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GEOTEXTILE TUBES AS A REPLACEMENT FOR ROCKFILL FOR THE POLDER DIKE IN SAEMANGEUM, SOUTH KOREA

ABSTRACT

The 33.9-km-long Saemangeum Sea Dike in South 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 both these rivers drain into it. Future development will involve land reclamation within the formed lake for agricultural, industrial, business, residential, wetland and ecotourism purposes.

This article 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. 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 and also helped 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.

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INTRODUCTION

Saemangeum is a region where an estuarine tidal flat existed on the coast of the Yellow Sea (also known as West Sea) in South Korea. Mangyeon River and Dongjin River flowed past the Saemangeum tidal flat to discharge into the Yellow Sea. In 1991, the South Korean government announced that a sea dike would be constructed to link two headlands just south of the industrial port city of Gunsan, 270 km southwest of Seoul. Water depths along the sea dike vary from 4 m to 27 m below MSL (Mean Sea Level). Deep tidal channels are developed at three locations: south of Sinsi Island, east of Yami Island and between Duri Island and Bukgaryeok Island (HR Wallingford, 2005).

The dike closing works were completed on 21 April 2006. Flow is regulated with two constructed sluice gates. The Garyeok Sluice Gate was completed in 2003 while the Sinsi Sluice Gate was completed in 2006. A navigation lock at the northern end of the Sinsi Sluice Gate is provided to allow vessel access between Mangyeon River and the Yellow Sea. The watersheds of the Saemangeum reservoir total 3,300 km^2. The 33.9-km-long Saemangeum Sea Dike was officially open to the public on 27 April 2010. On 2 August 2010, Saemanguem Sea Dike was certified by Guinness World Records as the longest human-made sea barrier in the world. The Saemangeum Sea Dike is 500 m longer than the Afsluitdijk in the Netherlands, which held the record prior to that. Figure 1 shows a map of Korea and location of Saemangeum.

Above: To fill the geotextile tube, a lifting crane is mounted on a flat barge which holds the sand slurry delivery pipe. The pipe is attached to the geotextile tube under the water. Sand slurry is delivered by a dredger through floating pipelines identified by the orange floats.

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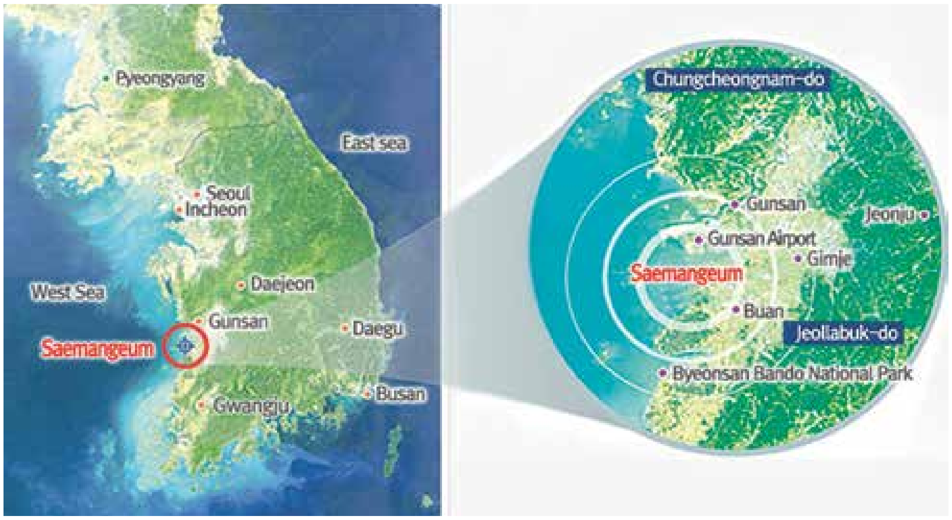


Figure 1. Map of Korea showing location of Saemangeum (adapted from Saemangeum Investment Guide, 2012).

The Saemangeum Development Project was mooted decades ago when South Korea had to import rice owing to droughts and cold weather extremes during the 1960s through 1980s. On 16 March 2011, the Saemangeum Development Project Master Plan was announced. The Master Plan involves the creation of 400 km2 of combined reclaimed land and freshwater reservoir behind the Saemangeum Sea Dike. Figure 2 shows the Saemangeum Development Project Master Plan indicating the reclamation and land use. From the 283 km2 of reclaimed land, 30% would be dedicated for agricultural purposes, 15% for ecological and environmental purposes, 8% for scientific research purposes and 7% for new and renewable energy purposes.

This article concerns primarily the construction of the Polder Dike for one of the construction packages of the Master Plan, namely the Dongjin 1 Package. However, apart from the brief introduction on the Saemangeum Sea Dike and the Master Plan this case study would be incomplete without a perspective on the construction of the Saemangeum Sea Dike and its impact on the tidal and sedimentation aspects at Saemangeum.

TIDAL AND SEDIMENTATION IMPACT OF SAEMANGEUM SEA DIKE

The tides in the Yellow Sea are dominantly semidiurnal. Prior to the construction of the Saemangeum Sea Dike, the Saemangeum estuary was a relatively shallow macrotidal embayment with average tidal range of 5.7 m on springs and 2.8 m on neaps (Min et al. 2011). Peak tidal currents among the shores of the western coast are often 1 to 1.5 m/s and reach a maximum of 4.4 m/s in the passage off the southwest tip of the Korean Peninsula.

Choi and Lee (2003) simulated M2 tide in the Yellow and East China Seas and found the simulations to be similar to the observed tide. Min et al. (2011) conducted comprehensive modelling studies on the tidal and sedimentation regimes at Saemangeum resulting from the construction of the sea dike. Figure 3 shows the modelled residual tidal currents of M2 before and after the construction of the Saemangeum Sea Dike.

The residual tidal currents were calculated by time-integrating the modelling results and averaging the time-integrated value of one periodic M2 tide. A sizeable eddy occurring in the area between Sinsi Island and Yami Island before the completion of the dike is shown in Figure 3(a). Residual currents in the area of interest are generally below 0.1 m/s, except in tidal flats in the river estuaries and around the islands of the Gogunsam Archipelago. After the construction of the dikes, the residual currents were generally smaller, except for larger residual currents seen between the islands of the Gogunsam Archipelago and at the end of the Gunjang waterway.

The Saemangeum region, including the huge

Figure 2. Saemangeum Development Project Master Plan showing the reclamation and land use (adapted from Saemangeum Investment Guide, 2012).

tidal flat, was shallower than 5 m in most areas except in the main waterways (Min et al. 2011). The seafloor around the Saemangeum Sea Dike is predominantly covered with sands (Lee and Ryu 2008). These sands have been found to be derived from the Mangyeon and Dongjin rivers (Lee 2010).

Before the dike construction, the riverine sands were accumulated in the form of tidal sand ridges in and around the estuary. These ridges were aligned roughly in the NE–SW direction conforming to the major axis of the tidal currents at the time.

