HYDRAULIC PERMEABILITY OF STRUCTURES MADE OF GEOTEXTILE SAND CONTAINERS (GSC-STRUCTURES) - LABORATORY TESTS AND RESULTS

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Coastal structures made of Geotextile Sand Containers (GSCs) are increasingly being used as breakwaters, artificial reefs, revetments and dune reinforcement. The permeability of any coastal structure made of GSCs significantly influences its hydraulic stability when subject to wave loads. Permeability also strongly affects wave transmission and other processes associated with wave-structure interaction. Despite the importance of the permeability for both functional design and hydraulic stability, no information is available for the assessment of the permeability of GSC-structures. Therefore comprehensive hydraulic model tests have been performed for the first time to determine the permeability of several types of GSC-structures and configurations.

INTRODUCTION

Coastal and hydraulic engineering problems were the starting point of the technical development of geotextiles. Various other geosynthetic disciplines of civil engineering were opened up later on. 50 years ago first trials with sandbags made of synthetic textiles were realised in the USA, the Netherlands and in Germany.

In recent years, geotextile sand container technology has experienced growth success and highly visible projects. Nowadays geotextile sand containers find their application as construction elements for erosion control, scour fill, reefs, groynes, dams, breakwaters and dune revetments.

At sandy beaches, where the use of rocks, steel and concrete as "hard coastal structures" is contrary to the soft coastal protection philosophy, geotextile sand filled containers made of needle-punched nonwovens offer more advantages as "Soft Rock structures".

Nowadays the technology has advanced to a stage where the containers are being used to construct complex structures, which are subjected to extreme physical and climatic conditions with a life expectancy of more than 25 years relating European Standard and actual experience.

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Motive

The permeability of coastal structures such as revetments, seawalls, breakwaters, etc. significantly affects their hydraulic stability when subject to wave loads. The higher the permeability of a revetment, the higher its stability. Higher permeability reduces the seepage forces and pressures "build-up" in the structure. Permeability also strongly affects wave transmission and other processes associated with wave-structure interaction (Muttray and Oumeraci, 2002). In addition, permeability is extremely important for GSC-structures used as flood defenses (e.g. dune reinforcement, seawalls, etc.), since it substantially affects the inundation rate.

Despite the importance of the permeability for both functional design and hydraulic stability, no information is available for the assessment of the permeability of GSC-structures. Therefore, comprehensive hydraulic model tests have been performed for the first time to determine the permeability of several types of GSC-structures.

Theoretical Background

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 in-homogeneity of the flow and its unsteadiness, the permeability of GSC-structure will preferably be described by the Darcy permeability coefficient *k*. It is assumed, that the flow through the structure is steady and laminar and Darcy's formula can be used (Figure 1):

$$Q = k \cdot i \cdot A \tag{1}$$

where Q is the flow rate; k the Darcy's coefficient of permeability (depends on the soil and viscosity of the pore fluid); A is the total cross area of filter sample normal to the flow and i is the hydraulic gradient:

$$i = \frac{\Delta h}{\Delta l} = const \tag{2}$$

with Δh is water head difference, before and after the filter sample ($\Delta h = h_1 - h_2$) and Δl is the length of filter sample.

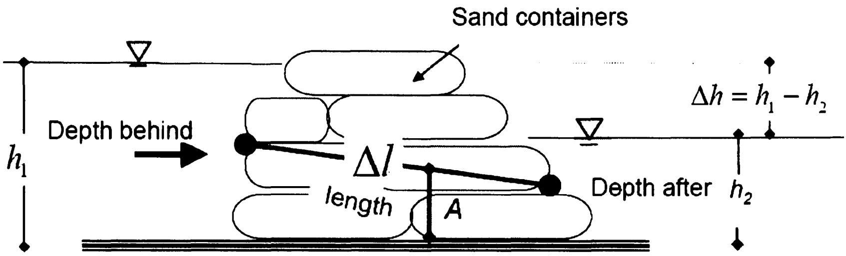


Figure 1: Flow through GSC-Structures.

