Stabilization of a sliding slope by using mixed wooden-concrete piles

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Abstract. This paper aims to present an ecological solution for stabilizing a sliding slope located near a saltwater lake, by using mixed wooden-concrete piles. Aspects about major disadvantage of wood degradation due to watering and drying were discussed since 1920. Today, due to a massive deforestation in Romania, ecological organizations are trying to limit the wood exploitation as global warming effects are becoming more and more obvious year after year. Therefore, by using mixed wooden-concrete piles, the life expectancy of a wooden structure is extended with about 80 years. This combination of wood and concrete could save natural and non-renewable materials consumption by extending the life of existing ones or, simply, by designing sustainable piles. The present research study includes a series of calculations and computer tests in order to determine the exactly dimension of the piles and their effect on slope stability.

1. Introduction

Wood is one of the oldest known materials used for different construction elements and is also in the top of sustainable resources available today.

There are a lot of characteristics that make wood an ideal construction material considering his strength to weight ratio, its durability and performance properties [1].

Wooden piles have a high durability when they are properly treated, detailed and built. Examples of ancient wooden piling system were used about 6000 years ago, by a tribe from Neolithic period also called “Swiss Lake Residents”, who lived in the current area of Switzerland.

Their houses were built on platforms supported by wooden piles, providing them protection against wild animal attacks. In 1997, workers from a federal railway project discovered the remains of 20 prehistoric villages in Concise, Vaud, near Lake Neuchâtel in Switzerland.

Countries like Germany, Austria, Switzerland, Slovenia, Italy and France have managed to have 111 of the most important dwelling on piles, located on the shore of the Alps lakes and forming UNESCO World Heritage Sites. From these, 56 belong to Switzerland [2].

Aspects about the main disadvantage of wood – degradation due to watering and drying – were discussed since 1920, when engineers started to design different solutions in order to extend the life of wooden piles.

This was the moment when capping piles were introduced, firstly made of wood or stone. After that, concrete capping was used and it is considered, by far, the best material that can be used for capping wooden piles [3].
2. Materials and methods

2.1. Materials

Today, due to a massive deforestation in Romania, ecological organizations are trying to limit the wood exploitation as global warming effects are becoming more and more obvious year after year. Also, it is an imminent need to reduce the consumption of all non-renewable resources and to limit the waste production from the construction sector. Concrete conceived in the classic recipe must be substituted by an eco-friendly concrete. In this way, a less quantity of materials need to take part to the industrial production and so, the overall quality of the surrounding environment is improved [4]. Another important aspect about this type of eco-friendly concrete is that the production costs are lower than for normal concrete as waste materials can be found at a lower price - the quantity of cement used in the mix is reduced and the aggregates are replaced with glass waste. So, the materials used are capable to provide a high durability structure, but also have also an ecological character [5].

By using mixed wooden-concrete piles, the life expectancy of a wooden structure is extended with about 80 years. This combination of wood and concrete could save natural and non-renewable materials consumption by extending the life of existing ones, or, simply, by designing sustainable piles [6].

2.2. Methods

The case study described in this paper evaluates the effect of using mixed wooden-concrete piles on the slope stability, for a new formed salted lake situated in Oglinzi Baths, located in Neamț County. The wooden piles structure is necessary to realize a wooden platform where people can relax. This study has been made using the methods recommended by European norms, by analyzing the slope in Geo Fine Software. The stability is checked by considering a polygonal and a circular sliding surface, using Morgenstern-Price method (Morgenstern 1965) [7].

In order to have more accurate analysis, four different stages were made: first stage considers the new lake and slope in its initial condition, the second stage evaluates the slope after inserting one row of piles, the third stage considers two rows of piles and the fourth stage is the most complex one, with three rows of piles.

These analyses were made in the Slope Stability Module of the geotechnical software Geo Fine Software, considering norms and information that can be applied in real practice for both engineering and architectural projects [8].

