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Life cycle analysis of an innovative reinforcement geosynthetic coupled with a detection and monitoring warning system

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ABSTRACT: The use of reinforcement geosynthetics to prevent localized collapses over cavities is now relatively common. During the REGIC research project, an innovative geosynthetic solution has been developed. It includes a specific reinforcement geosynthetic coupled with an autonomous and remote warning device to detect, to locate and then monitor a localized collapse or sinkhole. This study identifies technically and environmentally the implementation conditions of this innovative instrumented geosynthetic solution compared to the traditional solution. The Life Cycle Analysis is realized to carry out this comparison from an environmental point of view. The results, including a sensitivity analysis aim to provide information on the environmental performance of the developed instrumented solution in a R&D framework. This detailed analysis is extended to most current other possible solutions with same level of performance and safety. This life cycle analysis finally resulted in the publication of an EPD® for the geosynthetic range concerned.

1 INTRODUCTION

The coupling of an auscultation and warning system to a reinforcement geosynthetic is a judicious innovative solution in case of sensitive structures like areas with high risk of soil subsidence. Although there exist already some reference studies on the Life Cycle Assessment of solutions incorporating geosynthetics, it seems important to evaluate the influence of auscultation and warning system on the environmental impact and to compare it with other currently used solutions as concrete solution. During the REGIC (Reinforcement using Intelligent Geosynthetics over Natural or Anthropic Cavities) research project, an innovative and warming geosynthetic solution has been developed. The Life Cycle Analysis is realized to carry out this comparison from an environmental point of view. It presents a sensitivity analysis for identifying the most influencing parameters; it is then extended to other solutions offering the same level of performance and security to the Owner.

2 OBJECTIVE AND SCOPE OF THE STUDY

The data of this study is based on the characteristics of a real construction site in Lille (France). It concerns the reinforcement above a 2 m diameter cavity. The solutions require

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zero residual settlement for a service life of 100 years. Different technical solutions and monitoring and warning methods are proposed:

- Reference solution: concrete slab with a 16 m^2 and 25 cm thick of concrete. A volume of 24 m^3 of soil is excavated for pouring the 4 m^3 concrete slab. Then 20 m^3 of soil is covering the concrete slab and 4 m^3 is deposited. The slab is reinforced with 50 kg/m^3 of iron. Monitoring is planned with a visit every 7 years.
- Solution (a) - Reinforcement by geosynthetic without auscultation: This is designed in accordance with standard NF XP G 38065, for a service life of 100 years with zero residual settlement on the surface. Monitoring by the project owner is planned with a visit every 7 years. This geosynthetic will be called FPET-600.
- Solution (b) - Reinforcement by geosynthetic FPET-600 with automatic monitoring and inspection: As the same design as the solution (a) but with instrumented monitoring. Monitoring by the project owner is planned with a visit every 7 years.
- Solution (c) - Optimised reinforcement geosynthetic FPET-150-I with automatic monitoring and inspection: As the same design as other solutions but with optimized characteristics. Monitoring by the project owner is planned with a visit every 7 years. The optimization considers the reduction of the intervention time of the project owner linked to the alert system.
- Solution (d) - Pre-instrumented geosynthetic without a warning system: It allows the measurement of possible deformations of the geosynthetic but assumes a follow-up by the project owner through an annual visit.

3 LIFE CYCLE ASSESSMENT

The Life Cycle Assessment (LCA) study is conducted based on the standards ISO 14040, ISO 14044 and ISO 14025. In accordance with the European standard EN 15804 + A1, the "cut-off" approach is applied to the systems studied. This means that the materials resulting from recycling or reuse are considered free of any environmental impact. In order to be able to compare the different solutions, it is necessary to determine a Functional Unit (FU) common to all the products compared and defined in the ISO 14044 standard as "the quantified performance of a product system, intended to be used as a reference unit in an LCA". The FU will be used to weight and base the results of this LCA on a common basis in order to make optimal choices.

In this LCA, the functional unit considered is the following: Reinforcement of a cavity of 2 m diameter for 100 years.

The surface to be covered (64 m^2, to take into account the lateral anchors) is excavated to a depth of 1.5 m. A volume of 95.4 m^3 is excavated. The machinery used for the earthworks is estimated on the basis of (Suer P. & Andersson-Sköld, Y. 2011) which considers the use of a hydraulic excavator and a compactor. The same volume of soil is excavated and backfilled.

3.1 *Production data*

As the concrete slab is produced on site, only the production of geosynthetics, whether instrumented or not, is considered. For geosynthetic solutions, the production data is based on that of the factory in Saint-Didier-de-la-Tour (France) for the year 2019. They include raw material consumption including losses related to the manufacture of geosynthetics, consumption by suppliers of reinforcement yarns, considering the energy mix of the country where these yarns are manufactured and the consumption for assembly at the Saint-Didier-de-la-Tour plant (France). They also include packaging consumption, production waste and transport stage.