BASIC PERMEABILITY TESTS

Permeability tests were performed to obtain the permeability of various types of GSC-structures and to quantify the influence of parameters such as the size of the containers, the gap size and the mode of placement of structures made of geotextile sand containers (GSC) on the permeability.

Experimental Set-Up

The permeability tests were performed by constructing a GSC-structure in a tank (2m wide, 5m long and 1.5m high). The height of GSC-structure is 1.3m, width 2m and variable length depending on the model. The water head difference was kept constant during each test in order to ensure steady flow conditions (Figure 2). Several structure geometries and two sizes of sand containers (Figure 3) were tested under at least three different hydraulic gradients. The measurements during the model tests focused on the in-outflow (Figure 2). These were obtained by means of ADV-devices (Acoustic Doppler Velocimeters). The ADVs were located 0.11m from the structure, exactly faced to a gap between containers (closest possible location). The water depths at both sides of the structure and the steady flow were also recorded.

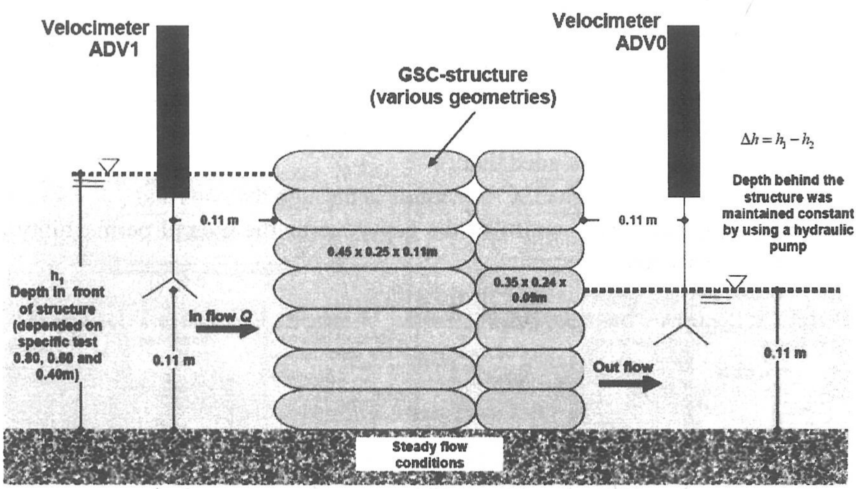


Figure 2: Experimental Set-Up for Basic Permeability Tests.

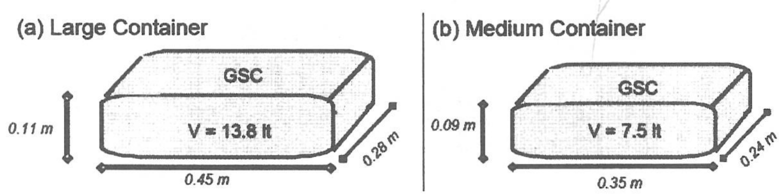


Figure 3: Sizes of Containers Used in the Permeability Model Tests.

The sand containers used in the model tests were made of a needle-punched nonwoven geotextile with a permeability coefficient of $k_v = 3 \times 10^{-3}$ *m/s* and sand with a median grain size of $D_{50} = 0.2$ *mm*, density of $\rho_S = 1800$ *kg/m*^{3} and permeability coefficient of approx $k = 1.1 \times 10^{-4}$ *m/s*.

A total of 11 model alternatives were tested, which differ from each other by the following items:

- Lay-out of the containers in the arrangement of the structure.
- Size of containers.
- Length of the structure.

RESULTS OF BASIC PERMEABILITY TESTS

Effect of the Size of the Gaps between Geotextile Containers

The first parameter that was investigated was the size of the gaps between neighbouring containers. Therefore, two GSC-structures with the same containers but different gap size between GSCs were compared. By laying the containers one directly above the other, the size of the gaps becomes maximum. On the other hand, if the GSC are laid with some interlocking, the size of the gaps is reduced (but more gaps will be present).

