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Contribution of sand filled geotextile tubes and containers to carbon footprint savings building marine structures

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ABSTRACT

A carbon footprint is a measure of the impact that our activities have on the environment, and in particular climate change. It is the measurement of all the greenhouse gases generated by human activity including construction works, measured in units of tonnes of carbon dioxide equivalent. The lower the carbon footprint, the lesser the impact construction works have on the environment. Engineering solutions are not just compared purely on economic terms, but are beginning to be compared on carbon footprint as well. Therefore engineering solutions that protect and improve the environment are increasingly favoured as opposed to those that have a negative impact to the environment. This paper describes and compares the carbon footprint of sand filled geotextile tubes and geotextile containers alternatives versus conventional engineering solutions for marine structures.

1. INTRODUCTION

Carbon footprinting as an approach is relatively new and has been developed from Life Cycle Assessment (LCA), which has been around since the late 60s. Both methods take a systematic view of the supply chain from raw material extraction through to the final disposal of the product. This approach crucially prevents decisions being made which may shift the environmental burden up and down the supply chain. The impact can be quantified as a total or can be broken down to present the results as its constituent sub-systems. The latter can be used to identify priority areas for improvements.

A product carbon footprint is an assessment of the global warming potential of a product and is also known as embodied carbon. This is often measured as a cradle to gate assessment, which includes all greenhouse gas (GHG) emissions up until the point where the product leaves the factory gate. For example raw material extraction, transportation at all stages, refining, processing and fabrication up to the product leaving its final factory gate. The boundaries of cradle to site also include the transportation up to the site of use for the product. Finally the boundaries of cradle to grave are the most holistic and include all lifecycle stages. This covers the cradle to site, usage (including operation and maintenance) and finally the end of life stage (recycling, reuse, and disposal). This study considered the cradle to grave carbon footprints of breakwater systems and sludge dewatering systems.

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2. GEOTEXTILE TUBE SOLUTION

A geotextile tube is a closed ended tubular formed fabric unit tailored with regular filling ports. Its circumference and length may be sized specific for each project and are limited only by constraints of handling practicalities and site conditions. The geotextile tube contains the slurry mixture of solids and water that is pumped in, allows water to dissipate through the permeable fabric skin and retains solids within the geotextile tube. Geotextile tube solutions include use as structural units for marine and hydraulic engineering applications and use as containment and dewatering units for municipal, industrial, mining, agricultural and environmental dewatering applications.

2.1 Marine and Hydraulic engineering applications

Geotextile sand filled tubes are used in the following marine and hydraulic applications: revetments, offshore breakwaters, protection dykes, containment dykes and groynes.

a b c

(a) Geotextile tube for core of breakwater (b and c) Geotextile tubes for an artificial island creation for bridge construction

Figure 1. Geotextile tube applications

3. CARBON FOOTPRINTING METHODOLOGY

The carbon footprint was calculated by collecting data from the supply chain (primary data) and combined with literature sources (secondary data). Data was collected throughout the lifecycle which covered:

Production of raw materials

Transport of raw materials

Manufacturing of the geotextiles

Transportation to final customer

Use

Transport to disposal

End of life

End of life was determined to be negligible in this study. The method used is called QuickSteps and is built upon the PAS 2050:2011 method of carbon footprinting, which is the most robust carbon footprint method to date. The main difference between these two methods is the different requirements to collect primary data from the supply chain and first tier suppliers. However the underlying principles and method requirements are otherwise the same.

The carbon footprint is measured in CO_2 equivalents (CO_2e) and all IPCC direct GHGs were included in this assessment and converted to CO_2 equivalents (CO_2e) using the latest IPCC (2007) global warming potentials (GWP). This study excludes capital goods (e.g. manufacturing of vehicles, roads, buildings, machinery etc.); human energy inputs to processes; transport of employees to and from the place of work; animals providing transport services and offsetting of emissions. These exclusions are in line with accepted international standards (ISO 14040:2006 and ISO 14044:2006, and the PAS 2050:2011). The most recent data for primary data collection were used, covering a period of the calendar year in 2010. The period of GHG assessment (i.e. the temporal boundary) is 100 years, which is in line with PAS 2050:2011 and all global warming potential factors are based on a 100 year timeline. These global warming potentials include carbon dioxide, methane, nitrous oxide, hydroflurocarbons (HFC), perflurocarbons (PFC) and sulfur hexafluoride.

