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# SLOPE STABILITY USING SELF-DRILLING ANCHOR RODS

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**Abstract**

Efficient transport infrastructure is vital for economic competitiveness, yet landslides pose significant threats to roads, endangering safety and infrastructure. This article focuses on the rehabilitation of landslides using self-drilling anchors. Micropiles, which are reinforced drilled piles offer advantages in areas unsuitable for conventional foundation systems due to their adaptability to challenging terrain and minimal vibrations during installation. Our study focuses on a road site in the Bradl belt, characterized by significantly inclined terrain and medium plasticity clay soils. Using numerical modeling through AutoCad and Plaxis 2D, we evaluate the stability of the slope and the effectiveness of the micropile-reinforced concrete beam system. The φ-c reduction method was employed to assess the safety factor, showing that the spatial arrangement of micropiles enhances slope stability significantly. The results highlighted that a spatial orientation of micropiles improves the structural integrity and safely absorbs impacts, outperforming traditional arrangements. This study underscores the potential of micropiles for effectively addressing landslide threats, offering design, safety, and maintenance advantages.

**Keywords:**

slope stability;
self-drilling anchor rods;
plaxis 2D;
micropiles;
spatial geometry.

## 1 Introduction

A good transport infrastructure enables fast and efficient transport of goods and services, which reduces costs and increases competitiveness. The threat of landslides to roads is a serious problem that can have consequences for transport, safety, and the economy. Landslides can block roads, damage infrastructure, cause traffic accidents, and lead to loss of life. The solution to this problem includes the identification of risk areas, the implementation of preventive measures, and the effective management of crisis situations. There are many technologies for landslide rehabilitation. This article will focus on micropiles. The technology of micropiles was first introduced in the 1950s in Italy, and later in the 1980s, it began to be developed in North America. Micropiles began to be used mainly as foundation support elements that resist high axial loads and as in situ reinforcements for the stability of slopes and excavations. A micropile is a drilled and injected pile of small diameter (less than 300 mm) that is reinforced. Micropiles are used where conventional foundation systems cannot be used. Micropiles are widely used to support existing structures and the device can be further adapted to operate in locations with low clearance and severely restricted access [1, 2]. Micropiles can be installed over most terrain conditions, obstacles, and foundations at any slope. They ensure minimal vibrations. They can be installed near existing walls. Or they allow the operation of the equipment to be maintained during construction. These are some of the few advantages of micropiles. The use of these advantages is possible because high-capacity steel elements are used as a load-bearing element, which occupies up to 50% of the volume of the opening, while the surrounding grout only serves to transfer the applied load between the soil and the steel. The improvement of the micropile method continues, motivated by the need to provide highly engineered and high-quality solutions for progressively more demanding construction challenges in an extremely competitive economic environment. Specialized construction companies were established or exported all over the world. These factors helped the growth of micropiles. [3, 4].

The technology of self-drilling anchor rods, which perform drilling, grouting, and anchoring in one step, is coming to the fore around the world. These self-drilling anchor rods are suitable for unstable conditions. When applying the rod anchoring system, it is primarily their direct drilling into the rock mass or structure. Therefore, the necessity of using a drill bit and pre-drilling a hole for their installation is eliminated. Part of the technology of anchoring using injection drilling anchor rods is the injection of installed elements. This can be done simultaneously during drilling or after drilling to the final length of the element. Depending on the purpose, cement-based materials or chemical materials specially designed for anchoring and stabilization are used for grouting. A rotary injection adapter ensures the transport of the injection medium through the anchor rod and the crown into the borehole during drilling [5, 6, 7].

