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Life-Cycle of Structures and Infrastructure Systems – Biondini & Frangopol (Eds)

Embedding functional performance in asset management of hydraulic structures

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ABSTRACT: In the coming decades, the storm surge barriers in the Netherlands will reach their end of the designed life time of 100 years. Therefore, the Dutch storm surge barriers are preparing for major renovations. Next to this, as a result of the expected sea level rise, the hydraulic loads and the number of necessary closures will exceed the original design requirements. This gives urgency to look further than an one-to-one replacement or conservation and it a good moment to include changes in functional requirements. The functional end of life is, however, typically surrounded by large uncertainties. Since storm surge barriers bear multiple functions (e.g. hydraulic safety, the environment, shipping and road traffic infrastructure connection), changes in conditions can lead in several ways to the *functional* end of life. In this paper we explore what aspects should be added to current asset management strategy to include the functional performance of our hydraulic structures.

1 INTRODUCTION

The Netherland's has a long history of protecting the hinterland against high water by building dikes and dams. After the flood disaster of 1953, by far the largest Dutch natural disaster of the 20th century, the Delta works were built to defend the 'provinces Zeeland' and 'Zuid Holland' for the high tide from the sea. This was done, in addition to the reinforcement of the dikes, by constructing dams and storm surge barriers to close the estuaries and reduce the length of the high water defense system. The complete system consist of five storm surge barriers, two locks and six dams. The fist storm surge barrier was built in 1958: the 'Hollandsche IJsselkering'. The last, the Europort barrier, consists of the 'Maeslantkering' and the 'Hartelkering', was finished in 1997.

Most barriers were designed for 100 years with the sea-level rise expectations set during construction. These predictions were conservative at that time but are rapidly caught up and underrated by the latest predictions. This implies that the storm surge barriers may reach their functional end of life well before the originally anticipated date. Therefore, it is important to also include the functional end of life the strategic asset management of the storm surge barriers.

This paper wants to answer the question if the current risk-based inspection method in combination with the Statutory Assessment of water safety is sufficient to determine the end-of-life of storm surge barriers.

2 DUTCH MAINTENANCE AND SAFETY ASSESMENTS

The infrastructure of the Netherlands that is maintained by Rijkswaterstaat (Rijkswaterstaat is part of the Dutch Ministry of Infrastructure and Water Management and responsible for

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the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands) has a great diversity. It ranges from floodplains and road(side)s to tunnels, pumping stations and storm surge barriers. To make the right choices risk-driven maintenance is introduced. This is done, depending on the complexity and the consequence of the objects, by qualitative or (semi)quantitative risk analyses. Separately from the risk-driven maintenance, the Dutch water act prescribes its own system for the periodic safety assessments of the main flood defenses. The two systems complement each other in the sense that the one focusses on technical and the other on functional aspects. Yet, both systems are not coordinated with each other. In this section of the paper we give a brief overview of the main aspects of both systems.

2.1 *Risk based asset management*

For the risk based asset management in the Nederland's line objects (roads and waterways) an initial risk analysis is made on which the maintenance is based. And in order to maintain the quality level and to determine the maintenance requirements of all the different objects every six years a technical inspection of all the infrastructural object is made. With the results of this technical inspection the financial reservation for the maintenance and a prediction for the end of life is made. With the prediction for the end of life, major replacement and renovation projects are started in a separate project with separate budgeting. The starting point of the end of life determination is this technical inspection. Afterward the economical choices are made with the option of renovation or replacement. In this process the new functions are combined in a new design or renovation plan. This is an organic and logical way to work with the majority of the infrastructural objects. For the more critical objects it's better to look at the different lifespans separately.

2.2 *The Dutch Water Act*

Since December 22, 2009, the Dutch Water Act merges eight previous water management laws, several water pollution laws and which we will discuss further here the law on flood defenses. The Dutch water act provides two types of standards for each dike trajectory. The lower limit is the actual standard and the (stricter) signaling level is established as an alert for when to take action. According to the Water Act, the flood defenses must be assessed if they meet the safety standards once every 12 years. This is elaborated in the Statutory Assessment Instruments (Van Waal 2018), which states that the uncertainties in load and strength are included in the assessment of the flood defenses.

When the dike or object meets the requirements for signaling value the barrier is approved. If the signaling requirements are not met, a plan must be drawn up to meet them. This signaling value is typically a factor 3 higher than the lower limit. In this way, the sea level rise is implicitly anticipated for.

If the barrier meets the requirement of the signaling value, it has to be proved it will stay that way through good management, translated from Dutch it is called 'duty of care'. This can be done by a good maintenance plan for dikes and simple structures. For more critical structures by the substantiation of the reliability based maintenance, with the aim that everything remains in good condition until the end of its life.