Considering the recommendations of SR EN 1997-1 [9] and the SR EN 1997-1/NB [10], the stability analysis were made considering that verification of the design effects of the actions (Ed) have to be lower than the corresponding resistance (Rd) equation (1):

$$E_d \leq R_d$$

In the stability analysis of the slopes, the effect of the actions is the overturning moment (Me,d) and the resistance is the resistance to the effect (Mr,d). So, the equation (1) becomes:

$$\frac{E_d}{R_d} = \frac{M_{Ed}}{M_{Rd}} \leq 1$$

In terms of safety factors, the relation can be written (3):

$$\frac{R_d}{E_d} = \frac{M_{Rd}}{M_{Ed}} \geq F_s$$
The Romanian standard SR EN 1997-1 introduces three design approaches in the analysis, the difference being given by the application of partial factors to loads, materials and resistances, as follows:

- **DA1** – verification is done for two sets of coefficients (Combination 1 and Combination 2) used in two separate analyzes; coefficients are applied for loads and material parameters; soil parameters are automatically reduced by appropriate partial factors;
- **DA2** – apply partial load factors and material resistance; the resistance on a sliding surface is reduced;
- **DA3** – applies partial factors to loads and material (soil parameters); soil parameters are automatically reduces by appropriate partial factors.

The national annex of Eurocode 7 recommends using the safety factors corresponding to the approach 1 in combination 2 (DA1-2) and the design approach 3 (DA3) for slope stability analysis. Considering the values of the safety factors for these two types of design approach as being identical, the calculation is performed using DA3.

The slope considered for the stability analysis has 28° and a length of 20 m, in order to observe the overall stability influence of the piles. The analyses were made considering a rapid drawdown water type and a land stratification consisting in a sequence of layers specific for Oglinzi baths terrain. From ground table to the bottom of the investigated area, the soil layers are:

- 2.89 m of mud (unit weight \( \gamma = 12 \text{kN/m}^3 \), angle of internal friction \( \phi_{ef} = 25.00^\circ \), cohesion of soil \( c_{ef} = 2.00 \text{kPa} \), saturated unit weight \( \gamma_{sat} = 18.00 \text{kN/m}^3 \) and skin friction \( g_s = 20.00 \text{kPa} \));
- 6.00 m of clay (unit weight \( \gamma = 19 \text{kN/m}^3 \), angle of internal friction \( \phi_{ef} = 5.00^\circ \), cohesion of soil \( c_{ef} = 35.00 \text{kPa} \), saturated unit weight \( \gamma_{sat} = 19.50 \text{kN/m}^3 \) and skin friction \( g_s = 40.00 \text{kPa} \));
- 0.61 m of muddy clay with salt lenses (unit weight \( \gamma = 19 \text{kN/m}^3 \), angle of internal friction \( \phi_{ef} = 15.00^\circ \), cohesion of soil \( c_{ef} = 50.00 \text{kPa} \), saturated unit weight \( \gamma_{sat} = 19.00 \text{kN/m}^3 \) and skin friction \( g_s = 60.00 \text{kPa} \)).

Under the water level, the first layer is represented by 2.27 m of mud and it continues with 4.61 m of clay and 0.61 m of muddy clay with salt lenses.

First stage considers the lake and its slope in its initial condition, without any pile. In this case, there were considered the recommendations offered in P100-1/2013 – Seismic design code [11] for earthquake analysis. The horizontal and the vertical coefficients for Oglinzi Baths are:

\[
K_h = 0.25 \quad \text{and} \quad K_v = 0
\]  

**Figure 1.** Slope stability analysis for the initial slope (polygonal slip surface) – Morgenstern-Price method: \( E_d/R_d = 1.725 > 1.00, \text{SLOPE NOT STABLE} \).

**Figure 2.** Slope stability analysis for the initial slope (circular slip surface) – Morgenstern-Price method: \( E_d/R_d = 1.548 > 1.00, \text{SLOPE NOT STABLE} \).
In this case (Figure 1, 2), both analyses (using circular and polygonal sliding surface) concluded that the slope is not stable and so, the occurrence of a landslide is imminent.

