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The use of Elastocoast in breakwater research

Melvin Koote, Wilmar Zeelenberg
Delft University of Technology
Supervisor: H.J. Verhagen

Abstract

To protect the mainland, dikes or ports against the destructive power of waves, breakwaters are used. In the available design formula for breakwaters the physical background of some parameters is still unclear, leading to overdimensioning. Research is needed to improve our knowledge regarding these parameters.

Research to breakwaters for different circumstances is difficult, because there is a problem: after a certain number of wave attacks, the top layer is changed of composition and properties. In this way it is complicated to make good comparisons, because there are different properties of the breakwater every time. The breakwater consists of loose rock, so when a second model is build, the exact properties of the rock layer become different.

In this report will be explained how breakwaters can be made with the use of Elastocoast, a sort of glue. This makes it possible to fix the individual rocks, and allows repetitive tests possible with exactly the same layer properties. We made six samples of breakwater rock layers, made with Elastocoast and stones, which can be placed and tested in the wave flume.

For doing tests it is important to know the properties of the breakwater, such as the grain size distribution, the porosity and the permeability.

The permeability and porosity tests were performed on smaller parts than the slabs to be used in the model breakwater.

After making the little samples we made the large ones, on the same way, for use in the wave flume.

For the testing of the permeability we used a construction in which we could let water flow through the samples.

This report shows the results of our tests, so these results can be used for further purposes,

when other people use these breakwater samples.

1 Introduction

1.1 Cause of the research

To control the huge power of waves, all kinds of breakwaters are constructed. These consist out of different stone sizes, large rocks, sand and clay. Most breakwaters allow water to flow through but will decrease the power of the waves.

In the laboratory different kinds of breakwaters are being used for experiments, to test new types or to improve existing types. For these experiments the model breakwater is placed in a wave flume, where you can simulate very realistic waves in a small scale.

The top layer of the breakwater consists out of small loose stones. Every time a wave hits the breakwater the consistency of the top layer will be changed. So every time it has other properties as to porosity and permeability. After a long time, so a lot of waves, the breakwater has a completely different consistency and the top layer could be flushed partially away. To have good comparable results of measurements, this isn't very useful.

That is why our main goal reads: "Produce a breakwater layer with a known grain size distribution, which has always the same porosity and permeability."

The solution for this problem is making samples of stones which are stuck together with Elastocoast, a sort of glue. The glue is a very thin cover of the stones, and does not change the permeability of the structure. The six samples we produce are plates which simulate the top layer of a breakwater. The plates have all the same height and width, so that they fit in the wave flume, but they all have a common, but different, thickness.

After building these plates, we determined the porosity and permeability of every plate, so this information is known for future users.

Our hypothesis reads: "The porosity increases with a bigger grain size and the permeability decreases with a thicker plate."

This article is structured as follows:

First we show an abstract of the article, were you shortly read all the important information. In the introduction we explain the material en methods we used.
The results of our measurements will be presented in chapter 2, followed by the discussions and assumptions of the results in chapter 3.
At last we conclude from the results and our findings in chapter 4. Our sources will be shown in chapter 6.

1.2 Materials en equipment

1.2.1 During production

The materials we used are two limestone types and Elastocoast.

Figure 1. The six small samples with the same thickness as the large ones.

The six samples have different thicknesses and three different grain sizes:

Sample 1: Yellow Sun limestone with an average grain diameter of 8 to 11 mm. A thickness of 39 mm

Sample 2: Yellow Sun limestone with a grain diameter of 20 to 40 mm. A plate thickness of 88 mm.

Sample 3: Yellow Sun limestone with a grain diameter of 20 to 40 mm. A plate thickness of 132 mm.

Sample 4: Norwegian limestone with a grain diameter larger than 40 mm. A plate thickness of 80 mm.

Sample 5: Norwegian limestone with a grain diameter larger than 40 mm. A plate thickness of 160 mm.

Sample 6: Norwegian limestone with a grain diameter larger than 40 mm. A plate thickness of 240 mm.

