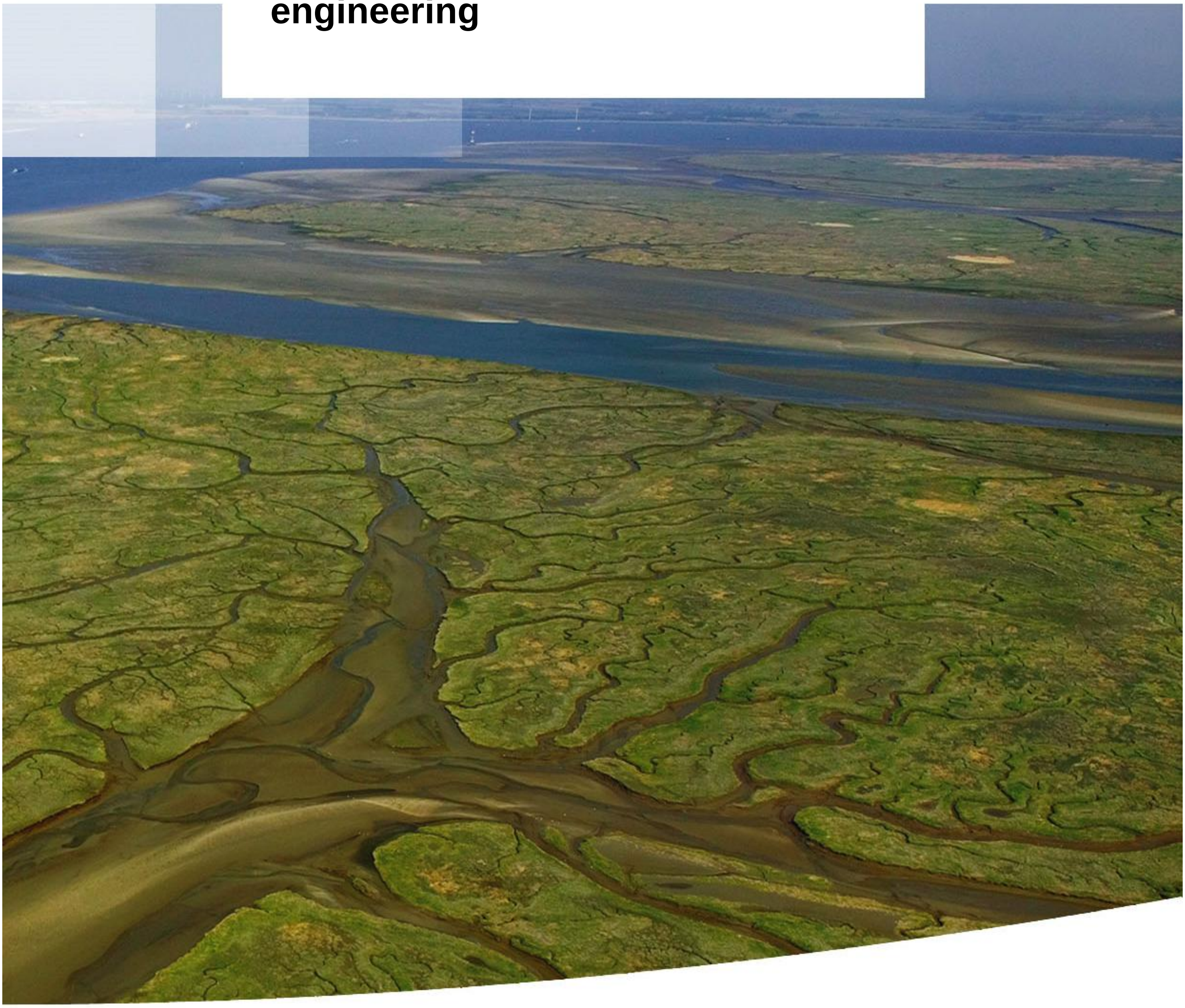
Investigation of Desso GrassMaster® as application in hydraulic engineering



Investigation of Desso GrassMaster® as application in hydraulic engineering

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Summary
Desso GrassMaster® is a reinforced grass system which is applied successfully on sports fields and enables to use a sports field more intensively than a normal grass field. In this report the possibility of an application of Desso GrassMaster® in hydraulic conditions, with a focus on grass dikes, is discussed.

A description of several aspects of grass dikes is given as well as other known reinforcement grass systems. A comparison between grass on sports fields and grass of grass dikes is made. Based on state-of-the art literature, requirements for Desso GrassMaster® as a revetment under hydraulic loading are provided. Potential applications are identified and knowledge gaps are given.

From the point of view of hydraulic engineering and based on theoretical and existing knowledge, it is concluded that Desso GrassMaster® may potentially be used as a dike revetment but more insight in the strength of this system is required before it will be applied as a revetment. It is currently not clear what effect Desso GrassMaster® will have on root volume and distribution in dike grasslands and how this influences overall strength of the grass cover. The strength of Desso GrassMaster® can be determined by performing physical hydraulic experiments.

Several knowledge gaps concerning ecological, toxicological and environmental issues have been identified that may hamper the implementation of Desso GrassMaster®. It is recommended to perform tests to quantify these potential impacts on the environment in order to find solutions to mitigate potential negative effects. This will lead to increased societal acceptability of application of the product on dikes. For comprehensive conclusions, longer-term full-scale tests (2-4 years) are recommended.

References
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1 Introduction

Desso GrassMaster® has been developed to improve natural grass sports fields such as soccer fields. The basic concept is to inject the soil with synthetic fibres to a depth of 20 cm. In between the fibres, which protrude approximately 2 cm above the soil, sport grass is sowed. The fibres are at a mutual distance of 2 cm. It is also possible to inject the fibres in an already existing grass field. The Technical Manual Desso GrassMaster® states that the natural grass roots interact with the synthetic fibres. Sports(wo)men experience Desso GrassMaster® grass fields as a natural field. However, due to the presence of the synthetic fibres the capacity of a soccer field is enlarged from 250 hours to approximately 1000 hours per year (Technical Manual Desso GrassMaster®). The advantage of this system is the natural look and feel while enhancing the capacity of the field. An impression of the application of Desso GrassMaster® for sports fields is given in Figure 1.1 to Figure 1.4.

Figure 1.1 Left: construction of Desso GrassMaster® in Emirate stadium – Arsenal FC, Right: Whitehart Lane Stadium, Tottenham Hotspur FC. (Source: Desso Sports).

Figure 1.2 Left: Sliding on a soccer field with Desso GrassMaster®, Right: synthetic fibres. (Source: Desso Sports).

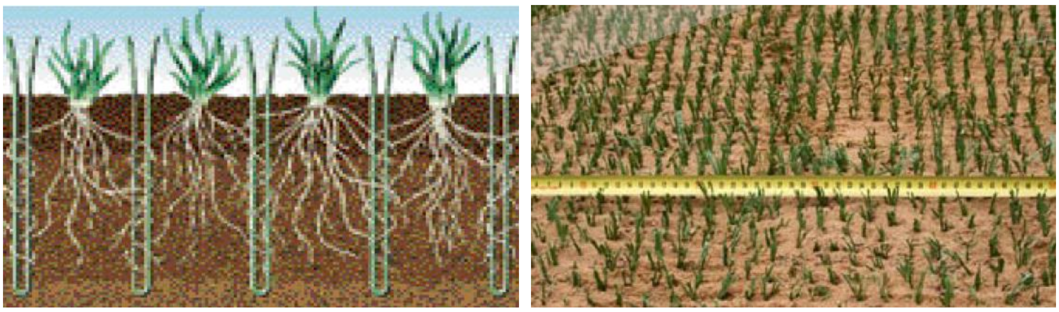

Figure 1.3 Left: roots interact with fibres, right: impression of synthetic fibres without natural grass (Source: Desso Sports).

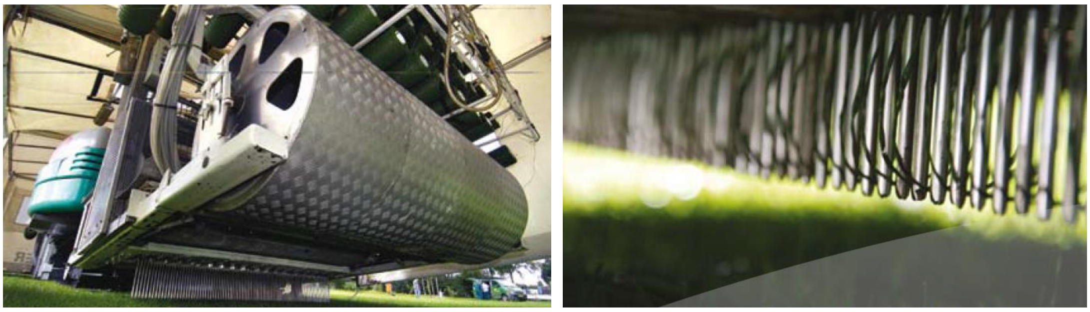

Figure 1.4 Impression of machine that injects synthetic fibres (Source: Desso Sports Systems).

This report investigates to what extent the advantages of Desso GrassMaster® on sports fields are potentially also applicable in the field of hydraulic engineering. Many dikes have grass as a top layer. This top layer protects the dike against erosion as a result of hydraulic loads (mostly waves) and other loads (such as tire tracks). Impressions of grass dikes are given in Figure 1.5.

Figure 1.5 Left: a typical Dutch grass dike, right: damage to a Dutch dike due to tire tracks (source: Digigids)

The application in hydraulic engineering (sometimes also indicated as Delta Technology) may be potential since 50 % of the world population lives in Delta areas. This number will grow to 70% in 2050 (source: Topsector Water). Delta areas are under constant pressure: more inhabitants, higher river discharges, higher flood safety requirements, and soil subsidence lead to necessary improvements to maintain flood safety to an acceptable level. Another important aspect is that society demands more sustainable and environmentally friendly solutions.

To investigate whether Desso GrassMaster® can contribute to the stability of grass dikes, taking into account relevant societal and environmental issues, Desso Sports Systems requested Deltares to perform a desk study to investigate this issue. The focus of the study is on Dutch grass dikes but attention will also be paid to non-Dutch applications and performed research.

1.1 Realisation of this report

Desso Sports (represented by J. de Bruijn, innovation manager sports) commissioned Deltares to study the possibilities of the application of Desso GrassMaster® on grass dikes. This report is a joint effort of Deltares and Alterra, Wageningen UR. The main focus of Deltares is on the engineering and (eco)toxicological aspects whereas the main focus of Alterra is on the biological and other environmental aspects of the grass reinforcement system.

1.2 Reading guide

In Chapter 2 an overview of the knowledge with respect to grass revetments and reinforcement systems on dikes is given. A comparison between a sports field and a grass dike is given in Chapter 3. To implement Desso GrassMaster® as a dike revetment, insight is required in the requirements of a revetment and in societal and environmental requirements. These requirements are worked out for Desso GrassMaster® in Chapter 4. Knowledge gaps that obstruct implementation of Desso GrassMaster® as a dike revetment and potential research methods are given in Chapter 5. Chapter 6 summarizes the conclusions and recommendations.

2 Grass revetments on flood defences and grass reinforcement systems

To explore the potential application of Desso GrassMaster® on flood defences a first insight is given in grass revetments on dikes. The aim is only to give a slight overview of this subject, not to give a complete view since that would not serve the purpose of this study. However, several references are given for further reading.

