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Comparative Life Cycle Assessment of Geosynthetics versus Concrete Retaining Wall

Analyse de cycle de vie comparative d'un épaulement géotextile et conventionnel

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ABSTRACT: Geogrids made of geosynthetics can replace conventional building materials like concrete. In this article, goal and scope, basic data and the results of a comparative life cycle assessment of concrete reinforced retaining walls (CRRW) and geosynthetics reinforced retaining walls (GRRW) are described. One running meter of a three meters high retaining wall forms the basis for comparison. The two walls have the same technical performance and an equal life time of 100 years. The GRRW has a lower demand of steel and concrete compared to the CRRW. The product system includes the supply of the raw materials, the manufacture of the geotextiles and the concrete, the construction of the wall, its use and its end of life. The life cycle assessment reveals that the GRRW causes lower environmental impacts. The cumulative greenhouse gas emissions of 300 m CRRW are 400 t and 70 t in case of GRRW. The use of an environmentally friendlier lorry in a sensitivity analysis and monte carlo simulation confirm the lower environmental impacts caused by the construction of a GRRW compared to a CRRW. More than 70 % of the environmental impacts of the geogrids production are caused by the raw material provision (plastic granulate) and the electricity demand in manufacturing.

RÉSUMÉ : Géogrids peuvent remplacer les matériaux conventionnels comme le béton. Cet article contient une description de la définition de l'objectif et du champ d'étude, de l'analyse de l'inventaire et des résultats d'un analyse de cycle de vie comparative d'un épaulement géotextile et conventionnel. La comparaison est faite sur un mètre courant d'un épaulement de trois mètre d'hauteur. Les deux alternatives ont les mêmes propriétés techniques et la même durée de vie de 100 ans. Les systèmes contiennent la provision des matériaux, la fabrication des géotextiles et du béton, la construction, l'utilisation et l'évacuation de l'épaulement. L'analyse de cycle de vie démontre qu'un mètre courant d'un épaulement géotextile cause moins d'impacts environnementaux qu'un mètre courant d'un épaulement de béton. 300 mètres d'un épaulement de béton entraînes 400 t CO_2-eq, celui de géotextile 70 t CO_2-eq des émissions des gaz à effet de serre. L'utilisation des camions aves les émissions réduites ne change pas les résultats. Une simulation « monte carlo » confirme la stabilité des résultats. La provision des matériaux et l'électricité utilisé dans la fabrication de la couche de filtre géotextile sont des facteurs primordiaux (plus que 70 %) en ce qui concerne les impacts environnementaux du géogrid utilisé dans l'épaulement géotextile.

KEYWORDS: retaining wall, slope retention, geosynthetics, concrete, geogrid, life cycle assessment, LCA

MOTS CLÉS : épaulement, géotextile, géogrid, béton, analyse de cycle de vie, ACV

1 INTRODUCTION

Geosynthetic materials are used in many different applications in civil and underground engineering, such as in road construction, in foundation stabilisation, in landfill construction and in slope retention. In most cases they are used instead of minerals based materials such as concrete, gravel or lime.

Environmental aspects get more and more relevant in the construction sector. That is why the environmental performance of technical solutions in the civil and underground engineering sector gets more and more attention.

The European Association for Geosynthetic Manufacturers (E.A.G.M.) commissioned ETH Zürich and Rolf Frischknecht (formerly working at ESU-services Ltd.) to quantify the environmental performance of commonly applied construction materials (such as concrete, cement, lime or gravel) versus geosynthetics (Stucki et al. 2011).

In this article, the results of a comparative Life Cycle Assessment (LCA) of slope retention are described. The slope retention is either provided by a concrete reinforced retaining wall (CRRW) or a geosynthetics reinforced retaining wall (GRRW).

