ComCoast

ComCoast

Development of Alternative Overtopping-Resistant Sea Defences

Phase 2: Elaboration of Smart Grass Reinforcement Concept

Interreg North Sea Region

Development of Alternative Overtopping-Resistant Sea Defences

ComCoast WP 3

This report has been prepared by Royal Haskoning.

The ComCoast project is carried out in co-operation with ten partners.

- Rijkswaterstaat (NL - leading partner)
- Province of Zeeland (NL)
- Province of Groningen (NL)
- University of Oldenburg (D)
- Environmental Agency (UK)
- Ministry of the Flemish Community (B)
- Danish Coastal Authority (DK)
- Municipality of Hulst (NL)
- Waterboard Zeeuwse Eilanden (NL)
- Waterboard Zeeuws Vlaanderen (NL)

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ComCoast

Work package 3
Smart Grass Reinforcement

Development of Alternative Overtopping-Resistant Sea Defecences

Phase 2: Elaboration of Smart Grass Reinforcement Concept

Final Report

Acknowledgement:
This report is a deliverable of WP 3 "Smart Grass Reinfocement"
The work is performed by Royal Haskoning
The report is written/edited by K.A.J. van Gerven, J.W. van der Meer, M.A. van Heereveld, G.J. Akkerman

SUMMARY

In the present report, a Smart Grass Reinforcement for overtopping resistant sea defences is elaborated on a theoretical basis, within the framework of ComCoast, Work Package 3 (WP3).
This study follows the terms of reference of 5th April 2005, issued by CUR in their request for proposal for new concepts and the proposal by the consortium between Royal Haskoning and INFRAM dated 9th May 2005. In this proposal, the approach for developing a smart solution for grass reinforcement has been indicated. Two other concepts have been proposed as well in this proposal. The grass reinforcement concept was awarded for further study by CUR at 26th May 2005.

The outcome of the present study has been discussed with the User Group and EU Team of WP3 of ComCoast at 20th October 2005. The comments and answers to the questions raised in the comments are attached to this report (Annex 4).

The smart grass revetment concept aims at strengthening the present grass revetments at the crests and inners slopes of sea embankments. 'Smart' denotes a significant reinforcement of the grass revetment, a high-cost effectiveness, easy installation with minimum disturbance of the existing grass revetment, hidden presence and thus invisible, and durable. In addition, the system should have no environmental adverse impacts.
The major innovative aspect of the Smart Grass Reinforcement is in the installation method, for which we tried to identify a geosystem and an installation method that do not require (permanent) removal of the present grass cover.

For the present study our consortium sought the co-operation of specialized grass installation and supplier firms, i.e.: Flevo Green Support at Lelystad and Queens Grass at Drouwen. Their experience in grass raising and handling (de- and re-instalment of grass covers) was important for this study. Within this co-operation, site visits were made to Queens Grass at Drouwen and a firm that harvests flower bulbs and plants, without removing the grass cover: Geerlings BV at Noordwijkerhout. In addition, Alterra has been consulted, for their knowledge on grass vegetations related to maintenance strategies.
Finally, the Hondsbossche Sea Defence and the North Frysian Sea Defence (grass test sections for studying the effect of maintenance strategies) have been visited in order to get insight in the feasibility of the meanwhile developed ideas in true field situations.

Two, potentially feasible, concepts have been identified:
1. Geogrid system, to be placed underneath the temporary lifted (thin-cut) grass layer;
2. Geocell system, to be penetrated through the existing grass revetment, without lifting it.

The Geogrid system can be applied at a rather flat surface and good grass cover.
The Geocell system can be applied as well at a more uneven surface and a poor grass cover.

The proposed application of these systems is new, as far as we know, and some engineering (system, equipment and installation) still needs to be done. At this point, we believe that this will lead to a successful and highly cost-effective application. A cost indication shows that smart application of the Geogrid and Geocell systems will reduce the costs by a factor 10 or more, as compared to raising the crest of the dike.

In addition, the risk of applying a smart reinforcement system is much smaller than of regular dike strengthening (raising and extending dikes), as the recovery time of the grass revetment is very short (months at the most) as compared to some years.
We recommend the systems to be tested during the anticipated field tests in the ComCoast WP research programme Phase 3.The engineering should preferably be done by the end of this year, in order to be able to apply the smart systems at the field test section by the end of April 2006. This will allow proper field testing in the summer and/or winter of 2006.

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1.1 Mission statement ComCoast

MISSION OF COMCOAST (= COMbined functions in COASTal defence zones)
ComCoast is a European project which develops and demonstrates innovative solutions for flood protection in coastal areas.

ComCoast creates and applies new methodologies to evaluate multifunctional flood defence zones from an economical and social point of view. A more gradual transition from sea to land creates benefits for a wider coastal community and environment whilst offering economically and socially sound options. The aim of ComCoast is to explore the spatial potentials for coastal defence strategies for current and future sites in the North Sea Interreg IIIb region.

ComCoast Goals:
- developing innovative technical flood defence solutions to incorporate the environment and the people and to guarantee the required safety level;
- improving and applying stakeholder engagement strategies with emphasis on public participation;
- applying best practice multifunctional flood management solutions to the ComCoast pilot sites;
- sharing knowledge across the Interreg IIIb North Sea region.

ComCoast Solutions:
Depending on the regional demands, ComCoast develops tailor-made solutions:
- to cope with the future increase of wave overtopping of the embankments;
- to improve the wave breaking effect of the fore shore e.g. by using recharge schemes;
- to create salty wetland conditions with tidal exchange in the primary sea defence using culvert constructions or by realigning the coastal defence system;
- to cope with the increasing salt intrusion
- to influence policy, planning and people
- to gain public support of multifunctional zones.

ComCoast runs from April 1, 2004 to December 31, 2007. The European Union Community Initiative Programme Interreg IIIB North Sea Region and the project partners jointly finance the project costs of 5,8 million.

1.1.2 Information

Information on the ComCoast project can be obtained through the Project Management, located at the Rijkswaterstaat in the Netherlands.

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1 INTRODUCTION

1.1 Background

In this report a new concept, i.e. a 'smart' reinforcement method of grass revetments at sea embankments, is elaborated as to contribute to overtopping-resistant sea defences. This theoretical study is being carried out within the ComCoast programme, Work Package 3 (WP3). ComCoast is an acronym for 'Combined functions in Coastal Defence Zones, an innovative concept awarded with European assignment within the Interreg IIIb programme.

The elaboration of this grass reinforcement as presented in this report, follows the terms of reference of 5 April 2005, issued by CUR in their request for proposal for new concepts and the proposal by the consortium of Royal Haskoning and INFRAM dated 9 May 2005[1]. In this proposal, the approach for tackling the elaboration of this concept has been indicated. Two other concepts have been indicated as well in the proposal. However, only the aforementioned reinforcement of the grass revetment was awarded for further theoretical study by CUR on 26 May 2005.

The activities as presented in this report are scheduled as Phase 2, within the context as outlined below:
- Phase 1: generation of alternative concepts;
- Phase 2: theoretical phase;
- Phase 3: testing phase.

Hence, the outcome of this study will be used for further practical testing in Phase 3, provided that the feasibility is positive.

The Smart Grass Reinforcement concept is focused on cost-effective applications for strengthening the grass revetment at the crest an inner slope of the sea defences, as to cope with increased wave overtopping rates. An important feasibility criterion will be the effectiveness of this concept as compared to raising of the crest level of the defences.

Two locations at the Dutch coast, known as 'weak sports' in the coastal defence system, serve as reference pilot locations: the Hondsbossche Zeewering and the Westkapelse Sea Defence. In the present report the potential application of the concept at the Hondsbossche Zeewering is included as well. In addition, issues for the testing phase will be briefly dealt with and a preparation meeting on Phase 3 will be attended.

Basis for the development of the Smart Grass Reinforcement is the state-of-the-art inventory that had been prepared earlier by Royal Haskoning and INFRAM for ComCoast Work Package 3 (Royal Haskoning, 2005[2]).

The present report will be presented in a partner meeting and comments will be incorporated in the final version.

[1] Royal Haskoning and Infram, 2005: ComCoast WP3, ***Development of Alternative Overtopping-Resistant Sea Defences, Proposal for Concepts,***
commissioned by CUR/ RWS DWW, 9P8624.C0, May 2005.
[2] Royal Haskoning, 2005: ComCoast WP3, ***State-of-the-art inventory,***
commissioned by CUR/ RWS DWW, 9P8624.A0, March 2005.

1.2 Description of activities for elaboration of the Smart Grass Reinforcement

The following deliverables have been indicated in the terms of reference:
- A technical report in which the characteristics of the new concept, as mentioned briefly in the proposal, are elaborated more in detail;
- Indicative design of the solution for the pilot location Hondsbossche Sea Defence at one characteristic cross-section;
- A description of required permits and risks involved;
- Participation in the testing phase preparation meeting.

The indicative design for the Hondsbossche Sea Defence will focus on the type of reinforcement and its application, rather than on the design. This may be obvious from the hidden presence of the reinforcement.

