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Geotechnical know-how that supports decision making towards sustainable infrastructure

Un savoir-faire géotechnique qui aide à la prise de décision en matière d'infrastructure durable

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ABSTRACT: To manage the geotechnical challenge of a road construction in a sensible region in Northern France, multiple options were considered and compared to minimize and mitigate impacts towards a sustainable and integrated solution. For the construction of the by-pass motorway around the city of Reims (France) three techniques were assessed: 1. On-site soil stabilization with lime, 2. Natural drying and 3. Soil replacement (transport and back fill with suitable soil). To handle the wet clay soils from a road construction site a Life Cycle Cost Analysis and Social impacts were developed based on this well-documented real example instead of using a theoretical generic case. The soil stabilization using this technique resulted in overall sustainable benefits of finalizing the works quicker (option 1), minimize exposure of road contractors to risks (fatalities/injuries) and concluded that option 1 (soil stabilization) is the cheapest solution followed by natural drying (2) and by soil replacement (3). Over time also the carbonation for lime-based applications results from the uptake of carbon dioxide from the ambient air. The presence of water vapour is required to enable the reaction between the CO_2 and the lime (calcium hydroxide). Through this carbonation reaction the hardening of air-lime is net uptaker of CO_2 as illustrated using lime in road stabilization.

RÉSUMÉ: Pour gérer le défi géotechnique de la construction d'une route dans une région sensible du nord de la France, plusieurs options ont été examinées et comparées afin de minimiser et d'atténuer les impacts en vue d'une solution durable et intégrée. Pour la construction de l'autoroute de contournement autour de la ville de Reims (France), trois techniques ont été évaluées: 1. la stabilisation des sols sur site avec de la chaux, 2. le séchage naturel et 3. le remplacement des sols (transport et remblayage avec un sol approprié) . Pour traiter les sols argileux humides d'un chantier de construction de routes, une analyse du coût du cycle de vie et des impacts sociaux ont été développés sur la base de cet exemple réel bien documenté au lieu d'utiliser un cas générique théorique. Grâce à cette technique, la stabilisation des sols a eu pour effet durable de finaliser les travaux plus rapidement (option 1), de minimiser l'exposition des entrepreneurs sur les routes aux risques (morts / blessés) et a conclu que l'option 1 (stabilisation des sols) était la solution la moins chère suivie de l‘ assèchement naturel. (2) et par le remplacement du sol (3). Avec le temps, la carbonatation des applications à base de chaux résulte de l'absorption de dioxyde de carbone par l'air ambiant. La présence de vapeur d'eau est nécessaire pour permettre la réaction entre le CO_2 et la chaux (hydroxyde de calcium). Par le biais de cette réaction de carbonatation, le durcissement de la chaux aérienne est un apport net de CO_2, comme le montre l'utilisation de la chaux pour la stabilisation des routes.

Keywords: Life Cycle Cost Analysis (LCCA); Social Impacts; Carbonation; Time; Hydrated lime; Quicklime

1 INTRODUCTION

Each year European public authorities spend an equivalent of 16-19% of the EU Gross Domestic Product on the purchase of goods (e.g. office equipment, building components, transport vehicles; services and so on) COM(2008). Studies have confirmed that there is considerable scope for cost effective green public procurement (GPP) - in particular in sectors where green products are not more expensive than the non-green alternatives considering the life cycle cost of the product. As "greener" goods are defined on a life cycle basis, GPP will affect the whole supply chain and will also stimulate the use of green standards in private procurement. However the European Commission has recognised some obstacles to take up the GPP such as:

-Insufficient information on life cycle costing of products and the relative costs of environmentally friendly products / services;

-Low awareness of the benefits of environmentally friendly products and services;

-The lack of a coordinated exchange of best practice and information between regions and local authorities in EU.