The presence of the dike has largely changed the tidal regime, particularly the tidal direction, aside from preventing the seafloor off the dike from accessing sands. Such an artificial change in tidal direction resulted in the change in sediment transport conditions for the offshore surficial sands (Lee and Ryu, 2008). The NWL (Normal Water Level) and

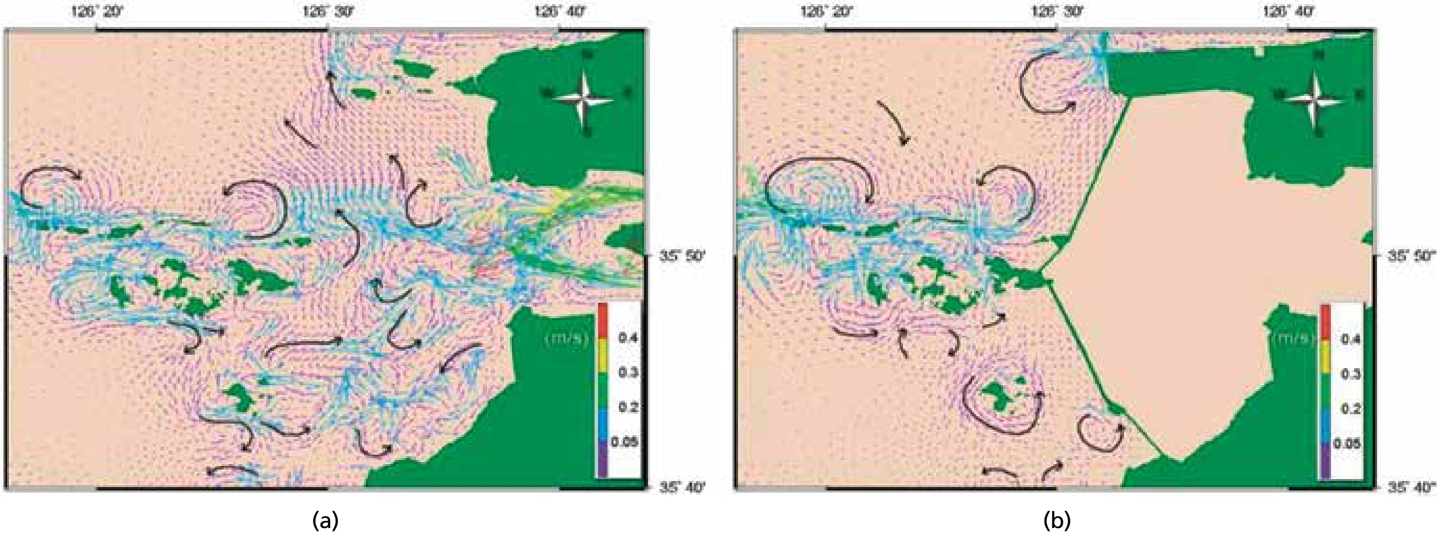


Figure 3. Modelled tidal residual currents of the M2 tides with eddies as potential traps for fine grained sediments (a) before construction of dike, (b) after construction of dike (adapted from Min et al. 2012).

Figure 4. Transformation of Saemangeum estuarine tidal flat into a reservoir from 1987 to 2010 (adapted from Korean Geotechnical Society 2012).

DWL (Dead Water Level) of the reservoir are at EL -1.5 m and EL -6.5 m respectively. The 100 year design flood level is at EL +1.3 m.

Figure 4 shows the transformation of the estuarine tidal flat into a reservoir from 1987 to 2010. These satellite photos also give an indication of the impact of Saemangeum Sea Dike on sedimentation as the dike construction progressed until completion in 2006. It can also be seen from the satellite photos (2010 versus 2006) in Figure 4 that significant sedimentation has occurred within the formed reservoir within 4 years of closure. The sediments trapped behind the Saemangeum Sea Dike do not pose a problem as long as sand is required for reclamation works within the reservoir area. However, this is expected to be an issue in the future, especially when the reclamation works are completed after 2020. Regular maintenance dredging of the waterways behind the Saemangeum Sea Dike may then become a necessity.

THE PROJECT POLDER DIKE

The Reclamation Project is implemented by the Korea Rural Community Corporation under the auspices of the Ministry for Food, Agriculture, Forestry and Fisheries. For areas of high population density and high economic risk, reclaimed platforms are designed at elevations higher than the long-term design flood levels. For areas of low population density and low economic risk, e.g., agricultural land, the reclaimed platform levels are relatively lower and polder dikes are constructed to protect them against flooding risks. A total of 68 km of such polder dikes are to be constructed in 11 construction packages.

The Dongjin 1 Package was undertaken by Hyundai Construction in 2012. The package involves the construction of a polder dike and formation of agricultural land and wetland area behind the polder dike on the southern bank of Dongjin River, adjacent to the proposed Ariul City. The polder dike for this package will be referred to simply as the Polder Dike for the rest of the article. Figure 5 shows the extent of Dongjin 1 Package and the location of the Polder Dike. Figure 6 shows the plan view with geotextile tube berms on both sides of the Polder Dike.
The Polder Dike consists of a sandfill core typically with rock revetment for erosion protection on both sides of the Polder Dike. Sand is used for constructing the core of the Polder Dike because it is available in abundance at site as bottom deposits. Figure 7 shows the bed subsoil profile along the Polder Dike (see also Figure 6). Generally, the subsoil profile consists of between 20-m to 40-m-thick deposit of sand, with isolated lenses of clay and gravel, overlying weathered rock and bedrock. A road pavement is provided on top of the Polder Dike with elevations ranging from EL +3.7 m to EL +6.77 m. For the original design of the Polder Dike rockfill berms are used to contain the sandfill core during construction of the Polder Dike. The rockfill berms are built to above the NWL.

An alternative design using geotextile tube berms as replacement for rockfill berms was provided for. The geotextile tube berms would be constructed in two stages. The first construction stage involves a one-on-two pyramid stacking to a top level of EL -2.2 m.

Figure 5. Map showing the extent of Dongjin 1 Package and the location of the Polder Dike.

This is then followed by construction of sandfill core to EL -2.2 m or higher. The second stage construction involves typically an additional geotextile tube before the sandfill core is completed. Figure 8 shows the typical cross-section of the Polder Dike for the alternative design using geotextile tube berm (the original design rockfill berm is indicated).

GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Geotextile tubes have been used in marine and hydraulic engineering in Korea since the beginning of the 21st century (Cho 2010; Choi et al. 2012; Lawson 2008; Oh and Shin 2006; Yee and Choi 2008; Yee et al. 2007, 2010). The main attractiveness of the geotextile tube berm alternative is that sand is readily available in abundance at site. Since the construction of the sandfill core of the Polder Dike requires dredging of sand deposits at site, the filling of the geotextile tube with sand is a natural extension of the dredging works with little incremental cost involved.

Geotextile Tube Analysis

Geotextile tubes are characterised by the circumference or theoretical diameter, the length and the fabric type used for the fabrication of the tube. The theoretical diameter is defined as the circumference divided by the factor, π. Geotextile tubes of five different theoretical diameters were used for this project, which may be made to various lengths using two different fabric types. The geotextile tube analysis was carried out using GeoCoPS (Version 3.0) software. Figure 9 shows the typical analysis output using GeoCoPS software.