The characteristics to be elaborated more in detail are (according to the terms of reference):
- Description of the concept, including the innovative aspects and position w.r.t. the Inventory Study
- Discussion of quality of the concept
- Allowable overtopping
- Relevant failure mechanisms
- Construction aspects and risks
- Life time expectancy of the concept
- Maintenance aspects
- Indicative impacts on 'LNC' values
- Relevant experience
- Indicative costs for construction & maintenance

It is remarked here that a more detailed study of the hydraulic aspects is included in the previous item 'Allowable overtopping' and temporary removal and re-installment of the grass sods will be included in the item 'Construction aspects and risks'.

1.3 Co-operation and projectteam

For the present study, the co-operation was sought with an expert of Alterra in Wageningen, Dr. Dick Melman (contribution in knowledge of characteristics of grass-systems), Flevo Green Support in Zeewolde and Queens Grass in Drouwen (handling of de- and re-installing grass sods and existing reinforcement methods). The representative of Flevo Green Support is Mr. Bert Hoiting. The representative of Queens Grass is Mr. Freek Rienks. Within the present study, a site visit was paid to Queens Grass in Drouwen and the Hondsbosssche Zeewering as well as the Nord- Frysian Sea Defence (grass test location). In addition, the consortium paid a site visit to a firm that harvests tulip bulbs by uplifting and lowering the soil: Geerlings Cultuurtechnisch Bedrijf & Machineverhuur, Noordwijkerhout. These site visits gave insight in the potentials of different methods for application of the reinforcement and led to the identification of a wholly new machine for the Smart Grass Reinforcement Concept.
The co-operation of the persons mentioned above is greatly appreciated.

Within the consortium the project was carried out by the following key-staff:
Mr. Gert Jan Akkerman (Royal Haskoning: team leader)
Dr. Jentsje van der Meer (INFRAM: deputy team leader and sea defence expert)
Mr. Michel van Heereveld (Royal Haskoning: design specialist)
Mr. Koen van Gerven (Royal Haskoning: project engineer)

1.4 Contents of this report

After the introduction in the present Chapter, the characteristics of the Smart Grass Reinforcement concept is described in Chapter 2. In Chapter 3 the potential application of the Smart Grass Reinforcement on the Hondsbossche Sea Defence is indicated. Next, in Chapter 4 conclusions are drawn and recommendations are given indicating points of interest for further testing in Phase 3. References are gathered in Chapter 5.

Detailed information supporting the findings in Chapter 2, are included in Annexes:
- Annex 1: System description of feasible systems;
- Annex 2: Analysis of wave overtopping and stability tests;
- Annex 3: Site visits and identification of installation methods;
- Annex 4: Comments User Group and EU team 20th October and answers.

2 CHARACTERISTICS OF THE NEW CONCEPT

2.1 Brief description of the Smart Grass Reinforcement concept

For details, please see Annex 1.

2.1.1 Definition of a Smart Grass Reinforcement system

The indication of 'smart reinforcement system' refers to some criteria that are specific for application at primary sea defence embankments:
- Optimum reinforcement of stability of crest and inner slope;
- Highly cost-effective as compared to raising the dike crest;
- Easy application with minimum disturbance of existing grass revetment;
- Invisible en hidden (at some distance below the surface of crest and slope);
- No adverse environmental impacts (landscape, vegetation, animals and humans).

A 'smart' concept aims at a high score at the above mentioned points, e.g. using innovative techniques for installation.

2.1.2 Position of the present smart system as compared to the grass reinforcement system as mentioned in the Inventory Study

The major improvement of the present grass reinforcement as compared to that in the Inventory Study is the elaboration of a practical way of installation of the system without definite removal of the present grass revetment. This has lead to other types of systems and other methods of installation. In addition, 'smart' performance indicators as shown above are better satisfied.

2.1.3 Selected Smart Grass Reinforcement systems

The development of the concept and selection of the most feasible systems was done by gaining increased insight in the above mentioned points. An important selection criterion was the feasibility to apply the system with minimum disturbance of the present grass revetment, avoiding seeding and growing of a new grass cover.

Finally, two potentially feasible systems have been identified:
1. 'Geogrid' system: a thin, open and strong geotextile grid ('netting') that can be reeled to a roll and unrolled during installation;
2. 'Geocell' system: a cellular system that can be fold into thin slab and unfold into a cell structure before installation.

As far as we know, these systems have not yet be applied at sea dikes to cope with wave overtopping conditions. Moreover, additional engineering on the present systems will be required, e.g. assessment of the optimum configuration and dimensions of the Geogrid, and the height, stiffness, configuration of holes and cell dimensions of the Geocell.

An impression of these systems is given in the figures below.

Figure 2.1: potential Geogrid system
Source: www.geosyntheticproducts.com

Figure 2.2: potential Geocell system
Source: Presto Products Company

Related to these systems, specific methods for application have been identified:
For the application the Geogrid two methods seem to be feasible:
1. 'Big Rolls' solution;
2. 'Uplift' solution.

After the the field visits and discussions with experts, it was concluded to favour the Uplift solution and to develop it further into a new application, which requires a new piece of installation equipment (see Section 2.5).

For the Geocell system these methods do not apply, mainly because the height of the cellular system is too large for unrolling. Instead, this system should be penetrated into the subsoil, cutting through the existing grass revetment, so without removing or lifting the grass cover. For more details on these constructional methods see Section 2.5.

The Geogrid system, to be placed at a depth of say 5 to 10 cm below the surface, may be feasible in well-maintained grass cover layers, e.g. maintained extensively. The surface should also be not too uneven. The reason of this is that the cover layer, when cut during uplifting, should remain intact. The relative flatness is of importance to reduce the layer thickness to be cut to say 10 cm at the most.

The Geocell system may be feasible as well at more uneven surfaces and for poorer grass covers and poorer substrates. The major reason for this is that the soil does not need to be temporarily displaced and will, when properly executed, hardly be disturbed by the penetration of the Geocell system.

2.2 Discussion of quality of the concept

Primary aspect of the quality of the concepts as outlined above is the improvement of the stability of the reinforced grass revetment, by which the overtopping rate can be increased. The stability improvement implies failure mechanisms to become less critical with reinforcement than without reinforcement.

The Geogrid or Geocell are expected to considerable add to the stability, as these systems provide a stable structure within the grass revetment, in which the roots will be intertwined with the grid (Geogrid) or in which they will especially be contained (Geocell). This contributes to the coherence of the vegetated topsoil as a whole. The systems can also absorb a surplus of forces acting on the revetment, by tensile stresses (Geogrid) or by sheltering the grass sods within the cells (Geocell). The occurrence of cracks or fissures in the surface (e.g. near the edge of crest and inner slope or core) may be avoided or mitigated by these systems, so saturation of the inner slope will be less, which is favourable for reducing the risk at shallow slip failure. A prerequisite is that the systems are not only applied at the inner slope but also over the crest and that they are well-anchored as to provide a stable structure on its own. A further improvement against slip failures can possibly be gained by adding vertical pins to the systems.

The quality of the concept can also be seen from other aspects as indicated in the following sections in this Chapter.
Hereafter a summary of qualities is given, based on the findings from this Chapter and from the Annexes. The qualities are assessed against the reference, i.e. raising of the dike crest.

	Geogrid	***Geocell***	***Reference***
reinforcement	Comparable		
cost-effectiveness	+	+	-
nature potentials	Comparable		
LNC impact	0	0	-
maintainability	Comparable		
proven technology	-	-	+
recreational potential	0	0	-
sensitivity to vandalism	Comparable		
sustainability (lifetime)	Comparable		
scenic quality	0	0	-
risk during/after construction	0	0	-

Table 2.1: Review of score of grass reinforcements as compared to raising the dike crest

Is it assumed that the reinforcement is able to cope with a similar overtopping rate increase that causes the dike crest to be raised, assessed at 1.2 m for the Hondsbossche Sea Defence case (Royal Haskoning & Infram, 2005).
Apart from the lack of experience, the grass reinforcement scores higher or the same as the reference. Especially the cost-effectiveness and the considerable risk reduction during and after construction is much better than for the reference.

2.3 Allowable overtopping

A detailed analysis of overtopping characteristics (loading) as well as overtopping resistance (from tests) of grass covered slopes is presented in Annex 2. The statements below are based on this analysis.

Whereas loading parameters are quite well-understood and predictable, knowledge on overtopping resistance is largely based on experimental data from flume experiments in which stationary overtopping has been applied. Translation of stationary loading towards the dynamics of wave overtopping is difficult, while during a very short period (e.g.

seconds or minutes during a storm) extremely high flow velocities will occur that have not been covered in the long-duration stability tests thus far (for more details see Annex 2).

The present theoretical phase will therefore not lead to quantitative answers on the potential stability improvement. Rather, an indication of the stability improvement will be arrived at by engineering judgement considering the qualitative effect on the failure mechanisms.