The general objective of the Communication 400 final (COM 2008) is to provide guidance on how to reduce the environmental impact caused by public sector consumption and to use GPP to stimulate innovation in environmental technologies, products and services. The specific objectives of this Communication are to address the obstacles to the uptake of GPP that have been identified above:

- a process for setting common GPP criteria;
- information on life cycle costing of products;
- legal and operational guidance;
- political support through a political target, linked to indicators and future monitoring

Recognising the benefit of the GPP and the obstacles to be overcome, the Comission with the Support of the Joint Research Center (JRC) developed Guidances for Green Public Procurement in road construction & maintenance (EC 2016; JRC 2016a; JRC 2016b).

In view of reducing the environmental footprint the issue is always addressed under the LCA studies mainly from the environmental point of view where the social and economic benefits are not always taken into account therefore not ensuring a sustainability approach. The aim of this study is to conduct a comparative study investigating the environmental (Life Cycle Assessment (LCA)), social (social impacts (LCSA)) and economic (Life Cycle Cost Assessment (LCCA)) impacts of three soil stabilization techniques 1. mix with quicklime; 2. natural drying; 3. borrow pits, for one construction site, the bypass motorway of Reims in France.

2 METHODOLOGY

The new by-pass motorway of Reims is an infrastructure that connects the Eastern part of the A4 motorway with the Western part of the same motorway as well as with the motorway A26 in the South of Reims city. With the construction of the 14 km long new highway, the traffic flows from the two main motorways (A4 and A26) which are diverted outside the Reims downtown.

In total about 2.2 × $10^6 m^3$ of soils were excavated. From which 1.7 × 10^6 m^3 were reused for the construction of the embankments and 0.2 × 10^6 m^3 were used for the capping layer. The earthworks started in spring 2009 and were completed within 7 months as shown in figure 1.

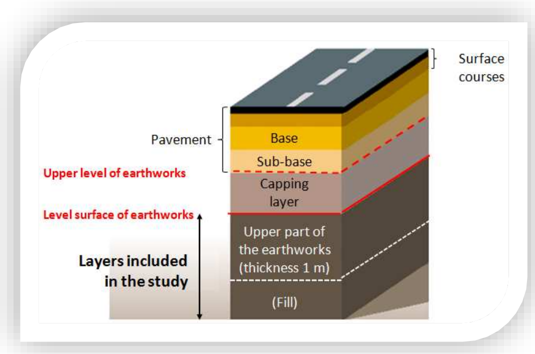

Figure 1: Illustrates the soil stabilization layers which are part of this study.

The following soil stabilization techniques were investigated for this job-site to decide on which was the most suitable option for the sensible region of Reims:

– ***Option 1:*** Soil stabilisation with quicklime for the re-use of wet soils. The excavated wet soils are mixed with quicklime. This mixing leads to a chemical reaction between the quicklime and the soil moisture. Since the reaction is highly exothermic, it leads to a water evaporation and consequently to a global reduction of the water content in the soils. This lower humidity enables then the re-use of the soils for the construction of the embankments.

– ***Option 2:*** Natural drying of wet soils before re-use. The excavated wet soils are spread on a large surface. They are regularly turned and ploughed until their water content has sufficiently decreased to allow their re-use.

– ***Option 3:*** Replacement of wet soils by external suitable soils. The wet soils are hauled off-site and disposed in the vicinity of the construction site. They are replaced by other geotechnical suitable soils which are excavated in borrow pits and transported to the construction site for the erection of the embankments.

The reference unit defined in the LCA study (environmental impact) and for the sustainability indicators study (social and economic impacts) is the same to facilitate the comparison of the results. The reference unit refers to: the surface of the earthworks of the new by-pass motorway of Reims limited in the length by the two motorway junctions with a spatial geometry (alignment, length profile and cross sections) as defined precisely by the project design of the infrastructure.

The general methodology used for assessing the sustainable development (SD) indicators consists of 5 steps and is summarized in Figure 2.

