3 Flood protection: planning, design and management of flood defence zones

3.1 Flood defence zone design and planning for multiple functions

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3.1.1 Robust multifunctional flood defence zones, an introduction

The interest in the Netherlands for broad, unbreachable flood defences that also offer space for other land use functions did increase due to the advice of the Second Delta Committee. In 2008 it advised the Netherlands' cabinet on an overall strategy for spatial planning and flood risk management in view of climate change, and also recommended to consider the concept of 'Delta dikes': embankments which are virtually unbreachable due to their width, height, or inner constructions(Delta Committee, 2008).

A broad, over-dimensioned embankment is more resistant to erosion and keeps its protective function, even when significant amounts of water flow over it during extreme conditions (Vellinga, 2008). Of course, such robust embankments require more construction material and space, but on the other hand they offer new opportunities for using the space as well (Vellinga, 2008, Hartog et al., 2009). Over-dimensioned embankments can be designed as multifunctional areas, combining flood protection with urban development, infrastructure, recreation, agricultural use, or nature conservation. They may also contribute to the attractiveness of the typical Netherlands' scenery.

In fact, a robust multifunctional flood defence zone is a broad, elevated area, subdivided in various subzones appointed for other functions in front, behind, or even on top of the embankment itself (Figure 3.1). The broad profile, in which these subzones are combined, forms a deliberately over-dimensioned erosion-resistant flood defence zone. Because of the over-dimensioning, no regular adjustments are needed as a result of changing boundary conditions, or a revision of the protection standards. Consequently, the concept is robust and focuses on the long term.
Figure 3.1 shows the main differences between a traditional embankment, a traditional reinforcement, a 'lean' unbreachable delta-dike and a robust multifunctional flood defence zone as proposed.

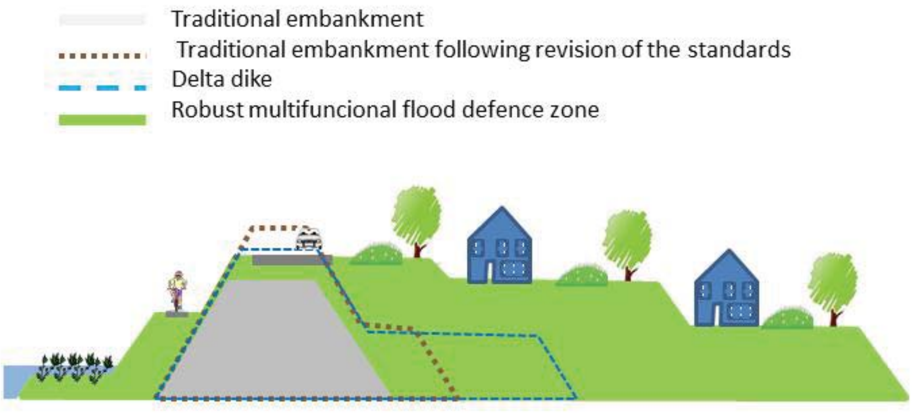

Figure 3.1 Scheme of a traditional embankment, a traditional reinforcement, a delta dike, and a robust multifunctional flood defence zone (adapted after Silva & Van Velzen, 2008; and STOWA, 2011).

Current situation

The design requirements for flood defences are currently exactly defined, and management as well as regular assessment are prescribed. The current Netherlands' flood risk management policy prescribes a 'robust design' of any reinforcement of the embankment to account for changes in hydrodynamic boundary conditions and in the protected values (Rijkswaterstaat, 2007). Such a 'robust' flood defence is thus dimensioned on *expected* changes in boundary conditions in a certain pre-fixed time frame. In addition, a certain amount of space is reserved for future adaptations. This 'reservation zone', however, is seldom appointed for permanent use.

Many traditional flood defences do already fulfil a range of other functions, as long as there is no interference with their primary protection function, Although the design of a traditional embankment takes functions such as transport into account, such additional functions have usually not been included in a long-list of additional design requirements.

Interest in robust multi-functional flood defences

Due to the intensive use of space in the urban area, improvement of a flood defence in this environment is extremely difficult. In the Netherlands' river cities often quay walls, or a combination of embankments and water retaining walls, are used for flood protection. At this moment, several cities and local water boards have started projects to explore robust multifunctional flood defences. The city of Rotterdam for example, is interested in the opportunities of a terraced quay-wall that host functions for transport and building. In such a terraced quay-wall the less vulnerable functions, like traffic roads, can be placed on the lower levels of the terrace or staircase, while functions as housing can be situated on the higher levels of the quay. In case of rising water level, the lowest level of the terraced system is flooded first, and the road may not be accessible for traffic, but the functions on the higher levels may not be influenced (Urbanisten, 2010). In other cities, like Nijmegen, opportunities are explored of a system in which buildings are part of the flood defence. In the concept Adaptable Flood Defences (AFD), structures like car parks, buildings, dwellings or roads are transformed and redesigned with the additional capability of protection of the hinterland against flooding (Stalenberg, 2010). Also, in rural or less densely inhabited areas, there is currently interest in possibilities to integrate flood protection with other functions (see Textbox 1).