The other dimensions were chosen so that the plates will fit in the wave flume: a width of 725 mm and a height of 925mm.

Elastocoast is a kind of glue which sticks the stones together, but will keep the pores open. It covers the stones like a coat, so the stones only stick together where the stones touch each other. Elastocoast is Polyurethane which is developed by BASF. The official name is Elastocoast 6551/100. It consists of two components: a Polyol-component and an Iso-component. The Polyol-component consists of a mixture of polyol and additions and the Iso-component consists of a preparation of diphenylmethane-diisocyanat (MDI) = IsoPMDI 92140.
To make Elastocoast, these two components have to be mixed in a mass ratio of 2:1.
To build the samples we used a weight scale, a mixer, a cement mixer and wooden mould. At the bottom of the wooden mould we placed plastic (polyethylene), so the Elastocoast doesn't attach to it.

1.2.2 During tests

During the porosity tests and the determinations of the average grain diameter we use a weight scale. For the permeability tests the equipment consists of a large reservoir with a pump in it, which pump the water to a small reservoir. The samples were attached underneath the small reservoir, so if water wants to leave the small reservoir, it has to go through the sample. To measure the runoff, we used a flowmeter between the pump and the small reservoir. In the small reservoir we hang a water level meter. To read the outcomes of the water level meter we connected it to a computer. To regulate how much water the pump pumps into the small reservoir, we used a control panel.

1.3 Methods

1.3.1 Building the samples

Before mixing the stones with the Elastocoast, we measure the mass of the stones. By knowing that the density of limestone is 2700kg/m^3 [(1)], we calculate the volume of the stones and subsequent the volume Elastocoast. Knowing that the density of Elastocoast is 1100kg/m^3 [(2)], we calculate the mass Elastocoast which had to be added by the stones in the cement mixer.
After the two components of the Elastocoast were put together and mixed, we put it together with the stones in a mixer.

[(1)] Determined by weighing the mass and measuring the volume of a couple of stones.
[(2)]BASF, *Elastocoast® An innovative Technology in Coastal Protection*, August 2008.

Figure 2. Mixing the two components of Elastocoast.

The developer of Elastocoast, BASF, recommends a volume ratio of 100:3 between stones and Elastocoast, so 1 liter of stone volume needs 0,03 liter of Elastocoast.

Figure 3. The large stones inside the cement mixer, before adding Elastocoast.

We first build six small samples, which fit underneath the already existing small reservoir. These blocks have the same thicknesses as the large samples but the dimensions height and width are both 260mm. The setup consist the small reservoir in the large reservoir connected by the pump(input) and the opening where the water flows through the sample(output). The porosity is also determined with the small samples.

The next steps need to be followed to produce the samples:

- Place plastic on bottom mould
- Put the right amount Elastocoast together and mix it up
- Put the stones and the Elastocoast together in the cement mixer.
- Mix it for a few minutes
- Drop the stones covered with a coat of Elastocoast in the mould.
- Let it harden for 24 hours

1.3.2 Testing the samples

Before the plates were made, we made a grain size distribution, so we could determine the $D_{n,50}$. Hundred stones of each grain size were weighed and their diameter determined.

The porosity is determined by weighting the small samples well dry as completely saturated with water.

The determination of the permeability happened with two reservoirs: a large reservoir and a small one inside the large reservoir.

The small samples were placed underneath the small reservoir, and then we filled the large reservoir. The water levels inside both reservoirs are equal at this point, because the small reservoir is a communicating vessel in this situation. Once the reservoir is at a certain level, we stop filling it. To make a water level difference between the two reservoirs, we started the pump to raise the water level inside the small reservoir. With controlling the runoff to the reservoir we kept the water level at a steady level and read the flowmeter and water level meter inside and outside the small reservoir. We repeated this action four times and after that emptied the reservoir to start all over again with the next sample. So we gained five results for each sample, for extra accuracy.

