Design challenges of multifunctional flood defences

A comparative approach to assess spatial and structural integration

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Abstract

Due to the changing climate and increasing urbanisation delta cities are faced with an increasing flood risk. In The Netherlands many of the flood defence infrastructures, such as dikes and flood walls, need to be adapted or improved in the near future, to comply to current or improved safety standards. These improvements directly affect landscape and urban development. In its 2008 report, the 2nd Delta Committee presented the idea of multifunctional flood defences, which are flood defence structures that deliberately provide opportunities for other functions. Since then, spatial designers and hydraulic engineers together delivered a wide palette of designs and concepts, resulting in a rather fluid and indefinable concept of multifunctional flood defences. This paper presents a method to describe the level of multifunctionality, based on two existing spatial and structural assessment methods from the fields of civil engineering and urban planning. The combined method distinguishes four ascending levels of integration, ranging from spatial optimisation to structural and functional integration. The combined classification method is tested on a selection of cases of multifunctional flood defences in the Netherlands. Based on this test, it is concluded that the classification method is a useful and generic method to describe the level of multifunctionality. Some of the selected examples look very innovative and multifunctional at first glance, while the level of spatial and structural integration is limited. Other examples might not be very spectacular from a spatial designers point of view, but show that true functional integration of flood protection with multiple other functions is already feasible, depending on the local context. The method helps to bridge the gap between the practices of civil engineering and urban and landscape design. Also, it makes clear that flood risk management is part of an overall process of integrated area development, anticipating on what could be described as a multifunctional flood defence zone.

KEYWORDS

multifunctional flood defence; multifunctional dike; integrated flood defence; integral flood design; interdisciplinary design; delta management; design; flood defence design; dike design; delta dike; climate dike; super levee; flood defence zone

1. INTRODUCTION

The densely populated Dutch delta is vulnerable to both coastal and fluvial floods. A large network of flood defence structures like dykes, dunes, dams and locks protect the major cities of Amsterdam and Rotterdam and the low-lying polders of the Randstad. These structures are gradually incorporated into the urban fabric as a result of rapid post-war urbanisation and – more recently – the transformation of former port areas outside the levee protected areas. Here future flood risk management conflicts with the spatial interests and ambitions of local stakeholders. In areas where dykes and the urbanised landscape have almost merged, traditional dyke reinforcement results in an undesirable claim on space, high expenses and an extended planning and realisation process (Van Veelen et al., 2010). In large urbanised deltas outside the Netherlands, whether it be highly developed urban areas such as the New York-New Jersey Estuary, or developing metropolitan regions such as Jakarta and Ho Chi Minh City, the integration of flood risk management with urban developments also presents a challenge. The question is how to improve flood defence structures, while avoiding enormous social costs and uncompromised spatial solutions.

Both in the Netherlands and other urbanised delta regions, concepts of integrating flood risk management structures with other functions are currently being developed and tested. The Dutch Second Delta Committee embraced the concept of 'multifunctional flood defences' (2^{nd} Delta Committee, 2008) as an overarching concept describing structures that are designed to integrate flood protection with functions like infrastructure, housing, recreation and ecological spaces. New ideas from research and practice such as the 'unbreakable' dyke, delta dyke, and climate dyke were developed. Although integrated flood defences have already been planned and realised in many different places throughout the Netherlands such as Katwijk, Scheveningen, Rotterdam, Dordrecht, Tiel and Vlissingen, an assessment method that integrates both the design approaches of civil engineering and spatial planning is still missing.