Table I shows the standard tube sizes (represented by their theoretical diameter or

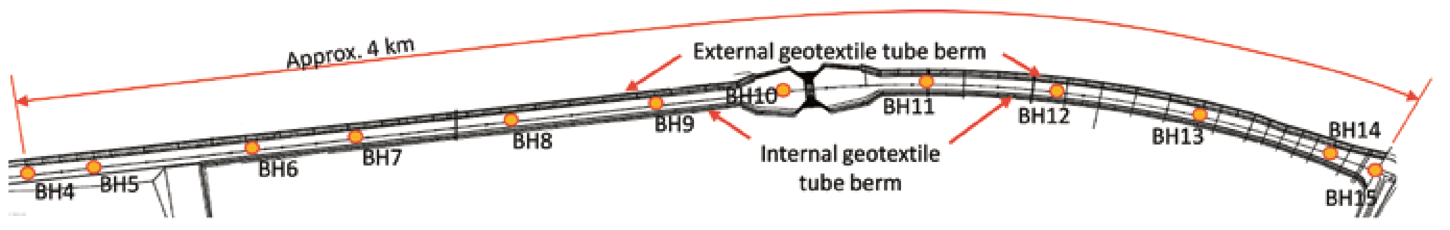
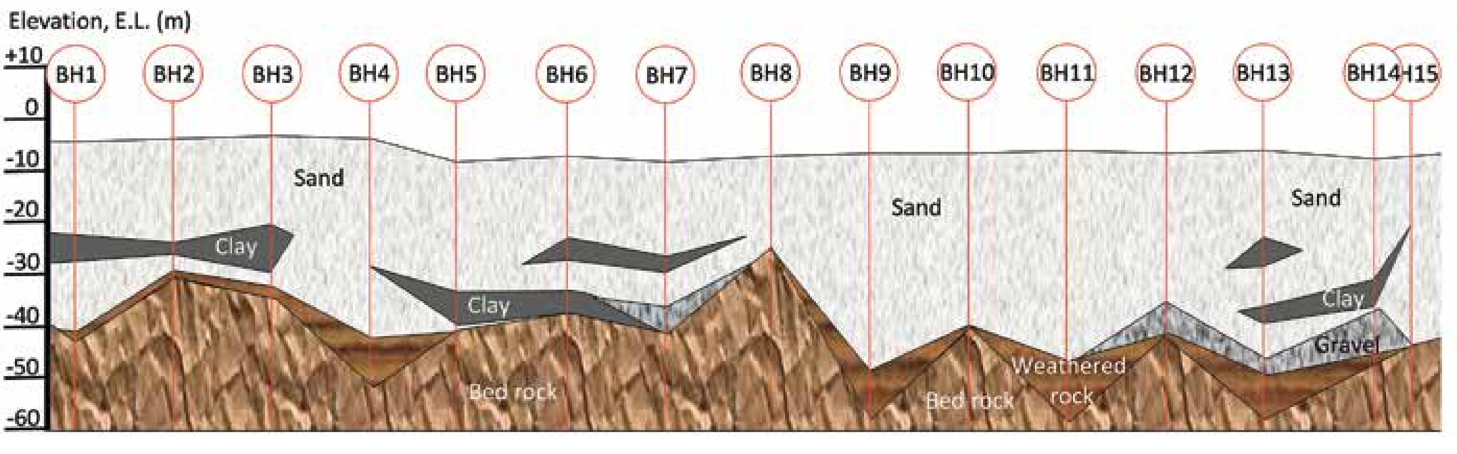


Figure 6. Plan view with geotextile tube berms on both sides of the Polder Dike.

Figure 7. The bed subsoil profile along the Polder Dike.



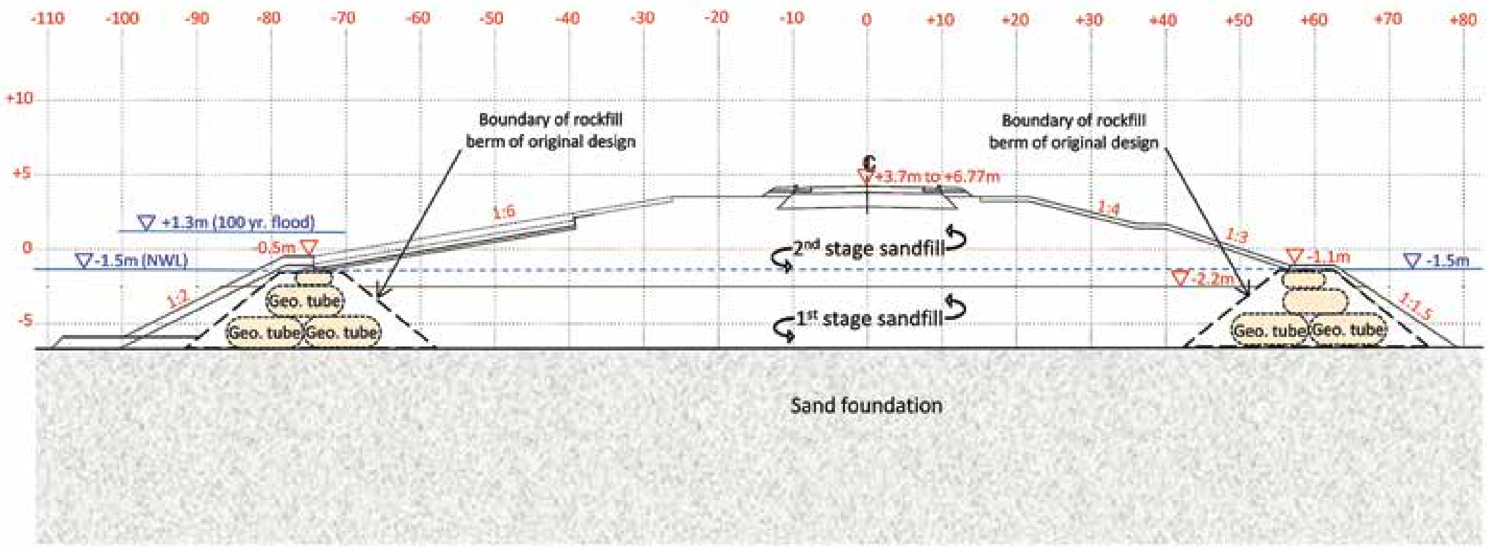


Figure 8. Typical cross-section of the Polder Dike for alternative design with geotextile tube berm (the original design rockfill berm is indicated).

Table I. Standard geotextile tube sizes, dimensions and volume.

type	Theoretical diameter (m)	Circumference (m)	Filled tube height (m)	Filled tube width (m)	Filled tube volume (m³/m)
A	2	6.3	1.1	2.5	2.2
B	2.5	7.8	1.4	3.1	3.5
C	3	9.4	1.7	3.8	5.3
D	3.5	11.0	2.0	4.3	7.2
E	4	12.6	2.2	5.0	9.4

Table II. Fabric type, circumferential and longitudinal tensions for various tube sizes and conditions.

Standard tube size	Theoretical diameter (m)	Filled tube height (m)	External water level (m)	Circum-ferential tension (kN/m)	Longi-tudinal tension (kN/m)	Tube fabric type	Fabric ultimate tensile strength (kN/m)
A	2	1.1	0.6	39	31	I	120
			1.1	21	14		
B	2.5	1.4	0.9	70	55	I	120
			1.4	35	24		
C	3	1.7	1.2	110	86	I	120
			1.7	53	36		
D	3.5	2.0	1.5	169	129	II	200
			1.0	79	53		
E	4	2.2	1.7	197	155	II	200
			2.2	92	63		

circumference) and the design filled tube height, filled tube width and filled tube volume. As a design rule of thumb, the filled tube height is taken to be about 55% of the theoretical diameter of the tube. The filled tube widths and filled tube volumes are determined using GeoCoPS software.