3.1.2 Effectiveness

The flood defence performance of the robust multifunctional flood defence zone is based on over-dimensioning of the profile. When exposed to design loads, overflow may occur, but in contrast to embankments with a traditional narrow profile, overflow-related erosion does not lead to the collapse of the flood defence. Therefore, the dose response relationship is far less abrupt for the broad flood defences in comparison with the narrow embankments (Figure 3.2), and hence a broad flood defence zone may be regarded as unbreachable. Silva & Van Velzen (2008) defined unbreachable as having a hundred times smaller probability of overflowing and subsequent erosion or failure due to piping or macro-instability at the land-side than according to the current standards.

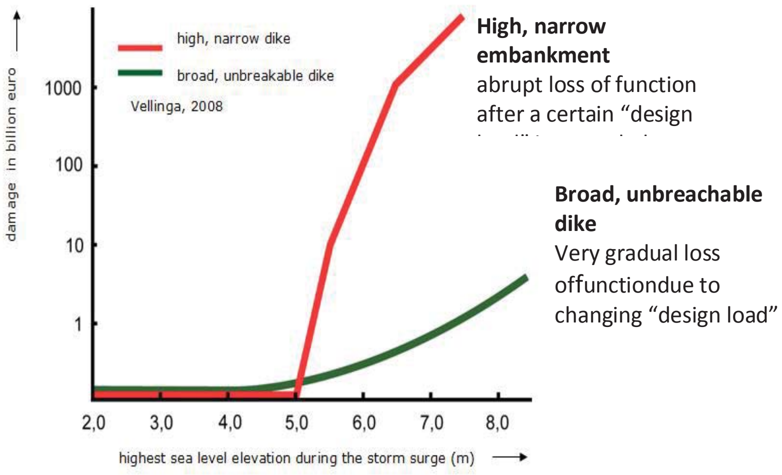

Figure 3.2 Damage functions of narrow and broad embankment (Vellinga, 2008).

Nuisance versus disaster

As a consequence of overtopping during extreme conditions, water will enter the low lying hinterland, but the damage would be limited in comparison with a complete inundation due to failure of the flood defence. Particularly relevant in this context is that the damage would increase only gradually with higher surge levels and not abruptly as with the narrow embankments. Therefore, much depends on the duration of the extreme conditions. In general storm surges at sea only last for a short period (hours), whereas in the rivers extreme rainfall can lead to a high and prolonged discharge (days to weeks). In case of long-lasting extreme conditions, overflow may cause an inundation level comparable to a breach, but creates at least time to prepare or to evacuate. Furthermore, the impact of overflowing is determined by the characteristics of the hinterland. Besides characteristics like economic value of land uses, the connections to other areas, and the number of people living in the flood prone area, also the financial situation determines the effect of an inundation and the ability to recover.

Climate change

All climate models predict changes in mean temperature and rainfall intensities. Accurate prediction of the future climate is constrained, however, by the complex nature of climatic variables and by the existence of many feedbacks in the climate system. Therefore, the robust, broad embankments will improve the robustness of the protective system significantly over a wide range of possible futures and uncertainties, and subsequently are feasible as a climate adaptation strategy (Vellinga, 2008).

Effect of multifunctional use on erosion

Especially in urban areas, integrating housing, transport and underground infrastructure into the multifunctional flood defence is attractive in view of efficient use of the limited space. However, there is yet not much knowledge available about the behaviour of buildings or infrastructure in flood defences, about their influence on erosion and the stability of the berm, and on the impact of overtopping water on these objects.

3.1.3 Cost-effectiveness

The current Netherlands' flood protection policy is based on a risk approach, which takes both flood frequency and the damage due to a breach into account. Therefore, protection standards for densely populated and vital economic regions are higher than for sparsely inhabited and economically less important regions. This approach implies that the costs of flood protection are deliberately weighed against the stakes involved.

