COMPARATIVE LIFE CYCLE ASSESSMENT OF GEOSYNTHETICS VERSUS CONVENTIONAL CONSTRUCTION MATERIALS, A STUDY ON BEHALF OF THE E.A.G.M., CASE 2, FOUNDATION STABILISATION

A. Elsing
HUESKER Synthetic GmbH, Gescher, Germany, on behalf of E.A.G.M.

I. Fraser
Tensar International, Blackburn, United Kingdom, on behalf of E.A.G.M.

M. Stucki, S. Büsser, R. Itten, R. Frischknecht
ESU-services Ltd., Uster, Switzerland

H. Wallbaum
ETH Zürich, Zürich, Switzerland

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 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 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, stabilised road foundation, landfill construction and slope retention. 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 2 – Foundation stabilisation, the general way 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

In road construction the sub-base needs to meet defined requirements for compaction and bearing capacity. Improvements of some soil characteristics may be necessary while building on weak soils. Besides the construction of a conventional road with a non-frost sensitive gravel/sand layer (case 2A), stabilisation can be undertaken with geosynthetics (case 2B) or by adding lime, cement or hydraulic binder (case 2C). Both cases 2B and 2C lead to a reduced thickness of the gravel/sand layer.

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

- extruded stretched grids,
- layed grids, and

All products included had an ultimate tensile strength of 30kN/m in both directions and were manufactured from PP or PET granules.

The case of a conventional road (2A) is compared to a road reinforced with geosynthetics (2B) and to a cement/lime stabilised road (2C). The example considered is a road class III with the same finished surface level in all cases. The road is built on frost-sensitive soil class F3. In regions where the frost penetration depth does not reach the frost-sensitive soil, this soil needs not being removed. This is considered the standard case 2B. In a sensitivity analysis the frost sensitive soil is removed and replaced by non-frost-sensitive soil to meet the class F2 soil criterion (case 2BS1). In case of the cement/lime stabilised road the improvement is achieved by mixing the existing soil with 50% cement and 50 % lime (case 2C). In a sensitivity analysis stabilisation is achieved by using limestone (case 2CS1) and cement only (case 2CS2). Figure 1 shows the profiles of the three alternatives.

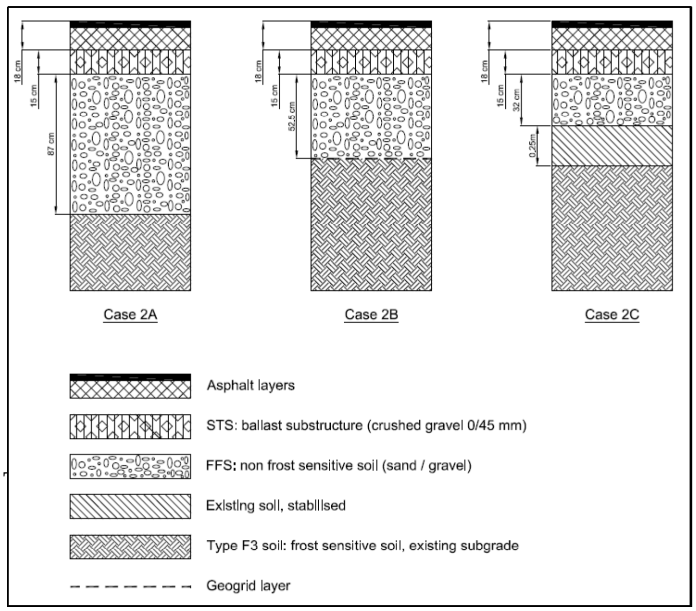

Fig.1: Scheme of the road profiles of a standard road (case 2A, left), a road using reinforcement with geogrid (case 2B, middle) and a road using soil improvement with lime/cement (case 2C, right).

Table 1 and table 2 show specific values of the roads for all three alternatives in their base case and their sensitivity analyses, respectively.

Parameter	Unit	Case 2A conventional road	Case 2B Reinforced with geosynthetic	Case 2C Stabilised with cement/lime
road width	m	12	12	12
geogrid	g/m²	-	250 (PP) or 260 (PET)	-
separation and filtration geosynthetic	g/m² (geosynthetic from case 1)	-	150 (PP)	-
stabiliser : cement/quicklime	weight-%	-	-	2.25 / 3.75
existing soil stabilised	cm	-	-	25
grade and subgrade FSS	cm	87	52.2	32
ballast substructure (0/45mm), STS	cm	15	15	15
asphalt layer	cm	18	18	18
- surface layer	cm	4	4	4
- binder course	cm	14	14	14