Table II shows the fabric type, circumferential and longitudinal tensions for various tube sizes and different submergence conditions in water. The tension values in Table II have been factored for various partial factors of safety that include installation damage, environmental degradation, and so on. Two standard types of tube fabric, namely type I and type II were assigned for the manufacture of the five different tube sizes. The tube fabric types are specified based on the tensile strength requirement from the analysis using GeoCoPS software. The tensile strength requirement for type I and type II tube fabrics are standardised at 120 kN/m and 200 kN/m respectively.

It should be pointed out that tensile strength is not the only criteria considered in the development of the geotextile tube specifications. Other mechanical performance requirements include static puncture resistance, dynamic puncture resistance and seam strength. Hydraulic performance requirements include the sand retention requirement and water dissipation requirement. Standard filtration criteria are used for determining the required fabric pore size and permeability. Durability performance requirement include UV degradation resistance. This is to cater for fabric strength reduction as a result of exposure of the geotextile tube to sunlight during construction.

Once the geotextile tube is covered with rock, UV degradation of the geotextile tube then ceases to be an issue. The complete specification for the geotextile tubes used is given in Table V. Polypropylene is specified based on historical reasons and fabric mass per unit area and thickness are specified as a quick index check on site. Mechanical and hydraulic properties can only be tested at the test laboratory but fabric mass per unit area can be easily checked on site if a simple weighing scale is available.

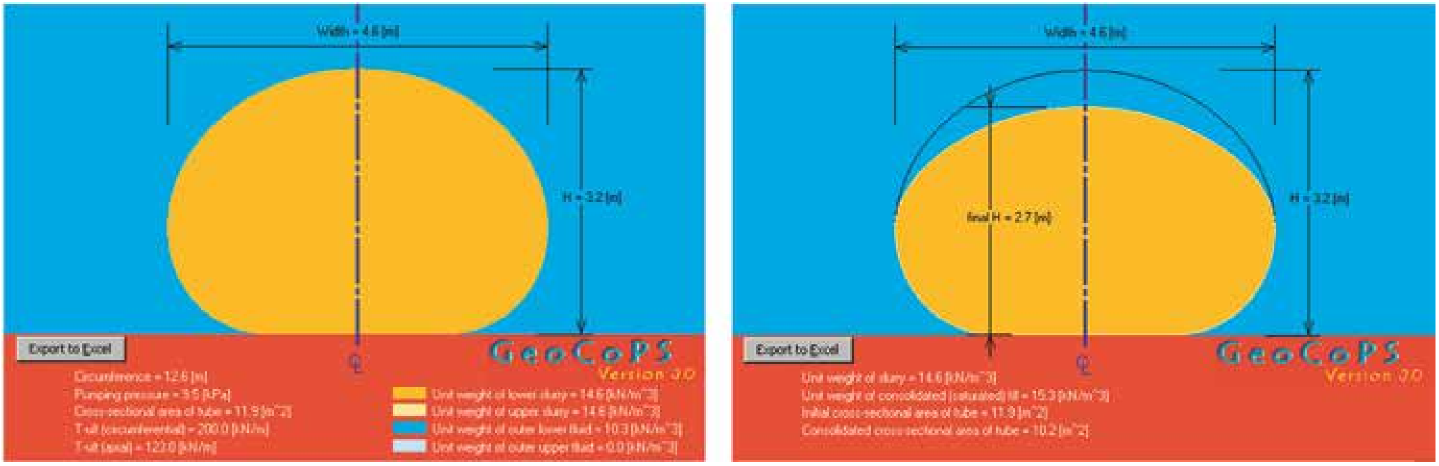


Figure 9. Typical analysis output using GeoCoPS software.

Table III. Geotextile tube stacking format.

Stacking format	Bottom layer tube size class	2nd layer tube size class	3rd layer tube size class	Stacked height (m)
1a	2 x E	E	D	6.4
1b	2 x E	E	C	6.1
1c	2 x E	E	B	5.8
1d	2 x E	E	A	5.5
1e	2 x E	E	-	4.4
2a	2 x E	D	D	6.2
2b	2 x E	D	A	5.3
2c	2 x E	D	-	4.2
3a	2 x E	C	B	5.3
3b	2 x E	C	A	5.0
3c	2 x E	C	-	3.9
4a	2 x D	D	A	5.1
4b	2 x D	D	-	4.0
5a	2 x D	C	B	5.1
5b	2 x D	C	A	4.8
5c	2 x D	C	-	3.7
6a	2 x C	C	B	4.8
6b	2 x C	C	A	4.5

Table IV. 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		m³	387,000	387,000	+450,000
Sandfill		m³	-	450,000	-450,000
Geotextile tube	Type A	m	-	9,386	-9,386
	Type B	m	-	7,235	-7,235
	Type C	m	-	5,333	-5,333
	Type D	m	-	1,281	-1,281
	Type E	m	-	2,888	-2,888
	Total	m	-	26,123	-26,123
Cost saving	USD		-	-	+6,200,000

Geotextile Tube Stacking Format

Table III shows the geotextile tube stacking format. The stacking format at a certain location along the Polder Dike is selected based on the water depth and other practical considerations.

Other Design Checks

The geotextile tube units were also checked for hydraulic stability for the 100-years return period. The stability against wave attack was checked using the significant wave height of 1.6 m with wave period of 4.1 s. The stability against flow attack was checked using a critical velocity of 0.4 m/s.

Geotechnical stability checks (see Figure 10) that included sliding, overturning, bearing capacity and global stability were conducted and found to be adequate. The minimum factor of safety adopted in design against sliding and global stability is 1.4 while that against overturning and bearing capacity is 2.

COST SAVING OF GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Figure 11 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 IV. The cost saving of the geotextile berm alternative design over the rockfill berm original design was US$ 6.2 million, based on actual tender prices.

CARBON FOOTPRINT SAVING OF GEOTEXTILE TUBE BERM ALTERNATIVE DESIGN

Engineering solutions are not just compared purely on economic terms, but are beginning to be compared on environmental terms as well. Engineering solutions that protect and

