COMPARATIVE LIFE CYCLE ASSESSMENT OF GEOSYNTHETICS VERSUS CONVENTIONAL CONSTRUCTION MATERIALS, A STUDY ON BEHALF OF THE E.A.G.M., CASE 4, SOIL RETAINING WALL

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ABSTRACT: The European Association for Geosynthetic Products Manufacturers (E.A.G.M.) commissioned ETH Zürich and ESU-services Ltd. to quantify the environmental performance of commonly applied construction materials (such as concrete, cement, lime or gravel) versus geosynthetics. Geosynthetic materials are used in many different applications in the civil and underground engineering. In most cases, the use of geosynthetic material beneficially replaces the use of other construction materials. To this end a set of comparative life cycle assessment studies are carried out concentrating on various functions or application cases. The environmental performance of geosynthetics is compared to the performance of competing construction materials used.

1 INTRODUCTION

Geosynthetic materials are used in many different applications in civil and underground engineering. In most cases, the use of geosynthetic material replaces or enhances the use of other materials. The European Association for Geosynthetic Products Manufacturers (EAGM) commissioned ETH Zürich and ESU-services Ltd. to quantify the environmental performance of commonly applied construction materials (such as concrete, cement, lime or gravel) versus geosynthetics. To this end a set of comparative life cycle assessment studies are carried out concentrating on various application cases, namely filtration, foundation stabilised road, landfill construction and retaining structure. The environmental performance of geosynthetics is compared to the performance of competing construction materials used.

The specifications of four construction systems are established by the E.A.G.M. members representing a significant majority of the European market of geosynthetic materials.

1. Filtration
2. Foundation stabilisation
3. Landfill construction drainage layer
4. Soil retaining wall

This paper presents the results of case 4 - Soil retaining wall, the basis of the whole assessment, and the detailed results of the further cases will be shown in further papers at this conference (see References).

The whole study, including the results of a critical review, is available on: http://www.eagm.eu/

2 CHARACTERISATION OF THE ALTERNATIVES

It may be necessary in some cases, especially in the construction of transport infrastructure, to build-up very steep slopes or walls. For such walls, supporting structures are necessary. The retaining structures must be designed to withstand the relevant disturbing forces, be based on an adequate foundation and providing an acceptable factor of safety against ultimate or limit state failure. A retaining wall reinforced with concrete (case 4A) is compared to a soil wall reinforced with geosynthetics (case 4B).

In figure 1 the retaining wall is 50 meters long and 3 meters high with a gradient of 5:1. In fact, the length of the wall has no influence on the LCA as the functional unit refers to 1 meter standard cross section.

The average of 3 types of different geogrids is used to represent its performance, namely

- extruded stretched grids,
- layed grids, and
- woven / knitted grids.

Polyethylene and PET granules are used as basic material in case 4B. In this case a long-term strength of 14kN/m must be achieved. Back calculated from that and applying the typical reduction factor A1-A4 per raw material the average weight of the polymer is calculated.

The concrete used in case 4A is classified in the strength class B300.

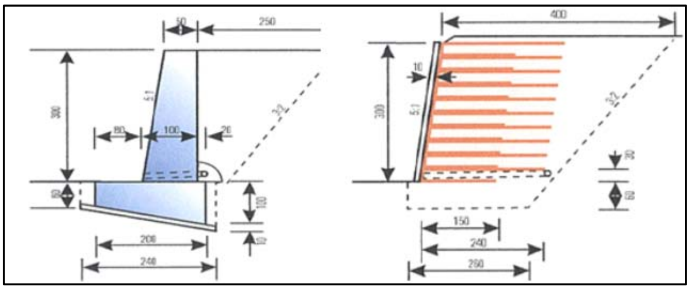

Fig.1: Scheme of retaining walls: the concrete reinforced wall (case 4A, left) versus the geosynthetics reinforced wall (case 4B, right)

Table 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 4B. A drainage layer made of gravel with a thickness of at least 30cm behind the concrete lining is necessary. To be consistent with case 4A, a gravel layer thickness of 80cm is assumed in both cases. Round gravel is used for drainage purposes.

