GEOSYSTEMS: GEOSYNTHETICS IN COASTAL AND HYDRAULIC ENGINEERING

Short Course: "Geosynthetics in Erosion and Sediment Control and Erosion-Resistant Hydraulic Structures"

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Solmax, Engineering Business Manager
Dewatering and Marine Group
February 05, 2023

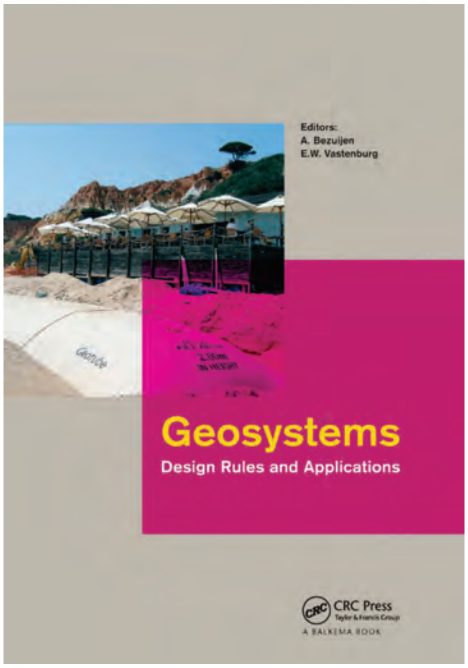
ATA GEOSYNTHETICS CONFERENCE

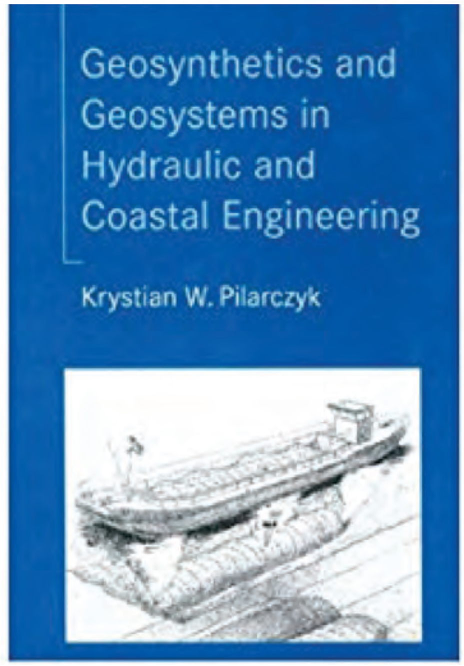
Kansas City, KS - 2023

INTRODUCTION – PART 1

- **What is a Geosystem?**
- **Why is There a Need for Geosystems Design?**
- **Materials and Testing**
  - Different types of geosynthetics
  - Testing of the properties (mechanical and hydraulic)
  - Modelling – large scale testing
- **Design Rules**
- **Geosystems & Design tools**

REFERENCES





WHAT IS A GEOSYSTEM?

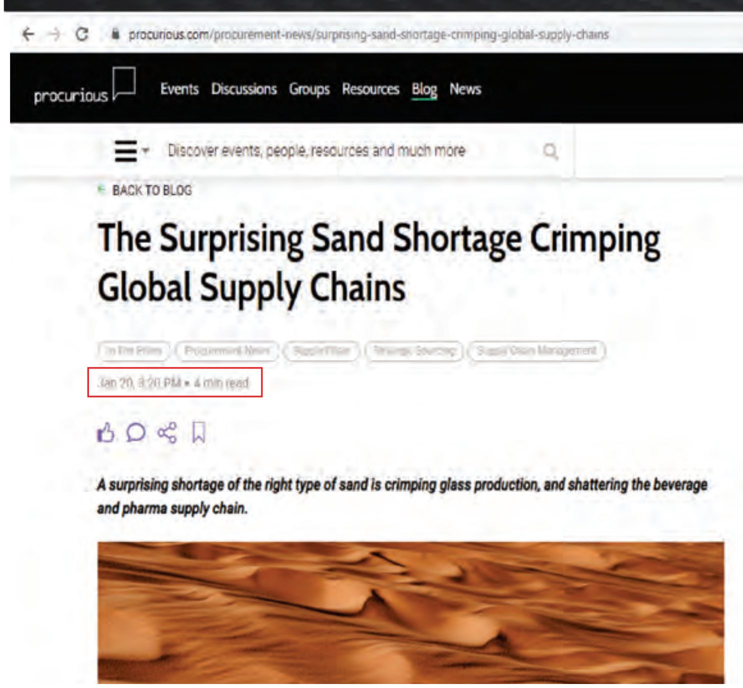
"Geotextile-encapsulated sand elements are three- dimensional systems manufactured from textile materials that are filled with sand. They form a sub-group of a wider system of geosynthetic solutions for erosion control that are known as ***Geosystems****. These elements are used in hydraulic engineering structures such as dams, dykes, and breakwaters as an alternative for quarry stone e.g., as core material. They may also be used for bottom or bank protection or to fill up a scour hole."*

Geosystems. Design Rules and Applications
A. Bezuijen & E.W. Vastenburg

WHY IS THERE A NEED FOR GEOSYSTEMS DESIGN?

- **Accelerated erosive process around the world**
- **Crescent necessity to protect coastal and inland shorelines**
- **Several types of geotextile-encapsulated sand elements (Geosystems)**
- **Each Geosystem has its own fabrication method and solves different types of marine challenge**
- **Sand is the world's most consumed raw material after water, so why not to do our best to protect it?**

WAIT, WHAT? SHORTAGE OF SAND?



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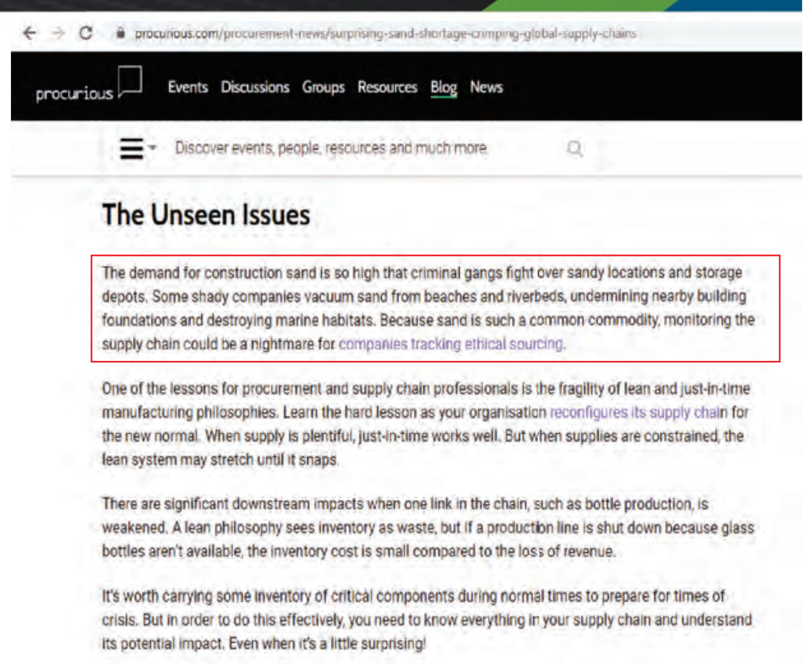
The Surprising Sand Shortage Crimping Global Supply Chains

A surprising shortage of the right type of sand is crimping glass production, and shattering the beverage and pharma supply chain.



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The Unseen Issues

The demand for construction sand is so high that criminal gangs fight over sandy locations and storage depots. Some shady companies vacuum sand from beaches and riverbeds, undermining nearby building foundations and destroying marine habitats. Because sand is such a common commodity, monitoring the supply chain could be a nightmare for companies tracking ethical sourcing.

One of the lessons for procurement and supply chain professionals is the fragility of lean and just-in-time manufacturing philosophies. Learn the hard lesson as your organisation reconfigures its supply chain for the new normal. When supply is plentiful, just-in-time works well. But when supplies are constrained, the lean system may stretch until it snaps.

There are significant downstream impacts when one link in the chain, such as bottle production, is weakened. A lean philosophy sees inventory as waste, but if a production line is shut down because glass bottles aren't available, the inventory cost is small compared to the loss of revenue.

It's worth carrying some inventory of critical components during normal times to prepare for times of crisis. But in order to do this effectively, you need to know everything in your supply chain and understand its potential impact. Even when it's a little surprising!

WAIT, WHAT? SHORTAGE OF SAND?

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The Surprising Sand Shortage Crimping…

Jan 20, 3:20 PM • 4 min read

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WAIT, WHAT? SHORTAGE OF SAND?

cnbc.com/2021/03/05/sand-shortage-the-world-is-running-out-of-a-crucial-commodity.html

MARKETS BUSINESS INVESTING TECH POLITICS CNBC TV WATCHLIST PRO

A sand shortage? The world is running out of a crucial — but under-appreciated — commodity

PUBLISHED FRI, MAR 5 2021·1:14 AM EST | UPDATED FRI, MAR 5 2021·10:20 AM EST

Sam Meredith

KEY POINTS

- Sand is the world's most consumed raw material after water and an essential ingredient to our everyday lives.
- Yet, the world is facing a shortage — and climate scientists say it constitutes one of the greatest sustainability challenges of the 21st century.
- "Is it time for panicking? Well, that will certainly not help, but it is time to take a look and change our perception about sand," said Pascal Peduzzi, a climate scientist with the United Nations Environment Programme.

LONDON — An insatiable global appetite for sand, one of the world's most important but least appreciated commodities, is unlikely to let up anytime soon. The problem, however, is that this resource is slipping away.

Our entire society is built on sand. It is the world's most consumed raw material after water and an essential ingredient to our everyday lives.

Sand is the primary substance used in the construction of roads, bridges, high-speed trains and even land regeneration projects. Sand, gravel and rock crushed together are melted down to make the glass used in every window, computer screen and smart phone. Even the production of silicon chips uses sand.

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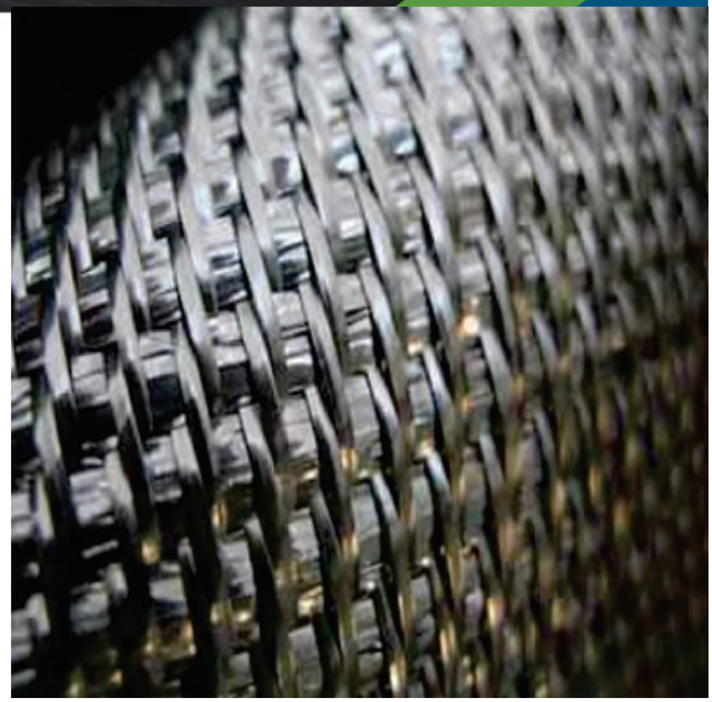
Dozens of trucks dump hundreds of thousands of tons of sand on Miami Beach as part of U.S. government measures to protect Florida's tourist destinations against the effects of climate change.

EVA MARIE UZCATEGUI | AFP | Getty Images

MATERIALS AND TESTING



MATERIALS

- **Raw Material**
  - Polyester
  - Polypropylene
  - Polyethylene
- **Specific Gravity(*)**
- **Type of Geotextiles**
  - Nonwoven (*)
  - Woven
  - Geocomposites

TESTING

- Pore size distribution
- Permeability
- Tensile Strength (Machine Direction and Cross Machine Direction)
- Seam Strength
- UV resistance
- Abrasion
- Impact
- Fill Port
- Modelling (Stability in Waves)
- Liquefaction

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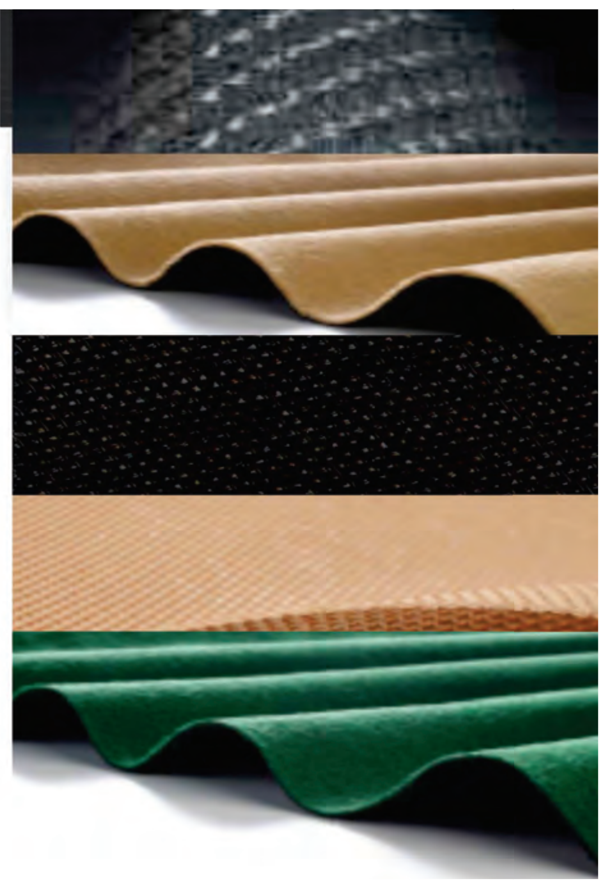
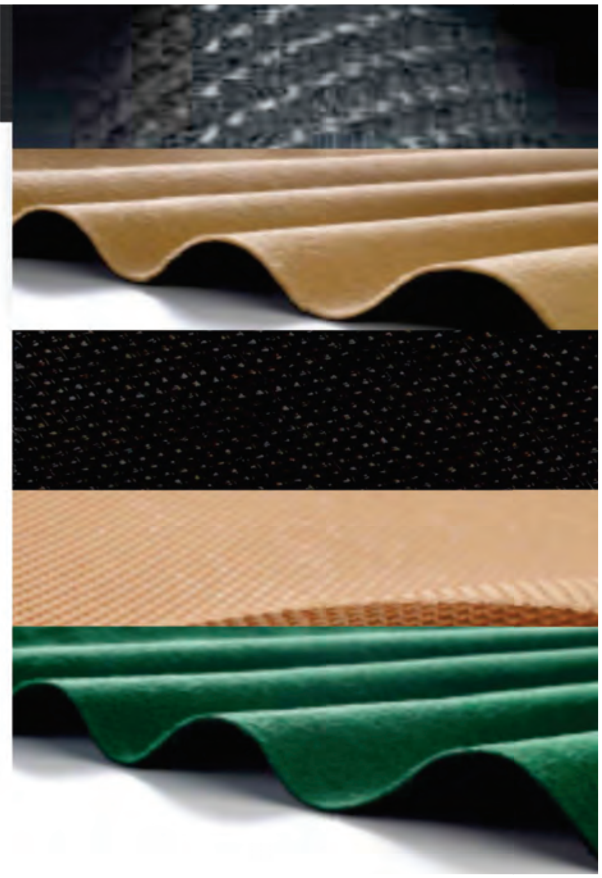
MATERIALS

- There are several types of geosynthetics in the market
- Geotextiles and Geocomposites are the main category for Geosystems
- The fabrication material selection should take into consideration:
  - Raw Material ✓
  - Fill Material
    - Initial loss during filling process is ok, however there must be no loss of fill material over time.



MATERIALS

- **Permeability**
  - Hydraulic Load
    - Stationary
    - Dynamic
  - Fill material vs. Fabrication material
    - Pore size distribution vs. grain size distribution
  - Combination of Fabrication Materials



MATERIALS – HYDRAULIC LOAD

Table 2.3 Recommended design retention criteria for geometrically closed geotextiles.

	Sand (D > 60 µm)
Stationary hydraulic load (current)	$O_{90} < 5\ D_{10}\ C_u^{1/2}$ and $O_{90} < 2\ D_{90}$
Dynamic hydraulic load (wave attack)	$O_{90} < 1.5\ D_{10}\ C_u^{1/2}$ and $O_{90} < D_{90}$

O_{90} = pore size of the geotextile that corresponds to the average diameter of the sand fraction of which 90% remains on the geotextile (in the wet sieving method). AOS
D_x = sieve size through which x% fraction of the sand material passes.
C_u = uniformity coefficient of the sand (D_{60}/D_{10}).

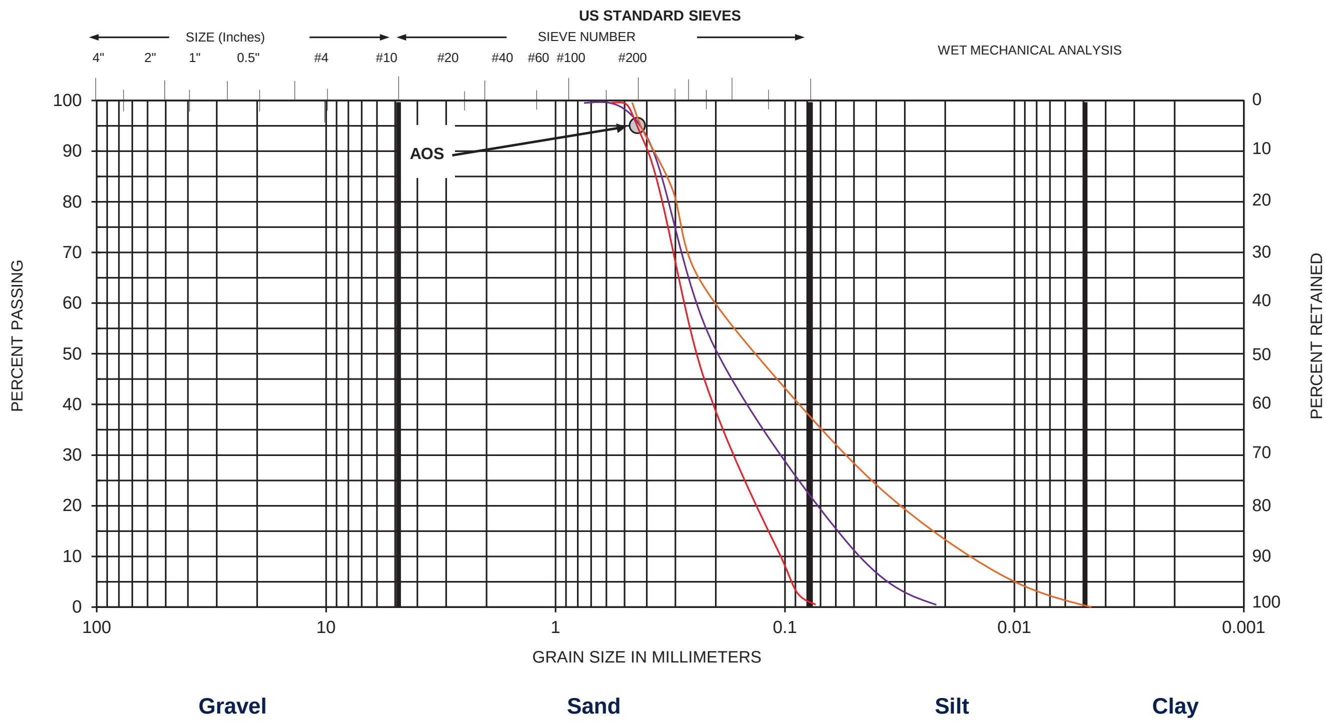
TESTING – APPARENT OPENING SIZE

- Glass beads
- Sieved through textile sample
- <5% of beads can pass
- ✗ Static electricity
- ✗ Breakage of beads

TESTING – PORE SIZE DISTRIBUTION (Capillary Flow Pore Size Test)