2.3 *The National Delta Program*

Besides the management and the Dutch Water Act, the Delta Program is a national program of the Dutch government that describes how to maintain a the climate-resilient and water-robust design of the Netherlands. How do we protect the Netherlands against flooding and how do we ensure sufficient freshwater? And how do we ensure a water-robust and climate-proof design. The Delta program provides qualitative and quantitative information about

Table 1. Overview of the rating categories of the WBI.

Cat.	Designation of test assessment category per subject per test track	Limit category $P_{f,dsn}$ = probability of failure per section (section or structure) [1/year] $P_{eis;sig}$ = signaling value [1/year] $P_{eis;ond}$ = lower boundary [1/year] $P_{eis;sig:dsn}$ = probability of failure [1/year]
I_v	Sufficiently wide of the signaling value	$P_{f,dsn} < 1/30\ P_{eis;sig:dsn}$
II_v	Meets the signaling value	$1/30\ P_{eis;sig:dsn} < P_{f,dsn} < P_{eis;sig:dsn}$
III_v	Meets the lower limit and possibly the signaling value	$P_{eis;sig:dsn} < P_{f,dsn} < P_{eis;ond;dsn}$
IV_v	May meet the lower limit and/or the signaling value	$P_{eis;ond;dsn} < P_{f,dsn} < P_{eis;ond}$
V_v	Does not meet the lower limit	$P_{eis;ond} < P_{f,dsn} < 30\ P_{eis;ond}$
VI_v	Well below the lower limit	$P_{f,dsn} > 30\ P_{eis;ond}$
VII	No judgment yet	

climate, water systems, water use and land use in different scenarios. With the purpose of a robust nation resilient to water related challenges in 2050 and 2100. The Delta Scenarios are based on the IPCC predictions which now predict stronger increases than were initially expected (Wolters). The Delta Scenarios will be updated in 2023 on this basis.

With the help of the scenarios and the forecast of the IPCC, the delta program has come to realize that the functional end of life of the storm surge barriers may be reached before 2050. The delta program has therefore initiated a study into the functional end-of-life of the Maeslant barrier, no results of this study have been produced yet.

2.4 *Discussion current asset management and assessment strategies*

The current asset management process does not pro-actively include changes in functional and performance requirements. The functional requirements are only assessed when the technical state requires renovation or replacement. This seems adequate for relatively simple, non-critical structures, as temporarily reduced performance has only manageable consequences for the greater network. For critical structures, however, replacements may take much more time and their reduced performance may have large consequences for the overall functioning of the network.

For flood defenses, potential future changes in the safety requirements or hydraulic loadings are implicitly accounted for by the introduction of the signaling safety level. The 12 year assessment cycle is likely to be sufficient for dams and dikes. For critical hydraulic structures this is however questionable, since they typically bear many other functions and their replacement can take several decades.

3 END OF LIFE INFRATRUCURAL OBJECTS

For the determination of the end of life of the objects, Rijkswaterstaat has identified three different ways for an object to reach it's end of life, corresponding with the used asset management. These are:

Functional, this is determent by the answer to the question if the object still fulfills the functional demands

Economical, this is determent by the costs to retain the object

Technical, this is determent by the initial expected end of life and the condition of the object

The definitions Rijkswaterstaat uses are given in Table 2.

Table 2. Definitions for three categories of lifespans.

Technical lifespan
The time period until an asset is no longer able to fulfill its functions according to the original functional requirements due to deterioration of non-replaceable components or the use of outdated technologies.
Economical lifespan
The time period over which the costs of owning and operating an asset are still less than the costs of equivalent alternatives. With equal functional requirements
Functional lifespan
The time period during which an asset complies with the functional requirements. The end of the functional life could be reached due to changing physical conditions, societal developments, or altering functional requirements.

For a timely anticipation of the end of life of critical hydraulic structures requires the combined assessment of all types of end of life.

3.1 *Procedure technical end of life*

The technical end of life of an object will be predicted by its designed lifespan and will eventually be determined by the inspection of the object. When the end of life is imminent the actions that can be taken are threefold:

(1) The functionality of the object can be reduced, for instance a reduction of the load on a bridge or the reduction of the speed limit on a highway.
(2) Or one could strengthen the bridge with an emergency solution or with an renovation program.
(3) And the last option is a replacement of the object.

The choice for renovation and the replacement of the object is re-evaluated after each inspection. Inspections help plan the necessary work and there will be time to take the appropriate action.

Actually for the technical end of life can be prolonged with an technical solution and this can be done endlessly, there is always a technical solution. The boundary here is not defined by the technical possibilities but by the economic value or changed desires.