In this chapter, a comparative assessment method and classification is introduced that aims to assess both the spatial and structural composition of multifunctional flood defences. This method is based on an integration of the design methods of urban planning and hydraulic engineering, to provide a way of design as an *"important and essential approach to intentional change"* (Nelson & Stolterman, 2012) that could help both urban planners and hydraulic engineers to develop a mutual language. It should also enable the link between the strategic level of landscape and flood risk planning with a concrete feasible level of structural design. The proposed method could thus form a useful tool to support both horizontal cooperation on operational level of design and improve communications between the strategic and tactical level of decision-makers and designers. In this way, this approach contributes to a design culture, as proposed by Nelson & Stolterman (2012), where *"it is important for leaders to recognise that their challenge is that of a designer."*

To get a grip on the structural design of multifunctional flood defences, the following section first briefly describes the evolution of flood risk strategies and flood defence design in the Netherlands. Following on from this, the composition of traditional flood defences and some new concepts are explained. Then, the assessment method of the structural and spatial integration is introduced, based on an overview of design perspectives. This method is applied to several cases: the Dakpark and Hilledijk in Rotterdam and the Noordendijk in Dordrecht. The chapter ends with conclusions and recommendations for the spatial and structural design of multifunctional flood defences. Although the cases studied in this chapter represent typical Dutch flood risk management structures, the assessment method is generic and can be applied in other delta regions where similar integration challenges play a role.

2. TOWARDS NEW FLOOD RISK STRATEGIES AND CONCEPTS

2.1 An introduction to the flood management system of the Netherlands

Dutch flood risk management has evolved over time and in recent years has been ever more influenced by societal developments (Heems & Kothuis, 2012). There are several recent changes to the current Dutch flood risk management system that have a substantial impact on the design and layout of flood defences. To understand the impact of these changes it is necessary to introduce some key elements of the Dutch flood risk management system and local design methods.

The Dutch flood protection system is based on closed networks of primary flood defences: so called 'dyke rings' that protect both urban and more rural areas along the North Sea coast and the main rivers. The traditional design of flood defences was based simply on experience and local conditions. After the catastrophic 1953 flood this deterministic approach was replaced by a flood protection philosophy based upon a cost-benefit optimum analysis wherein the cost of increasing protection is balanced against the reduction in flood risk. Because of the availability of statistical data of water levels and the development of an advanced analysis method, the flood risk could be related to the exceedance frequency of a critical water level. Flood defences had to be designed in such a way that this critical water level could be resisted. This method is known as the 'semi-probabilistic design method' because the strength of flood defences was still considered as a fixed value (TAW, 1998). This new approach resulted in flood protection standards that differ per dyke ring, depending on the economic value of the hinterland it protects and character of the local hydraulic conditions.

2.2 Towards a risk-based approach

In spatial planning, however, flood risk soon proved not to be a determining factor. Low-lying polders were urbanised, resulting in a gradual increase of the consequence of a flood. The Environmental Assessment Agency noted already in 2004 that human lives and economic values are less protected than originally intended when the current safety system was introduced in 1960 (Ten Brinke & Bannink, 2004). To address this imbalance between safety standards and growing consequences, these safety standards are currently under discussion. A tightening up of the flood protection standards, however, implies a drastic improvement of flood defences in the urban or rural environment.

In parallel, the design method of flood defences is changing. A full 'probabilistic design method', where the strength of flood defences is considered as a distribution instead of a fixed value, is a more accurate method than a semi-probabilistic method. Recently, numerical methods have been developed to carry out this way of design. In addition to the traditional design criteria based on overtopping and overflow of the structure, also failure mechanisms based on the stability of the structure (for example piping and sliding) are included in the risk calculation.

2.3 New flood defence concepts

The advancement in risk analysis together with societal developments has led to a new direction in a multi-layer flood risk approach where risks are not only reduced by preventing measures (layer 1), but also by adapting spatial planning and urban design (layer 2) and by introducing disaster management (layer 3) (Ministry of I & M, 2009). Although the cost-effectiveness of investments in reducing risk strongly varies per layer and depends on local conditions and the specific nature and probability of a flood (Kolen et al., 2011), this new approach offers possibilities for the integration of flood risk management and spatial planning.