The exclusion from the carbon footprint is in line with accepted international standards (ISO 14040:2006 and ISO 14044:2006, and the PAS 2050:2011). This study excludes:

Capital goods (e.g. manufacturing of vehicles, roads, buildings, machinery etc.)

Human energy inputs to processes

Transport of employees to and from the place of work

Animals providing transport services

Offsetting of emissions

The most recent data for primary data collection were used, covering a period of the calendar year in 2010. The period of GHG assessment (i.e. the temporal boundary) is 100 years, which is in line with PAS 2050:2011 and all global warming potential factors are based on a 100 year timeline.

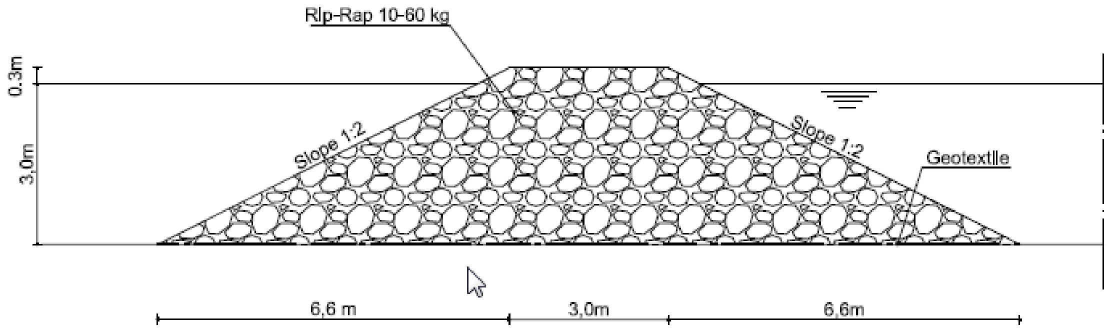
4. CARBON FOOTPRINT COMPARISONS

Carbon footprint calculations are project specific. In many instances, geotextile tube options result in lower carbon footprints when compared with conventional solutions. A proprietary Carbon Footprint Calculator was developed for the purpose of calculating carbon footprint of and comparison between conventional and geotextile tube solutions. One hypothetical example of a breakwater comparison between geotextile tube option against conventional rock solution in marine and hydraulic engineering application is provided. A project case study is also described whereby the geotextile tube solution resulted in significant carbon footprint savings over the conventional solution.

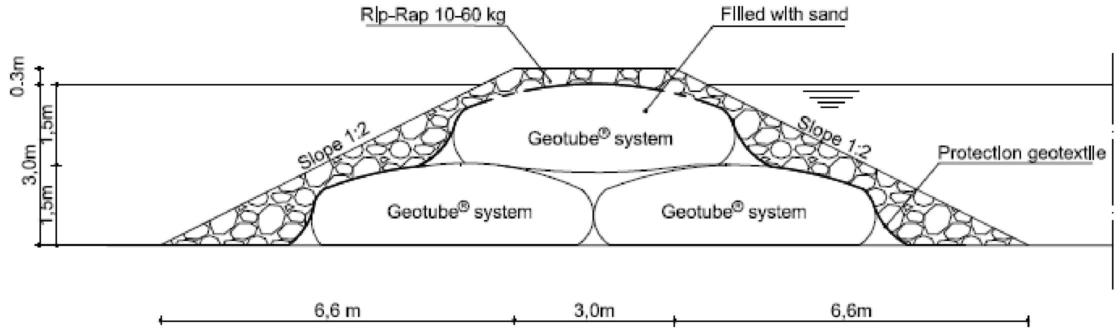
5. BREAKWATER EXAMPLE

In this hypothetical example a comparison is made between a breakwater built using only rock material and a breakwater built using a core consisting of stacked geotextile tube construction covered with rip-rap. This example is based on conditions applicable to the Netherlands. Figure 2(a) shows the conventional rock breakwater while Figure

2(b) shows the breakwater option with geotextile tube replaced core. Both have the same overall geometrical cross-sectional dimensions. The breakwater height is assumed as 3.3 m, with a base of 16.2 m, crown of 3 m and side slopes of 1:2. This breakwater geometry is not untypical of an inland breakwater application in the Netherlands. In Figure 2(b) three identical geotextile tube filled to height of 1.5 m are used as the core of the breakwater, replacing rock. A geotextile protection layer is used to cover the geotextile tubes before rip-rap is placed on. Both design options involved the use of a basal geotextile layer for the breakwater.