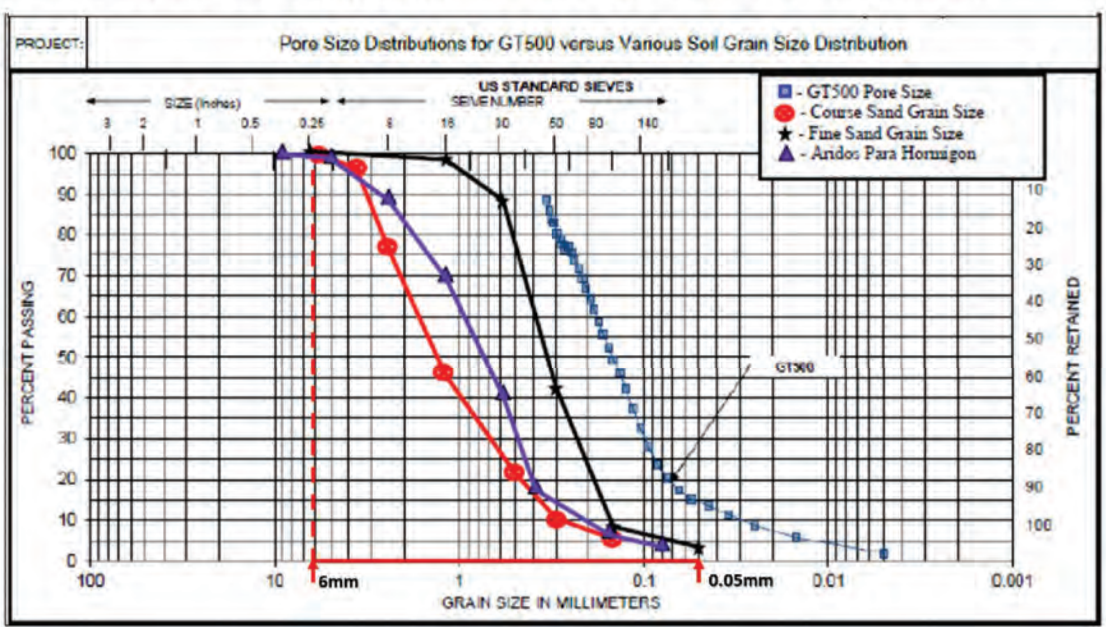
- 1” x 1” saturated sample of textile
- Sealed in porometer
- Air added in porometer
- Pressure increased until all pores open
- Histogram created

AOS vs PSD



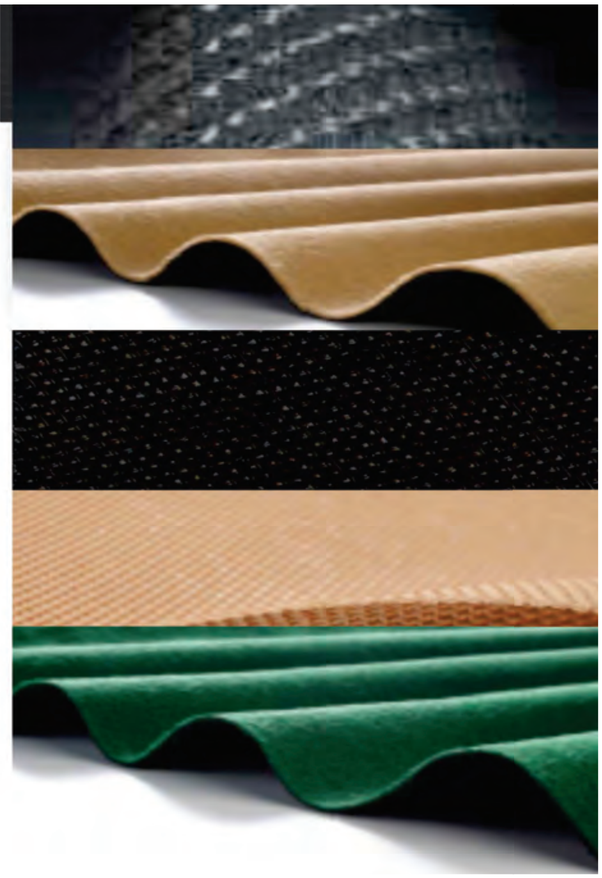
MATERIALS AND TESTING

Grain Size Distribution vs Pore Size Distribution



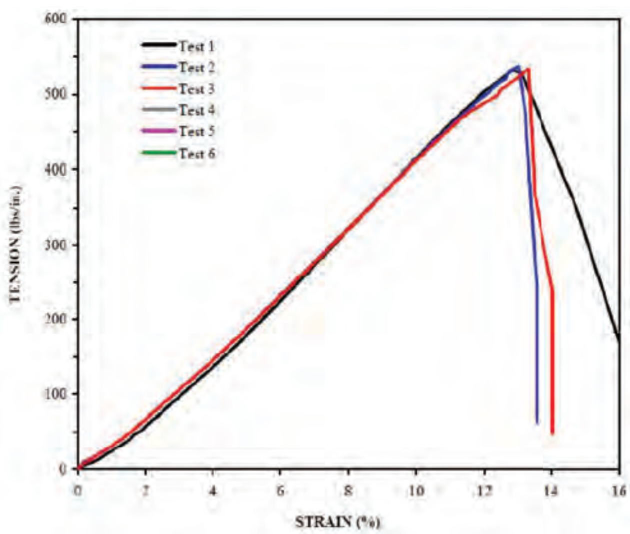
MATERIALS

- **Tensile Strength and Strain**
  - The tensile strength and seam strength must be sufficient to resist the loads impacted during the filling, transporting and placement of the elements
  - Woven geotextiles generally have relatively high tensile strength and a low maximum strain, while nonwoven geotextiles have a relatively low tensile strength and a high maximum strain



MATERIALS AND TESTING – STRESS X STRAIN

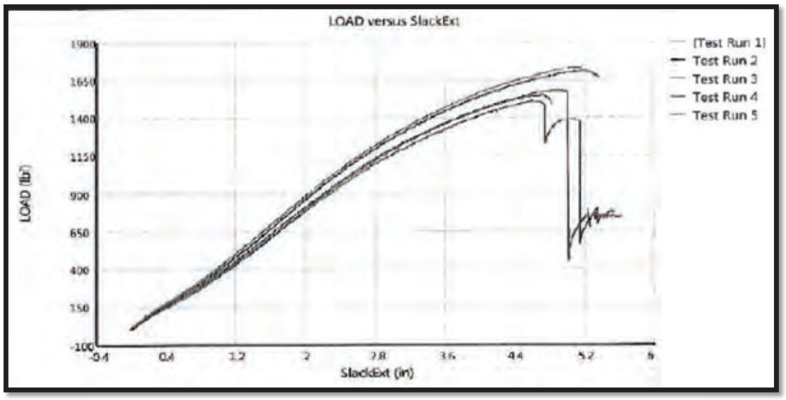
Repetitive Load Testing (Dewatering)



Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Wide Width Tensile Strength (at ultimate)	ASTM D4595	lbs/in (kN/m)	450 (78.8)	625 (109.4)
Wide Width Tensile Elongation	ASTM D4595	%	20 (max.)	20 (max.)
Factory Seam Strength	ASTM D4884	lbs/in (kN/m)	400 (70)	
CBR Puncture Strength	ASTM D6241	lbs (N)	2000 (8900)	

High Strength Polypropylene Woven Geotextile

MATERIALS AND TESTING

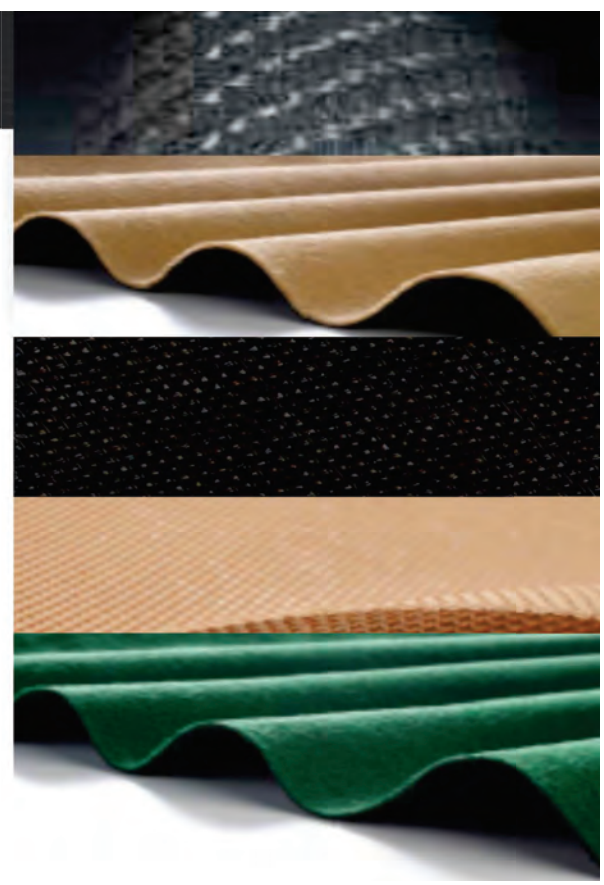


Test Run Results

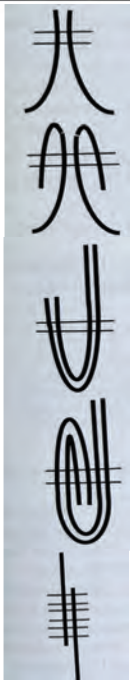
Name	Tagged	Comment	Peak Load In. (lbf/in)	%Strn @ Pk Ld (%)
Test Run 1	No		193.6	117.89696
Test Run 2	No		213.9	129.64716
Test Run 3	No		188.7	114.87404
Test Run 4	No		197.4	121.25146
Test Run 5	No		216.7	127.85367
	Mean		202.1	122.30466
	Standard D		12.5	6.33354

MATERIALS

- **Type of Seam**
  - The overall strength of sand filled element is in many cases governed by the strength of the seams
  - The seam strength depends upon its type, the thread, the geotextile and the sewing machine (number of stitches/needles, number of rows)
  - There are several types of seams



MATERIALS - SEAMS



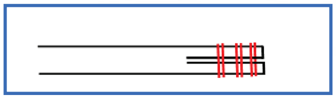
Prayer Seam

Butterfly Seam

"J" Seam

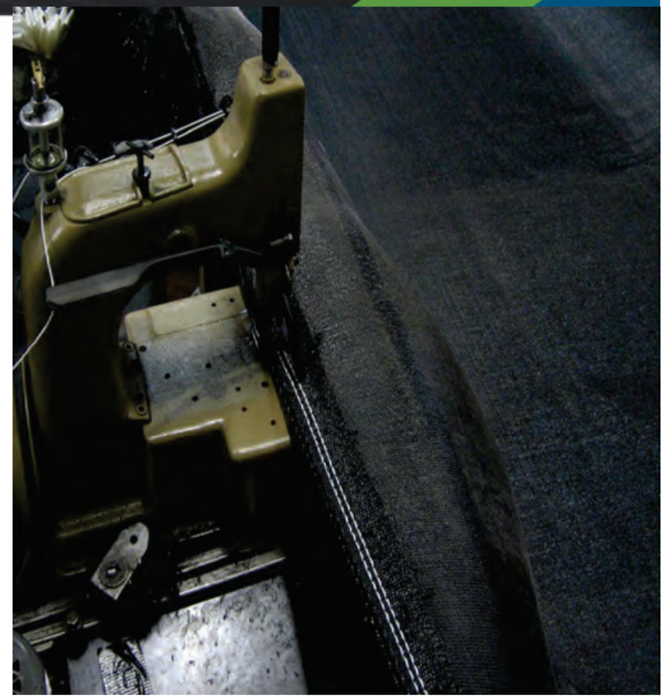
Double "J" Seam

Overlap Seam



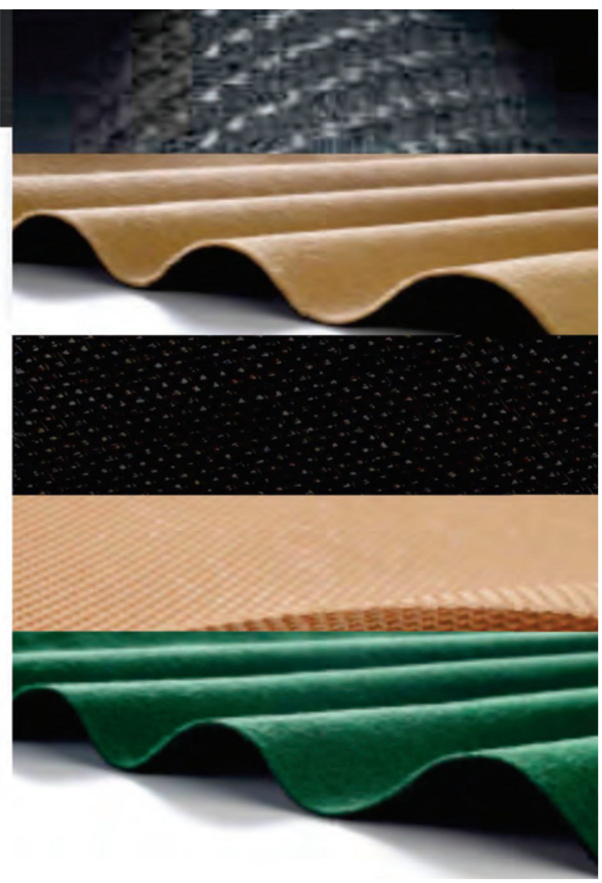
Inverted Butterfly Seam

We can always combine seam types when combining different types of geotextiles.

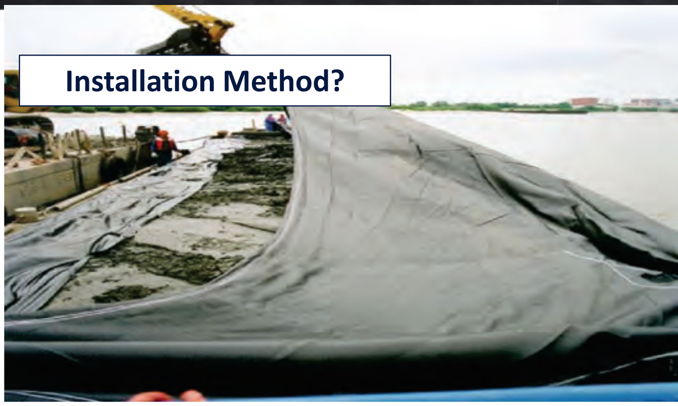


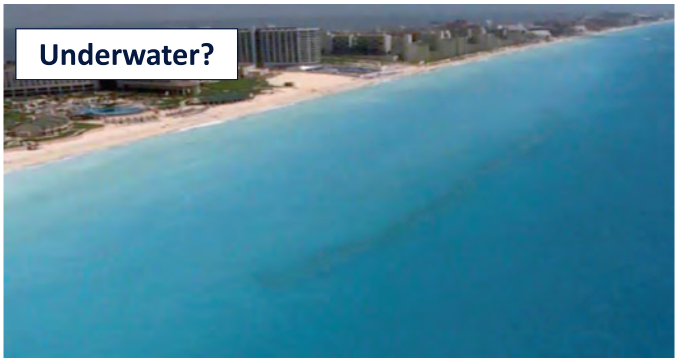
MATERIALS

- **Damage During Installation**
- **Durability**
  - UV exposure
    - Temporary
    - Permanent
    - Covered or not
  - Wave attack, Debris…
- **Aesthetics**
  - Color, Texture…
- **Environment**
  - Boats
  - Rocks
  - Existing structures



MATERIALS AND TESTING





TESTING

- ✓ Pore size distribution
- ✓ Permeability
- ✓ Tensile Strength (Machine Direction and Cross Machine Direction)
- ✓ Seam Strength
- UV resistance
- Abrasion
- Impact
- Fill Port
- Modelling (Stability in Waves)
- Liquefaction

TESTING

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
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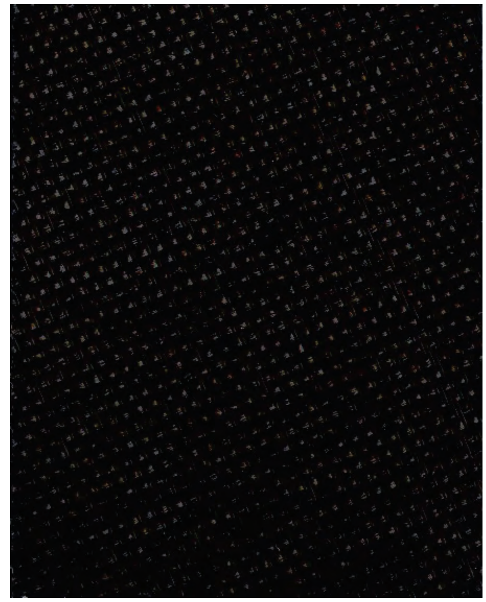
Factory Seam Strength	ASTM D4884	lbs/in (kN/m)	400 (70)	
CBR Puncture Strength	ASTM D6241	lbs (N)	2000 (8900)	
			Maximum Opening Size	
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	40 (0.425)	
			Minimum Roll Value	
Water Flow Rate	ASTM D4491	gpm/ft² (l/min/m²)	20 (813)	
			Minimum Test Value	
UV Resistance (% strength retained after 500 hrs)	ASTM D4355	%	80	

Filtration Properties	Test Method	Unit	Typical Value
Pore Size Distribution (O_{50})	ASTM D6767	micron	135
Pore Size Distribution (O_{95})	ASTM D6767	micron	305

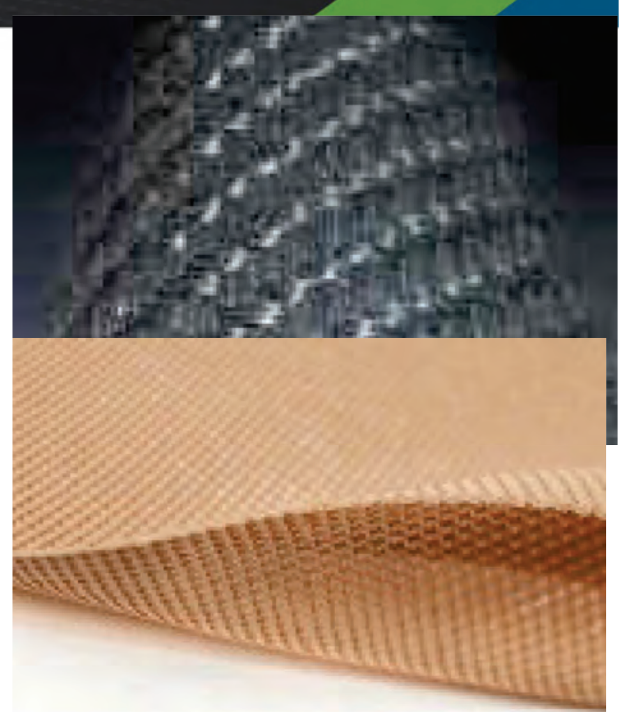
Physical Properties	Test Method	Unit	Typical Value
Mass/Unit Area	ASTM D5261	oz/yd² (g/m²)	16.4 (556)
Thickness	ASTM D5199	mils (mm)	70 (1.8)



TESTING

Mechanical Properties	Test Method	Unit	Minimum Average Roll Value	
			MD	CD
Wide Width Tensile Strength (at ultimate)	ASTM D4595	lbs/in (kN/m)	1142 (200)	1142 (200)
Tensile Strength (at 5% strain)	ASTM D4595	lbs/in (kN/m)	200 (35)	1000 (175)
Wide Width Tensile Elongation	ASTM D4595	%	17 (max.)	10 (max.)
Factory Seam Strength	ASTM D4884	lbs/in (kN/m)	914 (160)	
CBR Puncture Strength	ASTM D6241	lbs (kN)	4000 (17.8)[1]	
UV Resistance (% strength retained after 500 hrs)	ASTM D4355	%	96.5	
UV Resistance (retained tensile strength after 1400 MJ/m2 exposure)	EN 12224/EN 12226	%	50	

Hydraulic Properties	Test Method	Unit	Minimum Average Roll Value
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Water Flow Rate	ASTM D4491	gal/min/ft² (l/min/m²)	20 (815)
Permittivity	ASTM D4491	sec^{-1}	0.35



TESTING

Mechanical Properties	Test Method	Unit	Minimum Test Value	
			MD	CD
Wide Width Tensile Strength	ISO 10319	lbs/in (kN/m)	360 (63)	310 (54)
Factory Seam Strength	ISO 10321	lbs/in (kN/m)	286 (50)	
CBR Puncture Strength	ISO 12236	lbs (N)	1821 (8100)	
Rigid Port Strength[1]	ASTM D6241	lbs/in (kN/m)	1356 (53.4)	
Hydraulic Properties			**Minimum Test Value**	
Pore Size O_{90}	ISO 12956	(mm)	(0.14)	
Water Permeability	ISO 11058	gpm/ft² (l/min/m²)	(9.8)	
Durability Properties			**Test Value**	
Impact Energy[2]	ASTM E1886	ft-lbs (N-m)	1233 (1671)	
Abrasion Resistance[3]	BAW RPG 3.11	%	93	
UV Resistance	ASTM D4355	%	90	

Physical Properties	Test Method	Unit	TC120MB Typical Value	TC120MG Typical Value
Mass/Unit Area	ASTM D5261	oz/yd² (g/m²)	35 (1186)	35 (1186)
Color			Tan	Green

[1] Modified ASTM Method, Connection Strength (lbs/in) = P/$_E$D ?

