CHAPTER 14

Grass covers and reinforcement measures

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1 INTRODUCTION

1.1 General

A grassed clay dike revetment is one of the types of revetments used with the aim of preventing erosion of a dike by breaking waves. In fact it is, measured as dike surface area, the type of revetment which is applied most. On a suitable clay layer the active construction of a grass cover is not really necessary. Good accompanying of the natural evolution is fundamentally sufficient. If the spontaneously growing vegetation is mowed and removed once or twice a year, the growing of woody plant species will be prevented and the result will be a grassland consisting of grasses and forbs.

The grass cover not only protects against erosion but may have a number of other functions, e.g. agricultural (fodder for cattle), ecological and recreational. Sometimes the grass cover is used for traffic or as a lawn near buildings.

This chapter will mainly deal with the erosion resistance in relation to the agricultural and ecological functions.

As a result of the research of the last 10-15 years, a good insight has been gained into the relations between the management of the grass cover, the quality of the vegetation and the erosion resistance. Therefore a description of the various ways of management will be given as well as some relations between the quality of the grass cover and the hydraulic load it has to withstand.

Section 2 deals with general information and maintenance aspects.
Section 3 deals with the design aspects of a grass cover.

In some cases, especially when mechanic loads occur incidentally, a grass cover is not sufficient. A reinforced grass cover is preferred above stone or asphalt revetments.

There are two main types of grass reinforcement:
1. woven fabrics, meshes or mats and
2. concrete armour layers with open cells

Geocomposite mats, which also may considered to be a type of reinforcement of a grass cover, are treated in Chapter 15. Section 4 deals with concrete armour layers with open cells.
1.2 Definitions and general conditions

In Figure 1 some definitions are given of a grassed clay layer as a part of the crosssection of a dike.

![Diagram of grassed dike layer]

**Figure 1 Definitions**

In general the erosion protection against hydraulic loadings is supplied by a cover layer of clay on top of the core of the dike, with a grass cover on top. In the case of heavy hydraulic loadings, the function of the clay layer is not only to deliver nourishment and moisture to the vegetation, but also to contribute to the erosion resistance in cases in which the grass cover is not yet developed or when the grass cover is temporarily or locally absent. In this case the function of the clay is quite comparable with the residual strength of the clay layer underneath a placed concrete block revetment. The design rules and conditions for handling the clay are the subject of Chapter 6 "The impact of weathering on resistance of soils".

2 MAINTENANCE

2.1 Erosion resistance

The primary function of the grass cover as a dike revetment is to prevent erosion of the dike material by hydraulic forces. For a good understanding of the appropriate maintenance regimes and of the guides for construction and judgement of revetments, there is a need for insight into the origin of the strength. Due to the research of the past 10 to 15 years there is a reasonable understanding which, however, is partly just qualitative.

The strength of a grassed dike revetment consists mainly of its ability to withstand wave action: direct impact, runup and rundown after breaking. On the inner slopes there may be a downslope flow, caused by waveovertopping. In general, currents due to river discharge with water flowing along the dike are of minor importance. In those cases, the flow velocities and turbulence intensities are smaller than those caused by breaking waves of some decimeters high. Grass covers can resist flow velocities of up to 2.0 m/s without any problem. Higher velocities may occur at spillways of dams. CIRIA (Hewlett, 1985) published a design graph for the maximum permissible flow duration (Figure 2).
Figure 2 Limiting velocities for plain grass

Under breaking waves, the sward (the aboveground components of plant growth) only stands a limited time. It is the turf (the top layer of soil with a dense net of roots) that, in strong grass mats, withstands the hydraulic loading during a long period. This layer is 5 to 15 cm thick. The erosion progresses slowly and is evenly distributed over the surface. Hole development occurs only after the erosion has progressed through the turf. This description strongly differs from earlier models, developed for instance for spillways, that attributed the strength mainly to the sward.

