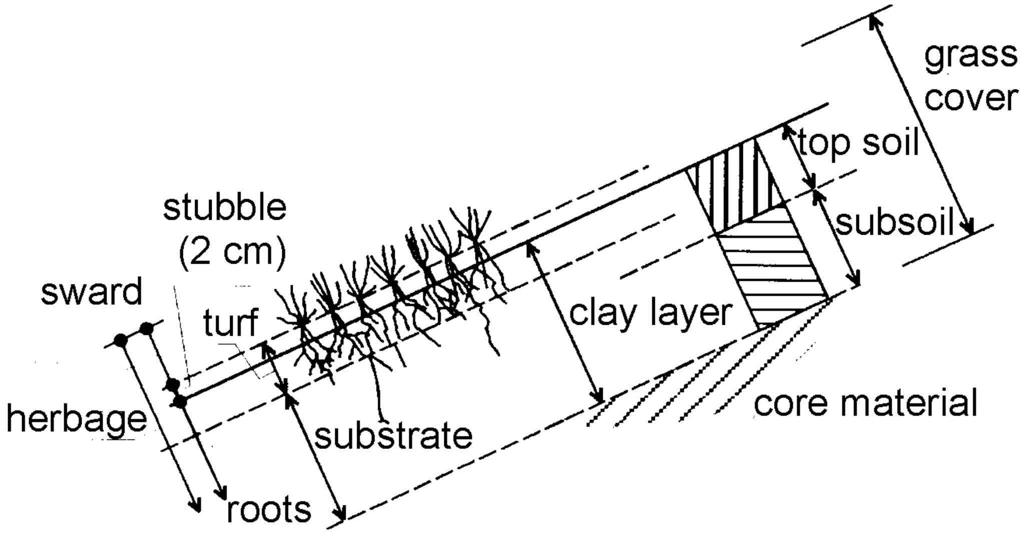
Grass covers on dikes and slope protections

A grassed clay dike revetment is one of the types of revetments used with the aim of preventing erosion of a dike by braking waves. In fact it is, measured as the dike surface area, the type of revetment which is applied most. The grass 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.

As a result of the research of the last 15 years, a good insight has been gained into the relations between the management of the grass cover and the quality of the vegetation and the erosion resistance.



In case of a load by current only, one may use the design rules published by CIRIA [HEWLETT, 1985]. The main results were that for plain grass of good quality, grass could resist 4 m/s during 2 hours, 3 m/s during 8 hours and 2 m/s during 50 hours. For a poor quality grass cover these values are 2.5 m/s, 1.5 m/s and 1 m/s.

Grass, as a cover layer for dikes and revetments is able to withstand considerable wave loads. Waves, as may occur along rivers are no problem for a good erosion-resistant grass-cover. On sea and lake dikes waves with a height up to 0.72 m (and maybe higher) will not cause any damage on a uniform, closed grass-cover with a high density of roots. The management is the governing factor: unfertilised hay-production or light fertilised cattle grazing lead to a strong grass-cover. After seeding on a bare soil the grass-cover will reach its full strength in three to five years.

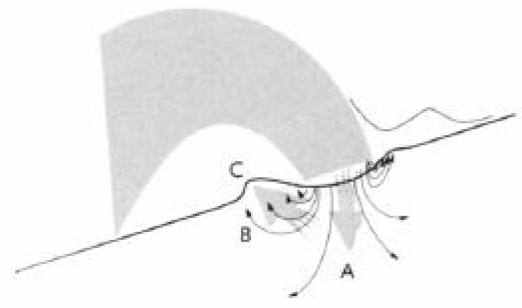
Unfertilised hay-production leads to the highest erosion resistance and also can be executed in the easiest way. Light fertilised cattle grazing leads also to a high erosion resistance, but the execution is from an organisational point of view more complicated, because it has to be executed in a shorter time frame with a number of cattle carefully adjusted to the biomass production. Additional maintenance is needed for the grass cover and the fences.

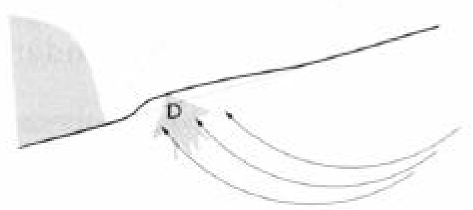
For dikes along rivers is sufficient knowledge available to formulate the requirements for a grass cover strong enough to withstand the occurring hydraulic loads. The same is valid for the grass-cover of sea and lake dikes, provided the wave height is not more than 0.75 m. For wave heights of more than 0.75 m is it not yet possible to formulate a management which excludes any damage. Also is till missing a good method for the determination of the required strength in that case.