The environmental performance is assessed with eight impact category indicators. These are Cumulative Energy Demand (CED, Frischknecht et al. 2007), Climate Change (Global Warming Potential, GWP100, Solomon et al. 2007), Photochemical Ozone Formation (Guinée et al. 2001a; b), Particulate Formation (Goedkoop et al. 2009), Acidification (Guinée et al. 2001a; b), Eutrophication (effects of nitrate and phosphate accumulation on aquatic systems, Guinée et al. 2001a; b), Land competition (Guinée et al. 2001a; b), and Water use (indicator developed by the authors). The calculations are performed with the software SimaPro (PRé Consultants 2012).

2 GEOSYNTHETIC VERSUS CONCRETE RETAINING WALL

It may be necessary in some cases, especially in the construction of traffic infrastructure, to build-up very steep walls. For such walls, supporting structures are necessary. The retaining walls need to meet defined tensile and shear strengths. Retaining walls can be reinforced with concrete or geogrid made of geosynthetics.

The functional unit is defined as the construction and disposal of 1 m slope retention with a 3 meters high wall, referring to a standard cross-section. Thus, the functional unit is independent of the length of the wall.

Polyethylene and PET granules are used as basic material of the geogrid. The geogrid has to achieve a long-term strength of 14 kN/m. A scheme of both types of retaining walls are shown in Fig. 1.

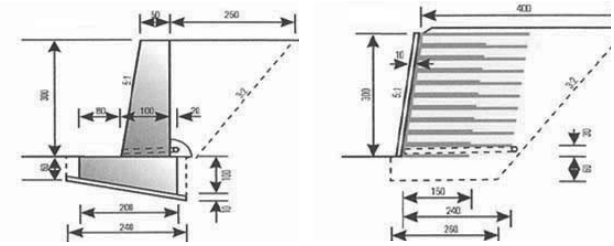

Figure 1. Scheme of the concrete reinforced retaining wall (CRRW, left) and the geosynthetics reinforced retaining wall (GRRW, right)

Some important key figures of the construction of a reinforced retaining wall are summarized in Tab. 1. The information refers to one meter of slope retention infrastructure and a time period of 100 years. Diesel is used in building machines for the excavation of the foundation and the compaction of the ground. The NMVOC emissions shown are released from the bitumen used to seal the concrete wall. The use of recycled gravel is not considered, since usually no onsite recycled gravel with specific properties is available when building reinforced retaining wall for the first time.

Tab. 1 shows specific values of the retaining walls for both alternatives. The material on site is used as fill material, wall embankments and cover material in case of a GRRW. A drainage layer made of gravel with a thickness of at least 30 cm behind the concrete lining is necessary. To be consistent with the CRRW, a gravel layer thickness of 80 cm is assumed in both cases. Round gravel is used for drainage purposes .

Table 1. Selected key figures describing the two constructions of one meter reinforced retaining wall

	Unit	*CRRW*	*GRRW*
Concrete	m^3/m	1.60	-
Lean mix concrete	m^3/m	0.24	-
Structural concrete	m^3/m	2.10	0.31
Reinforcing steel	kg/m	153	-
Gravel	t/m	4.3	4.3
Bitumen	kg/m	2.84	-
Three layered laminated board	m^3/m	0.01	-
Geosynthetic	m^2/m	-	39.2
Polystyrene foam slab	kg/m	0.25	-
Polyethylene	kg/m	1.74	2.02
Diesel in building machine	MJ/m	11.6	53.9
Transport, lorry	tkm/m	701	265
Transport, freight, rail	tkm/m	33.2	6.9
Land use	m^2/m	1.0	0.6
NMVOC	g/m	20	-

The difference between the CRRW and GRRW lies in the amount of concrete, steel and bitumen used, the energy consumption that is related to the slope retention used (material transportation, excavation etc.), and the use of geosynthetics.

In a sensitivity analysis, it is analysed how the results of the slope retention change, when a low emission Euro5 lorry (>32 t) is used for the transportation of the materials to the construction site instead of an average European lorry (>16 t).

3 MANUFACTURING OF THE GEOGRID

Data about geosynthetic material production are gathered at the numerous companies participating in the project using pre-designed questionnaires. The company specific life cycle inventories are used to establish average life cycle inventories of geosynthetic material.