Figure 3 The structure of the turf

The physical behaviour of the turf differs essentially from that of the original clay applied as soil. De turf forms slowly (years) under the influence of plant roots and a number of biological processes. The network of roots (turf matrix, Figure 3) is important for keeping
the soil together, but at least as important is the structure of the soil in between the roots. It is a structure of small aggregates (ranging from 0.1 to some millimeters) consisting of clay plates, bounded by gluey material, fungus wires and root fibres. The gluey material has several origins such as the activities of earthworms, small beetles and larvae. A large portion originates from a secretion from the roots; it is a product of the nourishment and moisture intake processes. When the turf is saturated by water it does not disperse at all, not even in course of time. Nevertheless it feels soft and can easily be damaged, e.g. by a heel of a shoe. When touched by hand, the turf reacts elasticall (unlike moist clay, which is plastic) and it is highly porous with the numerous holes of earthworms. Hence breaking waves larger than 1 m can be resisted without damage, caused by lumps of soil being broken out.

Conclusion: The strength of a grass cover as a dike revetment strongly depends on a dense net of roots.

2.2 Raising the turf

As mentioned before, the development of a strong grass revetment is a matter of time. However, in the end the success depends on maintaining a good maintenance regime. There are a number of adequate regimes. Research on experimental sites showed the essentials of an adequate maintenance regime. At least once or twice a year, the sward must be taken away and no (or very little) fertilizer must be applied. This way, a vegetation type will develop with species (grasses and forbs) adapted to this situation. These species have adapted to a low level of nutrients and moisture, and develop a deep and dense net of roots without leaving bare patches. It is these vegetation types exactly that are rich in forb species and have a great ecological value.

The process mentioned takes at least 3 to 5 years and certainly the first 2 winter seasons the grass cover will be vulnerable to erosion. A stabilization of vegetational types takes a much longer time, 15 to 30 years even.

The inadequate maintenance regimes were also demonstrated by the experiments performed: excessive fertilizing, no maintenance at all or burning. When, after storm tides or floods, a layer of litter remains on the grass, it must be removed to avoid the covered vegetation dying. These negative processes evolve much faster than the positive ones; in one or two seasons a good grass cover can be destroyed. This means for example that maintenance regimes based on fodder production by fertilization do conflict with erosion resistance. On the other hand, bare patches of limited dimensions can occur by the temporary absence of aboveground plant material while leaving the turf with root system intact.

2.3 The soil

A remarkable conclusion of the research done was that in strong grass covers the erosion resistance of the turf hardly depends on the quality of the originally applied soil material. Especially erosion resistant clays lose this property in the course of time by weathering (over a depth of several decimeters in a number of years). On the other hand, the erosion resistance of a densely rooted turf is much greater, compared with the most erosion resistant clay, while in the more sandy clays a net of roots develops faster and deeper than in heavy clays. So when applying a covering top layer of erosion resistant clay than constructing the dike revetment, applying a top layer of sandy clay of about 0.25 m thick (minimum 0.15 to maximum 0.35 m) is recommended. In the first winter season after construction this layer will be more vulnerable to erosion, but afterwards the grass cover will be stronger than with erosion resistant soil. Moreover it is possible to overcome this disadvantage by means of a
different construction procedure. When constructing the revetment in the autumn (which is often the case), it is profitable to finish the sublayer of erosion resistant clay by compaction and leaving it this way during the first winter. This clay, not yet affected by weathering, can withstand loading by breaking waves very well. In the next spring the revetment can be finished by adding the top layer of sandy clay and raising a good grassland vegetation.

2.4 Maintenance regimes

As mentioned before, there are several good maintenance regimes. Since taking away the sward periodically is essential, mowing (with removing the hay) and grazing by sheep both are adequate and so are combinations of these. Grazing by cattle (except the young ones) causes too much damage and even sheep must be taken away during periods of rain (especially in the autumn) when the soil is too weak. The period for grazing by sheep is from April up to and including October (in the climate of Western Europe).

With grazing by sheep, it is important to let them graze for short periods in fenced meadows, followed by a period in which the meadow is not grazed at all. In the alternative way, i.e. when the meadow is grazed by less sheep continuously, they eat more selectively so that some plants remain untouched. This requires much more mowing afterwards. Furthermore, grazing by sheep demands the spreading and equalizing of molehills, droppings etc. at least once a year.