A change to a risk-based approach has consequences for the design and layout of flood defences. The Dutch research institute Deltares studied the relative effectiveness of creating 'unbreachable' dykes to reduce the mortality rate for each dyke ring area (De Bruijn & Klijn, 2011). These unbreachable structures can be defined as flood defences that remain stable even when the Normative Water Level is exceeded, reducing the probability of an uncontrolled flood by 10 or even 100 times. This concept of unbreachable flood defence structures forms the basis for different multifunctional concepts that are known under a wide range of names, such as the delta dyke, super dyke, broad dyke, robust dyke and climate dyke (figure 1). The premise is that the concept of unbreachable and multifunctional dykes is more cost-effective than conventional dykes because of real-estate development opportunities and benefits of optimal land use. Although some case study research (De Moel, 2010, Veelen et al., 2010) supports this claim, the cost effectiveness of unbreachable and multifunctional flood defences has not yet been researched in depth.

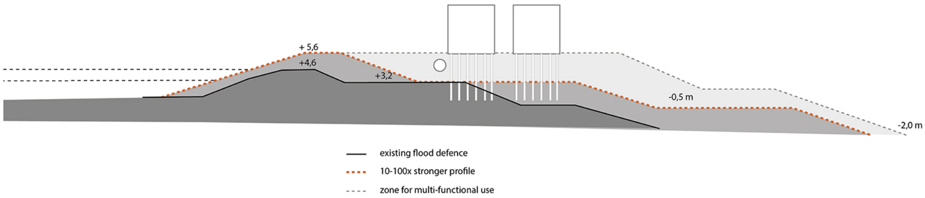

Figure 1 Cross-section of a multifunctional 10 x stronger dyke: in dark grey profile of a mono-functional river dyke, in light-grey a 10 x stronger dyke and zone for multi-functional use (adapted from: Tromp et al., 2012)

3. SPATIAL AND STRUCTURAL INTEGRATION

In this section a method is proposed to assess the structural and spatial integration of multifunctional flood defences, based upon combining a classification of the structural elements composing a flood defence, with a classification of dimensions in multiple spatial use.

3.1 Structural elements

To evaluate the degree of spatial and structural integration of flood defences, it is necessary to understand the geometry and composition of a traditional dyke. The composing elements can be derived from the main characteristic of flood defences: water-retaining elements, elements that provide structural stability and strength, and elements that have a positive (or negative) influence on hydraulic conditions.

Drawing on the research of Huis in't Veld et al. (1986) and Venmans (1992), the main elements of a flood defence can be grouped according to their structural role:

- *Water retaining elements* provide protection against floods through their height and water resistance (impermeability).
- *Supporting elements* support the water retaining elements by providing additional strength or stability. This element type includes erosion protective elements and transitional structures.
- *Objects* do not have a flood protection function but are part of the flood de-

fence and have influence on the strength and stability of the structure as a whole.
- *Structural elements that change the hydraulic boundary conditions*.
- *The subsoil*, which should finally resist all forces acting on the flood defence.

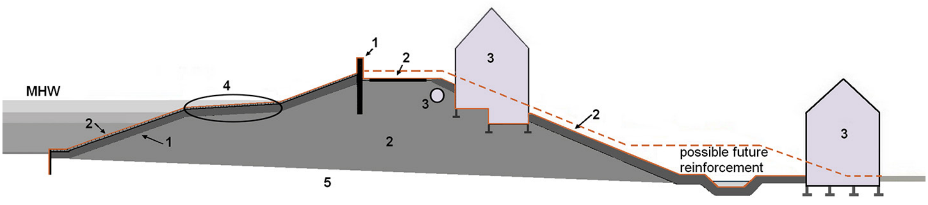

Figure 2 Cross-section of a lake dyke with indication of the structural element types

