Forces in geocontainer geotextile during dumping from barge

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Keywords: Coastal works, Design method, Failure, Geotextiles, Installation damage

ABSTRACT: The application of geocontainers is usually only economically attractive if the containers are large enough. However, the forces on the geotextile during the dumping process increase with the size of the geocontainer and bring about the risk of bursting. A qualitative survey of the results of recent research to predict these forces is presented. Application of the results to some typical examples is discussed. It is shown that the forces in the geotextile during release of the container are largely influenced by any cohesion or other internal friction in the soil and by the friction between geocontainer and barge bottom/wall. The largest forces, however, usually occur during the falling on the bed. Significant reduction of these forces by energy absorption of the soil in the bed or in the container, only occurs if the bed consists of soft clay or the container soil consists of sand with some air in its pores. In other cases forces in the order of 500 kN/m are to be expected for containers with a cross sectional area of 40 m^2. Larger geocontainers go along with larger forces and may not be feasible.

1 INTRODUCTION

A geocontainer is a very large, soil filled bag, fabricated in the bin of a split barge and released at the site, under water, by opening of the barge (Figure 1). Sand filled geocontainers are successfully applied in harbor and coastal engineering as shore protection, bunds for reclamation works or cores of breakwaters. Geocontainers are also used to store and isolate contaminated slurries as obtained from harbor dredging. In most cases, however, they are only economically attractive if their sizes are large enough. The forces on the geotextile increase with increasing size. Bursting of geocontainers may occur, especially during the process of dumping from a barge, as has been observed several times.

The prediction of forces in the geotextile of a geocontainer during dumping from a split barge is the subject of this paper. Such prediction requires a full description of the processes involved. This topic was discussed at EuroGeo 1 by den Adel et al (1996). The results of recent research have been presented by Pilarczyk (2000, chapter 6). This papers focuses on the application of these results to some examples.

Attention will be paid subsequently to the following stages of the dumping process:

- the release of the container from the barge
- the falling through the water
- the falling on the sea- lake or riverbed.

The process is influenced by the geometry of the split barge, the size of the container, the degree of filling, the unit weight of the soil, the air content of the soil, the friction between barge bottom and geotextile, the internal friction in the soil, water depth, the stiffness of the sea bed and the possibly uneven shape of the sea bed. Equations have been developed to describe these influences and to quantify the relevant design parameters. The general background of these equations will be discussed briefly in this paper and the most important results of their application will be presented. Practical measures meant to improve the design will be discussed.

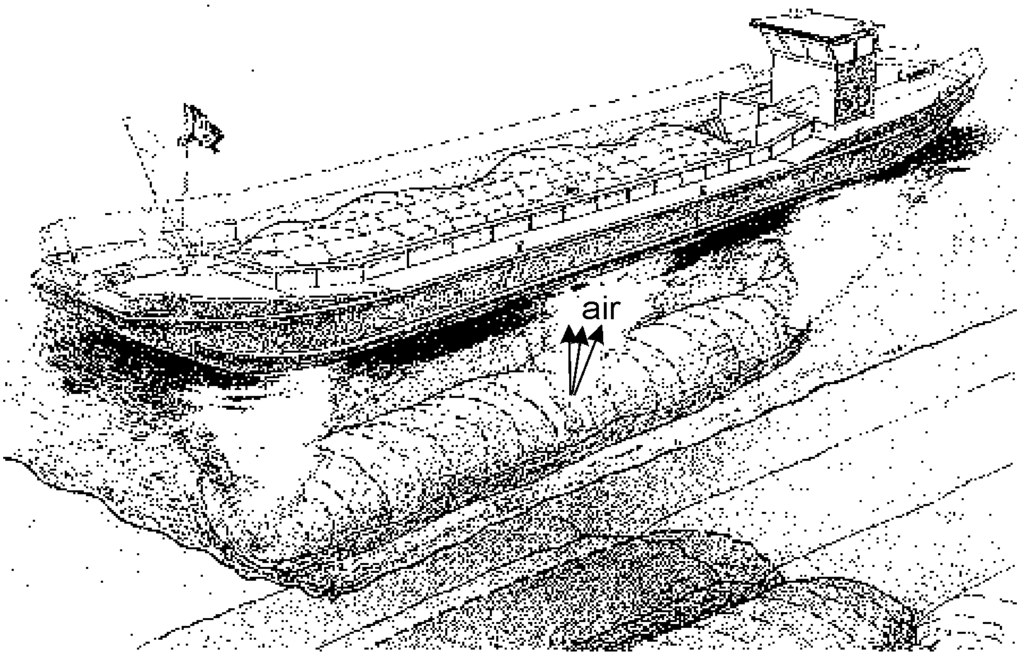

Figure 1. Artist impression of geocontainer dumped from split barge

2 INTRODUCTION

2.1 *Qualitative description*

The following sub-stages can be distinguished during the release of the geocontainer from the barge (Figure 2):