## 2 Problem definition

The site is located in the Bradl belt. It is an assemblage with a wider range of flysch facies. There is a facies with a predominance of medium- to coarse-grained sandstones with sandy-silt interlayers. There are conglomerate positions in several places in the assemblage. On the site there is a road to the quarry, the terrain of the slope is considerably inclined at 45° or 1:1. elevation approx. 10.0 m. Considerable terrain erosion took place. No springs of water were recorded, and a small forest stream runs at the foot of the slope. 2 static penetrations (CPT – Cone Penetration Test) were carried out at the given location. From the inspection of the site and from the CPT tests, the detected soils (Table 1) were classified under STN 72 1001 classification of soils and rocks [8] as F6/CI - clay with medium plasticity and sandstones.

Table 1: Classification of soil

| Depth [m] | Type of soil |
|---|---|
| 0 – 2 respectively 2.5 | F6/CI - clay with medium plasticity |
| from 2 respectively 2.5 | Sandstones |

### 2.1 Numerical model

Micropiles enable full use of space and at the same time support excavations or improve the slopes with an adequate safety factor. The assessment of the draft rehabilitation measure was carried out in the most unfavorable cross-section. The design and assessment of the reinforced concrete beam with micropiles were carried out in AutoCad, and Plaxis 2D programs. The Finite Element Method tool, PLAXIS 2D, is used to evaluate global stability and provide information on deformation displacements. Table 2 contains the input parameters of the soil, asphalt carpet, and reinforced concrete beam for the numerical model (Table 2). The geometry of the model was created in the Plaxis 2D program (Figure 1), and the geodetic measurement and the CPTu measurement served as the basis. From the model, the actual parameters of the soils were determined so that the degree of stability was approximately 1.0.

Table 2: Input parameters of soils, asphalt, and concrete

| Soil | Material model | Unit weight γ [kN.m$^{-3}$] | Poisson's ratio ν [-] | Deformation modulus Edef [MPa] | Angle of internal friction φ [°] | Cohesion c [kPa] |
|---|---|---|---|---|---|---|
| F6/CI | Mohr-Coulomb | 20.0 | 0.35 | 3.0 | 14.5 | 11.5 |
| Sandstone | Mohr-Coulomb | 20.0 | 0.25 | 23.3 | 27.8 | 30.0 |
| Asphalt | Linear Elastic | 22.0 | 0.2 | 7 500 | - | - |
| Concrete | Linear Elastic | 25.0 | 0.2 | 30 000 | - | - |

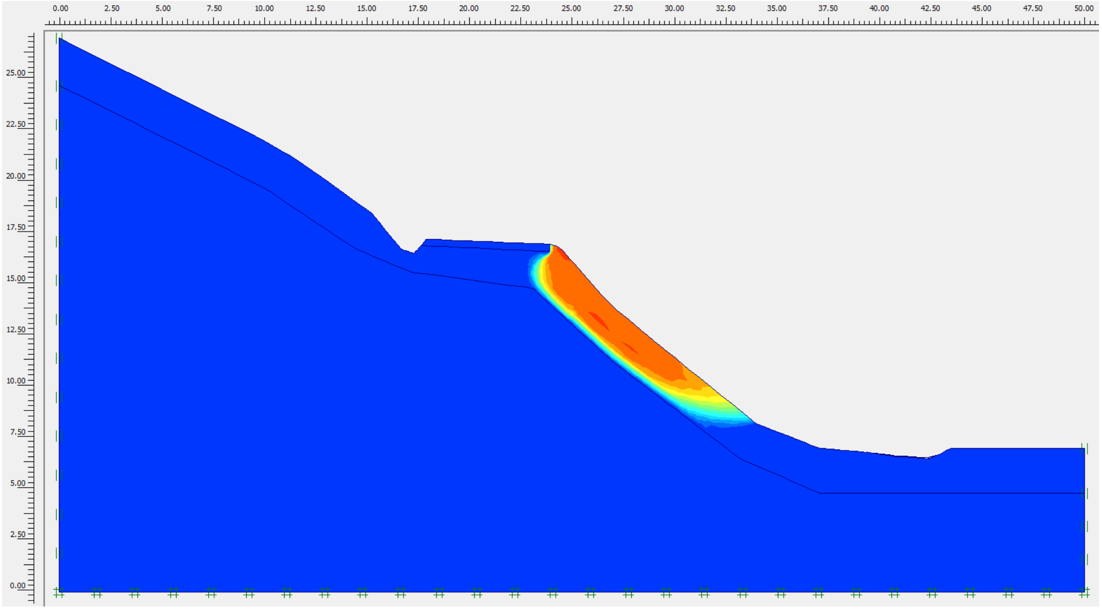

Fig. 1: Slope geometry – the most critical shear surface and Safety factor is 1.03