3.2 *Procedure economical end of life*

The economical end of life will submerge when the costs of maintaining will rise to a point that it is not justifiable anymore to maintain the structure with the required expenses. For the Dutch infrastructure after each technical inspection, the EELI 'Economical End of Life Indicator' is automatically determined by the results of the inspection. The Economic End of Life Indicator (EELI) is determined by the sum of the cost of future periodic replacement and current maintenance costs of the object divided by the sum of the costs of a new construction and maintenance costs of the new object 'formula 1' (Bakker 2016).

$$EELI = \frac{future\ periodic\ replacement + current\ maintenance\ costs}{new\ construction +\ periodic\ replacement + maintenance\ costs\ new\ object}$$

Formula 1 determination of the EELI

An EELI of 0,8 to 1,0 indicates that its becomes uncertain if the object is economically sustainable. With this indicator it's easy to make a first selection what objects will be reviewed with a more in-depth study to decide if maintaining the object is still economically justified. As already mentioned, the technical end of life can be prolonged endlessly, but with the technical information the economic end of life can be determined. With this information the schedule of the major structural project can be made.

3.3 *Procedure functional end of life*

The functional end of life is determined by changes in the functional and performance requirements of the network and other demanded functional changes, like changes of the law. All the Dutch objects have, in addition to all building standards, functional requirements which are usually set for an agreed capacity, availability and reliability. A change in the agreed capacity, availability and reliability, is a decision for change of network functionality, this is almost always a political choice. If the choice is made to change the requirements of a network link all the objects must comply with these requirements and all the objects reach their end of functional life. Although the objects still comply with the original technical requirements.

For instance, the road network is overcrowded, the functional requirements has changed overtime. Here there is a choice if we want to fulfill the new requirements or exempt more traffic jams, which is a political choice. If the politics want to reduce the traffic congestion, the traffic links have to be studied with the accompanying objects. In this case it is a political decision to improve the function.

This is the case with road networks and waterways. This will not be the case with high water safety objects. This is because of the Dutch water act that prescribes safety requirements, so that the technical requirements automatically grow along with the hydraulic loads. A flood defense can therefore be in perfect condition to withstand the original design loads, but still no longer meet the unchanged statutory safety requirements because the design loads have increased.

For instance a dike is in perfect condition but the waves pounding on the dike are increased. The dike can’t fulfill its safety water safety task and has to be strengthened. This is in the Nederland’s obliged by the water act and must be carried out.

The storm surge barriers are specials in this case and will be discussed in chapter 4.

4 END OF LIFE FOR STORM SURGE BARRIERS

Storm surge barriers are special objects for the reason that the decision to build a storm surge barrier is not only made to ensure water safety. If the storm surge barrier had no other function than high water safety the building of a dam would be sufficient. There are always other aspects that come into play. Some of these aspects for example are, an open passage for shipping, the preservation of an ecological system or the accessibility of an island. This has to be taken in account by determining the end of life of the object. Although the results of the determination of technical and the economical end of life give similar results as the other objects, for the functional end of life of the storm surge barriers this is different.

First thing is that the hydraulic conditions change and will become greater than the initial predicted conditions. The effect will be on all the functions the storm surge barriers end of life. The consequence of this is that the end of life of a storm surge barrier isn’t one end of life point but for every function there will be an end of life. Choices what function requirements are mandatory and which one not have to be determent and choices eve to be made.

For example a storm surge barrier has a functional description to close with a chance of failure of 1/1000 years and has to close at a certain high water level. In the design stage the prediction is that this would only occur in the winter, the storm period. Maintenance is done in the summer when there is no risk of high water. While in maintenance the barrier will be secured and fixated by a beam, while not obstructing the waterway (one of the design requirements) and the maintenance work can be done. This way in the summer the chance of failure will be greater than 1/100 years, this is no problem because no summer storm is expected. Till the end of the technical life cycle there are no problems to be expected. Unfortunately sea level rise is accelerated and the chance of closing in the summer period is imminent. The normal procedure of blocking the barrier while maintaining is not possible any more. The structure is still strong enough in this example the functional requirement change is dominant.

The above example suggest there is no other option and the life cycle of the storm surge barrier can’t be extended, this is true if not all functional requirements are reevaluated. By reassessing all the functional requirements and reevaluating all the consequence of not only the object but of the whole system affected by the storm surge barrier. And mitigating measures can be made were is has the best result, see Figure 1(Klatter 2019).