I Stretching of the lower part of the geotextile during first opening of the barge

II Nearly undeformed descent of geocontainer down the bin (the end of this sub-stage is shown in the figure)

III Bulging part of the geocontainer through the opening until sliding of geocontainer through opening or until stretching of whole geotextile around container

IV Further bulging with geotextile stretched around the fill until sliding of the geocontainer through the opening and out of barge (this stage only if geotextile perimeter small enough)

The sub-stages can be described briefly as follows:

ad Sub-stage I

Before the split barge is opened, the geotextile is perfectly aligned with the split barge. At first opening of the barge, friction between the geotextile and the barge bottom/wall keeps the geotextile fixed to the two upper parts of the bottom/wall, as if the geotextile is nailed to these bottom/wall parts. The two sides move apart and the distance between the two “nails” increases. As a result the lower part of the geotextile in the middle in between the two “nails” is stretched and is lifted up to compensate for the increased distance (the hypotenuse of a triangle is shorter than the sum of the two sides). This part of the geotextile no longer aligns with the barge bottom, but hangs freely above it.

The stretching causes a tensile force in the lower part of the geotextile. The width of the free-hanging part across the opening and the tensile force increase during further opening of the barge.

This continues until the tensile strength is so large that the other parts start to slide over the barge bottom.

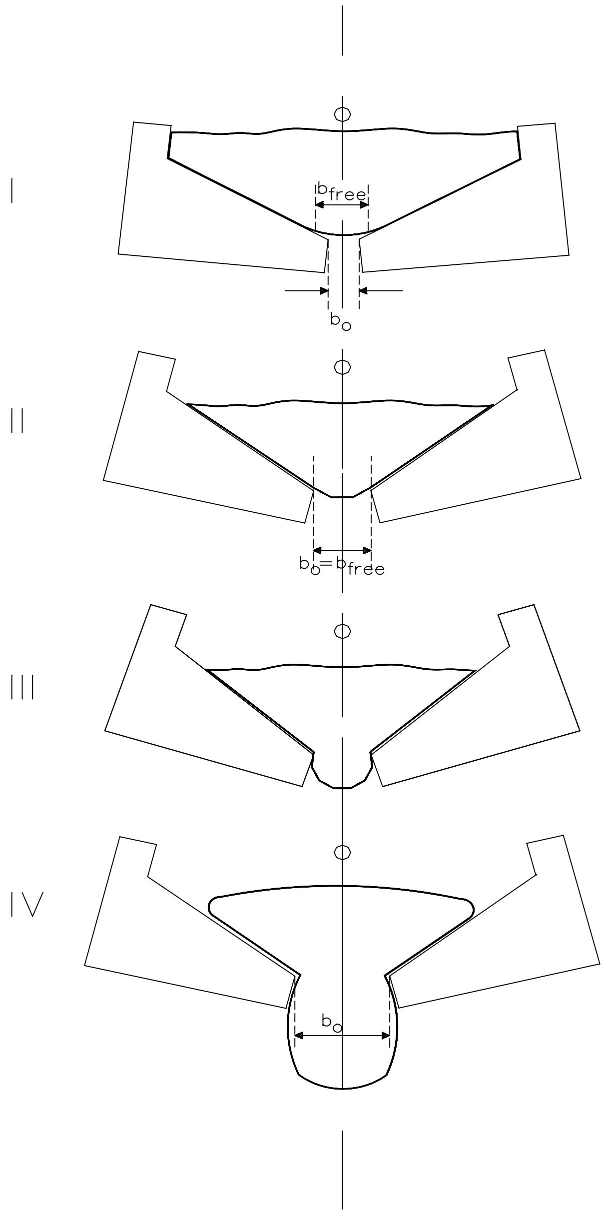

Figure 2. Sub-stages of geocontainer release from the barge

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ad Sub-stage II

This sub-stage starts when the tensile force in the stretched part of the geotextile has grown so high that the parts of the geotextile along the two upper parts of the bottom/wall start to slide along the barge bottom/wall. The soil moves together with the geotextile while pressing the geotextile to the bottom/wall. In this way the geocontainer (= geotextile + soil) descends without much deformation, sliding along the barge bottom/wall. The width of the free-hanging part in the middle, b_{free}, remains nearly constant and enables the geotextile to span the opening distance between the two jaws, b_o, because $b_o \leq b_{free}$ during this sub-stage.

ad Sub-stage III