Tab.1: Specification of three alternative road foundations

Parameter	Unit	2BS1 Reinforced with geosynthetic, soil replacement	2BS2 Reinforced with geosynthetic, no separation geosynthetic, no soil replacement	2CS1 Stabilised with quicklime	2CS2 Stabilised with cement
road width	m	12	12	12	12
geogrid	g/m²	250 (PP) or 260 (PET)	250 (PP) or 260 (PET)	-	-
separation and filtration geosynthetic	g/m² (geosynthetic from case 1)	150 (PP)		-	-
stabiliser: quicklime only	weight-%			7.5 (5 to 10)	-
stabiliser: cement only	weight-%			-	4.5 (3 to 6)
existing soil stabilised	cm			25	25
existing soil removed and disposed (sensitivity analysis)	cm	16.8	-	-	-
non frost-sensitive soil (gravel/sand), FSS	cm	69	52.2		
subgrade	cm	-	-	32	32
ballast substructure (0/45mm), STS	cm	15	15	15	15
asphalt layer	cm	18	18	18	18
- surface layer	cm	4	4	4	4
- binder course	cm	14	14	14	14

Tab.2: Specification of alternative road foundations using soil replacement (2BS1), no separation and filtration geosynthetic (2BS1), and quicklime and cement only for stabilisation (Cases 2CS1 and 2CS2, respectively)

The foundation is considered with a life time of 30 years because of the demanding conditions of the weak soil ground. The asphalt layer is assumed to consist of a 4cm surface layer with a life time of 15 years. The 14cm binder course has a lifetime of 30 years.

3 LIFE CYCLE IMPACT OF INFRASTRUCTURE ELEMENT

The cases 2A, 2B and 2C differ in the design of the foundation stabilisation. The material and energy consumption which is related to the construction and disposal of the binder course and the surfacing in the pavement are equal in all three cases. Hence, the difference between the three cases lies in the amount of sandy primary gravel and cement that is used in the foundation, the energy consumption that is related to the foundation (material transportation, excavation etc.), and the use of geosynthetics. Recycled gravel is not considered for the foundation, since no onsite recycled gravel is available when building a road for the first time.

	Unit	Case 2A		Case 2B		Case 2C	
		Total	Thereof foundation stabiliser	Total	Thereof foundation stabiliser	Total	Thereof foundation stabiliser
Bitumen	t/m	0.3	-	0.3	-	0.3	
Gravel	t/m	33.9	-	24.3	-	18.7	6.9
Cement	t/m	-	-	-	-	0.16	0.16
Quicklime	t/m	-	-	-	-	0.26	0.26
Geosynthetic separator layer	m²/m	-	-	12	12	-	-
Geosynthetic stabiliser layer	m²/m	-	-	12	12	-	-
Diesel used in building machines	MJ/m	1957	-	1972	-	1969	14.9
Transport, lorry	tkm/m	1711	-	1232	-	994	41.4
Transport, freight, rail	tkm/m	-	-	2.0	2.0	41.4	41.4
Land use	m²/m	12	12	12	12	12	12
NMVOC	kg/m	2.19	-	2.19	-	2.19	-
Particulates, > 10 ◊m	g/m	237	-	170	-	131	-
Particulates, > 2.5 ◊m & < 10 ◊m	g/m	63	-	45	-	35	-

Tab.3: Selected key figures referring to the road construction of one meter for the cases 2A, 2B and 2C (time period = 30 years)

Some important key figures of the construction of the case 2A, case 2B and case 2C road are summarized in Tab. 3. The information refers to one meter road and a time period of 30 years. The NMVOC emissions are released from the bitumen and the figures regarding the particulate emissions refer to emissions from mechanical processes.

4 LIFE CIRCLE IMPACT OF GEOSYNTHETIC LAYER

In total 7 questionnaires concerning the production of geosynthetic layers used in foundation stabilisation are included. The quality of the data received is considered to be accurate. Table 4 shows important key figures of the production of an average geosynthetic layer.

	Unit	Value
Raw materials	kg/kg	1.02
Water	kg/kg	0.50
Lubricating oil	kg/kg	$3.62*10^{-4}$
Electricity	kWh/kg	1.76
Thermal energy	MJ/kg	1.75
Fuel for forklifts	MJ/kg	0.15
Building hall	m^2/kg	$1.41*10^{-5}$

Tab.4: Selected key figures referring to the production of 1kg geosynthetic layer used in foundation stabilisation

5 LIFE CYCLE IMPACT ASSESSMENT OF FOUNDATION STABILISATION

Three alternative road foundations are analysed, a conventional foundation (case 2A), a foundation reinforced with geosynthetics (case 2B) and a foundation stabilised with cement/lime (case 2C). The life cycle includes the provision of raw materials as well as the construction and disposal phases.