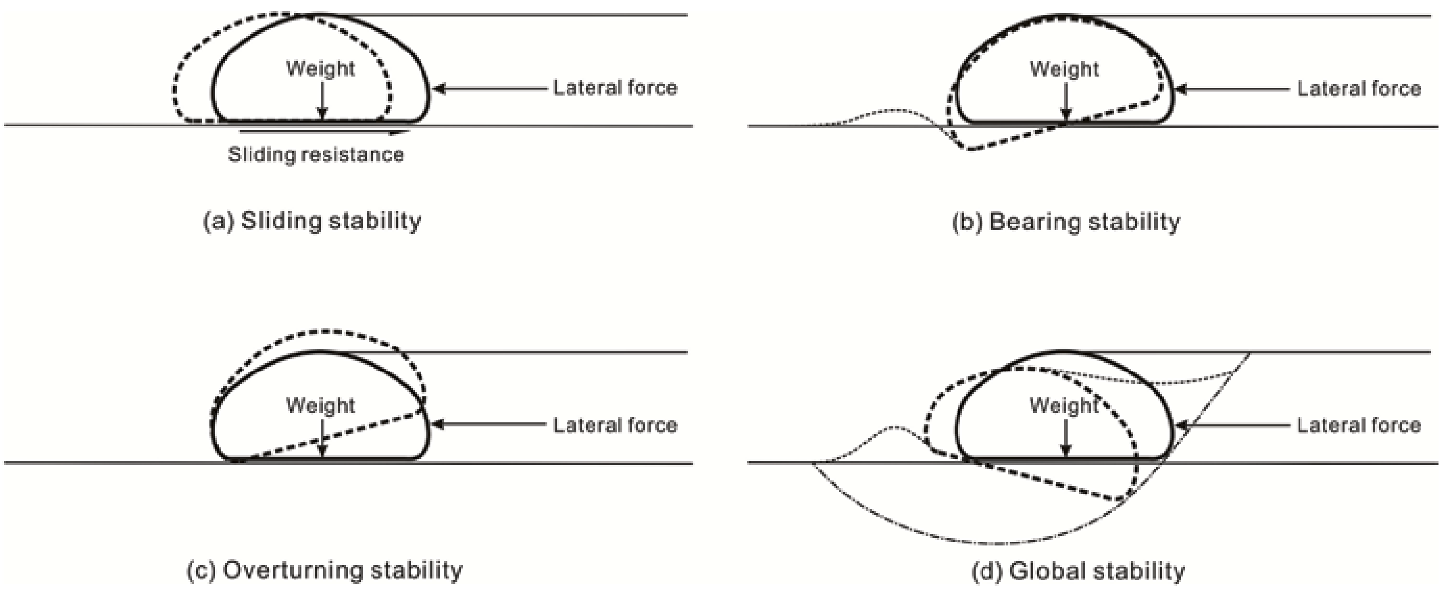
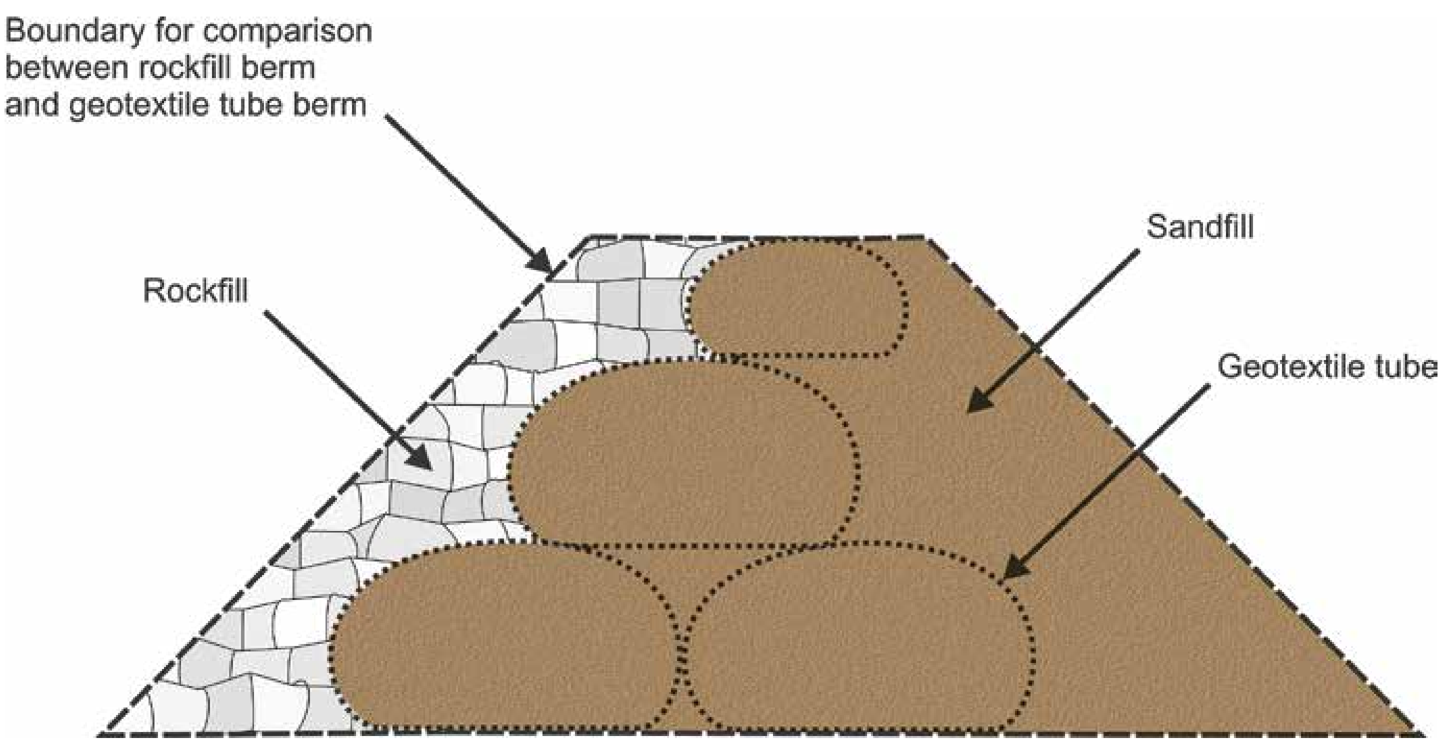


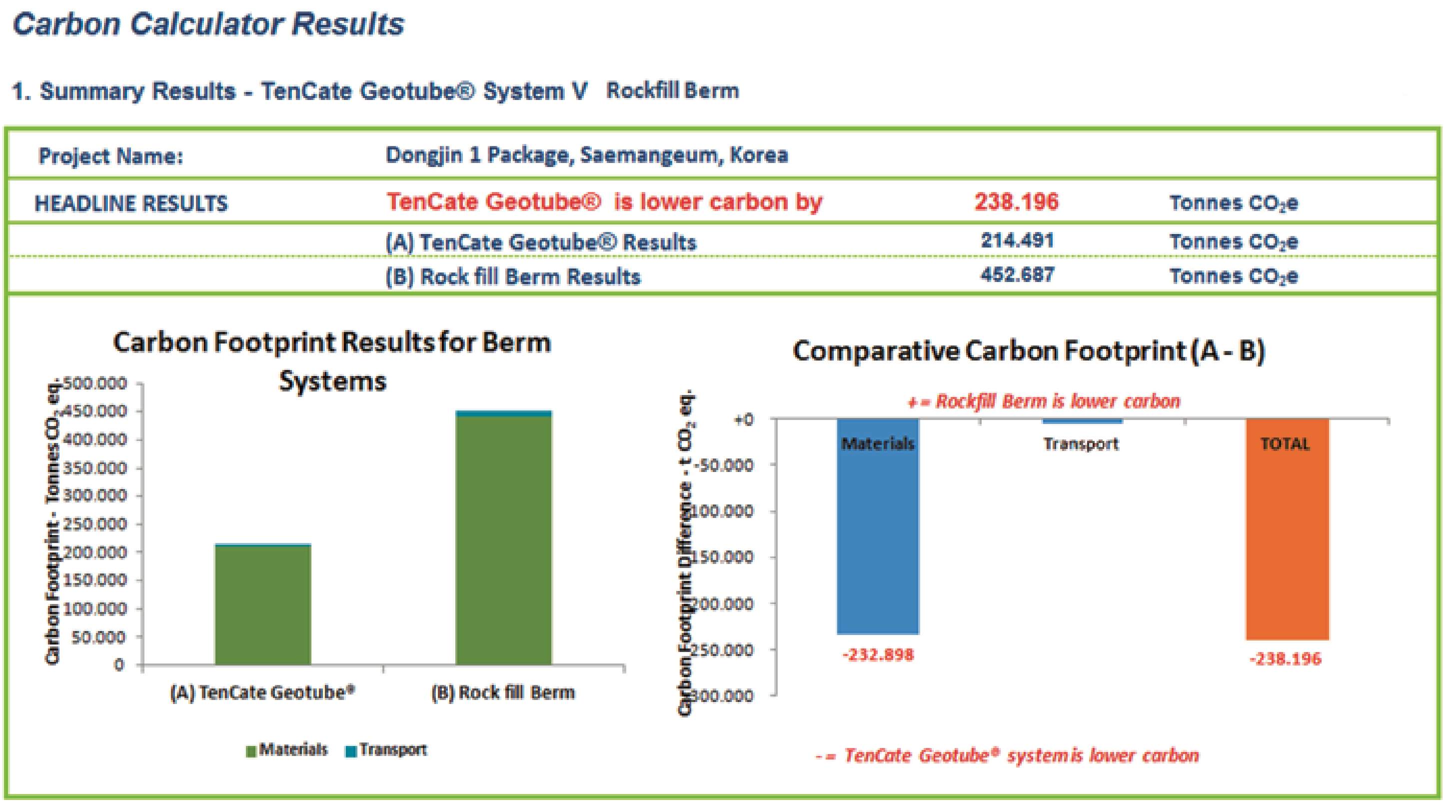
Figure 10. Geotechnical stability checks (adapted from Yee 2002).