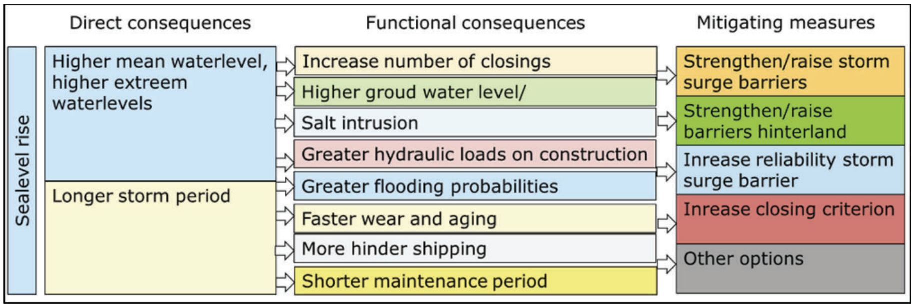

Figure 1. Overview of scenarios consequences of storm surge barrier functionality due to sea level rise.

As can be seen in Figure 1 a sea level rise can have several direct consequences, with the several subsequent functional consequences with the mitigating measures, this also implies that there is not one solution but multiple and the options are not only found in improving the object.

If we continue with the previous example, in the summer there is not a storm free period anymore. This influence has functional consequences for instance in the functions of shipping, aging and maintenance. And one must define the consequences is the safety of the hinterland. The consequences of a summer storm can be less than the winter storms. For example only buildings outside the dike could be flooded. Are there hinterland mitigating preventive or corrective measurements possible. An evacuation plan can be made and dikes can be strengthened.

We now only look at the function water safety, the key can be in the other functions the storm surge barrier has. We return design of the storm surge barrier, what were the functions and are they still of importance. For instance the storm surge barrier is built with the base of an open waterway. With the progress of time, the settings change. The reasons of the open waterway can be diverse, in this case we take only shipping. It must be determined all requirements are still opportune. For instance shipping can be less important than originally expected or a detour is possible. We could also be that the open waterway also has an ecological need. And it has to be researched if the waterway has to be opened all the way or can be closed for a longer time. These options open opportunities to maintain the storm surge barrier for a longer time.

The example shows that the functional requirements can’t be viewed separately and a functional end of life can’t be given on one of the functional requirement. It’s a combination of the different requirements. With the example you can also conclude that the different requirement are also not of the same importance and with all the functional requirements you have to take all the functional requirements and the influence for the hinterland into account.

Commissioned by Rijkswaterstaat an end of life study of the ‘Hollandsche IJssel’ storm surge barrier is made(Vader). This study states the following: ‘The Hollandsche IJssel storm surge barrier is designed to last another 40 years, but replacement or renovation may be needed sooner than anticipated due to factors such as climate change and societal developments’. The study indicates that with various sea level rise projections and the combination of the performance levels expressed the remaining life of the Hollandsche IJssel barrier were obtained. The study found that the end of life of the storm surge barrier was significantly shorter than originally designed. The study concluded that even with a moderate sea level rise scenario, there is a significant probability that the end of life of the barrier could be reached within 20 years. The storm surge barrier is technic and economical not for long at its end of life. With this study mitigating measures have to be re searched in the coming years to ensure the safety of the hinterland.

5 CONCLUSION

The end of life of most objects is determined by technical factors which often can be solved technically. The main factor is the technical solution is still financially viable. Therefore the economic factors become leading and the economic lifespan is decisive for predicting the end of life. The EELI is a good indicator to use in these cases.

For storm surge barriers the functional lifespan is a main factor for the determination of the end of life. The acceleration of the high water level rise is the main factor of the end of life of the storm surge barriers, and can significantly shorten the life span of all storm surge barriers.

The statutory assessment of flood defenses is a good instrument for a test whether it meets the requirements and a guarantee that the quality remains guaranteed with the maintenance.

As observed the water level rise can have surprisingly functional consequences. Due to the complexity of the functional consequence and the different mitigating measures, it will need time to get to an acceptable solution.

As indicated, the end of the life of barriers depends on the functional requirements of the barrier, it has to be clear whether all requirements, that were initially established, are still valid and whether the water system has not changed compared to the period of construction. It is therefore recommended to verify all functional requirements of the barriers at regular intervals, my proposal is to carry this out every 12 years in parallel with the safety assessments. And it need to be studied if the signaling value is sufficient for the storm surge barriers and other constructions that are hard to replace which have major consequences in case of failure.

REFERENCES

Bakker, J, 2016 Life-Cycle of engineering Systems: Emphasis on Sustainable Civil Infrastructure, Proceedings of the Fifth International Symposium on Life-Cycle Civil Engineering (IALCCE 2016), Delft, Balkema

Klatter, L. Prognoserapport 2019, 2019, Utrecht, Netherlands Rijkswaterstaat

Vader, H. Assessing the remaining life of the Hollandsche IJssel storm surge barrier, 2021, Delft, TUDelft

Van Waal, H. Basisrapport WBI 2017, 2018, Delft, Deltares

Wolters, H, Deltascenario's voor de 21^{e} eeuw hoofdrapport, 2018, Utrecht, Deltares