Sub-stage III starts when the barge opening width, b_o, becomes so large that the adjacent geotextile parts are no longer completely supported by the barge bottom: $b_o > b_{free}$. The weight of the soil above the barge opening is so large that it presses the geotextile between both jaws: the lower part of the geocontainer deforms and passes through the opening and a bulge forms.

The opening width, however, is still small enough to allow for equilibrium. Sliding down of the soil in the middle above the barge opening is counteracted by the increasing vertical component of the tensile force in the lower part of the geotextile and by the friction inside the soil, if available. Sliding down of the whole geocontainer is still counteracted by the friction between wall/bottom and geotextile. As soon as the process of opening stops ($\partial b_o/\partial t = 0$), the deformation and descending of the geocontainer also stops.

This sub-stage ends when b_o reaches the value b_{slide}, for which just no equilibrium is possible. The whole container starts to slide through the opening, while the opening width remains constant. In this way, the geocontainer passes, while deforming, through the opening, if the perimeter of the geotextile is large enough. During this stage: $b_{free} \leq b_o \leq b_{slide}$.

ad Sub-stage IV

Sub-stage IV is only relevant if the perimeter of the geotextile is relatively small and causes the sliding to stop after some deformation of the geocontainer. This occurs if the increasing deformation of the whole geocontainer causes such an increase in the soil perimeter that this perimeter becomes equal to the perimeter of the geotextile. Then, the geotextile is stretched around the whole container, the corresponding increase in stiffness of the container limits further deformation at constant barge opening and a new equilibrium arises. In the last case further opening of the barge causes further bulging, whereas equilibrium is present again for each value of b_o.

This stage ends when the barge opening width reaches the critical value, b_{crit}, for which just no equilibrium is possible and the whole container passes, while deforming, through the opening, while the opening width remains constant. During this stage: $b_{slide} \leq b_o \leq b_{crit}$.

2.2 *Some results of quantitative description*

Equations have been developed for each sub-stage *(Pilarczyk 2000)*. Some results are presented here for one example and several of its variants. The example concerns a geocontainer made in a split barge with the cross section sketched in Figure 3.