2.1 Grass revetments on flood defences

2.1.1 Classification of flood defences

In the Netherlands, a large network of so called primary and regional flood defences give protection against flooding. Other dike types such as dike relics (old dikes which do not have a water retaining function anymore but which do still exist), dikes with former military purposes (so-called *Waterliniedijken* which were used to control flooding of a particular area to hinder enemy forces) are not considered in this report since it is unlikely that Desso Grassmaster® would be applied on such dikes.

Primary flood defences give protection against flooding from the North See, the Wadden Sea, the large rivers Rhine, Meuse and Western Scheldt, the Eastern Scheldt, Markermeer, and Lake IJssel. The main focus is on areas where potential flooding will cause many casualties or high economic damage. The primary flood defences along the large rivers, the Wadden Sea, the former sea inlets and estuaries of the Southwestern delta and Lake IJssel are mostly dikes (in Dutch: *dijk*). At the North Sea the primary flood defences are mostly dunes. The Netherlands have 3,767 kilometres of dunes and dikes which are marked as primary flood defences (IVW, 2011). 254 km are dunes (TAW, 1995) and approximately 3.500 km are dikes (in the last years some dikes were built or removed). Almost all river dikes and most sea dikes in the Netherlands are covered with grass (TAW, 1998).

Regional flood defences give protection against flooding from inland water. A regional flood defence is a none-primary flood defence which is indicated as a flood defence based on legislation of the responsible province or the responsible Water Board.

The consequence of a flooding due to failure of a primary flood defence is large: almost 60 % of the Netherlands is vulnerable for flooding. In that area are also the largest cities and the most important economical centre of the Netherlands. The main focus of this report is therefore on primary flood defences. This choice is made since on this type of dikes the largest potential added value of Desso GrassMaster® is expected. Also, past research activities on the stability of natural grass slopes under hydraulic loading have mostly focused on this type of dikes (see also Section 2.1.4).

2.1.2 Hydraulic loads on dikes

There are many ways in which a dike might fail under hydraulic loading. One of the failure mechanisms is the erosion of the top layer. A top layer of a dike consists usually of a placed block revetment, asphalt, grass or rock. In this section a description is given of the hydraulic loads on a dike which might lead to erosion of the top layer. This is essential to get a first impression of the potential application of Desso GrassMaster®.

The main hydraulic loads are due to waves. Three different load zones are identified: the wave impact zone (2), the wave run-up / run-down zone (3) and the wave overtopping zone (4). This is illustrated in Figure 2.1.

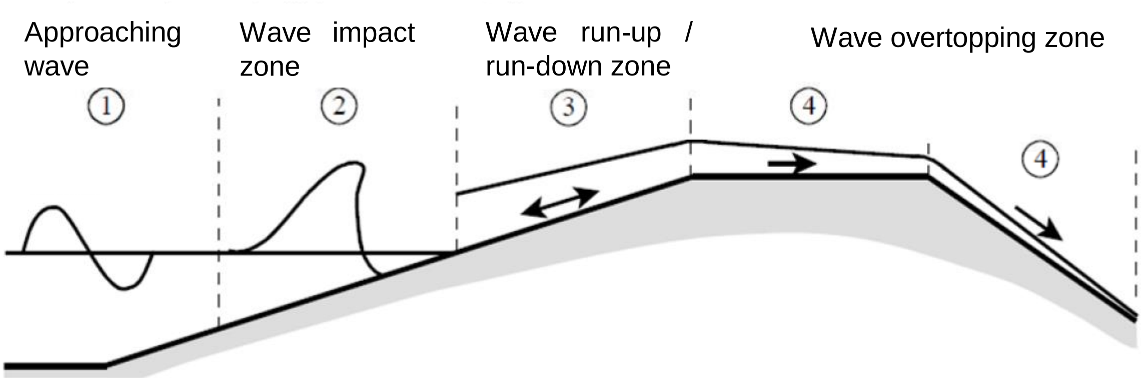

Figure 2.1 Hydraulic loads on a dike due to wave attack (source: RWS, 2012)

In some cases a current (parallel to the orientation of the dike) occurs (1). Since this is almost never decisive for the strength of the top layer of a dike this aspect is not covered in the remainder of this report.

<u>Wave impact zone</u>
The wave impact zone is the zone at the dike where waves break and 'impact' the dike top layer. During this breaking process a relatively large force is acting on the dike. In this area also wave run-up and wave run-down occurs.

Grass covers are usually not applied in the wave impact zone where relatively large waves occur. The wave height is usually relatively small at river dikes and at these dikes grass is also often applied in the wave impact zone. More information about wave impacts on a grass slope can be found in Van Steeg *et al* (2014) and RWS (2012). A first impression of the quantification of the resistance time of grass in the wave impact zone is given in Section 2.1.4.

<u>Wave run-up zone</u>
In the wave run up zone, wave tongues are running up and down the slope which potentially erodes the top layer of the dike. The load on this slope is usually characterised by a velocity during a wave run up and by the duration of the load. At higher positions at the dike the loads are lower and these parts usually have a grass cover. At lower positions, where more and heavier wave action occurs, usually (more costly) placed-block revetments, asphalt or rock is applied.

The *allowable* run up characteristics of grass covers are dependent on the hydraulic conditions, the quality of the grass and the location at the dike. A first impression of the quantification of the resistance time of grass in the wave run-up zone is given in Section 2.1.4. More information about wave run-up can be found in TAW (2002), RWS (2012) and EurOtop (2007).

<u>Wave overtopping zone</u>
At a specific combination of water level and wave conditions, waves will run over the crest and run over the landward slope of the dike: this is called wave overtopping. Wave overtopping can lead to failure of the top layer and failure of the dike (example: this occurred

at many dikes in the Dutch province of Zeeland during a large flood disaster in 1953). Wave overtopping is usually expressed in the mean overtopping rate (*q*). This rate *q* indicates the average amount of overtopping water during a certain time at a dike with a considered length of one meter. The unit for *q* is usually 'l/s/m' (litre per second per meter dike). In some cases the wave overtopping is quantified in different ways such as the volume per wave, *V* (l/m) or the front velocity per overtopping wave, *U* (m/s).

Many aspects determine the overtopping characteristics. Important aspects are the wave conditions (wave height, wave period, type of wave spectrum, angle of incident, storm duration et cetera) and the characteristics of the dike (geometry, roughness of outer slope, crest height). To quantify wave overtopping many physical experiments have been and are being performed in wave flumes (2D) and wave basins (3D), see also Section 2.1.5. Based on these experimental data, empirical models that can reasonably predict the overtopping characteristics as function of the dike characteristics and the hydraulic characteristics have been developed. It is however noted that the uncertainty around these empirical models is still relatively large. Therefore, additional physical models in flumes and basins are usually performed when designing a dike or a dike reinforcement.

Several theoretical and empirical models exist to quantify the *allowable* overtopping characteristics at grass dikes. A relatively high allowable overtopping rate corresponds with a relatively low crest. With a higher crest of the dike (often leading to increased costs and societal opposition) the overtopping will be less. A higher erosion resistance of the inner slope of the dike leads to a higher acceptable overtopping rate and thus a potentially lower crest height of the dike. The erosion resistance of a grass dike is dependent on the grass and clay quality of the inner slope. An impression of the quantification of wave overtopping amounts is given in Section 2.1.4. More information about wave overtopping can be found in TAW (2002) or EurOtop (2007).

2.1.3 Strength of grass revetments: grass and clay

According to the Dutch assessment methodology (*VTV, 2006; RWS, 2012*) a grass revetment is subdivided according to Figure 2.2.

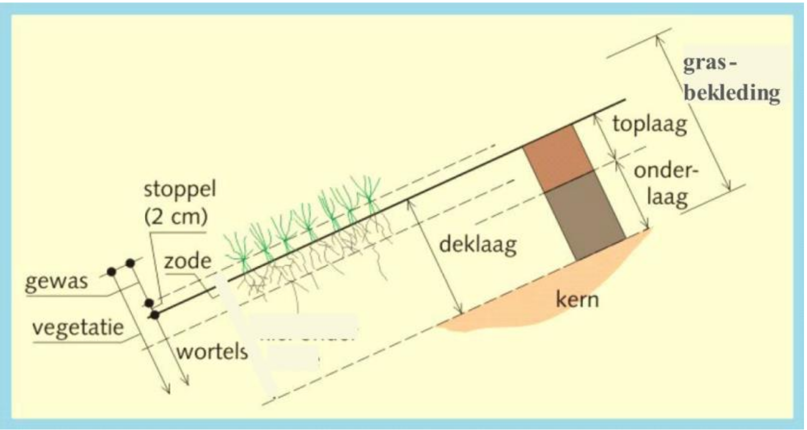

Figure 2.2 Definitions of a grass revetment (RWS, 2012)

The stability of the top layer of the dike depends on the (hydraulic) loads acting on the top layer (See Section 2.1.2) and on the strength of the top layer. The strength of the top layer of a grass dike depends largely on the quality of the grass and the quality of the soil (usually clay or sand).

The quality of grass can be described in different ways. The degree of rooting is probably the most important parameter with respect to the strength of the grass. This can be determined by taking samples with a gutter (3 cm diameter). The upper 20 cm are sliced into parts with a thickness of 2.5 cm. The amount of visible roots is counted in each slice leading to a so-called root diagram. An example is given in Figure 2.3. The grass quality is based on a diagram such as given in Figure 2.3.

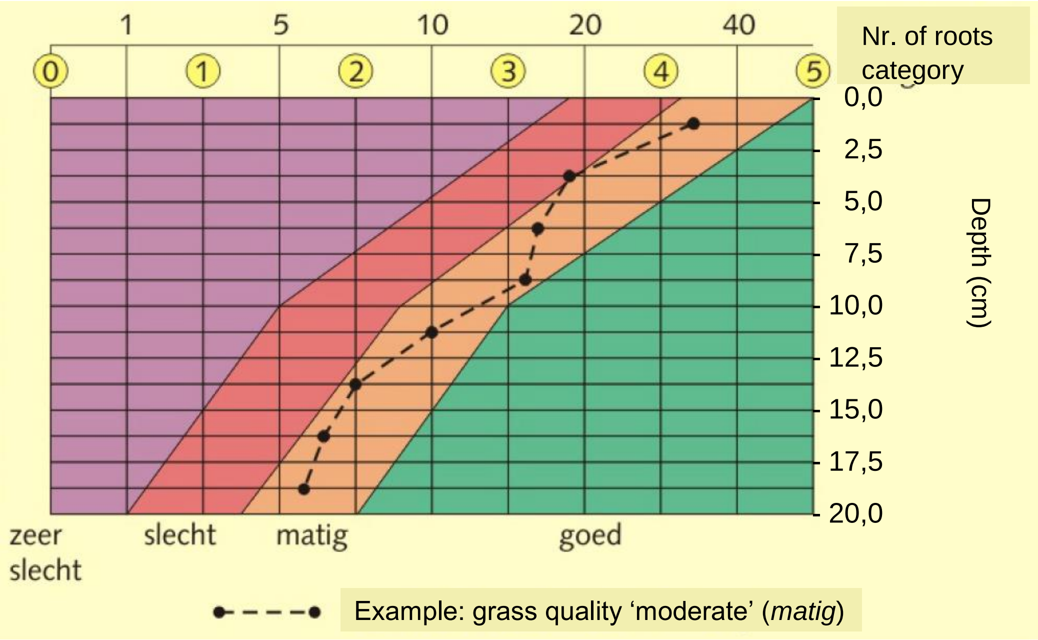

Figure 2.3 Grass quality as function of the root density (VTV, 2006).