In Annex 2 it is indicated that the present overtopping standard in the Netherlands of 1 l/s per m for non-reinforced grass covers, may imply a short duration flow velocity of 5 m/s during a total duration of 9 seconds (3 waves) for a 6 hour storm. This example shows that extremely high velocities can be attained during wave overtopping. Good grass covers are able to withstand a flow velocitiy during some time, e.g. some hours. Increasing the overtopping standard for reinforced grass to e.g. 10 l/s per m, will further increase these extreme velocities to some 7 m/s. At the other hand, dislocation and instability of a grass cover needs some time to manifest itself, so very short extreme peaks will not be as detrimental as follows from long duration stationary tests.

An indication of the enormous resistance of vegetation for a short duration impact comes from observations of the impact on a vegetated area of large waves generated during (sideways) launching of a vessel in the province of Groningen, 27 January 2005 [3]. In spite of the enormous wave overtopping (with an overtopping rate guessed at 0.5 to 1 $m^3/s/m$), damage to the vegetation did not occur. The huge impact is illustrated in Figures 2.3 and 2.4 below.

Figure 2.3: approach of overtopping wave

Figure 2.4: overtopping wave hitting vegetation

We anticipate that the reinforcement systems as proposed here will improve the stability of the grass over layer and supporting clay layer in different ways (see also Section 2.4):

- Improvement against ***surface erosion*** by the improved intertwinement of the roots (Geogrid) and/or by improved coherence of the grass sods (by containment Geocells);

[3] Royal Haskoning, 2005: Observation of wave overtopping, generated during launching of a ship, commissioned by Rijkswaterstaat DWW, 9R1347.A0, February 2005.

- Improvement of the resistant against ***shallow slip failures***

We think that this reinforcement is potentially capable to let reinforced grass cover survive a tenfold increase in overtopping rate, or more.

The very open structure of the Geocell implies that there is no influence on the permeability of the subsoil. For the Geogrid with holes in the membranes, there will be limited influence on the permeability along the slope and no influence on the permeability perpendicular to the slope.

It is obvious that the anticipated stability improvements need to be verified in a quantitative way through field testing in Phase 3, and that a realistic overtopping rate distribution, representative for true wave overtopping, will be required for this testing.

2.4 Relevant failure mechanisms

For the overtopped embankment as a whole, relevant phenomena and failure mechanisms are shown in Figure 2.5.

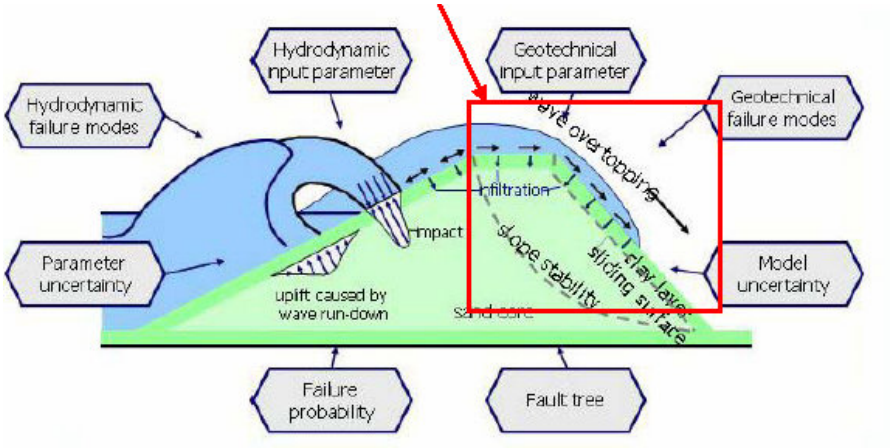

Figure 2.5 Sketch of phenomena and failure mechanisms in wave overtopping

Macro-instability (deep slip failure) of the inner slope and/or crest can be considered as not relevant for the present Dutch primary sea defences, as the inner slopes is quite gentle nowadays (generally about 1:3).
Referring to the total stability of the dike, it should be remarked that a further increase of outside water levels and wave heights in future will give rise to increased inward 'pressure' on the dikes. However, the design water levels for sea defences are still that far below the crest (e.g. 4 to 5 m), and the dikes are so voluminous as regards the gentle outer and inner slopes, that danger of a complete collapse of the dike will practically be absent. However, this assumption only holds when the dike structure has a solid base and when no large-scale piping occurs. Be as it is, increasing the strength of the inner slope and crest will not add to the stability against a complete collapse, so the defences will have to be checked for this failure mechanism anyhow.

It is remarked here that river dikes experience a totally different situation. Floods along rivers will give water levels very near to the crest of the dike and shallow slip of inner slope and crest, micro instability (by outward seepage water flow) , piping and uplifting of the hinterland may be triggered by the large water level difference

between the river and the hinterland. In addition, the extreme loads on the river dikes can sustain for a long period of many days or even weeks.
The most striking difference with sea dikes is that these dikes are much higher than the storm surge levels and that the loading is relatively short due to the tidal movement.

The remaining failure modes for grass slopes on sea defences are:
1. surface erosion: grass pulled out, dislocation of grass sods, rolling up of 'turf' layer (TAW, 1997), development of gulleys;
2. shallow slip failure: slip failure of the turf layer (0.2 to 0.3 m below surface) or of the clay layer (0.5 to 1.0 m below surface);

The shallow slip failures are often accompanied by uplift as a result of strong seepage flow.

Obviously, innovative systems to improve the strength of a dike for wave overtopping should focus on:
- reducing the load;
- improving the strength of the grass cover (against surface erosion) and reducing the danger for shallow slip failure.

Within the present concept, focus is put only to the second method.

Improvement of the stability of the cover layer ***against surface erosion*** will have to cope with extremely high, short duration peaks. By the presence of the reinforcement systems we think that these peaks can be tackled by the intertwinement of the grass roots (Geogrids) and/or by improved coherence of the grass sods (e.g. by the containment in the Geocells).

It is anticipated that the other failure mechanisms, such as shallow slip failure of the turf layer (= grass and root layer) or slip of the supporting clay layer, will also greatly benefit from the reinforcement system. The system will prevent the development of a fissure at the inner crest line of the dike due to in increase in tensile strength and hence less water will infiltrate in the dike.

As mentioned before, whereas loading parameters are quite well-understood and predictable, knowledge on critical overtopping resistance is largely based on experimental data from flume experiments in which stationary overtopping has been applied. In addition, experience is obtained from 'proven strength' data of present sea defences that survived extreme conditions (giving a lower limit of stability). Related to this, (practical) knowledge of failure mechanisms is quite poor as well. This emphasizes the need for proper field testing, wherever possible.

2.5 Construction aspects and risks

2.5.1 Construction philosophy

The key issue for the feasibility of a Smart Grass Reinforcement is a system that increases the safety of the grass revetment in a very short period. This rules out solutions that apply permanent removal of the present grass cover and seeding and growing of a new grass cover. Nevertheless, the latter methodology is widely applied when raising dike elevations at present. Hence, when we succeed in finding a smart installation concept for the grass reinforcement, the risk during construction will be

considerable less than in the present reference situation of raising the crest level (by increasing the dike volume).

2.5.2 Elaboration of solutions for installation

The potential solutions for smart installation of reinforcement systems are dependent on the type of system to be applied.
For the Geogrid system, it was concluded after the field visits and discussions with experts, to favour the Uplift solution (see Section 2.5). Reason of this is that the Big Rolls solution may be hard to be realized in natural grass revetments due to the natural irregularities in its surface. This results in a thick layer of grass that needs to be cut and rolled up, which will be hard to handle. For comparison, the well cultivated grass from which Big Rolls are being made, typically can be cut with a thickness of some centimetres.

For the Uplift-solution the Geogrid system can be applied very well, provided that the Geogrid consists of a thin, open and strong geotextile grid (‘netting’). Once reeled to a roll, it can be unrolled during installation. When this is done in strips of some meters wide, these strips can range from the toe of the dike to the upward part of the outer slope (where the strip needs to be anchored by deep-burying into the subsoil). The strips should never be laid parallel to the dike crest, as in that case tensile forces cannot be transferred to the anchoring point.

The dimension of the roll for one strip is critical when applying the Uplift-solution, as shown in Figure 2.6 below, but with a really thin and flexible grid the roll will remain thin enough. After discussions with the major manufacturer, a Geogrid comparable to system E’grid® of Texion Geosynthetics NV may be feasible. We expect this type to have a good configuration and strength. The Geogrid is made from polypropylene stretched punched sheets. The dimensions of the mesh vary between 3 and 4 cm and the standard rolls have a width of 3,90m. Additional engineering may provide for further elaboration of the Geogrid system.