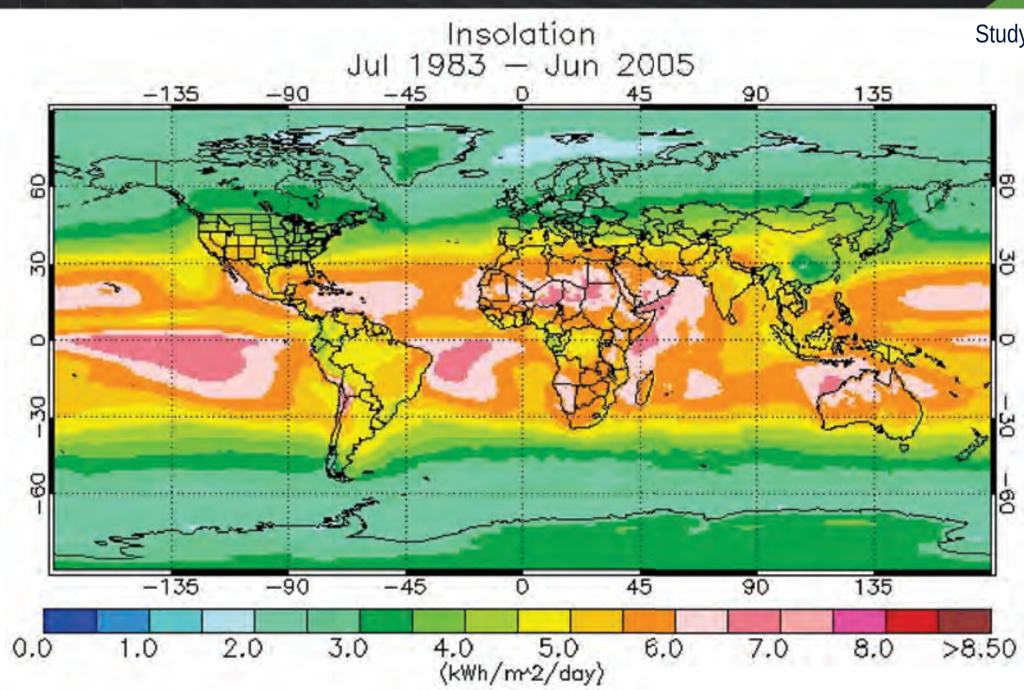
[2] Modified ASTM Method, Estimated Impact Energy (ft-lb) = mV^2/g

[3] German rotating drum test method based on conducting two abrasion cycles at 40,000 revolutions each. % strength retained after 80,000 cycles

TESTING – UV

Earth's Surface Annual Average Insolation Chart

Study by NASA Langley Project



First, determine the annual average surface solar insolation at a specific location. For example, Auckland, New Zealand is in the zone of 4.5 to 5.0 kWh/m²/day)

Map of Earth's surface annual average insolation in kWh/m²/day over 22 years (Chandler et al 2010)

TESTING – UV

Laboratory Accelerated UV Test (EN12224)

- **Accelerated test**
- **UVA-340 lamps has excellent simulation for sunlight UV-A spectrum from 295 nm to 340 nm; beyond 340 nm lamp radiation deviates from sunlight spectrum**
- **Explained in EN 12224:2000, Note 2:**
  - The durations required to reach a radiant exposure of 50 MJ/m^2 have been shown to be approximately
    - 320 h for devices with a combination of fluorescent UV lamps;
    - 350 h for devices with type I (340 nm) fluorescent lamps if the lamps are left on during the water spray;
    - 430 h for devices with type I (340 nm) fluorescent lamps if the lamps are turned off during the water spray.

TESTING – UV

Laboratory Accelerated UV Test (EN12224)

QUV Test Machine

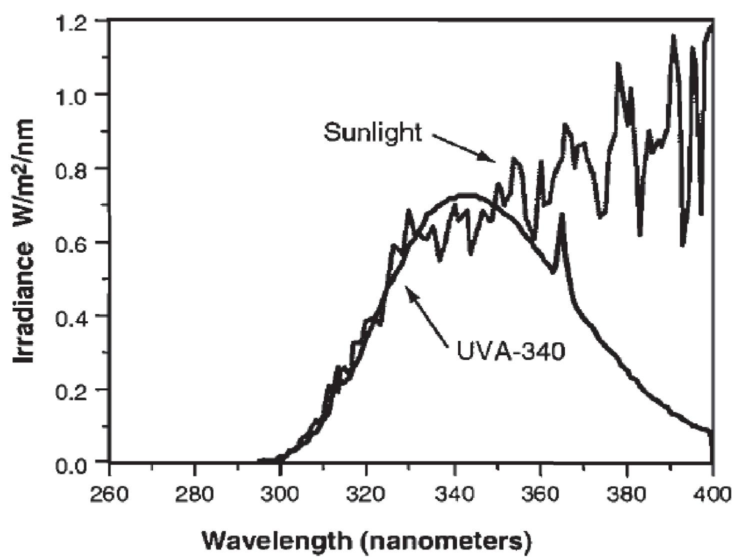
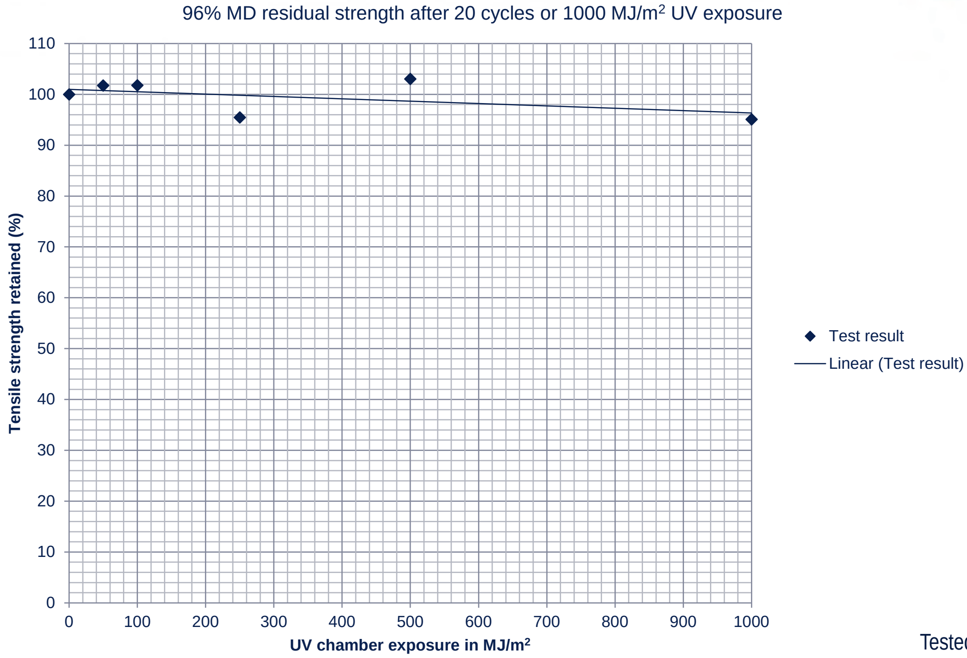


Figure 13 — UVA-340 and Sunlight

TESTING – UV

BW1200 Multiple Cycles UV Tests



Tested at Senawang Lab – EN12224

TESTING – UV

Estimation of UV Half Life (By earth's surface annual insolation zones)

The conversion of units are as follows; 1 kWh = 3.6 MJ, therefore 1 kW/m²/day = 365 kWh/m²/year = 1314 MJ/m²/year. The ratio of UV radiation to total solar radiation for South Florida was determined as 1:20 in the studies by Baker (1997). The same ratio is assumed to apply to the project sites presented in Table below. Estimation is conservative as any cover effect of lodged particles are ignored.

Earth's surface annual insolation zone	Examples of cities located in the zone	Upper bound annual solar insolation at site		Annual UV radiation at site	Time to 96 % strength at site	Projected UV half life at site
(kWh/m²/day)		(kWh/m²/day)	(MJ/m²/year)	(MJ/m²/year)	(year)	(year)
2.5 to 3.0	London, Amsterdam	3.0	3942	197.1	5.23	65
3.0 to 3.5	Otago, Vancouver, Paris, Quebec	3.5	4599	230.0	4.35	54
3.5 to 4.0	Seattle, Sapporo, Christchurch	4.0	5256	262.8	3.81	48
4.0 to 4.5	Tianjin, Seoul, Horbart, Tokyo, New York	4.5	5913	295.7	3.38	42
4.5 to 5.0	Xiamen, Sydney, Kuala Lumpur, Auckland	5.0	6570	328.5	3.04	38
5.0 to 5.5	Ho Chi Minh, Jakarta, Tampa,	5.5	7227	361.4	2.77	35
5.5 to 6.0	Maldives, Lhasa,	6.0	7884	394.2	2.54	32
6.0 to 6.5	Qatar, Alice Springs	6.5	8541	427.1	2.34	29
6.5 to 7.0	Broome	7.0	9198	459.9	2.17	27

TESTING

- ✓ Pore size distribution
- ✓ Permeability
- ✓ Tensile Strength (Machine Direction and Cross Machine Direction)
- ✓ Seam Strength
- ✓ UV resistance
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- Impact
- Fill Port
- Modelling (Stability in Waves)
- Liquefaction

37

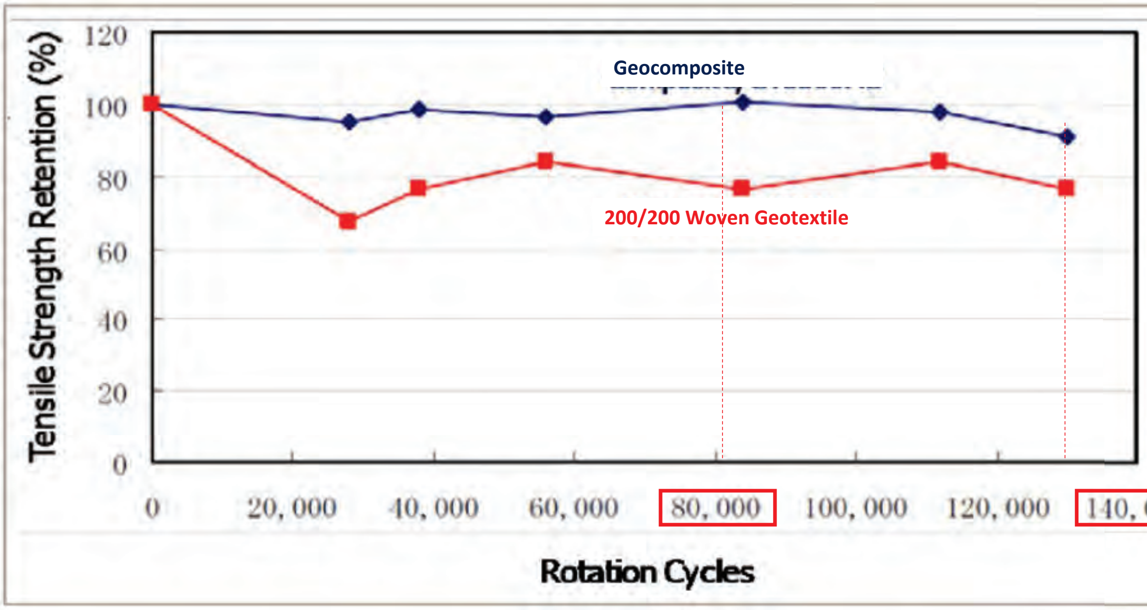
TESTING - ABRASION

BAW Slurry Abrasion Test

38

TESTING - ABRASION

BAW RPG 3.11 Slurry Abrasion Test



TESTING - IMPACT

ASTM E1886 Hurricane Impact Test (video)

TESTING - IMPACT

ASTM E1886 Hurricane Impact Test

- <u>Hurricane Impact Testing Results:</u>
- Three impacts @ 103km/h (64 mph)
- Minimum surface damage
- No fabric rupture

TESTING – FILL PORT

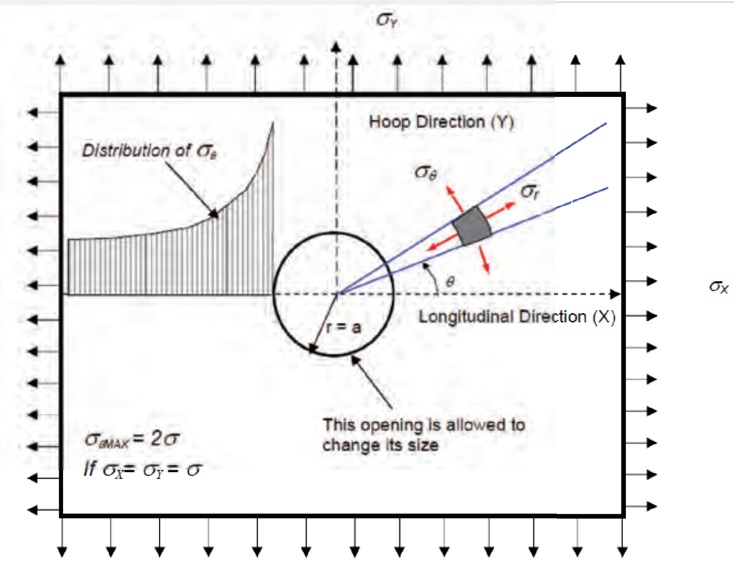
Mechanical port (Geoport™)

Sewn in sleeve port

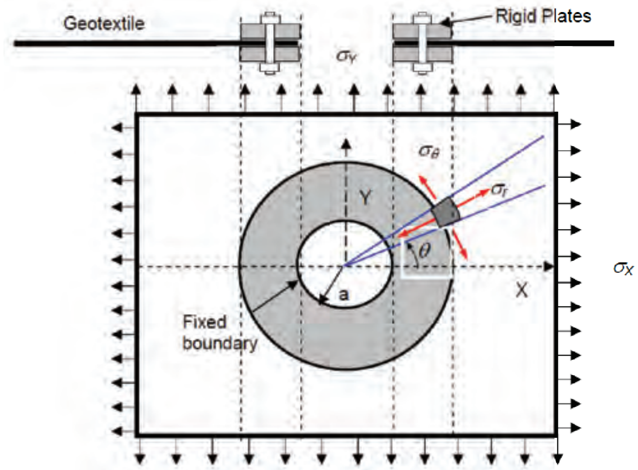
TESTING – FILL PORT

Stress Concentration Around Geotextile Tube Filling Port (Yuan et al, 2008)

The First Pan American Geosynthetics Conference & Exhibition 2-5 March 2008, Cancun, Mexico



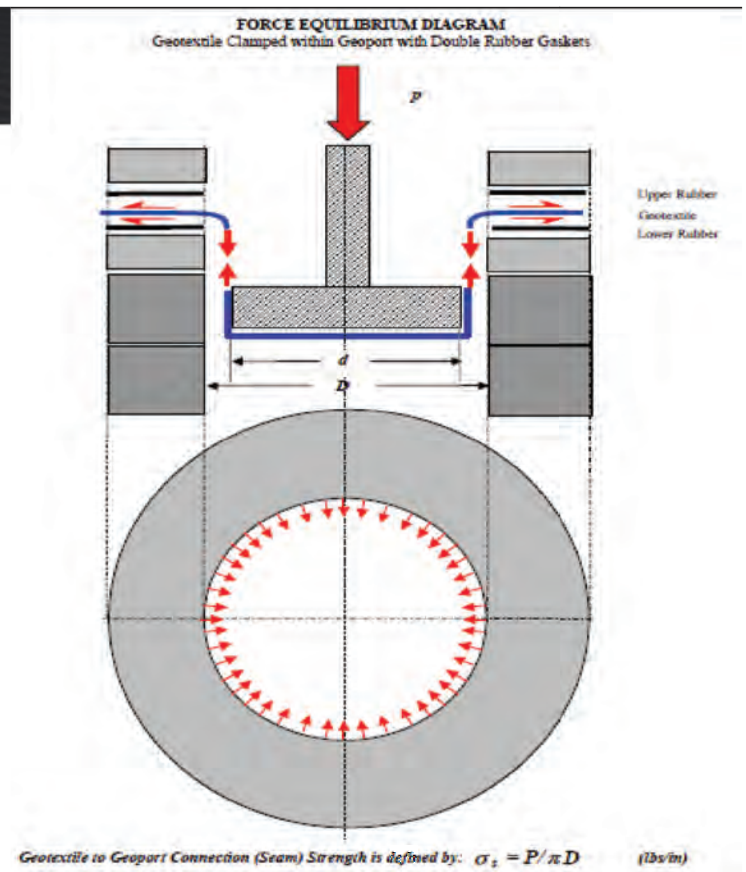
❖ Stress distribution around a deformable geotextile tube port.



❖ A rigid port by clamping the geotextile ring around the port between two rigid “donuts-shaped” plates.

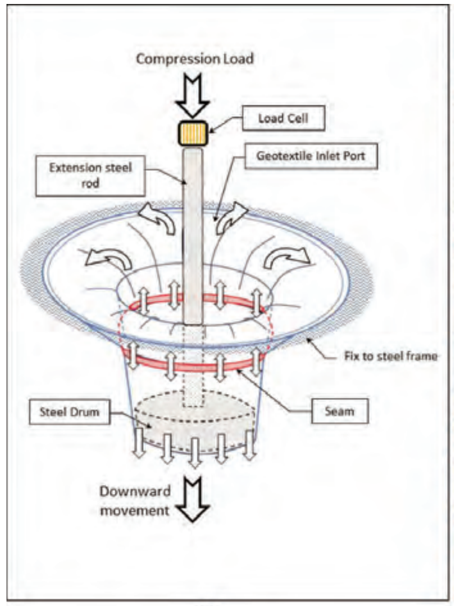
TESTING

Mechanical Port Test Method (ASTM D6241 – Modified)



TESTING – FILL PORT

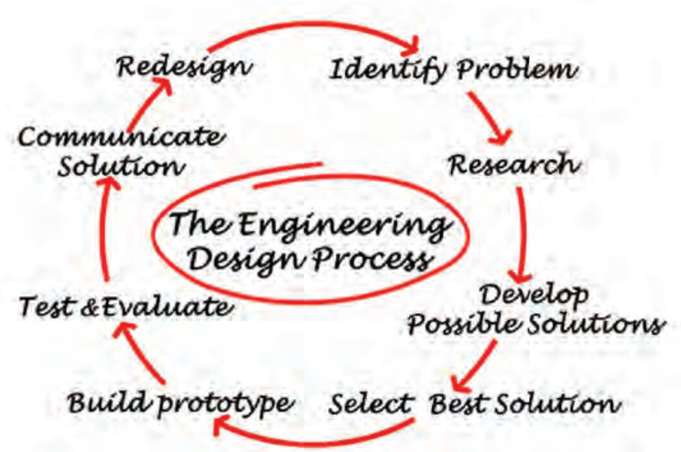
- **Sewn in Sleeve Port Test Method (**A Laboratory Full-Scale Tensile Test of Geotextile Tube Inlet Port, Eng Zi Xun, 10th International Conference of Geosynthetics, Germany 2014**)**



(a)

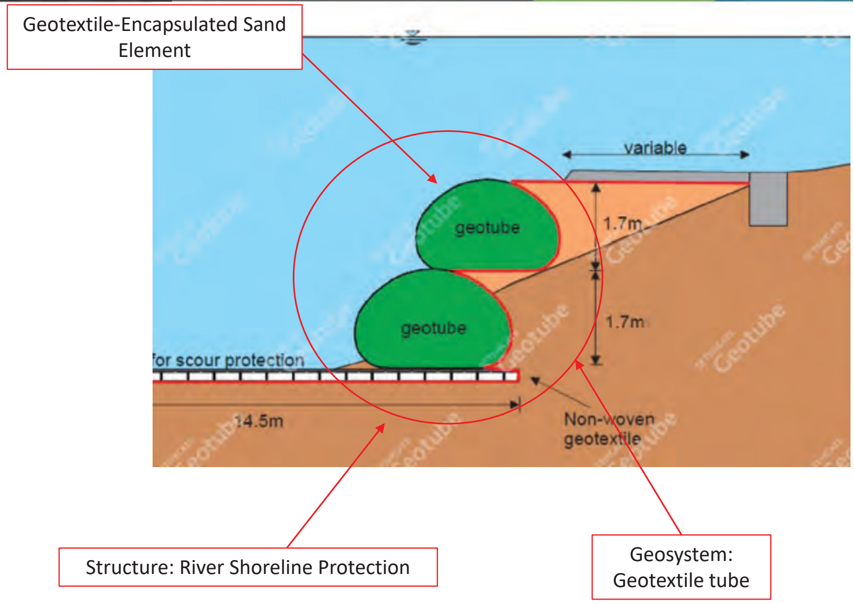

(b)