An over-dimensioned design provides more safety, but requires more construction material and space. Consequently the initial costs of a robust multifunctional flood defence are considerably higher than the initial costs of a traditional design. On the other hand, a multifunctional use of flood defences would help to optimize the use of limited space, like in Dordrecht and Arnhem, where the over-dimensioned profile is used for housing and recreation. Moreover, these other functions could bear (part of the) additional costs. If indeed costs are borne by other stakeholders, then in view of flood risk management a robust multifunctional flood defence is cost-effective: better protection for less money.

Moreover, on the long term a robust design may be more efficient due to lower maintenance costs and no need for short-term adjustments (see Textbox 3.1).

According to Silva & Van Velzen (2008) an unbreachable embankment requires at least a 1:3 inner slope. Due to the current design of sea defences, Klijn & Bos (2010) estimated that only ca. 140 ha is needed to convert these ca. 1000 km sea defences into 'Delta dikes', whereas ca. 3000 ha is needed to adjust the 1400 km river embankments. In order to prevent future adjustments, a robust multifunctional flood defence zone requires much more space.

Textbox 3.1: Case Streefkerk

For Streefkerk, a small village with ribbon building all along river ‘Lek’ and several socio-economic challenges, possibilities for a robust multifunctional design were explored by De Moel et al. (2010).

Figure 3.3 As a result of past reinforcements, many historic and characteristic houses are situated against or even on or in the current embankment (photograph: J.M. van Loon-Steensma).

The actual flood protection challenge in Streefkerk according to the last assessment comprises a reinforcement aimed at reducing the instability of the inner shoulder. A common solution would be the raising and enlargement of the inner shoulder. Without removal of a large number of houses, such a common reinforcement is impossible (Figure 0.3).

As alternative, a robust multifunctional embankment was designed (Figure 3.4). The design was based on the ‘W+’ climate change scenario (Van den Hurk et al, 2006), a protection level 100 times safer than current standards prescribe, and for a time frame of 100 years (instead of 50). Over-dimensioning offers the possibility retain many of the current characteristic houses and provides an opportunity to build new ones. This results in a possibility for co-funding of this over-dimensioned (and thus more expensive) design.

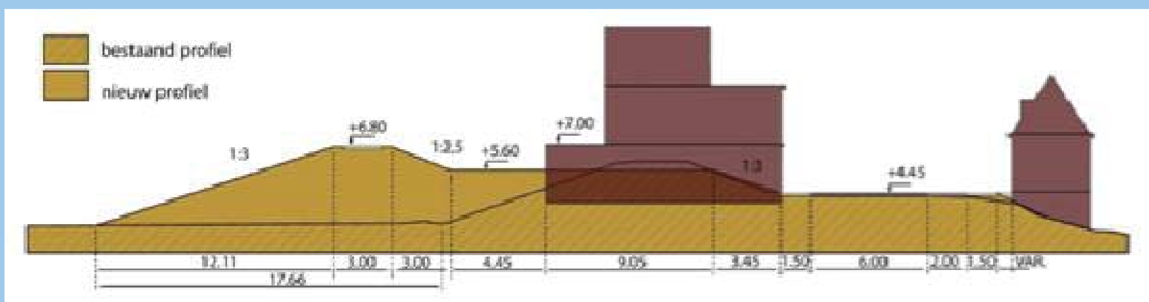

Figure 3.4 Robust multi-functional design for Streefkerk (De Moel et al. 2010).

De Moel et al. (2010) estimated the initial costs of this robust multifunctional profile of 200 m in Streefkerk at € 1.240.000, whereas a traditional design was estimated at € 960.000. However, they estimated maintenance costs of the robust profile at 75% of the costs of the traditional profile (i.e. € 9.600 per year versus € 7.200 per year) so the payback period is approximately 100 years. The calculated benefits due the reduction of potential damage was € 18.100 per year. Furthermore, De Moel et al. (2010) estimated that a second reinforcement of € 380.000 within the next 50 years could be prevented. Based on this analyses, the long term monetary benefits of the over-dimensioned profile outweigh the initial costs.

Total costs for converting all embankments along the coast, estuaries and large rivers into unbreachable 'delta dikes', was estimated at 11.5 billion euros (4.6 million euros per km) by Silva & Van Velzen (2008). Knoeff & Ellen (2011) estimated initial costs at 20 billion euros (8 million euros per km), whereby the costs for river embankments are mainly determined by widening the inner shoulder and costs for sea defences by strengthening the revetment.

