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Considerations Regarding the Choice of Construction Methods and Techniques to Limit the Environmental Footprint of Structures

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Summary

Environmental concerns are becoming increasingly central to construction and rehabilitation projects, calling for a more proactive role from geotechnical engineers in minimizing carbon impacts. This includes optimizing construction techniques, reducing material volumes, and evaluating a broad set of environmental indicators (*e.g.*, EN 15804). To support this effort, the software *Ecow*, developed by Terrasol, enables the environmental assessment of various geotechnical solutions using ten indicators, including climate change potential. The tool also aims to integrate the positive impacts of low-carbon technologies such as geothermal systems and energy geostructures. This paper presents a comparative study of three geotechnical reinforcement solutions for a single project, using *Ecow* to evaluate both environmental and geotechnical performance, as well as financial cost — a critical parameter in design decision-making.

1 Introduction

While greenhouse gas (GHG) emissions are a key driver of climate change and a major focus of carbon reduction strategies, they represent only one facet of the environmental footprint of construction. The EN 15804 standard highlights the need for a comprehensive life cycle assessment (LCA) across ten environmental indicators, including resource depletion, air and water pollution, and eutrophication. In geotechnical engineering, minimizing environmental impact goes beyond structural optimization — it starts with the informed selection of technical solutions. To achieve this, engineers must be equipped to quantify and compare the environmental performance of alternative designs, while also considering innovative, low-carbon technologies such as geothermal systems and energy geostructures.

2 Levers for the Geotechnical Engineer

Integrating environmental considerations into geotechnical design requires decision-support tools adapted to early project phases and available data. In response, Terrasol has developed *Ecow*, a module within the *Orbow* platform, enabling engineers to evaluate and compare the environmental footprint of various technical solutions. Beyond tools, a second lever for reducing impact lies in rethinking conventional design practices — particularly the use of safety factors, which significantly affect material quantities. By exploring displacement-based design approaches and refining the understanding of time-dependent behaviour, engineers can achieve higher material efficiency while maintaining performance and safety, ultimately supporting more sustainable geotechnical solutions.

3 Low Environmental Impact Design Choices

Assessing the environmental footprint of geotechnical solutions involves significant methodological complexity due to heterogeneous and often incomplete input data. This challenge is amplified by evolving standards and the variability of emission factors (EFs) across databases, which can differ in modeling assumptions and system boundaries. To ensure reliability, the *Ecow* tool incorporates a carefully curated selection of EFs, chosen for their consistency and relevance to geotechnical applications. EF values are subject to uncertainty. Beyond the values themselves, it is crucial to compare uncertainty ranges to adopt a cautious approach when interpreting results.

To address the limitations of existing carbon estimation tools Terrasol has developed the *Ecow* module, integrated into the *Orbow* platform. Designed to quantify GHG emissions across a wide range of geotechnical activities (e.g., earthworks, foundations, retaining structures, soil reinforcement), *Ecow* also enables scenario-based comparisons. By adopting the EN 15804 standard's ten environmental indicators, the tool supports a multicriteria life cycle assessment. Developed through a critical review of key databases, *Ecow* offers a streamlined yet robust interface suitable for both design and construction engineers, with future integration of low-carbon innovations such as geothermal systems and energy geostructures.

4 Study case

Within the scope of this study, a rehabilitation project of a retaining structure supporting a road infrastructure is analysed. The primary hypothesis assumes that the excessive displacements observed at the top of the wall are caused by the earth pressure induced by the loads applied at the wall head. To ensure the stability of the structure and limit these deformations, three distinct geotechnical reinforcement solutions were considered and compared (see Figure 1):

- solution 1 : slab on micropiles ;
- solution 2 : soil-nailed wall ;
- solution 3 : micro-Berlin-type walls.

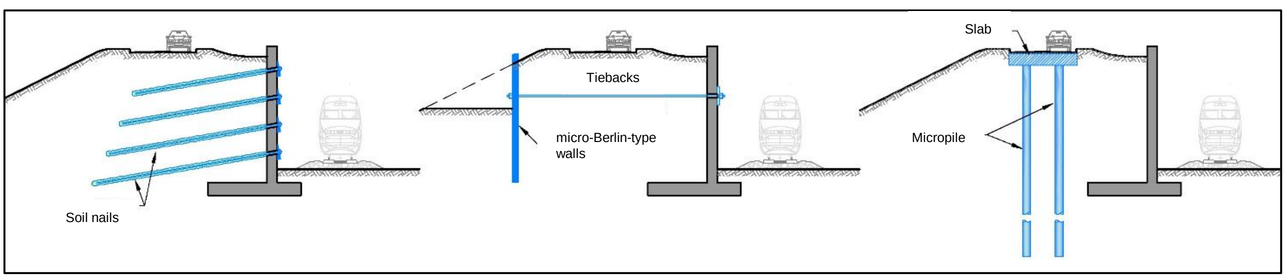

Figure 1: Diagram of the three geotechnical solutions studied

To enable a meaningful comparison between reinforcement solutions, geotechnical design calculations were performed to ensure uniform performance levels. Despite differing technical features and implementation constraints, each variant was designed using harmonized assumptions, ensuring comparable geotechnical efficacy.

5 Environmental Footprint of the Different Design Alternatives

A comparative chart of greenhouse gas (GHG) emissions is provided below (see Figure 2) for the three solutions: micropile slab (Solution 1), soil-nailed wall (Solution 2), and micro-Berlin-type walls (Solution 3).

