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Geotextile Sand Containers in Coastal Protection

-with Particular Focus on Hydraulic Stability

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Lecture I

Introduction, Basic Information, Engineering Properties and Durability Issues

1. Introduction to the Short Course

- Provide some basic information on geotextile and its increasing use as a construction material in civil engineering, incl. hydraulic permeability of GSC structures.
- Stress the problems associated with the durability and life time prediction of geotextile structures.
- Illustrate the versatility of the use of geotextile sand containers (GSCs) for shore protection as a soft alternative to hard structures made of rock and concrete.

- Provide overview of possible failure modes of GSCs.
- Propose simple HUDSON-type formulae for hydraulic stability.
- Underline the need to understand the processes associated with failure modes, particularly with the hydraulic stability.
- Provide more process-based stability formulae.

2. Basic Information, Engineering Properties and Durability Issues

2.1 General Information and properties of Geotextiles

Geosynthetics: Classification Based on Permeability to Water

Geosynthetics

- **Permeable to Water**
  - **Geotextiles** ≈70%
  - **Geotextile related products such as Geogrids, Geonets, etc.** ≈10%
- **Impermeable to Water**
  - **Geo-membranes** ≈13%
  - **Geomembrane related products such as Geosynthetic Clay Liners (GCL), etc.** ≈5%

Geocomposites ≈4%

Shukla, S.K.; Yin, J. H. (2006): Fundamentls of Geosynthetic Engineering. Taylor and Francis, London, 410 p. (Excellent Textbook)

Primary Function of Each Type of Geosynthetics

Types of Geosynthetics	Primary Function				
	Separation	Reinforcement	Filtration	Drainage	Containment
Geotextile (GT)	X	X	X	X	
Geogrid (GG)	X				
Geonet (GN)				X	
Geomembrane (GM)					X
Geosynt. Clay Liner (GCL)					X
Geocomposite (GC)	X	X	X	X	X

Geotextiles (Permeable to Water)

Non -Woven

directionally or randomly oriented fibres bonded into a loose web

Knitted

interloping one or more yarns together with a knitting machine (very extensible)

Stitched

interlocking/ bonding of fibres, yarns or both by stitching or sewing

Woven

interlacing two or more sets of yarns (one or several fibres) using conventional weaving process with weaving loom

Non-Woven: ≈60%

Knitted and Stitched: negligibly small

Woven: ≈40%

Non-Woven:
- Needle punching
- Chemical bonding
- Heat bonding

Woven:
- Monofilament yarns
- Slit film yarns
- Fibrillated yarns
- Multifilament yarns

Most Commonly Used Polymers in Manufacturing Geosynthetics

Type of Polymer		Developed
■ Poly Vinyl Chloride	(PVC)	1927
■ High Density Polyethylene	(HDPE)	1940
■ Polyester	(PET)	1950
■ Expanded Polystyrene	(EPS)	1950
■ Low Density Polyethylene	(CDPE)	1956
■ Polypropylene	(PP)	1957
■ Thermo set Polymers such as Ethylene Propylene Diene Terpolymer	(EPDM)	1960
■ Chlorosulphonated Polyethylene	(CSPE)	1965

Remark: Most used Polymer for Geotextile:
- Polypropylene (> 90%)
- Polyester (≈ 5%)
- Polyethylene (≈ 2%)

Properties of Geotextiles (Extracted from information compiled by Lawson and Kempton, 1995) (*)

Types of Geosynthetics	Tensile strength (kN/m)	Extension at max. load (%)	Apparent opening size (mm)	Water flow Rate (volume Permeabiltiy) (litres/m²/s)	Mass per unit area (g/m²)
Nonwovens					
Heat-bonded	**3-25**	**20-60**	**0.02-0.35**	**10-200**	**60-350**
Needle-punched	**7-90**	**30-80**	**0.03-0.20**	**30-300**	**100-3000**
Resin-bonded	**5-30**	**25-50**	**0.01-0.25**	**20-100**	**130-800**
Wovens					
Monofilament	**20-80**	**20-35**	**0.07-4.0**	**80-2000**	**150-300**
Multifilament	**40-1200**	**10-30**	**0.05-0.90**	**20-80**	**250-1500**
Flat tape	**8-90**	**15-25**	**0.10-0.30**	**5-25**	**90-250**
Knitted					
Weft	**2-5**	**300-600**	**0.20-2.0**	**60-2000**	**150-300**
Warp	**20-800**	**12-30**	**0.40-1.5**	**80-300**	**250-1000**
Stitch-bonded	**30-1000**	**10-30**	**0.07-0.50**	**50-100**	**250-1000**

(*) Lawson, C.R.; Kempton, G.T. (1995): Geosynthetics and their use in rainforest soils. Terram Ltd., UIC

- **UV-Resistance:**

  Although material used for GSCs has highest possible UV-resistance, an acceptable strength loss over life time can be achieved only through additional protection (coating, armour).

- **Abrasion Resistance:**

  Although material used for GSCs has highest possible abrasion resistance, additional protection (coating, armour) should be used to ensure satisfactory performance over life time (German rotating drum tests).

- **Puncture Resistance:**

  To enhance damage resistance against driftwood, drift ice, vandalisms or dropped rock material during construction of possible armour appropriate material should be used e.g. against vandalisms: Geotextile trapping sand (≥3kg/m²).

- **Retention of Finer Fraction:**

  To ensure that GSCs do not deflate and remain stable during wave action → BAW turbulence tests in Germany

Requirements for Geotextile used in GSC for Coastal Structures (2)

- **Hydraulic Permeability:**

  When subject to cyclic wetting and drying (tidal regime), water should be drained from the GSC fast enough to ensure stability → Geotextile designed as filter or adopt minimum permeability of 10 times higher than sand fill.

- **Friction Between GSCs:**

  Largest friction angle is desirable to enhance hydraulic stability of GSC against wave forces. → Large shear box (>300 x 300mm) to reduce edge effects.

- **Elongation Resistance:**

  High elongation is required to achieve a certain degree of self healing effect (flexibility of structure) reduce installation damage → elongation >50%.

- **Textbooks** (Basic information and Fundamentals)

  1. Koerner, R.M. (2005): Designing with Geosynthetics. 5th Ed. Pearson Prentice Hall. Ltd. London, 796 p. ISBN 0-13-143415-3
  2. Shukla, S.K. and Yin, J.H. (2006) : Fundamentals of Geosynthetics Engineering. ISBN: 0727731173

- **Handbooks** (Application in Civil, Hydraulic and Coastal Engineering)

  1. Van Santvoort, G. Editor (1994): Geotextiles and Geomembrandes in Civil Engineering, Balkema Rotterdam, 608 p.
  2. Pilarczyk, K. (2000): Geosynthetics and Geosystems in Hydraulic and Coastal Engineering, Bakema Rotterdam, 913 p. ISBN: 9058093026

- **Regulations and Standards**

  1. Intern. Standard Organization (ISO)
  2. American Society for Testing and Materials (ASTM)
  3. British Standards (BS)

Journals

1. Geotextiles and Geomembranes (since 1984): www.elsevier.com
2. Geosynthetics International (since 1995): www.thomastelford.com

Conferences

1. Intern. Conference on Geosynthetics (ICG) since 1977
   (Organisor: Intern. Geosynthetic Society (IGS): www.geosyntehticssociety.org
   8th ICG in XYokohama/Japan 2006, 4 Vol.
2. European Geosynthetics Conference (EUROGEO)
   Next EUROGEO in Edingburgh (UK) Sept. 7-12, 2008 will focus on Civil Engineering Applications, including coastal engineering and durability issues.

Websites

- International Geosynthetics Society (IGS): www.geosyntheticssociety.org.
- Geosynthetics. net

- 1920's: Polymer industries essentially started in Germany (PVC in 1927)
- 1950's:
  - First use of woven geotextile in 1957 as „sand filters" (PP) and „sand bags" in The Netherlands to close the small inlet of „Pluimpot" (Van Santvoort, 1994)
  - First use of woven geotextiles as „plastic filter" for Seawall in Florida (Barret, 1966)
- 1970's:
  - First use of non-woven geotextile (PET) as a filter in Valcros Dam, France (GIROUD,1992)
  - First Intern. Conf. on Geotextiles in Paris (1977)
- 1980's:
  - Term „Geosynthetics" introduced (ca. 1980)
  - Intern. Geosynthetics Society (IGS) established (1982)
  - Journal „Geotextiles and Geomembranes" started 1984
  - First Conference on Polymer Grid Reinforcement (Geogrid/Geonet) in London (1984)
  - First Intern. Conf. on Geomembranes in Denver (1984)
- 1990's:
  - Publication of Standards on Geosynthetics by ASTM, ISO, BS, etc.
  - Journal „Geosynthetics International" started 1995

Worldwide Consumption of Geosynthetics in 2003

Type of Geosynthetics	Quality 10^6 m²	%	Costs 10^6 USD	%
Geotextiles	**1000**	**68**	900	26.9
Geogrids/Geonets	150	10	350	10.4
Geomembranes	200	13.6	**1600**	47.7
Geosyntehitc Clay Liners	75	5	300	9
Geocomposites	50	3.4	200	6
Total	1475	100	3350	100

(Adapted from Koerner, 2005)

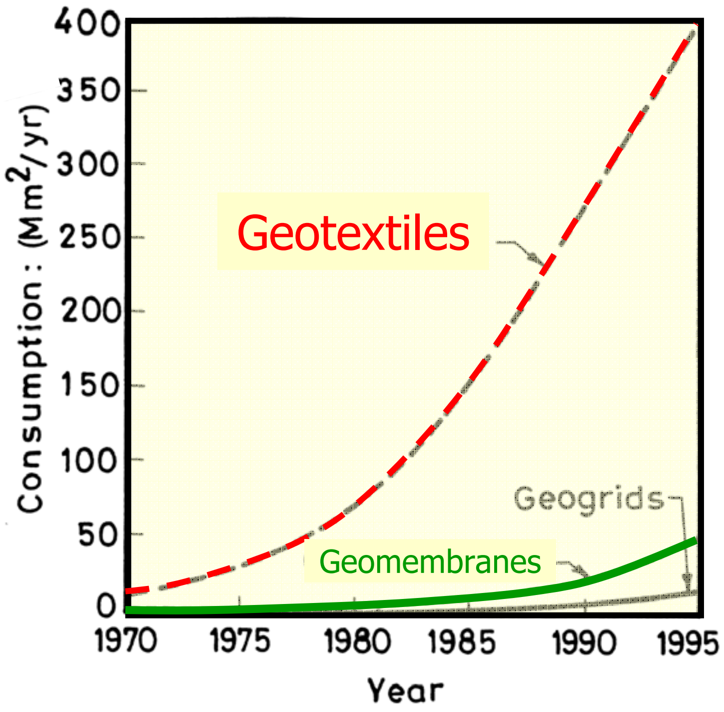
Geosynthetics Consumption in Europe (2005)

Type of Geosynthetics	10^6 m²	%
Geotextiles*	**> 255**	**69**
Geogrids/Geonets	35	9.5
Geomembranes	45	12
Geosyntehitc Clay Liners	20	5.5
Geocomposites	15	4
Total	370	100