Description	Unit	Case 4A	Case 4B	Material
length of the wall	m	50	50	
height of the wall	m	3	3	
excavation	m^3	109		
base compaction	m^2	121	262	On-site material
formwork placement	m^2	83		Laminated board
cleanness layer	m^2	120		Lean mix concrete
concrete placement	m^3	80		Concrete, sole plate
reinforcement placement	kg	2400		Reinforcing steel
formwork wall face work	m^2	153		Laminated board
formwork wall coarse	m^2	150		Laminated board
concrete wall	m^3	105		Structural concrete, with de-icing contact
reinforcement wall	kg	5250		Reinforcing steel
Building gaps	m^2	21		Polystyrene foam slab
insulating coat cold	m^2	154		Bitumen
drainage	m	62	72	Polyethylene HDPE
filter gravel	m^3	10	11	Gravel
frost wall backfilling	m^3	219		Gravel and on-site material
compaction backfilling	m^2	500		Gravel and on-site material
excavation sub-base	m^3		79	On-site material
sub-base fill material	m^3		79	On-site material
form work, support	m^2		153	Laminated board
geosynthetics delivery and laying	m^2		1960	Geosynthetic
wall embankment	m^3		480	On-site material
compaction layers	m^2		1550	Gravel and on-site material
Sprayed-concrete lining	m^2		155	Structural concrete, with de-icing contact
covering material	m^3		45	On-site material

Tab.1: Specification of reinforced concrete wall (case 4A) and geosynthetic reinforced soil retaining structure (case 4B).

The typical life time is estimated in both cases with 100 years. This is in line with EBGEO (Deutsche Gesellschaft für Geotechnik 2010) and the British Standard “Code of practice for strengthened/reinforced soils and other fills” (British Standard 1995).

3 LIFE CYCLE IMPACT OF INFRASTRUCTURE ELEMENT

Some important key figures of the construction of a reinforced concrete wall (case 4A) and a geosynthetic reinforced soil retaining structure (case 4B) are summarized in table 2. The information refers to one meter of retaining structure 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 (case 4A). The use of recycled gravel is not considered, since usually no onsite recycled gravel with specific properties is available when building a retaining structure.

	Unit	Case 4A	Case 4B
Concrete, sole plate and foundation	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	-

Tab.2: Selected key figures referring to the construction of a reinforced concrete wall (case 4A) and a geosynthetic reinforced soil supporting structure (case 4B) (life time = 100a)

4 LIFE CYCLE IMPACT OF GEOGRID

In total 6 questionnaires concerning the production of geogrids used in retaining structure are included. The quality of the data received is considered to be accurate. The level of detail is balanced before modelling an average geogrid. Table 3 summarizes most important key figures for the production of an average geogrid.

	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	$6.32*10^{-6}$

Tab.3: Selected key figures referring to the production of 1kg geogrid used in retaining structure.

5 LIFE CYCLE IMPACT ASSESSMENT OF RETAINING STRUCTURES

In this section the environmental impacts of 1m retaining structure with a height of 3m 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 table 3 the environmental impacts (detailed description see paper “Ehrenberg H. & Mermet J.P.” under References) over the full life cycle of the retaining structure are shown. The environmental impacts of the case with higher environmental impacts (case 4A) 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).