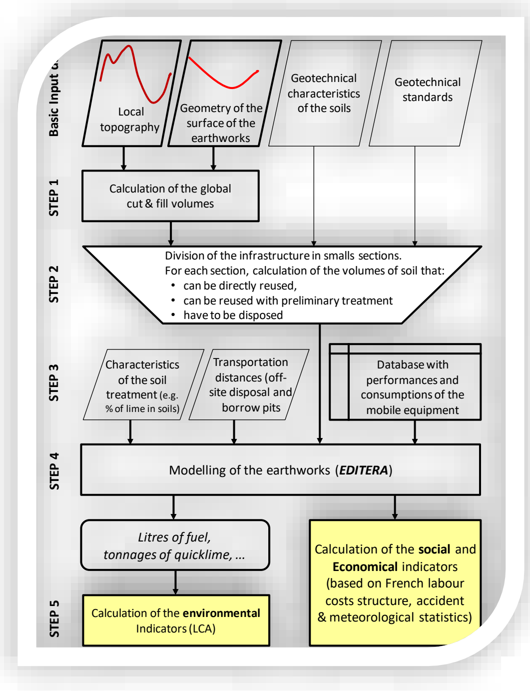

Figure 2: Methodology used for assessing sustainability indicators.

The three options and respective assumptions used to carry out the LCA are listed in detail in (EESAC 2013a). Since some of them have also an influence on the social indicators, they are summarized below:

1. **Soil stabilisation with quicklime**
   Quicklime content in treated soils: 1%
   Average transportation distance: 250 km
   Type of truck for lime shipping and loading conditions: 27 tonnes of payload, full one way, empty on the way back
2. **Natural drying**
   Dried under natural local weather conditions
3. **Soil replacement**
   Distance between construction site and borrow pits: 10km

The economic assumptions are the following: Diesel: 1.40 €/l; Quicklime delivered on-site: 110€/tonne.

The earthwork modelling was made using a specific software (EDITERA) that is dedicated to earthworks with records made over 40 years during earthworks. As an illustration see Figure3. The calculation uses an extended database about earthmoving machines. For each type of mobile equipment (excavators, dumpers, scrappers, bulldozers, graders, compactors, ...), the database includes detailed information about performance, capacity and fuel consumption of different machineries as well as the weather conditions of past sites. They are regularly updated with information provided by civil engineering companies and by manufacturers of earthmoving machines. The methodology and the assumptions used to assess the environmental indicators are extensively described in the LCA methodology report (EESAC 2013a). The data calculated by EDITERA are also used to assess some selected social and economic indicators. In this case following indicators were calculated by the extension of the EDITERA software (i.e. EDITERA DD):

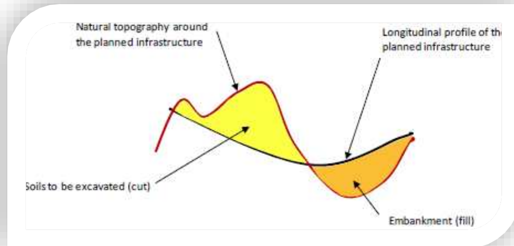

Figure 3. Illustration of EDITERRA modelling

3 RESULTS

3.1 Carbon footprint

For the calculation of the amount of CO_2 sequestrated, it is assumed that the quicklime consists of 98% free CaO. Influence of the carbonation: in the base case, no carbonation of quicklime over time was considered. Two scenarios are considered in the sensitivity analysis:

- 35% of the added CaO is carbonated over a lifespan of 100 years (intermediate case) in Figure 4.
- 52% of the added CaO is carbonated over a lifespan of 100 years (maximal carbonation scenario) in figure 5.

The data for the carbonation rate (35% (intermediate scenario), and 52% (the maximum carbonation scenario)) are measured values in the same German highway after 19 and 34 years after construction. The study and the values are explained extensively in the publications of Haas & Ritter (2018), Hass et al, (2019).

Since the carbonation of the quicklime will only affect the impact category “climate change”, the other impact indicators will remain identical to those determined for the base case. The global warming potentials calculated for the intermediate carbonation scenario and the maximal carbonation scenario are shown in the Figures 4 and 5 respectively.