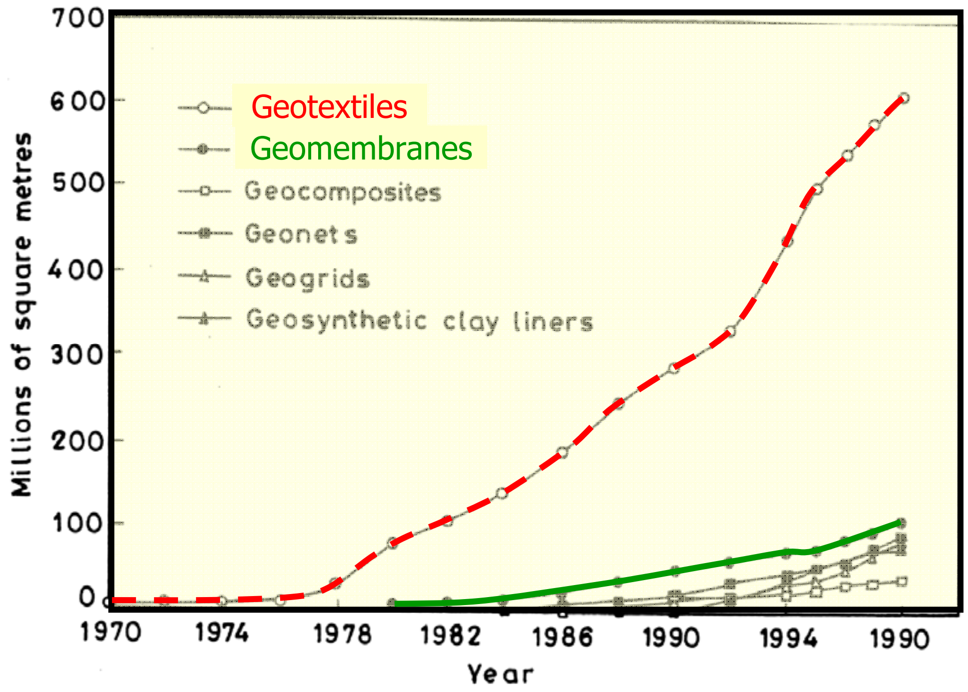
*Non-woven 180 m² and woven 75 Mio m²

(Adapted from Heerten, 2006)

Geosynthetics Consumption Growth



(a) Western Europe
(Lawson and Kempton, 1995)



(b) North America (Koerner, 2000)

2.2 Some Remarks on Durability and Life Time Prediction of Geotextile Structures

Most Frequently Asked Question:

„How long will a geotextile structure last?"

More Practical Engineering Question:

„How long must a geotextile structure last?"

↓

Degradation & Life Time Prediction

↓

Shore Protection Structures (exposed):
Typical expected lifetime: 50-100 years or more

↓

How to predict 100 years lifetime for geotextile structures applied for shore protection?

Available Knowledge

Degradation Mechanisms (e.g. CR ISO 134 34; Brown and Greenwood, 2001)

- Due to **Mechanical Load** (e.g. creep & env. stress cracking)
- Due to other env. effects (e.g. UV-radiation, PH, chemical, bio-logical, thermal)

Procedures to Reduce Degradation:

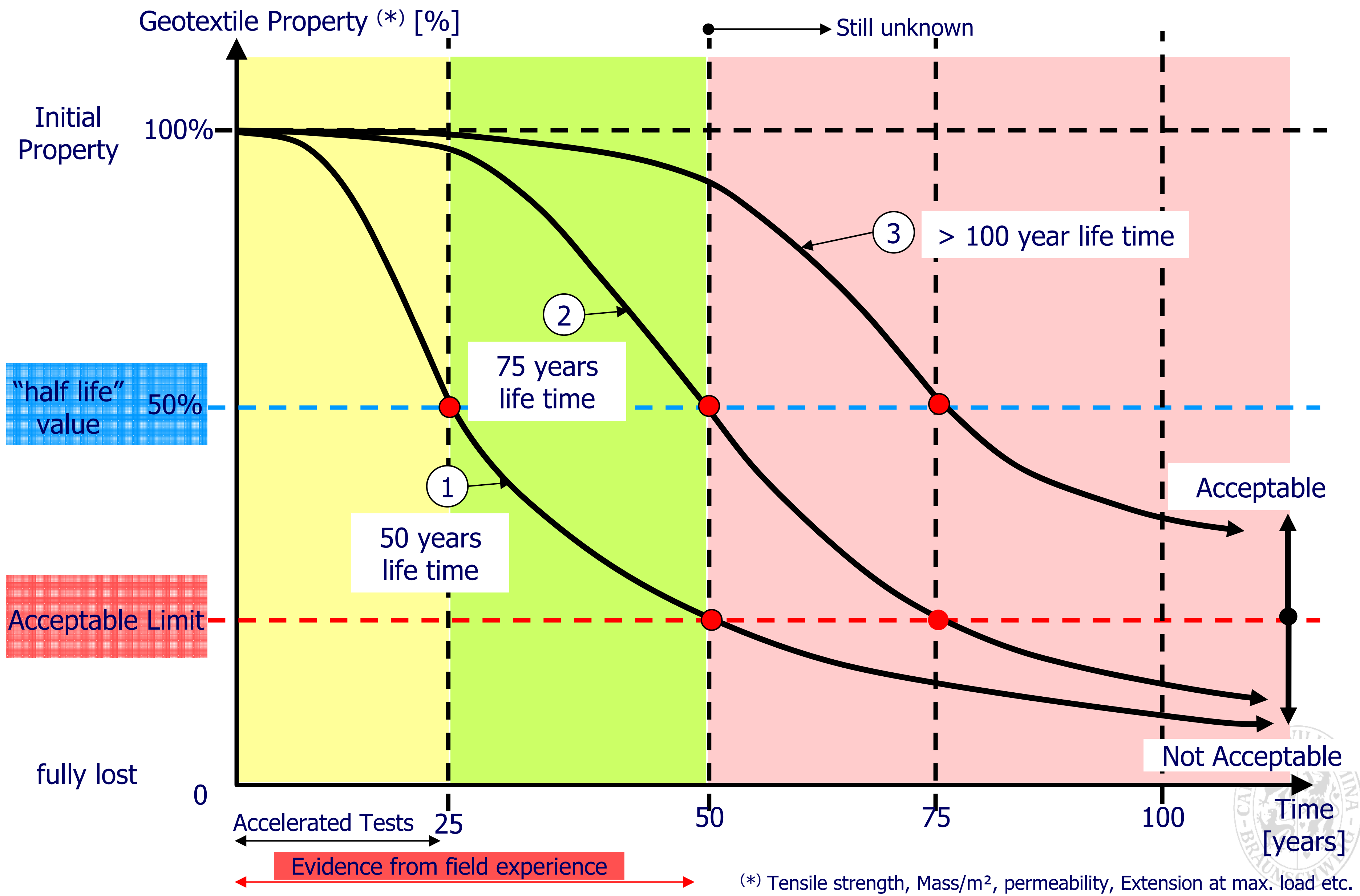
- **Modify Structure of Geotextile**
- **Include Additives to Geotextile!!** (e.g. black carbon against UV)

„Index" Testing established to ensure minimum durability up to 25 years:
(see Annex B in EN 13249 – 13257 and EN 13265)

see also EN 20432 for reduction factors

Basis for Planning and Interpreting Site Monitoring
(ISO 13437)

Degradation: Functional Property Reduction with Time (Principle Sketch)



(*) Tensile strength, Mass/m², permeability, Extension at max. load etc.

Difficulties and Unsolved Problems

Field Evidence (Site Monitoring)	Accelerated Testing (Laboratory)
■ Limited service time (≤ 50 years) ■ Earlier (weaker) version of geotextile ■ Design/installation conditions unknown/incomplete information ■ Env. effects and degradation rate not followed over time ■ Separation of diverse degra-dation cause impossible (Failure at joint, installation damage, etc.)	■ Only for life time < 25 years ■ Range of applications of all types of tests limited (not applicable to all degradation mechanisms) ■ Assume that dominant degradation mechanisms(s) should be known a prori. ■ Combination/interaction of different degradations causes not yet considered
↓	↓
Results difficult/impossible to transfer to other sites, to present geotextile versions and to other time durations	Extrapolation not physically based and thus questionable

<u>Consistent</u> methodology to combine both approaches still missing!!!

Accelerated Testing

Increasing Frequency

- Only for intermittent cause of degradation for instance:
  - + UV radiation increased to 24h/day instead of 12h/day
  - + Frequency of storm events (cyclic loading)
- Not applicable for continuous env. actions

Increasing Severity

- Identification of dominant degradation mechanism (eg. Hydrolysis, creep, oxidation).
- increase intensity of cause (e.g. PH, mech. load, oxygene pressure)
- Determine rate of degradation as a function of intensity of cause (and time)
- Not always possible to increase intensity without causing other effects

Increasing Temperature

- Widely used to accelerate both chemical &physical processes
- Use of ARRHENIUS' formula for extrapolation:

$$A=A_0 \exp(-E/RT)$$

- Example: Acceleration of creep-rupture tests by temperature using ZHURKOV's formula:

$$A=A_0 \exp[(-E-\sigma V)/RT]$$

Extrapolation

- Precautionary factors sometimes introduced (e.g. BS. 8006-2001, Appendix A)
- Power laws generally used for extrapolation (yet not physically based!!!)

A= degradation rate, A_0= const.
E= activation energy of process [J/mol]
R= universal gas constant (R=8.316 J/mol·K)
T= Temperature in K (°C+273)
σ= applied stress
V= const.

Recommendations for Future Site Monitoring

- **Define system to be monitored:**
  - Material structure, compositions and properties
  - Environmental actions (mechanical loads, PH and saturation of soil, chemical contamination, biological effects, temperature and light)
  - Design and installation conditions
  - Functions (primary and secondary)
  - End of life criterion
  - Necessary maintenance and other measures.
- **Separate considerations of:**
  - Failure at joints from those of bulk material
  - Mechanical installation failure from those due to long-term degradation
  - Weathering failures from those due to chemical degradation
- **Install geotextile samples for future extractions and testing (ISO 13437):**
  - Sizes and placement of samples
  - Method of extraction
  - Close monitoring of environmental effects
  - etc.
- **Extrapolation to other sites, duration , etc.:**
  - only based on good understanding of degradation mechanisms.

Remarks and Statements

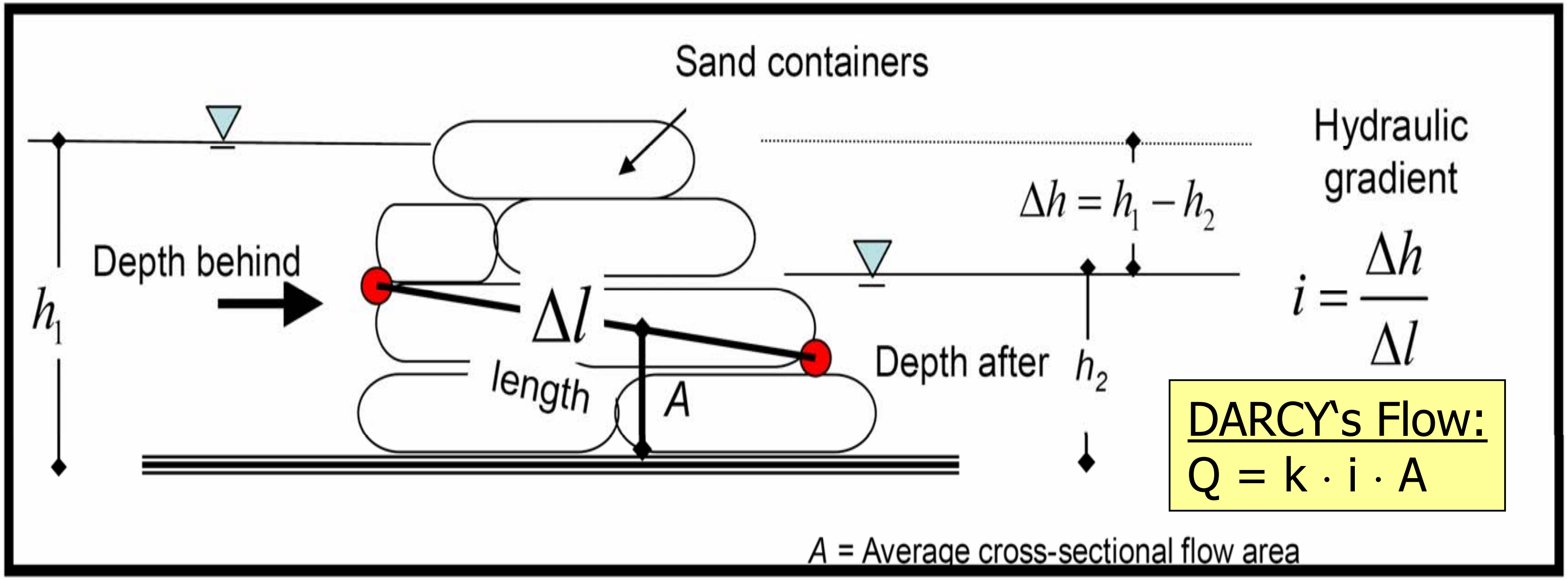
- **Geotextile applications, although with previous weaker versions, performed relatively well over many decades and most failure observed are rather caused by:**
  - faulty design
  - incorrect choice of material
  - poor quality or incorrect installation
- **Knowledge available does not allow to predict life times ≥ 100 years (even not more than 50 years)**
- **Rational prediction cannot foresee problems for which there is no evidence or scientific basis**

