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THE REINFORCEMENT DESIGN OF THE SLOPE IN TRZĘSACZ

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Abstract: The reinforcement design of the church ruins in Trzęsacz is produced. Such a reinforcement of the slope presents a real challenge to engineers. Instead of changing the wall location, it was decided to leave it exactly in the same place where it was built in the 15th century. The reinforcement design of the slope consists of soil-nailing, reinforced soil, gabion and tetrapod. For this solution the value of the safety factor of the slope was increased from $F = 0.98$ to $F = 1.34$.

1. INTRODUCTION

The ruins of the church in Trzęsacz are the most glamorous landmark on the Polish coast. This gothic church made of bricks is situated in the neighbourhood of the highest hill at a distance of about 1800 m from the sea. It was built in the 15th century and since then the sea has been coming closer and closer to the temple. In 1750, the church was situated about 50 m from the cliff, but by1850 this distance had been reduced to 5 m only (see photo 1). The first serious damage took place in 1901, when the entire north wall collapsed into the sea. From then on, the sea has taken next fragments of the wall year by year. Today the only remaining part of the church is the south wall (see photo 2). This unique "monument" of sea abrasion has become a major attraction fascinating tourists from Poland and abroad.

Photo 1. Trzęsacz, 1870

Photo 2. Trzęsacz, 1970

2. THE TECHNOLOGY OF REINFORCING THE SLOPE IN TRZĘSACZ

The information about this design is given in the author's Masters Thesis written in France within the framework of the Erasmus/Socrates programme. It based on geological-engineering information gathered by the "Consultant" company from Szczecin, which allowed the author to use it.

It is extremely difficult to reinforce the slope as engineers, instead of changing the location of the wall, aim at leaving it exactly in the same place as that from the 15th century. This can only make the history of the place and ruins more dramatic as a spectacular example of the destructive power of waves. Bacause of the above, the place attracts a large number of tourists who want to admire this natural phenomenon. The monument can be compared to the Leaning Tower of Pisa, where the civil engineers attempt to prevent the tower from the progressive inclination, but they do not want to straighten it.

The reinforcement of the ruins in Trzęsacz is a two-step action:

- reinforcement of the slope in order to maintain its stability,
- reinforcement of the foot of the cliff in order to prevent it from sea abrasion.

The purpose of this design is to halt the process of cliff destruction, which is caused by two phenomena, namely the sea abrasion at the foot of the cliff and the atmospheric erosion of the slope. The first of the above-mentioned threats is caused by waves attacking the coast and destroying the area. The degree of destruction depends on the direction and height of the waves as well as on the proximity of a water level. The second threat is due to wind and rain.

In order to preserve the slope stability, it was calculated in that section of the slope which seemed to be most threatened with its loss, i.e. at the height of approximately 16.20 m. The calculation was carried out with TalRen program according to the Bishop method [7].

The advantage of this program lies in the fact that it allows compression forces, tensile and shear forces as well as bending moment occurring in the reinforcement to be taken into account. This is the basic principle of the analysis which is based on many criteria [5], [6] and uses the principle of maximum plastic work. The experiment on a slope reinforced with soil-nails carried out at a height of 7.5 m at the Centre d'Etudes de Batiment et des Travaux Publiques (France) shows that soil-nails not only are responsible for the tension forces, but also for the bending moment. In this case, the model of the effect of the soil-nails on tension, shearing and bending was used for calculation. A number of potential sliding surfaces were analysed. The parameters for every layer of soil were based on the laboratory tests.

The parameters representing an individual soil were accepted on the basis of a soil survey. The calculated safety factor F amounts to 0.98. This indicates that the accepted strength parameters of the cliff slope are unstable. Nevertheless, in reality, the slope appears to be stable. This means that the calculated safety factor does not correspond to reality. This mistake is as a result of an inaccurate choice of soil parameters and inaccurate application of the Bishop method.

Because the cliff slope below the church ruins reaches its limit stability, any work on the top or slope footing is very risky and can cause collapse. Therefore, before commencing any reinforcement, an abamurus from non-cohesive soil was designed as a temporary embankment. This embankment should be inclined at the angle of natural slope backfill used and has to be built from a beach level to a height of 14.37 m above sea level and its minimum width should be 6.25 m. Such a width is indispensable for a safe work. The bottom part of the embankment was protected with gabions lined with geotextile, backfill material and reinforced concrete elements (tereapod). Tereapods are the first line of defence protection of the temporary embankment against the sea; it is designed to diffuse the sea energy. Based on the Hudson formula [1], terapods were calculated at the height $H = 1.10$ m.

Additionally, the slope was widened to enable pedestrians to walk on both sides of the monument. At the time the temporary embankment was performed, a stone backfill with waterproof membrane was built. A lining pipe in the soil-nail place allowed us to avoid problems with backfill drilling. The level of the backfill was assumed to begin at a height of +9.00 m above sea level and to finish at 16.20 m above sea level (figure 1).