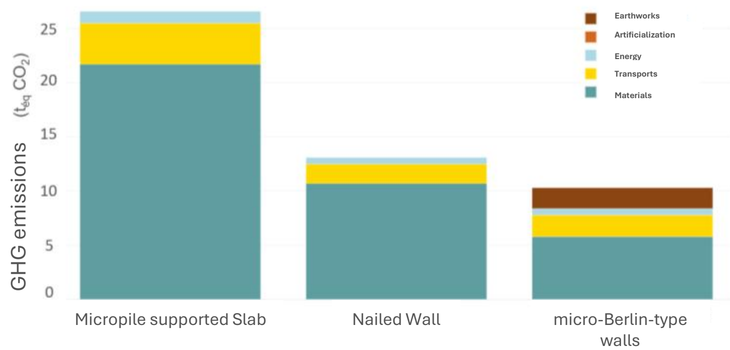

Figure 2 : Comparison of average GHG emissions across the three solutions by material

The carbon footprint analysis reveals that the micropile slab (Solution 1) has the highest greenhouse gas (GHG) emissions, mainly due to the substantial material use required for deep anchorage. In contrast, the nailed wall (Solution 2) and micro-Berlin-type wall (Solution 3) exhibit similar, lower emissions. Among them, Solution 3 emerges as the least carbon-intensive option. A multicriteria assessment (see Figure 3) confirms this trend, with Solution 1 performing worst across all environmental indicators. Notably, environmental and economic evaluations are aligned in this case: Solution 3 not only has the lowest environmental impact but also the lowest cost. These findings highlight the potential for environmentally and economically optimized geotechnical design.

Figure 3: Multicriteria analysis based on EN 15804 indicators

6 Impact of Regulatory Framework

Beyond the comparative analysis of alternatives, it is worthwhile to adopt a broader perspective and examine the impact of safety factors on the environmental footprint of selected design solutions. Within the Eurocode framework — and more generally in design codes based on the limit state approach — a safety factor is applied to resistance values. This implicitly limits displacements, although displacement verification is not always explicitly conducted. For certain structures, settlements or horizontal displacements may not impair their function, opening the door to further optimization through higher utilization rates. That said, reducing the safety factor can, in some cases, activate second-order mechanisms. Therefore, the objective is not to eliminate safety margins but to rationalize them on a case-by-case basis for potential optimization.

An example is given for the micropile slab solution (Solution 1). Figures 4 and 5 demonstrate that, in this study: reducing the global safety factor on bearing capacity from 2.0 to 1.5 (i.e., down to the creep load) increases settlement by a factor of 1.4 (from 5 mm to 7 mm — an acceptable increase) while significantly reducing GHG emissions. For lower safety factors, the creep load is exceeded, and settlements increase rapidly.

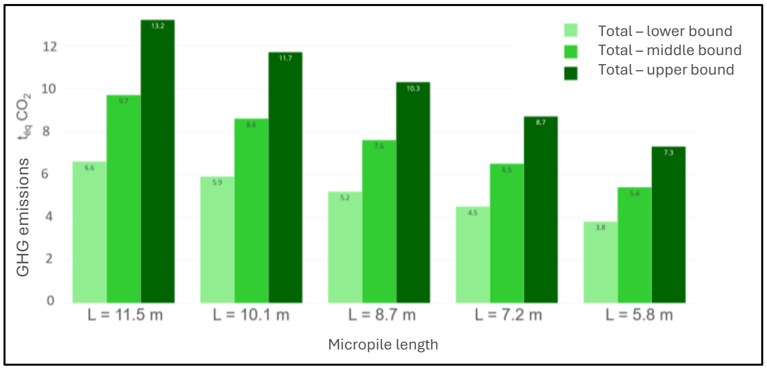

Figure 4: Carbon emissions of micropiles as a function of length

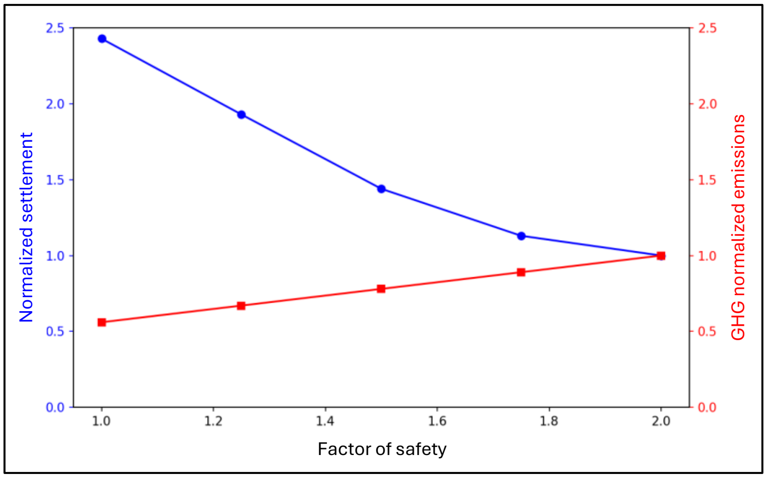

Figure 5: Normalized settlement and GHG emissions as a function of safety factor on ultimate bearing capacity

7 Conclusion

This paper presents a comparative analysis of the environmental impact of a geotechnical project by evaluating three distinct technical alternatives. The results reveal that, beyond structural optimization, rethinking design strategies from an environmental perspective can lead to significant reductions in greenhouse gas emissions and improvements across other environmental metrics. The study also highlights the influence of safety factors on bearing capacity verifications related to vertical settlement, as well as the associated emissions. Looking ahead, integrating the positive contributions of energy-generating structures — such as energy piles and thermal geostructures — into the global environmental balance offers a promising path forward.

References

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