No-regret measure

It is clear that a robust multifunctional design would have to be justified against other alternatives. Especially in areas with limited space, it is attractive to combine and integrate various functions and values into a multifunctional design. However, given the long life span of flood defences as well as buildings and infrastructure, it is important to consider long term effects in order to prevent regretful decisions with respect to infrastructure. Over-dimensioning may prevent costly implementation of adaptation measures on a later stage or short-term small adjustments, but on the other hand does claim the space for a long time span.

3.1.4 Side-effects

The concept of the robust multifunctional flood defence is based on the deliberate combination of flood protection with other desirable functions. These other functions may comprise:

- Transport (transport infrastructure on, along, or even in the broad flood defence)
- Housing development and businesses (including the integration of flood protection infrastructure with buildings);
- Nature (e.g. development of a vegetated foreland in front of the flood defence that dissipates incoming wave energy, and protects the flood defence against full wave attack; over-dimensioning of the profile provides space for trees on the embankment; a robust embankment forms a refuge place for animals during high water levels);
- Agriculture (e.g. aqua-culture in coastal areas with parallel embankments which allow regular inundation);
- Landscape values (river embankments as well as sea defences are characteristic elements in the Netherlands' landscape);
- Cultural heritage (conservation or even possible use of historical flood defences, reclamation patterns or historical land use in the coastal and river floodplain areas);
- Recreation (an over-dimensioned profile provides in urban areas space for parks);
- Energy (a robust multifunctional flood defence as suitable location for wind turbines or potential production area for the growing of biomass for energy production).

Competing claims

An over-dimensioned flood defence may conflict with other functions, such as nature conservation or agriculture. In the Netherlands, large parts of the river floodplains and the sea and coastal mudflats and salt marshes in front of the flood defence, are appointed as Natura 2000 sites because of their biodiversity value. Degradation of habitats is only allowed if the necessity of an intervention is shown, the effects of the intervention are studied extensively and any losses of protected habitat are compensated elsewhere.

Texbox 3.2: Streefkerk

As part of an integrated vision on the future development of Streefkerk, a flood defence zone was designed in such a way that it would allow realizing a square with shops as well as waterfront housing development (Figure 3.5 and Figure 3.6).

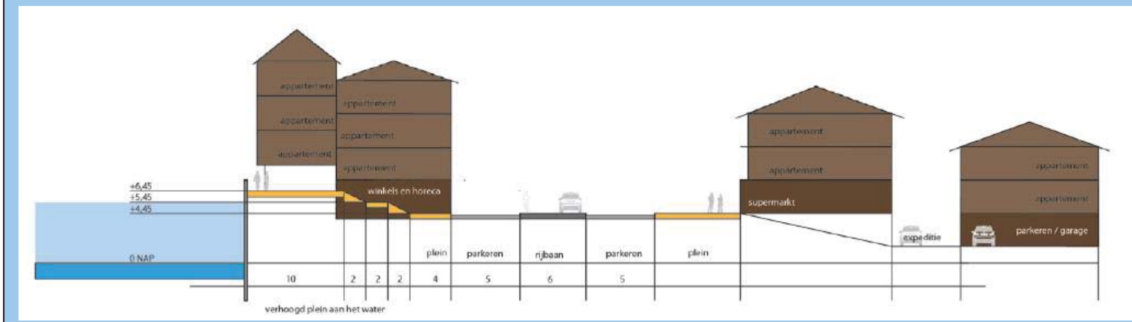

Figure 3.5 Design with a square and buildings adjacent to the waterfront (Terra Incognita, 2010).

Figure 3.6 Connecting the village to the river (Terra Incognita, 2010).

At a meeting in January 2011, municipality 'Liesveld' shared its ideas about the future development of Streefkerk with the inhabitants, and the water board presented the challenges that arose from the revision of the flood protection standards as well as some reinforcement alternatives. The meeting, which was very well attended, made clear that the residents of Streefkerk were primarily concerned about the preservation and enhancement of facilities and housing opportunities for young people. Based on this participatory process and on the results of an environmental impact assessment (EIA) the water board designed an over-dimensioned stretch of embankment.

Due to the intensive use of space in the urban area, adjustment of the flood defence is extremely difficult. It may be necessary to remove historical buildings, use private property such as gardens, or remove transport infrastructure to realize an over-dimensioned profile. In the Netherlands' river cities often quay walls or a combination of embankments and water retaining walls are used for flood protection.