In figure 2 the environmental impacts (detailed description see paper "Ehrenberg H. & Mermet J.P." under References) over the full life cycle of the road are shown. For each indicator, the case with the highest environmental impacts is scaled to 100%. The total impacts are divided into the sections road, bitumen, gravel, geosynthetic layer, cement, lime, building machine (includes hot mixing of gravel and bitumen and construction requirements), transports (of raw materials to construction site) and disposal (includes transports from the construction site to the disposal site and impacts of the disposal of the different materials). A significant share of the environmental impacts is equal for all three cases, because the asphalt layers and the ballast substructure are identical.

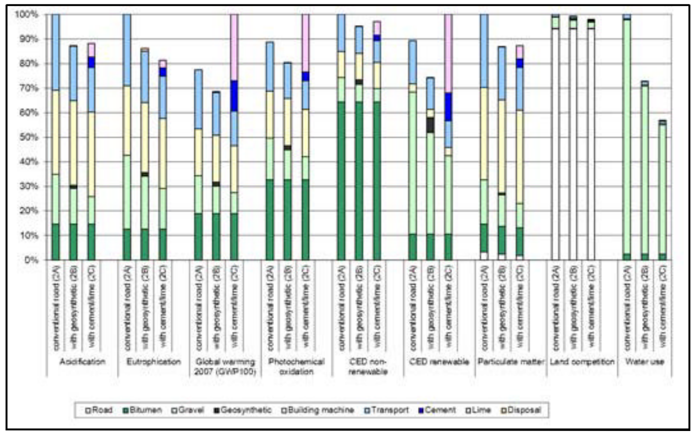

Fig.2: Environmental impacts of the life cycle of 1m road with different foundations, cases 2A, 2B and 2C. For each indicator, the case with highest environmental impacts is scaled to 100%.

The main difference lies in the amount of gravel needed, the cement and lime used in case 2C and the geosynthetics used in case 2B. Compared to case 2A about 28% less gravel is used in case 2B and 45% less gravel is used in case 2C. The environmental impacts of gravel are mainly caused by building machines and the use of electricity during mining. Furthermore, transport expenditures correlate with the amount of gravel needed, i.e. the more gravel used to build the road the more transports are required.

The use of cement and quicklime has a high influence on the result with regard to global warming and CED renewable. The impacts with regard to GWP stem mainly from the clinker production, namely from geogenic CO_2 emissions from the calcination process and fossil CO_2 emissions from traditional fuels. The use of geosynthetics contributes significantly to the CED renewable (8%) because of hydropower used in some electricity mixes that provide electricity used in manufacturing.

The disposal of the case 2A and 2C road has no environmental impacts, since the material content is considered as a gravel stock and the environmental impacts from excavation and transport to the place of reuse are allocated to the product where gravel is reused (see section 1.9.2). The bitumen content is left on-site as well. In case 2B the geosynthetic layer is incinerated, landfilled or recycled. For incineration and landfilling the respective impacts are included. The influence of disposal of the geosynthetics on the overall environmental impacts of the case 2B road is less than 0.7%.

The share of the geosynthetic layer to the overall impact of the road is between 0.75% and 6.1% with regard to particulate matter and CED renewable, respectively.

6 CONTRIBUTION ANALYSIS GEOSYNTHETIC PRODUCTION

In this section the environmental impacts of 1kg geosynthetic layer are evaluated. Included are 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.

In figure 3 the environmental impacts of the geosynthetic layer are shown. The cumulative greenhouse gas emissions amount to 3.4kg CO_2-eq per kg.

Environmental impacts are mostly dominated by the raw material provision and electricity consumption. Raw material includes plastics, chemicals, printing colours, and other additives. Plastic raw materials are responsible for between 2% (land competition) and 74% (CED non-renewable) of the overall impacts, printing colours, chemical and additives for between 9% (CED non-renewable) and 17% (land competition).

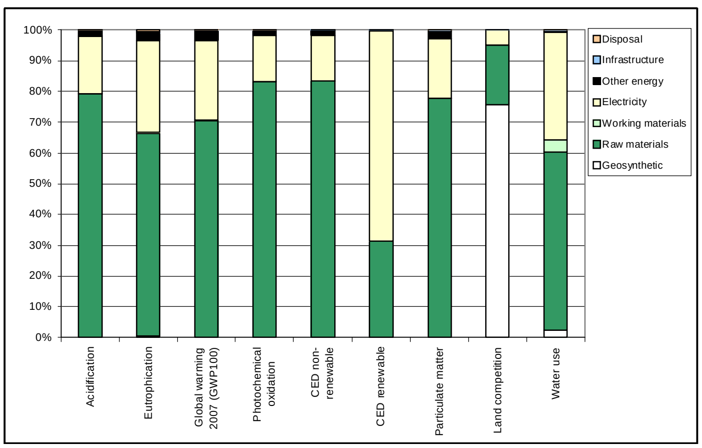

Fig.3: Environmental impacts of the life cycle of 1kg geosynthetic layer. Geosynthetic includes direct burdens of the geosynthetic production. Raw materials include plastic, extrusion if necessary and additives, working materials include water (tap and deionised) and lubricating oil, other energy includes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