improve the environment are increasingly favoured. Engineering solutions that have a lower negative impact (as opposed to those that have a higher negative impact) on the environment are also favoured and that includes their carbon footprint as well. The subject of carbon footprint associated with construction projects is gaining attention worldwide.

Examples of carbon footprint assessment associated with geotextile tube applications have been provided by Wortelboer et al. (2012) and Ter Harmsel et al. (2013). A carbon footprint is a measure of the impact that human activities have on the environment, in particular climate change. It is the measurement of all the greenhouse gases

Figure 11. Berm boundary to compare quantities of rockfill berm with the equivalent geotextile tube berm.





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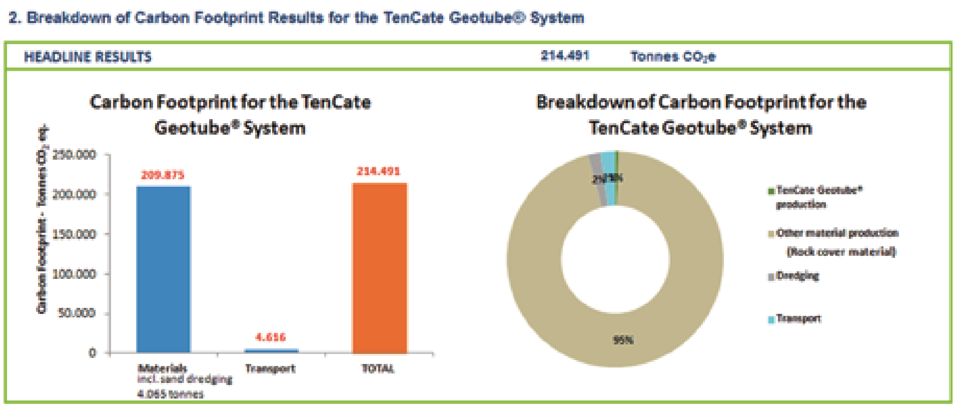

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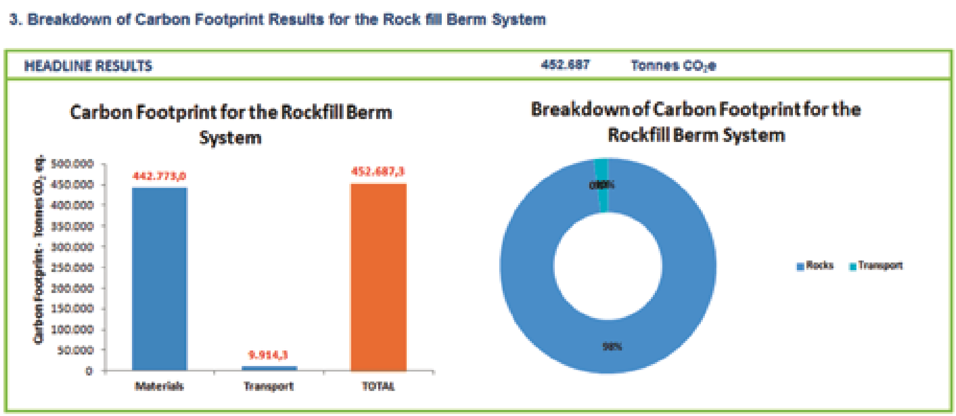

(c)

Figure 12. Results of Proprietary Carbon Footprint Calculator (a) carbon footprint comparison between geotextile tube berm and rockfill berm, (b) carbon footprint of geotextile tube berm and (c) carbon footprint of rockfill berm.

generated by human activity including construction works, measured in units of tonnes of carbon dioxide equivalent (CO2e). The lower the carbon footprint, the less impact the construction works have on the environment.

The accumulation of greenhouse gases in the atmosphere causes global warming. There is compelling evidence that global warming is causing a rising trend in sea level. The IPCC Climatic Change 2007-Synthesis Report (IPCC 2007) reported that from 1961 to 2003, global mean sea level rose at an average rate of 1.8 mm per year. The observed sea level rise is attributed to thermal expansion as the ocean water warms and the contribution of land-based ice caused by increased melting. Over the 21st century the sea level is projected to rise by 18 to 59 cm causing present coastlines to recede. This sea level rise and higher storm surges will result in inundations that will impact currently safe hinterland. Higher incident waves anticipated from stronger winds will intensify coastal erosion.

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 and transport to disposal.

All IPCC direct greenhouse gases (GHGs) were included in this assessment and, since carbon footprint is measured in CO2e, all were converted to CO2e using the latest IPCC (2007) global warming potentials (GWP). These GHGs include carbon dioxide, methane, nitrous oxide, hydroflurocarbons (HFC), perflurocarbons (PFC) and sulfur hexafluoride. 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 above exclusions from the carbon footprint 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

Table V. Test results of chosen geotextile tube conducted as part of the trial installation.

Property	Unit	Specification for tube fabric type I for type A, B & C geotextile tube	Specification for tube fabric type II for type D & E geotextile tube	Test results of type E geotextile tube supplied for trial
Polymer material		Polypropylene	Polypropylene	Polypropylene
Mass per unit area	g/m^2	> 550	> 850	1123
Thickness	mm	> 1	> 2	3.5
Tensile strength (MD)	kN/m	> 120	> 200	204.9
Tensile strength (CD)	kN/m	> 120	> 200	202.8
Tensile elongation (MD)	%	< 15	< 15	14.8
Tensile elongation (CD)	%	< 15	< 15	10.5
Permeability	m/s	α x 10-1	α x 10-1	1.5 x 10^{-1}
CBR puncture resistance	kN	> 11	> 16	18.2
Drop cone	mm	< 10	< 8	7.2
Seam strength	kN/m	> 85	> 160	183.7
Pore size	mm	< 0.3	< 0.3	0.25

Table VI. Equipment deployed for dredging, geotextile tube installation and construction of the sandfill core of the Polder Dike.