In general, it can be stated that the maintenance regimes consisting of mowing on a soil of sandy clay gives the best opportunities for nature conservation, while grazing by sheep and adding a small amount of fertilizer gives the best agricultural results. Therefore three management regimes are defined and characterized, from ecological to restricted agricultural, all of them being adequate concerning erosion resistance:

1. ecological
2. water-defensive
3. restricted agricultural

The main characteristics are explained below.

2.4.1 The ecological maintenance regime

This regime requires nutrient-poor soil and no fertilizing at all. There is a low yield of fodder (3000 to 5000 kg dry material per ha per year).

The maintenance can be done by periodic grazing by sheep 3 to 5 times a year during 3 to 8 weeks in an extensive way (5 - 10 sheep per ha) or by mowing and removing the hay. This way, species-rich vegetation types such as *Mesobromion Medicago-Avenetum* (in Dutch: stroomdalgrasland) and *Arrhenatheretum elatioris* (granshaverhoooland) will establish themselves, of which especially the first one is typical of river dunes and river dikes in the Netherlands, yet very rare.

2.4.2 The water-defensive maintenance regime

The predominant aim of this regime is the resistance against erosion. There must be no fertilizing and in most cases the maintenance will consist of mowing and removing the hay. The yield can be approximately 6000 kg per ha per year. So mowing twice a year will be sufficient. In cases where the yield is restricted to 4000 kg per ha per year, mowing once a year could be enough.

Periodic grazing, or mowing followed by grazing, can be good alternatives, although
they do have some practical drawbacks related to the mowing regime which are mainly caused by the costs of fencing the meadow. Finally, very frequent mowing (the sward should not become longer than 5 to 8 cm) can be an alternative in cases of a limited hydraulic load, especially along river dikes. This results in an even vegetation without open patches and a dense but relatively shallow turf. On slopes steeper than 1:3, grazing generally gives too great problems and risks of damaging the turf. So mowing must be practised, possibly with special machinery or even by hand.

The water-defensive regime will result in a vegetation type that can vary from the Poo-Lolietum (beemdgras-raagrasweide) with few forb species, to the Lolio-Cynosuretum (kamgrasweide) or the Arrhenateretum elatioris, (glanshaverhooiland) which can be rather species-rich.

2.4.3 The restricted agricultural maintenance regime

This maintenance regime is about the limit in agricultural production at which the water-defensive needs can be satisfied. Only once a year adding of fertilizer is permitted, to a limit of 50 to 70 kg N (nitrogen) per ha per year. This will result in a yield of 4000 to 8000 kg per ha per year. Maintenance by grazing by sheep (or young cattle not older than 18 months) will be dominant. Preferable is periodic grazing in periods of 4 weeks by 10-15 sheep per ha, succeeded by a period of rest and regrowth, and only during the summer period: April until October. In winter there should be no grazing, due to the moist situation in the soil. Additional mowing can be necessary for patches which have not been grazed and some herbs the sheep do not eat. With dike slopes steeper than 1:3 this regime should not be applied.

This regime will result in species-poor vegetation types such as Poo-Lolietum (beemdgras-raagrasweide) or Lolio-Cynosuretum (kamgrasweide) and will not have an ecological value.

3 DESIGN

3.1 Research activities

The resistance of grass covers against wave attack has been examined intensively during the past 15 years. Full-scale tests, laboratory tests, field surveys and literature studies were carried out. Attention was focused on all aspects related to the strength of grass covers, such as quality of the vegetation (root length, percentage of coverage) and soil quality (percentages of fines).

Three full-scale tests were carried out: one with relatively small waves with 12 different sods dug out of river dikes, and two tests with high waves on sods from a sea dike. All tests were carried out in the test facilities of Delft Hydraulics.

The following table summarizes some characteristics:

<table>
<thead>
<tr>
<th>test</th>
<th>wave height</th>
<th>wave period</th>
<th>duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>grass sods from sea dike (slope 1:8)</td>
<td>1.85 m</td>
<td>5.4 s</td>
<td>29 hours</td>
</tr>
<tr>
<td>grass sods from sea dike (slope 1:4)</td>
<td>0.75/1.35 m</td>
<td>3.4/4.7 s</td>
<td>17 hours</td>
</tr>
<tr>
<td>grass sods from river dikes (slope 1:3)</td>
<td>0.3 m</td>
<td>2.5 s</td>
<td>60 hours</td>
</tr>
</tbody>
</table>
The sods, with a clay layer, were excavated, transported to the laboratory and placed into the flume. The sods from the sea dikes were excavated and transported in pieces of 2.5 m each, and placed together in the wave flume as a closed grass cover. From the river dikes 12 grass sods, each of 0.7 m wide and 3 m long, were excavated from 12 locations and placed next to each other in a wave basin. These 12 sods were tested simultaneously.

