Engineering: Building with Nature 101x MOOC

Hints and Information for Building with Nature Design

Case 1: Climate-proof Noordwaard

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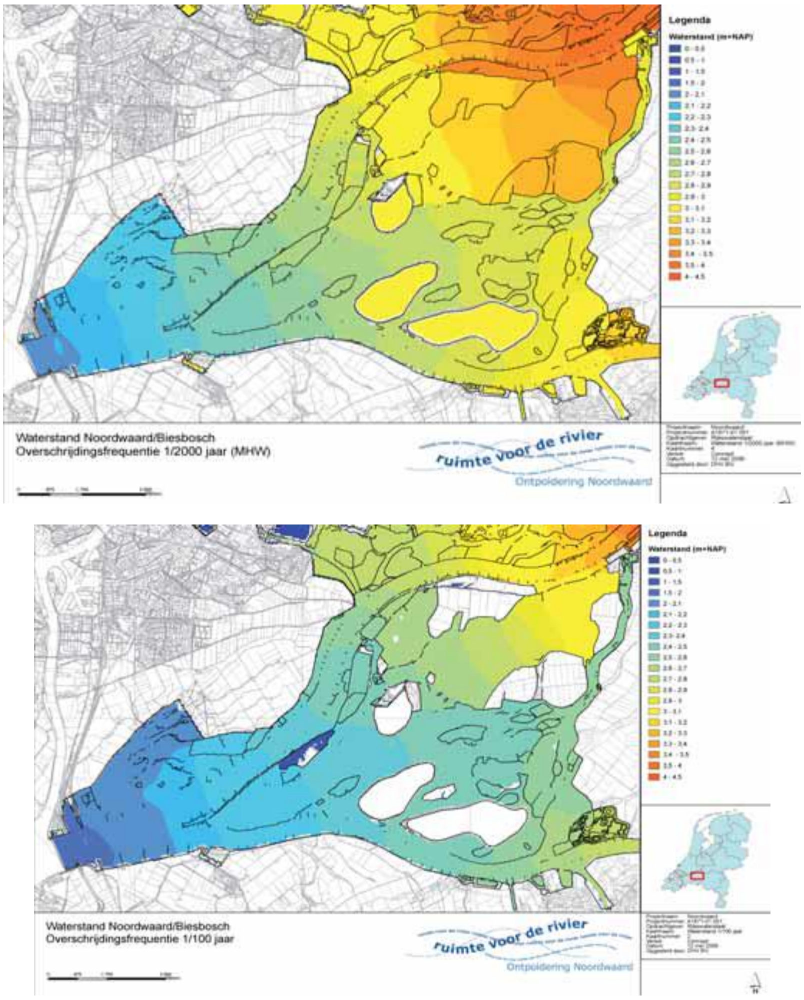
Before the lowering of the river dike to allow water to flow across the Noordwaard Polder, Fort Steurgat and the 11 nearby households were protected against a flood event with an annual probability of occurrence of 1/2000. The desired safety level for Fort Steurgat and the 11 households remains 1/2000. **The question is how you can protect this area both from high water levels and from the potential wave effects.** Have a look at the model simulations below (Projectbureau Noordwaard 2007). This will provide you with information on the flood water level that you have to take into account. Also, you will see that under river flood conditions there is a vast expanse of water. Wind blowing across this water will generate waves. As the predominant wind direction is South West, the effect of the waves in raising the water level, and in potentially impacting the dike must also be taken into account.



Figures 1a & b: Predicted water levels in the Noordwaard and Biesbosch under the 1 in 2000 year flood (a - above) and the 1 in 100 year flood (b - below). The warmer colours represent higher water levels with dark blue representing very little change (almost zero). The upstream water levels (to the north) are about 0,5 m higher than the downstream water levels and water levels in the central area are approximately +3.20 m above chart datum (1 in 2000 year) and +2,80 m above chart datum (1 in 100 year), respectively. The current speeds remain well under 1 m/s.