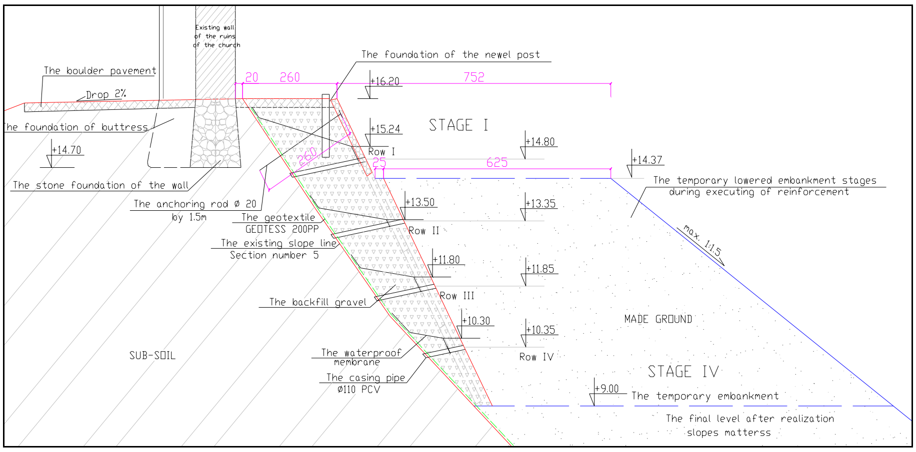

Fig. 1. The slope reinforcement above +9.00 m

In order to avoid future problems with backfill drilling during soil-nail installations at the site, a segment of pipe casing (ϕ110) made of PVC was put in. Once the temporary embankment has been raised to a level of 14.37 m, the upper part of the slope can be reinforced, while, at the same time, the temporary embankment at a level of 9.00 m above sea level can be removed. The facing slope was reinforced with gabion mattresses by laying backfill and soil-nailing arranged in 4 rows on the slope. The soil-nailing was designed with TITAN 73/53 of the a length of 12 m.

The bottom part of the slope was designed to resist the destructive power of the sea and the processes of atmospheric erosion. The reinforcement preventing the slope from sea erosion was a gabion construction being used to protect the coast on many fronts, for example, in Jastrzębia Góra [2], [3].

