

CHAPTER 133

USE AND BEHAVIOR OF GABIONS IN COASTAL PROTECTION

Kees d'Angremond¹, M.ASCE
Egbert J.F. van den Berg²
Jan H. de Jager³

Abstract

To limit erosion during severe storms, it is considered to apply a hard core in a dune, prior to beach nourishment. One of the potential structural alternatives is a gabion protection. The behavior of gabions was studied. It appeared that the rigidity is a factor that cannot be neglected in model investigations. Full scale tests have been carried out to establish the flexibility in prototype. A model material was developed to reproduce the flexibility on model scale.

Introduction

Erosion of sandy coasts is a well known phenomenon. It may be an ongoing process, caused by a gradient of the longshore transport, or it may be an alternating process, mostly caused by the cross section adapting itself to varying wave conditions. In many instances, the erosion will be noted first by a narrowing of the beach. Subsequently, the dunes along the beach will erode as well. In densely populated areas, or areas with a high recreational value, this process leads inevitably to loss of infrastructure and property and to a cry for remedial measures.

¹ Professor of Coastal Engineering, Delft University of Technology, Faculty of Civil Engineering, P.O.Box 5048, 2600 GA Delft, The Netherlands.

² Msc. Student, Delft University of Technology.

³ Koninklijke Wegenbouw Stevin, Celciusstr. 6, 1704 RW Heerhugowaard, The Netherlands.

Over the years, landowners have tended to choose for the most direct way of protection through the construction of seawalls and revetments. The latter method is not always favored by the coastal engineers because of the risk of undermining of the foundation in case of ongoing erosion. A wide variety of technical solutions is available nowadays, ranging from the construction of (offshore) breakwaters and groins to extensive beach nourishment schemes. Especially the option of beach nourishment has the advantage that the recreational function of the beach is maintained in the best possible way. Landowners, however, keep their reservations with respect to this method as it is mostly not a permanent solution and needs to be repeated from time to time. Extreme weather conditions short before a planned replenishment may still cause erosion of the dune face, and may consequently lead to damage of property.

In the Netherlands, this type of damage causes little concern with the Central Government, as the function of the dune as sea defense is not jeopardized. Local authorities and landowners, however, would like to prevent too frequent occurrence of such damage. The cost of remedial measures must therefore be low. For this reason, it is frequently considered to construct a hard element inside the dune when the coast is being restored (Figure 1).

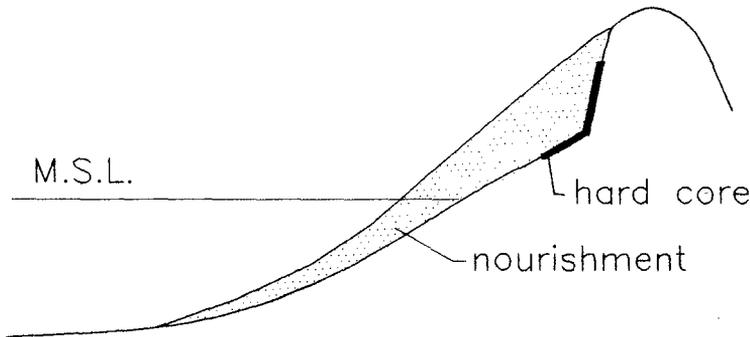


Figure 1. Hard core in dune.

In future storms this core may prevent erosion to make rapid progress. The core is not supposed, however, to survive extreme storms and to protect the hinterland from flooding under the most extreme conditions. Examples of such structures are available (or rather hidden under the sand) at various locations along the Dutch coast. Here again, however, the main risk is the undermining of the toe of such structures.

Flexible Toe Protection

To prevent this erosion of the toe it is good engineering practice to provide an anti scour apron in front of the toe. The apron is constructed at the actual beach level, or slightly below, to prevent large quantities of excavation during construction. When the apron gets exposed, it should settle along with the erosion of the beach in front of it, and thus prevent the scour hole to reach the actual structure. It is evident that both, the apron and the structure must be flexible enough to follow the settlements, and that it should be heavy enough to resist the wave forces. Asphalt, fascine mattresses, geotextile covered with riprap are known materials for this kind of application. They all have their specific advantages and disadvantages. Recently, also the use of gabions has been suggested for this purpose in the Netherlands, as this may lead to considerable savings with respect to the cost of armor. Although there are examples of a satisfactory performance of gabions in other countries, not all reports were favorable. Therefore, it was considered useful to study the behavior of gabions once more. One of the most important questions was in how far the gabions would settle along with the deformation of the seabed directly in front. Model investigations into this effect are hampered till now by the impossibility to scale down the flexibility of the gabion mattresses. The flexibility of the gabions may influence at the same time the stability under wave attack.

