PLACING ACCURACY AND STABILITY OF GEOCONTAINERS

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ABSTRACT: The placing accuracy of geocontainers has been investigated in the field. The positions of 55 geocontainers were measured before and after dumping. The results show the average position and standard deviation in the horizontal position before and after placing as a function of the water depth for depths between 15 and 22 m. The results show only limited placing accuracy is possible at larger depths. The measured standard deviation in the horizontal position was always more than 3 m. Deviation was larger than in previous reported model tests. Extrapolation of the results shows that a standard deviation of less than 1 m can only be expected at water depths of less then 10 m. Apart from the field measurements, the stability of a heap of geocontainers has been tested in a series of model tests. Results of the stability tests have been compared with a calculation model. It was shown that the calculation model was conservative. Results from literature and results presented in this paper are used to derive design rules to estimate the order of magnitude for various design aspects of this type of structure.

Keywords: Geocontainers, placing, stability, design rules

1 INTRODUCTION

Geocontainers are large bags of geotextiles containing up to several hundreds cubic meters of sand or slurry and are dumped by a split barge.
The application of geocontainers in the core of a breakwater or for the construction of bunds may be an attractive alternative for the application of rubble or gravel. A number of successful applications have been reported in literature, see for example Heerten et al. (2002). However, also failure of some of the geocontainers has been reported, Palmerton (1996), VAN OORD ACZ (1994).

An application is successful, if no tearing of the geotextile around the geocontainer occurs, if the containers can be placed with sufficient accuracy and if no slope instability or excessive settlement occurs in the heap of containers under wave attack. The first condition is discussed in Bezuijen et al. (2002[a,b]), the second and third are dealt with in this paper.

Field tests are reported where the position of the barge before dumping was determined and the position of the container on the sea bottom after dumping. The position of 55 containers was recorded in this way before and after dumping. Two containers were instrumented to determine their position during the dumping process and the forces during impact. Results are compared with results of model tests.

The stability of a dam constructed with geocontainers is investigated in model tests.

The paper will describe the field and model tests and concludes with design rules for geocontainer structures, for as far as they can be expressed in simple formula rules.

2 PLACING ACCURACY

2.1 *Field tests set-up*

Field tests were performed during the Kandia Dam project near Arnhem in The Netherlands. Details of the project have been presented in Bezuijen et al. (2002[b]). Geocontainers have been dumped on water depths between 21.6 and 15.5 m as bunds in a previous sand pit in the flood plane of one of the Rhine branches. The dimensions of the geocontainers are presented in Figure 1.

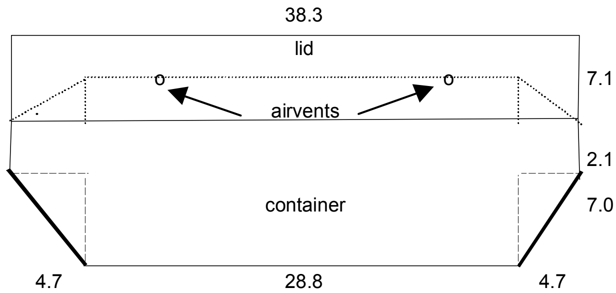

Figure 1. Dimensions geocontainer, dimensions in metres.

The Geocontainers were filled with wet or dry sand, See Figure 2 and Figure 3. Two containers were instrumented with pore pressure transducers, total stress transducers and strain gauges. Results of these instruments have been discussed in detail in Bezuijen et al. (2002[b]) and will not be repeated here.

The geocontainers were dumped in 4 layers with a different depth, see Table 1.

Table 1 : Number of containers dumped at 4 different depths.

Layer	Depth (m)	Number of Geoontainers
1	21.6	13
2	19.7	14
3	17.6	14
4	15.5	14

Grain diameter weight percentages of the fill sand were measured for the first instrumented geocontainer, see Figure 4. D_{50} ranged between 155 and 200 μm. Geolon PP 120S geotextile was used as fabric for the containers.

Figure 2: First instrumented container filled with wet sand.

Figure 3: 2nd instrumented geocontainer filled with dry sand. The picture also shows the location of the strain gauges.