It can be seen that, according to the method as given above, the grass quality is defined as 'good' (*goed*), 'moderate' (*matig*), 'poor' (*slecht*) or 'very poor' (*zeer slecht*).

Recently, an alternative method based more on visual inspection has been developed (RWS, 2012). In that method the quality is defined by using different categories such as 'fragmentary' (*fragmentarisch*), 'open' (*open*), and 'closed' (*gesloten*).

Besides the grass, also the soil of the top layer determines the strength, and thus the stability of the top layer. The soil is usually clay and in rare cases sand. The clay quality will change considerably after construction of the clay layer. These changes are chemical, physical, and mineralogical and have effect on the scale of the clay lumps. A clay texture will develop due to cracks which are a result of shrinkage and swelling. There are biological processes that contribute to a relatively loose structure of the clay. These processes include activity of plant roots, fungi and bacteria, worms and other invertebrates, and sometimes moles, rats and, in sandy soils, mice and rabbits. However, there are other biological soil processes that enhance soil stability in dikes (Reijers et al. 2014). For example, plant roots have symbiotic mycorrhiza fungi that excrete glomalin, which promotes aggregation of soil particles (Bardgett et al. 2014). An impression of a typical clay lay-out on a dike is given in Figure 2.4.

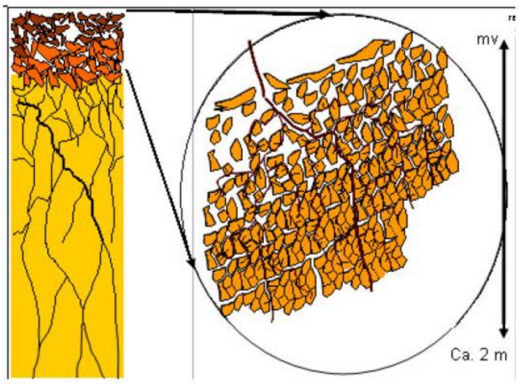

Figure 2.4 Soil structure in good clay ('stevige klei') on a dike with grass with a detail of the top layer with grass roots (RWS, 2012)

For engineering purposes clay is categorised as follows:

- Erosion resistant clay (in Dutch: *Erosiebestendige klei*)
- Little erosion resistant clay (in Dutch: *Weinig* erosiebestendige *klei*)
- Unsuitable soil (In Dutch: ongeschikte grond)

The category depends on soil characteristics such as the plasticity index (in Dutch: *plasticiteitsindex*) and the Liquid Limit (in Dutch: *vloeigrens*). This dependency is visualized in Figure 2.5. More information can be found in RWS (2012).

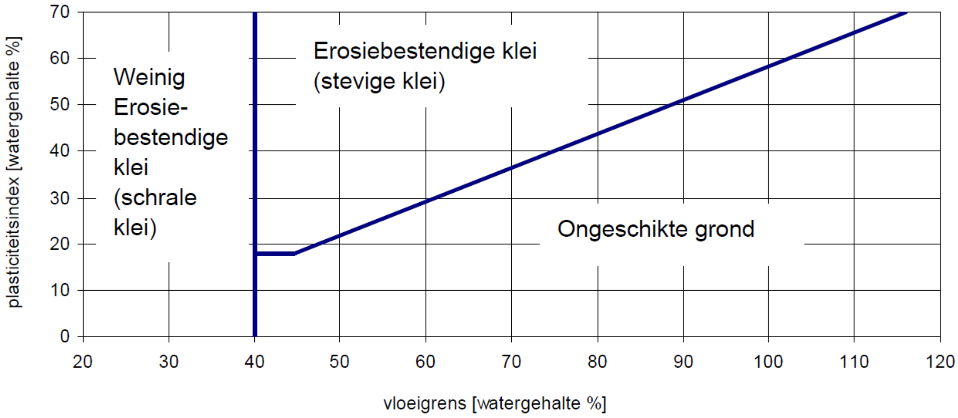

Figure 2.5 Atterberg diagram with classification of soil (RWS, 2012)

2.1.4 Quantification of the stability of grass revetments

Failure of grass dikes under hydraulic loads can occur in different ways. These mechanisms are categorized according to the different load zones (impact, run-up, and overtopping: see Section 2.1.2). The different identified failure mechanisms are worked out in more detail in RWS (2012). To quantify the resistance of grass dikes against erosion semi-empirical models are used which are briefly described below. That description is only given to get a first impression. For a full description reference is made to RWS (2012).

<u>Wave impacts</u>

To obtain an impression of grass under wave impact loading, reference is made to Figure 2.6. This figure gives the resistance time (*standtijd*) as function of the significant wave height (H_s) the grass quality (indicated as 'open' (in Dutch: *open*) or 'close' (in Dutch: *dicht*) and the type of used soil. The diagram is used for the assessment of Dutch dikes and includes a safety factor. The given graphs are therefore conservative (in reality the resistance time is likely larger than given in the figure).

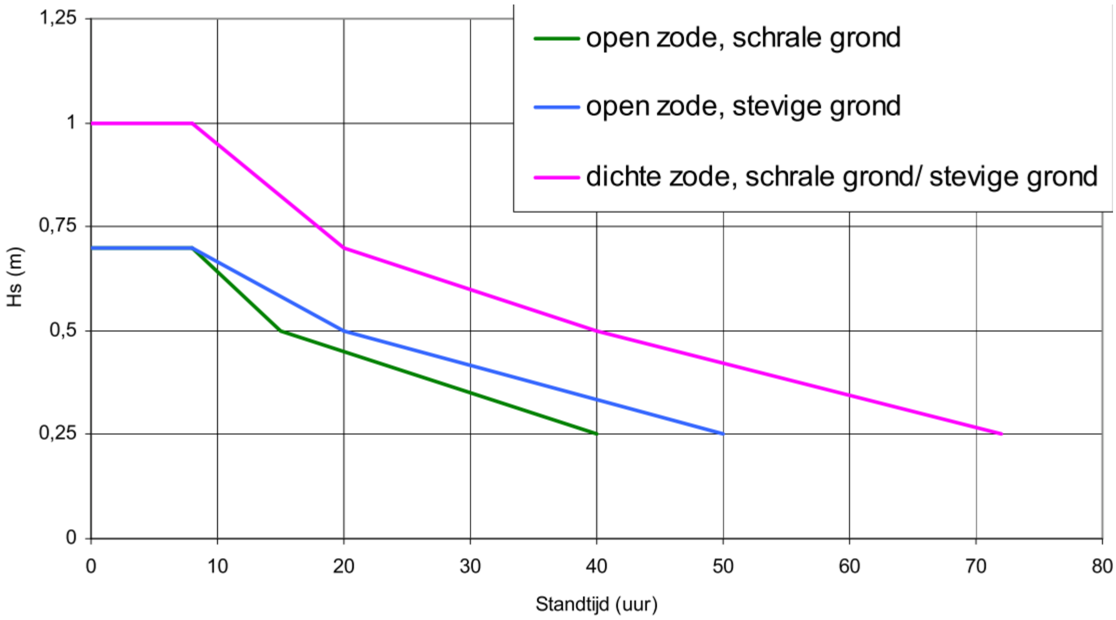

Figure 2.6 Resistant time of the top layer (outer slope) due to wave impacts (source: RWS, 2012)

In this figure it can be seen that an open grass sod (blue line) under a wave load with a significant wave height of H_s = 0.5 m has a resistance time of approximately 20 hours. A closed sod (pink line) under the same wave conditions has a resistance time of 40 hours.

<u>Wave run-up</u>
The resistance time of the top layer in the wave run up zone is visualised in Figure 2.7.

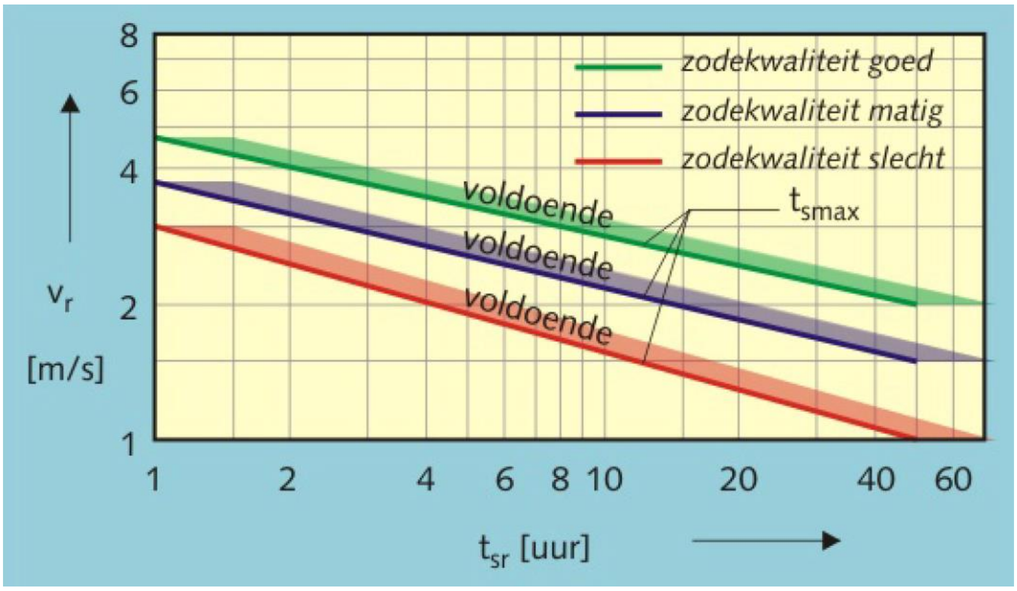

Figure 2.7 Resistance time of grass in wave run-up zone as function of load parameter v_r (RWS,2012)

As can be seen the resistance time (t_{sr}) is a function of the grass quality and the load parameter v_r. The load parameter v_r is a function of the wave conditions, the geometry of the dike and the position of the slope. Since the resistance time is a function of many parameters it is difficult to visualize this. For illustration purposes an example is given with the load parameter having a value of v_r = 2 m/s. It can be seen that the resistance time is 4 hours (low sod quality), 15 hours (moderate sod quality) or 50 hours (high sod quality). For more information reference is made to RWS (2012).

Wave overtopping
To determine whether a grass dike can resist wave overtopping, the flow diagram as given in Figure 2.8 is used in the assessment of dikes.

