarily deformations and displacements of the designed retaining structure, but also the results of the calculations taking into account changes in the water level, changes in time and space of the landmass, make a dig from the front of the designed structure, weight from existing structures, the impact of subsidence and extreme weather conditions (e.g., frost) and combinations of effects [16].

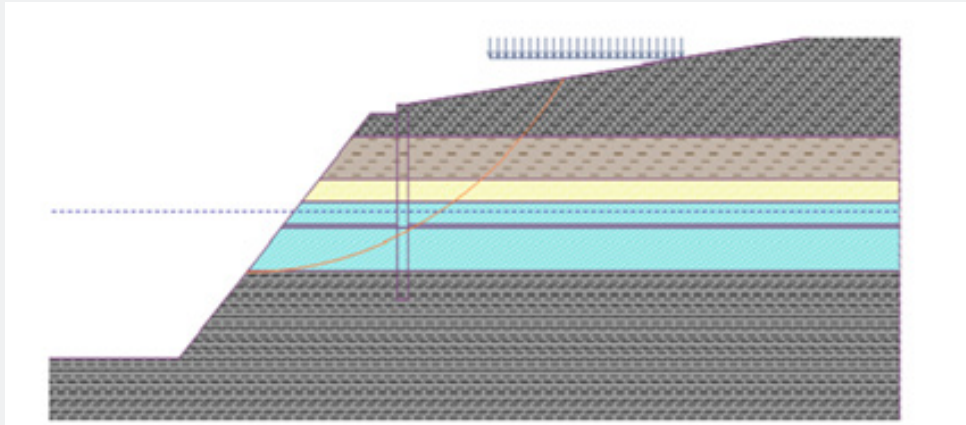


Figure 5: Slope stability analysis without retaining structure.

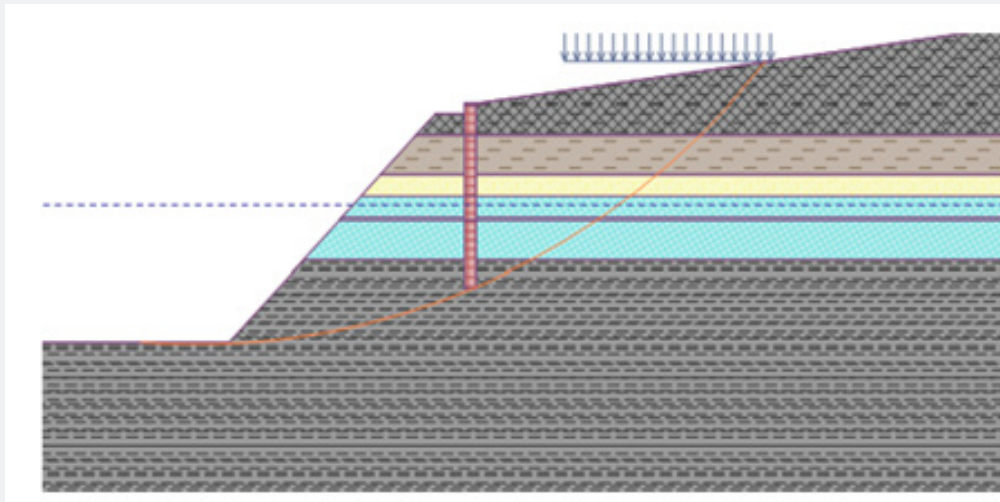


Figure 6: Slope stability analysis with retaining structure.

Materials & Experiments

Location

The beginning of the project is located - according to the kilometer of the road at 0 + 400km and the end at 0 + 455km in Żywiec.

The area of the active landslide covered by the study is located on the plots:

Description and assessment of soil and water conditions and geological conditions

During the geological works, anthropogenic deposits (drilled in

OG-2 and OG-6 wells) are associated partly with the embankment of the road in the form of mixed stones, old asphalt, glass, bricks, and organic parts (roots) were found. This uncontrolled embankment is associated with the wild garbage dump occurring in this area, i.e., on the entire southern slope below the road from the OG-1 to OG-3 well together with the entire landslide colloquium. Quaternary soils developed in the form of loam and sandy loam with stones, and at the bottom of the weathered clay shale occur throughout the entire surface of the slope falling south towards the Moszczanka stream. Paleogene (Oligocene) deposits are represented: sandy and clay shales (with a clear difference in shear strength R_c), sometimes separated by sandstone inserts. Slates alternate in the form of cracked and very cracked slate with less-cracked, less solid, slate. Coarse (conglomerate) sandstones, cracked, were drilled in the OG-1 well and along with the depth changed the grain fractions into smaller ones. The water table is usually free, and only locally it has a slightly thrust character - in places where aquifers are covered with poorly permeable sediments Figure 6. The water surface is usually at a depth of 2-4m, only locally deeper.