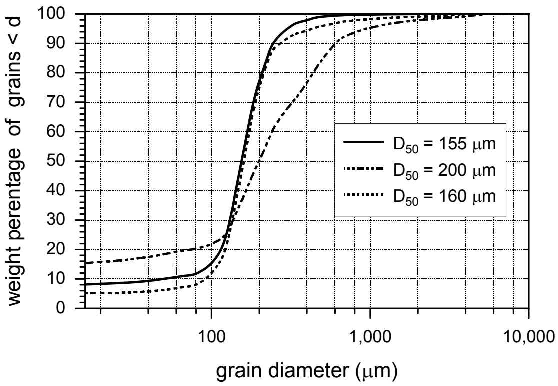

Figure 4: grain size distributions of fill sand.

2.2 *Field test results*

The location of the container before dumping was determined from the position of the barge that was connected to a pontoon. The position of the pontoon was determined by DGPS with an accuracy of centimeters. The position of the geocontainer after dumping was determined by a survey vessel with multi-beam sonar and again a DGPS. The position of the container was found by a difference in the bottom profile of the sand pit found by the sonar before and after dumping. This difference in bottom profile was interpreted by the contractor to determine the position of the container.

Results of this process for the first 4 dumped geocontainers are shown in Figure 5. This figure shows the horizontal positions of the barge hopper and the positions of the containers after dumping. Figures as these were used to estimate the centre of gravity for all geocontainers (this estimation was not very accurate since only the horizontal location of the container had been provided and not the heights of the containers at various positions). The centers of gravity after dumping were compared with the original centre of gravity before dumping (the centre of the hopper in Figure 5) to determine the mean deviation in the placement and the standard deviation parallel and perpendicular to the split barge.

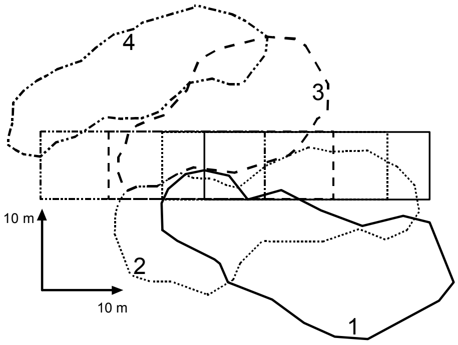

Figure 5: Top view of barge positions and locations of dumped containers for the first 4 geocontainers.

It appeared that the mean deviation between the location of the barge and the position after dumping is no clear function of depth, but the standard deviation in the positions is, see Figure 6. This means that the larger the dumping depth the less accurate the placing.

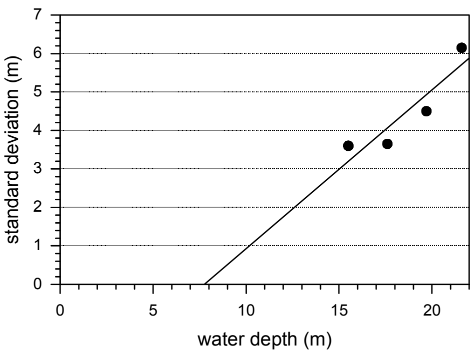

Figure 6: Standard deviation in the difference between barge position during dumping and final location.

2.3 *Comparison with scale tests and numerical modeling*

Model tests have been performed to investigate the placing accuracy (Bezuijen et al. 2002[a]). In these model tests, scale 1:20 the containers were dumped on 0.75 m water depth (15 m in prototype). Tests were run for different wave and current conditions, see Table 2.

The field tests were performed for the conditions without waves and currents. According to the relation derived from the field tests (see Table 5), the standard deviation would be 2.8 m, thus considerably more than found in the model tests (0.8 m). The reason for this difference is not clear, but may have been caused by scaling effects (the model had comparable sand as the prototype and a relatively too stiff geotextile). It is also possible that relative large deviations were measured in the field tests due to not evenly filled containers, air entrapped in one part of the container or damaged containers during dumping.

Table 2. average displacement (m) and the standard deviation of the most important tests (prototype dimensions).

	average displacement (m)		standard deviation (m)	
	H = 0 m	H = 1.2 m	H = 0 m	H = 1.2 m
u = 0 m/s	0.8	4.6	0.8	4.0
u = 0.5 m/s	10.6	16.6	6.4	7.0
u = 1.0 m/s	22.6	24.6	3.6	1.2

The dumping and placing has also been simulated numerically (Klein Breteler et al. 2002). It was found that the horizontal velocity component that causes the placing inaccuracy was caused by rotation of the geocontainer during dumping. It was shown that the horizontal velocity component was acquired close to the bottom and that its magnitude was large enough to explain the measured placing inaccuracy.