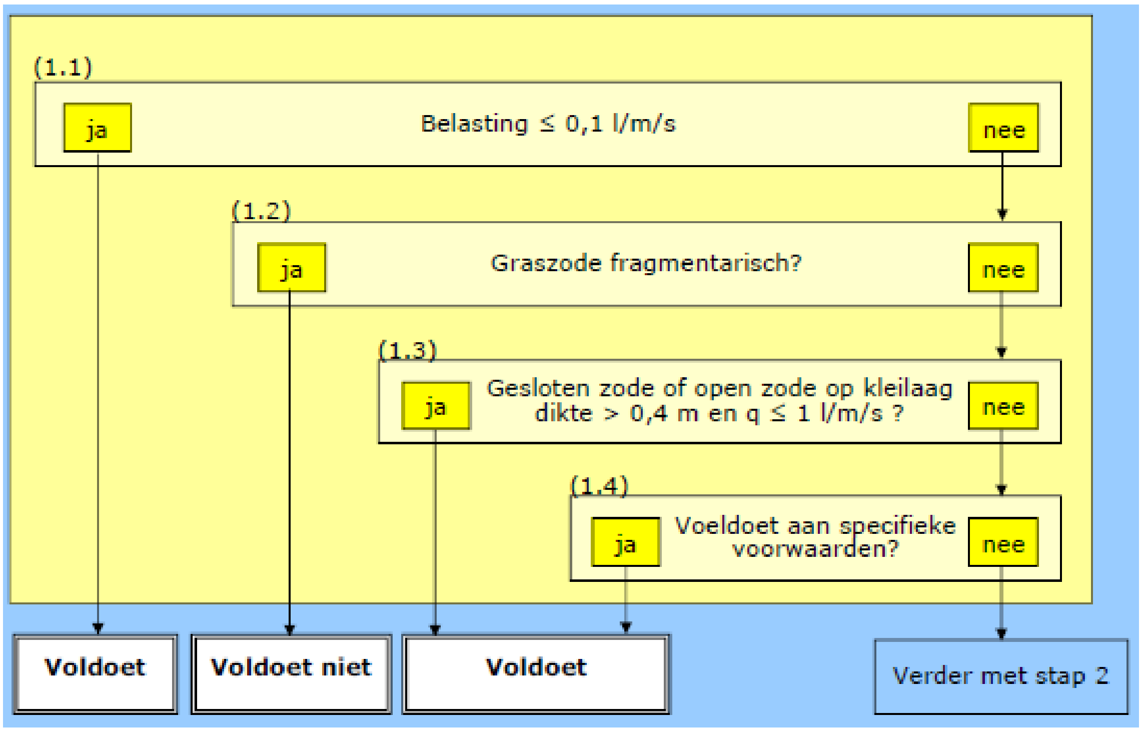

Figure 2.8 flow diagram to asses grass revetments for wave overtopping (source: RWS, 2012)

The specific steps given in Figure 2.8 are described below:

- (1.1) A wave overtopping quantity of q < 0.1 l/s/m is allowed for every type of grass dike

- (1.2) For q > 0.1 l/s/m a fragmentary grass sod is not allowed

- (1.3) For situations with
  - Mean wave overtopping discharge q smaller than 1 l/s/m AND
  - a clay layer with a thickness larger than 0.4 m AND
  - a grass sod categorised as closed or open

  the stability meets the requirements

- (1.4) For situations with
  - A closed sod AND
  - Mean wave overtopping discharge q smaller than 5 l/s/m AND
  - Significant wave height H_s smaller than 3 m AND

  - Clay layer with a thickness larger than 0.4 m or a slope angle gentler than 1:4
    The stability meets the requirement

- Step 2: In case the sod meets the requirements in Step 1.1, Step 1.2 and Step 1.3 but not Step 1.4 a more detailed analysis is required. This detailed analysis is a complicated semi empirical model which is described in RWS (2012).

2.1.5 Physical model testing of grass revetments

The above described calculation methods are based on data obtained with physical models. These physical models are amongst others wave flumes and hydraulic simulators.

Wave flumes are ideal to simulate natural wave patterns. In some cases physical processes can be scaled down (example: a geometric scale of 1:20 indicates that all length dimensions are scaled down with a factor 20). Downscaling is not always possible since specific characteristics of the loads or the strength will be lost. This is the case with grass revetments. Grass cannot be scaled down since the root characteristics of the grass and the clay characteristics on real scale are important for the strength and there are no techniques available to downscale these properties correctly. Therefore real-scale (1:1 scale) flume tests have been performed in the Deltares Delta Flume. An impression of this wave flume is given in Figure 2.9. The Delta Flume has a length of 300 m, a width of 5 m and a depth of 9 m. Irregular wave fields with a significant wave height up to 2.2 m (individual waves with a wave height of 4 m) can be generated. More information about the Delta Flume can be found in Van Gent (2014).

Figure 2.9 Large scale wave flume research in the Deltares Delta Flume. Left: wave run-up. Middle: test set-up prior to testing. Right: overtopping while a (secured) person was standing on the crest.

A different option is to apply hydraulic simulators such as the wave overtopping simulator, the wave run-up simulator and the wave impact generator. These simulators can be placed on a real existing dike and can simulate a certain process (wave impact, run-up or overtopping) to a certain extent. An impression is given in Figure 2.10. An overview of the simulators is given in Steendam *et al* (2013). Specific information about the simulators is given in Van Steeg *et* *al*, 2014 (wave impact generator), Van der Meer *et al*, 2006 (wave overtopping simulator) and Van der Meer *et al*, 2012 (wave run-up simulator).

Figure 2.10 Wave impact generator (left) and wave overtopping simulator (right)

2.2 Strengthening grass covers on dikes: two main concepts

There are basically two main concepts for strengthening grass covers on dikes. The first focuses on strengthening rooting profiles and resilience of the grass cover by increasing species-richness (section 2.2.1). The second looks at ways of reinforcing natural grasslands through the application of synthetic materials. The present report focuses on this second concept (section 2.2.2).

2.2.1 Improved rooting and resilience of grass by increasing species-richness

Experimental studies have shown multiple benefits of species-rich as compared to species-poor plant communities. Species-rich grasslands have increased root biomass compared to species-poor plant communities (Mommer et al., 2010; Ravenek et al., 2014). Moreover, from intercropping in agriculture it is known that increasing plant diversity reduces disease incidence and severity (Trenbath, 1993; Zhu et al., 2000). More biodiverse vegetation can also recover better from extreme weather events such as droughts (Van Ruijven and Berendse, 2010; De Mazancourt et al. 2013). Furthermore, Berendse et al. (2015) have shown that an increase in plant species diversity on a model dike led to decreased soil erosion. This was due to a compensation or insurance effect, that is, the capacity of diverse communities to supply species to take over the functions of species that went extinct as a consequence of fluctuating environmental conditions. In a recent study, this concept of ‘learning from nature’ has been worked out for application on dike grasslands (Reijers et al., 2014). In this study, new seed mixtures are proposed based on the selection of plant species according to their rooting patterns.

2.2.2 Grass reinforcement systems

The basic idea of reinforcement in a grassed waterway is to enhance the engineering functions of plain grass, while aiming at retaining its environmental and economic attributes (Hewlett *et al*, 1987). In the Netherlands, the UK, and the US, the application of grass reinforcement systems is currently being discussed.

In the Netherlands grass reinforcement systems were considered in the project ComCoast (ComCoast, 2007) and in a recent study with respect to transitions in grass revetments (Van Steeg, 2014). In that study also experiments with the wave impact generator (See Section 2.1.5) were carried out on open concrete blocks allowing grass growth (Van Steeg *et al*, 2015). In ComCoast (2007), where the wave overtopping simulator (see Section 2.1.5) was developed and applied, it was concluded that grass reinforcements (geogrid) had a significant

positive contribution (less erosion) to the strength. It is however noted that, during testing, artificial damage was made to both the unreinforced and the reinforced grass. This was done since the unreinforced grass section without artificial initial damage was able to cope with the highest possible load. The reinforced grass contributed to the stability due to two reasons:
- The reinforcement provided good anchorage to the grass sods by intertwinement of the root system to the applied geogrid.
- Shelter was provided to the under lying clay body by physical protection of the clay layer and by partial consumption of eroding forces.

In the UK a design guidebook for reinforced grass waterways was published by CIRIA (Hewlett et al, 1987). The following text is taken from these guidelines:

Use of geotextile reinforcement can provide some or all of the following advantages over plain grass:
- *Improvement of ground cover and consequent protection of the soil surface from erosion. The development of local weak spots, for example by concentrated traffic, livestock damage or drought, will also be retarded by the presence of the reinforcement.*
- *Assistance to the root structure in restraining surface soil particles from erosion by flowing water*
- *Improvement in lateral continuity between grass plants and consequently a reduction on the risk of localised failure due to erosion of individual plants, shallow slippage or 'rolling up' of the soil / root mat.*

Hewlett et al (1987) show a design graph which is given as Figure 2.11. It should be noted that the velocities as given in that figure are valid for steady overtopping flow only (which is different from the pulsive loading due to wave run-up, wave overtopping or wave impact as described in Section 2.1.2).

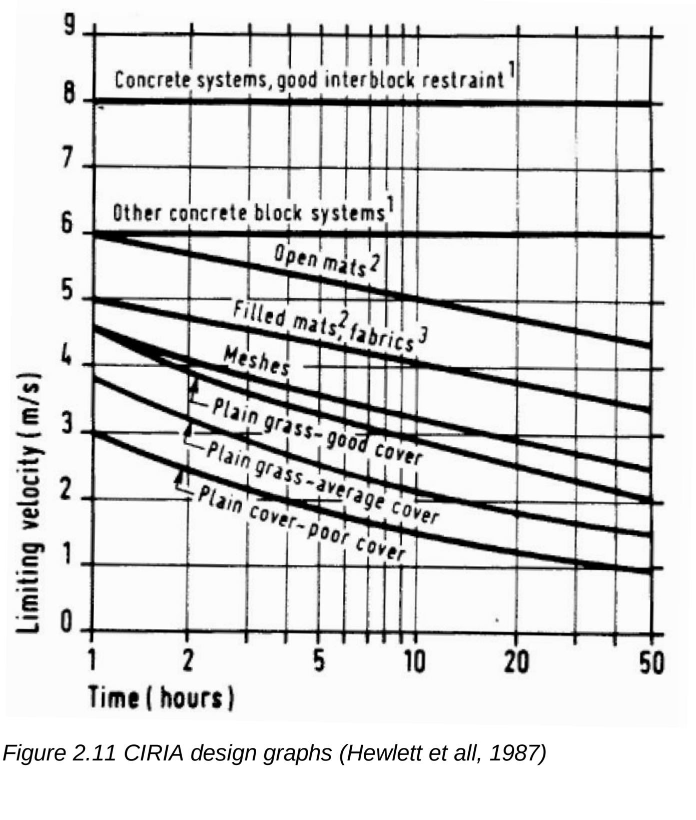

Figure 2.11 CIRIA design graphs (Hewlett et all, 1987)

It can clearly be seen that, according to CIRIA, reinforcement of grass covers contributes to the resistance time.

In the US research is conducted to reinforced grass dikes (Hughes *et al*, 2013). The tested conditions are representative for dikes in the state of Florida (high sand content and specific type of grass, so-called Bahiagrass). The research is conducted by placing soil in trays and ship these trays from Florida to Colorado. In Colorado the trays were installed under greenhouse conditions representative for Florida conditions. Twelve different conditions were applied were variations were made to the soil and the grass coverage. Two tests were carried out with reinforced sods (geogrids). The several samples were tested with a wave overtopping test facility which is comparable with the wave overtopping simulator (see Section 2.1.5). It was concluded that the resistance of the reinforced grass sods were significantly higher than the resistance of the unreinforced grass sods.