↓

Improve the understanding of degradation mechanisms associated with construction sites, including laboratory testing, and apply engineering judgement rather than extrapolations to assess durability and life time

2.3 Hydraulic Permeability of Structures made of Geotextile Sand Containers

Important Simplifying Assumption for the Flow through GSC- Structure



DARCY's Flow:

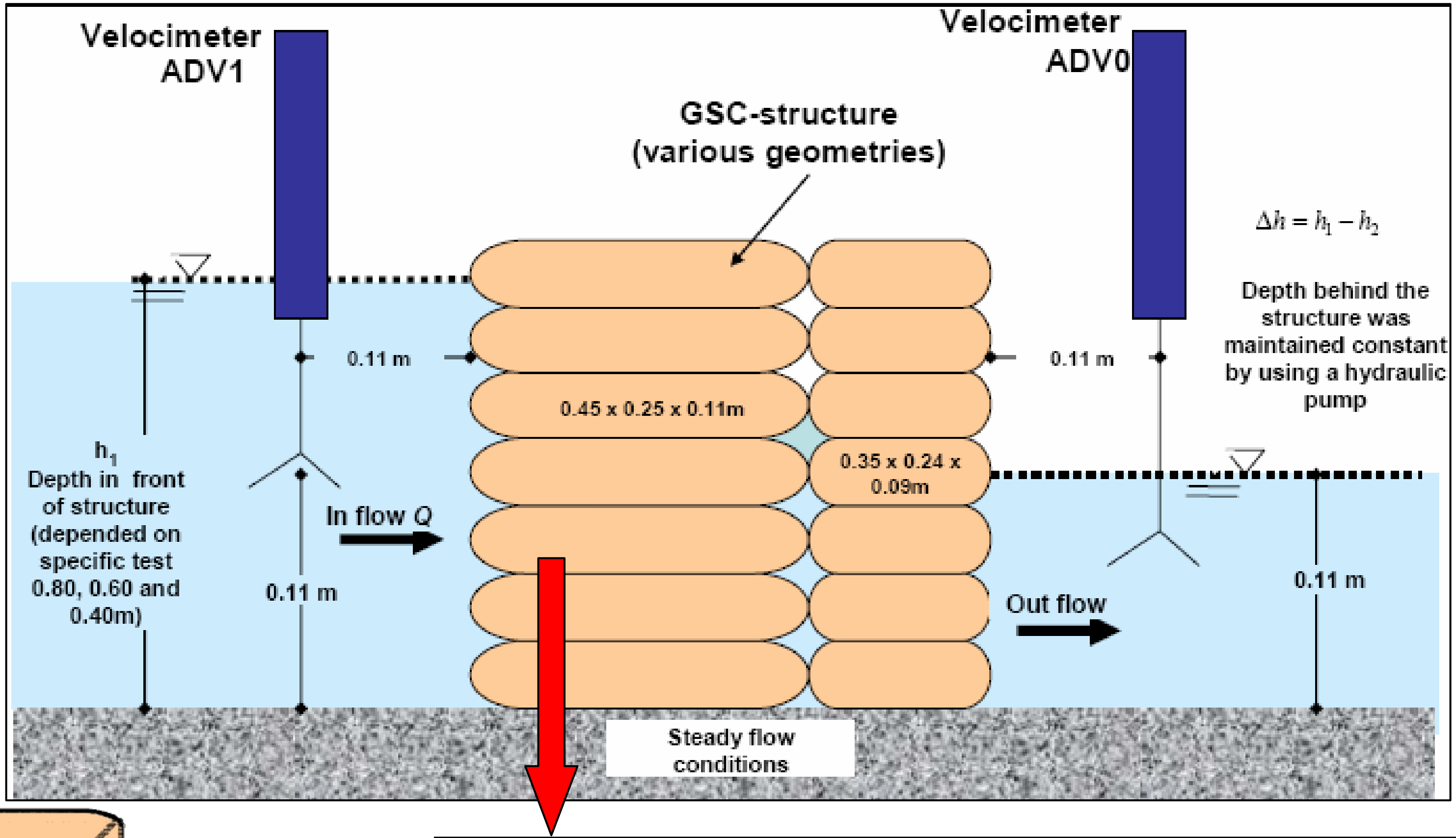
$Q = k \cdot i \cdot A$

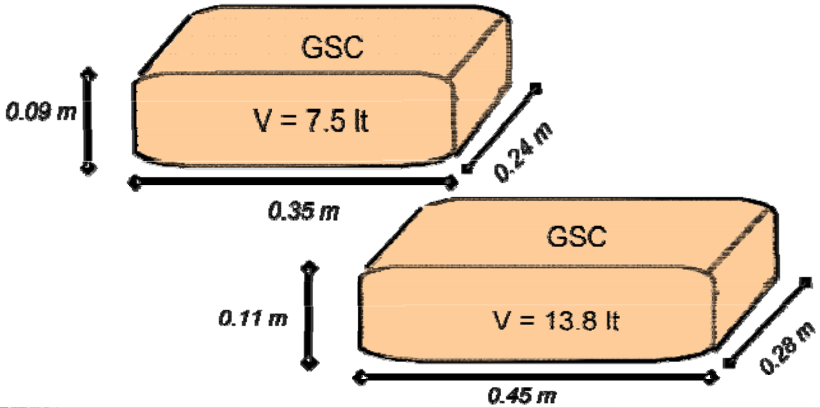
FORSCHHEIMER's Flow:

$$i = au + bu^2 + s\frac{\delta u}{\delta t}$$

The flow through a GSC-structure is not homogeneous. Turbulent flow is expected to occur in the gaps between containers, but the Rest of the flow is expected to be laminar. Despite the inhomogeneity of the flow and its unsteadiness, the hydraulic permeability of GSC- structure can be approximately be described by the DARCY permeability coefficient k [m/s].

Permeability Tests at LWI - Experimental Set-up

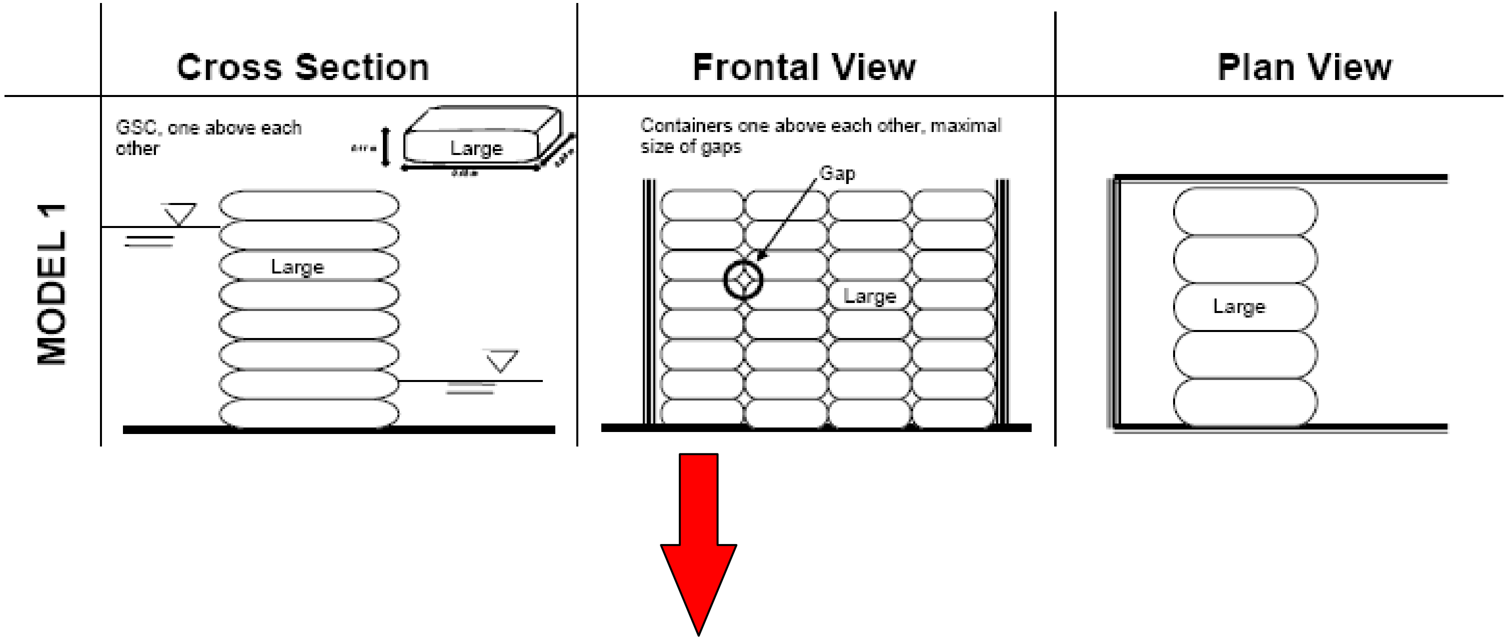




Geotextile Containers

- Two sizes: Large (13.8 lt) & Medium (7.5 lt),
- Needle-punched non-woven ($k_v = 3\times10^{-3}$ m/s),
- Fill ratio: 80%,
- Fill sand: $d_{50} = 0.2$ mm ($k = 5\times10^{-4}$ m/s),