2 Results

2.1 Grain size distribution

To determine the grain size distribution, we took random 100 stones of each grain size. We weighed all of these stones and determined the diameter of them with the following formula: $D_n = \sqrt[3]{\frac{m}{\rho}}$

Where: D_n= average diameter in m

m=mass of the stone in kg

ρ= density of stones = 2700 kg/m^3

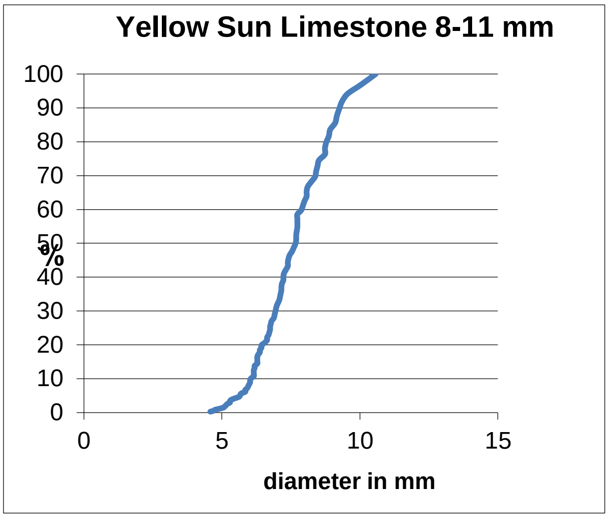
We used three kinds of limestone:

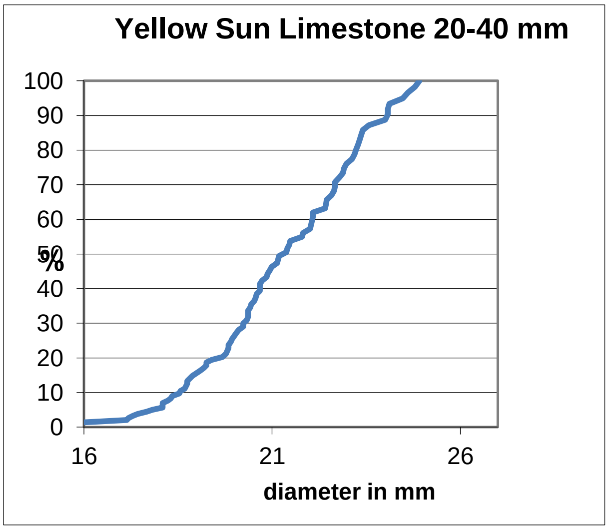
1 Yellow sun (8mm≤$D_{n,50}$≤11mm)

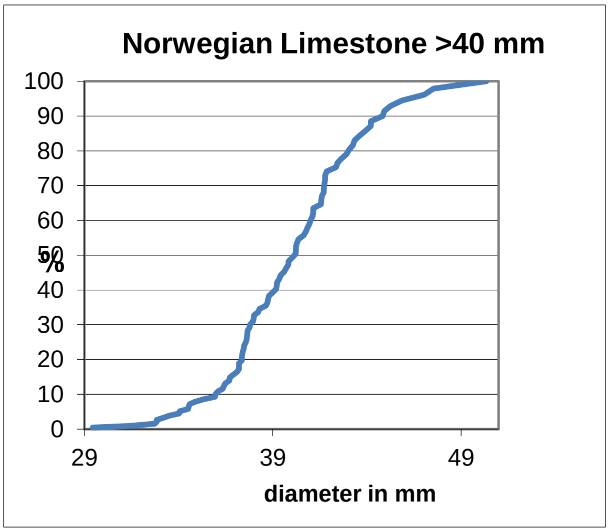
2 Yellow sun (20mm≤$D_{n,50}$≤40mm)

3 Norwegian ($D_{n,50}$>40mm)

All of these have the same density of 2700kg/m^3.







Type 1: $D_{n,50}$=6.93 mm

Type 2: $D_{n,50}$=20.45 mm

Type 3: $D_{n,50}$=39.00 mm

2.2 Porosity

To determine the porosity of the samples Elastocoast, we first weighed the dry samples and after that completely saturated it with water. We assumed that the water density is 1000 kg/m^3, because the temperature is 20°C.