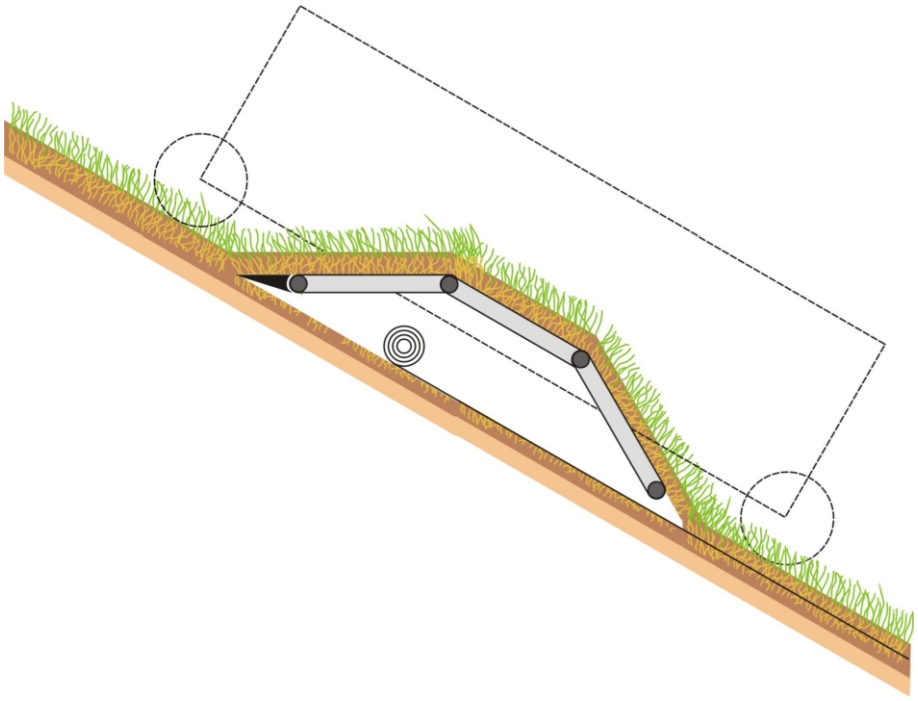

Figure 2.6 : Sketch of installation of Geogrid in combination with Uplift-solution © Royal Haskoning

The most difficult part in applying the Uplift-solution is to get the soil neatly cut, lifted and re-installed, including the Geogrid at some 5-10 cm below the surface. Prototypes of machines that can be used are shown in Figures 2.7 and 2.8. These machine are recently being used to lift the soil and harvest tulip bulbs (left) or cutting grass sods (right).

Figure 2.7: Cutting knife for uplifting of soil (courtesy Geerlings, Noordwijkerhout)

Figure 2.8: Conveyor belt for uplifting of soil (courtesy Queens Grass, Drouwen)

Placement of the Geocell system is, in principle, easier. Penetration through the upper grass layer can by means of a plated roller (see figure below). Pre-treatment (wetting / puncturing) may be necessary, after which in a first run, the geoweb is pressed into the revetment until it is equal to the slope surface. In a second run, again with the plated roller but with a higher pressure, is pressed deeper into the root zone. The plated roller and specifically the distance between the plate extremities needs to be developed, as

well as the thickness of the plates. The reasoning behind the plated roller is that damage to the existing grass cover is minimised.

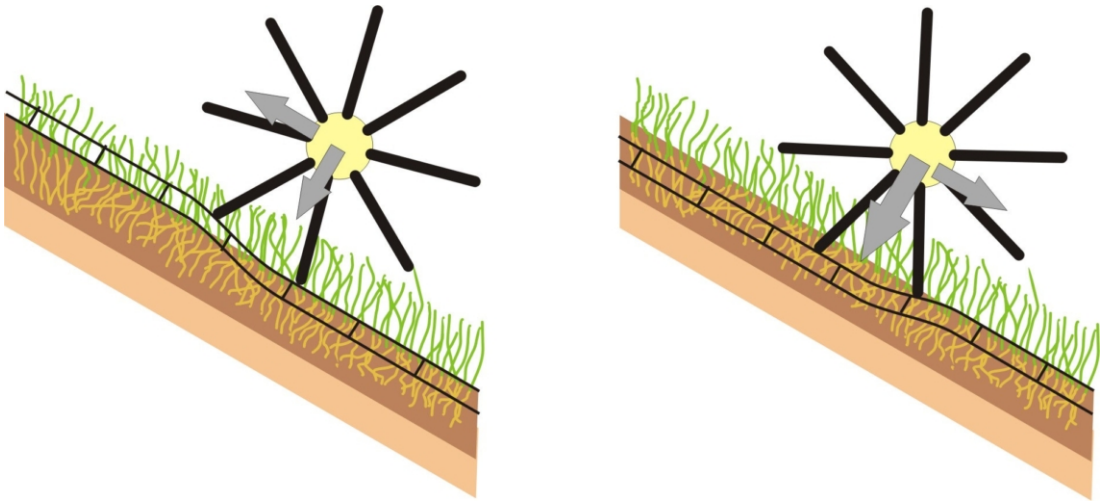

Figure 2.9: Using a plated roller to press the geoweb into the surface (left) and into the root zone (right)

The envisaged system has cells of 10 x 10 cm, a height of 5 cm and with holes in the membrane as to allow root intertwinement with adjacent cells. Penetration through the grass layer will require a rather thick / stiff system.

For both systems the grass roots will recover quickly, probably within weeks but certainly within some months. The best time to apply these systems is shortly after the storm season, e.g. April or May for the Dutch situation, as to avoid the dry periods during summer and to be set for the next storm season.

The above procedures rule out difficult points of interest with 'normal' application of geotextiles and seeding and growing of grass, such as: adding mold, watering (or hydro-seeding, etcetera).

2.5.3 Joints between the strips

In the foregoing the application of geosystem reinforcement in the form of strips (e.g. with a width of some meters) is indicated, which are being positioned from the toe of the inner slope of the defence towards the outer slope. The strips will be installed next to each other in order to cover a full section of the defence.

In our opinion the strips do not require lateral connection, as the systems are loaded in longitudinal direction (we recommend that this opinion is verified in the field tests). We think that small joints can be allowed, as the intertwinement of grass roots will safeguard relatively weakened spots, such as those that are present in the joints. The joints will be reduced as much as practical possible and will be some 0,1 to 0,2 m, dependent on the accuracy of the placement method. Reduction of the joint size is an important item in the development of the optimal installation system and geosystem.

In strongly curved dyke sections, the joints do pose a special problem, as the strips should be layed in a tapered way. We think that in that case, tailor-made V-shaped

geocell strips will be applied. These can be used to fit in the V-shaped joints (as seen from the top of the dyke), when the current strips are used to join at the anchoring position at the outside slope (hence leaving the V-shaped joints).

For the geocells, the tapering can probably be found in ‘opening’ of the system fully at the toe of the dyke (by which a wide strip is obtained) and ‘closing’ the system somewhat (narrowing the strip) in upward direction. This is also an important issue in developing/selecting the system in the detailed engineering phase.

2.6 Life time expectancy and functional sustainability

The life time expectancy is high when synthetic materials are applied. By their hidden presence, synthetic reinforcement systems may not be exposed to direct sunlight and thus will not be subject to UV-ray deterioration. From consultation of the manufacturers, a life time of at least 50 years.

Two major points add to the functional sustainability of the Smart Grass Reinforcement methods as mentioned here:

1. Basically, a good condition of the grass cover as well as of the reinforcement system adds to the stability. At present, the strength of grass revetments is widely investigated and knowledge is gained in improvements of the erosion resistance as a function of maintenance (Alterra, 2004, 2005). It can be expected that this knowledge will lead to further stability improvements of grass revetments. The open structure of the Geogrid as well as the Geocell allows for full utilization of improved grass vegetations.
2. Further improvement of the stability, in case of further increasing loads in future, may be realized by adding anchoring pins at a later stage. There is a problem of detection of the subsoil grid of cell structure, but this can be overcome e.g. by making very thin slots perpendicular at the dike, allowing visual guidance for installation of the pins.

2.7 Maintenance aspects

Systems protruding above the surface, are susceptible for damage by animals, mowers and vandalism, and hence, need regular inspection. Hence, this should be avoided anyhow. Basically, the systems should be placed so deep, e.g. between 5 and 10 cm below the surface, that protrusion will not occur. However, when the surface would be severely damaged, e.g. by sheep trails, local protrusion might still occur by accident. In that case the holes should be filled with soil (e.g. garden mould) and seeded again. We expect that when the Geogrid or Geocell would only locally be damaged, this will have no influence on the total functionality of the system, as a result of the grid structure, by which other parts of the systems will take over the protective function.

Apart from the above, which we think will be quite rare, further maintenance of the reinforcement systems will not be required.
The present maintenance of the grass cover will not be changed by the presence of the reinforcement systems.

2.8 Indicative impacts on 'LNC' values

The free development of grass vegetation is excellent for this type of reinforcement systems. After the adaptation of the root system of the grass vegetation, the geo-systems will be integrated in the grass revetment as a whole. The grass cover basically is the same as it is now, so nothing has changed from the outside, as the Geogrids and Geocells will not be visible. Hence, there will not be an influence on landscaping. Ecological values also do not change, apart from the allowance of burrowing animals (fox, muskrats). This allowance is reduced by the presence of the geo-systems.

During construction time will be short, and will be done with small, specialized equipment, giving the least disturbance. The solutions as presented here, do indeed pinpoint to small scale, well adapted equipment. The 'construction front' will only be some tenth of meters wide and will proceed gradually along the length of the dike.

After installation, the root system will recover and develop itself within a short time, generally in some weeks (Geogrid) or less (Geocell). This is not visible and has no further impacts on the environment.