In the case of instrumented geosynthetics, the production of optical fibres should also be considered. For the purposes of this study, it is assumed that one metre of optical fibre is required for the design of 1 m^2 of instrumented geotextile and the data is based on the data provided by (Unger & Gough 2008).

3.2 *Data for the completion of the project*

The construction data considers the phasing and quantities defined in paragraph 2.

The data from the operation phase considers the different scenarios defined in 2. For this study, it was assumed that an average distance of 100 km was covered during the visits to the structure. For the scenarios based on instrumented solutions, the use phase requires to consider the electricity consumption of the monitoring system, or even the use of a measurement box. The electrical consumption depends on the type of box, depending on the type of optic fibre used. For the present study, a box for Bragg gratings was considered, with a 15 minutes per day were devoted to measurements. In the case of a connection to the electrical network, the site being in Lille, the French mix was used. For data transfer, sending and storage of emails, different options were considered. The electrical consumption required for the transmission and storage of emails is taken from the studies (Pflueger 2010) and (Schmidt *et al.* 2009). The data on the Bragg grating measurement box takes into account different electronic components with a weight of 800 g. The steel casing was heavier than normal (7 kg) to allow for the later integration of components such as batteries and solar panels. The lifetime of the electronic components is estimated at 7 years.

As the use of the geosynthetics, or the concrete slab, is considered permanent (100 years), no end of life is considered in the analysis.

4 ENVIRONMENTAL IMPACT ASSESSMENT AND SENSITIVITY ANALYSIS

For the assessment of environmental impact, the indicators selected are those recommended by the EN 15804 + A1 standard for environmental declarations of construction products, to which is added the cumulative energy consumption.

For a complete sensitivity analysis to optimize the impact of the system, the study carried out in the framework of the research project integrated the influence of the following parameters:

- energy consumption for monitoring;
- the power source of the monitoring box: solar panels or others;
- the duration of daily use of the monitoring system
- the service life of the structure;
- the duration of storage of the e-mails sent by the box;
- the size of the site;
- the end of life of the geotextiles: in the case of a short-term application (e.g., reinforcement of cavities in a mining activity), next to the excavation and transport activities, a treatment by incineration can avoid the consumption of fossil resources.
- the country of implementation of the structure; in addition to the transport from the production plant to the construction site, this has an impact on the electricity mix used for monitoring and on the impact of alternative solutions.

4.1 *Impact on the cumulative energy consumption*

The global LCA analysis assesses environmental impact through several categories of impacts such as global warming, cumulative energy consumption, photochemical oxidation, resource depletion, water consumption, ozone depletion, etc. In this article we focus on the environmental impact on the cumulative energy consumption.

The cumulative energy consumption of the concrete slab solution is 20.8 GJ/FU, compared to 13.6 GJ/FU for the non-instrumented geosynthetic reinforcement solution (a) and 34.1 GJ/FU for the instrumented geosynthetic reinforcement solution (b) (Figure 1).

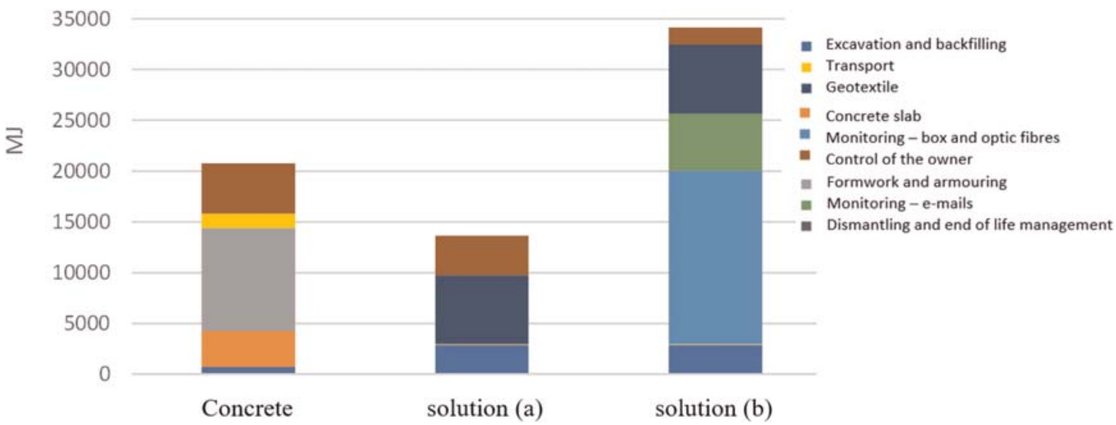

Figure 1. Comparison of the impact on cumulative energy consumption of the 3 reinforcement scenarios.