The size of the gaps substantially affect the permeability of GSC-structures. The difference between the permeability coefficients of the two GSC-arrangements in Figure 4 is more than twice ($k = 5\times10^{-2}$ *to* 2×10^{-2} *m/s*). It was also observed that with a big size of gaps, the flow velocities through the gaps are very high. From this analysis it can be concluded that:

- The main flow through GSC-structures is through the gaps and
- for GSC-structures, the size of the gap governs the overall permeability of the GSC-structure.

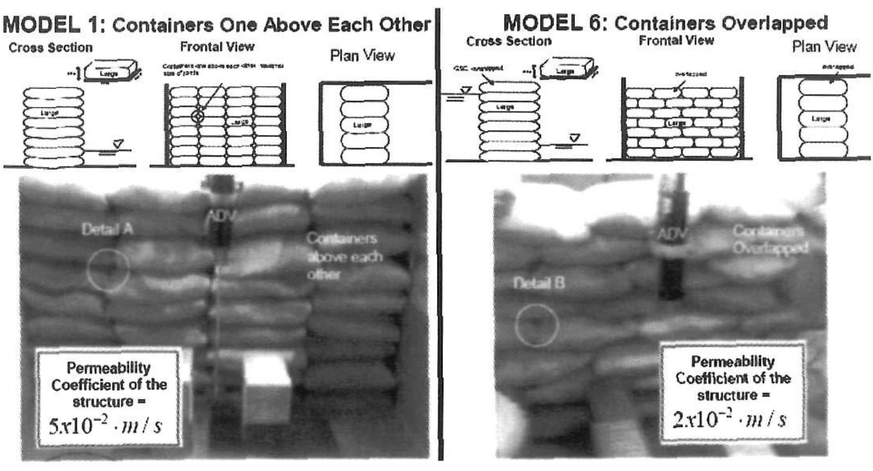


Figure 4. Effect of Size of Gaps on the Permeability of GSC-Structures.

Effect of Size of Geotextile Container on Permeability

In order to investigate the influence of the size of the containers on the permeability of GSC-structures, two containers with different sizes were tested under same flow conditions. The comparative results are summarized in Figure 5 showing that:

- The size of the container influences the permeability of structure.
- The smaller the container, the smaller the permeability coefficient of the structure.

This can be explained due to the size of gaps between containers. A structure built with smaller containers will have more gaps but the size of these gaps is smaller. This indicates that the friction between flow and the geotextile in the gaps is high and reduces considerably the flow through the structure. In example, the flow through a single gap with an area of 2 units is higher than the total flow through two gaps having each of them an area of one unit (due to the friction between geotextile and water).

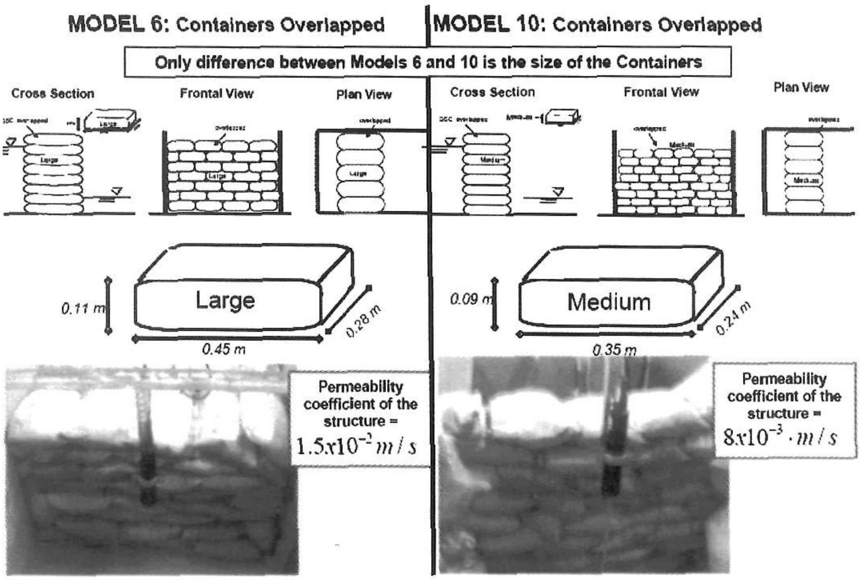


Figure 5. Effect of Size of the Geotextile Container on the Permeability.