General conclusions and recommendations

- A grass cover with a high erosion resistance consists of a closed vegetation with a high root density in the layer of 0 - 0.15 m. For hay-land a cover > 70% with sprouts, with an equal distribution of the sprouts. For cattle-land covers of > 85% is needed. The strength is mainly in the non-visible part: the root layer. The realisation of a closed grass-cover and dense root system depends on the way of execution of the management, and to a lesser extend of the soil properties. In case of a correct management the erosion resistance of the sod-layer becomes better than the erosion resistance of high quality clay.
- Essential for the development of a good quality sod is the removal of the produced grass as hay or by cattle grazing. Also the amount of fertiliser is determining. Unfertilised hay production or light fertilised cattle grazing (to a maximum of 75 kN per ha per year) leads to a strong sod. If in case of cattle grazing some spots re not grazed, these spots still have to be mowed and the grass removed. Many sheep on one area during short periods and then giving a number of weeks rest, is the best grazing method.

- In case of unfertilised hay production the grass-cover of the dike will get, besides the desired erosive strength, a very high natural value. There will be a high bio-diversity wit a relatively large number (mullet-year) plants, representative for the river area and rather seldom outside this area.
- Sods with a low root density have a low erosion resistance. Such a low root density occurs often in grass-covers with many open areas on high vegetation. These kinds of sods develop especially during maintenance by mowing without removing the hay. Also intensive fertilising combined with cattle grazing and hay production will lead to a loose root structure. These grass-covers may look very closed, but are not. Many one-year plans will die during winter and very often roots are superficial with a low variation in the root structure





The process of erosion

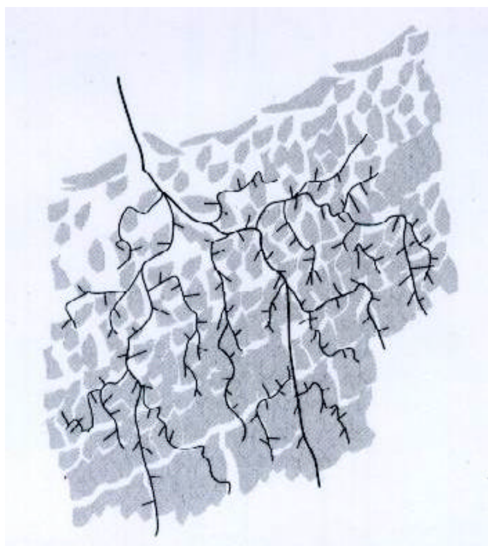
The process of wave attack to a grass cover consists of two steps. In first instance water will act on the slope (A) and water will infiltrate in the slope. At that moment at C will be an underpressure of water, consequently the water will flow out of the slope (B).

At the moment of maximum rundown, the waterlevel in the dike is higher than the outside waterlevel, and because of this hydraulic gradient also water wants to flow out (D).

So both during runup and rundown water is flowing out of the slope. This outflowing water causes instabilities in the bed.

Usually the bed does not consist of only uniform grains.

Usually the bed is build up from clay lumps, which are somewhat separated from each other. Near the top these lumps are relatively small, but deeper in the dike these lumps become larger. The root system of the grass grows into the crevasses in the clay. The roots make a mat which is protecting the clay lumps from being washed away.



So in fact there are two elements of importance in the strength of a grass cover:

- the flexibility and resilience of the sod;
- the fact that the clay lumps are kept together by the root system.

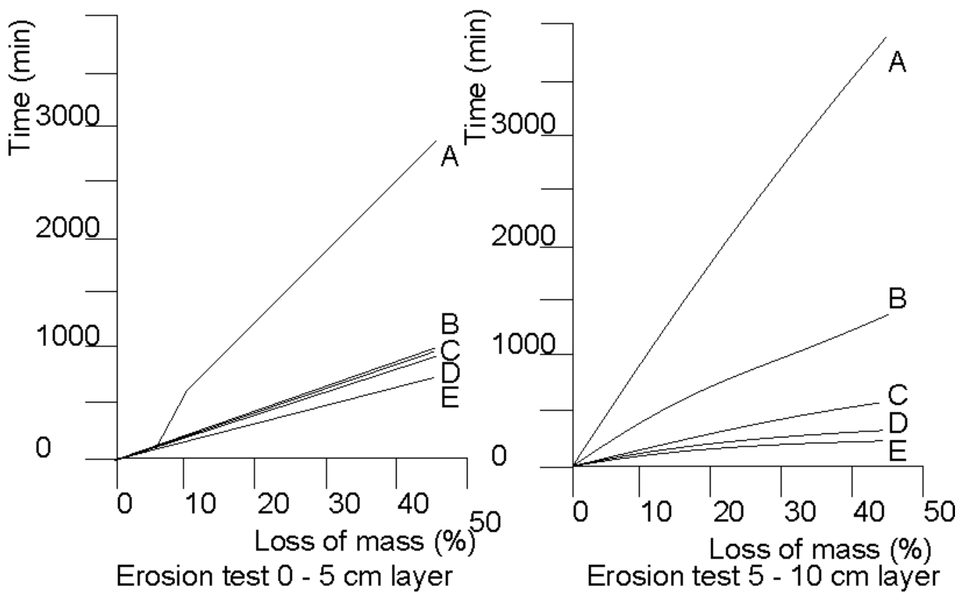
The top of the clay layer is being exposed, and erodes slowly (erosion speeds are in the order of 2.5 to 5 mm per hour). Details about this will be discussed later. The consequence is that the root system will become more exposed to the wave action. The roots are able to withstand wave forces for some time.