The instrumented geosynthetic reinforcement solution (b) requires the most energy resources over its life cycle. The impacts of the 'concrete slab' and non-instrumented geotextile (a) solutions are respectively 39 % and 60 % lower.

For the "concrete slab", the first contributor corresponds to the production of the reinforcement (48 %). The second is related to the project owner's travel (24 %), followed by the production of the concrete (17 %). For the non-instructed geosynthetic (a), the first contributor is linked to the production of the product (50 % of the total impact); this is mainly due to PET fibres. The second contributor is related to the project owner's travel (29 %), followed by earthworks (21 %).

For the instrumented geosynthetic (b): the first contributor is linked to the production of the monitoring and warning box (approximately 50 %), followed by the production of the geosynthetic and the transfer and storage of emails. The impact of the monitoring, assessment, and warning system ("box and optic fibre") is 60 % attributable to the production of the box and 40 % to electricity consumption.

The mechanical dimensions of the non-instrumented (a) and instrumented (b) geosynthetics are identical, which is debatable insofar as it does not consider the important contribution to safety made by the monitoring and warning system. Moreover, the high level of consumption related to the monitoring and warning system reveals a significant potential for optimization of the system design. Possible improvements include the power consumption of the monitoring and alert system, its type of power supply (electrical, solar, etc.), the daily duration of monitoring (geosynthetic measurement), the daily duration of the connection to the monitoring server (permanent, one-off in case of a local alert, etc.) and the storage of e-mails (in the cloud, locally).

4.2 *Trends in the evolution of Life Cycle Assessment as a function of reinforcement design parameters*

The parametric study carried out in this research project has enabled the following trends to be identified: First of all, in the case of a solution with an instrumented geosynthetic (b) with an associated monitoring and warning system:

- as the service life of the structure increases, the daily duration of monitoring has a significant impact on the cumulative energy consumption;
- reducing the storage of emails on the cloud to 1 week instead of 1 year significantly reduces the environmental impact;
- the power consumption of the monitoring box has little impact on the results;
- the electricity mix of the country where the instrumented geosynthetic solution is implemented has a strong impact on its environmental performance.

Then, by comparing of the "concrete slab" and instrumented geosynthetic solution (b) with an associated monitoring and warning system:

- the increase in the service life of the structure has a greater influence on the environmental impact of the "concrete slab" solution than on that of the instrumented geosynthetic with an associated monitoring and warning system;
- similarly, the larger the area of the structure treated, the lower the environmental impact of
- the instrumented geosynthetic solution with an associated monitoring and warning system compared to the concrete slab solution.

5 COMPARISON OF DIFFERENT SOLUTIONS ACCORDING TO THE LEVEL OF SAFETY ENVISAGED AS A FUNCTION OF THE RISK OF THE STRUCTURE

This section summarizes how, for a given level of safety, it is advisable to adapt the design of the geosynthetic reinforcement according to the use, or not, of a monitoring and warning system. It is important to analyse structures that are comparable in terms of safety and technically justifiable.

The following comparison (Figures 2, 3 and 4) is based on the example of a potential cavity, similar to the one presented in paragraph 2 and considering different hypotheses of risk evolution:

- The cavity is not likely to expand beyond the nominal diameter: If it is considered that there is no risk of the cavity enlarging beyond the nominal diameter, the competing solutions may be the "concrete slab" solution and a non-instrumented geosynthetic (a). For these two solutions, it was planned that the project owner would carry out a monitoring visit every 7 years.
- The risk of the cavity expanding beyond the nominal diameter is not well known but a priori is not very high: Considering that the risk of the cavity expanding beyond the nominal diameter is not well known but not very high at least at the beginning, the competing solutions can be the "concrete slab" solution and an instrumented geosynthetic with an optical sensor but without continuous monitoring (d). This geosynthetic solution allows for modular monitoring, punctual at the beginning (e.g. one measurement per year) which can be accelerated over time and can even be converted into continuous monitoring if things get worse.
- Analysis of the impact on the environment of the different solutions according to the hypotheses of risk regarding the cavity: For this analysis, assumptions were made for the electricity consumption of one hour per measurement, if the optic fibre measurement is carried out punctually; however, in the case of continuous monitoring, solar panels are systematically used. We also consider the daily transmission of measurement data to the central server, without online storage, except in the event of an alert.