3.1.5 Applicability and attractiveness

Complex process

Due to different or even conflicting interests, the realization of a multi-functional flood defence is a complex and often lengthy process, which requires an enthusiastic and strong advocate (Van Loon-Steensma, 2011). According to stakeholders, it is obvious that the parties who want to achieve their ambitions will act as initiator and driving force. Following their responsibility for the flood defences, the Water Boards usually begin (in case of a dike reinforcement) to collect information about hydraulic and physical boundary conditions, set design requirements, and involve stakeholders in the process. Therefore, the Water Board can often assess in an early stage whether a robust multifunctional flood defence is applicable. In a later stage, another party may take over the lead in the detailed planning (see Textbox 3.2).

Financial resources

As already mentioned, over-dimensioned flood defences require more material and space, and are subsequently more costly than flood defences with a traditional profile. Since water boards have no task or financial resources to realize other goals than flood protection, additional funds have to be found. This requires the coordination of various governmental or local programs, or public-private financial constructions. In case of the latter, proper arrangements about ownership, management and responsibility must be made. Combining the building of robust multifunctional flood defences with regular reinforcement, could save costs (Knoeff & Ellen, 2011).

Legislative framework

The legislative framework for flood defences is based on protection standards and design guidelines. Therefore, over-dimensioned flood defences can only be implemented on a voluntary base, and when it does not conflict with other statutory destinations, such as nature or landscape conservation. Expropriation on behalf of the over-dimensioned profile is not feasible. In case of initiatives of other parties for combining functions in a flood defence zone, the Water Board has to give preconditions based on the Water Act. However, to guarantee flood protection in the long term, flood protection has to be the main function in the planning process and management scheme.

Radical versus incremental adjustment

Replacing the existing high and narrow embankments by over-dimensioned multi-functional embankments can be considered to be a radical adjustment or a true system change (Vellinga et al., 2009). This is particularly attractive on the long run and has to be fixed for a long period, whereas an incremental heightening of existing embankments can be adjusted over time to the monitored effects of climate change. It is a noteworthy, however, that retrofitting technological solutions could be very costly, and in some cases even prohibitively expensive.

Locations

While in view of the flood risk management strategy, complete dike ring should be adapted rather than a small section, it may still be wise to start with some sections. The construction of over-dimensioned flood defences on risky places, which are densely inhabited areas adjacent to flood defences with a relatively short warning time and a difficult situation concerning evacuation (De Bruijn & Klijn, 2009), could prevent severe fatalities and economic damage, and reduce flooding risks substantial. Unbreachable flood defences are therefore recommended as an appropriate measure to reduce risks by the Netherlands Environmental Assessment Agency (Ligtvoet & Van Gerwen, 2011).

Conclusion

In general, initial costs for a robust multifunctional flood defences are higher, but on the long term an over-dimensioned robust design may be more cost efficient due to lower maintenance costs and no need for short-term adjustments. An over-dimensioned profile is better suited when considering uncertainties in climate change projections or changes in land use or socio-economic values than a tailored profile. Especially when functions with a long life span like buildings and infrastructure are integrated with flood protection in a multifunctional flood defence, it is advisable to over-dimension the profile.

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3.2 Coastal protection, dunes as natural climate buffers and integrated coastal zone management

Joep Keijsers, Jan Mulder, Alma de Groot, Ate Poortinga & Michel Riksen

3.2.1 Introduction

In sandy coastal systems, coastal dunes represent natural defence zones against flooding of the hinterland due to their self-regenerating capacity after storm erosion. On the condition that the total dune volume exceeds a certain minimum value related to the safety standard, coastal dune systems represent natural buffers to climate change. The quality of this buffer function is related to the sediment balance in the system. During the past centuries, the Dutch coastline has experienced negative sediment balance and consequently retreated landward, resulting in a loss of total dune area. This means that the quality of the Dutch coastal system as a climate buffer has deteriorated.

In 1990 the Dutch government decided to stop this negative trend, adopting a policy of Dynamic Preservation. Sand nourishments are applied to maintain the coastline at its 1990 position. Since 2001, the additional aim is to preserve the sand volume of the coastal foundation. Implicitly this should lead to preserving the quality of the coastal zone as a climate buffer. From 2001 on, the annual nourishment volume has been 12 million m^3. In the light of climate change predictions, the Delta Committee (2008) has recommended to raise the total yearly nourishment volume to 85 million m^3 per year. This allows to extend the climate buffer and prepares for an increasing rate of sea-level rise from 2 to 12 mm/year until 2050 (Mulder et al., 2011).

An underlying assumption of the nourishment policy is that natural processes will redistribute the nourished sand – on the shore face and beach – in such a way, that the coastal system will “grow with sea level”. To maintain the functions of the dune system under sea-level rise, the dunes require an input of sand proportional to the rate of sea-level rise.