Effect of Arrangement on Permeability

A structure with longitudinal placed GSCs (in Plan view) is compared with a structure with transversally placed GSCs. Recalling that the permeability coefficient in Darcy's formula (eq. 1 and 2) is inversely proportional to the length of the structure (Δl), a shorter structure has a smaller permeability coefficient. But comparing the flow behind the structure, it can be seen that the flow is similar in both cases (slightly higher flow with shorter structures). Both structures were built with identical containers, then the size of the gaps between containers should be the same. From the analysis it can be stated that a longitudinal structure has less gaps but the length of these gaps is longer. On the other hand, transversal structures have fewer gaps but shorter. From this comparison it can be concluded that:

- Transversally placed GSCs have smaller permeability coefficients than longitudinally placed GSCs.
- If only the permeability of the structure is important, then both longitudinally or transversally placed GSCs will provide similar total flows through the structure.

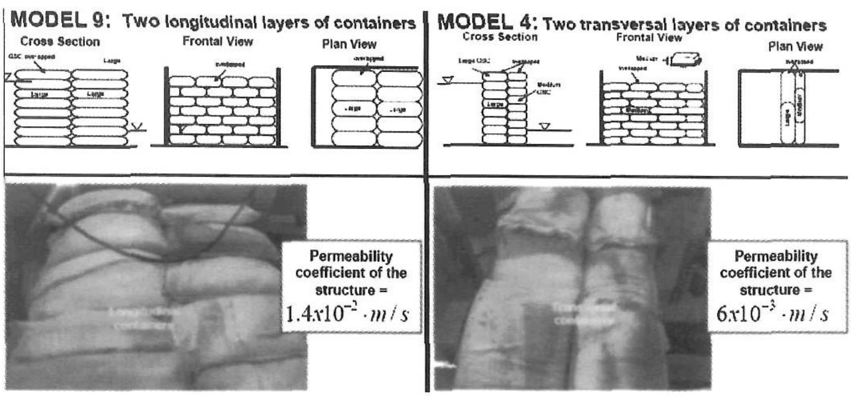


Figure 6. Effect of Mode of Placement on the Permeability of GSC-Structures.

Effect of Blocking the Direct Flow through the Gaps

The permeability of a GSC-structure is governed by the gaps between GSCs; therefore, some GSC-structures were built to investigate the reduction of the permeability by overlapping layers of containers transversally (in plan view), thus, blocking the gaps from the first layer. For comparison, the gaps of the first layer of containers were blocked with a second layer of transversal containers (Fig. 7).

The model tests results have shown that by blocking the gaps with another container, the permeability of the structure is considerably reduced. This can be clearly seen in the comparison from Models 1 and 2 (Figure 7), where the blocked-structure reduced its permeability considerably (more than twice). This "blocking" is much better achieved with transversal containers, since, the gap is completely blocked (a result that cannot be achieved using two longitudinally placed containers). This reduction can easily be explained considering that water flows in the first layer through the gaps but when it reaches the second layer, it is forced to flow (at least partially) through the containers and thus, the permeability is reduced (Figure 7). Therefore, it can be concluded that:

- The permeability of a GSC-structure (and thus the total flow through the structure) is drastically reduced if there is a second layer of overlapped containers that obstruct the flow from the gaps of the first layer.
- When a GSC-structure has two or more layers of containers (one transversal and one longitudinal), the flow through the structure is too complex and the way the water flow through the structure can hardly be predicted.