2.4 *Falling velocity*

The falling velocity of a geocontainer is determined by both the acceleration due to gravity and buoyancy and drag forces. The drag force (F_d) can be described as:

$$F_d = C_d A_s \rho_w v^2 \tag{1}$$

where C_d is the drag force coefficient, A_s the area of a gecontainer in the horizontal plane, ρ_w the density of the water, v the velocity. When a container is released below the water line, the velocity will increase until a final velocity is reached and the force due the weight of the container is in equilibrium with the drag and buoyancy forces. Assuming a constant shape (which is in reality not the case but can be used as a first approximation), the development of the velocity (v) as a function of time can be written as:

$$v = v_\infty \frac{1 - e^{-2t/\tau}}{1 + e^{-2t/\tau}} \tag{2}$$

with:

$$v_\infty = \sqrt{\frac{2V}{A_s C_d} \frac{\rho - \rho_w}{\rho_w} g} \text{ and } \tau = \sqrt{\frac{2V}{A_s C_d} \frac{(\rho + 1/2\rho_w)^2}{\rho_w(\rho - \rho_w)g}} \tag{3}$$

Where v_∞ is the final velocity at a large depth, V the volume of the container, ρ the density of the container, g the acceleration of gravity and τ a characteristic time indicating the time necessary to reach a certain velocity. The 2nd part of Eq. (3) includes the influence of added mass, the fact that also water have around the geocontainer has to accelerate when the geocontainter itself accelerates. The falling velocity can also be written as a function of the falling depth (Adel, 1996).

$$v = v_\infty \frac{1 - e^{2d'} + e^{d'}\sqrt{e^{2d'} - 1}}{e^{2d'} - e^{d'}\sqrt{e^{2d'} - 1}} \tag{4}$$

with:

$$d' = \frac{d}{v_\infty \tau} \tag{5}$$

The equations show that the final velocity is a function of the density of the container and that apart from the drag coefficient also the shape has an influence (the ratio V/A_s is influenced by the shape of the container). A more accurate, numerical description of the velocity is presented by Klein Breteler et al. (2002). However, the analytical solution presented here appeared sufficiently accurate to calculate the velocity. The numerical solution was, on the other hand, very helpful to explain the placing inaccuracy as mentioned above.

The fall velocity was also determined from the measurements with the instrumented containers. These containers were equipped with pore pressure transducers with measure the increase in water pressure as the depth of the container increases. Differentiation results in the falling velocity. This is not a very accurate measurement, because possible rotation of the geocontainer may influence the result and there is no hydrostatic situation. The velocity of the water around the container will also create a pressure head that influences the measurements. However, the instrumented containers were dumped at the second and third layer at 19.6 and 17.6 m. The pressure due to the water depth is then more than 150 kPa and the influence due to water flow, estimated to be less than 15 kPa, is not very high.

The measured results were simulated using Eq. (2). Calculations were run using the parameters shown in Table 3.

Table 3: parameters for fall velocity calculations.

Parameter	1st container	2nd container
ρ	1924 kg/m^3	1460 kg/m^3
mass container	493 ton	373 ton
A_s	72 m^2	72 m^2
V	256 m^3	256 m^3
C_d	1	1
v_∞	8.0 m/s	5.66 m/s
τ	2.14 s	2.46 s

In this table the first 4 parameters are really input parameters. The lasts 3 were determined using Eq. (3). From these parameters A_s has a significant influence on the results, but is difficult to determine. The length of the geocontainer follows from the length of the hopper in the barge, but during the fall the width depends on the opening of the hopper at the moment the geocontainer leaves the barge and is considerably smaller than the width of the hopper.

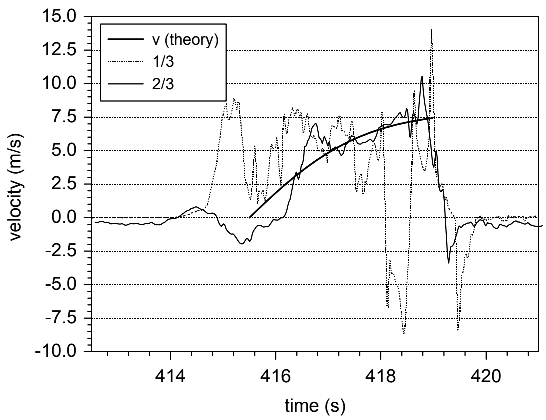

Figure 7: Velocities determined from pore pressure gauges compared with theoretical values. First instrumented geocontainer saturated sand, see also text.