### 2.2 The φ-c Reduction Method in FEM Stability Analysis

Stability analysis presents unique challenges due to the complexity of the built environment and the inherent uncertainties of subsurface conditions. This chapter examines the synergistic application of the Finite Element Method (FEM) stability analysis and project management principles, with a particular focus on the phi-c reduction method for assessing factors of safety. The φ-c reduction method, also known as the strength reduction technique, is a powerful approach for assessing the stability of geotechnical structures using FEM. This method involves gradually reducing the shear strength parameters of the soil (friction angle φ and cohesion c) until failure occurs, providing a safety factor against instability. The following equations govern the reduction of strength parameters:

$$c_{red} = \frac{c}{SRF}, \tag{1}$$

$$\tan(\varphi_{red}) = \frac{\tan(\varphi)}{SRF}, \tag{2}$$

where SRF is the strength reduction factor, which is incrementally increased until the numerical solution fails to converge, indicating imminent failure of the geotechnical system [9, 10].

### Advantages over Limit Equilibrium Methods

The φ-c reduction method offers several advantages over traditional limit equilibrium methods:

- No pre-defined failure surface is required; the critical failure mechanism emerges naturally from the FEM analysis.
- Complex soil-structure interactions can be accurately modeled, including the effect of support systems like micropiles.
- Progressive failure and stress redistribution are inherently considered in the analysis.

The φ-c reduction method plays a crucial role in assessing the overall stability of the excavation system. Our case study allowed for a comprehensive evaluation of the safety factor considering the complex interaction between the soil, excavation geometry, and micropile support system. By observing the deformation patterns at the point of numerical non-convergence, we identified potential failure mechanisms. This information was invaluable for optimizing the support system design and construction sequence. The φ-c reduction method facilitated detailed sensitivity analyses, allowing us to assess the impact of variations in soil parameters on the overall stability. While the φ-c reduction method is powerful, it's essential to note that convergence issues can sometimes occur before the actual failure state is reached, potentially overestimating the safety factor. The phi/c reduction method assumes a simultaneous reduction of strength parameters in all materials, which may only sometimes be realistic. The analysis does not directly account for Time-dependent effects, such as consolidation.

### 2.3 The technical recommendations to the problem

The rehabilitation of the slope is designed using micropiles made of injectable self-drilling anchor rods MAI SDA T 76 N and R 38 N and a reinforced concrete beam [11, 12]. RC beam made of concrete C 30/35 has a width of 0.7m, a height of 1.3m, and lengths of 16m and 11m [13, 14]. The injection anchoring rod MAI SDA R is an adjustable rod equipped along its entire length with a left-turning round R-thread. In the longitudinal axis of the rod, there is an injection hole intended for transporting the injection mixture. A thick-walled steel tube made of high-quality stainless steel is used for production. The anchor rods have an outer diameter of 76 mm and 38 mm and an inner diameter of 51 mm and 19 mm. The load-bearing capacity of the rod for T 76 N is 1200kN and for R 38 N it is 400kN and for intermediate strengths 1600kN or 500kN.

1. Example) The anchor rods are in one line alternated within the geometry (Figure 2a), the first is vertical, and the second is sloped by 45°. The vertical micropile T 76 N is 9m long, and the number of pieces is 27. The inclined micropile R 38 N is 6m long, and the number of pieces is 26. The total number of such micropiles is 53 pcs.
2. Example) The anchor rods are spatially arranged within the geometry and alternate (Figure 2b), the first two are vertical, and every third is sloped by 45°. The vertical micropile T 76 N is 9m long, and the number of pieces is 35. The inclined micropile R 38 N is 6m long, and the number of pieces is 18. The total number of such micropiles is 53 pcs.