Flexibility of Gabions

To obtain insight into the flexibility of gabions, full scale tests have been performed on mattresses with varying fill rate. The dimensions of the mattresses were 4.00 m x 2.00 m x 0.5 m (L x W x t). A single test was carried out on a mattress of 0.3 m thick.

The gabions proper consisted of steel wire mesh, twisted in a hexagonal pattern as shown in Figure 2. The characteristic size D amounted to 8 cm. The steel wire had a diameter of 2.7 mm, and was coated with PVC, resulting in a gross diameter of 3.8 mm. The tensile strength of the wire material amounted to 380-500 N/mm².

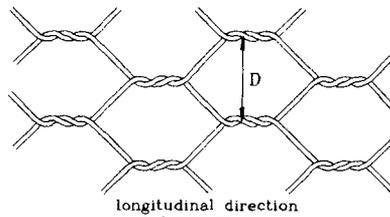


Figure 2. Wire mesh.

The gabions were filled with gravel with a density of 2600 kg/m^3 , and dimensions between 80 and 120 mm. The bulk density was measured and amounted to 1550 kg/m^3 , resulting in a porosity of about 40 %. The fill rate was determined by weighing the fill material and converting the weight into volume by using the measured value of the bulk density. The fill rate is defined as the ratio between the volume of the fill material and the nominal volume, $L \times W \times t$. The test conditions are summarized in Table 1.

Test no.	Thickness (mm)	Fill rate (%)
1	500	105
2	500	105
3	500	110
4	500	110
5	500	110
6	500	100
7	500	95
8	500	85
9	300	110

Table 1. Test Conditions

The stiffness was determined by lifting the mattresses in longitudinal direction, and measuring the curvature. Results of the tests have demonstrated the very high flexibility (or low stiffness). Originally, it was envisaged to derive a stiffness (EI) from the tests, and to relate the value of E to the fill rate of the gabions. The deformations, however, were so large that the normal theory of elastic bending could not be applied any more (Figure 3).

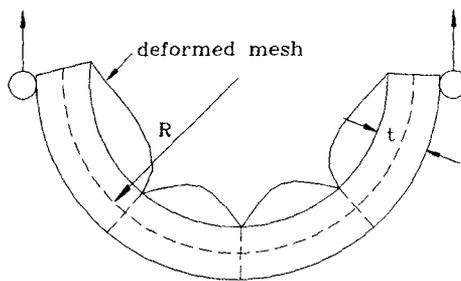


Figure 3. Deformation during lifting.

From the test results, it appeared that the gabions when lifted adapted with a reasonable accuracy to a circular shape. The diameter of the circles showed a direct relation to the fill rate (Figure 4).

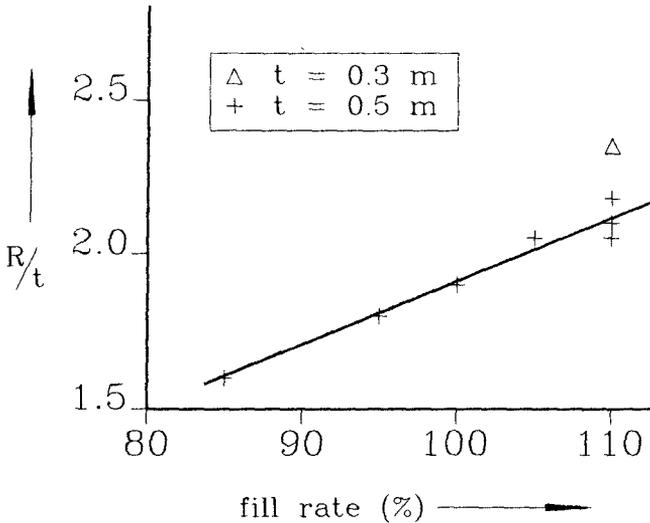


Figure 4. Results stiffness test.