These element types are illustrated in figure 2, which could represent a sea dyke, but the basic components can be recognised in other types of flood defence structures. Generally, water-retaining elements (type 1) consist of a clay layer or a wall (sheet piles or a gravity structure for example). Supporting elements (type 2) are the core of a dyke and the anchors of a retaining wall, but also the revetment that protects the inner slope of a dyke against erosion due to overtopping waves. Objects (type 3) consist of houses, roads, parking garages, etc. Often such an object is not currently part of a flood defence, but will become part of it when the flood defence is widened. An example of a structural element that changes the hydraulic boundary conditions (type 4) is an outer berm, which dampens the waves and thus reduces the wave overtopping volume. Also, foreland and vegetation can act as elements that influence the boundary conditions. Finally, all forces acting on the flood defence and the forces exerted by the flood defence itself (mostly its own weight) have to be resisted by the subsoil (type 5). For hydraulic structures it is typical that a major horizontal load (from the adjoining water) is transferred to the subsoil.

By classifying these element types, the degree of integration of objects with the basic elements of a flood defence structure can be determined.

3.2 Spatial dimensions of multifunctionality

In the context of urban planning, multiple land-use refers to situations where the existing space is more intensively used (Hooimeijer et al., 2001). This can be achieved by the morphological integration of functions (the stacking of multiple functions in one building or construction), by mixed space use (multiple functions in a certain defined area) and by temporal shared-use of the same space. The degree of spatial integration used in this chapter is based upon a classification by Ellen (2011) and adapted by Van Veelen (2013), who distinguishes four spatial dimensions of multifunctionality. These dimensions are used for evaluating the degree of spatial and functional integration, with slightly adapted terminology (see also figure 3):

- *Shared use.* A flood defence structure is (temporarily) used by another function, without any adjustments to its basic structure. It is generally possible to use the flood defence for infrastructure, recreation and agricultural uses, as long as the functioning of the flood defence is not impeded.
- *Spatial optimisation.* The basic shape of the flood defence is adapted to create space for other structures. These structures are technically not part of the flood defence structure. Spatial optimisation is found in many places in the highly urbanised areas of the Dutch delta. The most compact and spatially optimal shape is obtained if a vertical retaining wall is applied which replaces a dyke slope or berm, leaving space for housing or other functions.
- *Structural integration.* An object is built on, in or under the flood defence structure, but does not directly retain water. The concept of structural integration is used in situations where the current dyke is over dimensioned (super dyke) or many times stronger than necessary (unbreachable dyke).
- *Functional integration.* The water-retaining element of the flood defence also functions as a part of the structure with another function (the 'object'). Although this concept is technically feasible, it is hard to find realised examples of full integration. There are some historically evolved situations in which the dyke is part of a medieval city wall (as seen in Kampen) or a row of old buildings (as seen in Dordrecht).

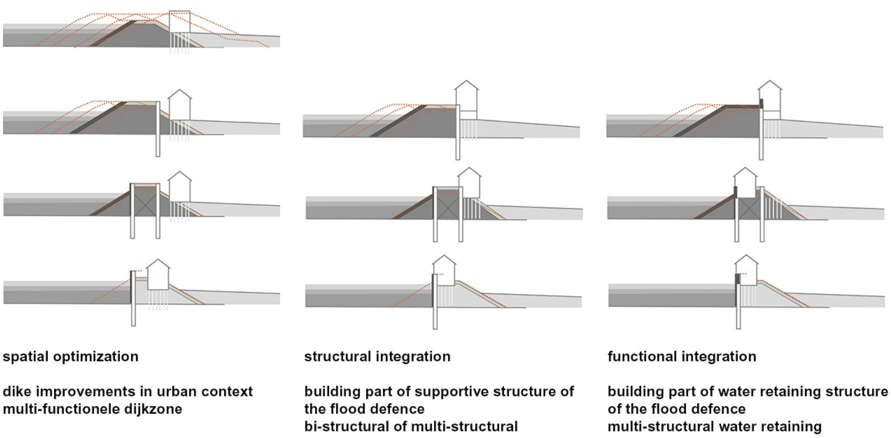

Figure 3 Various examples with different degrees of spatial integration

3.3 The combined approach

The determination of the degree of integration starts with identifying the compositional elements of a flood defence structure. As a first step it should be determined whether an element has a water-retaining function or influences the strength and stability of the flood defence structure as a whole. If this is not the case, the integration is categorised as 'shared use', as long as the basic shape of the flood defence is not altered. If the flood defence shape is adapted to allow more spatial compactness, the situation is categorised as 'spatial optimisation'. If the object, or part of it, fulfils a structural role in the flood defence structure, it is evaluated as 'structural integration'. If this structural role is retaining water, the category is called 'functional integration'.