Equipment	For deployment		For dredging and filling	
	Capacity	**Unit**	**Capacity**	**Unit**
Setting barge	1400HP	1	1400HP	1
Flat barge	1900HP	1		
Tug boat	650HP	1		
Lifting crane	65 metric tonnes	1	50 metric tonnes	1
Backhoe	0.6 m^3	1		
Dredger			2000HP	1
Anchor boat			280HP	1

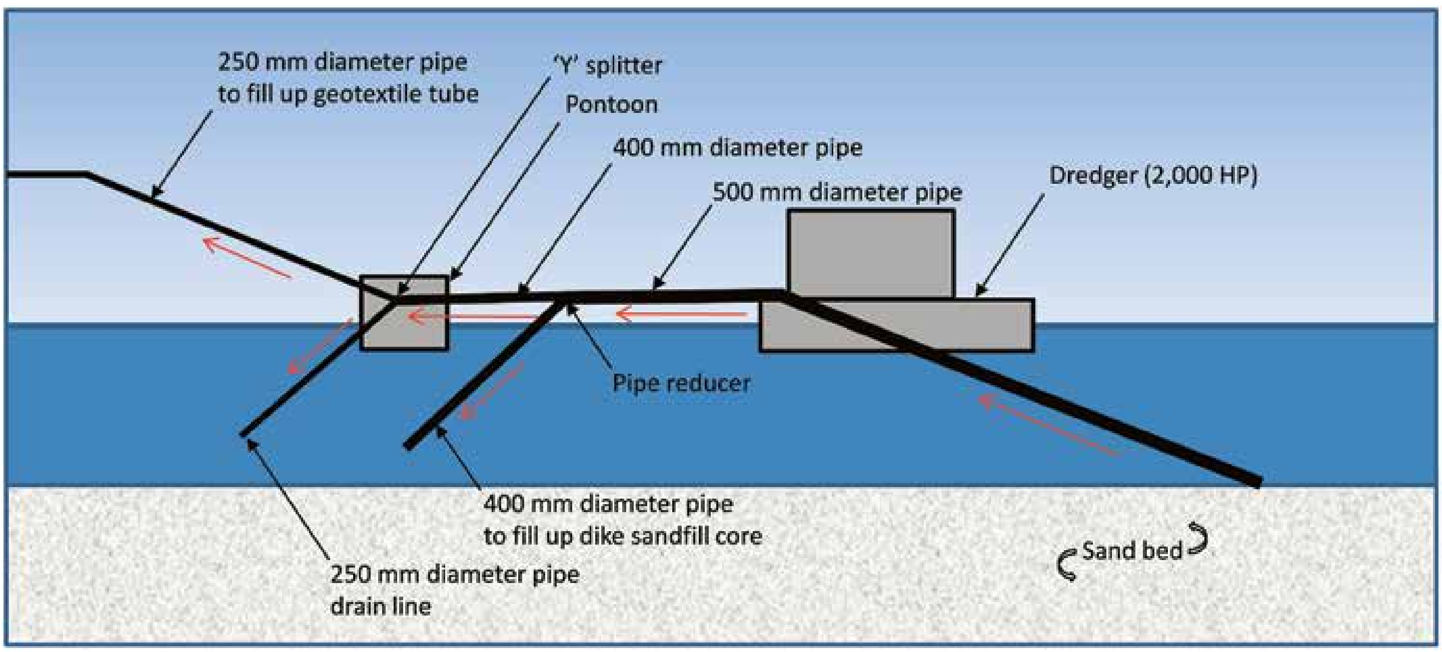

Figure 13. Diagram of the dredger and distribution pipes used to deliver sand for filling geotextile tube and sandfill core of Polder Dike.

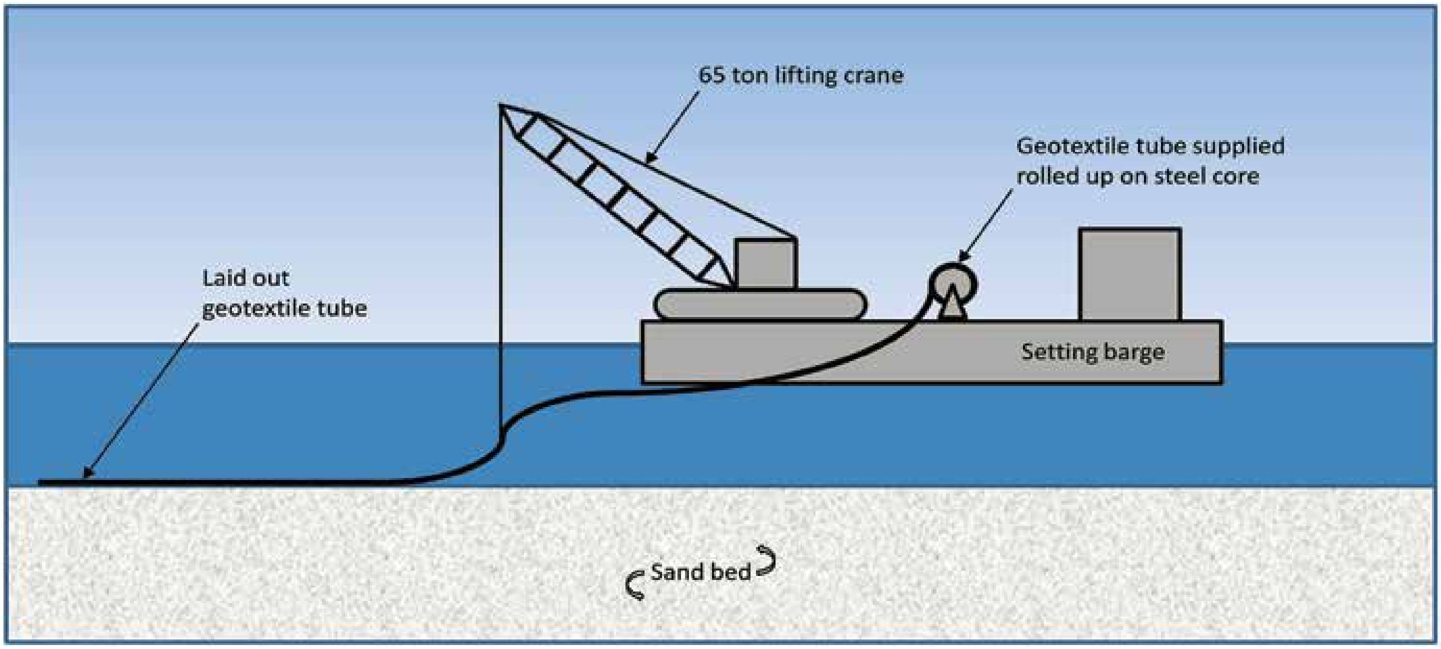

Figure 14. Diagram of the setting barge deployed for laying out the geotextile tube.