The volumes of the samples are known, so we can calculate the volume of the pores by measuring the weight of the added water.

The surface of each sample is the same, but the thickness varies.

The porosity from each sample is calculated as follows:

First measure the mass of water, then convert to volume, by using the water density.

$$\frac{m_{water}}{\rho_{water}} = V_{water}$$

Now the porosity n can be calculated by dividing the water volume with the total volume. The total volume contains the surface multiplied by the thickness of each separate sample.

$$n = \frac{V_{water}}{V_{total}}$$

The bottomsurface of each sample is equal to 6,76 dm^2 (260mmx260mm).

Sample 1: (8mm≤$D_{n,50}$≤11mm)
thickness: 39mm
V_{total}= 6,76dm^2x 0.39 dm= 2,64 dm^3=2,64 L
m_{water}=1016,4 g
V_{water}= 1016,4/1000= 1,02 L

$$n = \frac{1,02}{2,64} = 0.386$$

Sample 2: (20mm≤$D_{n,50}$≤40mm)
thickness: 88mm
V_{total}= 6,76dm^2x 0.88 dm= 5,95 dm^3=5,95 L
m_{water}=2410,2 g
V_{water}= 2410,2/1000= 2,41 L

$$n = \frac{2,41}{5,95} = 0,405$$

Sample 3: (20mm≤$D_{n,50}$≤40mm)
thickness: 132mm
V_{total}= 6,76dm^2x 1.32 dm= 8.92 dm^3=8.92 L
m_{water}=3776.6 g
V_{water}= 3776.6/1000= 3.78 L

$$n = \frac{3.78}{8.92} = 0.423$$

Sample 4: ($D_{n,50}$>40mm)
thickness: 80mm
V_{total}= 6,76dm^2x 0.80 dm= 5.41 dm^3=5.41 L
m_{water}=2219.6 g
V_{water}= 2219.6/1000= 2.22 L

$$n = \frac{2.22}{5.41} = 0.410$$

Sample 5: ($D_{n,50}$>40mm)
thickness: 160mm
V_{total}= 6,76dm^2x 1.60 dm= 10.82 dm^3= 10.82 L
m_{water}=5039.4 g
V_{water}= 5039.4/1000= 5.04 L

$$n = \frac{5.04}{10.82} = 0.466$$

Sample 6: ($D_{n,50}$>40mm)
thickness: 240mm
V_{total}= 6,76dm^2x 2.40 dm= 16.22 dm^3=16.22 L
m_{water}=7468.2 g
V_{water}= 7468.2/1000= 7.47 L

$$n = \frac{7.47}{16.22} = 0.460$$

2.3 Permeability

The measurements we obtained by the permeability proof are runoff and the water-height. Using these measurements we calculated the filtering velocity and the gradient of the water level between inside and outside of the small reservoir. By controlling the runoff through the sample, we kept the water height in the small reservoir on a certain steady level. In this way we exclude the derivative of the filtering velocity in time. We took five measurements a sample, to have a surer result, also we need at least two measurements to calculate the constants α and β.

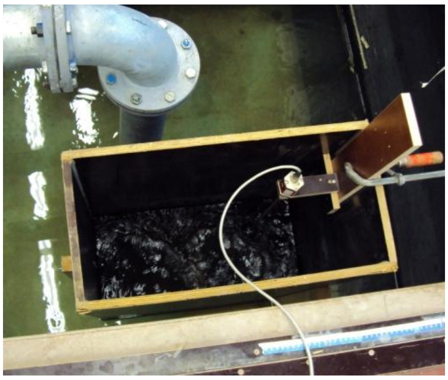


Figure 4 Measuring the water level inside the small reservoir

To determine the permeability, we use the following formulas:

$$\frac{dh}{dx} = i = au_f + b\left(u_f\right)^2 + c\frac{\partial u}{\partial t}$$

$$a = \alpha \frac{(1-n)^2}{n^3} \frac{\upsilon}{gD^2{}_{n,50}}$$

$$b = \beta \frac{(1-n)}{n^3} \frac{1}{gD_{n,50}}$$

$$u_f = k(i)^{\frac{1}{p}}$$

where: υ=kinematical viscosity
n= porosity
$D_{n,50}$= grain size
k= permeability
p=constant=2 (turbulent flow)
dx= thickness sample
dh= water level difference
g= gravitational acceleration=9,81m/s^2