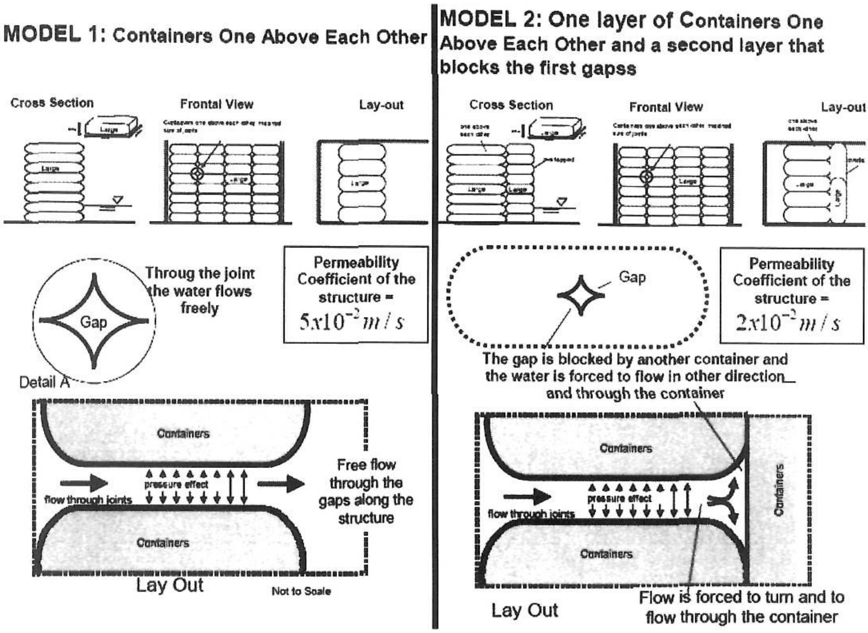


Figure 7. Effect of Blocking the Direct Flow of the Gaps on the Permeability.

Effect of the Number of Layers on the Permeability

It was seen that two overlapped layers of containers (in plan view) have lower permeability than one layer. Moreover, the influence of a third layer of containers was investigated (Figure 8). It was concluded from the results that:

- A third layer of containers do not reduce the permeability coefficient of the structure. The total flow will naturally be reduced but the permeability coefficient will remain constant.
- If a GSC-structure has two or more layers of containers then it can be treated as homogeneous structure and further layers will not reduce the permeability coefficient (less flow through the structure due to the increase of its length).
- After a second layer, the mode of placement does not have a significant effect on the permeability.

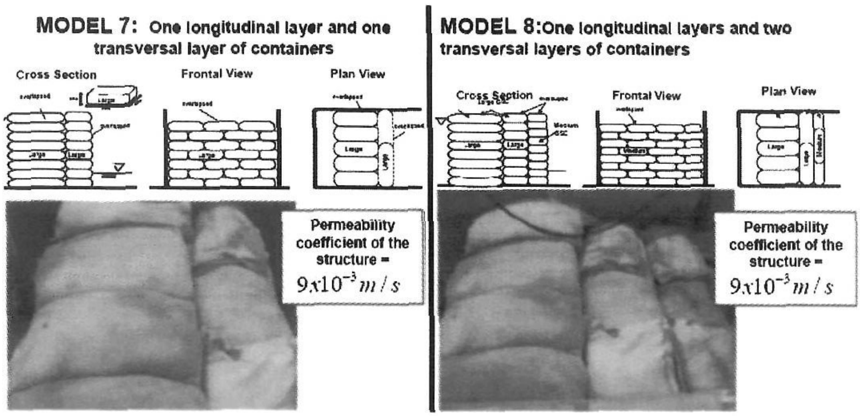


Figure 8. Effect of the Number of Layers of Containers on the Permeability.

GSC-Structures with Longitudinal Layers of Geotextile Containers

This analysis is important because most of the GSC-structures are constructed in two layers (in plan view) of longitudinal containers as typical arrangement for dune revetments. From the model tests it can be concluded that:

- The total flow through GSC-structures typically used as revetments depends on the size and number of layers of containers
- The permeability coefficient of these GSC-structures varies from 8 x 10^{-3} m/s (medium containers) to 1.5 x 10^{-2} m/s (large containers).
- Two layers of GSCs have very similar permeability coefficients as one layer of containers when both of the layers are placed longitudinally to the flow. In this case the gaps from the second layer (in Lay-out view) do not obstruct considerably the gaps from the first layer.