In the second stage (Figure 3, 4), a first row of wooden-concrete pile is introduced in the ground, at the bottom of the slope. The wood has the following characteristics: C24 class, diameter Ø0.20 m, length h = 5 m and pile spacing b = 3 m. For the concrete mixture, it was used the eco-friendly concrete mentioned before in the materials chapter.

The entire load of the structure (wooden circular piles Ø20 cm, wooden beams on two directions 10x12 cm, wooden floor h = 2.4 cm and connecting element) was calculated in MathCAD and after that introduced in GEO5 as maximum bearing capacity V_u = 20.13 kN.

In the third stage (Figure 5, 6), one more row of wooden-concrete piles with the same characteristics was introduced. The distance between the first pile and the second one is 3 m.

**Figure 3.** Slope stability analysis for first row of piles on the slope (polygonal slip surface) – Morgenstern-Price method: \( \frac{E_d}{R_d} = 1.647 > 1.00, \) SLOPE NOT STABLE.

**Figure 4.** Slope stability analysis for first row of piles on the slope (circular slip surface) – Morgenstern-Price method: \( \frac{E_d}{R_d} = 1.479 > 1.00, \) SLOPE NOT STABLE.

In the third stage (Figure 5, 6), one more row of wooden-concrete piles with the same characteristics was introduced. The distance between the first pile and the second one is 3 m.

**Figure 5.** Slope stability analysis for two rows of piles on the slope (polygonal slip surface) – Morgenstern-Price method: \( \frac{E_d}{R_d} = 1.548 > 1.00, \) SLOPE NOT STABLE.

**Figure 6.** Slope stability analysis for two rows of piles on the slope (circular slip surface) – Morgenstern-Price method: \( \frac{E_d}{R_d} = 1.415 > 1.00, \) SLOPE NOT STABLE.
Figure 7. Slope stability analysis for three rows of piles on the slope (polygonal slip surface) – Morgenstern-Price method: $E_d/R_d = 1.465 > 1.00$, SLOPE NOT STABLE.

Figure 8. Slope stability analysis for three rows of piles on the slope (circular slip surface) – Morgenstern-Price method: $E_d/R_d = 1.358 > 1.00$, SLOPE NOT STABLE.

In the fourth stage (Figure 7, 8), one more row of wooden-concrete piles having the same characteristics was introduced.

In this first case, for all the fourth stages performed, the slope is still not stable and shows an imminent occurrence of a landslide. This situation happened due to the earthquake effect introduced in the analysis.

In order to stabilize the slope, we have made several simulations, in order to rearrange the rows of piles which were at 3 m (in the previous case), at 2 m, but only at a distance of 1 m between rows, with a pile’s length of 5.5 m and with a diameter of Ø 30 cm, the slope becomes stable.

Figure 9. Slope stability analysis for the initial slope (polygonal slip surface) – Morgenstern-Price method: $E_d/R_d = 0.843 < 1.00$, SLOPE STABLE.

Figure 10. Slope stability analysis for the initial slope (circular slip surface) – Morgenstern-Price method: $E_d/R_d = 0.627 < 1.00$, SLOPE STABLE.

After several simulations of pile dimensions, the best model seemed to have a length of 5.5 m and a diameter of Ø 30 cm. The slope was finally stabilized. In order to verify if the piles are properly dimensioned, it was used the Anti-Slide Pile Module of the geotechnical software Geo Fine Software.

In Figure 11 are presented the displacement, bending moment and shear forces for pile no. 1. The maximum displacement is -13.0 mm, the bending + compression is satisfied (0.770 < 1) and the shear is also satisfied (0.278 < 1).
Figure 12 shows the displacement, bending moment and shear forces for pile no. 2. The maximum displacement is -10.0 mm, the bending + compression is satisfied (0.682 < 1) and the shear is also satisfied (0.288 < 1).

In Figure 13 are shown the displacement, bending moment and shear forces for pile no. 3. The maximum displacement is -8.8 mm, the bending + compression is satisfied (0.670 < 1) and the shear is also satisfied (0.344 < 1).