Under the Regulation of the Minister of Transport, Construction and Maritime Economy of 25 April 2012 on determining the geotechnical conditions for the foundation of building structures, the building has been included in the third geotechnical category in complex soil conditions.

Construction concept

Combination of materials [17-20]

i. Pikes

- a) Concrete: C30 / 37
- b) Reinforcement: IPE 140 Steel S235 profile

ii. Reinforced concrete retaining structure

- a) Structural concrete: C25/30
- b) Primer concrete: C8/10
- c) Exposure class: XC3
- d) Maximum w/c ratio: 0.50
- e) Minimum cement content: 300kg
- f) Minimal reinforcement cover thickness c_{om} : 50mm
- g) Reinforcing steel: A-IIIN (RB500W)

Result

Calculations were made using the GEO5 program, Slope Stability module, and Wall analysis. The first step of the project was to average and define the tested soil layers in the place where the slope protection is to be designed.

The next step was to assign optimal values to individual soil subsoil parameters. The next element of the project was the

task of the optimal slope shape for the created computational model, based on the slope stability analysis without the retaining structure. Computational simulations have shown that the slope in the adopted model does not meet the requirements, and the use of slope stability is:

- i. according to the bishop method: 101.1%
- ii. according to the Fellenius method: 103.2%
- iii. according to the Janbu method: 101.3%
- iv. according to the Morgenstern-Price method: 101.8%

and the escarpment is falling - the results of numerical calculations coincide with data from *in situ* tests for the analyzed area. Compliance in most cases oscillates around 100% - i.e., very good. This shows the model's compliance with the real issue.

The results of *in situ* tests and numerical analysis indicate a very high consistent risk of the linear construction in question - the road at 0 + 405km and 0 + 455km in Żywiec.

The next step in the project is to design an optimal retaining structure - a solution in the form of palisades was chosen for which simulations of spacing and diameter were carried out. Suitably converted variants gave the optimal solution to meet load capacity conditions. The last design step was a calculation simulation for checking the slope stability. The slope stability utilization using the designed structure is successively for each:

- i. Bishop's method: 57.0%
- ii. Fellenius method: 54.4%
- iii. Spencer method: 50.6%
- iv. Janbu method: 49.0%
- v. Morgenstern-Price method: 49.3%

The Tessin Wall technology is the optimal method chosen to strengthen the embankment. The photo below shows damage to the roadway near the landslide, as a result of badly drained rainwater:

Discussion & Conclusion

Designed by the selected method and with the initial assumptions given for the adopted calculation models, the structure of the road protection in question, as a reinforced concrete wall 2.0m high, mounted on a palisade of concrete pikes with a diameter of 40cm spaced every 1.2m, reinforced with a steel profile IPE140, meets all conditions perfectly optimally designed (provide values):

Maximum values of displacements and internal forces

Maximum displacement = -1.0mm

Maximum displacement = 0.2mm

Maximum bending moment = 5.04kNm

Maximum bending moment = -12.85kNm
 Maximum cutting force = 12.92kN
 Checking the composite cross-section according to EN 1994-1-1
 All construction phases were included in the calculations.
 Calculated section load factor = 1.00
 Forces per profile
 $M_{max} = 15.42 \text{ kNm}$; $Q = 0.27 \text{ kN}$
 $Q_{max} = 30.33 \text{ kN}$; $M = 1.26 \text{ kNm}$
 Checking max. Torque $M_{ax} + Q$
 Checking the shear cross-section:
 $Q / VRd = 0.002 \leq 1$ Meets the requirements
 Checking the folded section for bending:
 $M_{max} / M_{pl, N, Rd} = 0.284 \leq 0.9$ Meets the requirements
 Check the max. Shear force $Q_{max} + M$
 Checking the shear cross-section:
 $Q_{max} / VRd = 0.195 \leq 1$ Meets the requirements
 Checking the folded section for bending:
 $M / M_{pl, N, Rd} = 0.023 \leq 0.9$ Meets the requirements

The retaining structure is a reinforced concrete wall mounted on a palisade. Such a method is an additional drainage method for rainwater for the exposed area, and what is more, the planned building intentions, taking into account the integrated and developed protection of all-natural values, will not hurt the bed of the Moszczanica stream or the surrounding area.

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