This method will be used in the following sections where three multi-functional flood defence structures are evaluated.

4. ANALYSIS OF EXISTING MULTIFUNCTIONAL FLOOD DEFENCES

The described analytical method to determine the degree of spatial and structural integration is tested with help of real cases. These cases are selected based on an overview of existing studies and reports on multi-functional or innovative flood defences. The majority of these cases are briefly analysed in terms of spatial and structural integration based on the available literature. Three cases of multifunctional flood defences are analysed in more detail, using urban master plans, original building permits, archival research and interviews with key players during the design process. These cases are selected because they are clear examples of three different dimensions of multi-functionality and because these examples are well documented. The cases are assessed on (1) design criteria (2) spatial integration (3) structural integration and (4) flood defence concept.

4.1 Dakpark Rotterdam: Shared use

The 'Dakpark' is an elevated park on a former railway yard in the Delfshaven quarter in Rotterdam. The park is located on the roof of a new shopping centre, which includes a parking garage (hence its name: 'dak' in Dutch means 'roof'). The park is the largest green roof in Rotterdam and one of the largest in the Netherlands. The park offers a playground, communal garden and a Mediterranean garden with an orangery. The Dakpark is 1000 m long and 80 m wide. The park is situated 9 m above street level. The car park has space for approximately 750 cars. The Dakpark is combined with a dyke, the 'Delflandse Dijk', that is part of dyke ring 14, which protects the urban area of the Randstad.

The idea for a large city park is part of a longstanding agreement with residents to add more green space, stemming from the urban renewal process of the surrounding ‘Bospolder-Tussendijken’ district. The district authority finally decided to designate 80% of the space that became available for ‘green’ purposes. The project developer and owner of the area, the Rotterdam Port Authority, intended to develop a commercial and industrial zone, which was conflicting with the residents’ ideas. Ultimately a multifunctional structure has been designed that accommodates shops, offices, and a parking garage on the ground floor and first floor and a park with leisure functions on the rooftop (Kennisbank Platform31, 2013). Important issues that had to be solved were the division of the costs, the presence of objects like stair-cases in the flood defence, and the by-law of the Water Board which contains regulations regarding building in the vicinity of the flood defence (Van der Leeuwen, 2008).

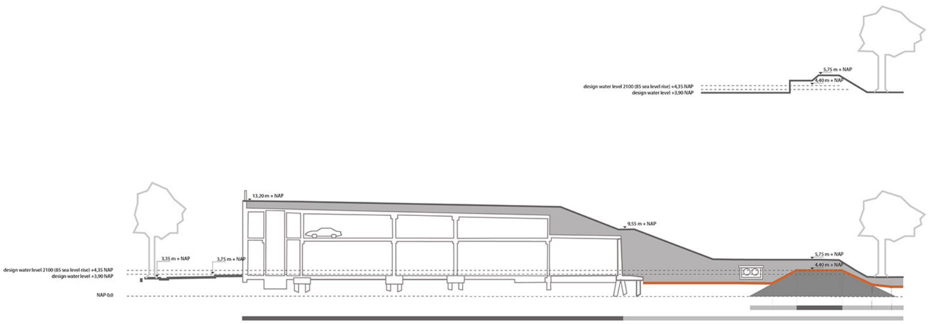

Figure 4 Cross-section of the ‘Roof Park’ Rotterdam

The original dyke is not integrated into the new structure of the Dakpark building itself (figure 4). Instead the shopping, office and parking complex is situated next to the old dyke and the space in between the complex and the dyke has been filled out by soil. Meanwhile, the crest height of the dyke was raised to make it ‘climate-proof’, which means that a worst-case scenario in terms of sea level rise has been taken into account for the design lifetime of the flood defence. The complex is situated in the outer zone, the ‘influence zone’ of the flood defence according to the definition by the Water Board. Building in this zone is only allowed under exceptional circumstances, but in this case it is compensated by the reinforcement of the park strip. Several agreements including those regarding the foundations of the core zone, and ease of inspection, ensure that Dakpark will maintain its flood protection function in the future (City of Rotterdam, 2008).

