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Environmental life cycle assessment of ground reinforcement using rigid inclusions

Analyse du cycle de vie du renforcement de sol par inclusions rigides

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ABSTRACT: There are increasing societal and political concerns about the consequences of human activities on climate change and other environmental issues. In that sense, methodologies such as Life Cycle Assessment (LCA) are being developed to evaluate technical systems based on their function, considering the whole life cycle in a multi-criteria approach. Applied to the construction sector since the 1990s, particularly to buildings and other civil engineering structures, little has been done so far on geotechnical works specifically. This contribution seeks to present an application of LCA to soil reinforcement solutions in the framework of the ASIRI+ National Project. The objectives of the assessment are, first, to quantify the environmental impacts potentially generated when implementing rigid inclusions as ground improvement techniques, and second, to compare them with the impacts of other possible solutions. The study highlights the contribution of materials such as cement, lime and steel to the overall impacts, and particularly climate change, the importance of optimizing their use when designing and implementing solutions, and the need for contextualized data for such materials. It also stresses the importance of extending the limits of the assessed system to include foundations, and not to strictly focus on rigid inclusions.

RÉSUMÉ: Les préoccupations sociétales et politiques concernant les conséquences environnementales des activités humaines vont croissantes. De ce fait, les méthodologies telles que l'Analyse du Cycle de Vie (ACV) sont développées pour évaluer les systèmes techniques sur la base de leur fonction, en considérant l'ensemble du cycle de vie, dans une approche multicritère. Appliquée au secteur de la construction depuis les années 1990, peu d'études portent spécifiquement sur les ouvrages géotechniques. Cette contribution vise à présenter une application de l'ACV à des solutions de renforcement de sol, investiguées dans le cadre du Projet National ASIRI+. Les objectifs de l'analyse sont, tout d'abord, de quantifier les impacts environnementaux potentiels générés lors de la mise en œuvre des inclusions rigides comme technique de renforcement de sol, et ensuite de les comparer avec les impacts d'autres solutions envisageables. L'étude souligne la forte contribution de matériaux tels que le ciment, la chaux et l'acier aux impacts totaux, et la nécessité de données contextualisées pour ces matériaux. Elle montre également la nécessité d'étendre les limites du système étudié pour inclure les fondations, et non pas regarder strictement les inclusions rigides.

Keywords: Life cycle assessment (LCA); soil reinforcement; rigid inclusion; ASIRI+.

1 INTRODUCTION

Governmental bodies, companies and the public are increasingly concerned about the consequences of human activities on climate change and other environmental issues (depletion of resources, biodiversity loss, or degradation of human health). To translate these concerns into action, it is necessary to understand what are the impacts of such activities, how to reduce them, and/or to identify alternatives delivering the same service, with better environmental performances. In that sense, methodologies such as environmental Life Cycle Assessment (LCA) are being developed to evaluate technical systems based on their function, considering the whole life cycle (from extraction of material to end of life) in a multi-criteria approach (Jolliet et al., 2017). Applied to the construction sector since the 1990s, particularly to buildings (Peuportier et al., 1997) and other civil engineering structures (Horvath 2006; de Bortoli et al 2020), little has been done on geotechnical works specifically, until recently (Basu et al., 2013; Raymond et al., 2021).

This contribution presents an application of LCA to soil reinforcement solutions using rigid inclusions, analysed in the framework of the ASIRI+ French National Project. Its objectives are, first, to quantify the environmental impacts potentially generated when implementing rigid inclusions as ground improvement techniques, and second, to compare them with the impacts of other solutions.

2 METHODOLOGY

2.1 Goal and scope definition

The approach adopted in this paper follows the guidelines described in ISO 14040 standards (ISO 2006) for the application of LCA (Saadé and Jolliet 2024). It consists first in defining a functional unit (FU), representing the function of the modelled system (goal and scope definition) and serving as the reference unit for the quantification of material flows and environmental impacts. For different modelled scenarios, flows of matter and energy emitted to and extracted from the environment are quantified per FU (life cycle inventory). Based on these flows, potential impacts are evaluated in different environmental categories or areas of protection (climate, human health, ecosystems…) in the life cycle impact assessment phase. During these different phases, results are being discussed and limitations described (interpretation).