During the tests the amount of surface erosion was measured by sounding the surface of the sod with a profile indicator. Furthermore, flow velocities, wave runup and water pressures in the soil were measured, as well as the percentage of coverage of the soil by vegetation, type of vegetation, soil characteristics, etcetera. In general, the turf was in good condition, although most grass leaves had vanished during tests with high waves. No holes or cracks caused by erosion were visible.

A typical test result is presented in Figure 4. The relationship between the erosion depth, wave height and wave impact zone can clearly be seen. The most severe attack is in the zone 0.3 to 0.6 times the wave height below the undisturbed water level.

![Graph showing erosion depth over time](image)

**Figure 4** Example of test results

From the tests the gradual erosion of the turf also became clear. When the turf is eroded, the erosion process becomes faster because of the decreasing root intensity. Generally, the conclusion is that grass covers with a high strength consist of a close vegetation (percentage of coverage larger than 70% and a high root density in the upper 0.15 m). The maintenance method determines the quality and in a lesser way the soil characteristics do.

### 3.2 Design rules

Two aspects play a part in models describing the behaviour of a revetment: load and strength. Most of the attention has been paid to the strength; only limited attention has been paid to the loads.
An integrated model which includes the relation: soil type - vegetation - maintenance root system - strength - load, is not available yet. At present, a simple empirical model is available which relates strength and wave height. In qualitative terms the strength of a grass cover can be described as follows:

Waves up to 0.50 m will cause no damage to a grass cover. Waves in the range 0.50 m to 1.50 m and a duration of 6 to 24 hours will in general not result in damage, but of course it depends on the quality of the grass cover. Waves larger than 1.50 m will probably cause severe erosion of grass covers, but experimental data are not available.

Based on theoretical considerations it is assumed that the speed of erosion \( E \) increases with power two of the significant wave height \( H_s \):

\[
E = c_E H_s^2
\]

in which \( c_E \) is the erosion coefficient.

![Figure 5 Erosion speed versus wave height](image)

For \( c_E \) the following values were derived from the test results (Figure 5):

<table>
<thead>
<tr>
<th>grass cover quality</th>
<th>( c_E ) (m(^{-1})s(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>good</td>
<td>( 0.5 \times 10^6 ) - ( 1.5 \times 10^6 )</td>
</tr>
<tr>
<td>average</td>
<td>( 1.5 \times 10^6 ) - ( 2.5 \times 10^6 )</td>
</tr>
<tr>
<td>poor</td>
<td>( 2.5 \times 10^6 ) - ( 3.5 \times 10^6 )</td>
</tr>
</tbody>
</table>

The presented equation can easily be transformed into an equation predicting the admissible duration of a wave load:

\[
t_{\text{max}} = \frac{d}{\gamma c_E H_s^2}
\]

in which:

- \( t_{\text{max}} \) = maximum permissible duration wave load (s)
- \( d \) = turf thickness (m)
- \( \gamma \) = safety coefficient (-)
In Figure 6 the relationship between $t_{\text{max}}$ and $H_s$ is presented for different values of $c_E$. The result is comparable with the results for water flowing over grass (see Figure 2).

![Figure 6 Maximum permissible duration of wave attack](image)

The coefficient $c_E$ is related to the quality of the turf and the soil in the sod. Relevant parameters seem to be: percentage of coverage by the vegetation, root length and amount of fines. The test results did not allow the derivation of clear answers. Moreover, it was not possible to determine an influence of the wave period (or wave steepness) and slope angle to implement into the above equations. Finally, the model can be improved by incorporating mechanisms that remove loose particles and mechanisms that take into account the failure of pieces of soil.