DESIGN RULES

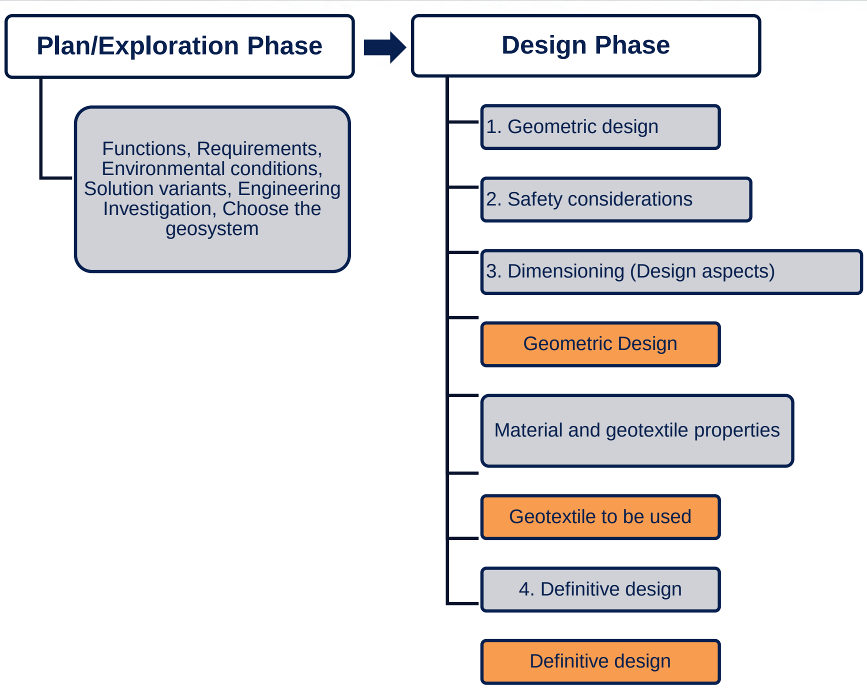


TECHNICAL TERMS AND DEFINITIONS

- **Geosystems**
- Geotextile bag, Sand Filled Mattress, Geotextile tube and Geocontainer
- **Geotextile-Encapsulated Sand Elements:**
- Considering the type of Geosystem, it is each part that forms the entire structure
- **Structure:**
- It is a group of Geotextile-Encapsulated Sand Elements



DESIGN RULES



STEP 1: GEOMETRIC DESIGN

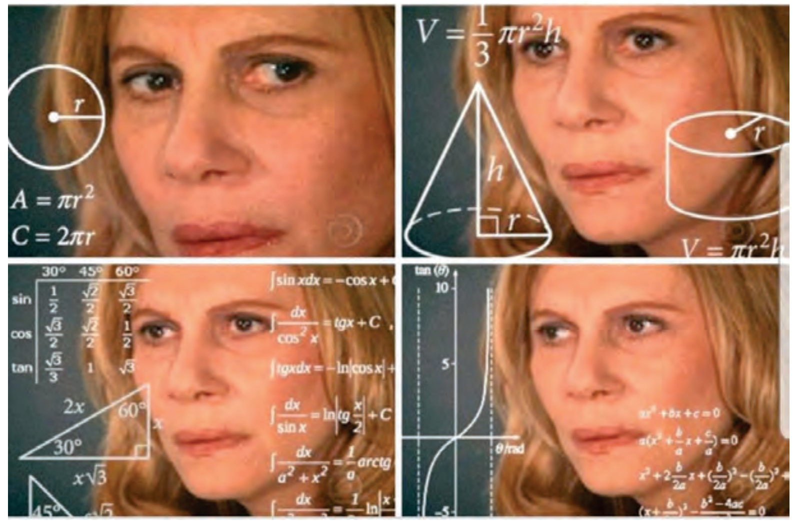
- **Determine global dimensions**
  - Length
  - Width
  - Slope angle
- **Determine key dimensions of the structure**
  - Water depth
  - Hydraulic loading
  - Elevations
  - Tidal, Floods
- **Determine the construction elements**
- **Chose most appropriate method of execution**
  - Necessary and/or available equipment

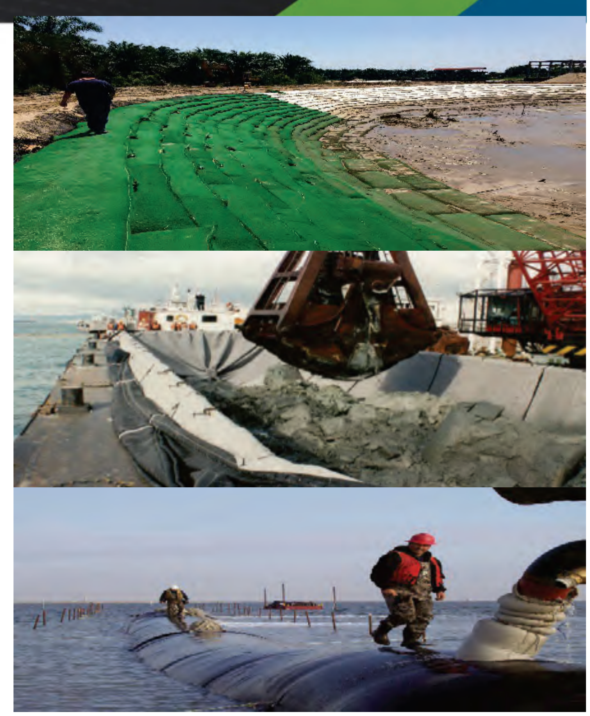
STEP 2: SAFETY CONSIDERATIONS

- **Deterministic method**
  - ***Resistance ≥ FS (overall) * Loads***
- **Potential failure mechanisms**
  - Inadequate stability (Waves, Current, Geosystem itself, Foundation)
  - Inadequate strength (Filling, Placement, Protection, Durability)
  - Loss of fill material (Porosity, Sand gradation)

STEP 3: GEOSYSTEMS DESIGN TOOLS

- Geometry Calculation (GeoCoPS, SOFTWIN, Deltares, Geotube® Simulator)
- Geosystem Specific Calculators
- Pilot Project
- Modelling
- Experience





GEOSYSTEMS & DESIGN TOOLS

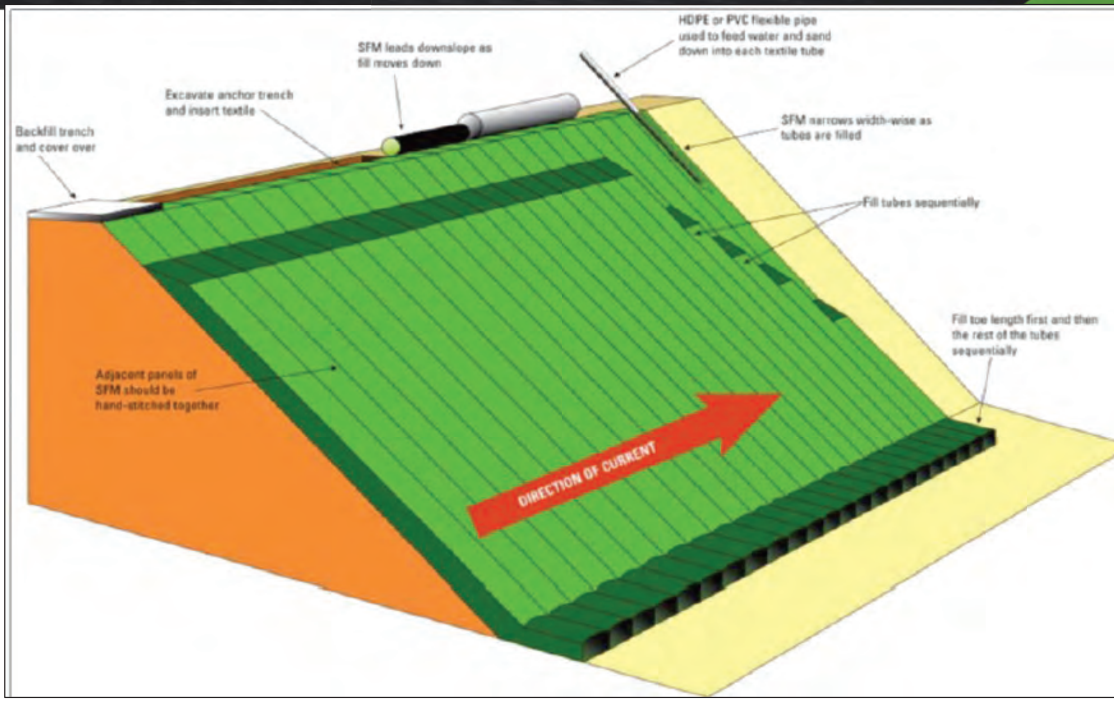
GEOSYSTEMS

Sand Filled Mattress	Geotextile Bag	Geotextile Tube	Geocontainer
• **River and stream:** soil and bank protection, scour hole protection • **Other:** Nature development areas	• **Coastal:** Beach groyne, breakwater, dune toe protection, channel repair, soil and bank protection, dyke closure • **River and stream:** Submerged breakwater, groyne and sediment management, soil and bank protection, scour hole repair • **Other:** Nature development areas	• **Coastal:** Beach groyne, breakwater, dune toe protection, submerged revetments, channel repair, land reclamation, artificial reef, sill structure • **River and stream:** Submerged breakwater, groyne and sediment management, river training, bank protection, dune core reinforcement • **Other:** Nature development areas, dewatering of dredged material, temporary structures	• **Coastal:** Breakwater, sill structures, channel repair, land reclamation, artificial reef, dyke closure, toe stability • **River and stream:** Submerged breakwater, groyne and sediment management, scour hole repair • **Other:** Storage of dredged material, temporary works

SAND FILLED MATTRESS

- **Comprises two interconnected layers of geotextile where the space between them is filled with sand and, in special cases, concrete. Cells, chambers or tubes form compartments within the mattress, which facilitates an even distribution of the fill material in the geotextile mattress and maintains its shape and combats movement of the fill material during use.**
- **It's important to secure it in place with anchor trenches and steel anchors along the length of the slope.**
- **Can be filled in place or filled separately and transported to the slope.**

SAND FILLED MATTRESS

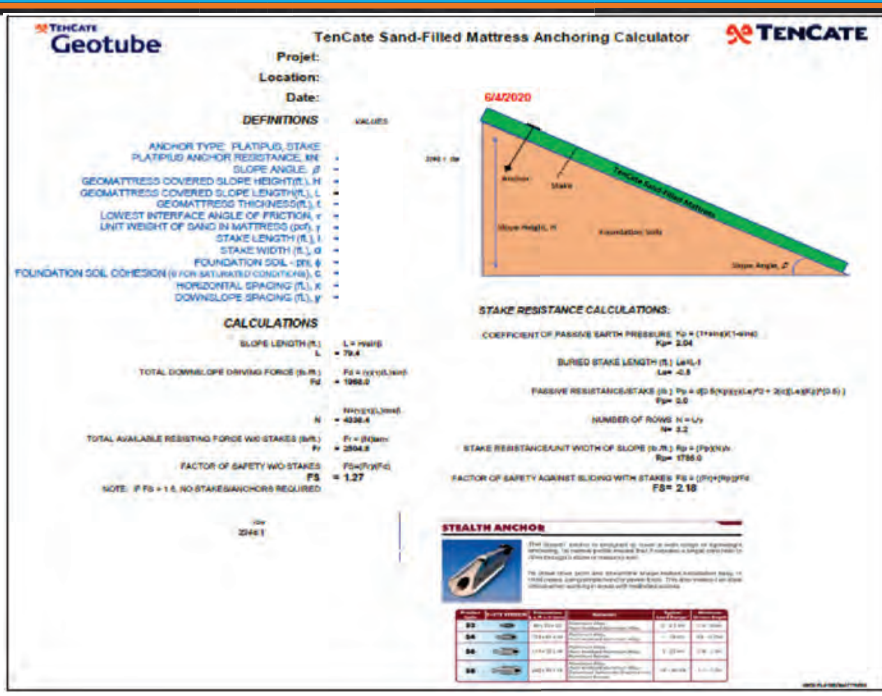


SAND FILLED MATTRESS

- **SFM Anchoring Calculator**
- **SFM Hoisting Calculator**

SAND FILLED MATTRESS

SAND FILLED MATTRESS – DESIGN TOOL



SAND FILLED MATTRESS – DESIGN TOOL

TENCATE Geotube

			Required Tensile Strength - SFM Hoisting
		Project:	
		Date:	
Geotextile	GT1000		
L		m	Length of the geotextile mattress
bm		m	Width of the geotextile mattress
bg		m	Width of the geotextile
Dk		m	Effective thickness of the geotextile mattress
ρ		kg/m3	Density of the geotextile mattress
g		m/s2	Acceleration due to gravity
T*	35.32	kN/m	Tensile load per unit width in the geotextiles in the mattress
FS	4.53		Factor of Safety for Seam Strength

Geosystems - Design Rules and Applications, A. Bezuijen, E. W. Vastenburg (2013) (pg.42)

Seam strength (kN/m)	
L (ft)	32.8

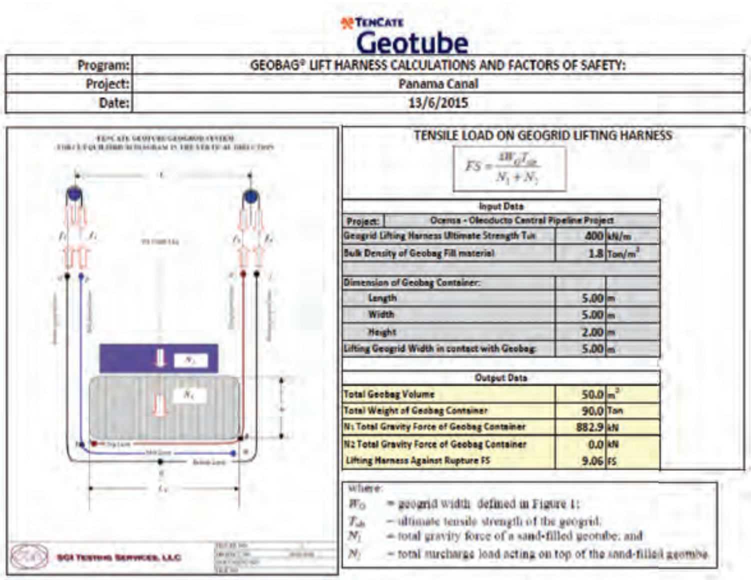
GEOTEXTILE BAGS

- **Bezuijen and Vastenburg define a Geotextile bag as a container that's normally filled with sand, and with volumes between 0.3 and 10 m3.**
- **Improvements to the installation methods have been allowing the use of Geotextile Bags with volumes over 160 m3 (300 tons).**
- **If the volume is lower than 0.3 m3, then they're called sandbags.**

GEOTEXTILE BAGS

- **Steps 1 and 2**
- **Lifting harness Calculator**

GEOTEXTILE BAGS – DESIGN TOOL



TENCATE Geotube

Program:	GEOBAG® LIFT HARNESS CALCULATIONS AND FACTORS OF SAFETY:
Project:	Panama Canal
Date:	13/6/2015

TENSILE LOAD ON GEOGRID LIFTING HARNESS

$$FS = \frac{4W_G T_{ult}}{N_1 + N_2}$$

Input Data		
Project:	Ocensa - Oleoducto Central Pipeline Project	
Geogrid Lifting Harness Ultimate Strength Tult	400	kN/m
Bulk Density of Geobag Fill material	1.8	Ton/m³
Dimension of Geobag Container:		
Length	5.00	m
Width	5.00	m
Height	2.00	m
Lifting Geogrid Width in contact with Geobag	5.00	m

Output Data		
Total Geobag Volume	50.0	m³
Total Weight of Geobag Container	90.0	Ton
N1 Total Gravity Force of Geobag Container	882.9	kN
N2 Total Gravity Force of Geobag Container	0.0	kN
Lifting Harness Against Rupture FS	9.06	FS

where:

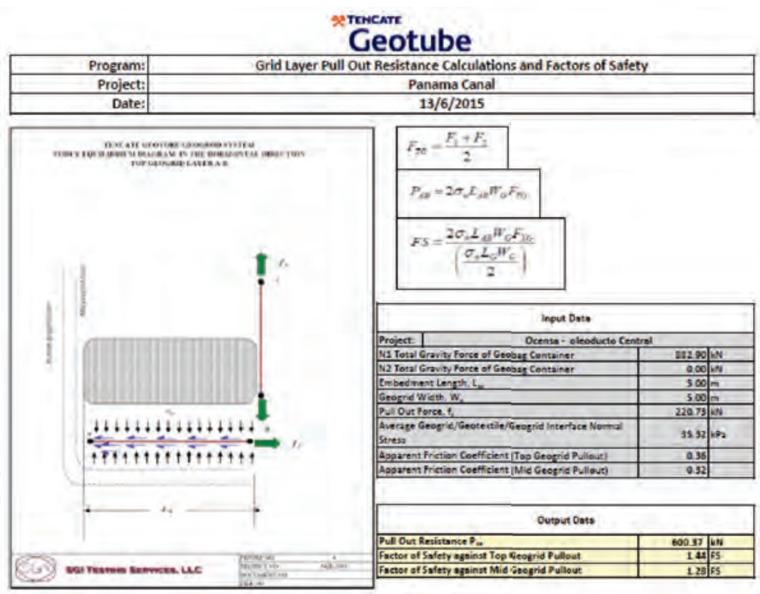
W_G = geogrid width defined in Figure 1;

T_{ult} = ultimate tensile strength of the geogrid;

N_1 = total gravity force of a sand-filled geotube; and

N_2 = total surcharge load acting on top of the sand-filled geotube.

SGI TESTING SERVICES, LLC



TENCATE Geotube

Program:	Grid Layer Pull Out Resistance Calculations and Factors of Safety
Project:	Panama Canal
Date:	13/6/2015

$$F_{TO} = \frac{F_1 + F_2}{2}$$

$$P_{AB} = 2\sigma_n L_{AB} W_G F_{TO}$$

$$FS = \frac{2\sigma_n L_{AB} W_G F_{TO}}{\left(\frac{\sigma_n L_G W_G}{2}\right)}$$

Input Data		
Project:	Ocensa - oleoducto Central	
N1 Total Gravity Force of Geobag Container	882.90	kN
N2 Total Gravity Force of Geobag Container	0.00	kN
Embedment Length, L_{ue}	5.00	m
Geogrid Width, W_c	5.00	m
Pull Out Force, f_i	220.73	kN
Average Geogrid/Geotextile/Geogrid Interface Normal Stress	35.32	kPa
Apparent Friction Coefficient (Top Geogrid Pullout)	0.36	
Apparent Friction Coefficient (Mid Geogrid Pullout)	0.32	

Output Data		
Pull Out Resistance P_{ue}	600.37	kN
Factor of Safety against Top Geogrid Pullout	1.44	FS
Factor of Safety against Mid Geogrid Pullout	1.28	FS

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GEOTEXTILE TUBE

Geotextile tube is defined as "***a large tube [greater than 7.5 feet (2.3 m) in circumference] fabricated from high strength, woven geotextile, in lengths greater than 20 linear feet (6.1 m)", according to GRI Test Method GT11: Standard Practice for "Installation of Geotextile Tubes used as Coastal and Riverine Structures***".