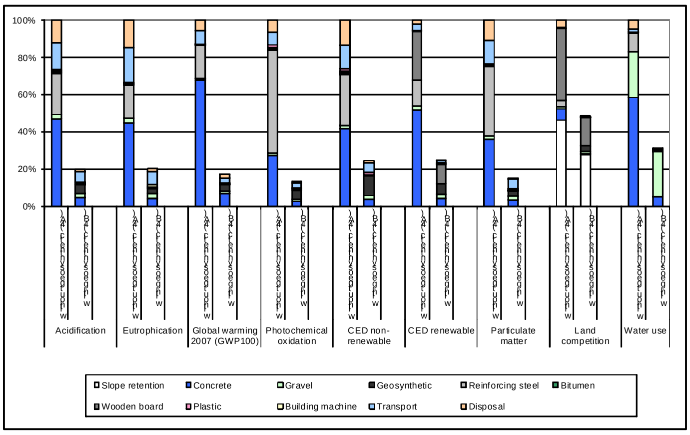

Fig.2: Environmental impacts of the life cycle of 1 linear meter of retaining structure, cases 4A and 4B. For each indicator, the case with higher environmental impacts is scaled to 100%.

Case 4B causes lower environmental impacts compared to case 4A in all impact categories considered. The non-renewable cumulative energy demand of the construction and disposal of 1 meter retaining structure with a height of 3 meters is 12,700MJ-eq in case 4A and 3,100MJ-eq in case 4B. The cumulative greenhouse gas emissions amount to 1.3t CO_2-eq in case 4A and 0.2t CO_2-eq in case 4B. Correspondingly, the cumulative greenhouse gas emissions of 300m retaining structure are 400t in case 4A and 70t in case 4B, respectively.

The most relevant aspects concerning the environmental impacts of the life cycle of the reinforced concrete retaining wall (case 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 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.

Concrete, the geosynthetic and transportation mostly cause the highest impacts of the life cycle of the retaining structure reinforced with geosynthetics (case 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 retaining structure are available on-site and thus do not cause substantial environmental impacts. 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 retaining structure wall during its use is dominating land competition.

The main driving forces for the difference between cases 4A and 4B are the higher amount of concrete used in case 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 case 4B because the sprayed concrete lining in case 4B is thinner than the concrete wall in case 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).

6 CONTRIBUTION ANALYSIS GEOGRID

In this section the environmental impacts of 1kg 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 figure 3 comprises the direct impacts 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 figure 3. The cumulative greenhouse gas emissions amount to 3.4kg CO2-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 several electricity mixes. 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 as e.g. 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.

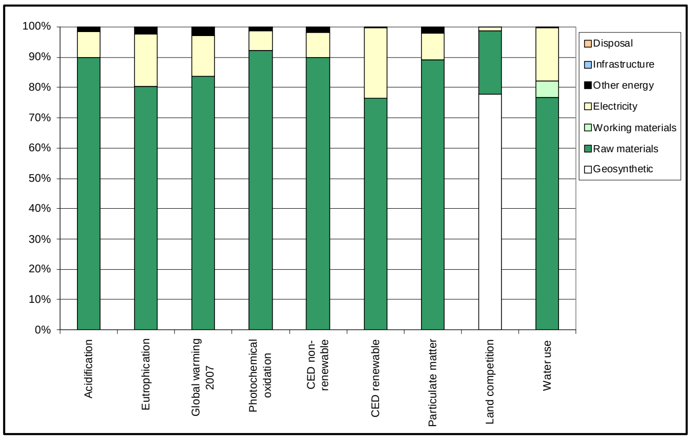

Fig.3: Environmental impacts of the life cycle of 1kg geogrid. Geosynthetic includes direct impacts of the geosynthetic production. Raw materials include plastic, extrusion if necessary and additives, working materials include water (tap and deionised) and lubricating oil, other energy includes thermal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

7 CONCLUSION

The use of geosynthetics leads to lower environmental impacts of retaining structure in all indicators investigated. The specific climate change impact of the construction of the retaining structure (1 linear meter of retaining structure with a 3 meter 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 retaining structure system during its 100 years lifetime.

Retaining structures are individual solutions in a particular situation. The height of retaining structure retaining structure 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 retaining structure. 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 retaining structure 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.

8 REFERENCES

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