2.9 Relevant experience

It was reported to the ComCoast project team that the Water Board Hunze en Aa's might have had negative experiences in applying geosystems as a reinforcement of grass revetments. This was reported to especially relate that the system was not really sticking good to the subsoil and pins would easily come out in the mowing machine.
By further inquiry at the Water Board (Mr Schuringa), however, a more subtle picture was obtained. A geotextile mattress had been considered at the outer slope (at instigation of Enka). However the stability improvement was considered to be too minor in case of breaking wave impacts. The anchoring between mattress and subsoil with pins, as regards shallow slip failure between mattress and subsoil, seemed to be inadequate. Hence, an open concrete mattress was selected as more appropriate. The Water Board does not foresee difficulties for application of a mattress at the crest or inner slope, provided that the system is laid deep enough as to avoid damage during mowing of the grass.

In addition, experts on grass revetments (i.e. of Flevo Green Support and of Queens Grass) did not believe in the danger that the reinforcement is working itself upward and eventually comes out of the surface. Their experience, e.g. with artificial grass fibres that are intertwined with natural grass (to strengthen the grass surface for intensive sport activities), indicates that this will not occur indeed.
Our conclusion is that when the upper side of the system is laid deep enough, e.g. 5 to 10cm below the surface, application of geo-reinforcement systems will practically be feasible.

As far as we know, the proposed installation methods of these systems are new. In addition, detailed experience with grass reinforcement at sea defences, subject to wave overtopping, is not available as well. Overflow tests that have been carried out for grass reinforcement systems cannot be translated well to wave overtopping (see Appendix 2). Based on engineering judgement considerations, we think that the reinforcement will be effective; this anticipation needs to be verified in the field testing in Phase 3.

2.10 Indication of required permits and risks involved

2.10.1 Permits

The activity of reinforcing the slopes of sea defences does normally not require a full environmental impact assessment, due to its restricted scale. However, according to article 12.1 of the environmental legislation, changes or extension of sea defences, requires a to proof that a full Environment Impact Assessment (EIA) is not necessary (in dutch: ***m.e.r. – beoordelingprocedure***). In that case, the initiator needs to describe:

- the activity itself;
- the location where the activity will take place;
- interaction with other activities;
- the impact of the activity.

If the size of the change or extension exceeds 5 kilometres in length or 250 m^2 in cross-sectional area (for sea defences), or when the environmental impact is significant, a full EIA is required. It is expected that, for the proposed Smart Grass Reinforcement, it will generally be easy to demonstrate that a full EIA will not be necessary.

Other applicable legislation may include:

- flood defence legislation (Wet op de waterkeringen, Wow);
- environmental legislation (Wet milieubeheer, Wm);
- flora- and fauna legislation (Flora- en faunawet);
- soil protection (Wet bodembescherming, Wbb);
- sustainable usage of construction materials (Bouwstoffenbesluit, Bsb).

Acceptance by the public should be promoted by explaining the concept of ComCoast. We think that acceptance of the present grass reinforcements is high, while there are no major visible remains of this reinforcement, Moreover, the construction effort is modest (small equipment) and quick, so inconvenience will be small and short. Public acceptance for a grass reinforcement option can even be higher than raising the crest of the dike for two reasons:

- The dike profile does not need to be widened, avoiding the removal of historic buildings, houses, etcetera;
- The dike crest is not raised further, so the dike will not get a more prominent place in the landscape.
- dike crest is not raised further, so views to and from the river remain the same.
- The construction time is far more shorter than in regular strengthening.

2.10.2 Risks

In strengthening the sea defence, risks will be decreased. However this also applies for regular strengthening, i.e. raising the dike crest.

The rate of strengthening of the grass revetment should be well investigated and formally acknowledged. This requires field testing (as in Phase 3) and formal acceptance by the scientific authority (in the Netherlands: TAW). Compared to the regular strengthening of the dike (raising the crest), there is some risk that the new method will not be formally accepted, which is valid for all innovative solutions.

Provided that the grass reinforcement sufficiently contributes to the strength, the actual risks will strongly reduce, as compared to raising the dike crest. This is attributed to the short recovery time of the present grass revetment, say 1 to 2 months. This is obvious, as for the smart systems presented in this report, the grass cover will not be removed and seeded (as in regular dike strengthening programs), but just lifted or penetrated. The recovery time of some months should be compared to recovery of a newly seeded grass cover which may last 5 years!

The risk of exposure of the grass reinforcement system and hence the danger of entanglement of man and animals, can be minimized by applying the proper depth at installation and by occasional monitoring.

2.11 Indicative costs for construction & maintenance

The construction costs for a reinforced grass revetment are composed out of the following components:

- Development and manufacturing costs for the machine installing the geosynthetic fabric;
- Material costs of the appropriate system;
- Costs for installation of the geosynthetic system;
- Maintenance costs.

The development and manufacturing cost of the machine that places the geosynthetic system are expected to be in the order of a hundred thousand euros. It should be noted here that for field testing, such a machine may be much more simple and less expensive. This amount must be seen as a rough estimate. It should be noted that he whole machine does not have to be fully developed for a testing phase and costs for a testing phase may be less.

The costs of materials for the Geogrid system differs from the geocell system. Making the assumption that large quantities are being purchased, the prize of the Geogrid system will be in the order of € 2 / m^2 and for the Geocell system in the order of € 4 / m^2. From this, it can be concluded that the material costs for the Geocell system are substantially higher than for the Geogrid system. For an indication of the prizes, product information of the following manufacturer is used: Texion Geosynthetics N.V. Belgium.
The installation costs of the geosynthetic system, by bringing the new manufactured machine in use, are roughly guessed at 200 € / m^1 dike.
It is assumed that for both the Geogrid system as the Geocell system no maintenance is required (high life time expectancy) and that monitoring costs for both geosynthetic systems are comparable to that of the traditional defence.

Economic feasibility

The indicative costs of alternative strengthening of the sea defences by installing geosynthetics in the top layer of the dike's crest and inner slope can be compared to the indicative costs for traditional raising of the crest level. This comparison allows for drawing conclusions about the economic feasibility of the solutions.

The indicative costs for raising the dike (= Reference), with a focus on the Hondsbossche Sea Defence, can roughly anticipated at 4,000 to 6,000 € per m of defence. These figures do not necessarily take into account all costs for surcharges and

engineering, but should be taken relative to the indicative costs of the concepts). These costs are to be expected for a 1.2 m crest level rise (Royal Haskoning & Infram, 2005).

The following assumptions are made to determine the construction costs for both reinforced grass revetments by means of using geosynthetics:
Thinking in terms of the realization of a stretch of 10 kilometers strengthened dike, the development and manufacturing costs (estimated at hundred thousand euros) for the machine installing the geosynthetic fabric by every metre dike will be in the order of magnitude of some € 10. Furthermore it is assumed that for every metre dike in longitudinal direction 25 metre geosynthetic material in transversal direction is needed, thus 25 m^2 geotextile by 1 m^1 dike.

In all, the construction costs add up to 260 € per m^1 of defence for the reinforced grass revetment by using Geogrid. The construction costs by using Geocells can be roughly guessed at 310 € per m^1 of defence.
Including 40% contractor's surcharges the cost for every metre strengthened sea defence will be about 365 € for the Geogrid system and 435 € for the Geocell system. These cost figures does not include engineering costs, as the costs indication of the reference does not include engineering costs as well.

applied method	**estimated costs (€ / m^1 dike)**
Raising the crest of the dike (reference)	5,000,--
Installation of Geogrid at crest and innerslope	365,-
Installation of Geocells at crest and innerslope	435,-

Table 2.2: Review of total estimated costs (indicative values in € per m dike)

This review shows that Smart Grass Reinforcement is highly competitive as compared to raising the defence. The costs of strengthening the dike by raising the crest are in the region of ten times the costs of a reinforced grass revetment at the dikes crest and inner slope.

In determining the life cycle costs, the Geocell system is taken as illustrative for the smart grass reinforcement concept. In table 2.3, the capitalized cost of the Geocell system is indicated for application at the Hondsbossche Zeewering. With the construction costs of € 435 per m^1 of sea defence given in table 2.2 , land purchase and maintenance for a lifetime 0f 50 years, the total life cycle costs of the system is € 2.5 million for 4,300 m^1 grass reinforcement. In addition to the relatively low construction cost of € 2.3 million (including land purchase), the capitalized maintenance amounts to some € 0.17 million, which is only 7% of the construction cost.

			length	
Dimensions are based on the Hondsbossche Zeewering			4300	m
Purchase of land	20	€/m2		
Required m2 of land needed behind the existing dike	5	m2/m	430000	
Construction costs				
earthmoving+purchase sand	0	€/m		
concrete/civil work	0	€/m		
special equipment	15	€/m		
geosystem and installation	420	€/m		
Total	435	€/m	1870500	€
Mobilisation cost per project			10000	€
Total construction costs			2310500	€
Maintenance				
yearly inspection cost			5000	€/project
expected repair cost	1	€/m	4300	€
Total yearly maintenance			9300	
Lifetime of the structure	50	years		
interest rate	5%			
Capitalised maintenance			169780	€
Total cost of structure			**2,5**	million €

Table 2.3 Estimated costs for the Smart Grass Reinforcement of ComCoast

light yellow: cost estimated by consultant

bright yellow: fixed number given by ComCoast team

As an explanation of the low maintenance costs, we expect that maintenance is restricted to occasional and local repair of the grass revetment, where Geocells should become exposed unexpectedly. The material itself, however, is assumed not to become damaged. Hence, an annual budget of € 4,300 per year (€ 1 per m^1) is reserved for small repairs, additional to the inspection cost of € 5,000. As regards the life time expectancy of 50 years (see also paragraph 2.6), the capitalized maintenance cost remain modest.