The data collected include qualitative information of system relevant products and processes from the producer, information from suppliers of the producer (where possible) as well as data from technical reference documents (e.g. related studies, product declarations, etc.). Average LCI are established on the basis of equally weighted averages of the environmental performance of the products manufactured by the participating companies.

The primary source of background inventory data used in this study is the ecoinvent data v2.2 (ecoinvent Centre 2010), which contain inventory data of many basic materials and services.In total, data from 5 questionnaires concerning the production of geosynthetic geogrids used in slope retention applications are included. The quality of the data received is considered to be accurate. The level of detail is balanced in a few cases before modelling an average geosynthetic layer.

Tab. 2 shows important key figures of the production of an average geosynthetic geogrid

Table 2. Selected key figures referring to the production of 1 kg geosynthetic layer used in slope retention

	Unit	*Value*
Raw materials	kg/kg	1.02
Water	kg/kg	0.86
Lubricating oil	kg/kg	$7.30*10^{-5}$
Electricity	kWh/kg	0.73
Thermal energy	MJ/kg	1.24
Fuel for forklifts	MJ/kg	0.13
Building hall	m^2/kg	$6.32*10^{-6}$

4 LIFE CYCLE IMPACT ASSESSMENT

In this section the environmental impacts of 1 m slope retention with a height of 3 m over the full life cycle are evaluated. The life cycle includes the provision of raw materials as well as the construction and disposal phases.

In Fig. 2 the environmental impacts over the full life cycle of the slope retention are shown. The environmental impacts of the case with the highest environmental impacts are scaled to 100 %. The total impacts are divided into the sections wall, raw materials (concrete, gravel, geosynthetic layers, reinforcing steel, bitumen, wooden board), building machine (construction requirements), transports (of raw materials to construction site) and disposal of the wall (includes transports from the construction site to the disposal site and impacts of the disposal of the different materials).

The GRRW (4B) causes lower environmental impacts compared to the CRRW (4A) in all impact categories considered. The non-renewable cumulative energy demand of the construction and disposal of 1 meter CRRW (4A) with a height of 3 meters is 12’700 MJ-eq and 3’100 MJ-eq in case of GRRW (4B). The cumulative greenhouse gas emissions amount to 1.3 t CO_2-eq in case of the CRRW (4A) and 0.2 t CO_2-eq in case of the GRRW (4B). Correspondingly, the cumulative greenhouse gas emissions of 300 m CRRW (4A) are 400 t and 70 t in case of GRRW (4B).

The most relevant aspects concerning the environmental impacts of the life cycle of the CRRW (4A) are concrete, reinforcing steel, transportation and disposal. This order of relevance changes depending on the impact category indicators. The high share of concrete in the global warming indicator can be explained by the production process of clinker. During its calcination process geogenic CO_2 emissions arise. Reinforcing steel consists of 63 % primary steel and 37 % recycled steel. Most environmental impacts of the reinforcing steel arise from the fuel consumption and the emissions during the sinter and pig iron production in the supply chain of the primary steel. Disposal includes the disposal as well as transports from the construction site to the disposal site in case the material is not recycled. Impacts of disposal are dominated by the high amount of concrete which is landfilled. While direct emissions of landfilling concrete are negligible, the construction of the landfill and the transport of concrete to the landfill site are important. The land competition indicator is strongly influenced by the direct land use of the slope retention as well as by the wooden board used in the formworks. Gravel is responsible for a considerable share of the total amount of water used because substantial amounts of water are needed in gravel production.

Concrete, the geosynthetic and transportation mostly cause the highest burdens of the life cycle of the GRRW (4B). The share of the geogrid to the overall impacts is relatively high because on one hand several layers, and thus a considerable amount of geogrid, are required. On the other hand most materials used in the construction of the slope retention are available on-site and thus do not cause substantial environmental impacts (compare Tab. 1). The disposal gains importance in the categories eutrophication and global warming. The global warming impacts of disposal are caused by burning geogrids in waste incineration plants, which leads to fossil CO_2 emissions. Gravel dominates the water use indicator and the direct land use of the slope retention wall during its use is dominating land competition.