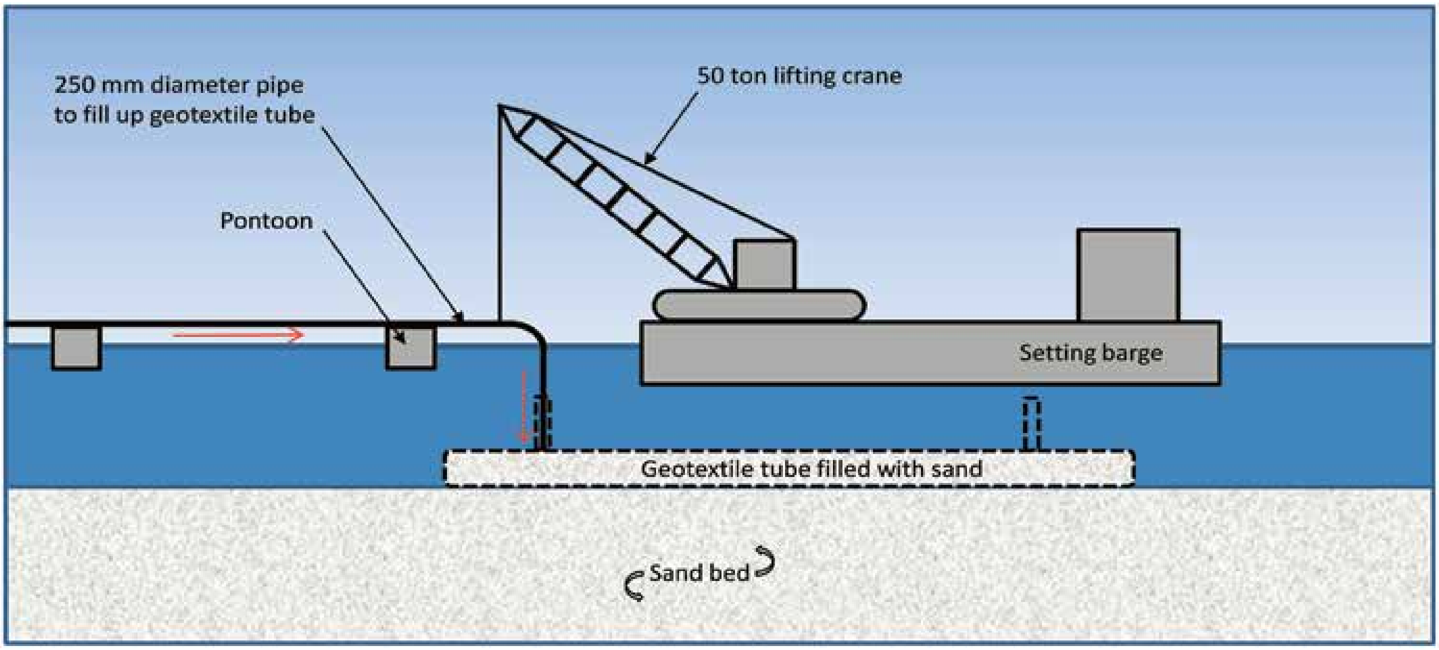

Figure 15. Diagram of the setting barge deployed for the filling of geotextile tube.

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.

A proprietary Carbon Footprint Calculator was developed for the purpose of calculating carbon footprint based on the described methodology. This proprietary Carbon Footprint Calculator was developed jointly with a leading specialist consultant on the subject of carbon footprint, Sustain Ltd in the United Kingdom, and also incorporates the principles of carbon footprint conversions according to guidelines given in DEFRA (2010).

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 III). 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 transport 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. Figure 12 shows the results of the Carbon Footprint Calculator. Figure 12(a) 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 tonnes of CO2e, representing a 52% carbon footprint saving. Figure 12(b) shows the breakdown of carbon footprint results for the geotextile tube berm alternative design while Figure 12(c) shows the breakdown of carbon footprint results for the rockfill berm original design.

Figure 16. Installation of geotextile tube and formation of sandfill core of the Polder Dike begins with setting out with the GPS equipment and then (a) the laying of basal geotextile (b) laying of geotextile tube (c) attachment of sandbag to weigh down the geotextile tube (d) attaching the filling pipe to the submerged geotextile tube and finally (e) filling of the geotextile tube with dredged sand to design height.

CONSTRUCTION

Trial Installation

Prior to award of subcontract for the supply and installation of the geotextile tubes, a trial installation exercise was carried out in early June of 2012. This trial installation involved geotextile tubes of prequalified suppliers. The trial installation exercise was conducted to ensure the prequalified geotextile tubes would perform according to design and to confirm the project time saving assessment. Besides cost saving, the geotextile tube berm alternative design was expected to result in a project time saving of 10 months.

The geotextile tubes prequalified for the trial installation were also tested for conformance to project specifications at a client nominated testing laboratory. The award of the subcontract for the supply and installation of the geotextile tubes was finally based on competitive bidding subject to satisfactory site installation performance and the tested product meeting the specification requirements.

Table V shows the specifications for tube fabric types I and II and the test results of the type E geotextile tube from the winning supply contractor. The trial installation involved two lower units and an upper unit of type E geotextile tube. The length of the lower units was 55 m while the length of the upper unit was 47.5 m. Based on the trial installation, it was determined that the time required to install a type E geotextile tube of typical length of 50 m was about 9 hours.

Equipment Deployed

Table VI shows the equipment deployed for dredging, geotextile tube installation and the construction of the sandfill core. Figure 13 shows the diagram of the dredger and distribution pipes used to deliver sand for filling geotextile tube and sandfill core of Polder Dike. Figure 14 shows the diagram of the setting barge deployed for laying out the geotextile tube. Figure 15 shows the diagram of the setting barge deployed for the filling of geotextile tube.

Installation Sequence

Figure 16 shows the installation of geotextile tube and formation of sandfill core of Polder Dike. The geotextile tube installation sequence is as follows:

- Setting out using GPS survey equipment on work barge (see opening photo)
- Laying of basal geotextile layer on bottom (see Figure 16a)
- Floating out the geotextile tube (see Figure 16b)
- Attaching sandbags to loops at sides of geotextile tube to sink and weigh down the geotextile tube (see Figure 16c)
- Attaching the filling pipe to one of the fill port of the geotextile tube (see Figure 16d)
- Filling of the geotextile tube with dredged sand to design height (see Figure 16e)
- Closing of all fill ports.

The sequence is then repeated for the next geotextile tube installation. The first construction stage of the geotextile tube berm involves a one-on-two pyramid stacking of geotextile tubes. When sufficient length of the first stage geotextile tube berms have been constructed on both sides of the Polder Dike, the sandfill core is then constructed by filling in-between the parallel geotextile tube berms (see Figures 17a and 17b). The third layer geotextile tube is then installed where required before the rest of the sandfill core of the Polder Dike is constructed.

Work Progress

The construction subcontract for the supply and installation of the geotextile tubes A commenced in July 2012. On average, the time required to install type A, B, C, D and E geotextile tubes of length 62 m each are 3.5, 4.6, 5.7, 6.8 and 9 hours, respectively.

The time required to install type E geotextile tubes during the construction contract was actually slightly faster than that achieved during trial installation.

The installation of geotextile tube berm for the Polder Dike was completed in May 2013. Despite a three-month delay in works because of severe winter conditions, the geotextile tube alternative solution still resulted in a saving in construction time of 7 months when compared with the original solution using rockfill berm.


Figure 17. Left, Discharging dredged sand to form sandfill core of the Polder Dike and right, the sandfill core of the Polder Dike surfacing above water level.

CONCLUSIONS

In this case study involving the use of geotextile tubes as a replacement of rock for the construction of a Polder Dike for the Dongjin 1 Package in South Korea, geotextile tubes provided a number of economical and environmental advantages. The Polder Dike is made 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. The geotextile tube berm alternative design resulted in:

- a cost saving of US$ 6.2 million,
- a carbon footprint saving of more than 230,000 tonnes of CO_2e or 52% over the rockfill berm original design, and
- a shortening of the overall project duration by 7 months.

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