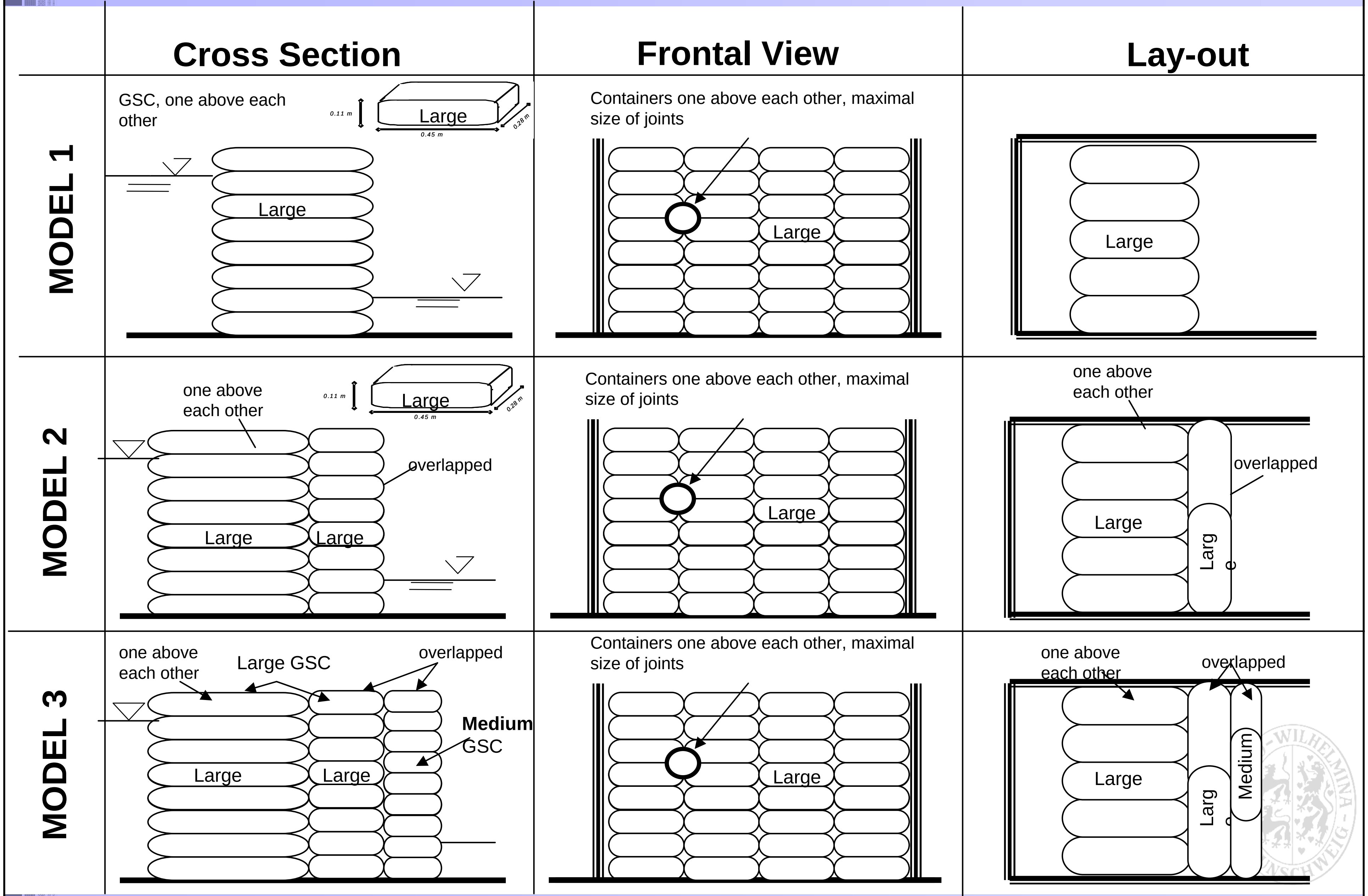
Model Alternatives Tested



Investigation of 11 alternatives, which differ by

- structure layers: single / multiple
- placement: accurate / overlapped
- arrangement: longitudinal / transversal
- medium / large sizes of containers

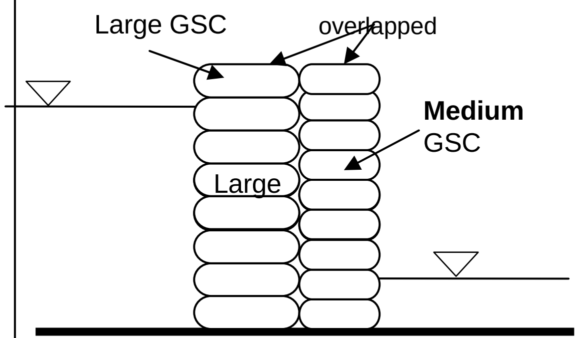
Model Alternatives Tested (2)



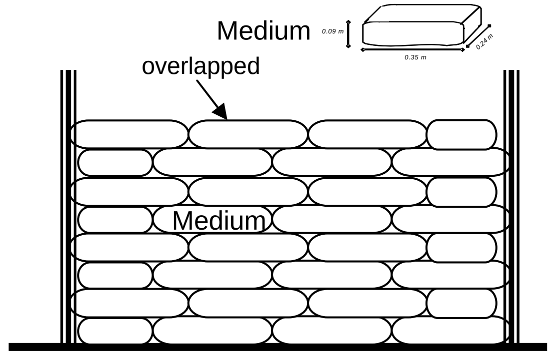
Model Alternatives Tested (3)

MODEL 4

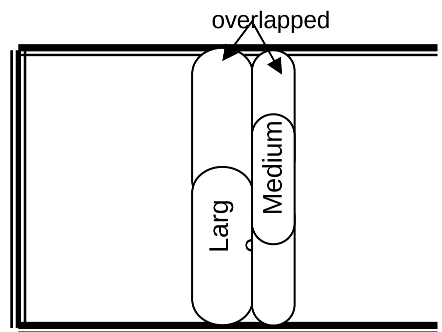
Cross Section



Frontal View

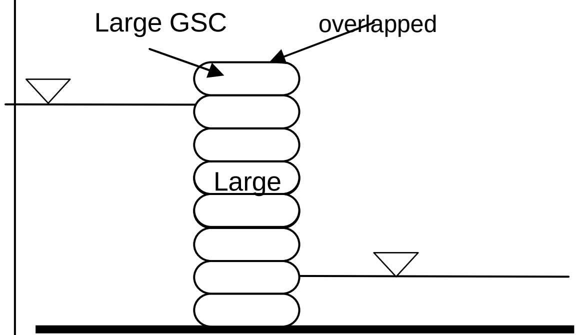


Lay-out

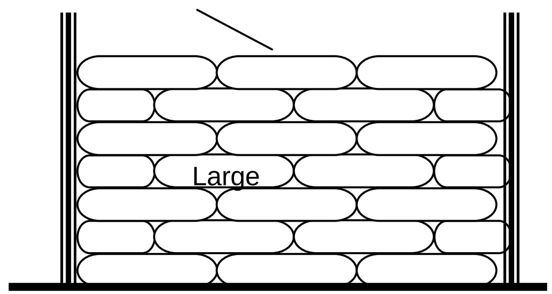


MODEL 5

Cross Section



Frontal View



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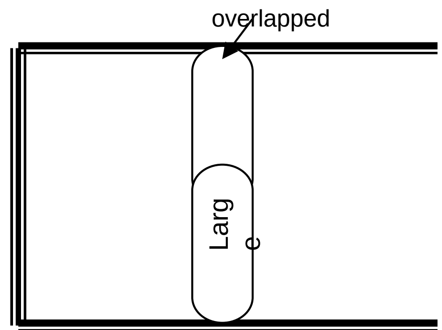
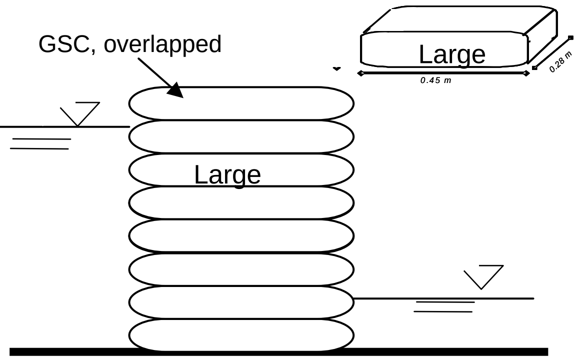
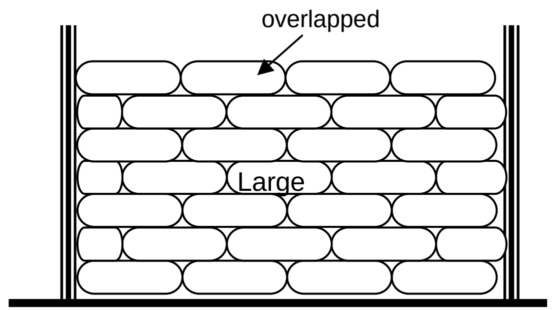


MODEL 6

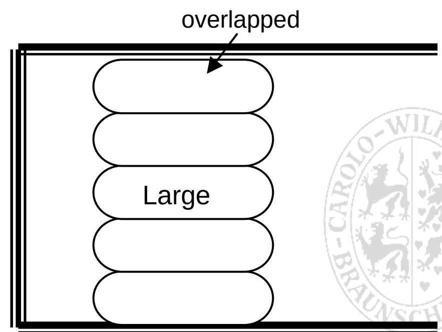
Cross Section



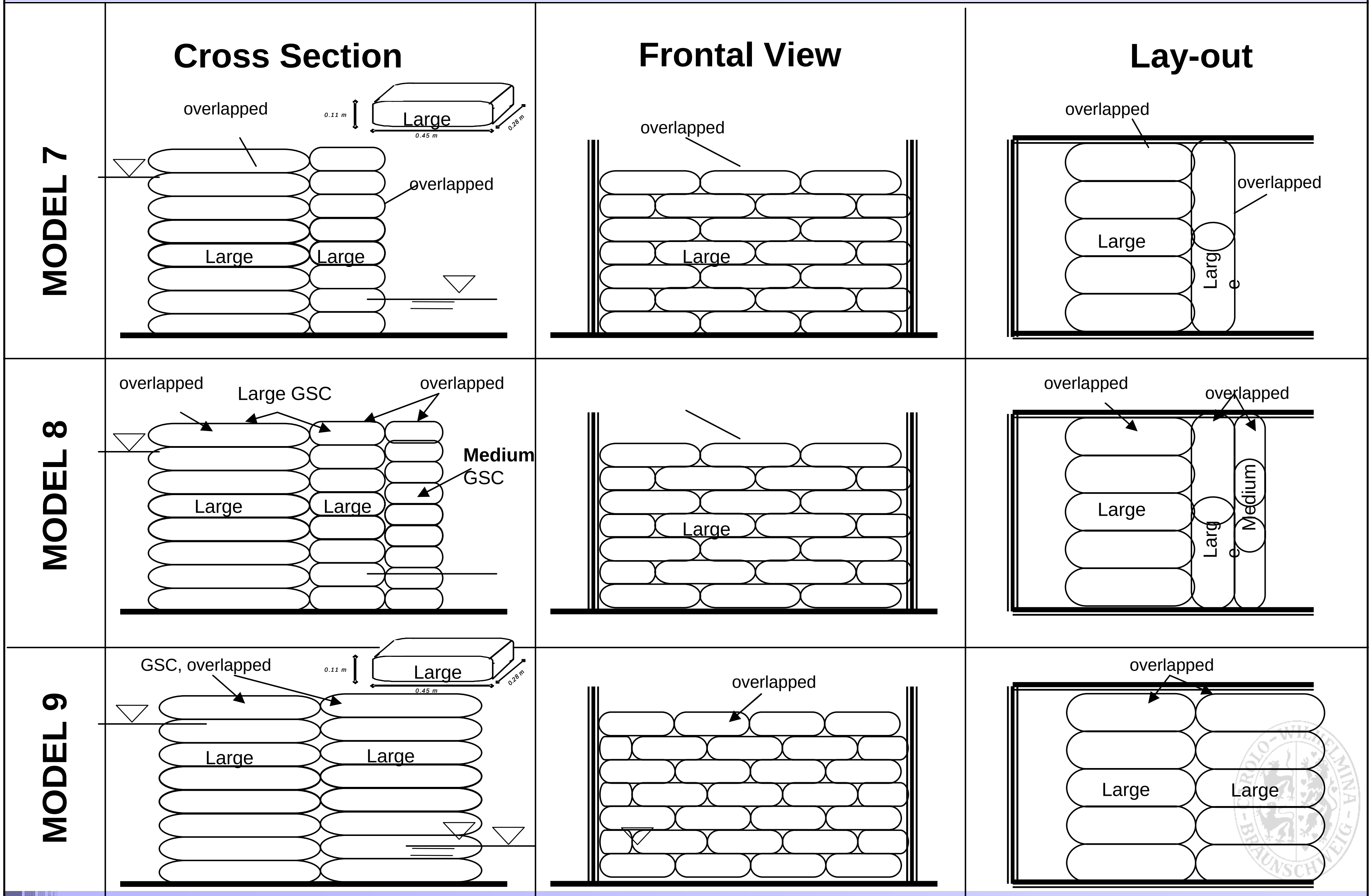
Frontal View



Lay-out



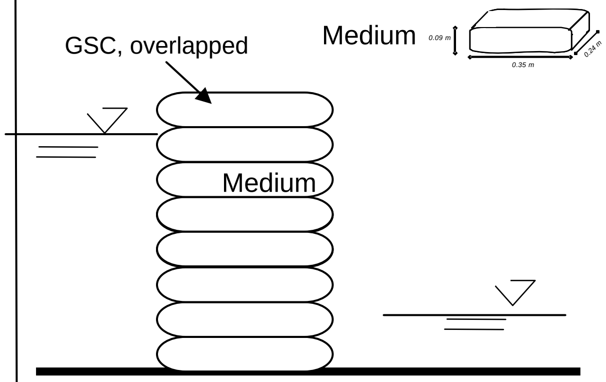
Model Alternatives Tested (4)