The Dakpark complex itself does not contain structural elements that are part of the flood defence. The additional soil layer on top of the dyke is not considered to contribute to the retaining height because the Water Board regards the existing profile as the flood defence. This dyke profile has not been adapted to make space for other functions. The Dakpark therefore is classified as 'shared use'.

4.2 Hilledijk Rotterdam: Spatial optimisation

The Hilledijk in Rotterdam is one of the last remnants of the old river dyke that protected the land from flooding from the river Maas. The dyke together with an old railway yard currently function as a spatial barrier between the Afrikaanderwijk and the new developments of Kop van Zuid. One of the key principles of the 2004 Parkstad masterplan is to dissolve this barrier by redeveloping the railway yard and transforming the dyke into a gradually ascending landscape, visually softening the height difference between the elevated area and the low-lying Afrikaanderwijk. This new 'dyke landscape' will be used as a base for the development of different building blocks accessed through a new road on the top of the existing flood defence. The area between the buildings will remain accessible for inspection and maintenance (Palmbout Urban Landscapes, 2009).

During the process of drafting the Parkstad masterplan the Hollandse Delta Water Board had scheduled a dyke reinforcement for a section of the Hilledijk, to be finished in 2014 as part of the *Flood Protection Programme* (*Hoogwaterbeschermingsprogramma*) 2. The spatial and temporal coincidence of both developments contributed to public support for a multi-functional solution, where both parties benefit.

An important design principle is that the new flood defence is spatially and functionally separated from the new buildings lined up on both sides of the crest. The new buildings are not integrated in the actual water defence, but will be constructed just outside a theoretical profile of the new flood defence. This means that when the buildings will be removed, the flood defence structure remains intact. The flood defence itself will be designed to a design water level corresponding with a 100-year moderate sea level scenario. One of the additional design criteria is that the water defence should resist a flood level corresponding with an average frequency of 1/10.000 per year, although the dyke ring 17 has been standardised to a 1/4000 per year exceedance frequency. Although the new buildings are legally not part of the flood defence they will contribute to the strength of the embankment, creating a virtually unbreachable dyke that is many times stronger than actually necessary. The Hilledijk can thus be considered as practically unbreachable (figure 5).

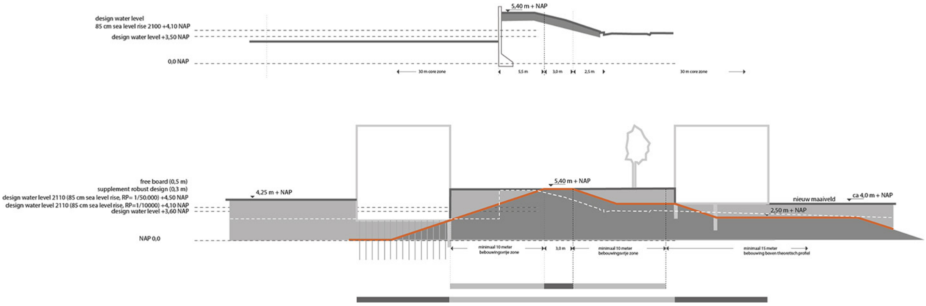

Figure 5 Cross-section of the 'Hilledijk' in Rotterdam

Because the floor levels of the existing houses along the Hilledijk are much lower than the desired level of the proposed street, demolition of these building blocks is inevitable (Palmbout Urban Landscapes, 2009). Due to the current financial crisis the development of the Parkstad Masterplan has slowed down and the demolition of buildings blocks has been postponed. The question has arisen whether the interdependence in the design of the flood defence and urban development is a restriction to adapting to changing circumstances.