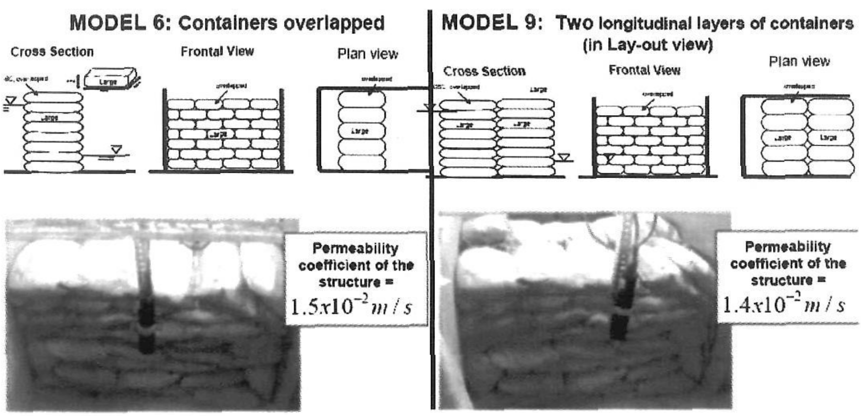
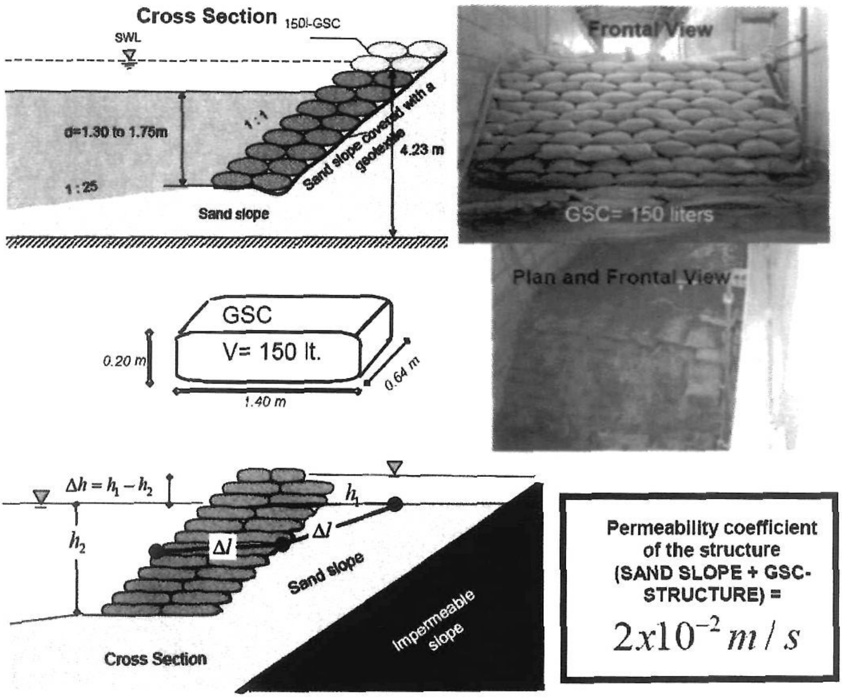


Figure 9. Permeability Results of Typical GSC-Structures used as Dune Revetments.

FURTHER PERMEABILITY TESTS

Model tests were conducted at the large wave flume at Hannover (GWK) in order to investigate the hydraulic stability of GSC-revetments. After the model tests, the time required for the water to flow from behind the structure and the variation of water level before the structure versus time were recorded (Figure 10). The entire structure consists of a structure made of 150 litre GSCs founded on a sand slope. The sand slope was covered with a nonwoven geotextile.

Since the GSC-structure is placed on a sand slope that is also protecting the coastal area, the permeability was calculated for both GSC-structure and sand slope. For this GSC-structure $k = 2\times10^{-2}$ m/s is derived.



Permeability Test Results

Exp No.	V (m3)	Δ t (s)	Q (m3/s)	A (m2)	Δ h (m)	Δ l (m)	k (m/s)	k (m/s)
02070203	13.07	900.00	0.0145	9.75	0.4050	5.93	0.0218	
02070205	12.05	900.00	0.0134	9.75	0.4080	5.93	0.0200	0.0209

Figure 10. Results of Permeability Tests of a GSC-Revetment in the Large Wave Flume of GWK (modified from Oumeraci et al, 2002).