3 APPLICATION FOR THE HONDSBOSSCHE SEA DEFENCE PILOT

3.1 Situation Hondsbossche Sea Defence

The inner slope of the Hondsbossche Sea Defence is approximately 1:3. The average height of the defence is 6,5 m, making a total length of the slope of order 20 m. Recent structural assessment (2004) of the sea defence has resulted in categorizing it as “unsafe”. Therefore the Hondsbossche Sea Defence is designated a “weak link” with high priority for improvement: the current level of safety is approximately 1/3.000 years, whereas 1/10.000 year is required by law. In order to improve the safety on short term, the grass vegetation at the outer slope has been replaced by concrete elements in a rough arrangement. This measure reduces wave run-up and wave overtopping and can be considered as a ‘no-regret measure’. This relieves to some extent the inner slope which is, at some places, in a rather poor condition. In doing so, the safety has increased to approximately 1/6.000 years which is deemed acceptable for the time being, until more permanent improvements are made in 2007. Roughening the outer slope has reduced the overtopping rate from mean (time-averaged) intensities of 5,04 l/s per m to 3,78 l/s per m[4].

Figure 3.1 Roughened outer slope of the Hondsbossche Sea Defences by introducing different height of the concrete elements

The inner slope is covered with a grass vegetation (see Figure 3.2) with quite variable quality and strength. Structural assessment of this grass revetment has resulted in categorizing the inner slope as insufficient to cope with wave overtopping, which was one the reasons for roughening the outer slope. Apart from usual grasses, other vegetation could be observed found as well, e.g. herbs and eelgrass. The consistency of the vegetation is rather poor, possibly related to insufficient maintenance. Local rehabilitation of the poor grass revetment prior to reinforcing the inner slope may be necessary.

[4] Royal Haskoning 2004
Dijkversterkingsplan Hondsbossche Sea Defences, 9P6569.A0

Figure 3.2 Current situation Hondsbossche Sea Defences
left: holes in grass cover
middle: irregularities in the surface
right: variation in vegetation

With respect to lifting the grass sods, Mr. Rienks (Queens Grass) expects that the consistency is insufficient to apply Big Rolls. Root density is that poor that when put at Big Rolls, soil may separate from the grass. At some places, the (geometrical) irregularity of the surface is that large that a layer of 5 cm can possibly not lifted well; to keep the sods intact, a thicker layer needs to be lifted. In that case a reinforcement in the vegetative root zone is only possible at a deeper level. However at a deeper level, the root system is less dense. The above difficulties arise especially at poor vegetated areas. It will be interesting to check the applicability of a Geogrid system here. At those places that a Geogrid cannot be applied, a Geocell will probably be feasible, as the grass cover does not need to be lifted in that case. Locally, deep holes may need to be filled up prior or after installation of the Geocell system. In the next paragraph, the method of placement at the Hondbossche Sea Defence for both systems are given .

3.2 Method of placement

In this paragraph, the method of placement of the Geogrid system and the Geocell systems is explained. Please note that for illustrative purposes, the strengthening of the inner slope is shown only. In reality, the reinforcement continues on the crown of the sea defence and ends some distance below the crown on the outer slope, where the Geogrid and Geocell is anchored into a trench.

3.2.1 Geogrid system

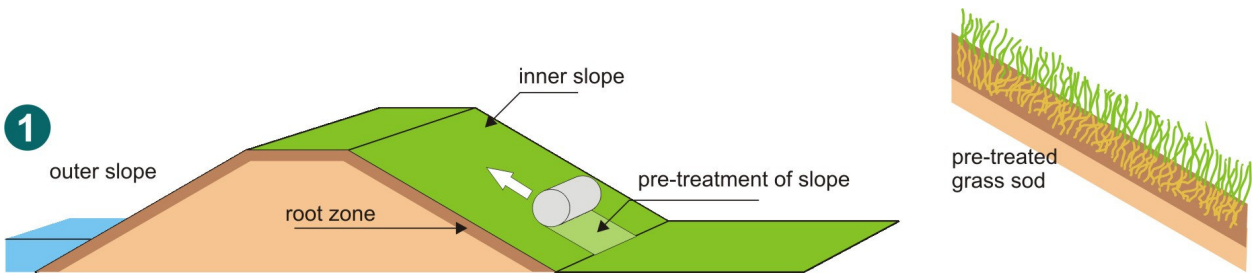

Figure 3.3 Preparing the grass revetment for reinforcement, © Royal Haskoning

As mentioned, depending on the actual condition of the grass revetment, pre-treatment may be necessary. Possible preparations may be wetting the surface if the vegetative root zone is dried out and / or compacting the layer (carefully).

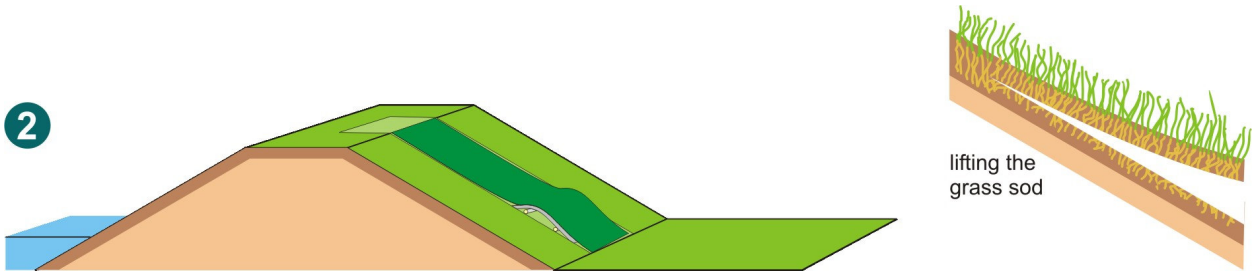

Figure 3.4 Lifting the grass sod, © Royal Haskoning

Using the machine shown in diagram 2.6, the vegetative root zone is lifted. The process is carried out starting at the toe of the revetment. Lifting the root zone implies that the grass roots are cut, so that recuperation time is needed after the reinforcement is carried out.

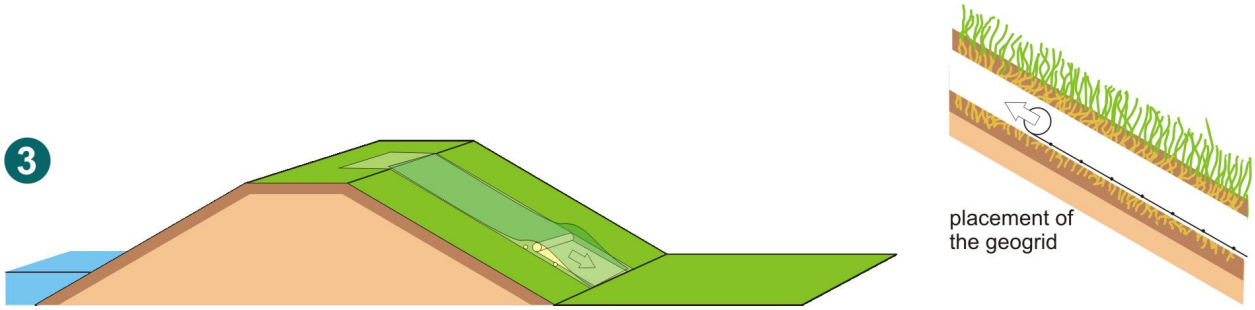

Figure 3.5 Placement of the Geogrid, © Royal Haskoning

Once the grass sod is lifted at the toe, a small roll of Geogrid, long enough to extend across the top of the sea defence is placed underneath the machine. The machine now progresses up the slope, cutting and lifting the root zone and rolling off the Geogrid at the same time. Behind the machine, the lifted sod is laid back onto the slope.

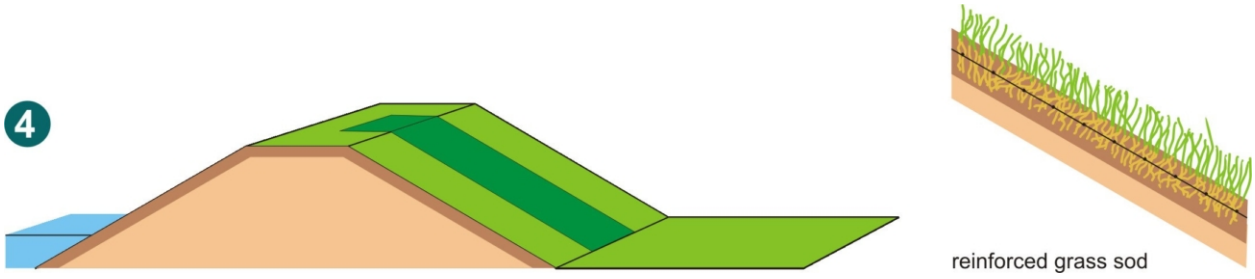

Figure 3.6 Reinforced slopes, © Royal Haskoning

Behind the machine the lifted root zone is carefully lowered back onto the slope, thus leaving a reinforced grass revetment. As mentioned above, the roots will require some recuperation time for the strength to have increased.