The Hilledijk can be classified as a situation of spatial optimisation by using overlay of urban functions, without structural or functional integration.

4.3 Noordendijk Dordrecht: Functional integration

After the disastrous flood of 1953 the urbanized part of the Noordendijk (North Dyke) in Dordrecht was reinforced with a cofferdam, to avoid demolition of the historical buildings lined up on both sides of the dyke. In the late seventies this dyke, although sufficiently strong, did not comply with the more stringent height requirements posed by the first Delta Committee. Creating a higher dyke proved to be difficult. The initial plan of the water board consisted of a traditional dyke reinforcement by strengthening the outer-slope of the dyke towards the river slack tide. This required demolition of a row of historical buildings and relocation of a power plant and the last windmill of Dordrecht. When in September 1987 all reinforcement projects were provisionally suspended by new plans for a storm surge barrier in the Nieuwe Maas, the planning process came to a halt (Erfgoedcentrum DiEP).

After the realisation of the Maeslant barrier in the early nineties the possibility appeared to integrate the reinforcement of the flood defence with an urban renewal project on the south slope of the dyke. A floodwall was realised in sections with insufficient space for a slope. This 500 meter long L-shaped concrete floodwall with a seepage screen (of steel sheet piling) is at some places fully integrated into the structure and the foundation of a new row of single-family homes (figure 6). The retaining wall derives its stability from concrete partition walls that connect the floodwall with the structure of the houses (Waterschap De Groote Waard, 1997). The resulting space functions as a private parking garage, accessible from the low-lying polder level. The roof slab of the parking garage is used as a public space, side walk and bike path (Van den Merkenhof, et al. 1998).

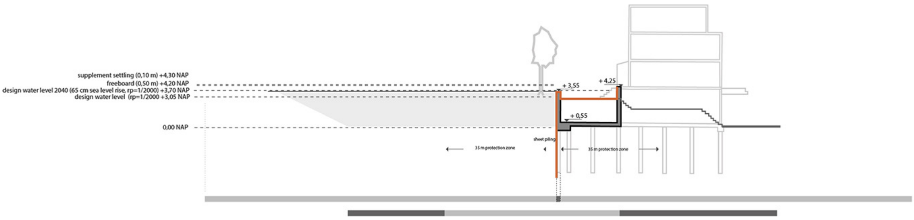

Figure 6 Cross-section of the 'Noordendijk' in Dordrecht

The retaining wall is over-designed with a surplus height of 65 cm to anticipate future climate change. Although the concrete structure is designed for a life span of 100 years, no additional provisions have been made in the structure of the houses to allow the functional separation of the two structures, in case of eventual future demolition or renewal (Van den Merkenhof, et al. 1998).

Although the floodwall is almost entirely covered by a 3.5 metre elevated built-up waterfront zone, making the wall technically functioning as a soil retaining wall, the Hollandse Delta waterboard considered the wall as the primary flood retaining structure (Waterschap Hollandse Delta, 2010). The floodwall is owned by the water board, but given that it is situated on private property the water board had to make special arrangements with the homeowners to obtain access rights to the parking garage for inspection and maintenance. Additionally, in the purchase contracts binding restrictions are incorporated on making changes in the water retaining walls (Koekkoek, 2013). Because there is clear evidence of the integration of the water-retaining floodwall with the structure of a row of houses (the 'objects') the Noordendijk can be classified as an example of functional integration.

Several other multifunctional flood defences have been analysed using the assessment method. It appears that only a few of them can be classified as functionally integrated, while most of them are examples of structurally integration, spatially optimisation or shared use.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Evaluation of the method

The aim of the proposed assessment method is to find a way to describe the degree of structural and spatial integration of the flood defence function with other functions. This section discusses the findings coming from the application of the proposed method.