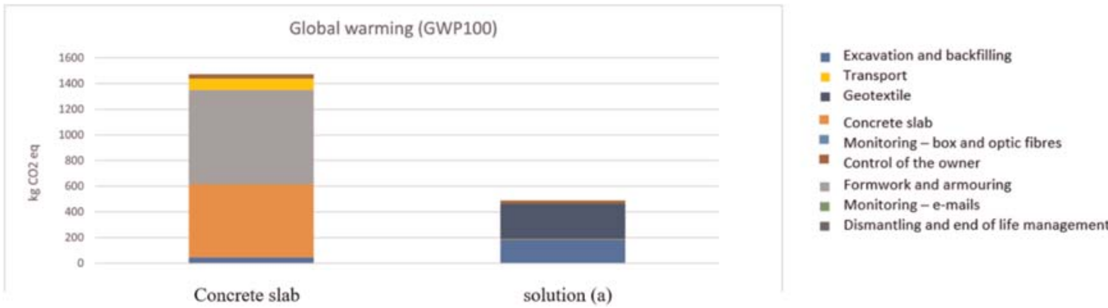

Figure 2. The cavity is not likely to expand beyond the nominal diameter.

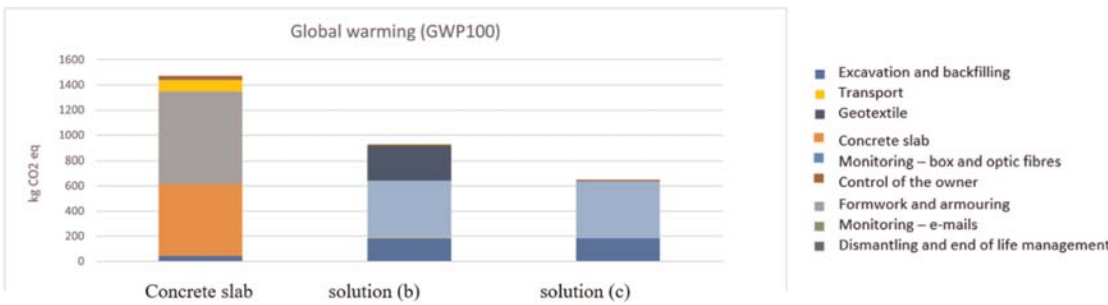

Figure 3. The cavity may present a non-negligible risk of expanding beyond the nominal diameter.

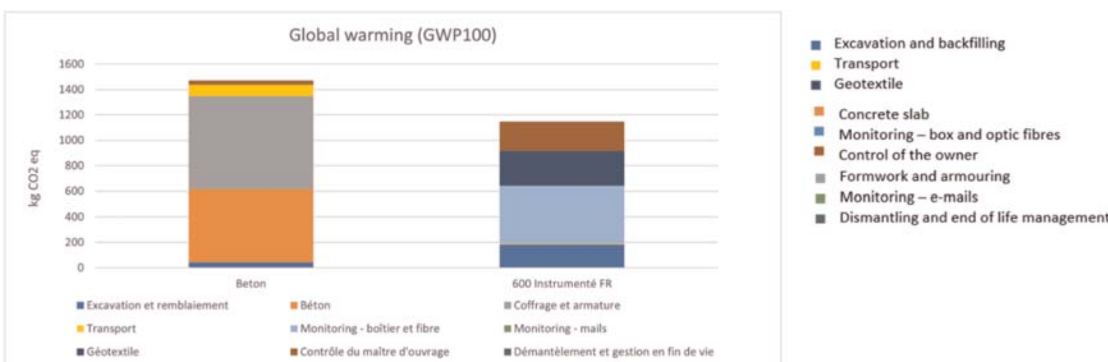

Figure 4. The risk of the cavity enlarging beyond the nominal diameter is unknown but not very high at least at the beginning.

6 CONCLUSION

The analysis of the Life Cycle Assessment of solutions integrating instrumented geosynthetics, with monitoring and warning devices, showed how important this assessment was to optimize the design of the reinforcement system, especially for sensitive structures such as those above areas at high risk of localized collapse. It was possible to evaluate and quantify the influence of the different design parameters of the system (geosynthetic, instrumentation, monitoring and warning system) on the impact on cumulative energy consumption.

The tool developed shows that it is possible to adapt and optimize the treatment and monitoring solution for an area at high risk of localized collapse according to the level of risk linked to the potential evolution of the cavity.

The addition of instrumentation and an optimized monitoring system is particularly relevant from an LCA point of view as well as from a safety and technical aspects. This study validates the expected benefits of this innovative instrumented geosynthetic solution compared to the traditional reinforcement solution, under optimized conditions adapted to each site, as in this case in the Lille region on a 2 m diameter cavity.

This Life Cycle Assessment has finally led to the publication of an EPD® Environmental Product Declaration for the range of geosynthetics concerned, which provides data on the environmental impact of the geosynthetic. This document presents the data in a standardized format for comparison with other solutions on the market.

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