The main driving forces for the difference between CRRW (4A) and GRRW (4B) are the higher amount of concrete used in CRRW (4A) as well as the use of reinforcing steel, which additionally leads to higher transport expenditures. With regard to CED renewable and land competition the wooden board additionally increases the difference in total impacts because wood is a renewable resource with a high direct land occupation. Direct land competition is lower for the GRRW (4B) because the sprayed concrete lining is thinner than the CRRW (4A) and the embankment and backfilling area is not considered as occupied land.

The share of the geosynthetic material on the overall environmental impacts is between 3 % and 44 % (water use and CED non-renewable, respectively).

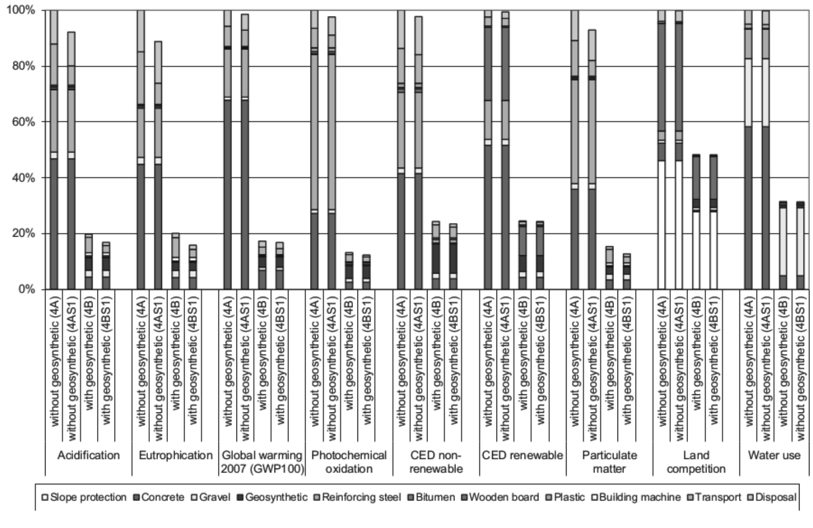

Figure 2. Sensitivity analysis: Environmental impacts of the life cycle of 1 m conventional (4A) and geosynthetic retaining wall (4B). 4AS1 and 4BS1 refer to the sensitivity analysis with a Euro5 lorry transportation. For each indicator, the case with highest environmental impacts is scaled to 100°%.

4.1 *Sensitivity analysis*

In a sensitivity analysis, it is analysed how the results of the slope retention change, when a Euro5 lorry (>32 t) is used for the transportation of the materials to the construction site instead of an average European lorry (>16 t).

Fig. 2 reveals that if a Euro5 lorry with lower exhaust emissions is used for the transportation, the environmental impacts of the GRRW (4BS1) are reduced between 0.1 % and 22.8 % (land competition and eutrophication respectively), whereas the environmental impacts of the CRRW (4AS1) are decreased between 0.2 % and 13.2 % (land competition and eutrophication respectively). The use of a Euro5 lorry leads among others to lower NO_X emissions, which influences eutrophication. Land competition is obviously not influenced much by using another type of lorry.

4.2 *Contribution Analysis Geosynthetic Production*

In this section the environmental impacts of 1 kg geogrid are evaluated. The life cycle includes the provision and use of raw materials, working materials, energy carriers, infrastructure and disposal processes. The category geosynthetic in Fig. 3 comprises the direct burdens of the geosynthetic production. This includes land occupied to produce the geosynthetic as well as process emissions (e.g. NMVOC, particulate and COD emissions) from the production process but not emissions from electricity and fuel combustion which are displayed separately. The environmental impacts of the geogrid are shown in Fig. 3. The cumulative greenhouse gas emissions amount to 3.4 kg CO_2-eq per kg.