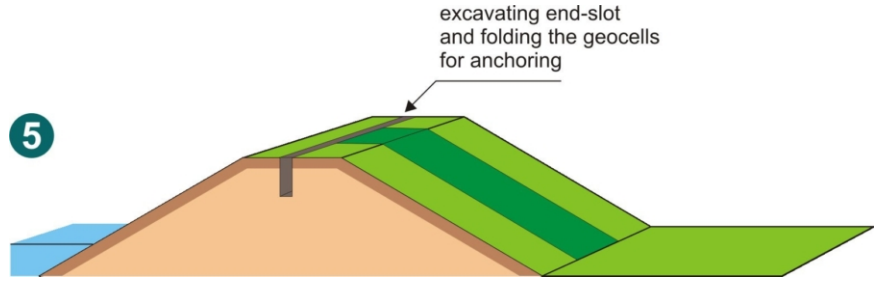

Figure 3.7 Anchoring the Geogrid on the outer slope, © Royal Haskoning

After a number of Geogrids has been placed in the root zone, a gulley of 1 – 1,5 m deep is dug somewhere down the outer slope. The remainder of the Geogrid is lowered into the gulley which is then filled up again. It may be necessary to weigh the end of the Geogrid down with a bar of some sorts.

3.2.2 Geocell system

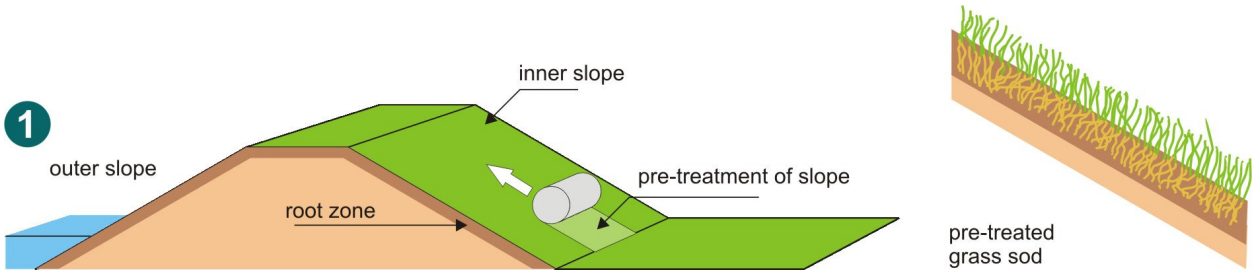

Figure 3.8 Preparing the grass revetment for reinforcement, © Royal Haskoning

As is the case with the Geogrid system, depending on the actual condition of the grass revetment, pre-treatment may be necessary. However, in order to be able to press the geoweb into the slope, loosening up the top layer of the slope may be necessary. This needs be done carefully however: it is suggested to use a pinned roll, which should not damage the revetment too much, whilst loosening it up just enough to allow the geoweb to penetrate the top layer.

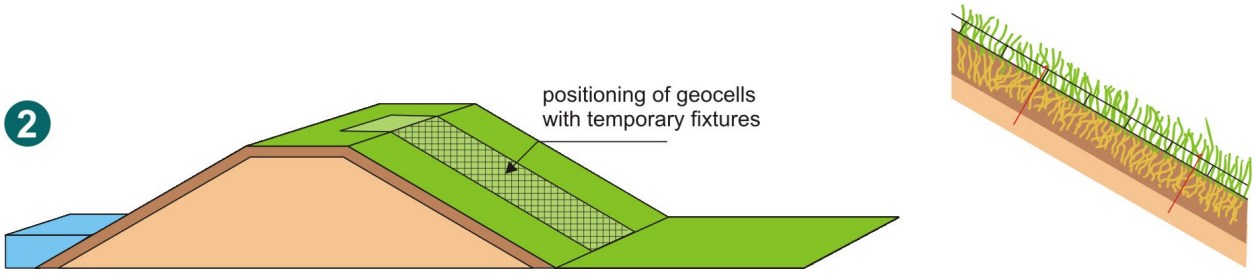

Figure 3.9 Positioning of the Geocells, © Royal Haskoning

The Geocells which arrive on-site as strips are extended and positioned on the slope. It is then fixed temporarily on the slope. The honey-rate geosystem now rests on the slope, crown and a part of the outer slope.

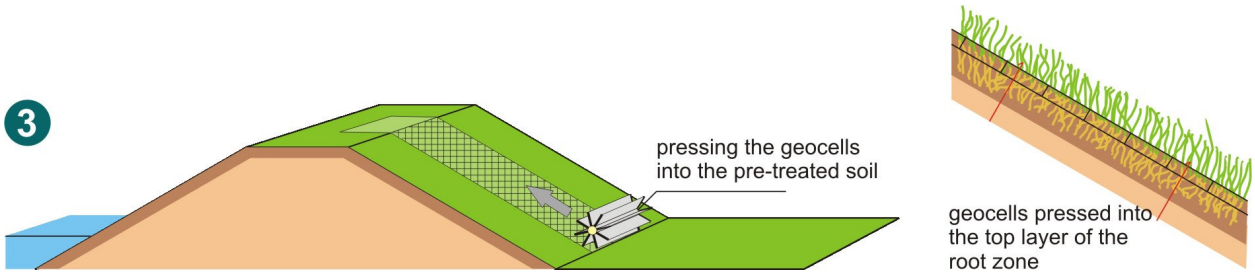

Figure 3.10 Pressing the Geocells into the top layer, © Royal Haskoning

Using a plated roll, the Geocells are now carefully pressed into the top layer, so that the top of the cells are at equal level with the slope surface. A plated roll is used, so as not to damage the grass and to press the Geocells deep into the root zone later.

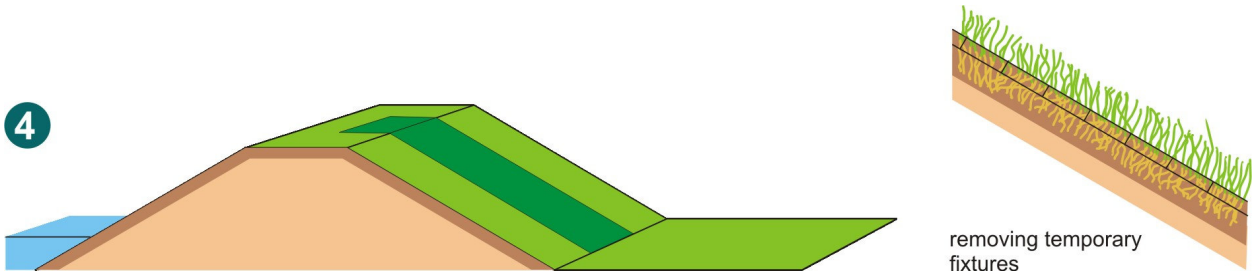

Figure 3.11 Removing the temporary fixtures, © Royal Haskoning

The fixtures to keep the Geocells spread are now removed.

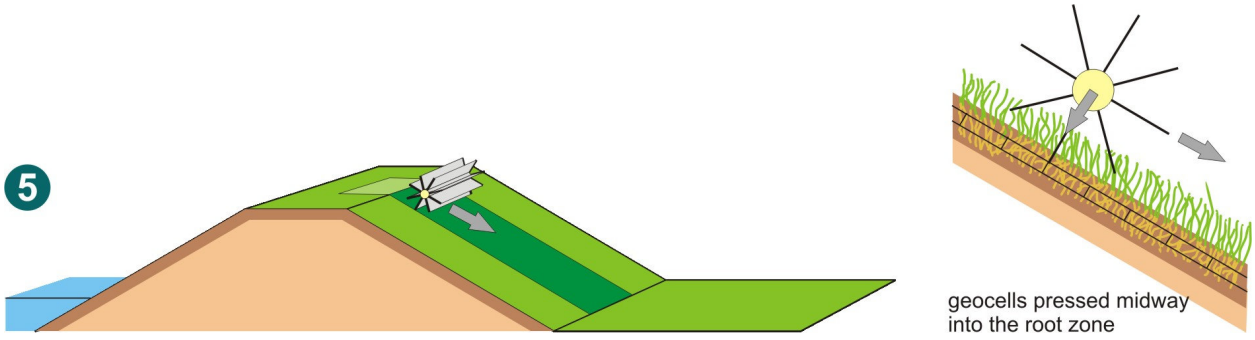

Figure 3.12 Pressing the Geocells into the root zone, © Royal Haskoning

Using the same plated roll, but now with a higher pressure rolls backwards across the Geocells, pressing the Geocells further down into the root zone so that the reinforcement cannot be seen from the surface.