Some useful engineering concepts

“From a safety point of view, the total dike height is always composed of water level plus incoming wave height.” (Delatres wiki 2010). So, for a simple estimate of the height that the dike would need to have if we adopt a conventional engineering approach, we need to know the *design high water level* (see Figures 1a & b) and the *wave height*. The design high water level is the flood water level, plus a freeboard to prevent overtopping and compensation for settling of the dike. The wave height needs to be added to the design water level. If you are unsure of this , consult the video of **ir. Mark Voorendt** in Week 2. In the case of Noordwaard, the freeboard and compensation for settling totals approximately **1,2 m**. You can work out the necessary crest height by first working out the wave height as given below.

Fetch

Wind fetch is the (undisturbed) distance over which wind can blow in one direction, causing wind-generated waves in a water body. A longer fetch over a stretch of open water is associate with higher waves. Unlike in the sea, in rivers, dams and lakes the fetch is often limited by the land around the water body.

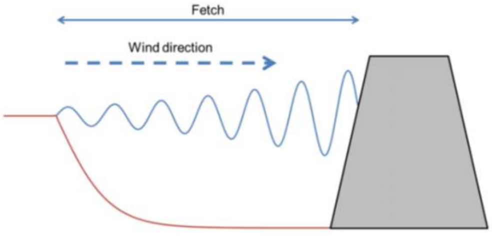


Figure 2. Sketch of wind fetch

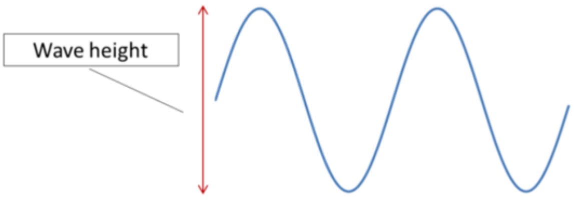


Figure 3. Sketch of wave height

Wave height

The wave height is the distance between the crest and the neighbouring trough of a wave (Figure 3). In a water body a variety of waves of different heights occur simultaneously. The significant wave height is a parameter that is often used to characterise the height of the waves in a water body. It is the average wave height of the highest one third of all the waves. The significant wave height is used by engineers in dimensioning a dike.

Wave height - Fetch

If you don’t wish to use a formula, you can work out the significant wave height from the graph below (Figure 4) and use this to determine how high a dike might need to be.

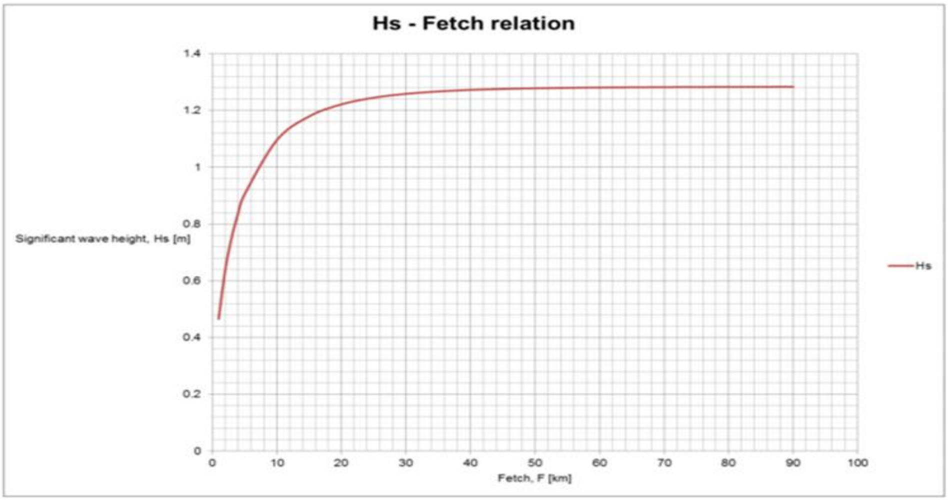


Figure 4. Significant wave height - fetch relationship, for water depth 3,2 m and wind speed 30 m/s

In Figure 4, a significant wave height – fetch relationship is presented, it is assumed that the water depth (in case of flooding of the polder) is 3,2 meter and the relevant wind speed is 30 m/s. By first estimating the fetch and then using the graph to determine the significant wave height can be estimated from the figure below. Note that the significant wave height is the mean of highest 1/3 of the waves. In addition the wind speed is measured at a height of 10 m, this value is default for all calculations. These figures are computed based on the safety level of the dike ring (1/2000 year).