In the above figure the grass cover is shown after a wave attack of 11 hours with waves with an H_s of 1.35 m and a period T_p of 4.7 seconds. (tests are from the Deltaflume of Delft Hydraulics).

In the previous figure is indicated how these tests were executed. A slope was constructed in the flume. On the slope a real grass mat from a dike was placed (samples with a thickness of approx. one meter, with the width of the full flume). These were tests with a relatively long duration under prototype conditions (so it were no scale models). The original grass was used in the past for grazing of sheep and was normally fertilised.

There was only a limited variation of species in the grass cover. When waves of H_s of 75 cm were used, no damage occurred, even after 24 hours of wave attack. Th grass leaves were damaged or even removed, but there was no serious damage to the subsoil.

With the waves of 1.4 m, damage started after approx. 6 hours, but the whole grew very slowly. On the picture the whole at the end of the test is indicated. Also remarkable is the place where the impact of the wave runup on the separation between the grass sample is (horizontal lines in the flume). During the test also the water pressures in the clay layer have been measured. The measured pressures where high enough to cause uplift of the clay lumps. This did not happen because of the presence of the clay. Comparable tests on clay without grass should considerably more erosion than in this test with a grass cover. Apart from the wave erosion tests in the Deltaflume also a number of in-situ erosion tests have been done.



Tests were done in a centrifuge to test the erosion rate of the bed. Measured what the amount of erosion due to a concentrated flow of water over the top of the bed. Two tests were usually performed. The first one was on the top 0 - 5 cm; the second one was on the layer of 5 - 10 cm depth. In the graphs the relation is given between the loss of mass in % and the time of the test. This has been done for five different types of management of the dikes:

a. 25 years unfertilised mowing
b. unfertilised mowing
c. unfertilised mowing +grazing
d. unfertilised grazing
e. fertilising + grazing

These test are given in the following figures:

From all these test a relation could be derived between the erosion speed and the wave height for various types of grass. On a theoretical basis it is assumed that there is a cubic relation between the wave height and the erosion speed. This can be described as:

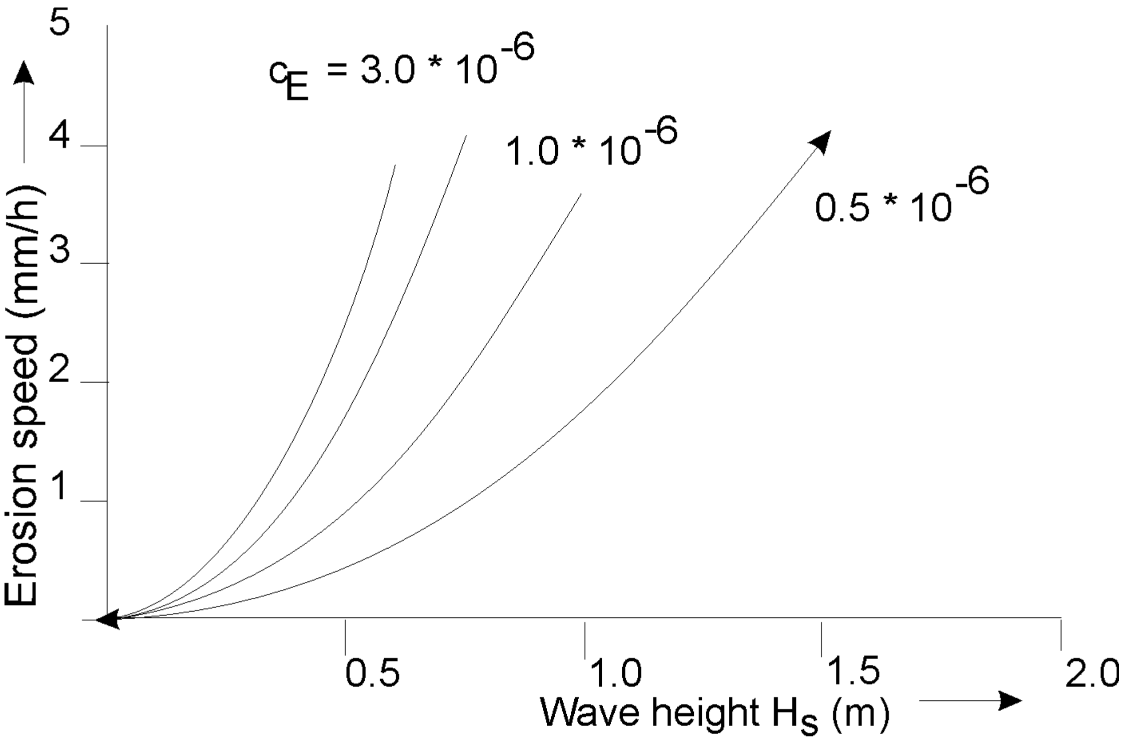
$$E_{gras} = c_E * H_s^2$$

in which:

E_{gras} = erosion speed of the grass (m/s)
c_E = erosion coefficient ($m^{-1}s^{-1}$)
H_s = significant wave height

For c_E the following values can be used:

good quality grass	0.5 - 1.5	($*10^{-6}$ $m^{-1}s^{-1}$)
modest quality grass	1.5 - 2.5	($*10^{-6}$ $m^{-1}s^{-1}$)
low quality grass	2.5 - 3.5	($*10^{-6}$ $m^{-1}s^{-1}$)

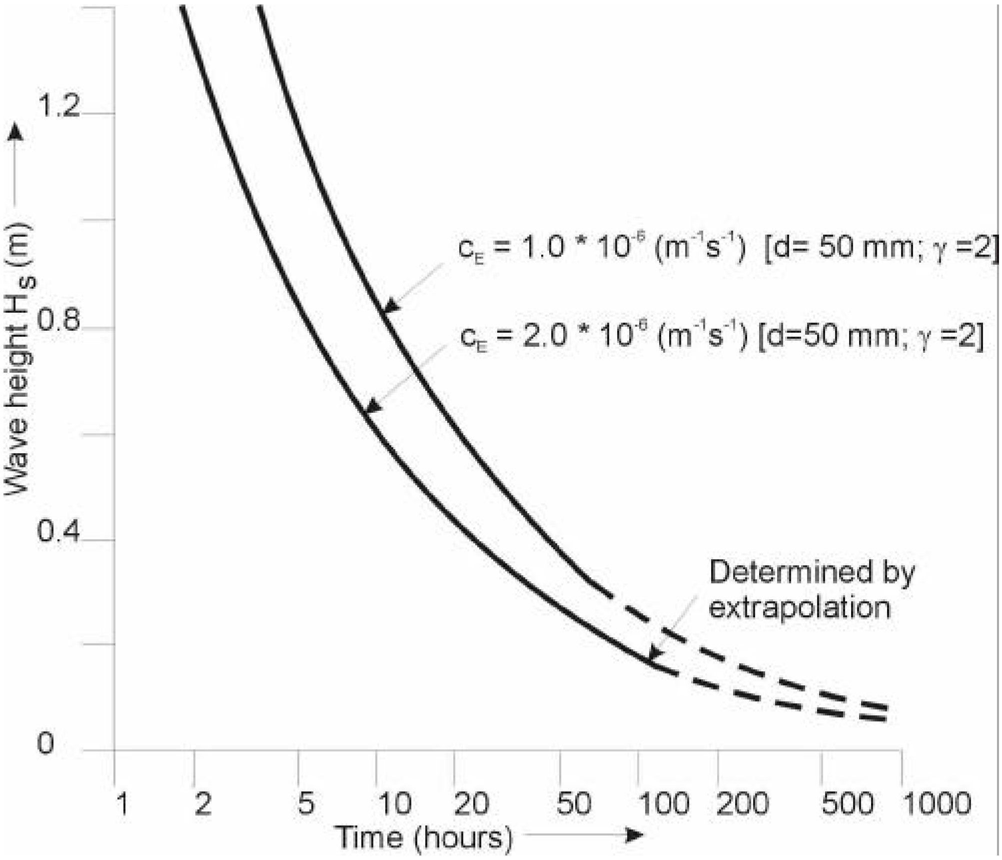


On this basis one can also make a graph of the allowable duration of wave attack versus the duration of the attack. The equation to be used is:

$$t_{max} = \frac{d}{\gamma c_e H_s^2}$$

in which:

t_{max} = maximum allowable load duration
d = thickness of the grass + clay layer
γ = safety coefficient



Tests in Great Britain support this relation. It has been tried to correlate the grass erosion coefficient to the quality of the root system and the soil between the roots. The relevant parameters are the density of the roots, the length of the roots, and the amount of fine clay particles. However, the tests did not yet result in any usable number.