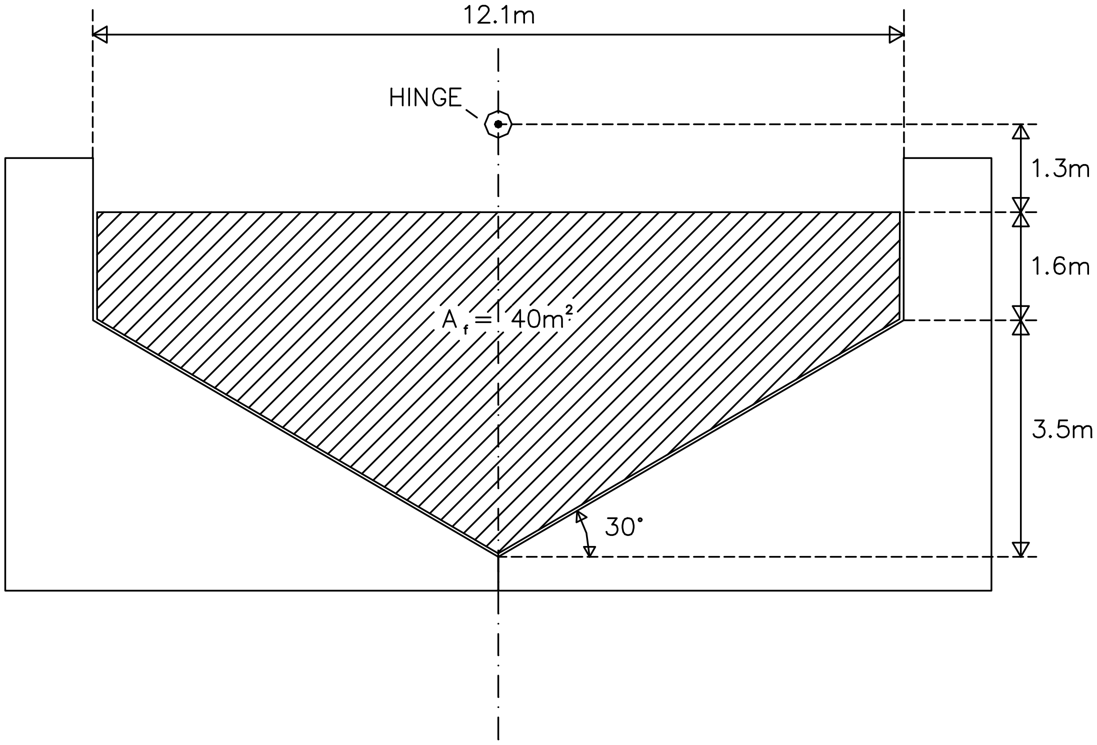

Figure 3. Example

The main cross section characteristics of the geocontainer are: cross section area, A_f = 40 m^2, and perimeter of the geotextile, S = 33 m. At the seabed, this geocontainer will have a width of about 11 m and a height of 3.5 to 4 m. The example geocontainer is filled either with a frictionless slurry with a unit weight of γ_s = 14 kN/m^3 or with a cohesive slurry with the same unit weight and a cohesion of c = 1 or with sand with a unit weight of γ_s = 18 kN/m^3 and an angle of internal friction of φ = 30°. The friction factor between geotextile and barge bottom, μ = 0.3. The whole container is assumed to be under water at the end of the sub-stages III and IV. Some results of the calculations are presented in Table 1.

- b_{free} is the width over which the lower part of the geotextile in the middle is lifted up from the barge bottom/wall and hangs freely above it at the end of sub-stage I and during sub-stage II
- b_{slide} is the value of the opening width, b_o, at which the geocontainer starts to slide down at the end of sub-stage III
- b_{crit} is the value of the opening width, b_o, at which the geocontainer is released from the barge bin at the end of sub-stage IV
- T_{max} is the maximum tensile stress in the geotextile. It occurs in the cases with slurry at sub-stage IV; in the case with sand at the end of sub-stage III.

Table 1. Some results of calculations

	b_{free}	b_{slide}	b_{crit}	T_{max}
Example with frictionless slurry	1.3 m	1.4 m	2.2 m	28 kN/m
Example with cohesive slurry	0.8 m	2.9 m	2.9 m	60 kN/m
Example with sand	0.4 m	5.7 m	5.7 m	190 kN/m

Several parameters have been varied to find their influences on the results. These can be summarized as follows:

Soil friction

The soil friction is especially relevant for a sand filled container. Traditional theories consider the container as if filled with a heavy, frictionless liquid. They find too small barge opening sizes at which the container would fall out of the barge and consequent incorrect forces in the geotextile. The influence of the soil friction is illustrated by the calculation results in the table and can be explained with the help of Figure 4. The value of b_{free} is reduced by friction. This is caused by the fact that the friction hinders the uplift of the middle part of the soil by the stretching of the lower part of the geotextile. The stretching induced tension force in this part of the geotextile increases earlier, which causes the start of sliding along the barge bottom to start earlier.

During the next sub-stage, however, the soil friction works in the other direction and causes the value of b_{slide} to increase with the soil friction. When filled with sand the soil turns from an active to a passive state. The horizontal effective stress increases considerably enabling a large friction stress along the vertical boundaries of the middle part of the soil: arching effect or silo effect.