The results were compared in terms of micropile geometry. The axial distance of the anchor rods is 0.5m and in FEM they are modeled like the "plate" element. The most important input material parameters for plate elements are bending stiffness EI and axial stiffness EA. The plate structural elements are shaped rectangular. Since the micropile is circular in cross-section and placed at the proposed horizontal spacing, the equivalent axial and flexural stiffness must be determined for proper simulation [7, 15]. Figure 2 shows the layout design of micropiles per meter length. The STP-09M/2 steel bridge guardrail was also modeled through the "plate" element. Input parameters for "plate" elements are in the following table 3.

**Estimation of axial and bending stiffness**

Input parameters are very important in FEM analysis. In our case, it was used Plaxis 2D. In Figure 2 we can see the layout design. In Example 1 vertical rods are behind each other in cross-section. So we must apply factor n = 2. On the other side, In Example 2 vertical rods are independent arrangements in cross-section. So, factor n is 1.

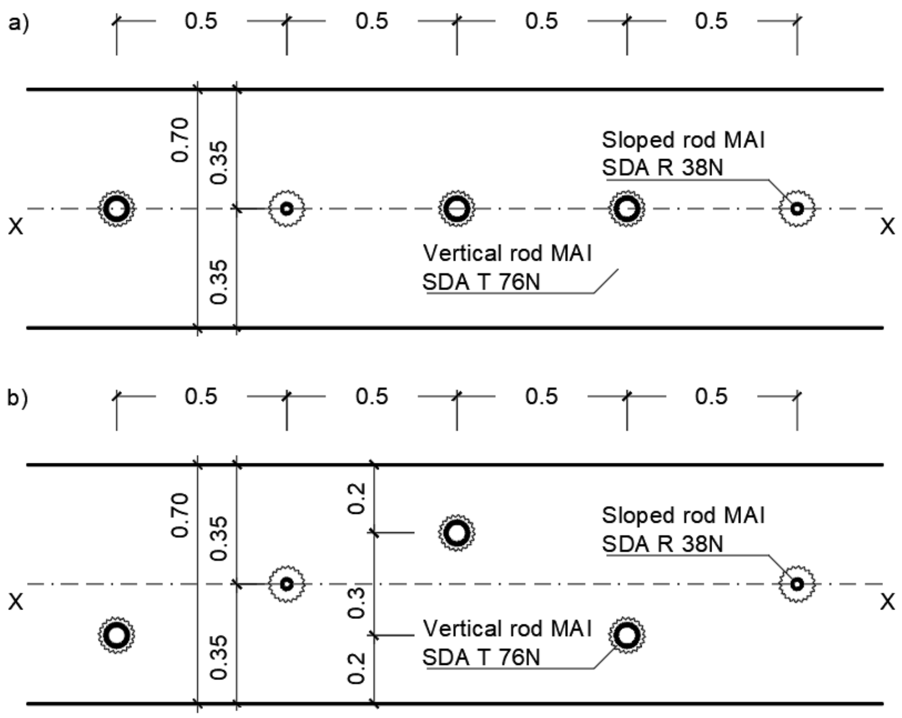


Fig. 2: Layout design of micropiles a) Example 1, b) Example 2

Calculation of axial stiffness EA for equivalent element

$$EA = E.A = 210.10^9.n.\left(\left(\frac{\pi}{4}\right).(D_1^2 - D_2^2)\right), \tag{3}$$

Calculation of bending stiffness EI for equivalent element

$$EI = E.I = 210.10^9.n.\left(\left(\frac{\pi}{64}\right).(D_1^4 - D_2^4)\right), \tag{4}$$

Where: E is elastic modulus = 210 GPa, A is a cross area of anchor rod [mm2], I is the inertial moment [mm4], n is how many rods are in 1m, D1 is the outer diameter of anchor rod, D2 is the inner diameter of anchor rod.