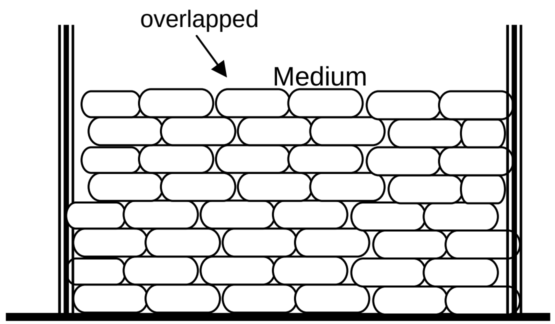


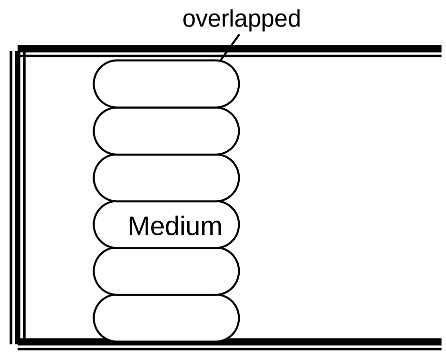
Model Alternatives Tested (5)

Cross Section | Frontal View | Lay-out

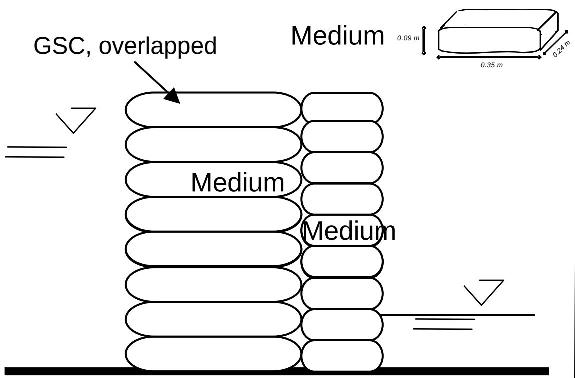
MODEL 10

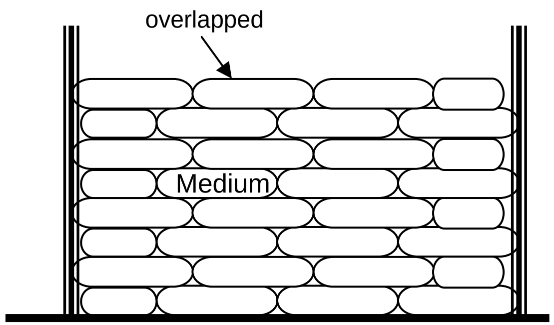


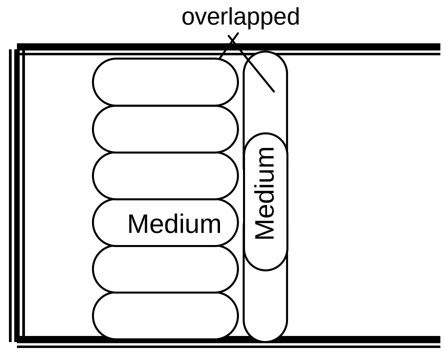




MODEL 11



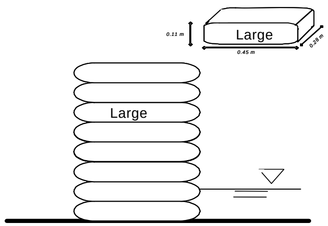




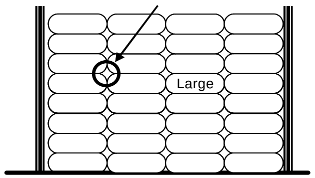
Effect of Gap Sizes on Permeability

MODEL 1: Containers One Above Each Other

Cross Section

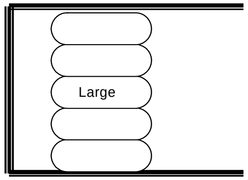


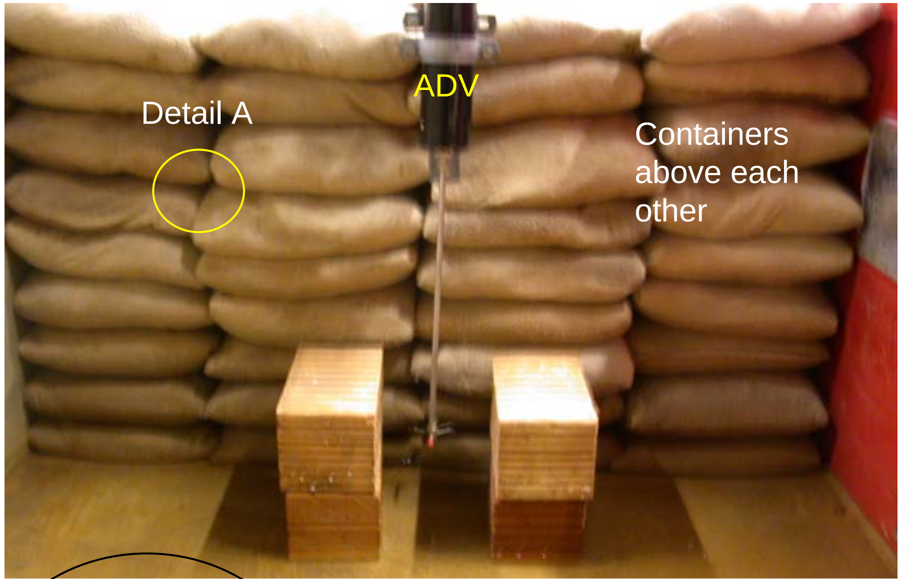
Frontal View

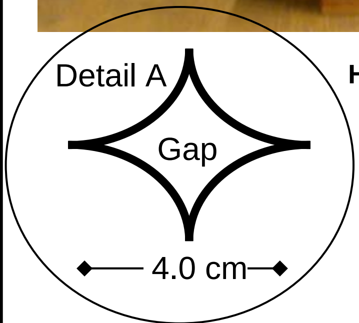


Lay-out

Plan View





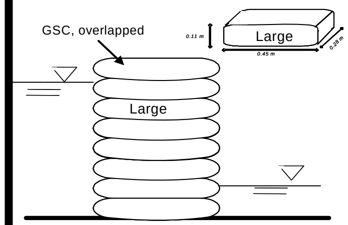


Higher size of joint induces higher permeability

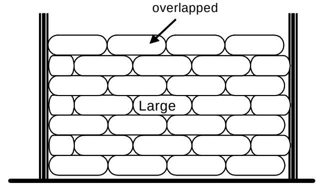
Permeability Coefficient of the structure = $5x10^{-2} \cdot m/s$

MODEL 6: Containers Overlapped

Cross Section

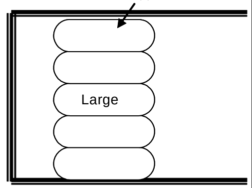


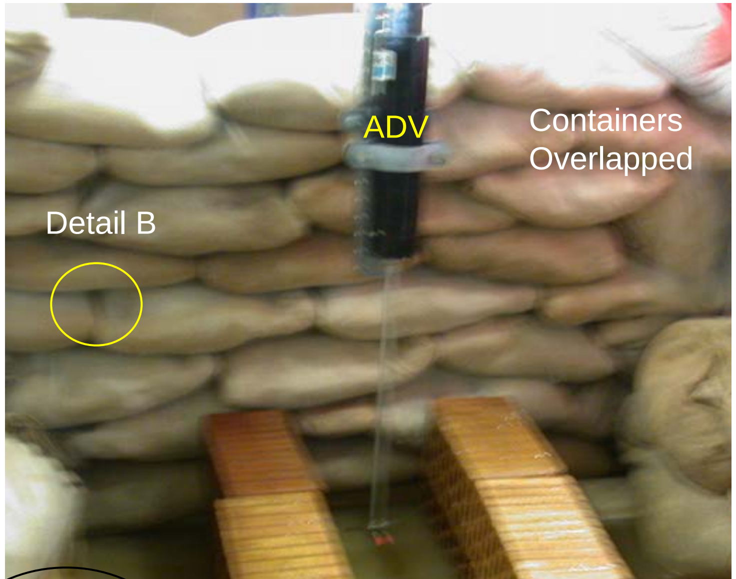
Frontal View

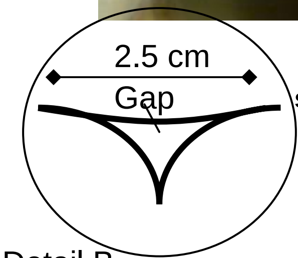


Lay-out

Plan View







Detail B

More joints but smaller, thus, less permeability

Permeability Coefficient of the structure = $2x10^{-2} \cdot m/s$

CONCLUSION:
The size of the gaps governs the permeability of the GSC-structure

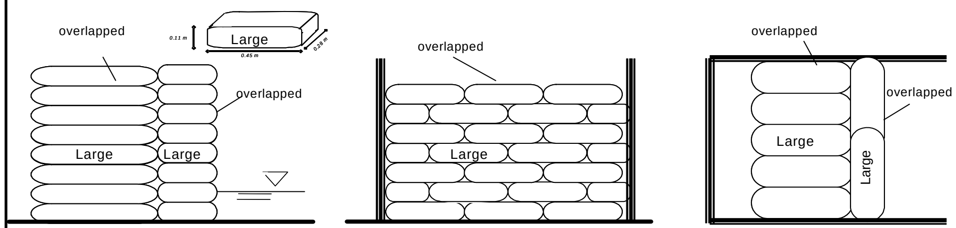
Effect of the Coantainer Size on Permeability

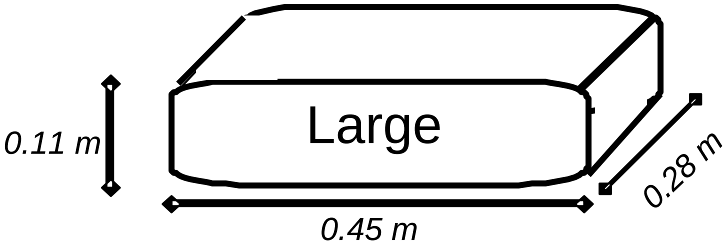
MODEL 7: Two layers (Containers Overlapped)

MODEL 11: Two layers (Containers Overlapped)