The proposed assessment method is tested on a set of cases, of which three are presented in this chapter. In all cases it proved to be possible to distinguish the composing structural parts and to determine the integration category. It also appeared that the method is systematic and transparent and can be generally applied to a wide range of multifunctional flood defences.

During testing it turned out that application of the method contributes to a better understanding of the structural composition of the sometimes inconsequently used spatial concepts like 'super dykes' and 'broad dykes'. It also increases insight into the efficiency of the combination of functions: some of the selected examples look very innovative and multifunctional at first glance, while the level of spatial and structural integration is limited. Many examples are spatially optimised, but not structurally or functionally integrated. Other examples may not be very spectacular from a spatial designers point of view, but show that true structural integration of flood protection with multiple other functions is already feasible, depending on the local context.

A better understanding of the integration of functions or structures could also contribute to a better allocation of responsibilities for inspection, maintenance and future investments. After all, a clear understanding of what structural element serves what purpose provides a common starting point for discussions.

The main generic conclusion is that the method will help both urban planners and hydraulic engineers to develop a mutual understanding of the various interests from a flood management and spatial development perspective. Because of the design-based classification, the method can be applied to discuss spatial integration of multifunctional flood defence structures in different governance contexts.

5.2 Design challenges of multifunctional flood defences

The cases show that all categories of integration are technically feasible and in compliance with the current safety standards. This does not imply however that the authorities responsible for flood protection have no reservations when it comes to issues of inspection, maintenance and sustainability of multifunctional flood defences.

The case Hilledijk shows that the strategy of oversizing the flood defence is a promising strategy to increase space for intensive urban use and at the same time to redesign the flood defence into a virtually unbreachable structure. Especially in highly urbanised areas all over the world where traditional dyke reinforcement would have negative spatial impacts and be an extended and costly process, this concept is a promising strategy to align spatial development with flood risk management structures. Although wide and multifunctional used flood defences already can be found at several places (for example Maasboulevard and Hilledijk in Rotterdam, the Super Levee in Tokyo and the boulevard in Wuhan, China), the realisation of this approach on a larger scale would imply a complete redevelopment and redesign of the urban waterfront zone, which is not always feasible and applicable.

The case Noordendijk shows that it is necessary to develop design strategies that are able to deal with dissimilar life cycles of urban and flood risk management structures. In general, flood protective infrastructures have a designed life cycle of at least 50 to 100 years, while urban functions are designed for a life cycle between 20 to 50 years (TAW, 2003, NEN-EN 1990). Also uncertainties, caused by demographic changes and climate change, require flexible design concepts. It is necessary to develop construction methods and design that enable easy replacement or adjustment if necessary, with minimal destruction or demolition.

5.3 Multifunctional flood defence zones

To fully exploit the spatial and functional benefits of multifunctional flood defences, modifications to the regulatory framework are necessary. While considering the degree of integration, for example, it becomes clear that the Dutch ledger zones (legal zones that restrict building activities in a certain area) are often not tailor-made for multifunctional flood defences. A striking example of this situation is the Noordendijk in Dordrecht, where the integrated floodwall has not resulted in a protection zone that matches the actual failure mechanisms of a floodwall. This mismatch between legal protection and structural and spatial state of a flood defence is particularly relevant for oversized multifunctional dyke concepts, where the water boards still lack the legal instruments to appoint the oversized multifunctional zone as a crucial part of the structure.

This is also the case for the legal protection of structural elements that influence the hydraulic boundary conditions. Forelands, for example, often play a role in wave reduction, but are not included in the dyke height estimation because they are out of the regulatory framework of water boards (i.e. beyond the widest ledger zone). By not considering flood defences as line infrastructures, but more as multifunctional flood defence zones, forelands could become legal elements of flood defences, resulting in more cost-effective designs.

The challenge is to deal with these issues and to take them into account during the planning and design phase. The method described in this chapter helps making ideas more specific and easier to discuss. It is therefore recommended to use this method in both national and international contexts.

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