GEOTEXTILE TUBE - HYSTORY

The Netherlands, 1962 – TenCate Geosynthetics

GEOTEXTILE TUBE – 1ST MARINE APPLICATION IN AMERICA

1993

2019

67

GEOTEXTILE TUBE - DEWATERING

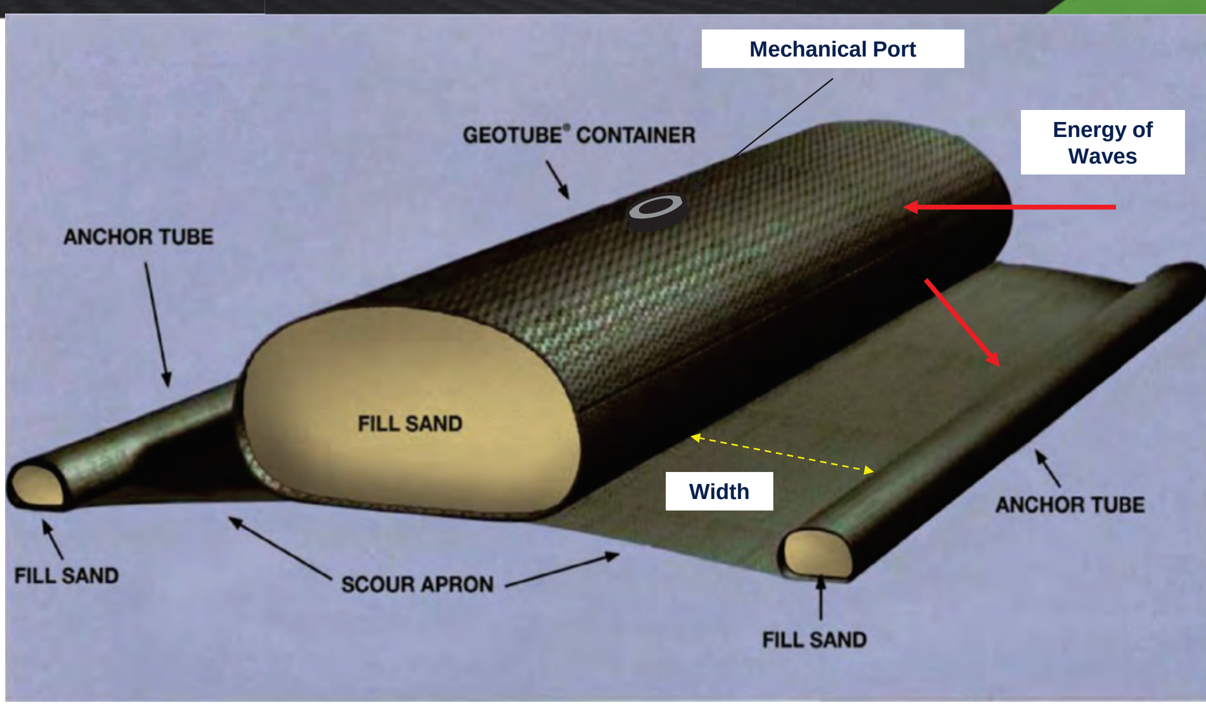
Vicksburg, MS -1995

68

GEOTEXTILE TUBE - DEWATERING

Lake Onondaga Project, NY-2015

GEOTEXTILE TUBE



GEOTEXTILE TUBE

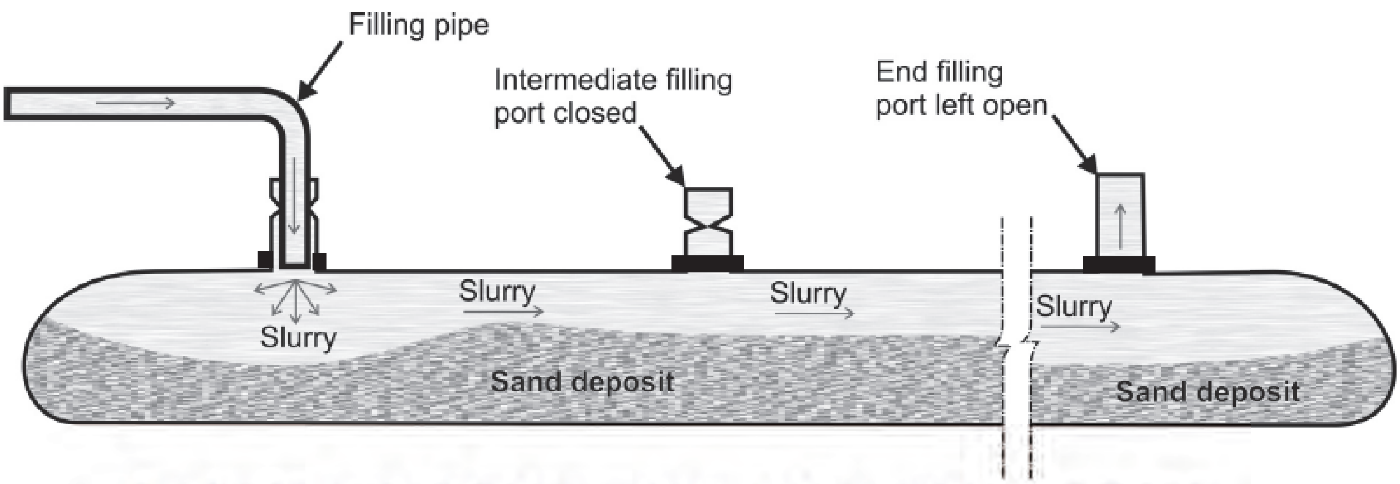
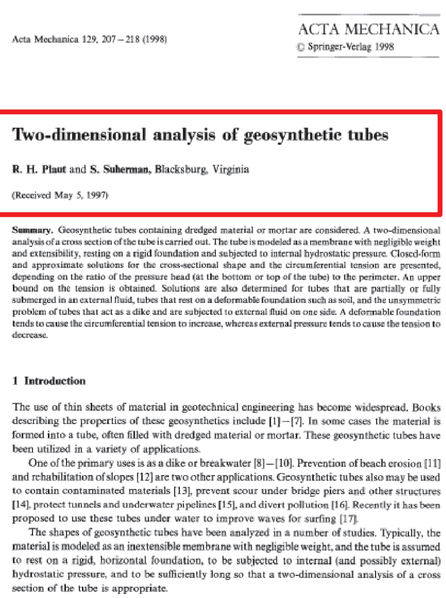


Fig. 10: Schematic of the hydraulic filling of a geotextile tube with sand (T.W. Yee, 2016)

GEOTEXTILE TUBE - DESIGN TOOL



Acta Mechanica 129, 207 – 218 (1998)

ACTA MECHANICA
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Two-dimensional analysis of geosynthetic tubes

R. H. Plaut and **S. Suherman,** Blacksburg, Virginia

(Received May 5, 1997)

Summary. Geosynthetic tubes containing dredged material or mortar are considered. A two-dimensional analysis of a cross section of the tube is carried out. The tube is modeled as a membrane with negligible weight and extensibility, resting on a rigid foundation and subjected to internal hydrostatic pressure. Closed-form and approximate solutions for the cross-sectional shape and the circumferential tension are presented, depending on the ratio of the pressure head (at the bottom or top of the tube) to the perimeter. An upper bound on the tension is obtained. Solutions are also determined for tubes that are partially or fully submerged in an external fluid, tubes that rest on a deformable foundation such as soil, and the unsymmetric problem of tubes that act as a dike and are subjected to external fluid on one side. A deformable foundation tends to cause the circumferential tension to increase, whereas external pressure tends to cause the tension to decrease.

1 Introduction

The use of thin sheets of material in geotechnical engineering has become widespread. Books describing the properties of these geosynthetics include [1]–[7]. In some cases the material is formed into a tube, often filled with dredged material or mortar. These geosynthetic tubes have been utilized in a variety of applications.

One of the primary uses is as a dike or breakwater [8]–[10]. Prevention of beach erosion [11] and rehabilitation of slopes [12] are two other applications. Geosynthetic tubes also may be used to contain contaminated materials [13], prevent scour under bridge piers and other structures [14], protect tunnels and underwater pipelines [15], and divert pollution [16]. Recently it has been proposed to use these tubes under water to improve waves for surfing [17].

The shapes of geosynthetic tubes have been analyzed in a number of studies. Typically, the material is modeled as an inextensible membrane with negligible weight, and the tube is assumed to rest on a rigid, horizontal foundation, to be subjected to internal (and possibly external) hydrostatic pressure, and to be sufficiently long so that a two-dimensional analysis of a cross section of the tube is appropriate.

Two-dimensional analysis of geosynthetic tubes

R. H. Plaut and **S. Suherman,** Blacksburg, Virginia

(Received May 5, 1997)

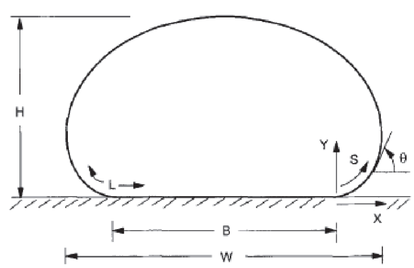


Fig. 1. Cross section of tube on rigid foundation

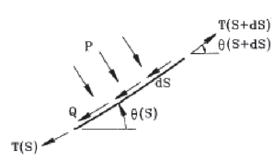
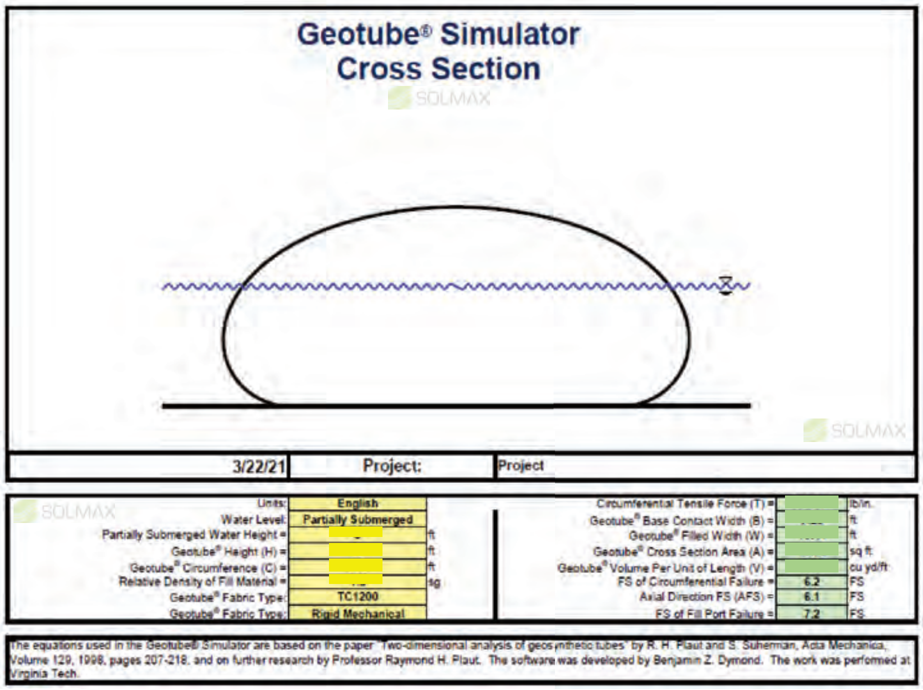
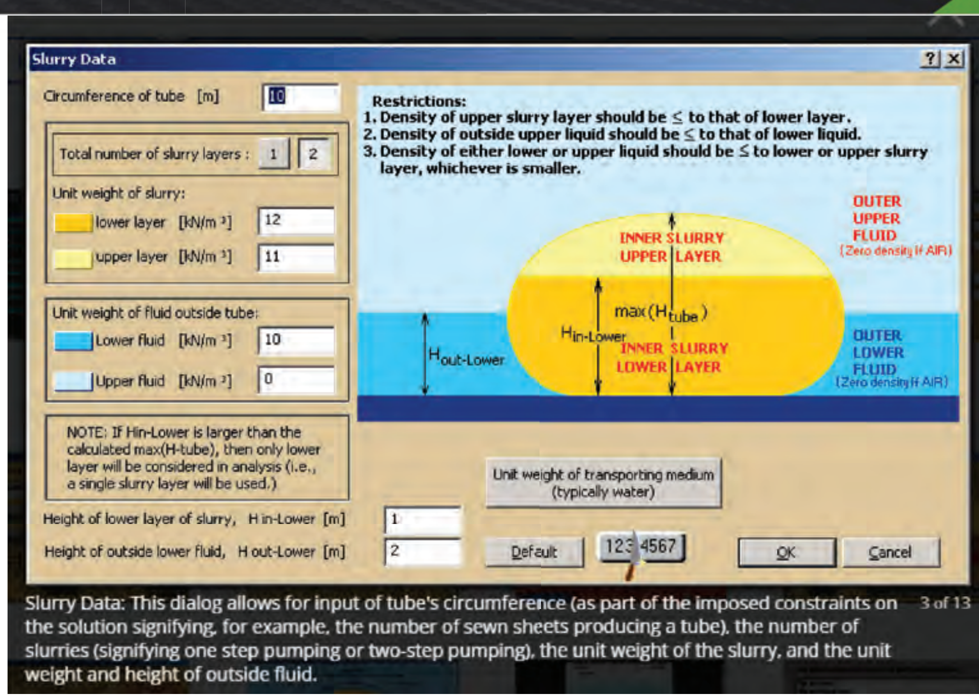


Fig. 2. Element of tube

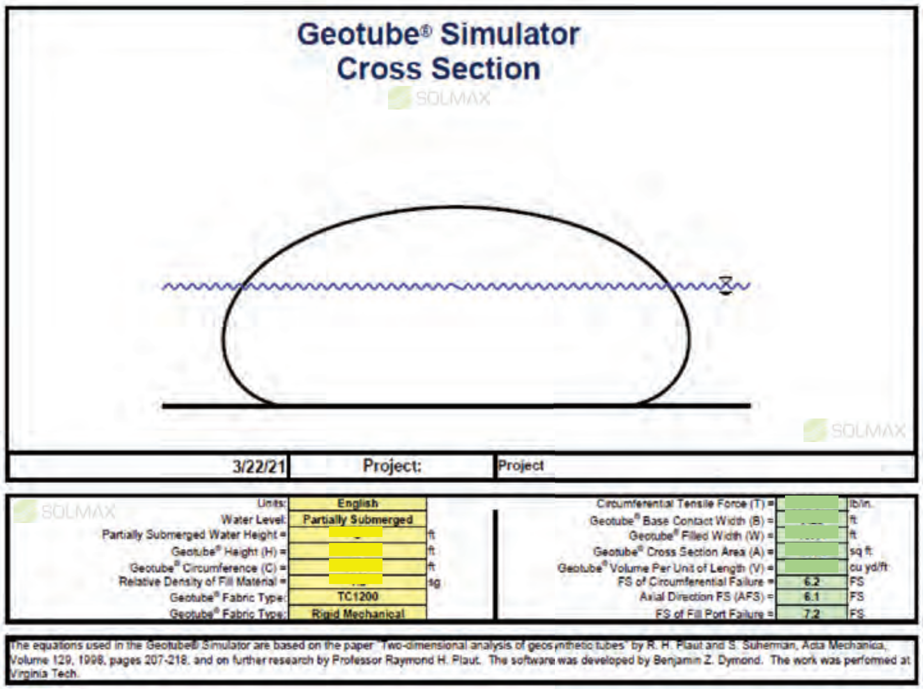
GEOTEXTILE TUBE – DESIGN TOOL



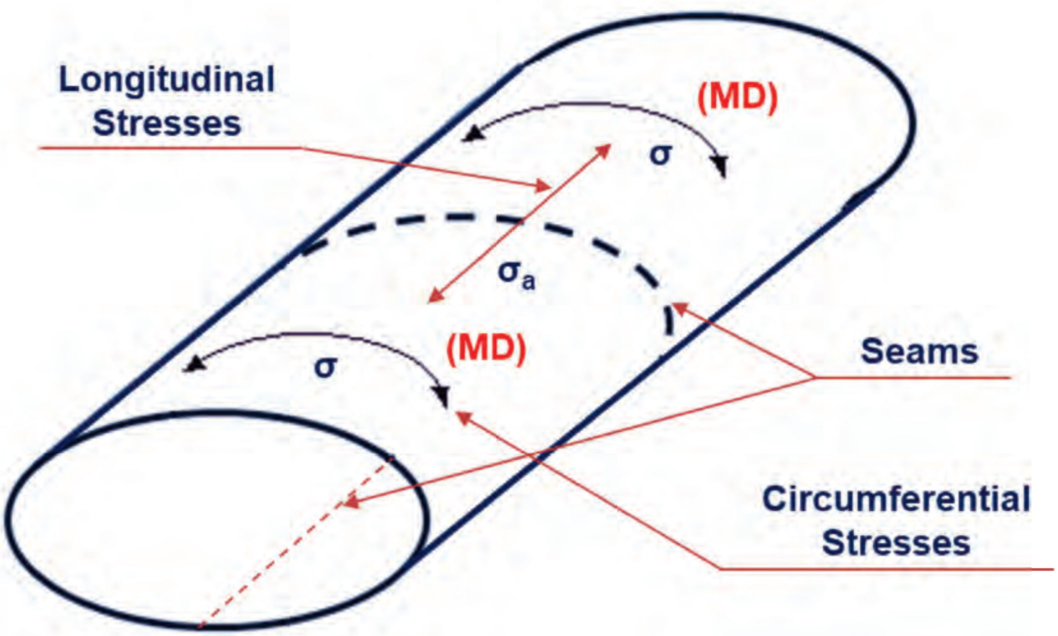
GEOTEXTILE TUBE - DESIGN TOOL



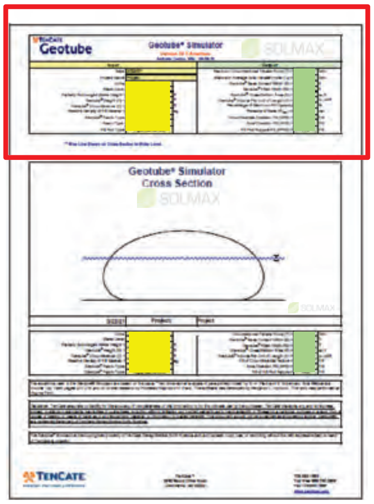
GEOTEXTILE TUBE – DESIGN TOOL

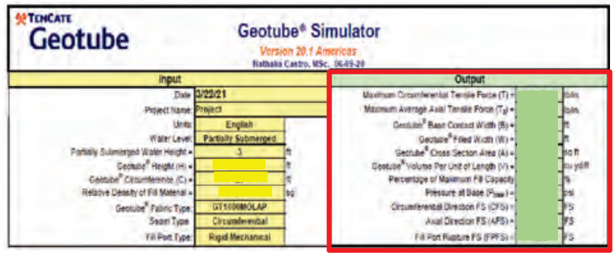


GEOTEXTILE TUBE – DESIGN TOOL



GEOTEXTILE TUBE – DESIGN TOOL





Output		
Maximum Circumferential Tensile Force (T) =		lb/in.
Maximum Average Axial Tensile Force (T_a) =		lb/in.
Geotube® Base Contact Width (B) =		ft
Geotube® Filled Width (W) =		ft
Geotube® Cross Section Area (A) =		sq ft
Geotube® Volume Per Unit of Length (V) =		cu yd/ft
Percentage of Maximum Fill Capacity		%
Pressure at Base (P_{base}) =		psi
Circumferential Direction FS (CFS) =	17.7	FS
Axial Direction FS (AFS) =	19.5	FS
Fill Port Rupture FS (FPFS) =	16.5	FS

GEOTEXTILE TUBE – DESIGN TOOL

	Mechanical Properties	Test Method	Unit	Minimum Average Roll Value MD	Minimum Average Roll Value CD
(CFS)	Wide Width Tensile Strength (at ultimate)	ASTM D4595	lbs/in (kN/m)	1142 (200)	1142 (200)
	Tensile Strength (at 5% strain)	ASTM D4595	lbs/ft (kN/m)	200	1000
	Wide Width Tensile Elongation	ASTM D4595	%	17 (max.)	10 (max.)
(AFS)	Factory Seam Strength	ASTM D4884	lbs/in (kN/m)	914 (160)	
	CBR Puncture Strength	ASTM D6241	lbs (kN)	4000 (17.8)[1]	
	UV Resistance (% strength retained after 500 hrs)	ASTM D4355	%	85	

Hydraulic Properties	Test Method	Unit	Minimum Average Roll Value
Apparent Opening Size (AOS)	ASTM D4751	U.S. Sieve (mm)	30 (0.60)
Water Flow Rate	ASTM D4491	gal/min/ft² (l/min/m²)	20 (815)
Permittivity	ASTM D4491	sec⁻¹	0.35

GEOTEXTILE TUBE – DESIGN TOOL

Output		
Maximum Circumferential Tensile Force (T) =		lb/in.
Maximum Average Axial Tensile Force (T_a) =		lb/in.
Geotube® Base Contact Width (B) =		ft
Geotube® Filled Width (W) =		ft
Geotube® Cross Section Area (A) =		sq ft
Geotube® Volume Per Unit of Length (V) =		cu yd/ft
Percentage of Maximum Fill Capacity		%
Pressure at Base (P_{base}) =		psi
Circumferential Direction FS (CFS) =	17.7	FS
Axial Direction FS (AFS) =	19.5	FS
Fill Port Rupture FS (FPFS) =	16.5	FS

- Circunferential Direction FS (CFS) = $\dfrac{\text{GT1000 MD Ultimate Tensile Strength (Wide Width)}}{\text{Maximum Circumferential Tensile Force (T)}}$

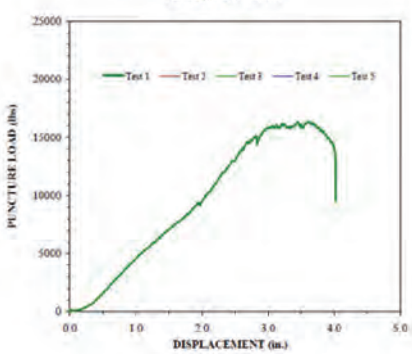
Circunferential Direction (CFS) = **17.7**

- Axial Direction FS (AFS) = $\dfrac{\text{GT1000 Factory Seam Strength}}{\text{Maximum Average Axial Tensile Force (Ta)}}$

Axial Direction FS (AFS) = **19.5**

GEOTEXTILE TUBE – DESIGN TOOL

TENCATE GEOSYNTHETICS
GEOTEXTILE-GEOPORT CONNECTION STRENGTH TESTING (ASTM D 6241 MODIFIED)
GT1000 Geotextile (NWGT Protection Layer) Clamped between Two 8" Rings
Loading Plate Diameter: 7.5"
Tightening Bolt Size: 1/2"
SGI Sample ID No. S22227



Test Specimen	Internal Port Diameter D	Loading Plate Diameter d	Displacement Rate (in./min)	Maximum Puncture Load P (lbs)	Maximum Displacement (in.)	Mobilized Connection (Seam) Strength $\sigma_s = (P/\pi D)$ (lbs/in.)	Failure Mode
1	8.5	7.5	1.0	16386	3.44	614	Rupture of geotextile
2							
3							
4							
5							
Mean:							

GEOTEXTILE TUBE – DESIGN TOOL

Output		
Maximum Circumferential Tensile Force (T) =		lb/in.
Maximum Average Axial Tensile Force (T_a) =		lb/in.
Geotube® Base Contact Width (B) =		ft
Geotube® Filled Width (W) =		ft
Geotube® Cross Section Area (A) =		sq ft
Geotube® Volume Per Unit of Length (V) =		cu yd/ft
Percentage of Maximum Fill Capacity		%
Pressure at Base (P_{base}) =		psi
Circumferential Direction FS (CFS) =		FS
Axial Direction FS (AFS) =		FS
Fill Port Rupture FS (FPFS) =	16.5	FS