Important for dikes with a grass cover in the runup zone and a stone pitching or another civil engineering revetment in the breaker zone, is that the speed of erosion in the runup zone is less than the speed of erosion in the breaker zone. Subsequently, waves which are about two times higher than those in the breaker zone are allowed.

The strength of an existing grass cover has to be checked regularly. At present, experts give their opinion about the quality of the grass cover during a site visit. However, the availability of a simple testing device is a necessity. The sprinkler apparatus, a non-destructive method in which the eroded soil is collected by water being sprinkled over a certain area, may be such an apparatus (Verheij et al., 1998). It clearly indicates a poor grass cover, but it does not make distinctions between good grass covers. Further research on this aspect is required.

Finally, the test results provided information on wave runup (test result with respect to the wave loads). The reduction coefficient $r$ for runup on grass covers is 0.9 to 1.0 for large waves compared to the runup on smooth revetments and for small waves which is 0.55 to 0.65. The reason for this is that because of the lesser thickness of the water layer in the runup zone with small waves, the hydraulic roughness is higher. The following reduction coefficient could be derived:

$$r = 1.15 \ H_s^2 \ \ \ \ (H_s < 0.75m)$$
3.3 Constructive aspects

3.3.1 Construction of a grassed revetment

The construction of a grassed revetment starts with the building of a cover layer of clay, possibly with a top layer of sandy clay (see the general conditions in the introduction of this chapter and Chapter 6: "The impact of weathering on resistance of soils"). Strictly speaking, construction of a grass cover is not necessary: provided there is a proper maintenance regime, the natural development of a vegetation results in the course of time in a strong grass cover which has adapted to the local circumstances.

Nevertheless there is often the need to accelerate the development of an erosion resistant turf. That can be done by sowing or, in special cases, by placing grass sods. The latter is costly and therefore only applicable to small areas. Sowing of grasses, however, restricts the development of forbs and the adaptation of the vegetation to the local circumstances. Especially the development of a species-rich and hence an ecologically valuable vegetation type will be hampered.

The development of an ecologically valuable vegetation type can be stimulated by not sowing with a standard dike mixture (like D1 and D2 in the Netherlands) but with hay from grassland in the vicinity or seed from the vegetation formerly present on the very location. Moreover it is important that the top layer of the soil on the spot consists of sandy clay. The more sandy the clay (and poor of nutrients), the more species-rich the vegetation will become. By reason of erosion resistance it is recommended, in places where wave loading can be expected, to limit the sand content of the clay to 50% and apply clay with a minimal cohesion (that means that the plastic limit just can be determined, which is the case at a range of 15 to 18%).

On dike sections that are to be to be reinforced, where up to now a species-rich and ecologically valuable vegetation was present, there are a number of possibilities to re-establish this vegetation after the reinforcement:

- by partly leaving the present vegetation with the soil untouched, e.g. in a small strip of 1 or 2 m wide.
- by digging, taking up, storing and replacing sods of the present vegetation and turf. However, this is very costly and therefore usually not manageable.
- by digging up and storing the top layer of soil and later on putting it back as a new top layer of about 0.25 m thick.

As appears from the research done in field experiments, the latter possibility is rather effective.

Steep slopes as such hardly limit the establishment and growth of grassland vegetation and the creation of an erosion resistant turf when mowing is the maintenance regime. The practical problems of going or driving on a slope and the restrictions of the machinery for mowing on steep slopes restrict the development of a good turf. It is usually the lack of timely and adequate mowing that causes weak spots.

A similar effect occurs near joints and transitions with other revetment types or with constructions. At those places, the hydraulic loads often are greater than on unobstructed areas, though the effect of restricted development of a good turf seems to be much more the cause of damage occurring to the grass cover in those places.

Therefore, one should keep in mind that in the end only a lasting and careful maintenance determines the quality of a good turf.
3.3.2 Sowing

With respect to the sowing of grass covers, some new insights have been derived from recent research. We now understand that the most productive grasses as Perennial Ryegrass (*Lolium perenne*) only need a small amount of roots, and therefore are not very effective in making an erosion resistant turf. Other grass types are much more effective for that purpose, e.g. Fescues (*Festuca*) and Meadow grasses or Kentucky Blue Grass (*Poa pratensis*).