Here we have used the results of small scale model tests to determine the width, but these are normally not available. With this estimate there appears to be a reasonable agreement between measured and calculated velocities assuming that the first instrumented container was saturated with water and the second one dry, see Figure 7 and Figure 8.

The measurements were done a 1/3 and 2/3 of the length of the geocontainer. It is clear from the measurements that the pressure measured outside of the geocontainer during the fall is not only determined by the velocity. The impact on the bottom results in a pressure peak that is incorrectly shown as a velocity peak in Figure 8. Furthermore the container does not fall evenly from the barge (Bezuijen et al. 2002[b]). However, final velocities measured are comparable with the calculated ones.

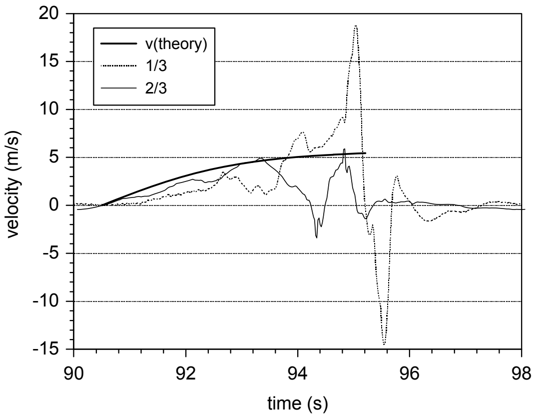

Figure 8: Velocities determined from pore pressure gauges compared with theoretical values. 2nd instrurmented geocontainer dry sand, see also text.

3 STABILITY OF GEOCONTAINERS

The stability of geocontainers has been investigated in small scale model tests, scale 1:20. A structure of containers was made with a slope 1:3.1 (see Figure 9) and loaded with regular and irregular waves.

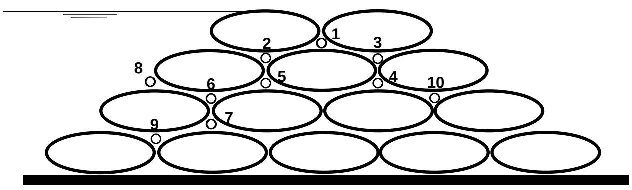

Figure 9: Configuration of geocontainers tested with positions of pore pressure transducers.

Two types of structures were tested. One composed out of geocontainers with a filling percentage of 46 % and another one with a filling percentage of 70%. Filling percentages of geocontainers presented in literature are sometimes confusing. The percentage can be related to the volume of the hopper or to the maximum volume that can be put in a geotextile with a certain circumference. The percentages mentioned here are related to that theoretical maximum determined from the circumference. This means that the 70% fill is not realistic for geocontainers. Such filling percentages can exist in geotubes, but not in geocontainers, because a geocontainer with such a fill cannot leave the hopper. Therefore we will focus on the tests with geocontainers with 46% filling grade. Dimensions of this container are given in Table 4 .

Tests were run with the water level equal to the highest point of the heap of higher. Waves up to 0.3 m could be generated, which corresponds to 6 m in prototype. Pore pressures were measured at various locations in the heap to measure the pressure loading on the geocontainers, see also Figure 9. The main purpose of the tests was to determine the outward pressure gradients; however, here we will focus on the stability of the heap. This stability was remarkable, no damage occurred in the tests. Thus the heap was stable for model waves up to 0.3 m.

Table 4: Model and corresponding prototype dimensions of geocontainers tested.

	height (m)	Width (m)	length (m)	dry weight (kg)
model	0.06	0.37	1.40	49
protype	1.2	7.40	2.80	392.000

Pilarczyk (2000) presents stability formula's for geotubes. These tubes are stable when:

$$\frac{H_s}{\Delta.b} < 1 \quad or \quad \frac{H_s}{\Delta.D} < 1 \tag{6}$$

where H_s the significant wave height, b the width of the tube, D the thickness and Δ can be written as:

$$\Delta = (1-n)\frac{\rho_g - \rho}{\rho} \tag{7}$$

with n the porosity of the sand and ρ_g the density of the grains. As can be seen from Eq. (6), these formulas cannot be used directly for geocontainers. It is assumed in Eq. (6) that b and D are comparable. This may be the case for well filled geotubes, but not for geocontainers where b is much larger than D. The formulation is likely to be too simple; there is no influence of the angle of the heap, nor of the fill material. Furthermore the heap will be more stable if there is some overlapping of the containers. Yet it is attractive to use a formulation as presented in Eq. (7) to describe the stability and with only a limited number of tests available there is no justification for a very complicated formula. As stability formula we chose the second equation of (6), the first one has the theoretical possibility to calculate the stability of a container that is not filled at all, which seems a bit unrealistic. The geocontainers in the tests described here had a D over b ratio of 1 to 6. Pilarczyk (2000) described tests with containers were D/b=4.7. For the tests described here H/(ΔD)>3.7. In the tests described by Pilarczyk failure occurred for H/(ΔD)=2.3.