Table 3 Input parameters of elastic elements „plate“

| Example | Element | Material element | Axial stiffness EA [kN/m] | Bending stiffness EI [kNm2/m] | d [m] |
|---|---|---|---|---|---|
| 1 | Vertical rod MAI SDA T 76 N | Elastic | 1047328.8 | 548.34 | 0.079 |
| 2 | Vertical rod MAI SDA T 76 N | Elastic | 523664.4 | 274.17 | 0.079 |
| 1, 2 | Sloped rod MAI SDA R 38 N | Elastic | 178621.8 | 20.15 | 0.037 |
| 1, 2 | Bridge guardrail STP-09M/2 | Elastic | 531300.0 | 485.1 | 0.105 |

## 3 The calculation results

The road load was added as a strip load on the asphalt carpet surface with a value of 50.0kPa. The extraordinary load impacting the bridge guardrail was modeled as a single force at a height of 0.75 m with a value of 120 kN/m [16]. According to works [17, 18] was a set interface in the numerical model. The sequence of calculation steps was the same for both examples:

1. plastic analysis: calculation of the original slope,
2. plastic analysis: installation of micropiles,

3. plastic analysis: RC beam, installation of bridge guardrail,
4. plastic analysis: load from transport,
5. plastic analysis: extraordinary load, crash into a barrier,
6. pí/c reduction: calculation of the most critical shear surface

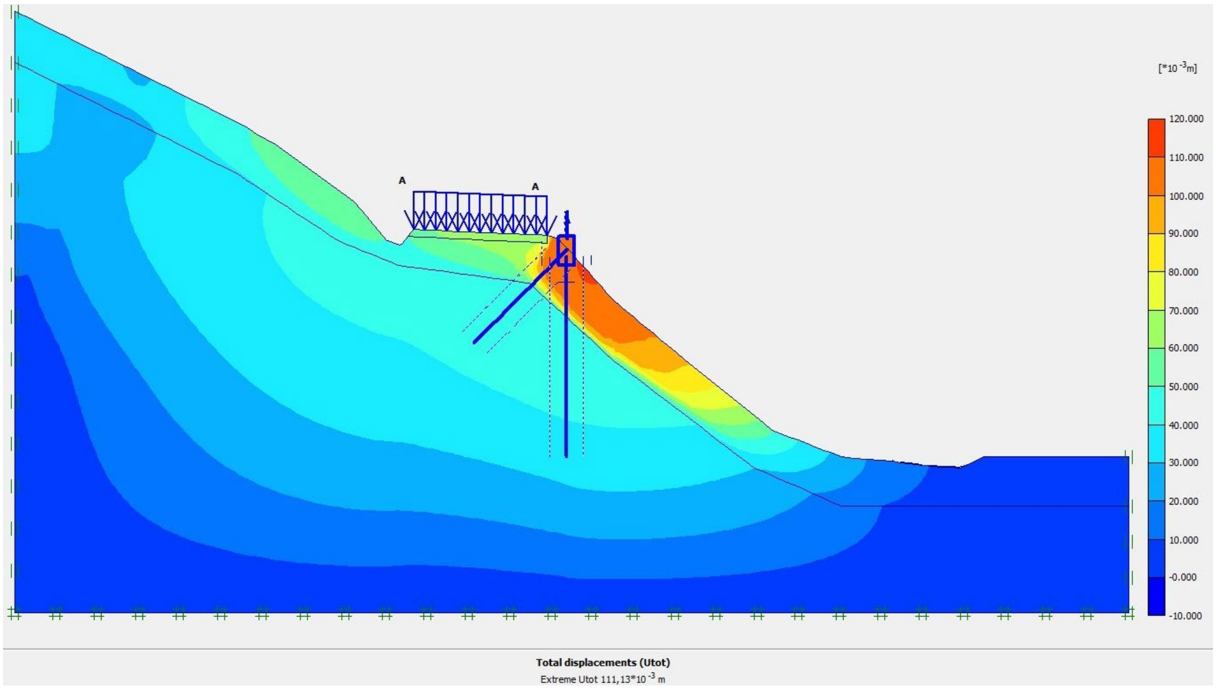


Fig. 3: Total displacement for E1, when vertical rods are behind each other in cross-section