Alternative with formula

You can try to schematise the problem, and then apply a formula to work out how high the dike should be. For instance, you can think of a rectangular water body with a water level h (without waves, without set-up), a fetch F (7 to 10 km), and wind speed U. Then, using the gravitational acceleration g = 9.81 m/s^2, the approximate height determined purely on the basis of water levels and waves is:

$$h_{WL+Wave} = h + 3.75 \cdot 10^{-6} \frac{U^2}{gh} \cdot \frac{F}{2}$$

The freeboard and compensation for settling still need to be included.

From above, your simple model looks like this:

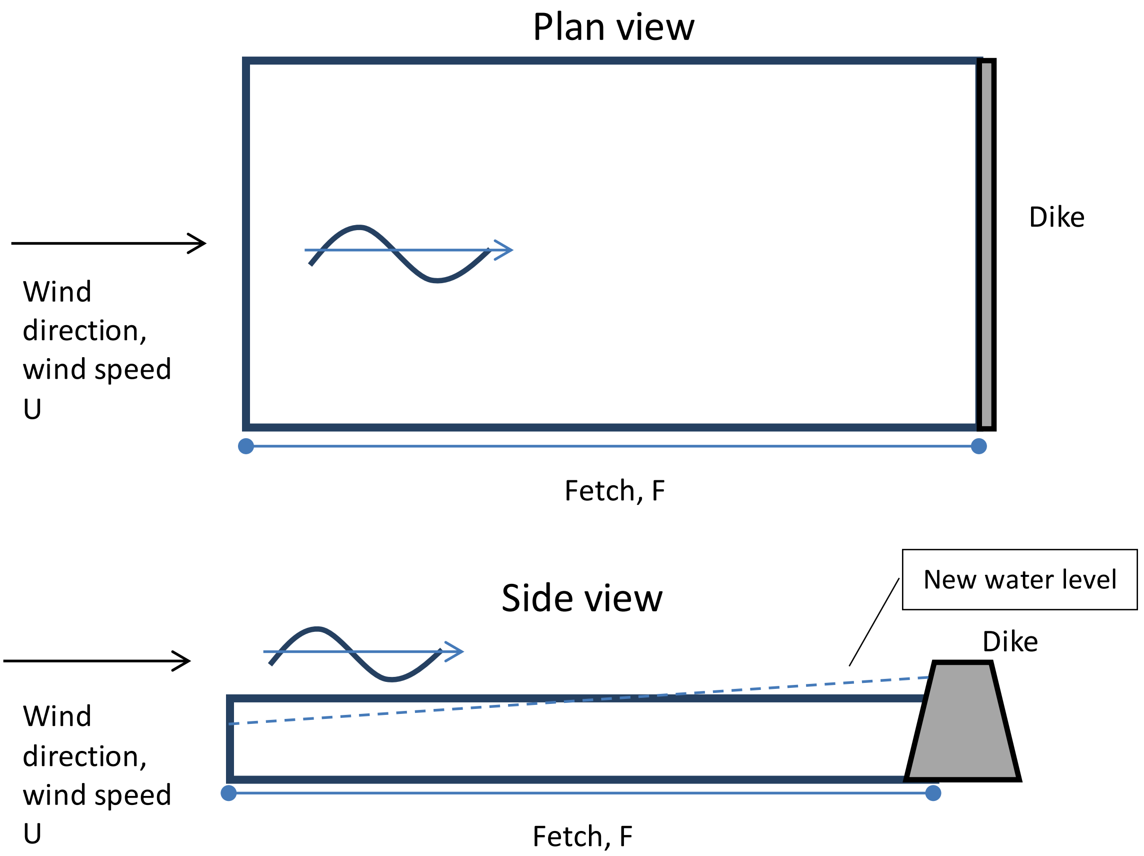


Figure 5: Plan view schematised problem

The width of the dike crest must be at least 3 m and wider if the design includes a road or other functions. At a first estimate the slopes of the inner and outer berms should be 1:3. More gentle slopes are more favourable for the slability and for limiting wave run-up (Helpdesk Water, 2016).