Scaling

In order to prepare scale model tests with gabions in a dune base, one should analyze which effects need to be reproduced in the model, and which effects can be neglected for the time being. The main design aspects are:

- stability under wave attack
- erosion at the toe
- deformation of the toe
- sand tightness

When testing the stability under wave attack, one should ascertain the wave climate at the toe of the structure. This wave climate is fully determined by the water depth in front of the dune, and as such determined to a large extent by the (eroded) level of the foreshore. Unfortunately, erosion of the foreshore is not reproduced adequately under the scales that are usually applied for stability tests. The eroded level of the foreshore is therefore determined with the aid of the mathematical model DUROSTA, which in turn is based on large scale model experiments. Steetzel, 1990). For the actual stability tests, thus, a fixed bed model can be used with a calculated bottom profile. A similar procedure can be followed when stability is calculated on the basis of a Hudson-type formula. When selecting the scale for stability tests, proper attention shall be paid to the permeability in the model. To avoid complications in the transition between laminar and turbulent conditions inside the gabions, model material should preferably be larger than 1 cm diameter, which leads to model scales in the order of 1:10 to 1:20.

The erosion process at the toe of the structure is largely affected by the ratio between orbital velocities and the fall velocity of the sediment. This effect causes strict limits for model scales to be applied, as the grain size of the model material can not be reduced infinitely. Traditionally, this problem is solved by accepting distorted model scales. In case of a combination of morphological and stability problems, application of distorted models is not well possible, since distortion leads to different slopes in model and prototype. Proper reproduction of both phenomena in the same model necessitates model scales in the order of 1:5 to 1:10.

Deformation of the toe itself is a complicated process, which is initiated by erosion creeping forward under the edge of the structure. The extent of this process depends on the capability of the structure to follow the deformation without losing its coherence. It is evident that the flexibility of the structure should be similar in model and prototype. On the basis of the experiments described above, it is necessary that model gabions demonstrate a similar deformation when lifted. In general, model gabions tend to be far too rigid. Initially, two different model materials have been developed. One is consisting of model gabions made out of fabric, and filled with small size gravel. The flexibility is adjusted by manipulation of the fill rate. The other consists of a (fabric) base material of the proper flexibility, covered with artificial ballast. Before making a final choice, it was realized that another process influences the deformation, i.e. loss of base material through the voids of the structure. Although the idea of losing base material seems against the proper functioning of the structure, a closer look leads to a different judgement. By a controlled loss of material, it will be easier to achieve a condition where the toe structure will slowly follow the eroding bed, and eventually bring the erosion to a halt.

It is clear now that requirements for sand tightness must be defined in two different ways for the main body of the structure and for the toe. As sand tightness is ensured in prototype by the application of geotextile under the gabions, this can be done in model as well. The quality of the geotextile can be tested separately. The model scales are therefore hardly affected by considerations of absolute sand tightness. To reproduce the controlled loss of material from the deforming toe, it must be attempted to keep the ratio between base material and filter material constant. This leads to model scales in the order of 1:5 to 1:10, and to the selection of model gabions instead of a base with fixed ballast.

Design

Before any model tests could be carried out, a preliminary design had to be made. It was decided to select a frequent problem area along the Dutch coast near Egmond as an example. The deep water design wave height was estimated to be around 8 m. Taking into account the erosion in front of the core and the storm surge level, wave heights up to about 2.5 m height could be expected just at the toe of the structure.

For reasons of hydraulic and soil mechanical stability, the main slope was designed under 1:3 between a level of M.S.L. + 2.5 m to M.S.L. + 8.0 m. This part of the slope should be sand tight and statically stable. Sand tightness is achieved by the application of geotextile under the gabions. To avoid local fluidization and micro loss of stability it is considered necessary to apply a layer of gravel in between gabion and geotextile. (Negative experiences reported elsewhere may be due to omission of such layer).

In front of this slope a toe is foreseen under a slope 1:10. As it is the purpose that this part of the structure will follow deformation of the sand bed, sand tightness is deliberately reduced here by leaving out both, geotextile and granular filter.