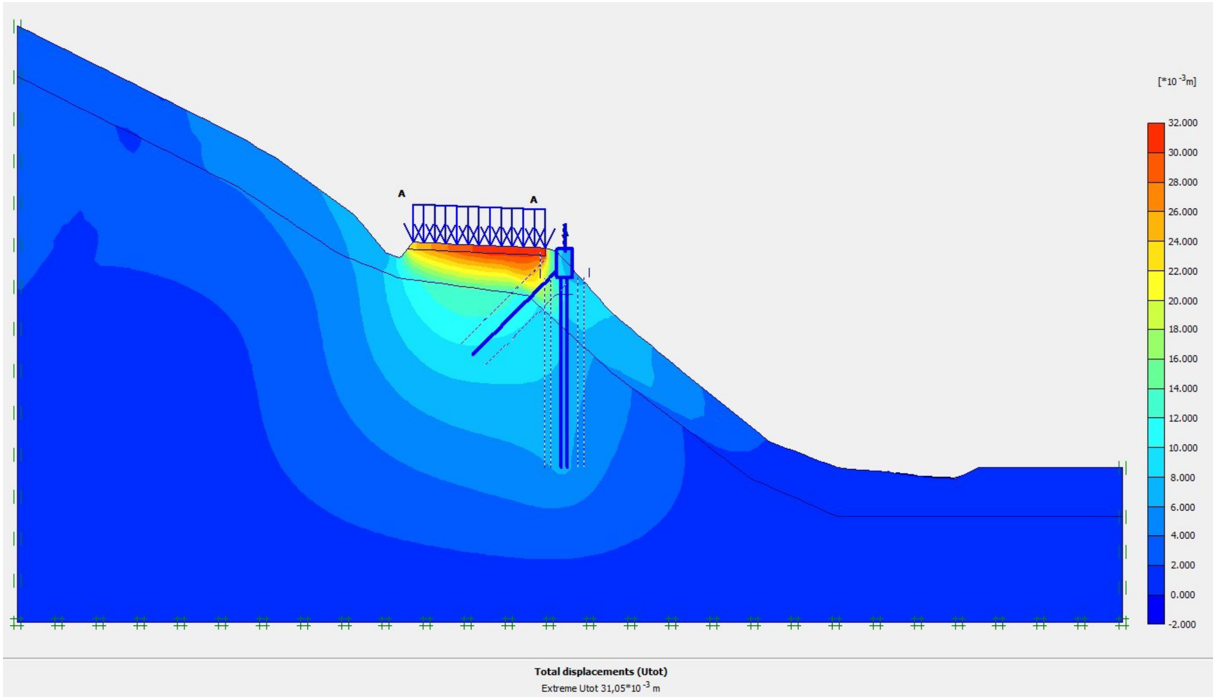


Fig. 4: Total displacement for E2, when vertical rods are independent arrangements in cross-section