Only difference between Models 7 and 11 is the size of the Containers

Cross Section | **Frontal View** | **Lay-out**

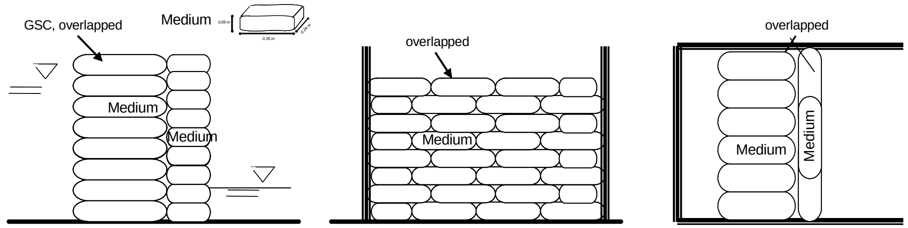


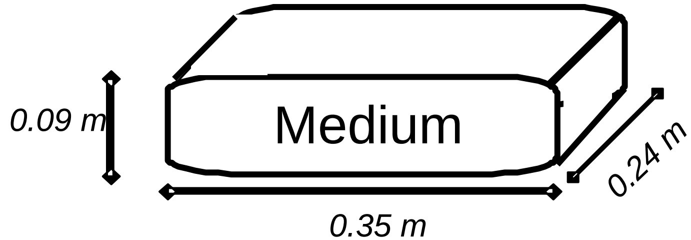


Permeability Coefficient of the structure =

$$9x10^{-3} \cdot m / s$$

Cross Section | **Frontal View** | **Lay-out**





Permeability Coefficient of the structure =

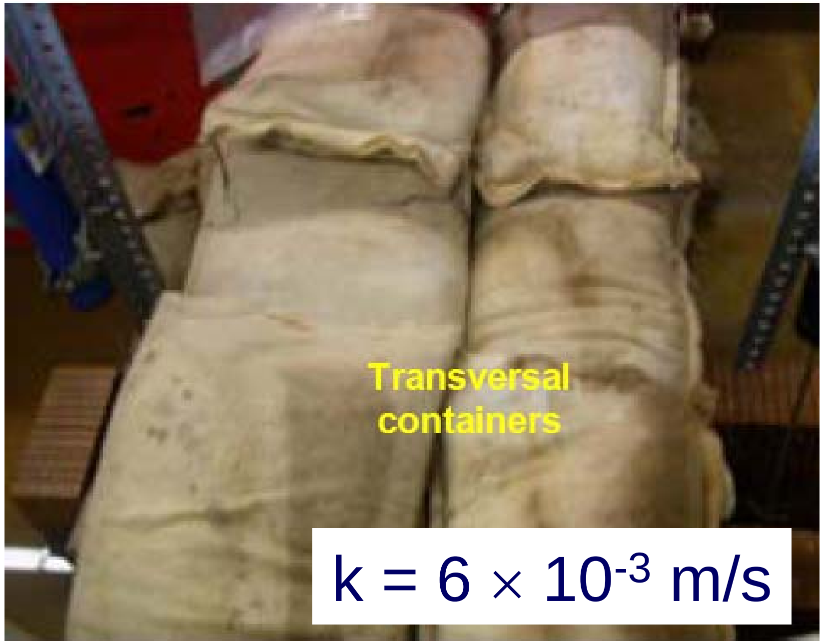
$$7x10^{-3} \cdot m / s$$

CONCLUSION:
The smaller the container, the smaller the permeability of the structure

Effect of GSC-Arrangement on Permeability

Model 9: two longitudinal layers

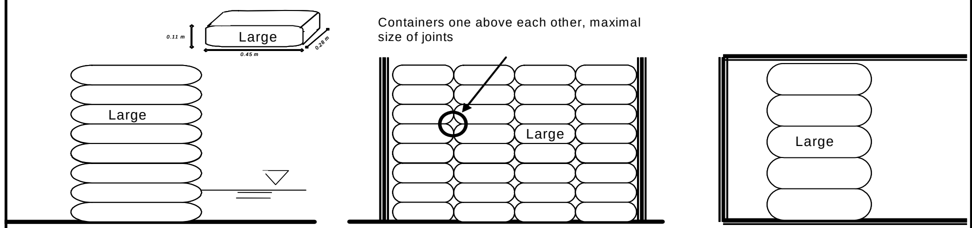
Model 4: two transversal layers

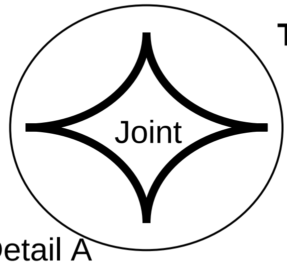


Longitudinally placed containers have higher permeability coefficients then transversally placed containers (less number of gaps)

MODEL 1: Containers One Above Each Other

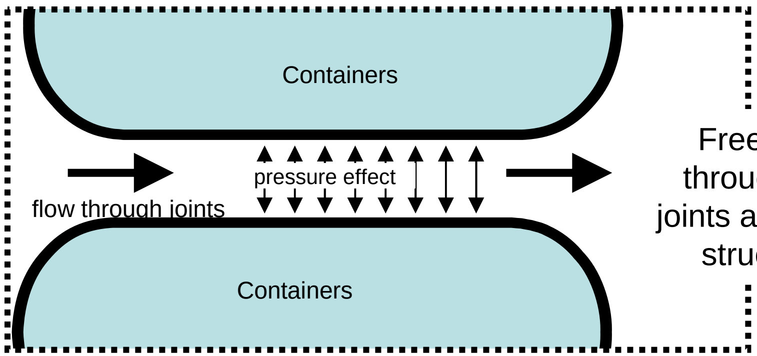
Cross Section | **Frontal View** | **Lay-out**





Through the joint the water flows freely

Permeability Coefficient of the structure =
$$5x10^{-2}\,m/s$$



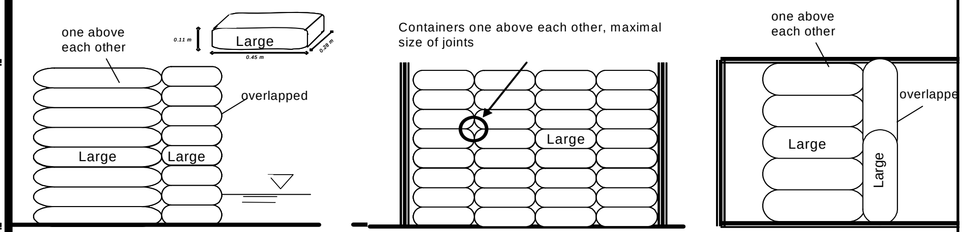
Free flow through the joints along the structure

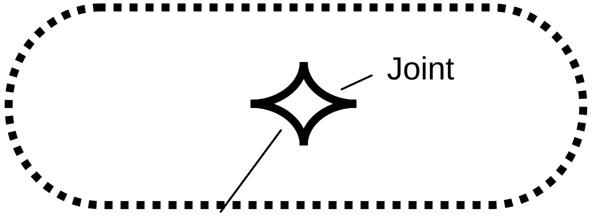
Lay Out

Not to Scale

MODEL 2: One layer of Containers One Above Each Other and a second layer that blocks the first joints

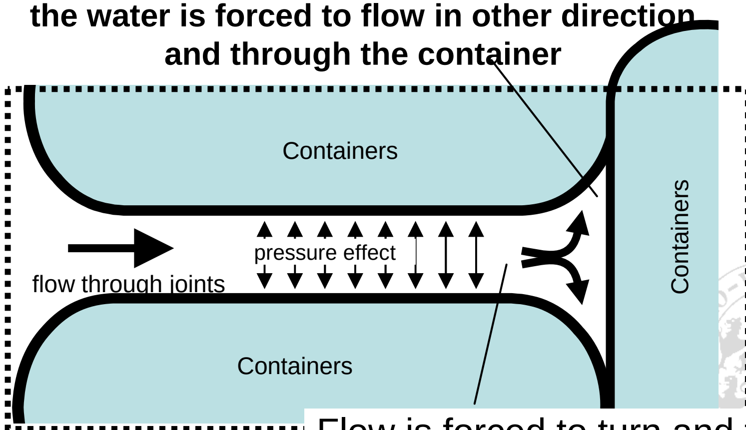
Cross Section | **Frontal View** | **Lay-out**





Permeability Coefficient of the structure =
$$2x10^{-2}\,m/s$$

The joint is blocked by another container and the water is forced to flow in other direction and through the container



Flow is forced to turn and to flow through the container

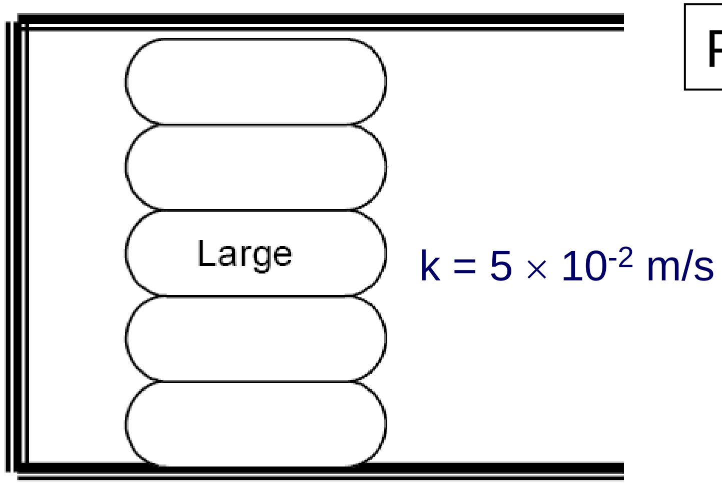
Lay Out

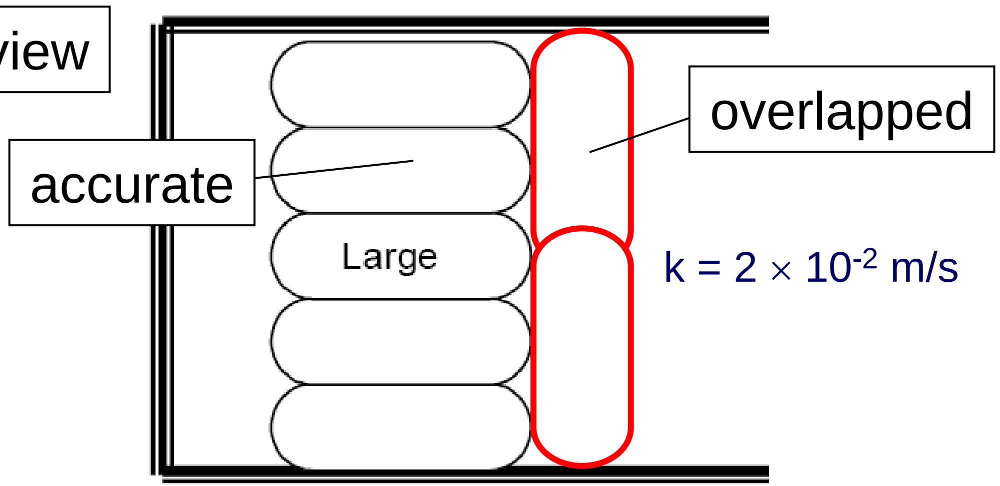
Effect of Blocking the Gap Flow by Additional GSC-Layer (2)