Large differences in test results and only a limited number of tests introduce a large uncertainty in the stability calculations. However, geocontainers are large elements and that means that stability due to wave attack is in most cases not critical. Based on the limited number of tests available we conclude that geocontainers with b/D>4.7 are stable under wave attack for:

$$\frac{H_s}{\Delta D} < 2 \tag{8}$$

Assuming that there is a regular geocontainer structure with overlapping of the geocontainers. Stability will be less when, for example due to inaccuracy of the placement, there is no good overlapping between the geocontainers. It should be realized that the construction as shown in Figure 9 is a idealized one, as was already clear from the field test section where it appeared that the placing accuracy is limited. It was also proven by small scale model tests where the construction of a dam with geocontainers was simulated under difficult conditions (waves and currents), see Figure 10. Such a irregular structure will have a lower stability than a regular one.

Model tests are recommended for situations where higher values of H/(ΔD) are necessary or conditions differ a lot from the conditions tested here.

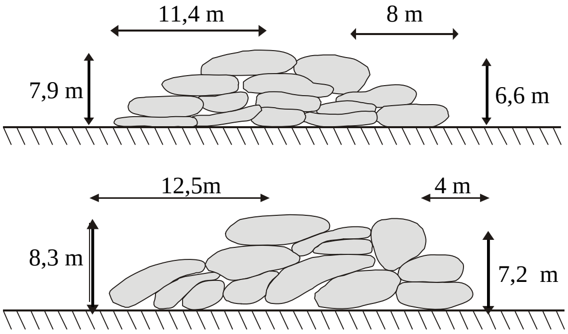

Figure 10: Geocontainer structures realized in small scale model tests (scale 1:20) in waves (1.2 m) and currents (0.5 m/s). Prototype dimensions.

4 DESIGN RULES

Experience gained during the described field tests, but also during other projects, has learned that the first and most important design rule for this type of projects is craftmanship. A lot of small details determine the success or failure of these projects and in most cases there will be a learning curve to get all these 'details' sorted out. The following details have proven to be of importance:
- Fill material. The geocontainer should be filled with clean sand in case of a large water depth. Clean sand can absorb a significant part of the fall energy during the impact on the bottom and reduces the risk of tearing of the geotextile (Bezuijen et al. (2002[a,b])
- Filling of the container. The container has to be filled evenly over the container. If this is not the case, it will fall on one side during the opening and will be hampered in the fall at the other side see Figure 11, this will rather certain lead to a rupture of the geotextile. There is no need to argue whether the geotextile will be loaded with 50 or 70% of the fill weight when the fall is hampered, leading to a much higher loading locally.
- Strength of seams. Loading on the geotextile will be significant during unloading and impact on the bottom. Weakest parts of the container are normally the seams. Therefore the strength of the seams determines the strength of the geocontainer.
- Saturation of the fill. The degree of saturation significantly influences the weight of the container and thus the falling velocity. Therefore this degree of saturation significantly influences the loading on the geotextile during the opening of the hopper and the impact on the bottom. A low degree of saturation also helps to increase the capacity of the sand to absorb energy during impact.
- Quality of barges. Barges that have hoppers with sharp edges will damage the geotextile. Hoppers that open unevenly over the length will result in an angled fall of the geocontainer.

Apart from the craftsmanship there are also design aspects that are of importance. Describing the various design aspects for geocontainers in detail is for some aspects rather complicated; see for instance Pilarczyk (2000). However, a complicated theory is not always necessary, if the aspect is not critical in the design, it is enough just to know the order of magnitude. Based on research performed in the past, Table 5 is composed with this idea in mind. It presents design formulas for different aspects. The criterion was that a formula fits into the table and that the result is on the safe side. More accurate descriptions are available for most aspects, but these require more complicated calculations. Reference to these descriptions is presented in the table.

Figure 11: Geocontainer hampered during the fall from a hopper.