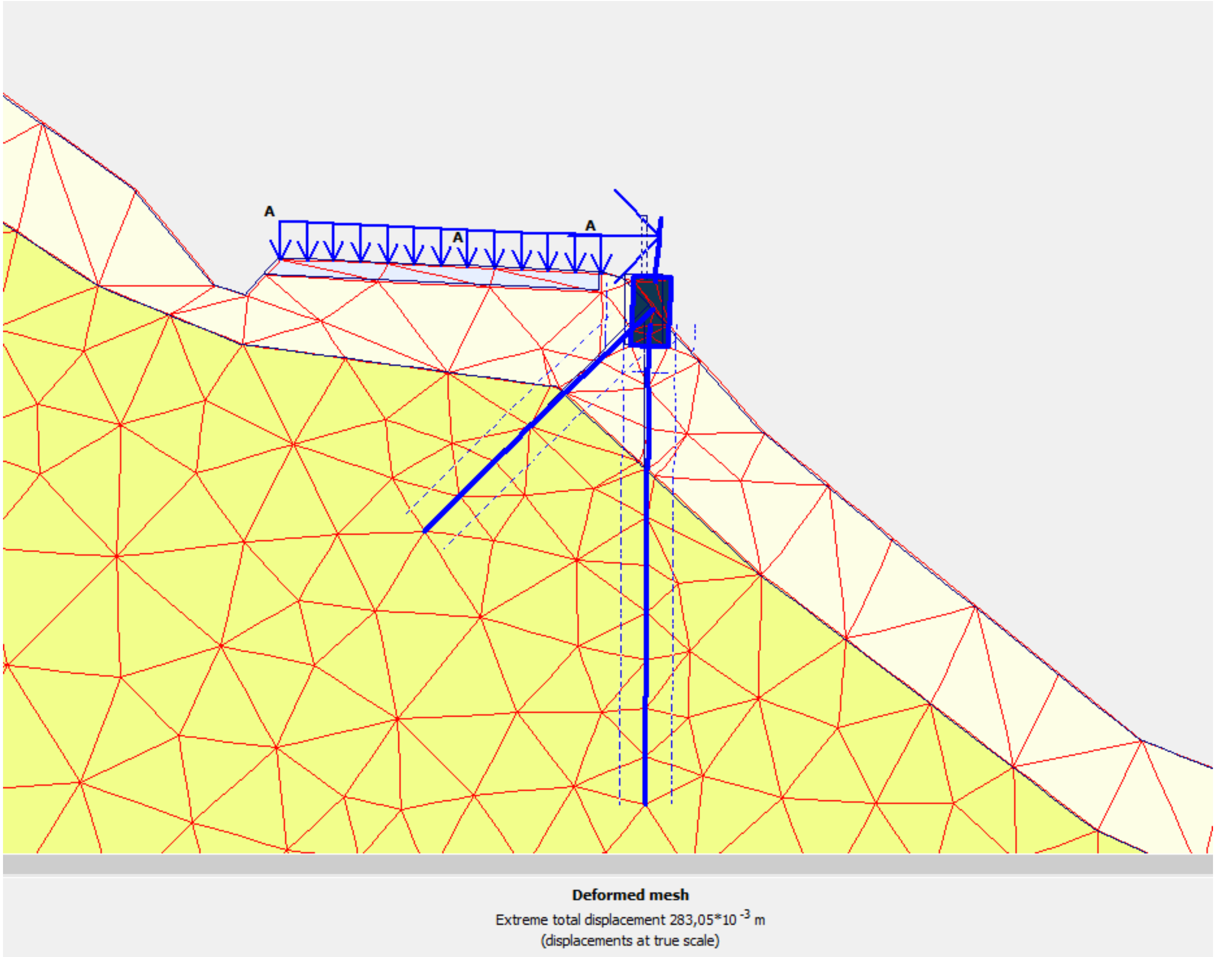


Fig. 5: Displacement of bridge guardrail for E1

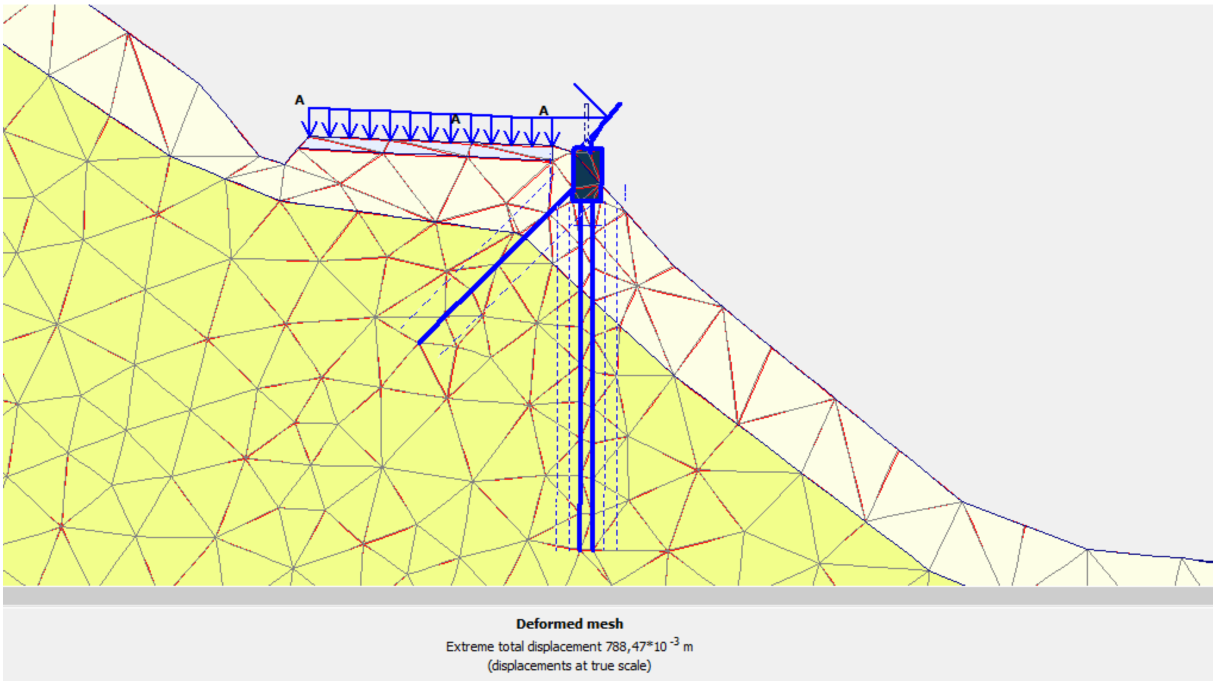


Fig. 6: Displacement of bridge guardrail for E2

## 3 Results

Numerical modeling is a very good tool for complex tasks in any segment of civil engineering. In geotechnical engineering, the FEM helps us solve often complex tasks for analytical solutions. In Figures 3 and 4, we can see that even the spatial arrangement of micropiles within the geometry can stabilize the slope in question better. The improvement in maximum deformations is up to 72%. While in Example 1 the maximum deformations are in the embankment slope, in Example 2 the maximum deformations reach the area with road traffic. These results were compared after the fourth step before the impact was applied to the bridge guardrail. In pictures 5 and 6 we can see the deformation of the bridge guardrail. While in the first Example, the guardrail-beam system moves slightly as a whole and the bridge guardrail has minor deformations, in Example 2 the spatial geometry is activated when the guardrail-beam system is stiffer in cross-section and the entire impact of the car on the guardrail is absorbed by the bridge guardrail. In this case, it turned out that the tram-micropiles system is better constructed with a spatial orientation of the micropiles from the point of view of design, safety, and maintenance.

## 4. Conclusion

The paper presents a FEM analysis of a slope slide, which is stabilized using micropiles, a reinforced concrete beam and a bridge guardrail. FEM analysis showed that the safety of the slope with micropiles was significantly improved. A plate element is used to model the micropiles. The calculation of EA and EI is shown to evaluate the equivalent values of a plate element representing the arrangement of micropiles. The spatial stiffness of the micropile-beam-barrier system was compared. The beneficial effect of the spatial orientation of the micropiles on the stiffness of the micropiles-beam-guardrail system was shown.

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