Model 1: accurately placed

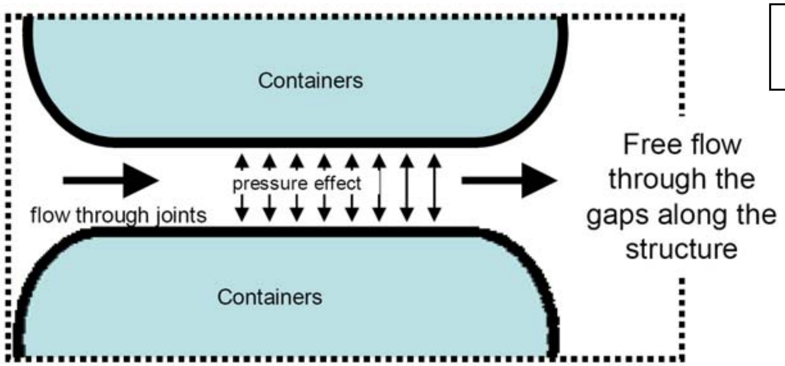
Model 2: two layers, one blocks

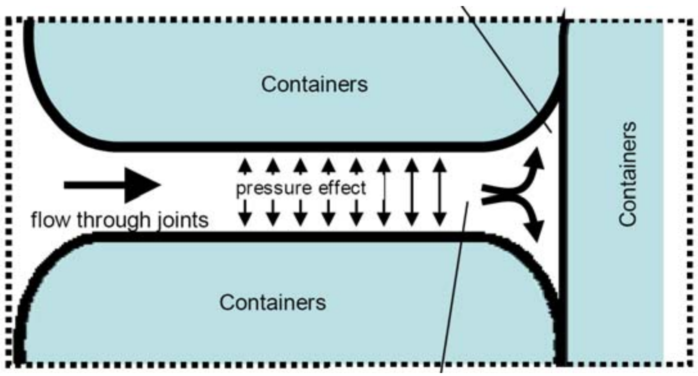
Plan view





Detail



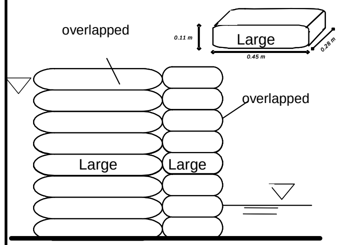


Blocking the gaps by additional containers considerably reduces the overall permeability of the structure

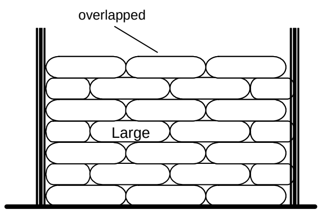
Effect of Additional GSC- Layers (in Plan View)

MODEL 7: One longitudinal layer and one transversal layer of containers

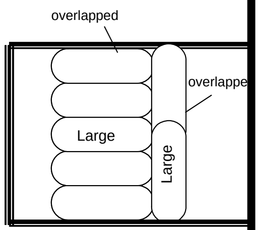
Cross Section



Frontal View



Lay-out

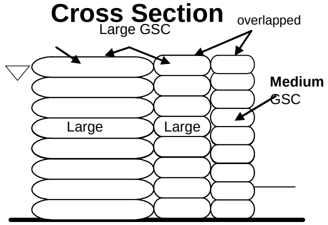


Permeability Coefficient of the structure =

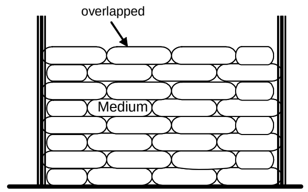
$$9x10^{-3} m/s$$

MODEL 8: One longitudinal layers and two transversal layers of containers

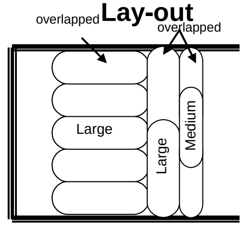
Cross Section



Frontal View



Lay-out



Permeability Coefficient of the structure =

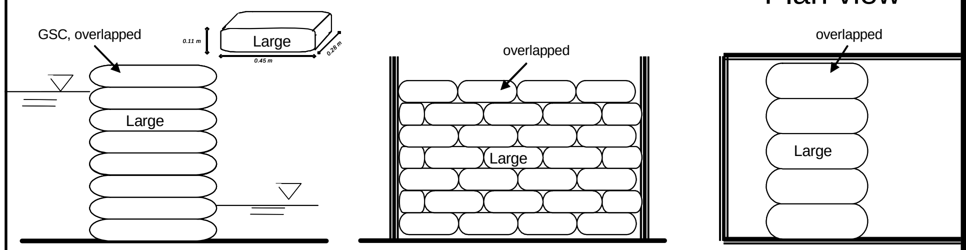
$$9x10^{-3} m/s$$

CONCLUSION:

Given two layers of containers (in plan view), adding a third layer does not reduce the permeability

MODEL 6: Containers overlapped

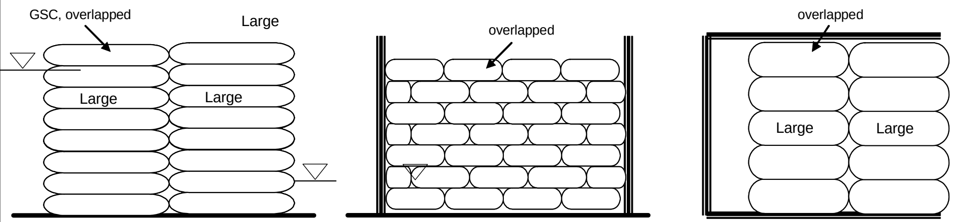
Cross Section | **Frontal View** | **Lay-out** Plan view



Permeability coefficient of the structure = $1.5x10^{-2}\,m/s$

MODEL 9: Two longitudinal layers of containers (in Lay-out view)

Cross Section | **Frontal View** | Plan view **Lay-out**

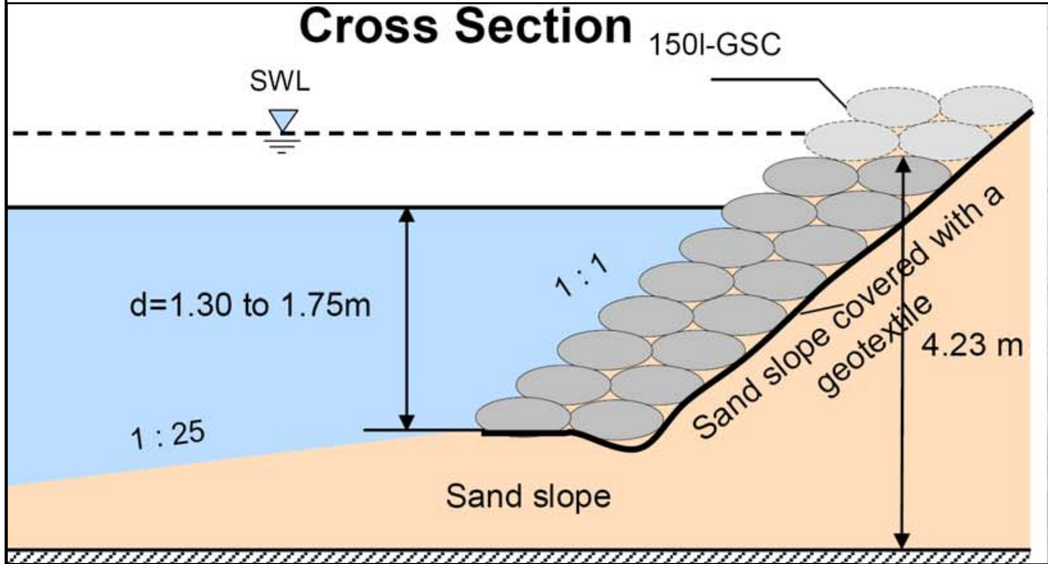


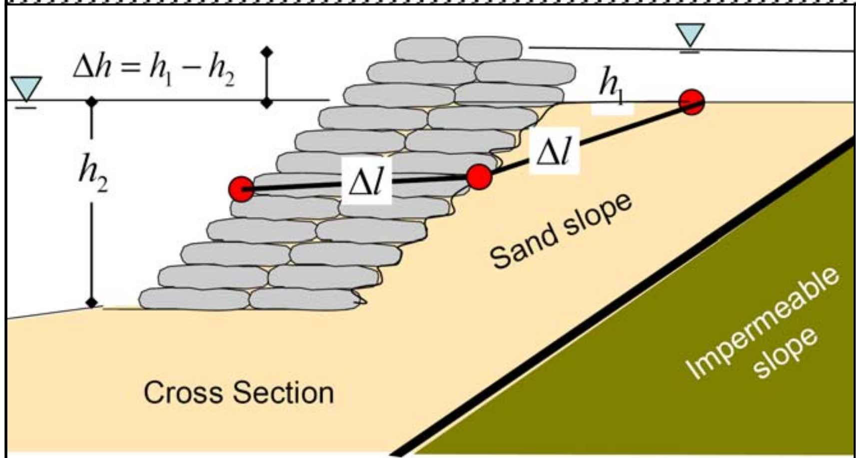
Permeability coefficient of the structure = $1.4x10^{-2}\,m/s$

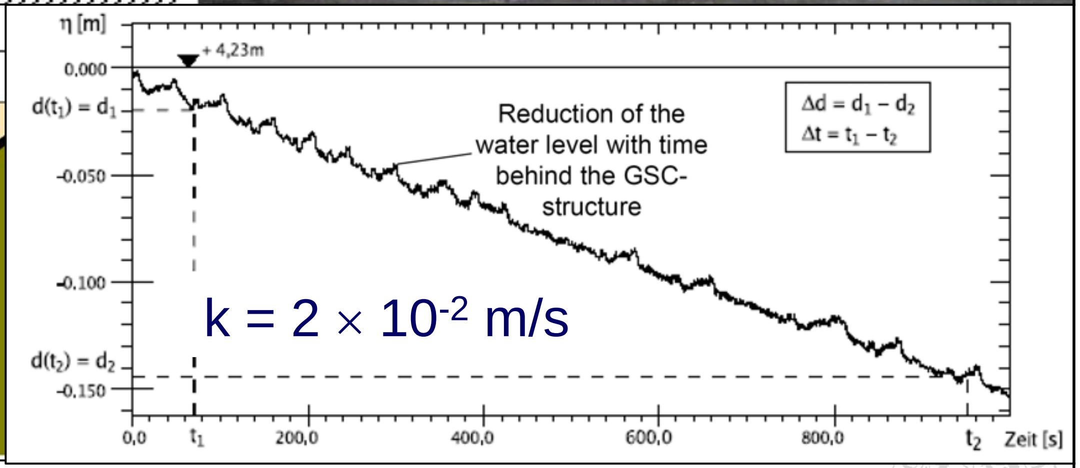
Conclusion:

The permeability coefficient of GSC-structures typically used as revetments longitudinally placed depends on the size of GSC, arrangement and length of structure

Further Permeability Tests – GWK (2002)