So for each sample we got three results:

- Permeability k
- Constant α
- Constant β

Sample nr.	k	α	β
1	*0.065*	*700*	*1.1*
2	*0.136*	-	-
3	*0.131*	*1200*	*1.25*
4	*0.154*	*1900*	*1.7*
5	*0.214*	*1150*	*1.6*
6	*0.213*	*1020*	*1.45*

We don't have results for α and β for sample 2, because we didn't get a solution out of the equations. We may have done something wrong with the measurements, so the values don't give a solution after putting them in the equations.
We lifted two of the large samples into the wave flume, to observe what will happen. Both samples sure break the waves that hit it and both remain completely and easily intact.

Figure 5. Breakwater sample 3 after testing in wave flume.

3 Discussion

3.1 Assumptions

The most important assumption we made is that the small blocks will have the same porosity and permeability as the big samples. We made this assumption, because they have the same thickness, so the same resistance for the flowing water. The only thing that differs is the surface perpendicular to the flow.

3.2 Possible errors

Human errors
It is possible that the water level meter is wrongly calibrated, which causes wrong values. However, this should not be much taken into account, because we used the difference between values and the difference stays the same.
Incorrectly reading the values of the measurement could also be an error, especially the values showed by the flowmeter were sometimes varying and so difficult to read well. The solution for that was waiting till it was almost steady.

Figure 6. Large breakwater sample 1

Systematic errors

At the sides of the samples, the stones are positioned in a different way, which causes larger gaps between the sides and the stones, because there is not always space for the stones to come between other stones and the side. This is a larger problem by the rocks with the large grain size. This has effect on the total porosity and permeability. With the large samples the effect is smaller due to the larger surface of the samples. This leads to a small difference in porosity and permeability between the big and the small samples.
The thickness of the samples is not completely constant. At the bottom, the sample can be considered as flat, but at the top there are some outstanding stones and some holes. However, we assume that these occurrences will compensate each other.

The calculations of α and β were uncertain, because the results were not the same as expected ($\alpha \approx 1000$ and $\beta \approx 1{,}1$). Nevertheless our calculations of α and β are in the right order of magnitude as the theoretical values. Only the values of sample 2 didn't give us an answer. This can be a result of errors in the calculation or measures, so the values don't give any result after filling in the equations. The values we expected are also just theoretical values and difficult to determine.

4 Conclusion

The conclusion of this research is that it is possible to use Elastocoast to create plates of riprap with the same hydraulic properties as loose rock. As shown by the trial in the wave flume the large samples really work as model breakwater layers and stay intact. This way you can do multiple tests with it in different circumstances with again and again the same properties for the sample. We produced six good useable samples with about its properties.

About our hypothesis: In general, the permeability of the samples with a larger thickness is smaller, but only when you compare them with blocks of the same grain size distribution. Our hypothesis was correct, with the remark that blocks with a smaller grain size have a smaller permeability. The porosity of the samples with a larger grain size is indeed larger than samples with a smaller grain size.

5 Recommendations

We recommend that it is better to test the permeability of the large breakwater samples, because the side effects will then less influence the results, and that the porosity and permeability are really the ones of the sample. A great disadvantage of this is that you have to build a very large setup to test the permeability.

A natural recommendation is that at the edges and the sides have to be sealed in the wave flume, because otherwise a small amount of the flow will go beside the breakwater and the damping will be less effective.

6 References

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