(a) Conventional rock breakwater



(b) Breakwater with geotextile tube core

Figure 2. Breakwater details

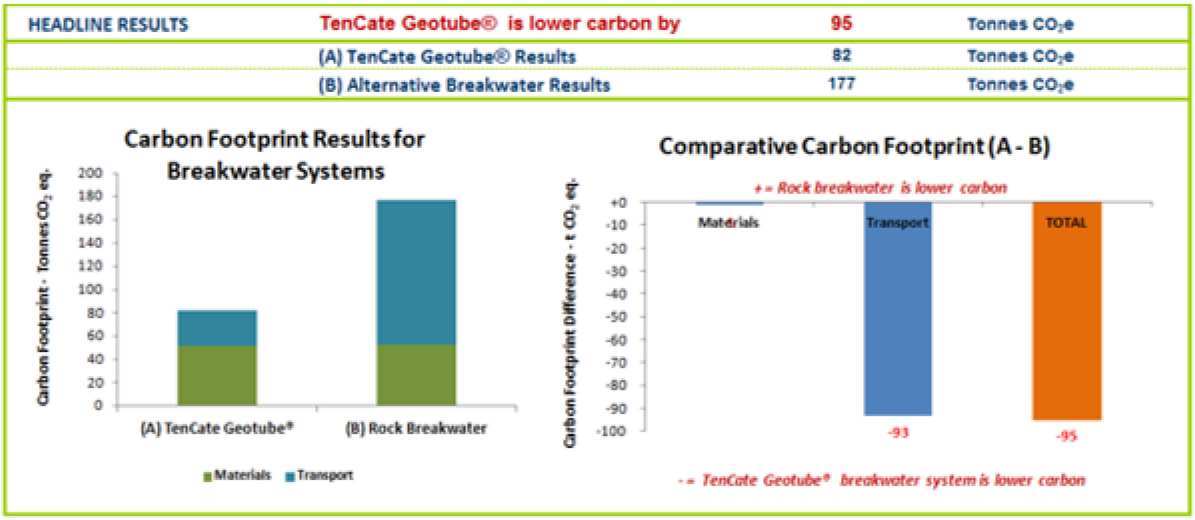
Table 1 shows the materials, transport quantities and quantities per 100 meter of breakwater for the conventional rock only system and the alternative geotextile tube core system. The carbon footprints for both systems were determined using the proprietary Carbon Footprint Calculator. Figure 3 shows the summary of the carbon footprints per 100 meter of breakwater for the conventional rock breakwater and geotextile tube alternative. Figure 3 also shows a savings of 95 tonnes of CO_2e in carbon footprint per 100 meter when the geotextile tube system is used in replacement of the conventional rock breakwater system.

These results show that, in the context of this example, the carbon footprint of the geotextile tube solution was lower because of the lower transport emissions. This is largely a result of the lower quantity of rocks used when compared with the conventional total rock solution, due to replacement of core with geotextile tubes filled with sand. The sand was dredged onsite for this case example and the pumping energy from this operation has been included in the study.

However if the sand was imported to the site the transport distance would likely be small. This is because sand is typically sourced from a local resource.

Table 1. Materials, transport distances and quantities for conventional and geotextile tube solutions for a hypothetical inland breakwater in the Netherlands.

		Quantities per 100 meter of breakwater	
Materials	Transport distance	Conventional	Geotextile Tube
Geotextile tube (4 m diameter)	150 km by road	N.A.	300 m
Sand to fill geotextile tube	Site available	N.A.	4600 tonnes
Riprap (10 – 60 kg)	1200km by sea + 50km by road	7300 tonnes	1800 tonnes
Protection geotextile (200 g/m^2 nonwoven)	150 km by road	N.A.	2300 m^2
Basal geotextile (300 g/m^2 nonwoven)	150 km by road	1650 m^2	1650 m^2



HEADLINE RESULTS	TenCate Geotube® is lower carbon by	95	Tonnes CO$_2$e
	(A) TenCate Geotube® Results	82	Tonnes CO$_2$e
	(B) Alternative Breakwater Results	177	Tonnes CO$_2$e