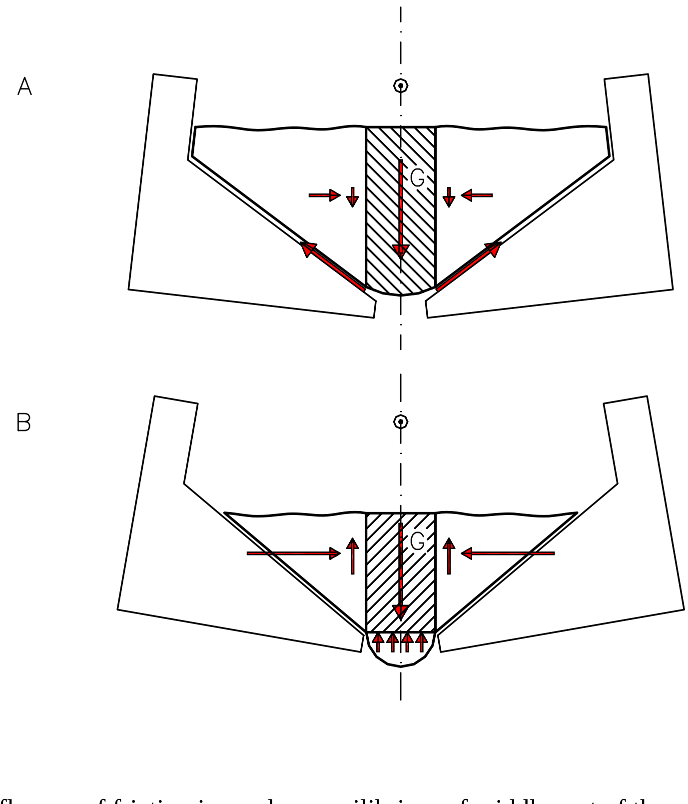

Figure 4. Influence of friction in sand on equilibrium of middle part of the soil

Friction between geotextile and barge bottom, μ.

This factor has a very large influence on b_{free} and b_{slide}, if frictionless slurry is applied: with μ = 0.1 instead of 0.3, $b_{free} = b_{slide}$ = 0.4 m; with μ = 0.5 instead of 0.3, b_{free} = 1.4 m and b_{slide} = 1.8 m. If slightly cohesive slurry is applied (cohesion s = 1 kPa) and if μ = 0.5 instead of 0.3, b_{slide} = 5.3 m. If sand is applied, the influence is smaller. The maximum tensile force in the geotextile, T_{max}, is roughly proportional to μ, if slurry is applied and if the perimeter of the geotextile is so large that it has no influence on the soil perimeter. Otherwise the influence of μ is smaller.

Influence of soil unit weight, γ_s..

The unit weight of the soil does not influence b_{free}, b_{slide} or b_{crit}. The tensile force in the geotextile, however, is proportional to $\gamma_s - \gamma_w$, where γ_w is the unit weight of the water.

Influence of limited geotextile perimeter, S.

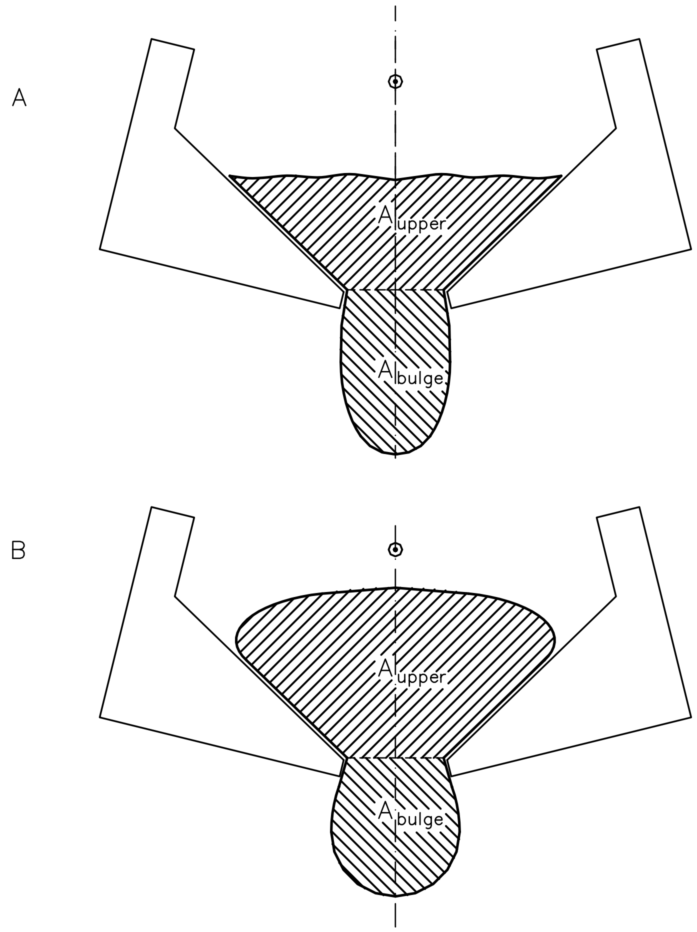

Figure 5. Influence of limited length of geotextile perimeter, S, on release from barge