Environmental impacts are mostly dominated by the raw material provision and electricity consumption. Raw material includes different types of plastics. Country-specific electricity mixes are modelled for each company and thus impacts of electricity consumption depend not only on the amount of electricity needed but also on its mix. The higher share of electricity in CED renewable can be explained by the use of hydroelectric power plants in the electricity mixes of several factories. And the relatively high share in eutrophication is mainly due to electricity from lignite.

The share of heating energy and fuel consumption for forklifts is between 0.01 % (land competition) and 2.8 % (global warming) and is thus not considered to be of primary importance. With regard to land competition the geosynthetic production plays an important role. The impacts are dominated by the direct land use, i.e. land which is occupied by the manufacturer plant in which the geosynthetic is produced. Indirect land uses, i.e. land occupation stemming from upstream processes, are significantly lower because no land occupation is reported in the inventories of plastic feedstock and no land intensive products such as wood are used in considerable amounts. Water consumption is included in the working materials. As a consequence, this category bears about 5 % of the total amount of water used.

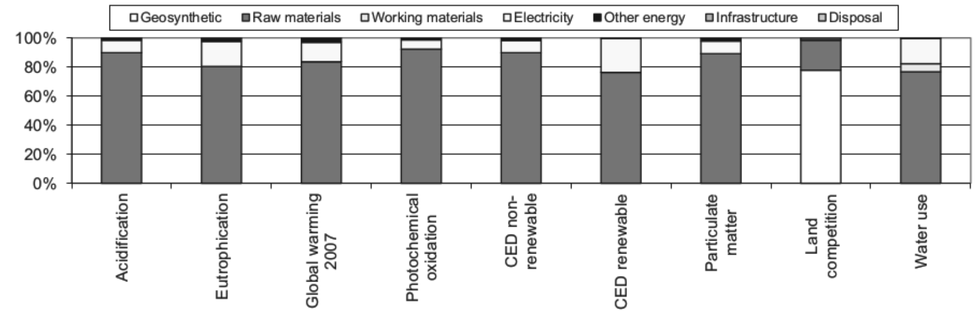

Figure 3. Environmental impacts of the life cycle of 1 kg geogrid. Geosynthetic includes direct burdens of the geosynthetic production. Raw materials include plastic, extrusion if necessary and additives, working materials include water (tap and deionised) and lubricating oil, other energy includes thermal energy and fuels, infrastructure covers the production plant and disposal comprises wastewater treatment and disposal of different types of waste.

5 DISCUSSION AND CONCLUSION

The use of geosynthetics leads to lower environmental impacts of slope retention in all indicators investigated. The specific climate change impact of the construction of the slope retention (1 m slope retention with a 3 meters high wall) using geosynthetics is about 1 ton CO_2-eq per meter lower compared to a conventional alternative. This difference is equal to about 84 % of the overall climate change impact of the construction and disposal efforts of an entire conventional slope retention system during its 100 years lifetime.

If a Euro5 lorry with lower exhaust emissions than an average fleet lorry is used for the transportation of materials, the environmental impacts of both cases are somewhat reduced regarding some indicators. However, this does not affect the overall conclusions of the comparison.

Slope retentions are individual solutions in a particular situation. The height of slope retention walls and the horizontal loads on it may differ, which may lead to differences in thickness and reinforcement. Thus, generalising assumptions were necessary to model a typical slope retention. Data about on-site material used, gravel extraction, concrete and the use of building machines are based on generic data and knowledge of individual civil engineering experts.

Based on the uncertainty assessment it can be safely stated that the geosynthetics reinforced slope retention shows lower environmental impacts than the concrete wall. Despite the necessary simplifications and assumptions, the results of the comparison are considered to be significant and reliable.

A geosynthetic reinforced wall used for slope retention constitutes a different system compared to a concrete reinforced wall. Nevertheless, both systems provide the same function by enabling the build-up of steep walls. Compared to the conventional slope retention, the geosynthetic reinforced wall substitutes the use of concrete and reinforcing steel, which results between 63 % and 87 % lower environmental impacts.

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