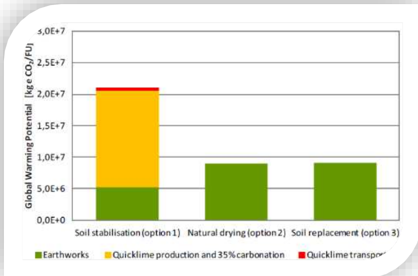

Figure 4: Global Warming Potential [kg eq. e-CO_2) / FU] – Intermediate carbonation scenario

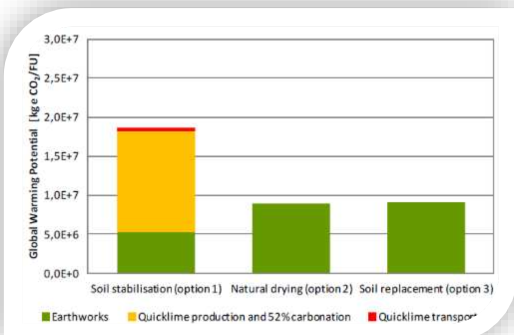

Figure 5: Global Warming Potential [kg eq. e-CO_2) / FU] – Maximum carbonation scenario

3.2 Cost/economic indicator

As mentioned in the methodology section, the project costs were chosen as a proxy for the economical indicator. Figure 6 provides an overview about the contribution of: the quicklime, the diesel, and the remaining costs (mainly labour costs and depreciation costs of the mobile equipment) to the total project costs for the three options.

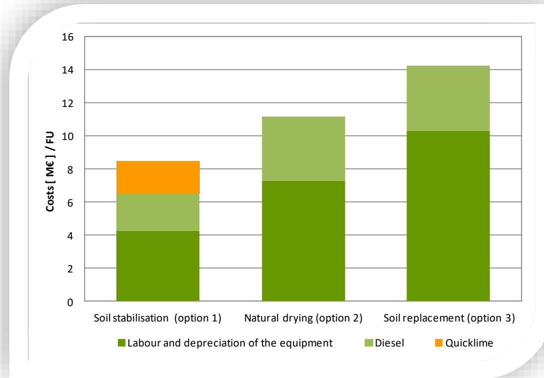

Figure 6: Project costs [M€ / FU]

3.3 Social indicator

The duration of the earthworks was introduced as a proxy for evaluating nuisances to neighbours of construction sites that cannot be precisely quantified like fugitive dust emissions, noise, vibrations from circulating trucks and other heavy equipment. Indeed, the longer these nuisances lasts, the higher the number of complaints. Moreover, the timeframe for completing the earthworks has a direct influence on the completion deadline of the final road: the quicker these works are completed, the earlier the new infrastructure can be used. A shorter duration of the earthworks can hence help reducing traffic jams around the new infrastructure thus leading to lower-emissions of pollutants (additional environmental benefits) and reduced lost time in traffic jams (additional social and economic benefits). Figure 7 shows the calculated duration of the earthworks for the three options in the case of the Reims by-pass motorway project.
From this graph is obvious that less than half of the time is needed for the earthworks when soil stabilisation with quicklime is applied (option 1). This decisive advantage for option 1 is linked to the fact that the use of quicklime enables drying quickly the wet soils and thus their fast re-use on the spot avoiding the travelling distances and nuisances. In the Reims case the earthworks

could thus be completed within few months before the wet winter time started.

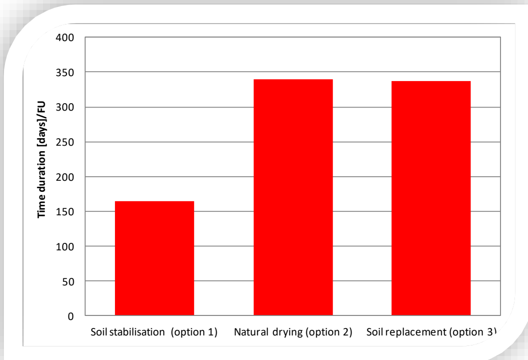

Figure 7: Timeframe for the completion of the project [Days / FU]