Based on literature from the UK, US and the Netherlands it is concluded that reinforcement of grass sods under hydraulic loading gives more strength to the grass sod. It is however noted that the knowledge with respect to these systems is limited and empirical data is usually only valid for very specific conditions (type of grass, clay, reinforcement, and hydraulic load). It should also be noted that the reinforcement systems from UK, US and Dutch studies discussed above (i.e. continuous fabrics of geotextile and geogrid) are different from the Desso GrassMaster® system.

2.2.3 Reinforcement with Desso GrassMaster®

According to the Technical Manual Desso GrassMaster® the natural grass roots interact with the synthetic fibres leading to a higher anchorage. Also the growing points of the grass are protected by the synthetic parts. At sports fields this leads to a better quality of the grass compared with grassfields without Desso GrassMaster®. Due to the presence of the synthetic fibres the capacity of a soccer field is enlarged from 250 hours to approximately 1000 hours.

The influence of Desso GrassMaster® on less intensively managed grass covers such as dike grasslands and on the strength of grass dikes under hydraulic loads is unknown. The fact that it has a positive influence on the strength of grass sports fields suggests that this may also be the case for grass under hydraulic loads.

The application of Desso GrassMaster® might have positive and negative influences on the strength of grass revetments under hydraulic loads. A potential negative influence may be a diminished growth of plant roots due to the presence of the synthetic material (see also Section 3.4). A potential positive influence may be physical reinforcement of the soil due to the presence of the synthetic fibres, analogous to reinforced concrete. According to Desso, another potentially positive influence is the perforation of the root zone, allowing better aeration and promoting root development. In our view it is plausible that perforation, through creating space and aeration, can promote root growth. However, in soils that are not waterlogged most of the time (as is the case on dike grasslands) sufficient aeration for root development will under normal conditions be guaranteed by the activity of soil invertebrates and other natural soil formation processes. In this respect, it is currently not known if there will be an additional positive effect on root development by applying Desso GrassMaster®. To summarize the preceding information, it is currently not known what the *net* contribution of the application of Desso GrassMaster® to dike grassland strength will be. This should be investigated in experimental set-ups with Desso GrassMaster®.

3 Comparison between the application in sports fields and hydraulic engineering

The current application of the Desso GrassMaster® system in sports fields and the potential application within the domain of hydraulic engineering (i.e. on dikes) have in common that the aim is to reinforce the strength of a grass cover. The primary functions of sports fields as well as dikes both demand a well-developed and closed grass cover. However, there are several marked differences between sports fields and dike grasslands when it comes to the type of loads (Section 3.1), the vegetation composition and management (Section 3.2), the functions of the grass covers (Section 3.3), and the resulting effective reinforcement that is needed (Section 3.4). Finally, we will discuss environmental issues to be considered (Section 3.5).

3.1 Timing and characteristics of loads, and critical areas

The load of a sports field, or at least certain parts of it, may well be more frequent than that of dike grassland. Intensive use during training or matches may occur (bi)weekly. The occurrence of hydraulic loads on a dike grassland is in most cases much less frequent, but on the other hand, the occurrence of extreme events is less predictable. If extreme hydraulic events occur, they often happen in the winter, when the strength of the grass vegetation is reduced compared to the summer (Schaffers et al, 2011).

A series of full-scale wave overtopping tests on Dutch primary dikes has shown that in general dike grasslands are - also in winter - to a high degree resistant against erosion due to wave run-up or overtopping (RWS, 2012). Still, there are interesting perspectives of reinforcing dike grasslands, such as larger allowable overtopping discharges which leads to a lower required crest height of the dike, as well as stronger grass covers in other critical zones of dike grasslands.

When considering reinforcement of dike grasslands with the Desso GrassMaster® system, it is important to compare the types of loads that may occur on dike grasslands to those occurring at sports fields (Table 3.3.1). Doing so is a first step in judging to what extent this reinforcement system is promising given at what time and place either hydraulic load or grass strength may be most critical. Are the hydraulic loads to dike grasslands sufficiently similar to those on sports fields, and if not, what design requirements does this involve for a reinforcement system?

From a recent series of full-scale wave overtopping tests (Steendam et al 2010), and wave impact tests (Van Steeg et al, 2014), it has become clear that on dike grasslands, especially transitions are critical areas, see also Section 4.2.4. Such transitions include geometric transitions from a slope to a horizontal level (e.g. berms), but also transitions from concrete or asphalt to grass or vice versa (RWS, 2012). Similar transitions are either not present on sports field, or are not relevant because the load in these areas is negligible (e.g. at the edges of a pitch).

Table 3.3.1 Comparison of loads and resulting risks to grass cover on sports fields and dike grasslands.

Type of load on grass cover	Occurrence on sports fields	Occurrence on dike grasslands	Risk to grass cover
Lateral erosion	During sliding-tackles or dives by players	During wave run-up/down or overtopping	Loss of protective and nourishing soil material. Rupture or damage of grass meristems (higher risk on sports fields)
Vertical compressive stress	Impact at landing after a player jumps	Can be significant in wave impact, run-up and overtopping zones	Minor, as forces are mainly absorbed by soil matrix
Vertical tensile stress	Not significant?	Can be significant in wave run-up and overtopping zones	Large-scale rupture of roots leading to detached grass cover

3.2 Vegetation composition and management

Sports fields and dike grasslands (at least in the Netherlands and neighbouring countries) usually differ quite markedly in their vegetation composition and structure. The vegetation of dike grasslands is usually more species-rich, including many non-grass species. The benefits of species-rich as compared to species-poor grasslands have been described in Section 2.2.1 and include increased root growth, reduced disease incidence and severity, reduced soil erosion, and more resilience against weather extremes.

The differences in vegetation composition and species-richness between sports fields and dike grasslands have three main causes: different sowing practices, different subsequent management practices, and different likelihoods of spontaneous establishment of new grassland species. Below, we will briefly elaborate on these causes.

Table 3.3.2 shows that both seed mixtures that are commonly applied on Dutch dikes and seed mixtures for (reinforced) sports fields are relatively species-poor and dominated by (cultivars of) two or three grass species native to Europe. These are relatively fast-growing species capable of quickly reaching significant cover. Red fescue (*Festuca rubra*) is capable of producing high root densities (Cong et al., 2014), while White clover (*Trifolium repens*) has a natural fertilizing capacity as it brings nitrogen into the root zone. The differences between the mixtures are in the ratio between the species but mainly in the amount of seed applied per hectare. This amount is more than twice and up to about 10 times as high in sports fields as on dikes.

Sports fields and dike grasslands also differ in their management. Common management types of sports fields are described in the Technical Manual Desso GrassMaster® and common management types of dike grasslands in VTV (2006) and RWS (2012). In brief, most (reinforced) sports fields have an artificial drainage system in the shallow underground, have an intensive lawn-mowing type of management which includes heavy fertilizer addition (250-400 kg N/ha/yr), sprinkling and disease control. Under such fertilizer schemes, plants do not need to invest heavily in rooting. In contrast, dike grasslands are usually either mown once or twice per year (haymaking, in Dutch: hooibeheer) or grazed (not continuously) by sheep. Fertilizer addition is either not applied or in lower amounts (max. 70 kg N/ha/yr) than on sports fields. Higher N addition rates may occur locally on dike grasslands, but will most likely lead to less strong and less biodiverse grasslands. These less intensive management types – as compared to sports fields – contribute to the development of more species-rich grass covers on most dikes. Low fertilizer application not only promotes species richness, but also promotes the development of a root network which is considerably denser and deeper than in more heavily fertilized grasslands. In Dutch dike grasslands on primary flood defences, the occurrence of up to ca. 30 plant species per 4-25 m^2 is not exceptional and is considered beneficial from a strength and resilience point of view (see Section 2.2.1). A considerable part of these species are forbs (i.e. herbaceous flowering plants other than grasses, sedges and rushes), while several moss species may also occur on dike grasslands.

Table 3.3.2 Composition of seed mixtures as commonly applied on Dutch dike grasslands and on sports fields in temperate zones. Sources: Reijers et al. (2014) for dike grasslands and Technical Manual Desso GrassMaster®.

Species name	Species name in English/Dutch	Delta1 (D1) mix for Dutch dike grasslands (60-70 kg/ha)	Delta2 (D2) mix for Dutch dike grasslands (60-70 kg/ha)	Sports fields (160-700 kg/ha)
Festuca rubra	Red fescue/Roodzwenkgras	25%	60%	-
Lolium perenne	Perennial rye-grass/Engels raaigras	40%	10%	60-75%
Poa pratensis	Smooth meadow-grass/Veldbeemdgras	25%	30%	40-25%
Trifolium repens	White clover/Witte klaver	10%	-	-

A final important factor contributing to the more species-rich character of established dike grasslands is the fact that they are ecologically more integrated into the surrounding environment than sports fields. Unlike sports fields in stadiums, dike grasslands are not sheltered from the outside world by artificial barriers. Also, in many low-lying areas, dikes form more or less continuous networks of hundreds or even thousands of kilometres. Although the initial vegetation of most dikes is sown by man - a process which may be repeated after a certain number of years, e.g. during dike improvement works -, the fact that dikes are more integrated in and less sheltered from their surrounding environment greatly increases the likelihood of spontaneous establishment of new plant species.

3.3 Functions of the grass cover

Both sports fields and dike grasslands have one dominant function, which is to accommodate sports games and to contribute to dike stability and thus to water safety, respectively. However, dike grasslands differ from sports fields in that they also serve other purposes. In the Netherlands, these other functions are often referred to as ‘LNC values’, meaning Landscape, Nature and Cultural heritage values. These LNC values are explicitly recognised by the Dutch responsible authorities. When a dike is constructed, modified or improved, these LNC values have to be taken into account (RWS, 2012).

3.4 Effective reinforcement needed and effects on the rooting zone

3.4.1 Differences in effective reinforcement

From a plant ecophysiological viewpoint, there may be very different effects of application of Desso GrassMaster® on the quality of the grass in sports field and on dikes. It is stated that bending of the Desso GrassMaster® fibres prevents the damage of shoot meristems, which occur due to slidings and intensive trampling on sport fields (Technical Manual Desso GrassMaster®). When Desso GrassMaster® is applied in sports fields, the soil will be nutrient-rich, as fertiliser will be available in high amounts, and therefore nutrient uptake by roots is not limiting plant growth. Providing sufficient light for assimilation of photosynthates is most likely more limiting. In sports fields a high rooting density may not be the primary criterion.

In contrast, high rooting density and an even distribution of root biomass are the most important criteria determining the strength of dikes (VTV, 2006; RWS, 2012; Reijers et al., 2014).

3.4.2 Effects of obstacles on plant rooting patterns

Rooting patterns of grass species are dependent on resource availability such as water and nutrients, and on soil texture, structure and compaction. Roots have been observed to clump into biopores and cracks (Passioura, 1991; White and Kirkegaard 2010), suggesting that roots navigate the soil. Roots also navigate around obstacles such as stones, compacted soil and neighbouring roots (Bengough, 2003), and thus potentially also navigate around Desso GrassMaster® fibres. The ability of roots to navigate around obstacles has been known for many years (e.g. Montagu et al., 1998), but the topic has received relatively little attention experimentally.