- Fill Port Rupture FS (FPFS) = GP8/GT1000 Pullout Resistance / [Average Tensile Force (Circumferential and Axial) * 0.67 (Reduction of Circumferential Stress Around a Rigid Port)]

Average Tensile Force (Circumferential and Axial) = **A**

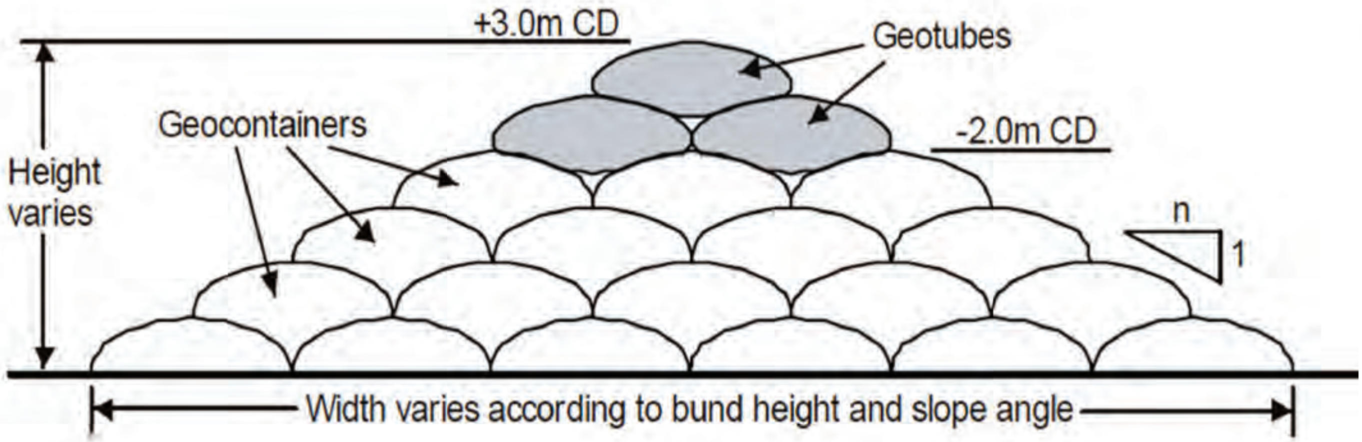
Average Tensile Force (Circumferential and Axial) * 0.67 (Reduction of Circumferential Stress Around a Rigid Port) = **A * 0.67**

Fill Port Rupture FS (FPFS) = 16.5

GEOCONTAINERS

- **Geotextile container or Geocontainer is a large geotextile-encapsulated sand element containing 100 m3 to 800 m3 of sand and is dropped through water from a split bottom barge.**
- **The available barge determines the size of the container which, consequently, leads the final design.**
- **Commonly used when water depth is deeper than 3m (~10ft)**

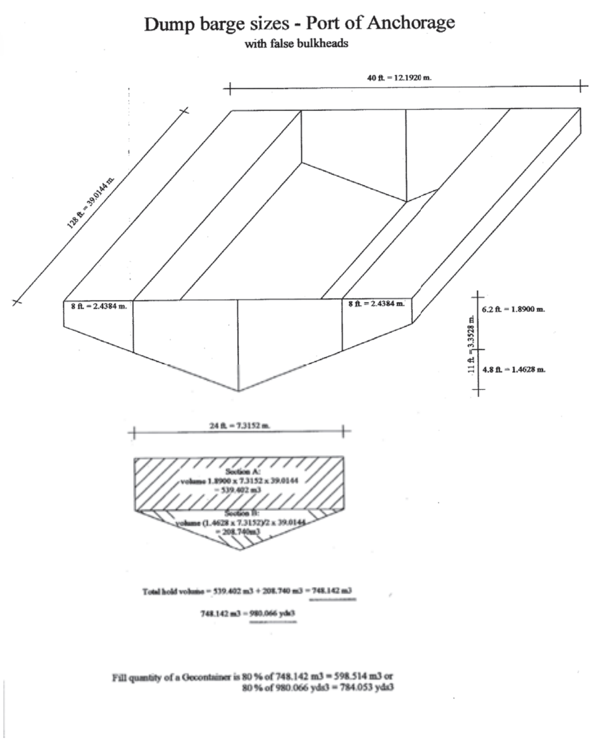
GEOCONTAINERS



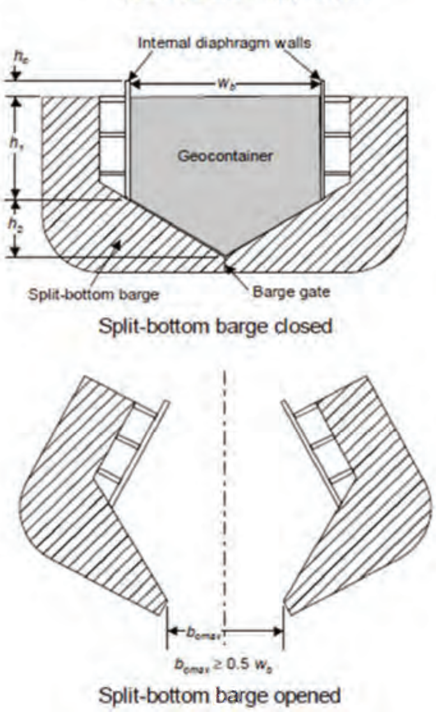
Seabed

Schematic cross section through temporary containment bunds.

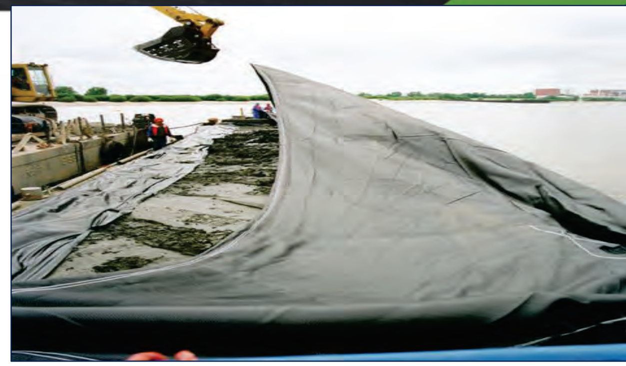
GEOCONTAINERS - DESIGN

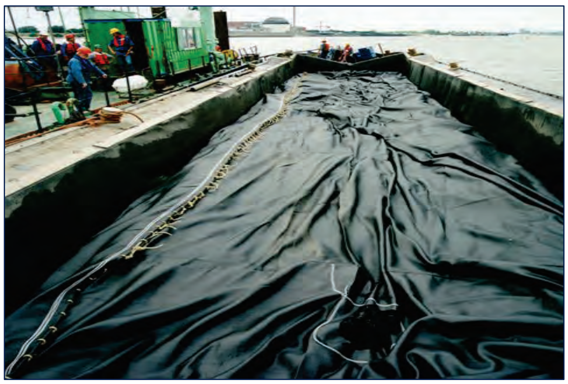


Typical split-bottom barge hopper.

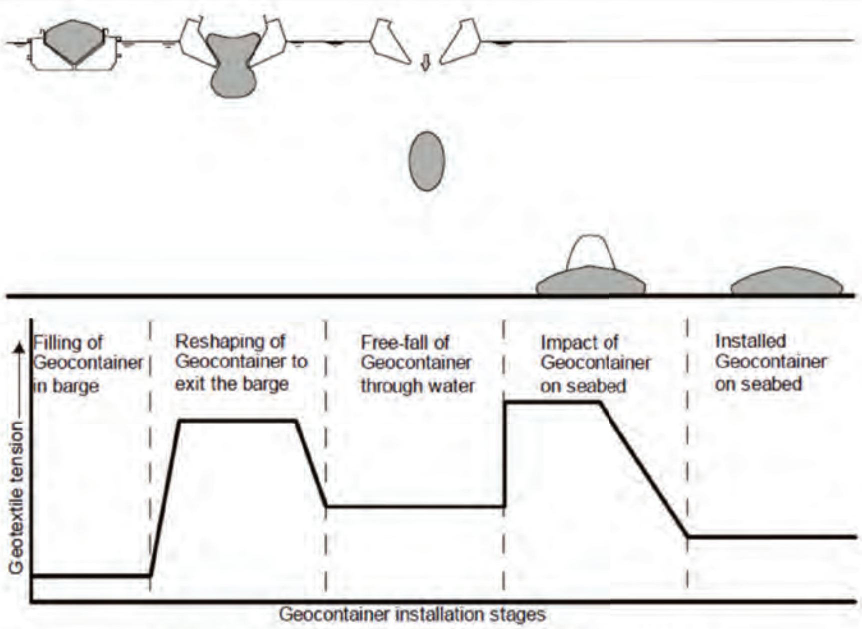


GEOCONTAINERS



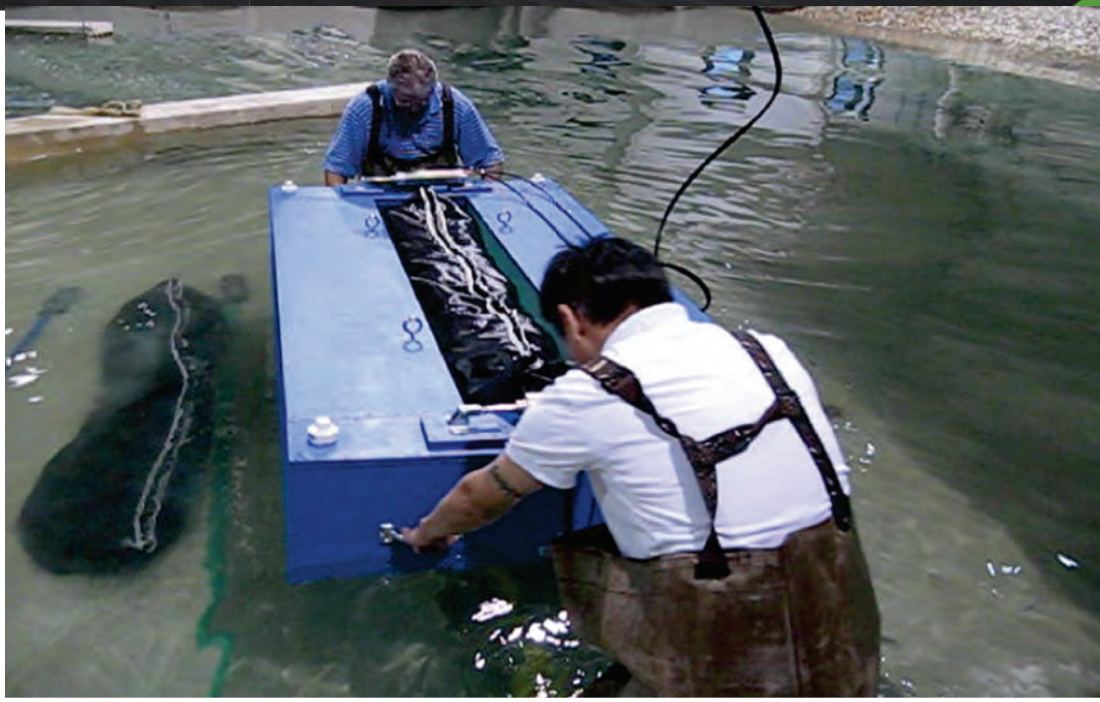


GEOCONTAINERS

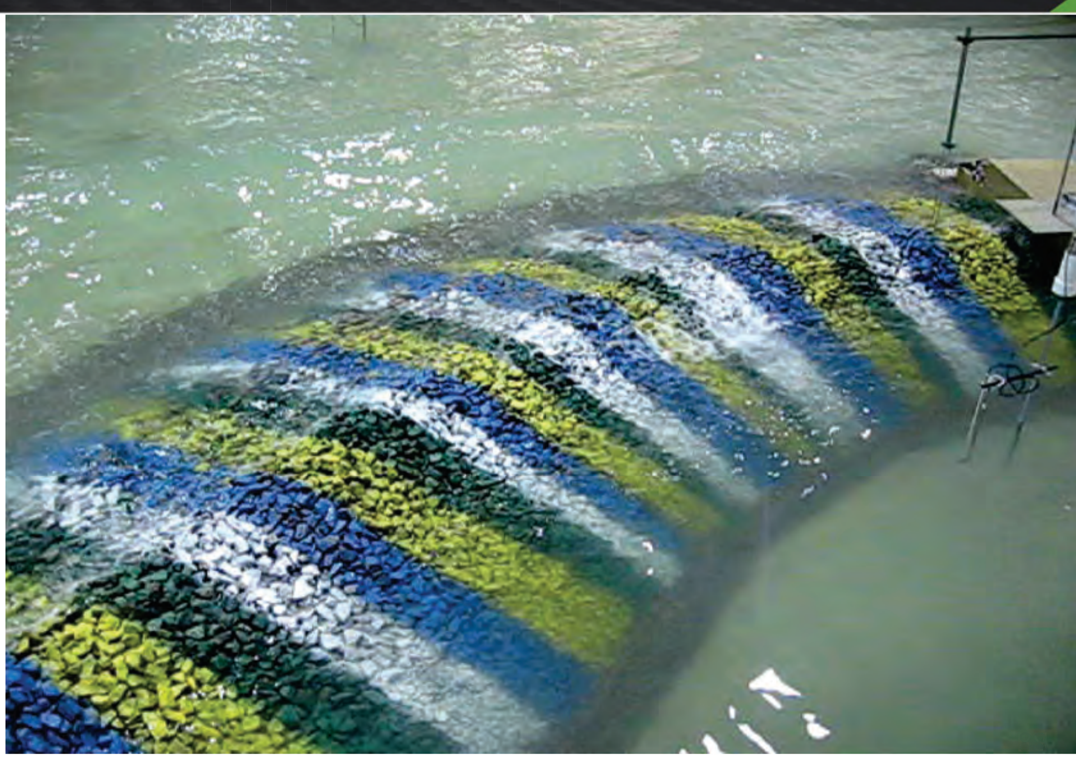


Geotextile tensions generated in Geocontainers during installation.

GEOCONTAINERS - MODELLING

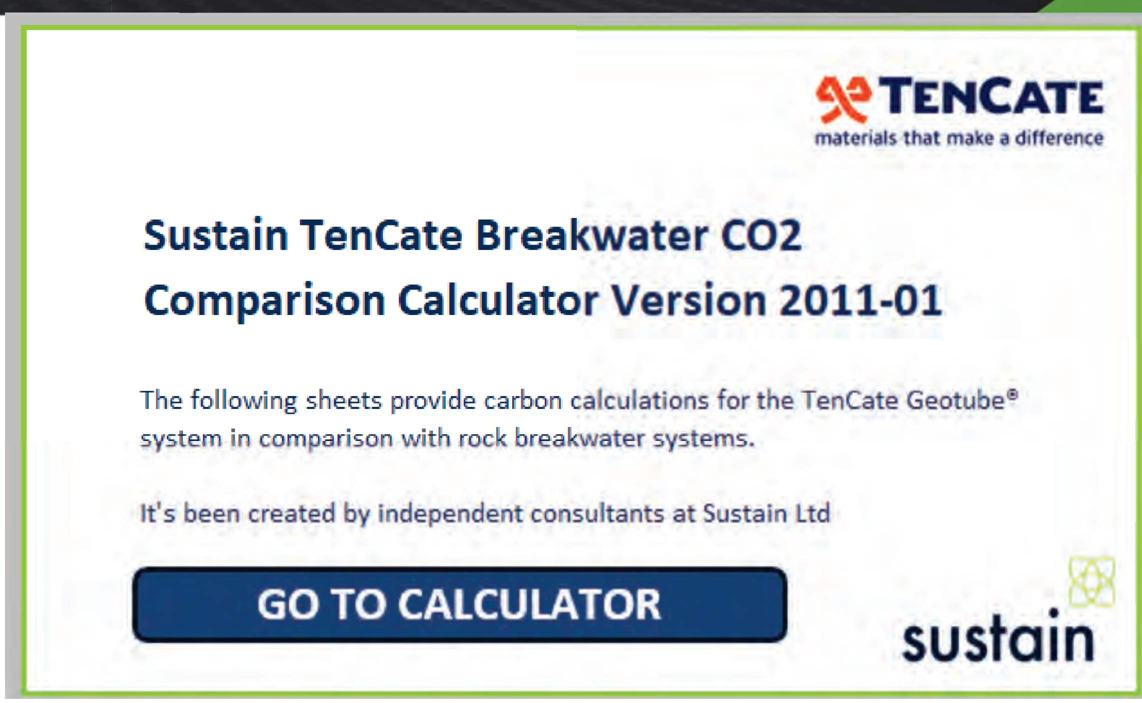


GEOCONTAINERS - MODELLING



GEOCONTAINERS - MODELLING

DESIGN TOOL - CARBON FOOTPRINT



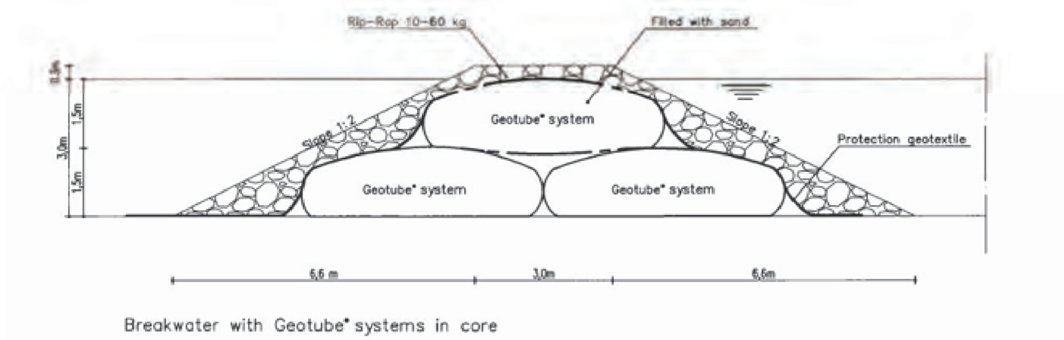
DESIGN TOOL - CARBON FOOTPRINT

Geotube® Breakwater System

TENCATE materials that make a difference — sustain

1. System Description

Description	Note
Included processes	All processes that are not the same in the TenCate Geotube® system and rock breakwater system have been included.
Excluded processes	Processes that are the same in both systems have been excluded from the comparative study. If the conditions are the same then it will have the same effect on both systems.