2.2 Case study

The case study considered corresponds to the foundation system of the bus station attached to the multimodal transport centre of the City of Nice, France (Chen 2022), located in a moderated sismic hazard area (zone 4) according to the French regulation.

Table 1. Soil characteristics.

Level	γ [kN/m^3]	p_l [MPa]	E_M [MPa]	α [-]
+6,5 to -10,5	20	0,3	5,0	½
-10,5 to 14,5	21	2,5	23,0	¼
Under 14,5	20	0,3	5,0	½

The foundation of the bus station covers a surface of 5800 m^2, on of B2 class soil according to the Natural Riks Prevention Plan (Table 1). The solution implemented for the foundation is a concrete slab on a soil reinforced by rigid inclusions and ductile cast iron piles. An alternative solution considered consists of a concrete slab on soil reinforced by concrete and ductile cast iron piles. Data for both solutions are provided by the company Keller Fondations Spéciales.

2.2.1 Functional unit

The functional unit is defined as the "foundation of the bus station operational for a duration of service of 50 years for the soil characteristics given in Table 1".

2.2.2 System boundaries

The system boundaries are given in Figure 1. They include the extraction of resources and the processes required for the production of materials (concrete, mortar, cast iron, reinforcing steel…), transport of materials, the use of engines on the construction site, demolition and recycling. Transportation of engines and workers are not taken into account.

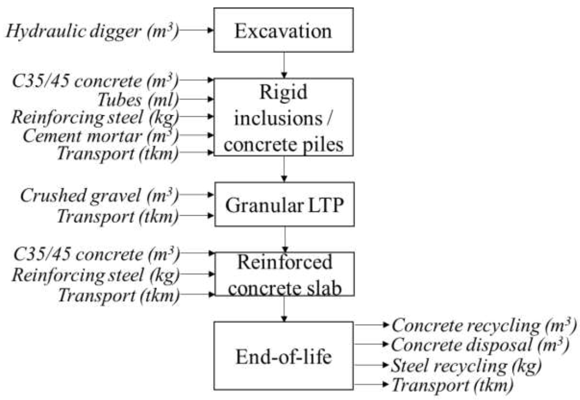

Figure 1. System boundaries.

2.2.3 Scenario definition

The two previously described scenarios are considered.

Table 2. Material quantities per scenario.

Material	Scenario 1	Scenario 2
Armed RI		
Concrete	749 m^3	-
Tubes	34600 kg	-
Concrete piles		
Concrete	-	695 m^3
Reinforcing steel	-	34760 kg
Ductile cast iron piles		
Tubes	16950 kg	16950 kg
Cement mortar	53 m^3	53 m^3
Platform	2320 m^3	1740 m^3
Slab		
Concrete	2030 m^3	2900 m^3
Reinforcing steel	111650 kg	261000 kg

The first scenario (actually implemented and proposed by the contractor) consists of a C35/45 reinforced concrete slab (0,35 m thick) + granular load transfer platform LTP (0,4 m thick) + armed rigid inclusions and ductile cast iron piles (functioning as rigid inclusions). Rigid inclusions are constituted of a

XA2 C35/45 concrete and armed with a 114 mm diameter tube; 6,2 mm thick. Ductile cast iron piles consist of tubes with a diameter of 118 mm and 9 mm thick. They are covered with a coating of cement mortar to avoid corrosion. The steel ratio in the slab is 55 kg/m^3.

The second scenario (basic solution proposed by the project manager) consists of a C35/45 reinforced concrete slab (0,5 m) + granular load transfer platform LTP (0,3 m) + concrete piles (below the structure loads) and ductile cast iron piles (functioning as rigid inclusions). In this case, the steel ratio in the slab is about 90 kg/m^3.

2.2.4 Data and assumptions, LCI database and LCIA method

Foreground data regarding the material quantities have been collected from the Keller company (Table 2). For concrete, the transport distances considered to the concrete plan are 30 km for aggregates, 49 km for cement (Portland), 232 km for blast furnace slag, 1230 km for additives. The distance between the concrete plan and the construction site is estimated at 15 km. Steel and granular material for the LTP are transported over a distance estimated at 100 km and 50 km respectively.

Background data are provided by the ecoinvent database (Frischknecht et al., 2007). The impacts are calculated using the set of indicators provided by the EN15804 standard (AFNOR 2014).