The second analysis was performed without taking into account the earthquake action. Slope stability analysis for the first stage was made by considering the initial slope for both slipping surfaces (polygonal and circular).

In the second stage (Figure 16, 17) is introduced the first row of mixed wooden-concrete piles with a length of 5 m and a diameter of Ø 20cm.

In the third stage (Figure 18, 19), one more row of wooden-concrete piles with the same characteristics was introduced. Like in the previous case, the distance between the first pile and the second one is 3 m.

In the second case, the slope was stable from the beginning. Even so, the displacement of three rows of mixed wooden-concrete piles lead to a consolidation of the site. In order to verify if the piles are properly dimensioned, it was used the Anti-Slide Pile Module of the geotechnical software Geo Fine Software [12].
Figure 14. Slope stability analysis for the initial slope (polygonal slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.711 < 1.00 \), SLOPE STABLE.

Figure 15. Slope stability analysis for the initial slope (circular slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.708 < 1.00 \), SLOPE STABLE.

Figure 16. Slope stability analysis for first row of piles on the slope (polygonal slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.662 < 1.00 \), SLOPE STABLE.

Figure 17. Slope stability analysis for first row of piles on the slope (circular slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.606 < 1.00 \), SLOPE STABLE.

Figure 18. Slope stability analysis for two rows of piles on the slope (polygonal slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.560 < 1.00 \), SLOPE STABLE.

Figure 19. Slope stability analysis for two rows of piles on the slope (circular slip surface) – Morgenstern-Price method: \( E_d/R_d = 0.510 < 1.00 \), SLOPE STABLE.
Figure 20. Slope stability analysis for three rows of piles on the slope (polygonal slip surface) – Morgenstern-Price method: $E_d/R_d = 0.506 < 1.00$, SLOPE STABLE.

Figure 21. Slope stability analysis for three rows of piles on the slope (circular slip surface) – Morgenstern-Price method: $E_d/R_d = 0.440 < 1.00$, SLOPE STABLE.

Figure 22. Dimensioning analysis for pile no. 1.

Figure 23. Dimensioning analysis for pile no. 2.

In Figure 22 are presented the displacement, bending moment and shear forces for pile no. 1. The maximum displacement is -1.6 mm, the bending + compression is satisfied ($0.179 < 1$) and the shear is also satisfied ($0.052 < 1$).
Figure 23 shows the displacement, bending moment and shear forces for pile no. 2. The maximum displacement is -2.2 mm, the bending + compression is satisfied (0.184 < 1) and the shear is also satisfied (0.054 < 1).

In Figure 24 are shown the displacement, bending moment and shear forces for pile no. 3. The maximum displacement is -2.1 mm, the bending + compression is satisfied (0.156 < 1) and the shear is also satisfied (0.034 < 1).

3. Conclusions

After several simulations using Geo Fine Software using Morgenstern-Price method with both polygonal and circular sliding surface, we concluded that, an earthquake will affect the slope stability even with three rows of anti-slide wooden-concrete piles. In order to make this slope stable, the piles rows must be at a distance of 1 m and the piles must be at least 5.5 m long and with a diameter of at least Ø 30 cm. On the other side, if an earthquake is not taken into consideration, the slope is stable and by adding three more anti-slide piles with a length of 5 m, a diameter of Ø 20 cm and a distance between rows of 3 m, it becomes even more stable.

The results of the study shows that by displacing three rows of piles, they will provide an improvement of slope stability, but not enough to increase shear resistance for the earthquake action. Even so, taking into account that the price of this structure is quite small and it can be easily made, it should be taken into consideration. This structure is not presenting any risk for people located on it because they can easily step out of it.

In conclusion, in our opinion, the proposed structure using mixed wooden-concrete piles can be used near a saltwater lake in Oglinzi Baths. Depending on the importance of the construction, it is authorities decision what case to use for implementation.

4. References

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