Figure 3. Summary output using proprietary Carbon Footprint Calculator

6. CASE STUDY CONSTRUCTION OF A POLDER DIKE IN SAEMANGEUM, SOUTH KOREA

The 33.9 km long Saemangeum Sea Dike in Korea links Gunsan in the north to Buan in the south. As of now it is the world's longest sea dike. Before the dike was constructed, Mangyeon River and Dongjin River discharged directly into the Yellow Sea. When the dike was completed, a 400 km2 reservoir was formed and is drained into by both rivers. Future development would involve land reclamation within the formed lake for agricultural, industrial, business, residential, wetland and ecotourism purposes. This paper concerns the land reclamation works for one of the development packages. The Polder Dike that serves as a land reclamation dike during the construction period and as a flood protection dike for the longer term is constructed. The polder dike consists of a sandfill core with rock revetment for erosion protection on both sides of the dike. A road pavement is provided on top of the Polder Dike. For the original design of the Polder Dike rockfill berms are used to contain the sandfill core during construction of the Polder Dike. As an alternative to the original design, geotextile tubes were used to replace the rockfill berms for the construction of the Polder Dike. More than 26 km of geotextile tubes were used for this project. The geotextile tube alternative was more economical than the rockfill berm design. The geotextile tube alternative also help save up to 7 months in construction time. The geotextile tube alternative was also more environmentally friendly, giving a smaller carbon footprint when compared with the rockfill berm design.

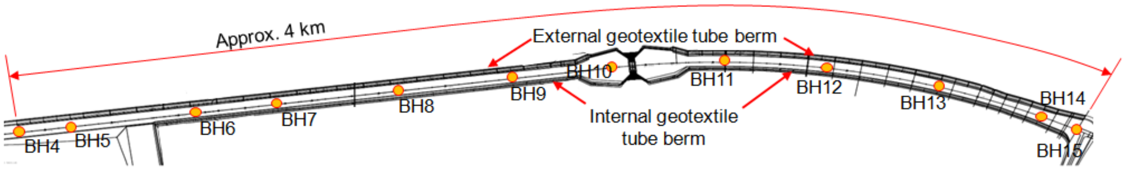


Figure 4. Plan view with geotextile tube berms on both sides of Polder Dike.

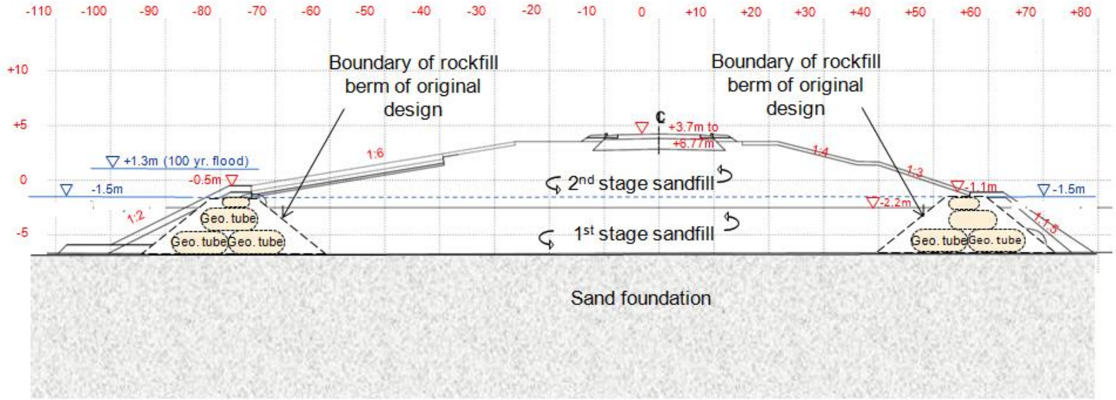


Figure 5. Typical cross-section of the Polder Dike for alternative design with geotextile tube berm (the original design rockfill berm is indicated).

7. COST SAVING OF GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Figure 6 shows the berm boundary used to compare quantities of rockfill berm with the equivalent geotextile tube berm. Within the defined boundary, it should be pointed out that the sum of rockfill and sandfill for both designs should add up to the same number. The material quantity differences for the entire Polder Dike are shown in Table 2.

The cost saving of the geotextile berm alternative design over the rockfill berm original design was USD 6.2 million, based on actual tender prices.