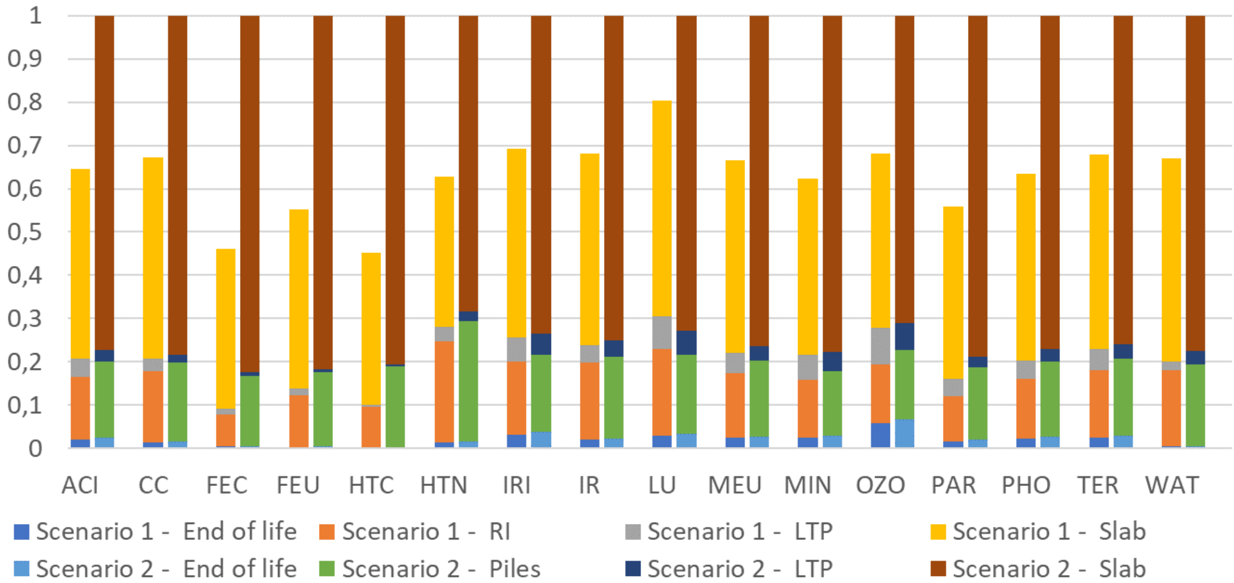

Figure 2. Comparison between the two scenarios, relative to the maximum impact score per environmental category. ACI: Acidification; CC: Climate change; FEC:Freshwater ecotoxicity; FEU: Freshwater eutrophication; HTC: Human toxicity, cancer effects; HTN: Human toxicity, non-cancer effects; IRI: Ionizing radiation E (interim); IR: Ionizing radiation HH; LU: Land use; MEU: Marine eutrophication; MIN: Mineral, fossil & ren resource depletion; OZO: Ozone depletion; PAR: Particulate matter; PHO: Photochemical ozone formation; TER: Terrestrial eutrophication; WAT: Water resource depletion.

3 RESULTS

3.1 Comparison of the two scenarios

Figure 2 compares the impacts of scenarios 1 and 2 considering the contribution of the different sub-processes of the system. Taking into account the foundation system (slab + load transfer platform + soil reinforcement solution), scenario 2 appears to have the largest impact for all categories. Most of its impact comes from the concrete slab, which explains between 70 and 80% of the overall impact, according to the environmental category. For example, respectively 45% and 35% of the climate change score are related to the production of concrete and reinforcing steel used in the slab. 20 to 30% of the impacts are related to the production and transport of the soil reinforcement solution. The granular mattress represents a few percentages of the total impact. The contribution of materials transport to the overall impact is also limited compared to materials production (Figure 3).

The impacts of scenario 1 are also dominated by the reinforced concrete slab, but in a relatively lesser extent. The relative contribution of the soil reinforcement solution is in the same order of magnitude (between 20 and 30% of the total impact depending on the environmental category). The better environmental performance of the first scenario is explained by the lower amount of concrete and reinforcing steel used for the slab, but is still dominated by production of materials (concrete, reinforcing steel, cast iron) as illustrated by Figure 3.