During the second stage of model tests at the LWI-wave-flume a smaller size of containers has been used for this purpose. The primary objective of these tests is to investigate the influence of the mode of placement of GSCs on the permeability of the entire GSC-structure. The structure has a height of approx.

0.81 m, and was built with sand containers with the following dimensions: 0.26m length, 0.13m width and 0.052m height. With this size of container, three types of mode of placement were tested:

1. GSC-structure with containers placed longitudinally in the wave flume,
2. GSC-structure with containers placed both longitudinally and transversally (interlaid) in the wave flume in order to block the gaps of the previous layer,
3. GSC-structure with the containers placed randomly by dropping them from an elevation of about 1m in the wave-flume.

The results of the permeability tests are summarized in Figure 11. The structure made of randomly placed containers has the highest permeability coefficient of the three tested GSC-structures, because the probability of the water flowing through the structure of finding a "direct" way (with large gap size) across the structure is higher than in the other two configurations.

The smallest permeability coefficient is expectedly obtained for the containers placed interlaid in a way that the second layer blocks the gaps of the first layer of containers.

Further interesting results is the comparison among the obtained permeability coefficients: the permeability of the sand material ($k=10^{-3}$) is approximately ten times smaller than the permeability of the GSC-structure ($k=10^{-2}$); moreover, the permeability of the GSC-structure ($k=10^{-2}$) is approx. ten times smaller than the coefficient of a gravel structure ($k=10^{-1}$).

Finally, randomly placed sand containers and longitudinally placed containers have similar permeability (randomly placed slightly higher than longitudinally). This can be explained because in the longitudinal containers, the water-flow has a direct way across the structure through the longitudinal gaps. However, these gaps are smaller than the gaps that appear between randomly placed containers.

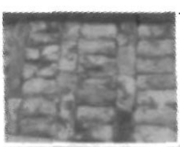
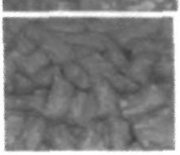
Model Structure	**Description**	**Darcy's Permeability Coefficient *k* (m/s)**
	Structure made of geotextile sand containers placed interlaid blocking the gaps of the previous layer	1.244×10^{-2}
	Structure made of geotextile sand containers placed longitudinally to the flow	2.274×10^{-2}
	Structure made of geotextile sand containers placed randomly	2.412×10^{-2}

Figure 11. Comparison of Permeability with Different Mode of Placements.

SUMMARY

Geotextile nonwoven sand containers as "soft rock structures" for flexible coastal protection measures provide significant advantages over "hard coastal structures" made of concrete, steel and rocks.

Such geotextile sand container structures (GSC) are variable or removable if necessary and there is always the possibility to combine geotextile structures with conventional elements like rip-rap or rock revetments. The geosynthetic solution provide more effectiveness relating costs, time and equipment than conventional methods.

Because of the importance of the permeability for both functional design and hydraulic stability of such structures comprehensive hydraulic model tests have been performed for the first time to determine the permeability of several types of GSC-structures. The most important results obtained from all permeability tests are showing that:

1. The permeability of a GSC-structure depends mainly on the size of the gaps. The flow through a GSC-structure is governed by flow through the gaps and thus, the flow through the sand container can be neglected.
2. If no reliable data are available, a permeability coefficient for GSC-structures of $k = 10^{-2}$ m/s would be reasonable.
3. The optimal arrangement to reduce the permeability of a GSC-structure is by blocking the gaps of the fist layer with transversal containers of a second layer. With this mode of placement the permeability coefficient is approximately 5×10^{-3} m/s.
4. The mode of placement of the sand containers in a GSC-structure considerably affects the permeability of the structure. Random placing has the highest permeability, but smaller hydraulic stability for surface piercing structures than longitudinally placed containers.
5. The smaller the container, the smaller the permeability coefficient of the structure. A structure made with smaller containers will have more and smaller gaps, subsequently the friction losses of the gap flow will be higher.
6. If only the permeability performance of the structure is important, then either longitudinally or transversally placed GSCs will provide similar total flows through the structure. However, the hydraulic stability of sand containers under wave action is lower for transversally placed containers than for longitudinally placed GSCs (Oumeraci and Hinz, 2002).

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