Useful information about Landscape and Ecology

The Noordwaard area is primarily composed of agricultural polders surrounded by willow trees along the margins of old stream beds. The openness of the grassy, marine clay areas, the raised vegetated stream margins and the lower stream beds characterize the landscape. The landscape is open towards the northeast, while the western and southern areas are more compartmentalized by bushy thickets.

The Noordwaard polder borders the Biesbosch, a protected nature reserve under Dutch and European Law (Natura 2000 area, Ramsar wetland). It is one of the last extensive areas of freshwater tidal wetlands in Northwestern Europe. The Biesbosch consists of a rather large network of rivers and smaller and larger creeks with islands. The vegetation is mostly willow forests, although wet grasslands and fields of reed are common as well. The Biesbosch is an important wetland area for waterfowl and has a rich flora and fauna. It is especially important for migrating geese. The protected status was granted because of the presence of characteristic freshwater tidal biotopes, many of which have disappeared in the Netherlands owing to the closure of tidal inlets by dikes and barrier dams. Species such as the beaver and the vole[1] (*Microtus oeconomus*) live in the Biesbosch and have difficulty surviving elsewhere. It is also the habitat of geese and swans with the agricultural and pastoral polders outside of the protected nature area, in the Noordward polder, functioning as a resting and foraging area for the geese and swans. A number of the smaller existing agricultural polders in the Noordwaard have already been turned over to nature via governmental funding to the farmers.

Different species of trees grow in the area. There are two species of willow tree (*Salix alba* and *Salix viminalis*) which can be inundated several times a year for weeks and still survive. These species are tolerant of high groundwater levels and are quite sturdy.

Integrating ecology and engineering

Willow trees and bushy thickets on a floodplain increase the resistance to flow and can increase mean high water levels during floods. However, they can also act as wave breakers when they lie across the direction of propagation of the waves. Although this type of vegetation can reduce the wave effect on a dike, it does not make the dike itself sturdier, nor do they prevent piping effects. Because the 1 in 2000 year flood is likely to occur in combination with heavy storms and strong winds, either a high and broad dike or a broad dike with more wave protection is needed.

The effect of vegetation on wave conditions has been tested using a modified version of the numerical wave model SWAN; a module was added in which the vegetation is represented as a series of cylindrical obstacles of a particular diameter, density (e.g. number of trees per square meter), height, and drag coefficient. For willow trees model results reveal that for a 1/2000 year event the reduction of the wave height lies between 60 and 80%.

With this in mind, it looks promising to think of alternatives that reduce the waves. By reducing the wave height it may not be necessary to raise the dike so much, a relief to the people protesting about their loss of view because of the proposed construction of the dike. The breadth of the dike cross-section could then also be smaller by some 15 to 20 m.

The costs of expropriating the land, planting 100 m wide willow trees or bushes, and the operational and monitoring costs of such an alternative are € 33 - 55 /m dike. But given that the reduction in wave height occurs in the first 20m , it is possible that a 50m wide zone would be sufficient with costs in the order of € 25 – 30 /m dike. These costs are substantially lower than a conventional dike strengthening approach. This usually involves raising the crest of the dike or strengthening the revetment(s), which costs between €150 - €1500/m dike!

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[1] Occurs in protected areas. It is listed on Appendix III of the Bern Convention. The subspecies *arenicola* (from the Netherlands) is listed on Annex II of the EU Habitats and Species Directive.

Bibliography

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