The influence is illustrated in Figure 5 and Figure 6. The perimeter of the soil increases during formation of the bulge. If the geotextile perimeter is very large, it does not influence the soil perimeter (Figure 5A). The unlimited soil perimeter, S^*_{free}, increases until it reaches a maximum when the bulge is roughly as large as the upper part of the container ($A_{bulge} \approx A_{upper}$ in Figure 5). In many cases, however, the geotextile perimeter, S, limits the soil perimeter and stretches around the soil. This stretching has 3 effects:

- increase in curvature of the soil perimeter, S*, such that it remains limited to the geotextile perimeter: S* = S.
- increase in soil stress, which hinders the deformation of the container required to pass through the barge opening and makes further opening of the barge necessary.
- increase in maximum geotextile tension, T_{max}.

The maximum curvature is sketched in Figure 5B and the corresponding perimeter is indicated as S^*_{mc}, for the case of Table 1 with frictionless slurry and for the value b_o=b_{crit} =2.2 m is presented in Figure 6. It can be observed that, for this case, S lies in between S^*_{free} and S^*_{mc}, which means that the actual curvature is strong but not extremely strong. The value of the soil perimeter corresponding to this actual curvature is indicated with S*. The influence of the limited geotextile perimeter is relatively small with cohesive slurry and sand, as the value of b_{slide} is relatively large and, consequently, the increase in S* is relatively limited.

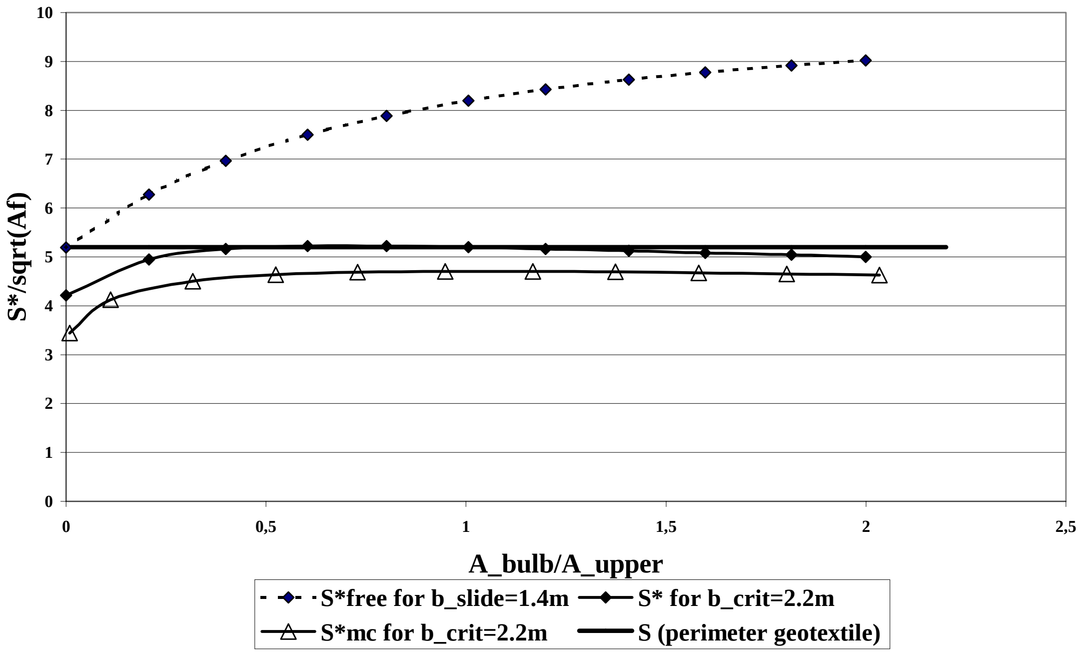

Figure 6. Example of changes in soil perimeter as a function of descend out of barge

3 FALLING THROUGH THE WATER

The falling through the water yields the boundary conditions for the impact of the container when hitting the seabed. The container may fall parallel to the sea-bed, but also non-parallel, yielding a loading concentrated at just a part of the container. Generally the geocontainer starts to accelerate downwards as soon as it has been released from the barge. It continues to accelerate until the forces by gravity and flow resistance reach equilibrium and it falls with a constant velocity. Theoretically, an infinite falling depth is needed to reach this velocity; in practice a limited depth is sufficient to arrive at a nearly equal velocity, as illustrated in Table 2. The values in Table 2 are based on the assumption of C_D = 1.0, where C_D is the drag coefficient.