Two studies exist that explicitly investigated the effect of obstacles on root behaviour. Falik et al. (2005) used obstacles that structurally seem similar to Desso GrassMaster® fibres: a piece of monofilament nylon string, 0.8 mm in diameter, similar in shape and size to a neighbouring root. The results of Falik et al. (2005) suggest that the development of lateral roots of the pea (*Pisum sativum*) is strongly inhibited by non-living obstacles. Roots that grew next to a physical object as small as a monofilament nylon string were shorter and/or withered (i.e. died) before getting in contact with the string. Chemically, nylon is hydrophilic while the polyethylene Desso GrassMaster® fibres are hydrophobic. It is not known to us whether this makes a difference in the response of plant roots to synthetic fibres.

In another study testing eight grass species - four originating from nutrient-rich habitats, four from nutrient-poor habitats - similar results were obtained (Semchenko et al., 2008). Inhibition responses of the species from nutrient-poor conditions were more significant, but the responses from the species from nutrient-rich sites (Creeping bentgrass - *Agrostis stolonifera*, Meadow fescue - *Festuca pratensis*, Timothy-grass - *Phleum pratense*, Rough meadow-grass - *Poa trivialis* – species that can also be found in Dutch dike grasslands) were not. In this study the obstructions were pieces of gravel; which are less comparable to Desso GrassMaster® fibres, but relevant in the context of this report is that the obstacle effect on root inhibition was partly independent of nutrient status or soil compaction. It should be noted that both studies were performed on individual plants under controlled conditions in the greenhouse on a time frame of several weeks.

Inhibition responses in both studies are explained by the fact that the addition of fibres reduces the space which hampers the ability of roots to explore the substrate. Moreover, both studies provide evidence that obstacles in the soil are sensed by roots due to accumulation of allellopathic (autotoxic) root exudates. It would be necessary to investigate how root growth and root turnover interact with Desso GrassMaster® on a longer time scale.

In conclusion, experimental evidence on individual plants suggests that effects of obstacles in soil, such as Desso GrassMaster® fibres, on root growth are negative rather than positive, but long term studies on effects of obstacles on root growth in plant communities are currently lacking. It is therefore unknown what the exact influence of Desso GrassMaster® on the root development of a grass cover is. It is emphasized that a potential positive influence may be physical reinforcement of the soil due to the presence of the synthetic fibres, analogous to reinforced concrete. However, given that there is a potential positive and a potential negative effect, it is important to know the net contribution of Desso GrassMaster® to grass cover strength. This should be assessed experimentally.

This aspect is discussed in more detail in Section 2.2.3.

3.5 Potential environmental impact of the reinforcement system

The fact that dike grasslands are less sheltered from and more integrated in the surrounding environment than sports fields may lead to a higher potential environmental impact of the application of reinforcement systems, in this case the potential application of the Desso GrassMaster® system. The degree of decomposability of Desso GrassMaster® fibres and the potential interactions with roots, as well as soil macro and microfauna should be investigated before application on dikes, (including aspects of potential toxicity of Desso at high fibre densities). From the perspective of the soil food web, it is important to recognize the potential environmental impact of reinforcement systems. The presence of this material in ecologically non-isolated environments such as dike grasslands may have a negative impact on its different biotic components.
The environmental impact can be divided into a chemical stressor, caused by the chemicals present in the product, and a physical stressor, caused by the application form (fibre/thread) of the product. Both aspects will be elaborated upon in the next sections.

In case Desso GrassMaster® is used as an alternative for traditional revetments such as asphalt, concrete or placed blocks, the avoidance of these materials should be taken into account when determining the environmental impact of this product.

3.5.1 Chemical stress

In the product, chemicals can be present which may leach out of the product during the application phase of the product in the field. Especially during long-term flood events this leaching may be increased. A complete Environmental Risk Assessment of Desso GrassMaster® was not anticipated within the underlying project. Therefore we refer to the information provided by Desso Sports. In an earlier stage, Desso GrassMaster® has been evaluated by a consultancy (EPEA) according to their Cradle to Cradle® principles. Three important aspects of this principle with respect to materials are (1) that all constituent parts of a product have to be known, (2) that all chemicals contained in the product are identified by their CAS number, (3) and that these chemicals are then evaluated by EPEA using the chemical evaluation regarding their toxicological and eco-toxicological properties (http://www.epea-hamburg.org/en/content/certification-criterion). In an earlier stage, EPEA concluded that Desso GrassMaster® contained one substance with a potential risk. This substance was replaced by Desso Sports with a less harmful substance, thereby passing the Cradle to Cradle Principle®, according to the information provided by Desso Sports. Assuming that EPEA will provide the official documents concerning the Cradle to Cradle® principles approval, we conclude that no environmental risks occur from the chemicals potentially leaching out from Desso GrassMaster®.

Desso Sports is intending to produce all their goods according to the Cradle to Cradle principle in the near future (source: interview with Desso Sports).

3.5.2 Physical stress

In recent years, increasing concerns have been risen about the possible environmental impact plastics may have. These concerns focus merely on the physical stress these materials may cause in (aquatic) organisms, caused by a special category within the group of polymers, namely microplastics, defined as synthetic polymer particles <5 mm. Within the group of microplastics a difference can be made between primary particles, which are intentionally produced (i.e as an additive for cosmetics) and secondary particles, which are formed by abrasion and wearing of plastic products. Because of the formulation (fibres) and presence of the Desso GrassMaster® in ecologically non-isolated environments such as dike grasslands it is likely that secondary microplastics may be formed in the application phase of the product, consequently entering the soil and aquatic environment. It cannot be excluded in advance that these plastics have a negative impact on soil and aquatic biota such as invertebrates and other parts of the food web. Although the environmental effects of these particles are not clear yet, and no Environmental Quality Standards exist for these particles, one should be aware that there is a growing societal and political concern about the presence of plastics in the aquatic environment, and consequently a growing pressure for ‘cradle to cradle’ solutions.

Potential solutions to these environmental risks may exist and be further explored. For example, it might be possible to apply the Desso GrassMaster® system using slowly biodegradable alternative materials.

4 Requirements for Desso GrassMaster® as dike protection

4.1 Introduction

To stimulate the use of innovative materials in dike covers, the Dutch Ministry of Infrastructure and Environment (Rijkwaterstaat) developed, in cooperation with Deltares and Witteveen + Bos, a report (van den Berg et al, 2010) in which criteria for (Dutch) dike covers are given. This report is developed to create a framework for both the product developer and the dike manager to develop and evaluate an innovative dike cover. This report is ideal to use as a basis since other reports or guidelines focus on a specific topic such as rock armour, placed-blocks, asphalt or grass.

Within the mentioned report three main requirements are addressed:

1. The dike cover should meet all legal requirements
2. The dike cover should protect the dike sufficiently
3. The developer should demonstrate this

Since this is rather abstract this is worked out in more detail by using four different categories:
- Legal requirements
- Primary requirements
- Secondary requirements
- Aspect requirements

The legal requirements in the Netherlands related to dike covers are the '*Waterwet'* (Waterlaw) and the '*Wet bodembescherming*' (law on the protection of the (sub)soil). The Waterwet involves the legal framework for construction, adaption, replacement et cetera of primary flood defences. The *Waterwet* also dictates that a primary flood defence should be assessed every twelve years according to a prescribed method. Almost every technical requirement is based on the 12-yearly assessment method. It is therefore important that an innovative solution can be assessed properly. The Waterwet also involves issues concerning the contamination of water bodies. The *Wet bodembescherming* involves issues related to the contamination of soil and the use of construction materials.

The primary requirement of a dike is to protect the hinterland against floodings. To protect the dike itself, a top layer is applied that prevents the dike against erosion. The primary function of the top layer is therefore to protect the dike body against erosion.

Several secondary functions are identified. Besides several constructional functions there are also several non-constructional functions such as traffic, landscape, ecology, recreation, agricultural use et cetera (see also Section 3.3).

Aspect requirements describe aspects that do not necessarily contribute to a function but that are still important. Aspect requirements are amongst others placement method, quality control, maintenance, assessment according to the Dutch VTV standards (see VTV, 2006), removability, transitions, durability, value of a dike from the perspective of landscape, nature and cultural heritage ('LNC values'), life time, and costs.

In the mentioned report the following steps are suggested to implement a product as a top layer on a dike.

1 Determine the range of application
2 Check on legal issues
3 Check on other aspects
4 Dimensioning (assessment and design method)
5 Assessment by responsible dike body

The steps as given above are described for the Desso GrassMaster® system in the following sections.

4.2 Step 1: Determine range of application

It is estimated that Desso GrassMaster® may have a potential added value on the following applications on a dike:

4.2.1 Wave run-up zone

Lower parts of the wave run-up zone are subject to higher loads (more run ups and a higher velocity during each run-up cycle). For this reason the lower parts are usually protected by 'hard' revetments such as placed concrete blocks or asphalt. On the higher parts of the wave run-up zone usually grass is applied. By applying grass reinforced with Desso GrassMaster® the transition from a 'hard' revetment to a grass revetment may potentially be lowered enhancing the 'green ecological' perception of the dike and potentially leading to lower costs.

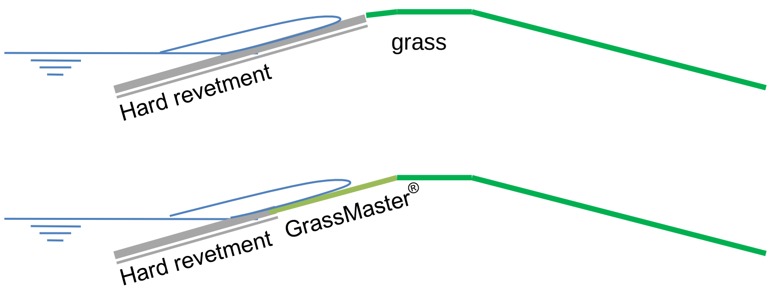

Figure 4.1 Schematised example of lowering the hard revetment in the wave run-up zone which may potentially be allowed applying Desso GrassMaster®

4.2.2 Wave overtopping zone

The resistance against erosion of the wave overtopping zone (crest and landward slope of the dike) determines to a large extent the height of the crest of the dike. By applying Desso GrassMaster® instead of a non-reinforced grass cover, the erosion resistance may potentially be higher leading to larger allowable overtopping discharges which leads to a lower required crest height of the dike. A lower crest height will significantly contribute to lower costs and higher acceptability of society. These benefits should be evaluated against other aspects related to Desso GrassMaster® (see sections 4.3 to 4.6).

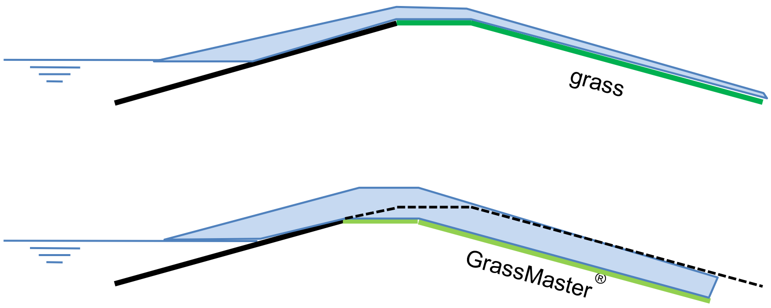

Figure 4.2 Schematised example of lower crest and more overtopping which may potentially be allowed at the inner slope due to the presence of GrassMaster®

An example to quantify the potential reduction in crest height is given below.