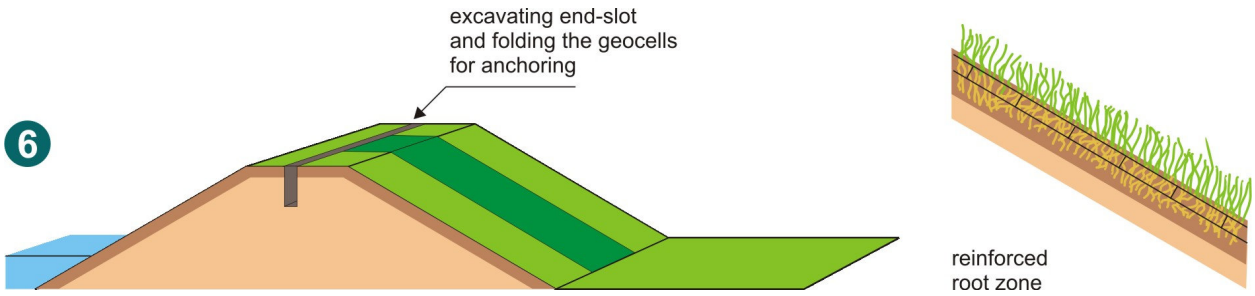

Figure 3.8 Anchoring the Geocells on the outer slope, © Royal Haskoning

After a number of Geocells has been placed in the root zone, a gulley of 1 – 1,5 m deep is dug somewhere down the outer slope. The remainder of the Geocells is lowered into the gulley which is then filled up again. It may be necessary to weigh the end of the Geocells down with a bar of some sorts.

3.3 Rough design for the Hondsbossche Zeewering

Below the end result is shown for the Geocell system, as well as the Geogrid system.

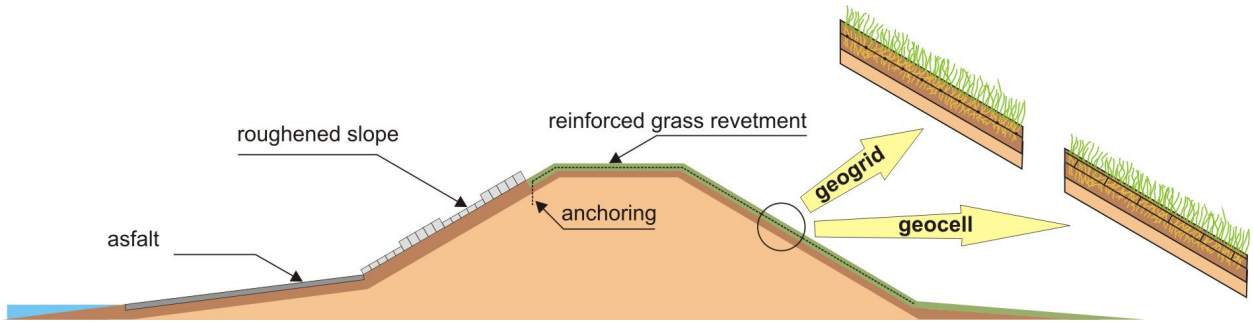

Figure 3.14 Rough design for Hondsbossche Sea Defences in Geogrid and Geocell reinforcement

4 CONCLUSIONS AND RECOMMENDATIONS FOR FIELD TESTING

4.1 Conclusions

Based on the present theoretical elaboration on Smart Grass Reinforcement systems, the following conclusions can be drawn.

1. Two types of Smart Grass Reinforcement systems have been identified: Geogrids and Geocells, see Photographs and .
2. Geogrids can be used at sea dikes at relative flat crest and inner slopes with a good grass covers and coherent (i.e. clayey) substrate. This system can be used e.g. at the Nord Frysian sea dike (grass monitoring location). Geogrids will be introduced at some depth below the grass surface and, hence, can only be applied when the (upper) grass layer is lifted or temporary removed.
3. Geocells can be used as well at dikes with irregular surfaces. This system should be penetrated through the grass cover, so it does not require lifting or removal of the grass layer.
4. it is anticipated that the reinforcement systems will largely contribute to the reduction of danger of major failure mechanisms for the (Dutch) sea dikes, i.e. surface erosion and shallow slip failure.
5. A quantitative prediction of this stability improvement cannot be obtained with the present knowledge: field tests as envisaged in Phase 3 will be required to validate the feasibility of the Geogrid and Geocell concepts.
6. As regards the economic feasibility it is clear that Smart Grass Reinforcement is highly competitive as compared to raising the defence. The costs of strengthening the dike by raising the crest are in order of thousands of euros per m^1. The costs of a reinforced grass revetment at the dikes crest and inner slope are in the order of several hundreds of euros.
7. We think that the systems can be designed in such a way that they are highly durable, e.g. more than 50 years. The systems do not affect the possibility for further future improvement of the grass cover by improved maintenance (extensive mowing and fertilizer/manure reduction). Further stability improvements might also be gained by introducing vertical pins. Maintenance of the systems is expected to be practically nil.
8. Apart from some influence on burrowing animals (positive effect), the hidden presence of the systems will not influence LNC values. By the open structure, the systems do not have a significant effect on the permeability of the dikes as a whole.
9. The innovative character of application of these systems, implies a further practical selection and/or design, in close co-operation with the manufacturers. In addition, equipment needs to be engineered further (Geogrid: lifting equipment; Geocell: penetration equipment), with special attention for the joints in between the systems. This engineering work can be done at an early stage, prior to preparation of the field test sections of Phase 3.
10. The systems will be fully hidden, so permits (environmental) legislative difficulties are not expected. For the short duration of improvement of the dike sections, no permits will be required. Obviously, the potential improvement of the overtopping stability of the sea defences will need further certification by the governmental certification body (e.g. TAW in the Netherlands). The fields tests of Phase 3, together with a good understanding of the effectiveness of the reinforcement systems will be required to get the system officially certified.

11. In the present report, application on the Hondbossche Sea Defence has been indicated. This dike has weak spots with respect to grass cover and the surface is also quite uneven. It is therefore a suitable case to test both the Geogrid and the Geocell system. An other suitable location would be at the Nord Frysian sea dike, where various test sections are available with different grass management. Testing would not only give results for different grass management, but would also make a direct comparison possible with the reinforcement systems!
12. By applying a Smart Grass Reinforcement concept, the risk at insufficient strength after installation, as compared to a dike reinforcement with a new grass cover, is significantly reduced as strength recovery with smart reinforcements will only take some weeks (Geogrid) or less (Geocell). Instead, growing a new grass cover up to the ultimate strength will take some years.

4.2 Recommendations for field testing

1. Both systems (Geogrid and Geocell) will benefit from some additional engineering prior to testing. This is especially true for the installation equipment. Both, system and equipment, need to be engineered in close interaction. We recommend that combined engineering will be carried out at short notice, e.g. by the end of this year, well in advance of the installation for the field testing, as to allow manufacturers of the geo-systems to adjust or select optimum products and to allow construction of the installation equipment. As an important part of the additional engineering, the detailed specifications of the geosystems and installation equipment should be surveyed and agreed upon.
2. When field testing is planned to take place in the summer and/or winter of 2006, the reinforced grass sections will have to be installed a sufficient time in advance. Hence, the installation should be aimed at immediately after the dikes have become formally available for (re)construction work, i.e. mid April. This allows a minimum time of about 2 months for recovery and development of the grass root system, being sufficient for obtaining the ultimate strength.
3. The Geocell and Geogrid system reinforce the present grass layer and, hence, are dependent on the actual condition of the grass layer. As regards the vivid progression in knowledge on maintenance and strength (and composition) of natural grass revetments on dikes, testing of the reinforcement is to be recommended at various types of grass covers. Hence, the grass study location at the North Frysian sea dikes is a favourable place. In addition, the reinforcement systems may be tested at the Hondsbossche Sea Defence as well, at different sections with rather poor (and for comparison with rather good) grass conditions.
4. As a reference to the reinforcement tests, corresponding tests need to be carried out on the present grass revetments without the reinforcement, as to determine the influence of the reinforcement.
5. Prior to application of the systems at the final test location, pilot installation tests are to be carried out. For preliminary testing of the installation equipment this can be done at an arbitrary test site. Final testing, however, should be done at a true sea dike, e.g. close to the field test section. During final testing the optimum (practical) depths for the Geogrid and Geocell systems can be determined. Remark: the depth should be as small as possible to offer optimum reinforcement to the root system, it should be deep enough however to avoid protrusion above the surface and to enable proper placement.
6. For the field testing set-up it is essential that wave overtopping is simulated in a representative way, i.e. by the wave overtopping simulator as proposed by INFRAM.

7. During the tests the degree of saturation need to be taken into account, as this may have a considerable effect on the stability behaviour.
8. For practical reasons, the above tests may focus on the surface erosion resistance of the (reinforced) grass revetment. In addition, tests on the potential effect on shallow slip behaviour, considering a wider test section with and without reinforcement, is recommended as well.

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