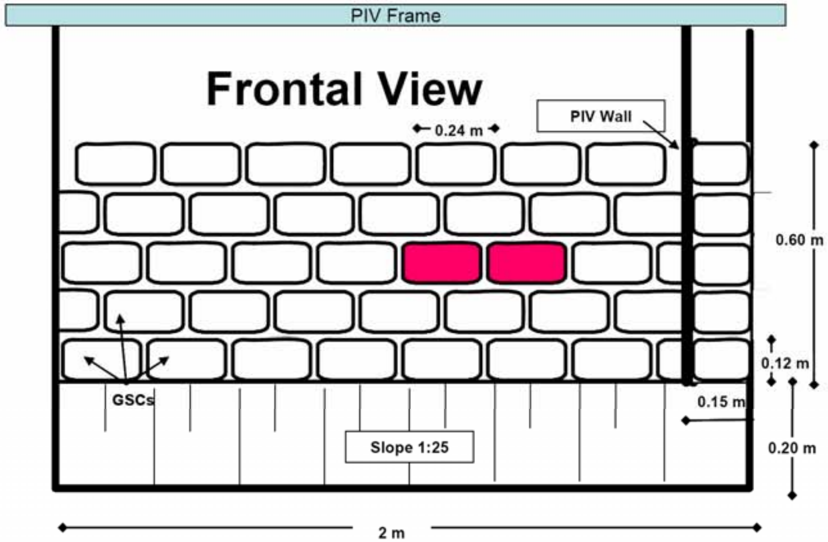


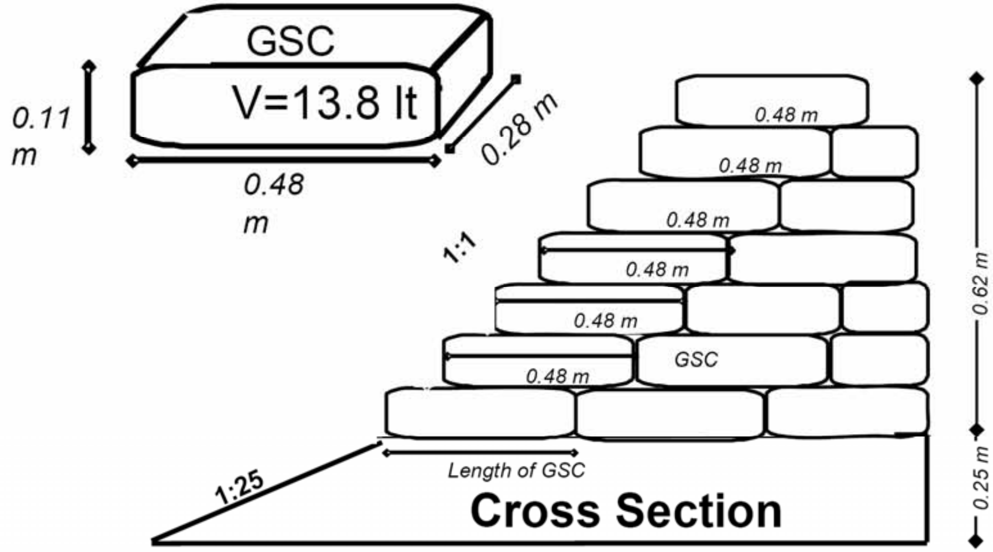




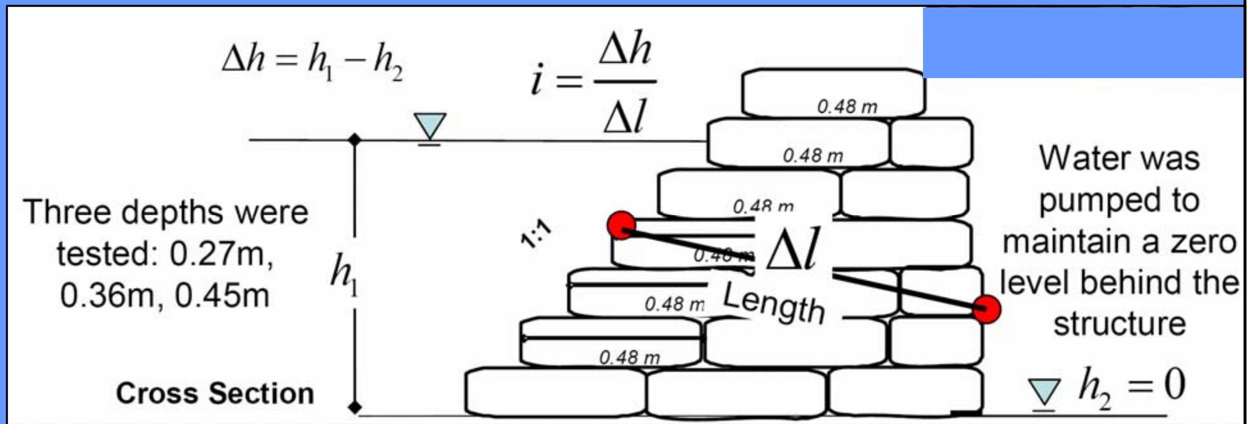
Modified from (Hinz and Oumeraci, 2002)

Further Permeability Tests – LWI flume





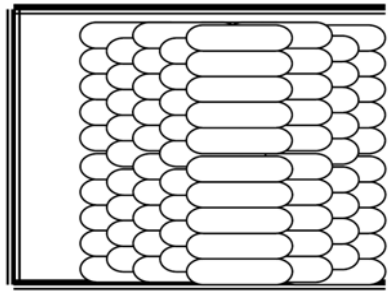
k = 1.4 × 10^{-2} m/s



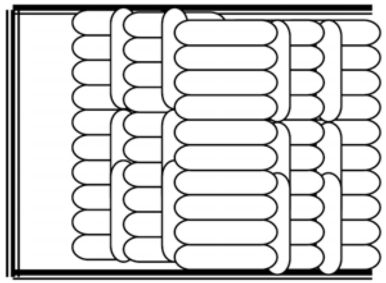
Effect of the Mode of Placement - LWI

Plan View

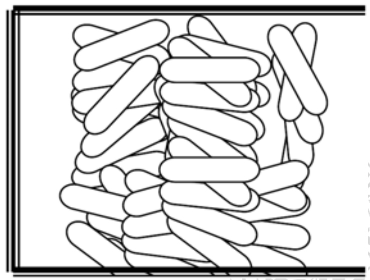
Model A



Model B



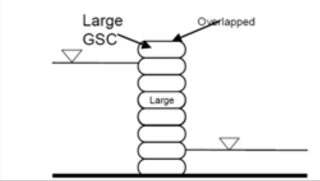
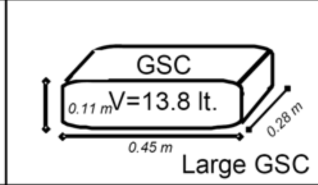
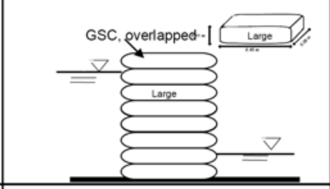
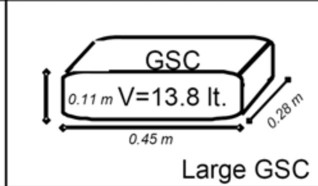
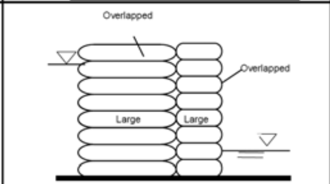
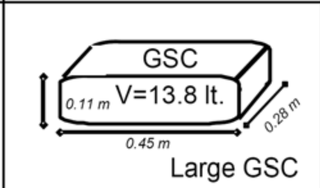
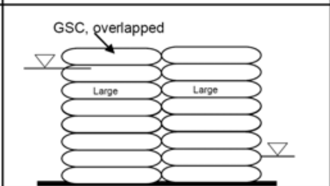
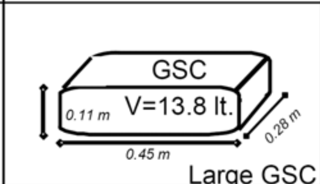
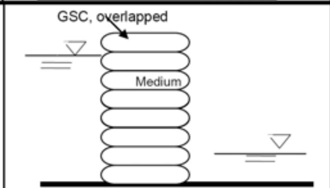
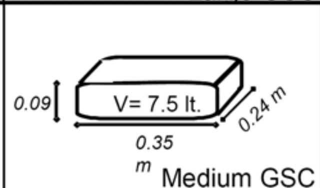
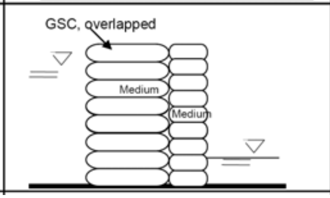
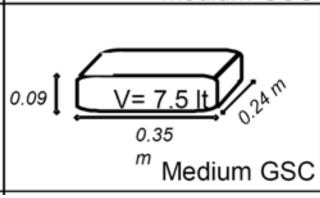
Model C



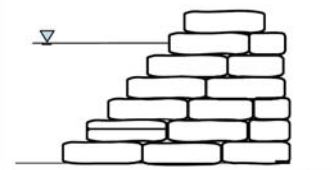
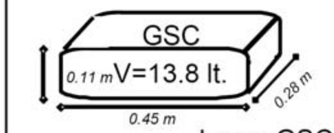
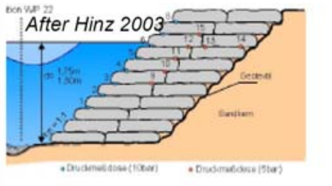
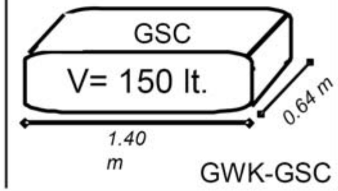
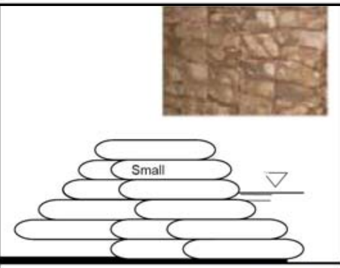
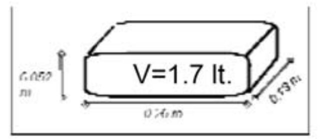
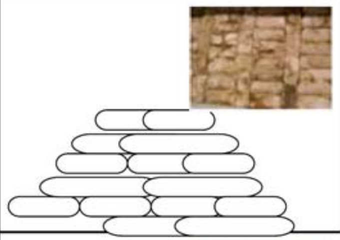
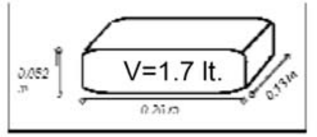
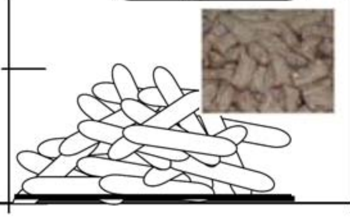
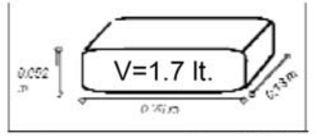
Effect of the Mode of Placement

Model A		Interlaid placement, blocking the gaps of the previous layer	$k = 1.2 \times 10^{-2}$ m/s
Model B		Longitudinal placement to the flow direction	$k = 2.3 \times 10^{-2}$ m/s
Model C		Random placement	$k = 2.4 \times 10^{-2}$ m/s
Model D		Comparison: gravel structure (D_{50} = 23 mm, D_{max} = 29 mm)	$k = 3.9 \times 10^{-1}$ m/s

Summary of Test Results (1)

	Cross Section	Size GSC	Permeability k (m/s)		
MODEL 5			$8x10^{-3}$	➡	Transversal GSC-structures have smaller permeability
MODEL 6			$1.5x10^{-2}$	➡	One typical structure used for revetments
MODEL 7			$9x10^{-3}$	➡	Optimal structure if minimal permeability is needed
MODEL 9			$1.4x10^{-2}$	➡	Most typical structure used as GSC-revetment
MODEL 10			$8x10^{-3}$	➡	Small containers induce lower permeability
MODEL 11			$7x10^{-3}$	➡	Blocking directly the gaps reduces the permeability

Summary of Test Results (2)

	Cross Section	Size GSC	Permeability k (m/s)
LWI		 Large GSC	$1.4x10^{-2}$
GWK		 GWK-GSC	$2x10^{-2}$
MODEL A		 Small GSC	$2.2x10^{-2}$
MODEL B		 Small GSC	$1.2x10^{-2}$
MODEL C		 Small GSC	$2.4x10^{-2}$

- GSC-revetments built only with sand containers
- GSC-Structures with sand slope (data from Hinz & Oumeraci 2002)
- Small containers placed longitudinally: higher hydraulic stability than randomly placed for surface piercing structures
- Small containers placed longitudinally and transversally: each layer blocking the gaps from previous layer. Lowest stability.
- Small containers placed randomly: higher permeability but smaller stability compare with longitudinal containers

Summary and Concluding Remarks on Permeability of GSC-structucre

- The **Permeability of a GSC-structure:** mainly governed by the **size of the gaps**. Thus, the flow through the sand container itself can be neglected.

- Range of k for Design: If no reliable data are available, a permeability coefficient for GSC-structures, in the range $k = 10^{-2}\ m/s$ might be considered.

- Possible arrangement to substantially **reduce the permeability: blocking the gaps** of the first layer with transversal containers of a second layer.

- Mode of placement: **Random placing has the highest permeability**, but smaller hydraulic stability for surface piercing structures than longitudinally placed containers.

- Simple **conceptual model**: proposed by *Recio* and *Oumeraci* (2008) for estimating the permeability of GSC-structures.