The first formula can be used as an example of the procedure followed. To derive the formula presented in the table it was assumed that in case less than 10% of the fill is still in the hopper, the geocontainer will certainly slide down. The maximum possible loading on the geotexile is therefore 0.9 times the under water weight and the maximum tensile loading is 0.9/2=0.45 the under water weight per meter length. Groot (2003) has shown that for a certain geometry and fill the loading is only 0.5 times the weight.

Such a calculation can be performed if this aspect is critical for the necessary tensile strength of the geocontainer. At water depth of 10 m or more the loading during impact will be greater and there is no need to go into more complicated calculations.

Since for a lot of situations the impact loading is critical, the formula given for that will normally not be sufficient. It does not take into account the dissipation of the impact energy in the fill, which is proven to be an important mechanism for geocontainers filled with sand (Bezuijen et al, 2002[a,b]).

5 CONCLUSIONS

The research described in this paper has led to the following conclusions:
- Placing accuracy of geocontainers is limited at water depths larger than 15 m.
- The fall velocity of a geocontainer corresponds reasonably well with the theoretical description using a C_d of 1.
- Stability of geocontainers under wave attack, as tested in the model tests described, appeared quite high. It is likely that this is partly caused by the regular structure that was made in the model and it is likely that stability is lower if such a regular structure cannot be constructed (for example due to limited placing accuracy.
- For a lot of aspects in the design of geocontainers it was possible to present relatively simple formula to estimate the order of magnitude. More complicated calculations will be necessary for the aspects that appeared critical in the design. However, it should be realized that craftsmanship is very important for a successful geocontainer project and can hardly be described with formulas.

6 ACKNOWLEDGEMENTS

We thank Rijkswaterstaat, Waterbouw Innovatie Steunpunt and Delft Cluster for permission to publish the results of this research and Fernhout Contractors for their cooperation during the field tests.

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8 LIST OF SYMBOLS

A cross-sectional area perpendicular to the axis of the geocontainer.
A_s maximum cross-sectional area in the horizontal plane.
b width of geocontainer or geotube.
b_0 opening width of the barge.
C_d drag coefficient
d water depth.
d' $=d/(v_\infty\tau)$ characteristic water depth.
D thickness, or height of geocontainer.
E' stiffness modulus of geotextile .
F_d drag force.
g acceleration of gravity.
H wave height.
H_s significant wave height.
L length of the geocontainer.
n porosity.
S circumference perpendicular to the axis of the geocontainer.
t time.
T tensile strength.
u_{cr} critical current
v velocity.
v_∞ end velocity of container when dumped in water.
V volume of geocontainer.
W' under water weight of geocontainer.
Δ see equation (8).
ρ density fill.
ρ_g density grains.
ρ_w density water.
σ_p standard deviation in placing accuracy.
τ characteristic time, see equation (3).

Table 5: Formulas to determine the order of magnitude of various aspects in the design of geosystems, see also text.

Aspect	Formula	literature	More information	Remarks
Loading during opening	$T = 0.45\frac{W'}{L}$		Bezuijen et al. (2000), De Groot (2003)	Conservative approach chosen, normally not critical.
Circumference	$S = 2.5(\frac{A}{b_0} + b_0)$	Den Adel et al. (1996)	Bezuijen et al. (2000)	
Falling velocity	$v = v_\infty \frac{1 - e^{2d'} + e^{d'}\sqrt{e^{2d'} - 1}}{e^{2d'} - e^{d'}\sqrt{e^{2d'} - 1}}$	this paper, Eq. (4)	Klein Breteler et al. (2001) present a numerical solution	See Eq. (3), and (5) for the explanation of the parameters
Placing accuracy	$\sigma_p = 0.4d - 3.2 \quad d > 8m$	this paper, Figure 6	Bezuijen et al. (2002)[a] Results of model tests.	Model tests + experience other projects indicate higher placing accuracy.
Impact loading	$T = v\sqrt{\frac{A\rho E'}{S}}$	Den Adel et al. (1996) modified	Bezuijen et al. (2000), Bezuijen et al. (2002)[a,b]	Formula takes not in account energy dissipation by the fill.
Width and height of geocontainer	$b = 0.32S + 0.57\sqrt{0.1S^2 - 1.27A}$ $d = 1.6A/b$	Schaap (1999)	Leshchinsky (1995,1996) Bezuijen et al. (2000)	
Stability in waves	$\frac{H_s}{\Delta D} < 2 \quad for \quad b/D > 6$	This paper	Pilarczyk (2000)	
Stability in currents	$\frac{u_{cr}}{\sqrt{g\Delta D}} < 0.5\,to\,1$	Pilarczyk (2000)		Limited information available.