To initially assess the required thickness of the gabions, use was made of model experiments reported by Brown (1979). According to his studies the stability can be expressed in a Hudson-type stability formula:

$$H/\Delta t = C(1-n) (\cot(\alpha))^{1/3}$$

wherein

H	=	Wave Height in m
t	=	Thickness of gabion in m
C	=	Coefficient
n	=	Porosity
α	=	Slope Angle
D	=	Relative Density

It must be noted, however, that derivation of stability on the basis of mechanical analysis would lead to the use of $(1-n)^{1/3}$ instead of $(1-n)$. Fortunately, the variation in the porosity n is limited.

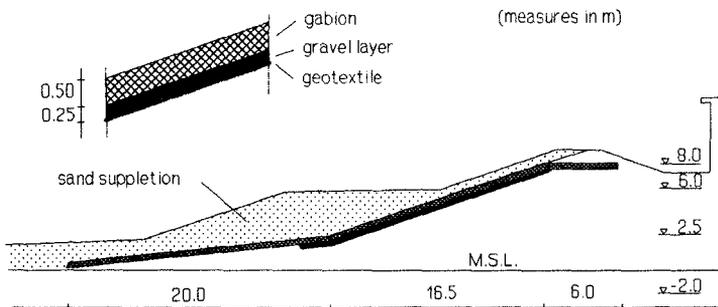


Figure 5. Design of dune core.

Pilarczyk et al(1987) have converted the Brown formula for irregular waves, leading to the expression:

$$H_g / \Delta t = 4 (1-n) (\cot(\alpha))^{1/3}$$

Here again, $(1-n)$ is used instead of $(1-n)^{1/3}$.

Under the prevailing design conditions this leads to a value of 0.5 m for t , the thickness of the gabions. A schematic design of the cross section is given in Figure 5.

Model Tests

Due to space limitations, it was not yet possible to carry out model tests on the structural design according to the preferred model scale 1:10. Instead, preliminary tests had to be performed on a linear scale 1:20. The prototype sand diameter of 0.24 mm was reproduced in model by a material with a grain size of 0.11 mm. Conditions in the flume could be reproduced in such a way that a scour hole of about 2.5 m deep developed right in front of the toe, well in line with the calculated scour depth. As can be noticed from Figures 6 and 7, the toe of the gabion structure was able to follow the erosion and thus to prevent undermining of the actual 1:3 slope.

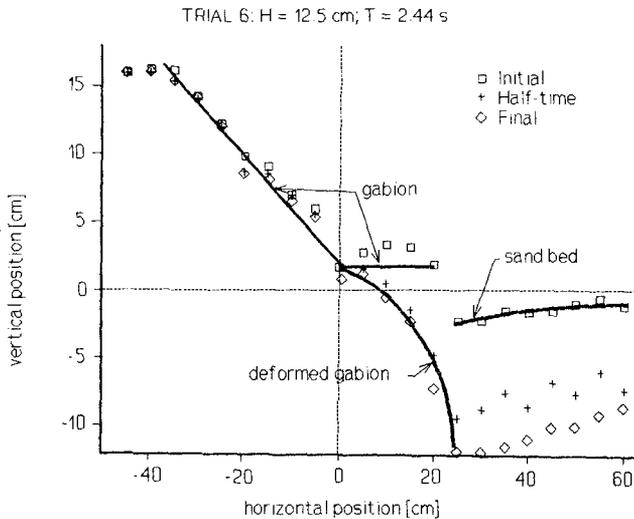


Figure 6. Erosion at flexible toe.

Further Research

The results of the investigations so far have demonstrated the possibility to design a satisfactory structure using gabions. The tests will have to be continued on a larger scale to further analyze problems of sand tightness and stability. These tests shall also make clear why in some cases gabion structures did not perform



Figure 7. View of scour test.

satisfactorily where they certainly did in other conditions. It is the present preliminary conclusion that failure in some cases was due to (micro) loss of stability due to the absence of a granular layer between gabions and geotextile.

References

- Brown, C.T., 1979. Gabion Report. The University of New South Wales Water Research Laboratory, Manly Vale, N.S.W., Australia.
- Pilarczyk, K.W., et al., 1987, Guidelines for the Design and Construction of Flexible Revetments incorporating Geotextiles for inland waterways, PIANC working Group I/4, Supplement to Bulletin no. 57, ISBN 2/87223/000/9, Brussels.
- Steezel, H.J., 1990, Cross-Shore Transport during Storm Surges, Proc. 22nd Int. Conference on Coastal Engineering, Delft.