Table 2. Some results of the calculated fall velocities at the moment of hitting the bed

	Falling depth = 3 m (waterdepth ≈ 13 m)	Falling depth = 10 m (waterdepth ≈ 20 m)	Infinite falling depth
Example with slurry $\rho_s = 1400$ kg/m^3	3.4 m/s	5.2 m/s	6.2 m/s
Example with sand $\rho_s = 1400$ kg/m^3	4.4 m/s	6.9 m/s	8.7 m/s

An interesting feature for sand filled containers is the compression of the grain skeleton if the pores of the sand are partly filled with air (unsaturated sand). The water pressure outside the geocontainer increases during the fall downwards. The pore pressure in the middle of the container, however, remains nearly the same, because a pore pressure increase in unsaturated sand requires a flow of water into the pores to compensate for the volume reduction of compressed air. Such a flow can hardly take place in the brief falling period due to the flow resistance in the outer part of the container sand (Figure 7).

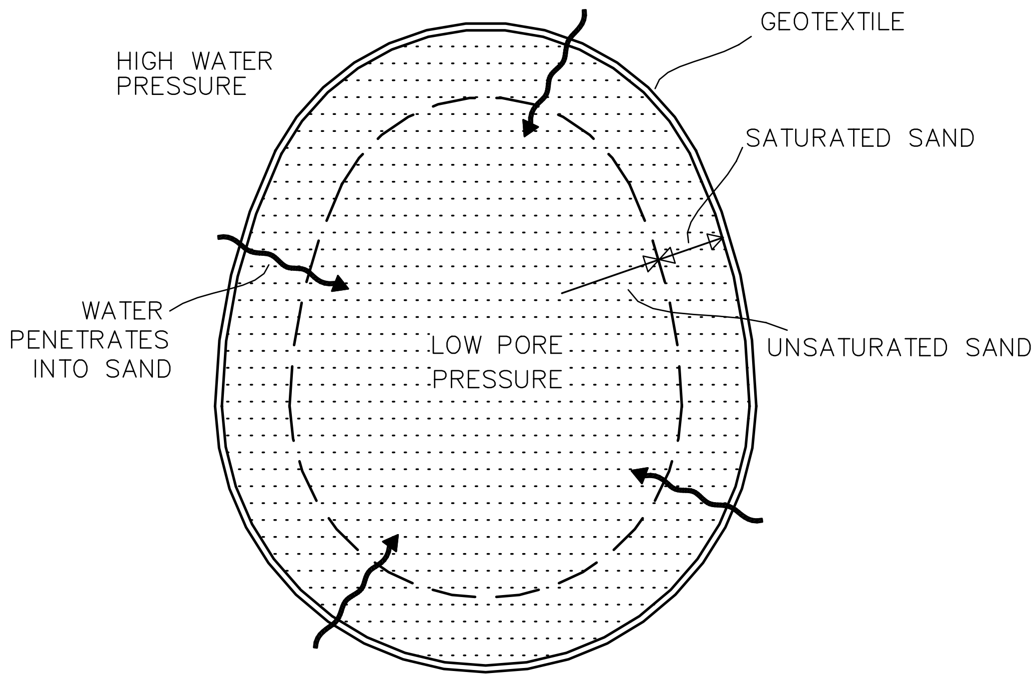

Figure 7. Grain skeleton compression of sand filled geocontainer during its fall through water

As a consequence, the grain stresses (“effective stresses”) and the resistance to deformation increase temporary. This can be considered as a temporary increase in undrained shear strength, c_u. Calculations have been performed for the above described sand filled geocontainer, assuming a permeability of $k = 10^{-4}$ to 10^{-3} m/s, as to be expected for clean fine or medium fine sand and an air percentage in the order of 1%. The following undrained shear strengths are found:

– $c_u \approx 70$ kPa for a falling distance of 3 m
– $c_u \approx 110$ kPa for a falling distance of 10 m.