Breakwater with Geotube® systems in core

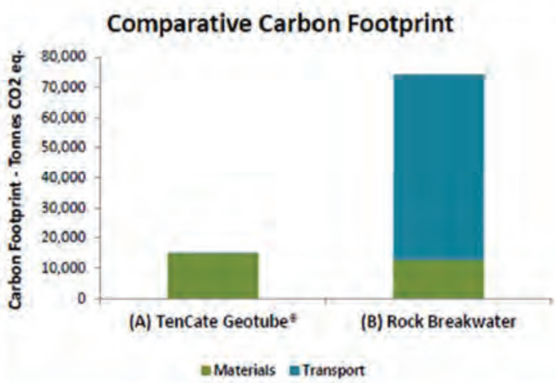
DESIGN TOOL - CARBON FOOTPRINT

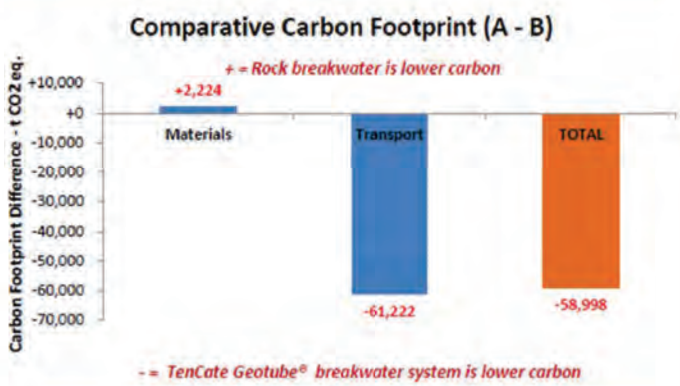
Breakwater Carbon Calculator Results

TENCATE materials that make a difference — sustain

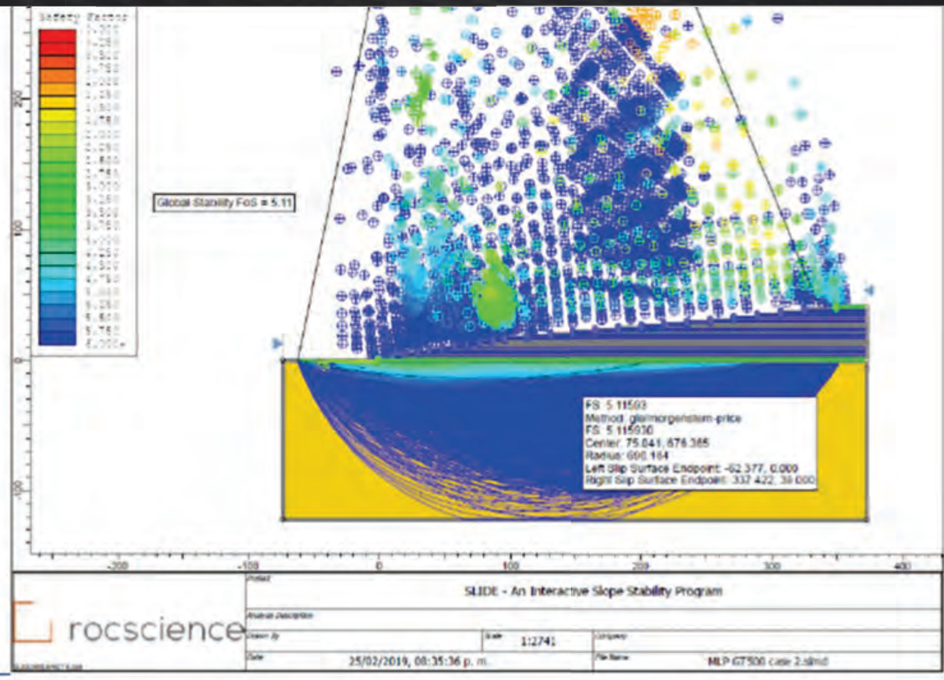
1. Summary Results - TenCate Geotube® System V Rock Breakwater

HEADLINE RESULTS	TenCate Geotube® is lower carbon by	58,998 tonnes CO2e
	(A) TenCate Geotube® Results	15,207 tonnes CO2e
	(B) Alternative Breakwater Results	74,205 tonnes CO2e



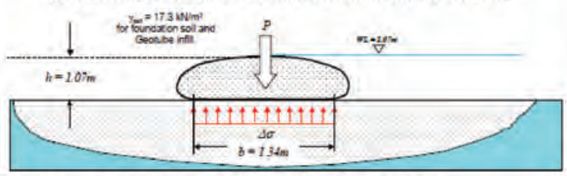


DESIGN TOOL – SLOPE STABILITY



DESIGN TOOL – SETTLEMENT ANALYSIS

ESTIMATE OF CONTACT STRESS AND BEARING CAPACITY
CASE #1: ONE LAYER OF GEOTUBES PLACED ON TOP OF FOUNDATION SOIL



CONTACT NORMAL STRESS BETWEEN GEOTUBE AND FOUNDATION SOIL:
$\Delta\sigma = W/b = [1.34x1.07x(17.3\text{-}9.8)]/1.34 = 8.03$ kPa

UNDRAINED SHEAR STRENGTH OF FOUNDATION SOIL :
Layer #1 from 0 to 2 m: $S_u = c - \sigma(\tan(\varphi))$, $= 0.96 - 1 x (17.3 - 9.8) x (\tan(0))$ (kPa)
Assume the average S_u of the 1st soft soil layer can be used to estimate bearing capacity of the soft soil to support the single layer geotube, then the average undrained shear strength is:
$S_u = 0.96$ kPa

BEARING CAPACITY OF FOUNDATION SOIL
$q_{ult} = cN_c$
where N_c *= bearing capacity factor, and c = cohesion = undrained shear strength*
$q_{ult} = 0.96 x 5.7 = 5.5$ kPa

FACTOR OF SAFETY AGAINST BEARING CAPACITY FAILURE:
$FS = q_{ult} / \Delta\sigma_c = 5.5 / 8.03 = 0.68$
However, it is noted the average S_u *of the 1st soft soil layer is = 0.96 kPa then Geosynthetic Reinforced bearing capacity is increased to,*
$q_{ult(reinforced)} = 0.96 x 6 = 5.76$ kPa
and the Reinforced bearing capacity FS is.

TENCATE Geotube

DATE 10/18/2021
PROJECT
AUTHOR NPBC

Project

ESTIMATE OF SETTLEMENTS

Soil Layers From the top of Soil Test Boring	Depth Below Bottom Surface	Layer Thickness H_i	Mid Layer Depth	Assumed Saturated Unit Weight of Soil Layer γ_{sat}	Initial Verticle Stress at middle of Layer σ'_{vo}	Increase of Verticle Stress For Weight of Embankment $\Delta\sigma$	Stress Ratio R $\frac{\sigma'_{vo}+\Delta\sigma}{\sigma'_{vo}}$	Compression Index C_c	Initial Void Ratio e_o	$\frac{H_i}{1+e_o}$	Settlement S = Cc*Ho/(1+eo) logR
	(m)	(m)	(m)	(kN/m³)	(kPa)	(kPa)	(kPa)			(kN/m³)	(m)
1	0 to 2	2.0	1.0	17.3	7.5	14.8	3.0	0.58	2.00	0.667	0.18
Total Settlement (m):											**0.18**

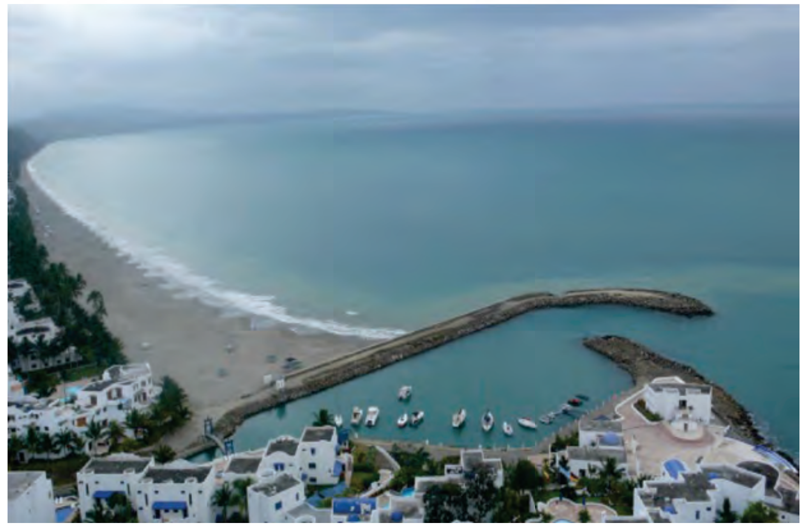
Notes: Soil Properties are Assumed.
Disclaimer: **No warranty or guarantee expressed or implied is made regarding the performance of any product since the manner of handling and use is beyond our control. This document should not be construed as engineering advice, and the final design should be the responsibility of the project engineer and/or the project manager.**

TENCATE Geotube

DATE: 10/18/2021
PROJECT:
AUTHOR: NPBC

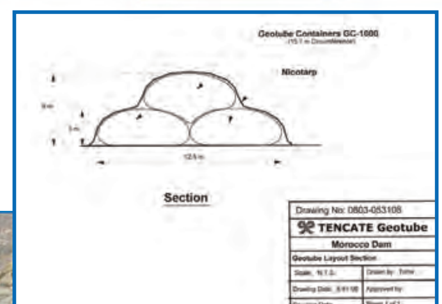
LIQUEFACTION

- Physical phenomenon that the soil loses its strength when a shaking or other rapid loading makes the particles to spread, losing confinement/compaction. The mass of soil then behaves as a liquid.
- Geotextile-Encapsulated Sand Elements prevent particles from lateral spreading.
- Over time, sand becomes so tightly packed that no excess hydrostatic pressure is generated to cause liquefaction (wave-induced)



2003 - 2012

MISCELANEOUS – BE CREATIVE! ☺



Coffer Dams

MISCELANEOUS – BE CREATIVE! ☺

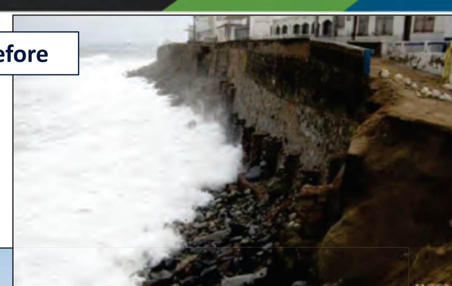
Shoreline Protection + Retaining Wall

Before

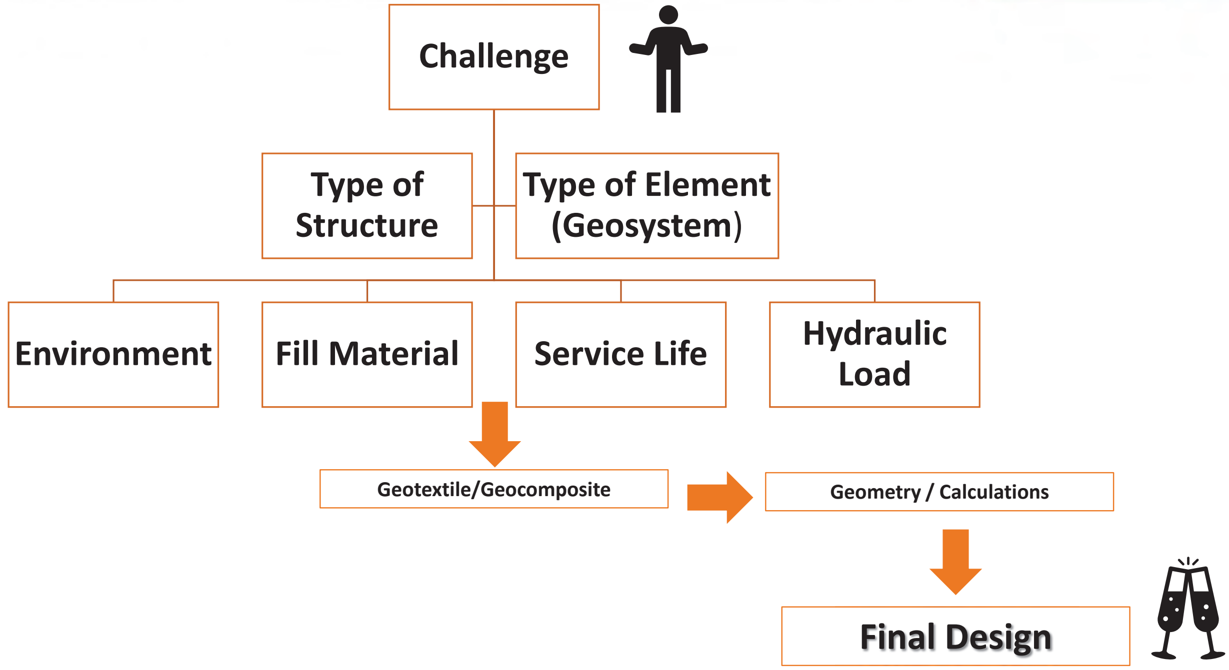
MISCELANEOUS – BE CREATIVE! ☺

Shoreline Protection + Retaining Wall

Before



HERE'S WHAT YOU SHOULD KEEP IN MIND



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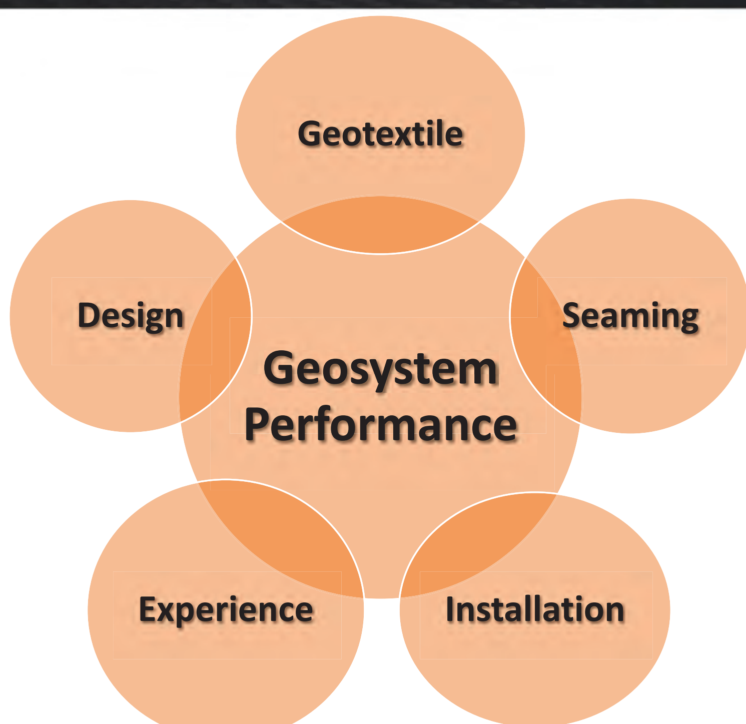

HERE'S WHAT YOU SHOULD KEEP IN MIND

When designing with Geosystems, there is no one-size-fits-all!

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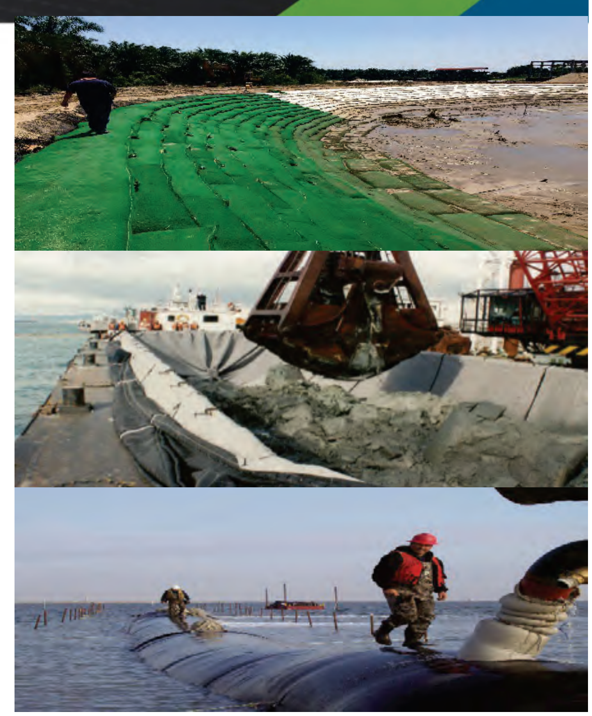
CASE HISTORIES



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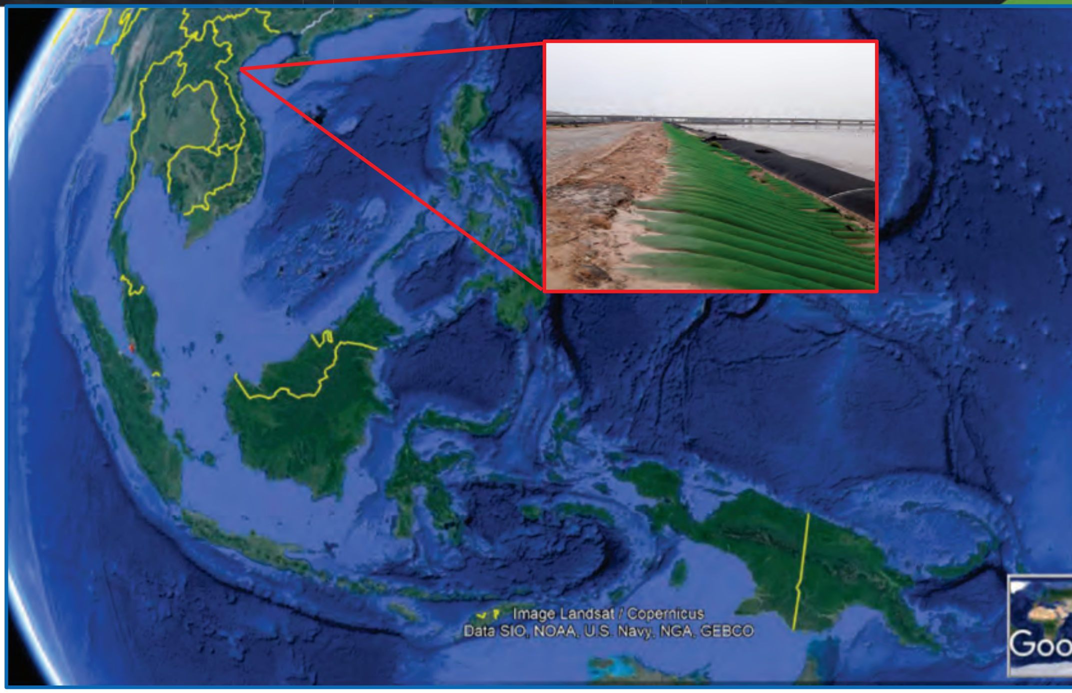
Sand Filled Mattresses – Case Histories – Haiphong, Vietnam



Sand Filled Mattresses – Case Histories - Haiphong, Vietnam

2014

2017

Sand Filled Mattresses – Case Histories - Haiphong, Vietnam

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Sand Filled Mattresses – Case Histories - Haiphong, Vietnam

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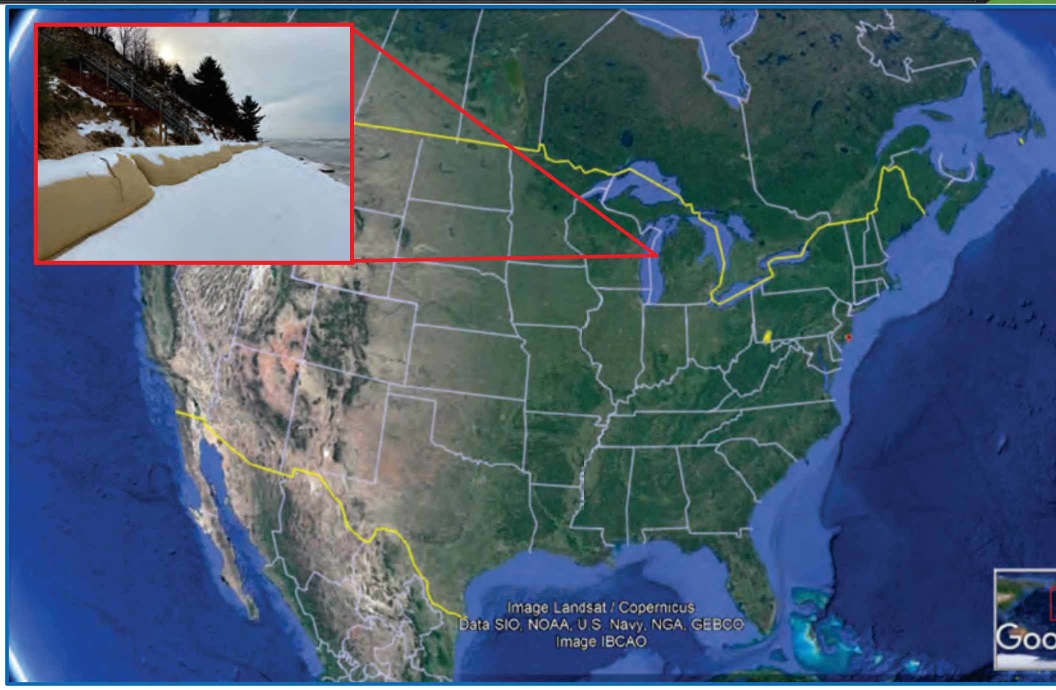
Sand Filled Mattresses – Case Histories - Haiphong, Vietnam

Sand Filled Mattresses – Case Histories - Haiphong, Vietnam

Geotube® – Case Histories – Lake Michigan, Michigan



Geotube® – Case Histories – Lake Michigan, Michigan

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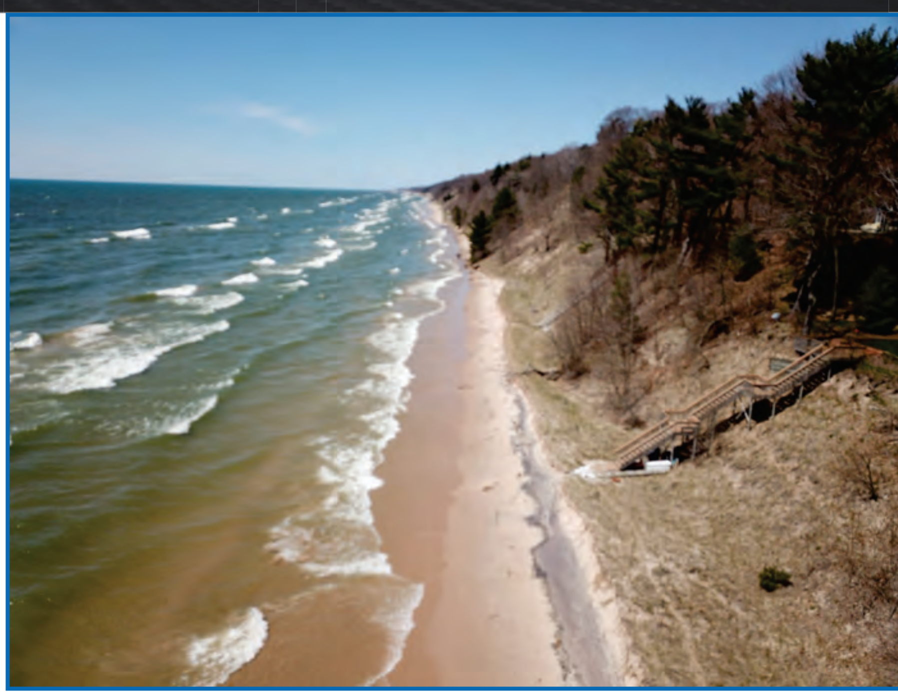
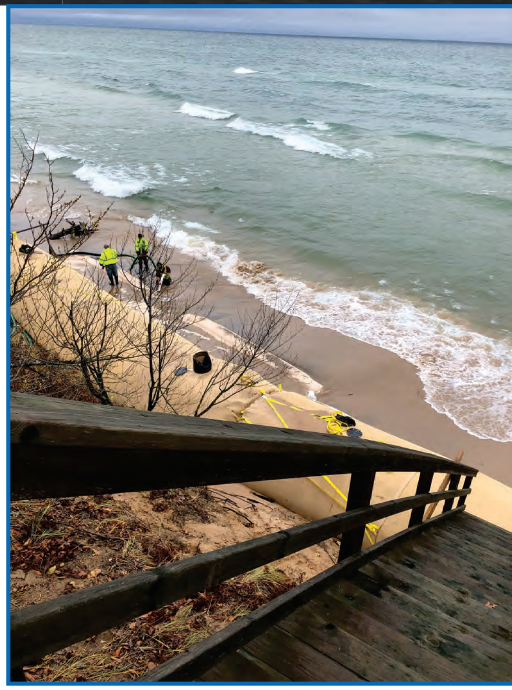