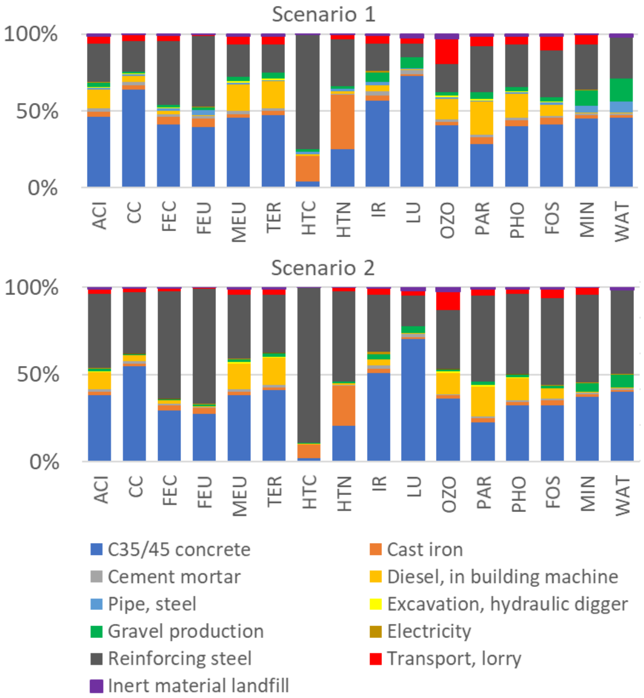

Figure 3. Scenario 1: Contribution analysis.

4 CONCLUSIONS

The study shows that materials such as cement and steel are major contributors to the overall impacts, and particularly climate change. It is therefore important to optimize their use when designing and implementing soil improvement solutions. It also stresses the need for contextualized data for such materials. The study also highlights the importance of extending the limits of the assessed system to include foundations, and not to strictly focus on soil reinforcement solutions, here rigid inclusions.

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REFERENCES

AFNOR (2014) NF EN 15804+A1, Sustainability of Construction Works - Environmental Product Declarations - Core Rules for the Product Category of Construction Products. AFNOR.

Basu, D., Misra, A., Puppala, A.J., Chittoori, C.S. (2013) Sustainability in Geotechnical Engineering, In: *Proceedings of the 18th International Conference on Soil Mechanics and Geotechnical Engineering*, Paris, France, pp. 3171- 3174.

Chen, Y. (2022) *Impacts environnementaux des solutions de renforcement de sol par incusions rigides: focus sur la Plateforme de Transfert de Charge (PTC)*, Master Mécanique des sols et des roches dans leur environnement 2021-2022, Ecole des Ponts ParisTech.

de Bortoli, A., Bouhaya, L. & Feraille, A. (2020) A life cycle model for high-speed rail infrastructure: environmental inventories and assessment of the Tours-Bordeaux railway in France, *International Journal of Life Cycle Assessment*, 25:814–830. https://doi.org/10.1007/s11367-019-01727-2.

Frischknecht, R., Jungbluth, N., Althaus, H.-J., Doka, G., Heck, T., Hellweg, S., Hischier, R., Nemecek, T., Rebitzer, G., Spielmann, M., Wernet, G. (2007) Overview and Methodology. ecoinvent report No. 1, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

Horvath, A. (2006) Environmental Assessment of Freight Transportation in the U.S., *International Journal of Life Cycle Assessment*, 11:229–239, https://doi.org/10.1065/lca2006.02.244.

ISO 2006a. ISO 14040: Environmental Management—Life Cycle Assessment—Principles and Framework.

Saadé, M. and Jolliet, O. (2024). *Analyse du cycle de vie, Comprendre et réaliser un écobilan*, 4th edition, EPFL Press, Lausanne, Switzerland.

Peuportier, B., Kohler, K., Boonstra, C. (1997) European project REGENER, life cycle analysis of buildings. In: 2nd International Conference "Buildings and the Environment." Paris, 9-12 Juin 1997, p 8.

Raymond, A.J., DeJong, J.T., Kendall, A., Blackburn, J.T., Rick Deschamps, R. (2021) Life Cycle Sustainability Assessment of Geotechnical Ground Improvement Methods, *Journal of Geotechnical and Geoenvironmental Engineering*, 147(12):04021161 https://doi.org/10.1061/(ASCE)GT.1943-5606.0002646.