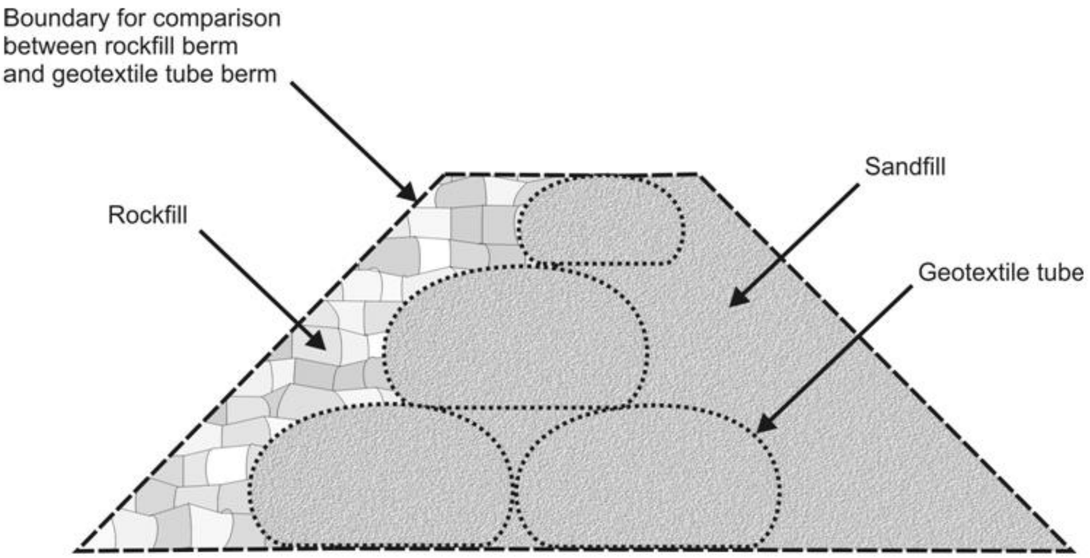


Figure 6. Berm boundary to compare quantities of rockfill berm with the equivalent geotextile tube berm.

Table 2. Material quantity differences between original rockfill berm design and geotextile tube berm alternative design.

Item	Unit	(X) Rockfill berm	(Y) Geotextile tube berm	(X-Y) Difference
Rockfill	m^3	837.000	387.000	+450.000
Sandfill	m^3	-	450.000	-450.000
Geotextile tube	m	-	26.123	-26.123
Cost saving	USD	+6.200.000		

8. CARBON FOOTPRINT COMPARISON

Carbon footprint calculations are project specific. For comparison of carbon footprint savings of the geotextile tube berm alternative design over the rockfill berm original design, likewise to the cost saving comparison, only the difference in quantities between the two berm designs are compared (see Table 2). The transportation distance between the source location of the rockfill and the project site include a road journey of 50 km and a barge journey of 4 km. The transportation distance between the manufacturing location of the geotextile tubes and the project site include road journeys of 500 km and a sea journey of 3,000 km.

For the carbon footprint of the rockfill berm original design the energy consumptions involved in the quarrying of rock, in the transportation of the rockfill, that of mechanical equipment in transferring the rock from dumper trucks onto barges and that involved in the placement of rockfill at site are determined. For the geotextile tube berm alternative design, the carbon footprints of the geotextile tubes used (based on cradle to site life cycle) and that of the sand dredging and filling works involved are determined. In the comparison exercise, the carbon footprint of basal geotextile is not included because it is common for both options. Table 3 shows the summary for carbon footprint comparison between the geotextile tube berm alternative design and the rockfill berm original design. The total carbon footprint saving for the geotextile tube berm alternative design over the rockfill berm original design is more than 230,000 tons of CO_2e, representing a 52% carbon footprint saving.

Table 3

Berm type			
Sandfilled geotexile tube core		Full Rock	
Activity	Tonnes CO_2e	Activity	Tonnes CO_2e
Geotube Embodied carbon	1.087	Rock cover fill material	442.773
Transport to site tube	32	Transport to site rock	9.946
Dredging sand for filling tubes	4.066		
Rock cover fill material	204.723		
Transport to site rock	4.599		
Total	214.506	Total	452.719

9. CONCLUSIONS

This paper described the methodology for carbon footprinting of geotextile tube solutions and the conventional systems they replace. A case study involving the use of geotextile tubes as economical and environmental replacement of rock for the construction of polder dike for the Dongjin 1 Package in Korea has been presented. The geotextile tube berm alternative design resulted in cost saving of USD 6.2 million and carbon footprint saving of more than 230,000 tons of CO_2e or 52% over the rockfill berm original design. The geotextile tube berm alternative also helped shorten the overall project duration by 7 months.

Geotextile tube solutions appear to have more favorable carbon footprints over conventional systems in the cases presented.

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