Geotube® – Case Histories – Lake Michigan, Michigan



Geotube® – Case Histories – Lake Michigan, Michigan

Geotube® – Case Histories – Lake Michigan, Michigan

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Geotube® – Case Histories – Lake Michigan, Michigan

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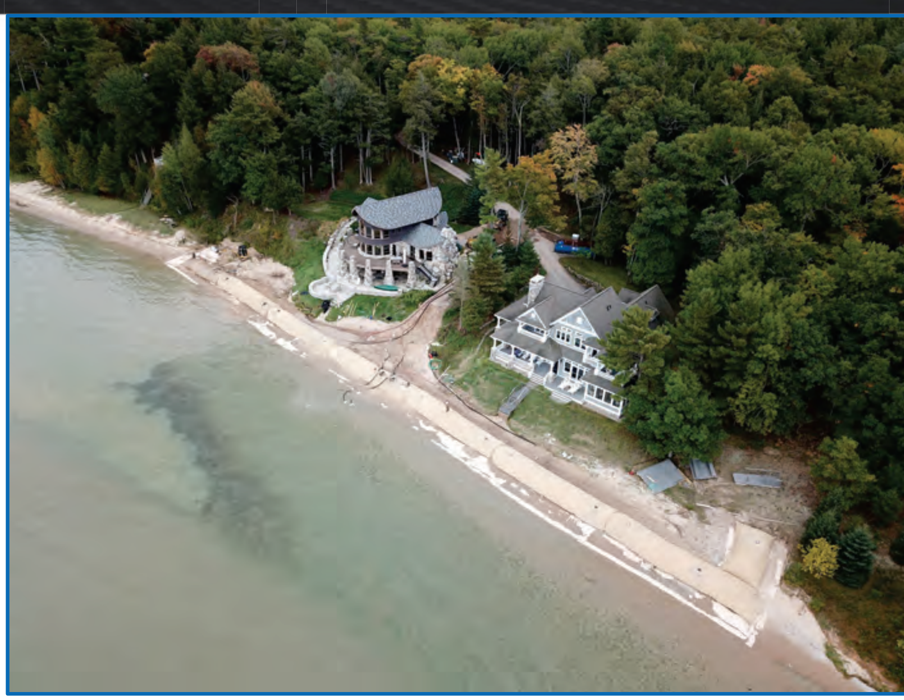
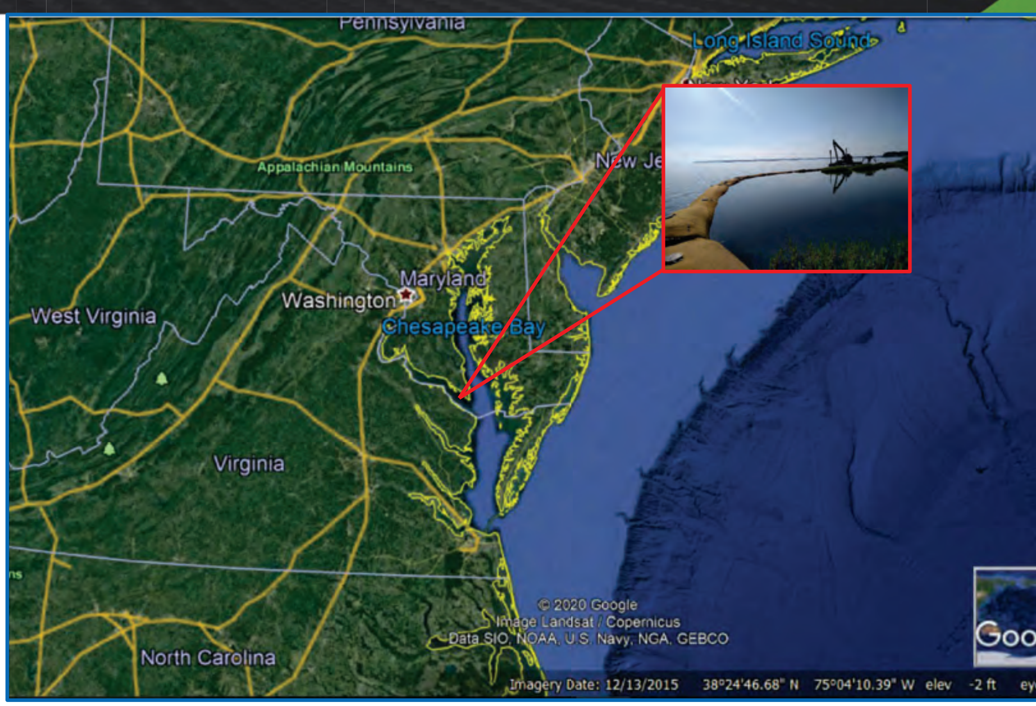
Geotube® – Case Histories – Lake Michigan, Michigan

Geotube® – Case Histories – Lake Michigan, Michigan

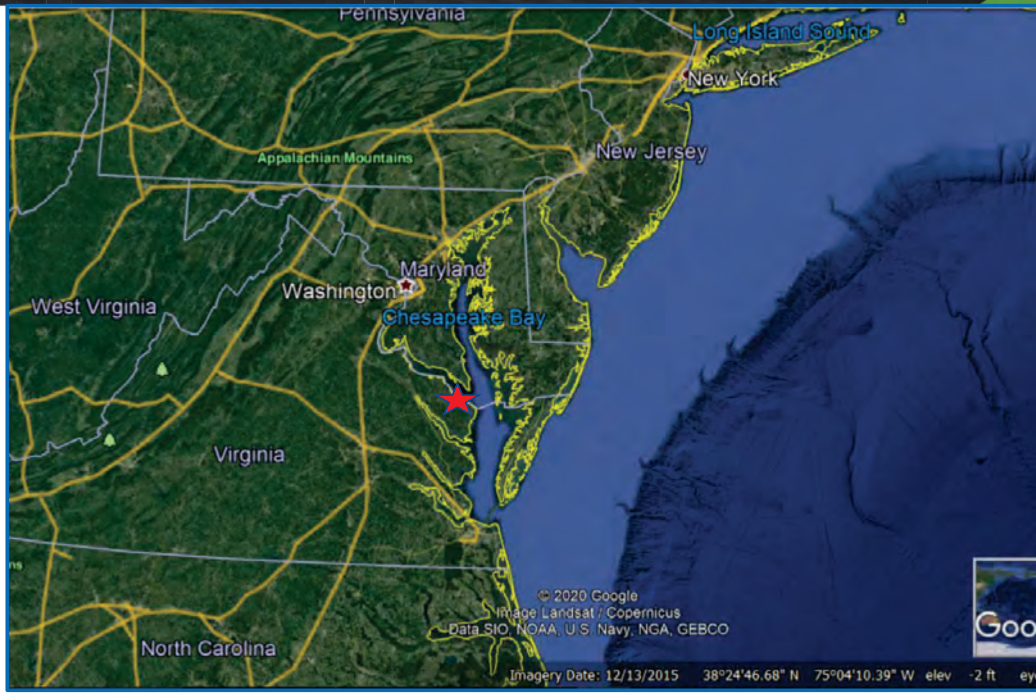


Geotube® – Case Histories – Lake Michigan, Michigan

Geotube® – Case Histories – Potomac River, Virginia



Geotube® – Case Histories – Potomac River, Virginia



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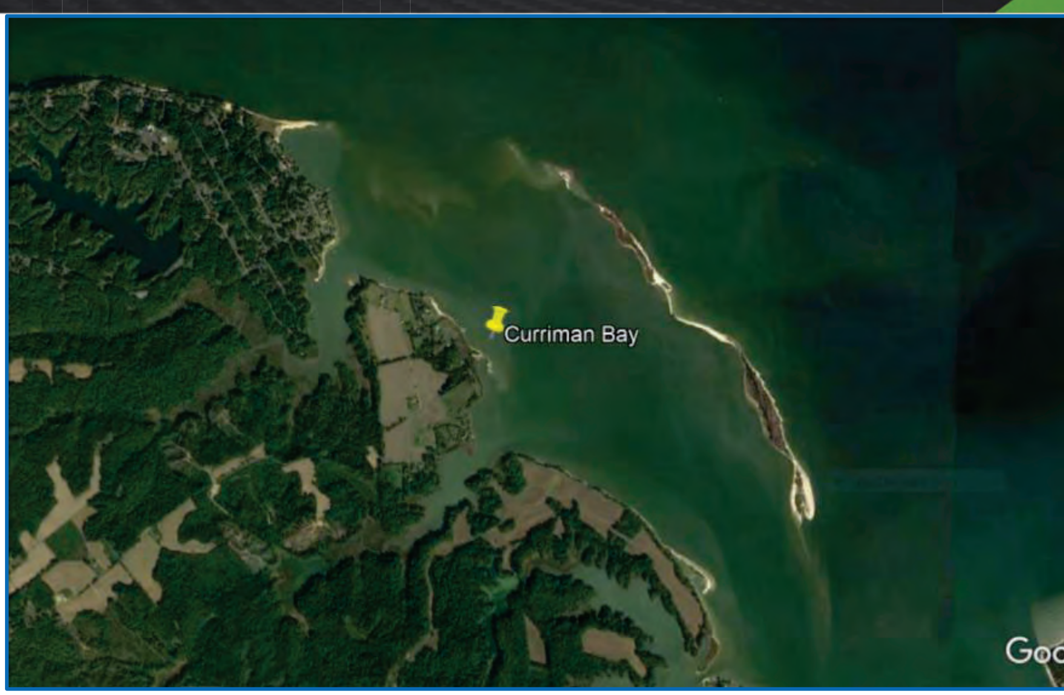

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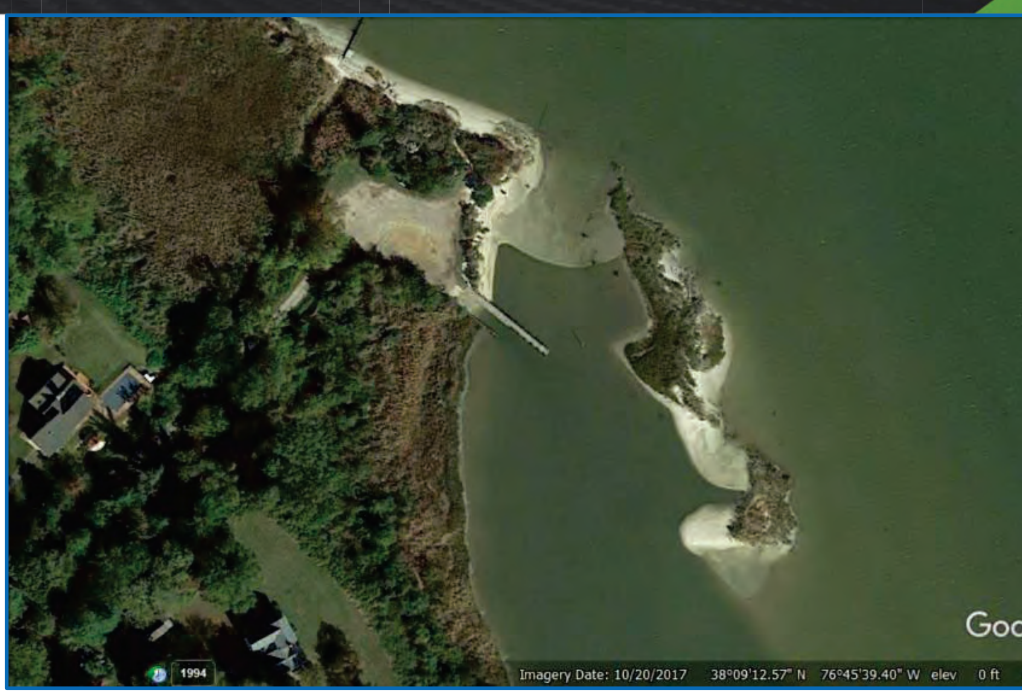

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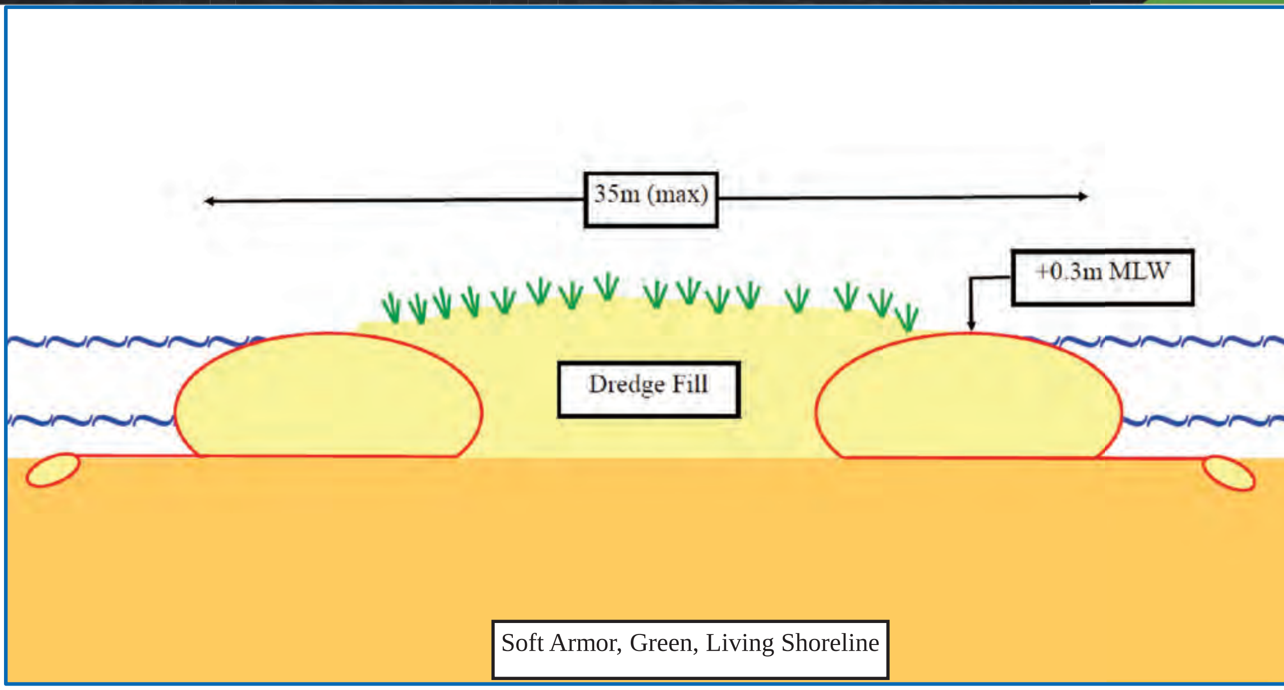

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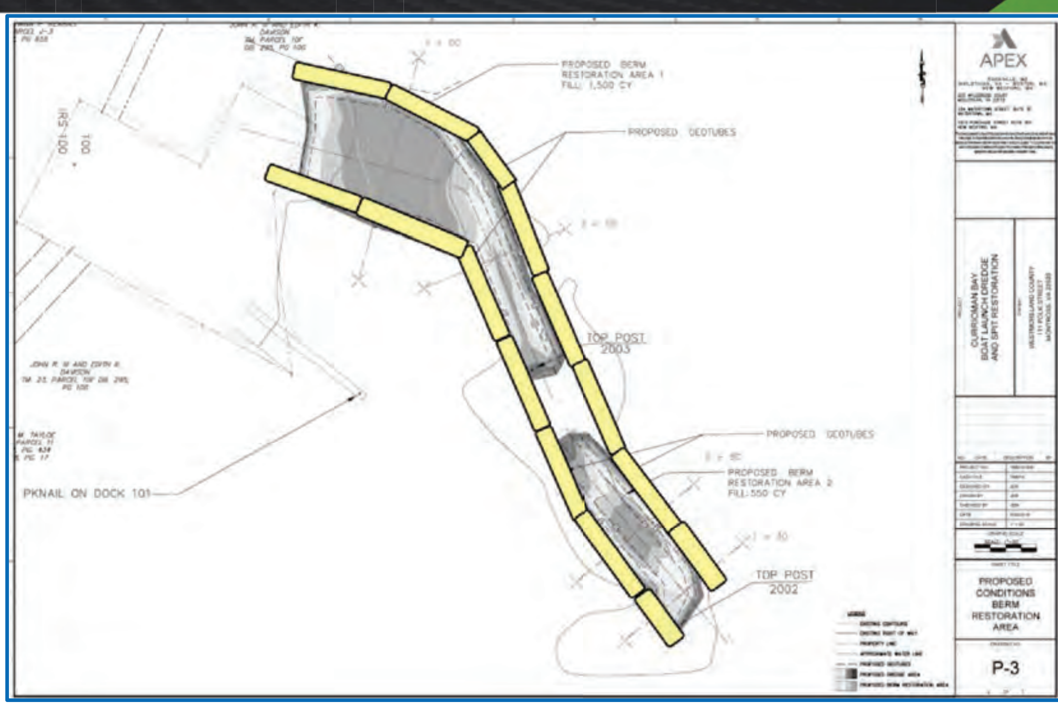

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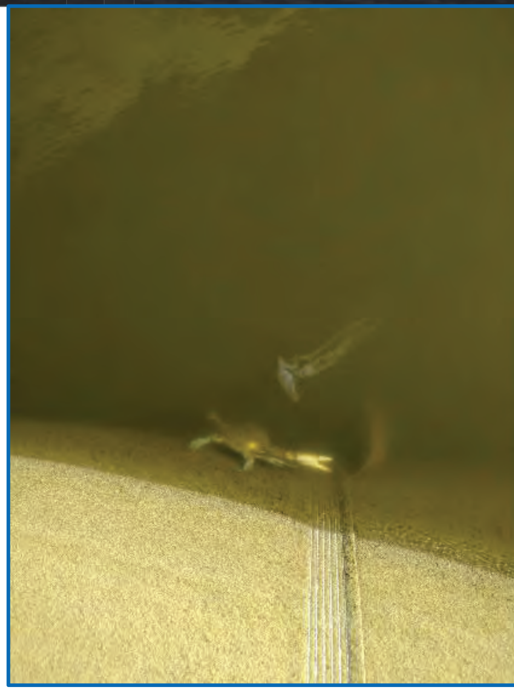

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Geotube® – Case Histories – Potomac River, Virginia

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Geotube® – Case Histories – Potomac River, Virginia

Geotube® – Case Histories – Potomac River, Virginia

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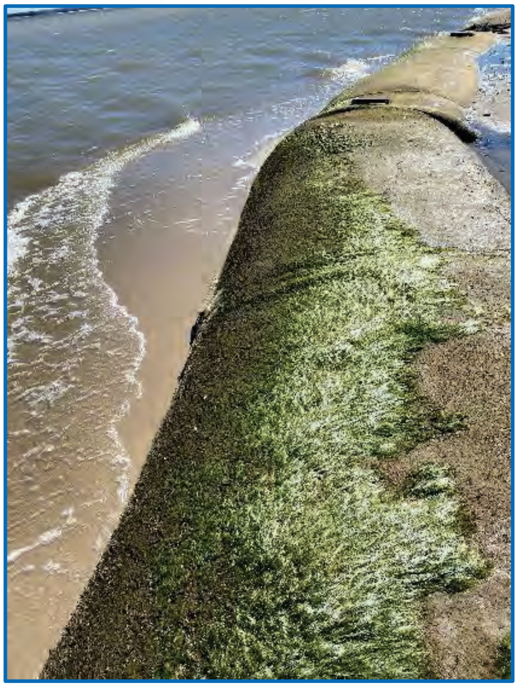
Geotube® – Case Histories – Potomac River, Virginia



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Geotube® – Case Histories – Potomac River, Virginia

THANK YOU!

ANY QUESTIONS? ☺

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Solmax, Engineering Business Manager
Dewatering and Marine Group
February 05, 2023

ATA | GEOSYNTHETICS CONFERENCE

Kansas City, February 2023