4 DISCUSSION

An assessment of environmental (EESAC 2013a), social and economic indicators (EESAC 2013b) was carried out at the request of the EuLA to evaluate the Sustainability Indicators of various common techniques used in earthworks. The calculation of the environmental indicators is based on the methodology described in the standards ISO 14040 ÷ 44 for LCA studies. It is worth mentioning that there is no common accepted procedure for weighting the different environmental impacts so that it is not possible to derive a unique aggregated environmental indicator. Since there are no standards for the calculation of social and economic indicators, bibliographical sources Jatteau et al. (2010) were used to assess these indicators. The key outcome of the different calculations is summarized in the below subsections. Since the results of this assessment are very closely linked to site-specific conditions (i.e. the Reims by-pass motorway), special care is required if the following conclusions are to be replicated or used in other job sites and/or other conditions that the ones detailed for Reims.

4.1 Soil stabilisation

For the following environmental impact categories the soil stabilisation with quicklime has always the highest environmental footprint:

- Energy consumption,
- Abiotic depletion,
- Climate change,
- Stratospheric ozone depletion,

Concerning the remaining environmental indicators, the situation is mixed.

Regarding social aspects, this solution is the technique with the shortest duration for completion of the earthworks. Moreover, it is the option with the second lowest accident rates which are not very different from those calculated for best performing solution.

In terms of economics, this solution is also the best performing with project costs that are respectively 25% and 40% lower than those calculated for the natural drying and the soil replacement solutions.

4.2 Natural drying

The natural drying of the soils is the most environmental friendly solution (except for the freshwater aquatic eco-toxicity potential) if one assumes that the emission standards of the Diesel engines for earth soil moving and spreading correspond to the Euronorm IV standard.

Its main inconvenient is linked to the duration of the earthworks that is any case long and is largely influenced by the weather conditions. In the case of Reims, the duration is almost doubled compared to the option with soil stabilisation. In terms of safety, this technique will always be the best performing as the traffic of trucks on public roads is minimized compared to the two other solutions.

Regarding the project costs, this option is just at the midpoint between soil stabilisation and soil replacement.

4.3 Soil replacement

The environmental indicators for this solution are very close to those calculated for the natural drying. However following factors will lead to a reduction of the environmental indicators:

- Reduction of the distance between borrow pits and construction site (e.g. 5 km instead of 10 km considered in the base case of this report),
- Enforcement of stricter emissions standards for Diesel engines (e.g. Euronorm V or VI instead of nowadays Euronorm IV).

Thus in the long term it can be anticipated that this solution will have the lowest environmental footprint among the three techniques.

As regards the duration of the earthworks, there is no significant difference between this solution and the previous one (natural drying). Both are largely affected by the weather conditions, thus leading to lengthy project durations. Since this solution requires a large amount of trucks using public roads, it is the option with the highest risks of accidents.

The option with soil replacement is clearly the most expensive technique in the specific case of the Reims. This is due to two main factors: 1. The sensibility of the region; 2. The transportation distance for the material for the borrow pits which for the Reims case was investigated to be 10 km.

The use of existing materials along the alignment of a road is an essential issue within the Sustainable Development policies, which is being promoted worldwide since many years now. In the World Road Association (PIARC-AIPCR) this subject has been investigated by different Technical Committees during the last 20 years as summarized in the contribution of Perucho and Mittiga (2018).

5 CONCLUSIONS

The study presents the results of a thorough investigation carried out in Reims, northern France and the comprehensive assessment undertaken to make the most suitable choice adapted to the local conditions of the region as well as adapt to the sensibility of the area. This study indicates that multiple considerations must be undertaken to assess the impacts being environmental, economic and minimize the nuisance in the area. The integrated approach undertaken in the selected case study indicates that guidelines such as the GPP and their uptake via the development of the National Technical Guidelines will support the national authorities to implement these EU guidelines in a consistent manner across EU (Denayer, 2018). Thus, training and exchange of practices between the different national authorities in charge of infrastructure will help the uptake of the EU GPP guidelines and strengthen the link between geotechnical know-how of road construction and sustainability.

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