<u>Example</u>
In this example a strongly schematised dike profile is given. Suppose a dike with the following conditions:

- 1:3 outer slope
- No berms
- No roughness on outer slope
- Normative wave conditions with the following characteristics:
    - Significant wave height of H_s = 2 m
    - Spectral wave period of $T_{m-1.0}$ = 8 s
    - Angle of incident wave is 0^o (perpendicular to dike orientation)

The above given hydraulic conditions are typical sea-state conditions. In this example the diagram as given in Section 2.1.4 is applied. This basically comes down to an acceptable mean wave overtopping discharge q for grass inner slopes of 1 l/s/m or 5 l/s/m depending on the grass and clay conditions. Several exceptions are made but are for simplicity reasons not taken into account in this exercise.

What is the required crest height (R_c) for this case? The wave overtopping discharge q as function of the crest height R_c for the given conditions is determined using the software tool PC-Overtop (version 3.0).

An overview of the mean wave overtopping discharge as function of the crest height is given in Table 4.1. The values in that table are determined with PC-Overtop. The crest height R_c is the vertical distance between the crest and the still water line.

Table 4.1 Mean wave overtopping discharge q as function of the crest height R_c for the given example. (x.y) refers to step number as given in Figure 2.8

wave overtopping discharge *q* (l/s/m)	**Crest height R_c (m)**	**Lowering crest w.r.t *q* = 1 l/s/m**	**remark**
0.1	8.5	-	For each situation accepted (1.1)
1	6.5	0.0 m	For specific situations accepted (1.3)
5	5.1	0.6 m	For specific situations accepted (1.4)
10	4.5	2.0 m	
50	3.1	3.4 m	Assumption*: Accepted for GrassMaster®
75	2.8	3.7 m	
100	2.5	4.0 m	

* The assumption is only for illustration purposes.

Suppose

- Desso GrassMaster® is accepted as a revetment that can be applied under conditions with a mean wave overtopping discharge *q* of 50 l/s/m AND
- A reference grass section has an allowable wave overtopping discharge of 5 l/s/m

THEN

- the crest height can be lowered from 5.1 m (q = 1 l/s/m) to 3.1 m (q = 50 l/s/m) leading to a potential crest height reduction of 2 m.

It is however unknown what the strength of a revetment reinforced with Desso GrassMaster® is, because scientific evidence for effects of Desso GrassMaster® fibres on root responses and root interactions with the soil microbial community are unknown. In this example it is just an assumption that an overtopping rate of 50 l/s/m is acceptable. It is therefore needed to determine the resistance of Desso GrassMaster® by conducting physical experiments as described in Section 2.1.5 before assumptions as given as above are justified. Also testing in more controlled (greenhouse) conditions, to quantify the effect of Desso GrassMaster® on root development and mortality, is recommended. After determining the above-mentioned resistance and with a better understanding of the interaction between Desso GrassMaster® and plant species, the range of application (expressed in overtopping quantities) can be determined.

4.2.3 Wave impact zone

The resistance of grass in the wave impact zone may potentially be enlarged by applying Desso GrassMaster®. Due to the relatively high loads, grass is often not considered strong enough to resist wave impacts and therefore alternative materials such as concrete placed blocks or asphalt is applied. Desso GrassMaster® may be a potential alternative for these materials. A quantification of the applicable range can be done by comparing a situation with only grass and a situation where Desso GrassMaster® is applied. For a first impression of the application range of grass use can be made of Figure 2.6. To determine the resistance of Desso GrassMaster® empirical data is required which can be obtained by performing full-scale physical model tests in a wave flume such as described in Section 2.1.5.

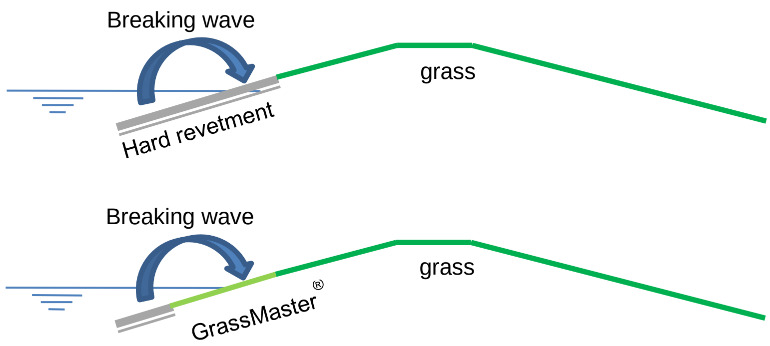

Figure 4.3 Schematised example of lowering the hard revetment below the wave impact zone which may potentially be allowed when applying Desso GrassMaster®

4.2.4 Transitions

Transitions between grass and other revetments or objects (trees, buildings, hydraulic structures such as sluices et cetera) are considered as weak links in a dike (Steendam et al, 2010; Van Steeg, 2014; Van Steeg et al, 2014). The transition often leads to local higher hydraulic loads and/or lower strength. In both cases the stability will be lower. Basically three types of transitions exists:

1) Transition from grass to a ‘hard’ revetment such as asphalt, concrete or placed block revetments
2) Geometrical transitions consisting of a sharp bend (example: a berm)
3) Objects (examples: dike furniture, buildings, trees et cetera)

Design protocols for transitions in grass slopes are given in TAW (1992).

Grass reinforced with Desso GrassMaster® may be a potential solution for these types of transitions.

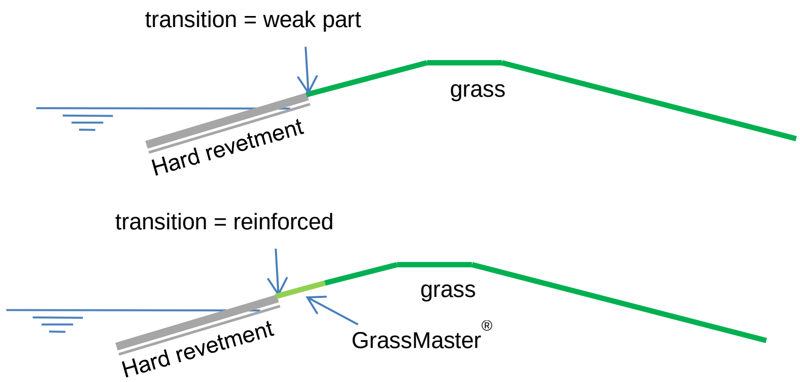

Figure 4.4 Schematised example of reinforcing of grass around a transition with Desso GrassMaster®

Desso GrassMaster® consists of loose fibres which are not interconnected. However, Desso Sports is developing an alternative reinforcement systems which is based on Desso

GrassMaster®. With this system, the fibres are connected with each other as indicated in Figure 4.5. This system may be more effective to stabilise the grass sod around transitions.

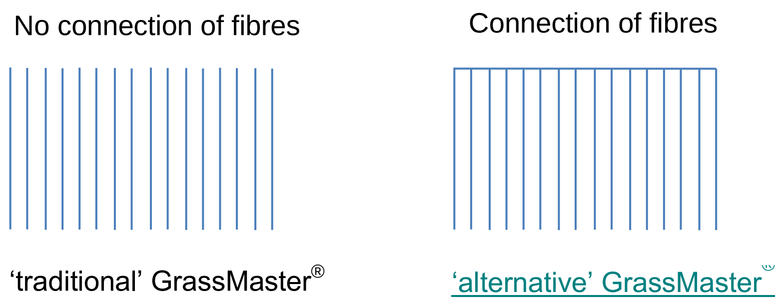

Figure 4.5 Schematised difference between traditional GrassMaster® and alternative GrassMaster®

4.2.5 Other applications

From a hydraulic engineering point of view, it is estimated that Desso GrassMaster® , when assuming a net positive effect on the strength of the grass cover, may have a potential added value on both sea/lake dikes (relatively high waves) and river dikes (relatively small waves). For both sea/lake dikes and river dikes a non-reinforced grass cover with a high quality usually has sufficient strength. However, for several reasons it is sometimes not possible to keep the grass cover in good conditions. In that case reinforcement of the grass with Desso GrassMaster® might be a good alternative. It is however stressed that it is uncertain whether Desso GrassMaster® has a net positive effect on the strength of grass. This should be determined first before conclusions with respect to the application of Desso GrassMaster® can be given.

To quantify the range of application there is a need to determine the resistance of grass with and without Desso GrassMaster®. This can be done with experimental research as described in Section 2.1.5. To obtain a first estimate of the resistance of unreinforced grass, reference is made to Section 2.1.4.

Desso GrassMaster® cannot be applied permanently under water since grass cannot survive under water for extended periods of time.

Since the concept of Desso GrassMaster® is based on the supposed positive interaction of natural grass and the injected fibres, the conditions of the environment should be such that natural grass can exist. In some cases grass cannot grow well. For these specific cases it might also be interesting to investigate the added value of the application of Desso GrassMaster® without grass as alternative for traditional revetments such as concrete, asphalt or placed block revetments.

4.3 Step 2: Check on legal issues

Most legal issues involve environmental aspects and flood safety aspects and are covered in this report. For a more comprehensive overview of the legal issues with respect to a dike cover reference is made to Appendix II of Van den Berg et al 2010.

4.4 Step 3: Check on secondary aspects and other aspects

'Other aspects' are given in Chapter 5 (secondary requirements) and Chapter 6 (other aspects) of Van den Berg et al (2010).

The so-called 'secondary requirements' are:

- Traffic
- Recreation
- Ecology
- Living
- Agricultural use
- Demonstrability

The so-called 'other aspects' are:
- Construction phase
- Quality system en quality control
- Maintenance
- VTV assessment (VTV, 2006)
- Removability
- Transitions and curves
- Sustainability – environmental effects of used materials
- Spatial quality
- Life span
- Costs

A selection of the above given aspects is considered in this report.

Traffic
In practice, grass dikes may be damaged by traffic (e.g. tire tracks due to tractors or trucks). It should be investigated whether this will still be the case when applying Desso GrassMaster®. Usually grass revetments next to roads (and thus vulnerable for damage due to traffic) are strengthened by using open concrete blocks allowing grass growth.

Recreation
In several cases dikes have a recreational function. In that case the dike is entered by persons, animals et cetera which might damage the grass. In this case Desso GrassMaster® is a potential countermeasure since it may be more resistant against these type of loads than natural grass covers.

Ecology
In many cases a dike grassland has ecological functions. Addition of synthetic elements to the grass revetment may influence these ecological functions. Effects of the application of Desso GrassMaster® on ecological processes have to our knowledge not been tested. The scientific evidence that we found in the literature, looking at the effects of (synthetic) obstacles in the root zone, indicates negative rather than positive impacts of obstacles to plant root growth and survival, at least on the short term (Section 3.4.2). Although the chemical constituents of Desso GrassMaster® don't appear to pose an environmental risk, in Section 3.5 it is concluded that secondary microplastics may likely be formed in the application phase of the product, and that negative effects of these microplastics on soil and aquatic biota cannot be excluded in advance. The effects of Desso GrassMaster® on the feeding behaviour and health of vertebrates (such as rabbits, moles, but also sheep) is an additional issue that needs to be addressed. It is remarked that mole and mice activity at sport fields is absent at fields where Desso GrassMaster® is applied (source: interview with Desso Sports), although this effect has so far not been experimentally demonstrated. There is a growing societal and political concern about the presence of plastics in the aquatic environment, and consequently a growing pressure for 'cradle to cradle' solutions.