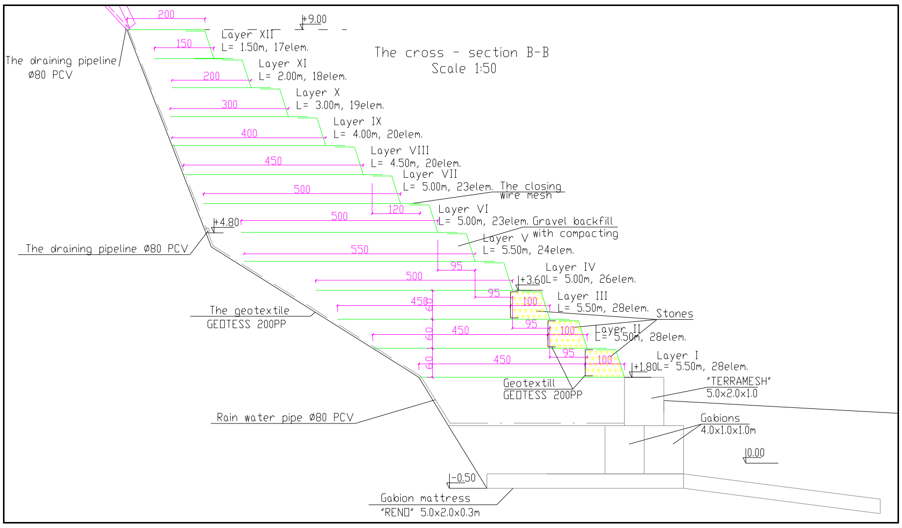

Fig. 2. The reinforcement of slope below +9.00 m

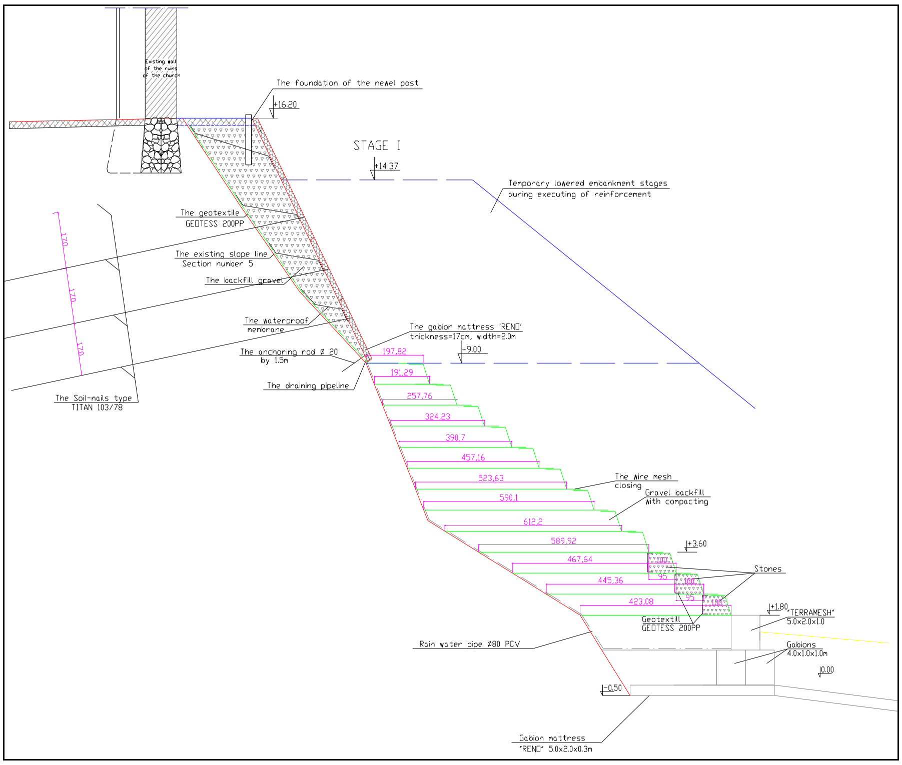

Fig. 3. The slope is reinforced with soil-nails, Terramesh and Green Terramesh

The seashore is protected by two “Reno”-type gabion mattresses (5.0 m × 2.0 m × 0.3 m) and by Maccaferii net, galvanized wire and PVC covering. This structure is filled with stones. The front gabion mattress is inclined towards the coast side, and the second one towards a level of 0.5 m below sea level. Two gabions filled with stones (4.0 × 1.0 × 1.0 m) are placed on these mattresses, and on top of these gabions the Terramesh elements are placed. The Terramesh net (5 m long) is embedded in the backfill. The top of the highest gabion is 1.80 m above sea level. Above this level, soil is reinforced by means of Maccaferii “Green Terramesh” net technology [4]. The “Green Terramesh” net those length ranges from 1.50 m to 5.50 m is filled with soil. The face of the first three layers of the “Green Terramesh” is filled with stones to protect the seashore from storm damage (figure 2).

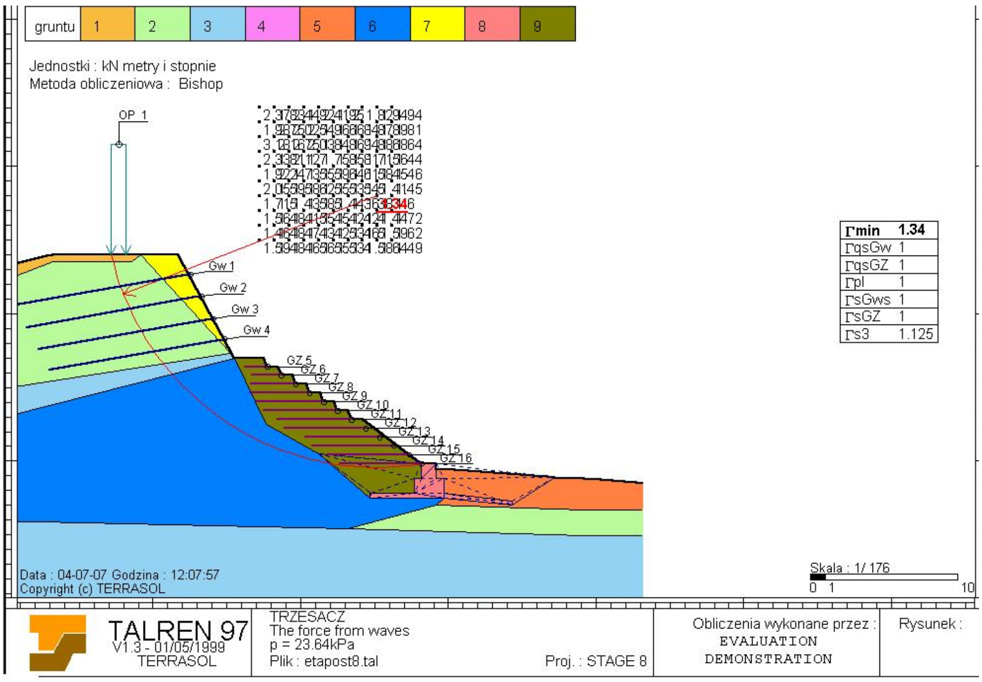

Fig. 4. The minimum global safety factor for reinforced slope

In addition, the whole surface of the cliff’s slope should be protected against atmospheric factors (e.g., wind and rain) by “MacMat” antierosion mesh. In order to hide the artificial origin of the slope and to boost its aesthetic value, the slope surface was stabilized by barren soil (above 1.80 m). For that purpose, antierosion net anchored by round steel bars and “BioMac” coconut matting (food for plants) was used. For this solution the minimum global safety factor *F* is 1.34 (figure 4).

3. CONCLUSIONS

This proposal for the slope reinforcement allows the ruins of the church to be made safe without changing its place. Because of this, Trzęsacz will still attract tourists who want to admire this phenomenon. The material that is used for building the cliff is environmentally friendly and the design itself does not change the natural surroundings.

As a result of the slope stabilization after the reinforcement design, the safety factor F has increased to the value of 1.34 (figure 4).

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