7 RESULTS AND CONCLUSIONS

A conventional road (case 2A) is compared with a road stabilised with geosynthetics (case 2B) and a road stabilised with cement/lime (case 2C). The non-renewable cumulative energy demand of the construction and disposal of 1 meter stabilised road with a width of 12 meters and a life time of 30 years is 25,200MJ-eq in case 2A, 23,900MJ-eq in case 2B and 24,400MJ-eq in case 2C. The cumulative greenhouse gas emissions amount to 0.73t CO_2-eq/m² in case 2A, to 0.65t CO_2-eq/m² in case 2B and to 0.95t CO_2-eq/m² in case 2C. Correspondingly, the cumulative greenhouse gas emissions of 1km stabilised road are 730t CO_2-eq in case 2A, 650t CO_2-eq in case 2B and 950t CO_2-eq in case 2C. Using quicklime as stabiliser causes the highest environmental impacts with regard to global warming, photochemical oxidation, CED non-renewable, and CED renewable. Choosing cement as stabiliser leads to higher environmental impacts for global warming, CED renewable and water use compared to case 2B.

As indicated above, compared to a conventional road (case 2A), the use of geosynthetics leads to lower environmental impacts concerning all indicators investigated (case 2B). The comparison between a road stabilised with geosynthetics (case 2B) and a road stabilised with cement/lime (case 2C) is less marked. On the one hand case 2B shows lower global warming impacts, photochemical oxidation impacts and renewable cumulative energy demand. On the other hand acidification and particulate matter impacts as well as non-renewable cumulative energy demand are similar and case 2C shows lower eutrophying impacts, land competition and water use. The global warming impact of a road (class III, 12 meters wide, 30 years lifetime) using geosynthetics is about 80 tons CO_2-eq per km lower compared to the impacts from the construction of an equivalent conventional road. This difference is equal to about 11% of the overall global warming impact of the construction and disposal efforts of an entire road during its 30 years lifetime (excluding traffic emissions).

If we compare a road reinforced with geosynthetics to a road stabilised with cement/lime the climate change impact of a class III road reinforced with geosynthetics is about 300 tons CO_2-eq per km lower compared to the impacts of road class III stabilised with cement/lime.

This difference is equal to about 30% of the overall global warming impact of the construction and disposal efforts of an entire road during its 30 years lifetime (excluding traffic emissions).

If quicklime or cement is used as stabiliser instead of a cement/quicklime mixture, the global warming impact is increased compared to a conventional road and compared to a road reinforced with geosynthetics. The use of quicklime further increases the environmental impact for the categories photochemical oxidation and CED renewable

Roads constructed in Europe may differ in cross section and materials used. Thus, generalised assumptions were necessary to model a cross section of a lisation and the use of building machines are based on generic data and knowledge of individual civil engineering experts.

Despite the necessary simplifications and assumptions, the results of the comparison are considered to be significant and reliable.

8 REFERENCES

- Ehrenberg H. & Mermet J.P. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., General, EUROGEO 5, Valencia, Spain
- Fraser I. & Elsing A. (2012), 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, EUROGEO 5, Valencia, Spain
- Laidié N. & Shercliff D. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., Case 1, Filter Function, EUROGEO 5, Valencia, Spain
- Stucki M. et al. (2011), Stucki M., Büsser S., Itten R., Frischknecht R. and Wallbaum H., Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Material. ESU-services Ltd. commissioned by European Association for Geosynthetic Manufacturers (EAGM), Uster and Zürich, CH.
- Wallbaum H. et al. (2012), Wallbaum H., Stucki M., Büsser S., Itten R., Frischknecht R., Comparative Life Cycle Assessment of retaining walls in traffic infrastructure, 12th Baltic Sea Geotechnical Conference, Rostock, Germany
- Werth K. & Höhny S. (2012), Comparative Life Cycle Assessment of Geosynthetics versus Conventional Construction Materials, a study on behalf of the E.A.G.M., Case 3, Landfill Construction Drainage Layer, EUROGEO 5, Valencia, Spain