For a fast development of a grass cover, mixtures with Ryegrass can be used. Mixtures with much less or no Ryegrass grow slower, but are in the end more persistent and have deeper and finer roots. It is strongly recommended to consider the use of mixtures with the slower but more persistent grass types, because the Ryegrass replacing the other grasses is a time-consuming process.

When sowing, often an amount of seed of 70 to 80 kg per ha is used. In which case the forbs can hardly establish for a long time. In order to stimulate the development of a species-rich vegetation, the amount of seed to be applied should be reduced. About 20 to 25 kg per ha is sufficient to get a close vegetation, while natural herbs still have the opportunity to develop in between. In cases where the outer slope is expected to be subjected to wave loading soon, this amount could be increased to up to a maximum of 40 to 50 kg.

4 CELLULAR BLOCKS

Grassed clay revetments can be applied in areas where the grass is allowed to grow. Thus in the zone around the daily water line (the so-called wet/dry zone) and just next to a maintenance road (mechanical loads) other solutions are required. Moreover at the transition between a grass cover in the runup zone and for instance a stone pitching in the wave breaking zone, the attack by the overflowing water is relatively heavy because of the change in hydraulic roughness and in addition to this the growing conditions are bad. At these places cellular blocks, i.e. concrete blocks with open cells filled with soil, may be applied (Figure 7). These blocks allow the vegetation to grow through them, but it is of vital importance that the cells do not erode completely before the vegetation is fully grown. In the following the results of physical model tests will be presented with respect to erosion of cell fillings.

Erosion of sediment out of cells of cellular blocks depends on the water motion just above and in the whole structure, cell dimensions and sediment characteristics. Two failure mechanisms may be distinguished (Figure 8): overflowing water in the runup zone and outflowing water in the wave breaking zone during rundown of waves. Bank protections along canals are attacked by ship waves, which are comparable with wind waves, and stern waves, for which the failure mechanism is identical to that of overflowing water.

In Figure 9 an example of test results for stern waves of ships is presented. Waves with a height up to 1.0 m are simulated; the block thickness was 0.15 m while the cells were filled with sand and clay.

Examples of test results for wind (and ship) waves are presented in Figure 10. The wave height varied between 0.2 and 1.1 m (wave periods in the order of 2.3 to 5 s). The block thickness was 0.15 m and the cells were filled with sand and gravel. All tests were carried out at Delft Hydraulics.
Figure 7 Examples of cellular blocks

Figure 8 Parameter definition and failure mechanisms
Figure 9  Example of test results for stern waves of ships

Figure 10  Examples of test results for waves on dikes

From all results it can clearly be seen that the erosion depth reaches a more or less constant value which differs for the types of soil. Based on the results for wind waves the following equations were derived:
\[ \frac{Y}{G} = 0.2 \left( \frac{H}{D_{50}} \right)^{0.33} \]

G < 0.1 m:

\[ \frac{Y}{G} = 25 \left( \frac{H}{D_{50}} \right)^{0.20} \left( \frac{D_{50}}{G} \right)^{1.5} \]

in which:

- \( H \) = wave height (crest to trough)
- \( Y \) = cell depth
- \( G \) = typical cell diameter
- \( D_{50} \) = characteristic diameter of the soil in cells

In addition, it is remarked that the first equation also may be applied in the case of small cells in the wave runup zone.

For the stern waves of ships the following equations were derived:

- non-cohesive cell filling:

\[ \frac{Y}{G} = 0.7 \ Z_{\text{max}}^{0.5} \ \log(N + 1) \]

- cohesive cell filling:

\[ \frac{Y}{G} = 0.25 \ p_t^{-0.2} \ Z_{\text{max}}^{0.5} \ \log(N + 1) \]

in which:

- \( Z_{\text{max}} \) = height stern wave (m)
- \( p_t \) = percentage fines, i.e. particles smaller than 0.002 mm
- \( N \) = number of ship passages (-)

Finally, the design criterion is: \( Y < D \), with \( D = \) block thickness.

For more details reference is made to Klein Breteler and Verheij (1988).

REFERENCES


Verheij et al., 1998, Erosiebestendigheid van grasland als dijkbekleding, TAW, Delft.