With finer sand even an air percentage of 0.3 % may be sufficient to create a temporary undrained shear strength with this order of magnitude.

4 FALLING ON THE BED

The extreme loading of the geotextile usually occurs when the container hits the sea-, lake- or river bed, especially with frictionless slurry filled containers falling on a bed of dense sand, solid clay or rock. Such soils in the bed do not absorb a significant part of the kinetic energy of the geocontainer and the deforming soil in the container doesn't absorb any energy either.

As soon as the container touches such a sea-, lake- or river bed, it starts to deform: the height decreases, while the width increases. The kinetic energy of the vertical downward moving container is transformed into kinetic energy of the two halves of the container moving horizontally in opposite directions. The halves are only kept together by the geotextile. This is stretched under increasing stress and absorbs in this way all the kinetic energy, at least if the elongation and the strength are sufficient.

Assuming an elongation of 10% in the geotextile of the above described geocontainer filled with frictionless slurry, the average maximum tension is found to be:

- $T_{10} \approx 250$ kN/m for a falling distance of 3 m
- $T_{10} \approx 600$ kN/m for a falling distance of 10 m.

It must be realized that these values are average values for the whole container. Uneven falling, an uneven bed and other secondary effects most likely bring about higher forces at some locations. Such forces can only be met if the geotextiles are very strong and very high quality sewing is performed.

More favorable is the case of frictionless slurry filled containers falling on a bed of soft soil. Plastic deformation of such soils goes along with absorption of part of the kinetic energy of the falling container. According to calculations, the undrained shear strength of the sea bed soil should be smaller than ca 20 to 40 kPa to have this effect for the geocontainers of the example above. Then, 30 % to 100 % of the kinetic energy is absorbed and the tensile force in the geotextile reduces to less than 70 % of the above given values. If the soil strength is larger, no plastic deformation occurs and the energy absorption is practically zero.

The forces in the geotextile are even more reduced in case of sand filled containers, even when falling on a relatively solid bed. At least this is the case if the above-described effect of grain skeleton compression takes place. Even with half the c_u - values predicted above, all the kinetic energy is absorbed by the soil in the container during the process of deformation of the cross section from more or less circular to oval or rectangular with height much smaller than width.

In a similar way it is found that the energy absorption by the soil in the container of the example above with cohesive slurry is limited to 5% to 10% of the kinetic energy. Significant energy absorption by cohesive slurry is only possible if the undrained shear strength is much larger than 1 kPa. In that case, however, it will be very difficult to have the container released out of the barge.

5 CONCLUSIONS

The following can be concluded from the previous analysis:

1. During the release of the container out of the barge the maximum tensile force in the geotextile is influenced as follows:
   - A high soil friction, as with sand, causes a high tensile force
   - The force is roughly proportional to the coefficient of friction between geotextile and wall, μ, unless the geotextile perimeter is relatively small
   - The force is proportional to the under water unit weight of the soil

– In case of frictionless slurry the maximum force is determined by the perimeter of the geotextile, S, if this relatively small: $S/\sqrt{A_f}$ < ca 4.5, where A_f is the cross sectional.

2. The largest forces in the geotextile usually occur during the falling on the bed.
3. Nearly all kinetic energy from a slurry filled geocontainer falling on a normal bed, must be dissipated by the stretching of the geotextile. The geotextile must have a large strength and low stiffness to avoid tearing.
4. Significant reduction of the geotextile forces due to energy dissipation by the soil of the sea-, lake- or river bed only occurs if the soil consists of soft clay.
5. The kinetic energy of a sand filled geocontainer falling on the bed may be completely dissipated by deformation of the container sand, due to the compression of the grain skeleton, at least with fine or medium fine sand if the pores are not completely saturated.
6. It may not be possible to enlarge the size of slurry filled geocontainers above the largest size, used up to now, i.e. with a cross section area of about 40 m^2 if forces in the geotextile larger than about 500 kN/m must be avoided. It is due to the fact that the actual available strength in the geotextile is about 1000 kN/m and that the strength of the seams is roughly half this strength. Larger slurry filled geocontainers may become feasible if a more gentle dumping method will be developed. Larger sand filled geocontainers may be feasible with the present dumping method.

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