Agricultural use
Dikes often have an agricultural function. This can be grazing on the dike itself (many dike grasslands in the Netherlands and neighbouring countries are leased for sheep grazing) or the dike can be used as a corridor for transport of animals (e.g. grazing of animals in areas at the seaside / riverside of the dike and at the landward side of the dike). It is unknown what the effect of grazing sheep will be on the quality of a grass revetment strengthened with Desso GrassMaster®. Similarly, it is not known what effects Desso GrassMaster® may have on grazing animals. Concerning the risk of animals eating parts of the aboveground synthetic fibres, negative impacts on animal health cannot be excluded in advance. It is therefore recommended for the manufacturer to demonstrate that (incidental) intake of the parts of the synthetic fibres by grazing animals does not negatively impact the animals and the reinforced grass revetment. To this end requirements with respect to this aspect are needed.

Demonstrability (of secondary functions)
To demonstrate that the revetment fulfils the so-called secondary functions, van den Berg et al (2010) recommend to create a field test (pilot project) to demonstrate that the revetments fulfils its secondary functions. This pilot project probably will cover a relatively long period (> 2 years).

Construction phase
Construction is an important aspect since the construction determines whether the design criteria will be met and determines to a large extent the costs. In van den Berg et al (2010) several issues with respect to construction are given. The most relevant constructional aspects for Desso GrassMaster® are the degree of complexity of construction, tolerances and quality control.

The complexity of construction should be assessed based on at least the following requirements:

- Construction can be performed on a sloping area (maximum steepness of dike is approximately 1:2 although most dikes are more gentle).
- Construction can be performed on irregular terrain. Although the irregularity is not quantified, it is estimated that most grass dikes are more irregular than soccer fields.
- Construction should be possible on the local soil. Usually this is clay or sand (or a mixture). The soil of dikes is usually relatively heterogeneous and contains sometimes objects (bricks, tiles, et cetera).
- Construction should be possible near transitions (transitions to objects, sharp bends, other types of revetments).
- Construction should meet requirements with respect to ecology. It is unknown whether the perforating pins will disturb local animals and whether this will be accepted.

It is important to set acceptable tolerances with respect to the construction. Important aspects with respect to tolerances are:

- Distance of injections
- Depth of injections.
- Material characteristics
- Extrusion above ground

The quality control during the construction is important. It is recommended to describe a procedure in which the quality can be controlled.

Maintenance
Sometimes a grass dike is damaged and needs to be repaired. For small damage (example 0.5 x 0.5 m) it would be attractive to have a small repairing machine available. It is recommended to draw up a maintenance prescription for grass reinforced with Desso GrassMaster®.

VTV assessment
Every twelve years, the responsible bodies (mostly Water Boards) of the primary flood defences assess their dikes according to the so-called VTV method (for grass covers reference is made to RWS 2012. A new assessment methodology is expected in 2017). In this assessment the normative loads on the revetment and the strength of the revetment is determined. For this purpose the characteristics of the revetment have to be determined. Usually the strength of the revetment is known prior to construction but since the revetment can change over time it is for some types of revetments required to determine relevant aspects again during each VTV assessment. For the legal dike body it is important that it is possible to determine the characteristics of Desso GrassMaster® relatively easy and against low costs. This includes that damaging the reinforcement system during the strength assessment ideally should be avoided.

Transitions and curves
Reference is made to Section 4.2.4.

Sustainability – environmental effects of used materials
A sustainable revetment is not legally compulsory (although there are some legal issues with respect to the use of materials, see Section 4.3) but is likely an important acceptability criterion of the responsible dike body and the broader public. Several issues with respect to sustainability are discussed in Van den Berg et al (2010). An important development is the tool DuboCalc, which is developed by Rijkswaterstaat. This tool gives the possibility to calculate the environmental effects during the entire life cycle of a structural design which is in specific cases used in tenders of the Dutch government. More information can be found in (RWS, 2015).

Spatial quality
It is estimated that Desso GrassMaster® does not impact spatial quality (in Dutch: ruimtelijke kwaliteit) compared to a non-reinforced grassland, since the added fibres are normally not visible. Should Desso GrassMaster® replace 'hard' revetments such as placed block revetments, rock or asphalt, it is expected to be more attractive than these 'hard' revetments due to its more natural look.

Life span
Usually a flood defence is constructed for a life span of 50 to 100 years. This does not necessarily mean that the revetment with Desso GrassMaster® should remain for this period. If required the revetment can be strengthened or replaced. To minimize costs and inconvenience it is however desirable to minimize this.

Costs
The costs of a revetment are usually an important aspect in the design of a dike. Costs are usually differentiated into construction costs and maintenance costs. Although the costs of Desso GrassMaster® applied on a dike are (yet) unknown it is assumed that these costs will

be lower than the costs of alternative material such as asphalt or concrete. This should however be verified.

4.5 Step 4: Dimensioning (assessment and design method)

The dimensioning should be such that the strength of the revetment is higher than the loads. An introduction to the dimensioning of grass dikes (without Desso GrassMaster®) is given in Section 2.1.4. It is assumed that the strength of grass revetments with Desso GrassMaster® is higher than non-reinforced grass revetments. This should however be verified with physical models such as described in Section 2.1.5.

Within the design there are several degrees of freedom. It is estimated that the most important aspects are:

- The distance between the fibres
- Grid orientation
- The angle of injection of the fibres
- The depth of the fibres
- Extrusion of the fibres above the ground
- Individual of continues fibres (see Figure 4.5).

Distance of the fibres

It is unknown what the optimal distance of the fibres will be. A smaller distance will presumably lead to higher costs; a larger distance will lead to less strength. However, if there is indeed a negative effect of synthetic fibres on root development, as suggested in Section 3.4.2, this effect may be less pronounced with increasing distance between the fibres. For now it is recommended to use the same distance of the fibres as used at sports fields but additional research may optimize the optimal mutual distance.

Grid orientation

Several grid orientations can be applied, see Figure 4.6 for an impression. It is estimated that a triangular grid is the most effective.

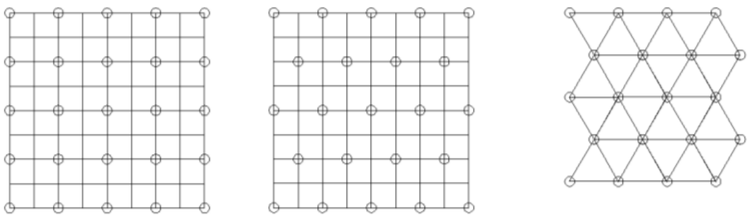

Figure 4.6 Options of grid orientation. Left: rectangular, middle: staggered rectangular grid, right: triangular grid.

The angle of injection of the fibres

At sports fields the fibres are injected vertically and, since sports field are horizontal, therefore perpendicular to the field. At grass dikes the slope is under an angle (exception for horizontal grass berms). Basically the designer can choose between vertical injection or injection perpendicular to the slope. Suppose a 1:3 slope is injected to a depth of 0.2 m. In case of injection perpendicular to the slope the ‘injection depth’ is equal to 0.2 m. (the injection depth is here defined as the distance between the deepest point and the slope measured perpendicular to the slope). In case of a vertical injection, the ‘injection depth’ is 0.19 m. The difference (0.01 m) is negligible and from this point of view there is no (severe) reason to favour one of the two options.

The depth of the fibres

It is estimated that a protrusion depth larger than 0.20 m does not significantly contribute to the strength of the grass sod, although it may help to anchor the top layer to the underlying dike body. Although grass roots still exist at depths larger than 0.2 m, it is estimated that, due to the limited amount of roots at that depth, see also Figure 2.3, reinforcement of these roots does not contribute to strength. Furthermore, it should be stressed that the stated positive interaction between Desso GrassMaster® and plant roots (Technical Manual Desso GrassMaster®) can thus far not be confirmed from the studies into the effects of obstacles on root development (Section 3.4.2).

4.6 Assessment by legal dike body

The legal dike body (usually Rijkswaterstaat or a Water Board) is responsible for the dike and the revetment and therefore decides which type of revetment will be built. This body is also responsible for the 12 yearly VTV assessment as described in Section 4.4.

The body responsible for the water quality will, in case of emissions of Desso GrassMaster® to the surface water, check the requirements as described in Section 4.3 with respect to water quality and should provide a licence.

5 Knowledge gaps and potential research methods

There are several knowledge gaps with respect to the implementation of Desso GrassMaster® at a grass dike.
The identified most important knowledge gaps are:

- The strength of Desso GrassMaster® under hydraulic loading compared with natural grass.
- Constructional aspects and related costs
- The long term behaviour of the material
- Ecological and environmental impacts of application in dike grasslands

To determine the strength of Desso GrassMaster® it is recommended to perform physical experiments with Desso GrassMaster® in a full-scale wave flume or with simulators as described in Section 2.1.5. It is thereby advised to perform a test on a test section with and without Desso GrassMaster® to illustrate the influence. These type of experiments are very common for dike revetments to enhance the acknowledgement of this innovation by legal dike bodies such as Rijkswaterstaat and Water Boards.

It is also recommended to perform tests of the ecological and environmental impacts of Desso GrassMaster®. This includes the effect of the presence of the fibres on root development, which is important for potential application of Desso GrassMaster® on dike grasslands. We recommended to study this in more detail.

Physical model testing may be done at various time and spatial scales, under laboratory or field conditions. For ecologically comprehensive conclusions, a long-term full-scale experiment (2-4 years) is recommended. The perspective of such tests is that they allow further optimization (strength and environmental impact) of Desso GrassMaster® for use in dike grasslands.

6 Conclusions and recommendations

From a hydraulic engineering point of view and based on theoretical considerations and existing knowledge, Desso GrassMaster® may be a potential alternative for current existing dike revetments. The visual attractiveness of a naturally looking grass revetment is combined with a possible strength improvement of the synthetic fibres. In this way the use of traditional revetments such as rock, concrete placed blocks or asphalt can possibly be reduced. Another potential advantage, when placing Desso GrassMaster® at the landward slope of the dike, is that – assuming improved strength - the crest of the dike can be lowered leading to lower costs of the dike and better societal acceptability (high dikes usually gives a strong opposition).

Although we have not found published evidence that root growth is promoted by obstacles such as Desso GrassMaster®, it may be possible that physically the soil is reinforced by insertion of Desso GrassMaster®. Until further tests have brought more clarity, it is estimated that the current knowledge about this product under hydraulic loading is not sufficient and should be improved before this product will be accepted by potential customers such as Rijkswaterstaat or Water Boards. Generally, the resistance of revetments under hydraulic loading is determined based on full-scale hydraulic experiments. In these experiments the system will be exposed to hydraulic loads (waves) which enable to quantify the strength of the revetment. This is also suggested for Desso GrassMaster®. Furthermore, it is recommended to perform controlled (greenhouse) tests to determine the influence of Desso GrassMaster® on root and plant growth.

Secondary aspects, such as construction, other ecological and environmental issues, for Desso GrassMaster® are considered in this report. It is recommended to work out the constructional aspects in such a way that the system can be built on irregular sloped grass revetments. Knowledge gaps concerning ecological and environmental issues that may hamper the application of Desso GrassMaster® have also been identified.

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