Raising the turf

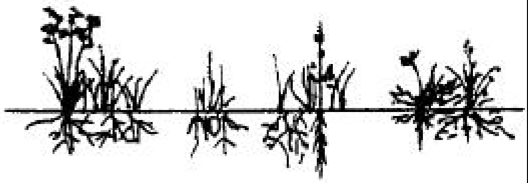
As mentioned, the development of a strong grass revetment is a matter of time. However, in the end the success depends on maintaining a good maintenance regime. There are a number of adequate regimes. Research on experimental sites showed the essentials of an adequate maintenance regime. At least once or twice a year the sward must be taken away and no (or very little) fertiliser 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. These vegetation types are 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 two winter seasons the grass cover will be vulnerable to erosion. A stabilisation of vegetation types takes much longer time, 15 to 30years even.
The inadequate maintenance regimes were also demonstrated by the experiments performed: excessive fertilising, no maintenance at all or burning. When, after a storm surge or a flood, a layer of litter (flotsam) 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 fertilisation do conflict with erosion resistance. On the order hand, bare patches of limited dimensions can occur by the temporary absence of aboveground plant material while leaving the turf with root system intact.

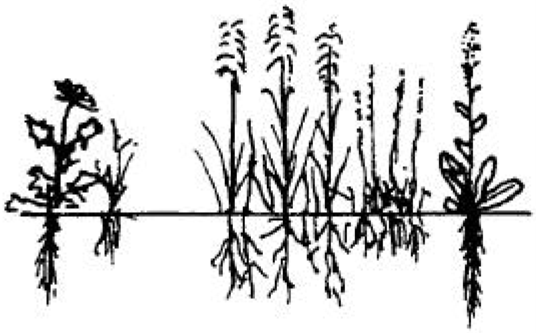
A remarkable conclusion of the research done was that in strong grass covers the erosion resistance of the turf hardly depends on the quality of the originally applied soil material. Especially erosion resistant clays lose this property in the course of time by weathering (over a depth. On the other 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 that in heavy clays. So when applying a covering top layer of erosion resistant clay with grass, it is recommended to use for the upper 25 cm a sandy clay layer. In the first storm season after construction this layer will me more vulnerable to erosion, but afterwards the grass cover will be stronger than with erosion resistant clay in the top 25 cm. Moreover it is possible to overcome this disadvantage by means of a different construction procedure. When construction 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 storm season. This clay, not yes affected by weathering, can withstand loading by breaking waves very well. In the next spring adding the top layer of sandy clay and raising good grassland vegetation can finish the revetment.

Maintenance

The type of management of the grass slope is quite important. In the following figure the four different types are indicated:

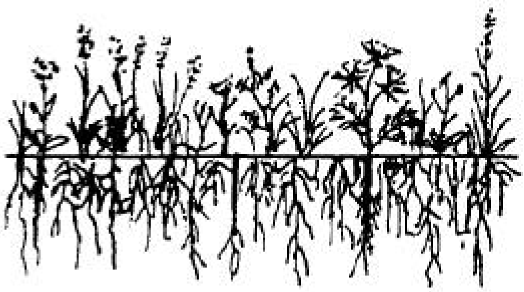


Grazing + fertilising + use of herbicides



Mowing and fertilising

Grazing and a light fertilising



Mowing and no fertilising

It is clear that the management method has a lot of influence on the quality of the root system. In case of fertiliser the roots become 'lazy", and will remain short. This is not good for the hydraulic strength of the system. It is also clear that a natural diversity in species is quite good. A combination of fertiliser, grazing and the use of herbicides leads to individual plants with a lot of open space between them. It is obvious that this is a quite undesirable condition.

References

HEWLETT, H.W.M., *et.al.* [1985] Reinforcement of steep grassed waterways, CIRIA report 116, London

SEIJFFERT, J.W. AND VERHEIJ, H. [1998] Grass covers and reinforcement measures, in: *Dikes and Revetments*, *K.W. Pilarczyk, ed*, Balkema, Rotterdam
TAW [1998] Technisch rapport Erosiebestendigheid van grasland als dijkbekeleding,
TAW [1999] Grasmat als dijkbekleding