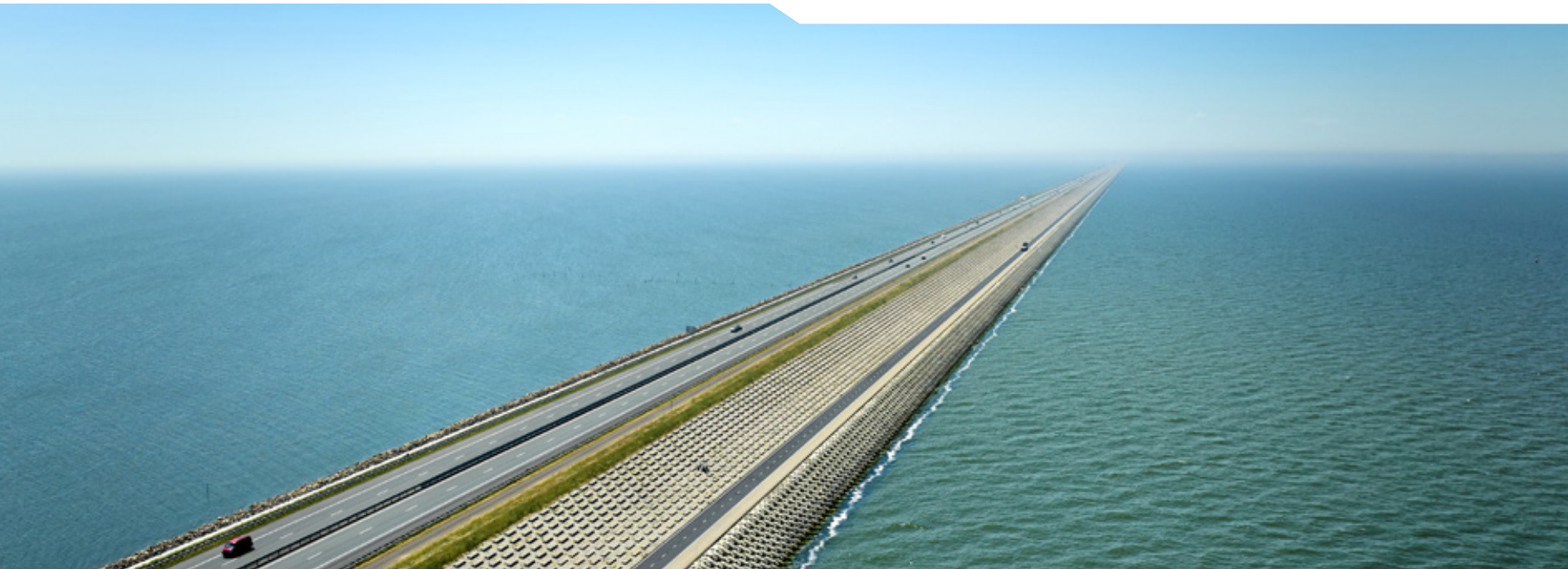




Rijkswaterstaat
Ministry of Infrastructure
and Water Management

Project Afsluitdijk

Focusing on Technology



Innovation

Without courage and innovation, the Afsluitdijk would never have been built in 1932. Even now, in the 21st century, the large-scale reinforcement and regeneration task presents ample scope for many innovative and sustainable solutions. Each of these initiatives put Dutch hydraulic engineering on the map, both nationally and internationally.

Project Afsluitdijk

Focusing on Technology



PREFACE

“God created the world, but the Dutch created the Netherlands”

'The battle against water is deeply rooted in Dutch history. Looking back at the water landscape of a century ago, it's amazing how we've been able to guide our own water future. Our relationship with water dates back more than 1,000 years, and this relationship has evolved. We have learned to live in harmony with water.

Even as a little girl, I was fascinated by technological ingenuity. Engineer Cornelis Lely, the mastermind behind the Afsluitdijk, was a great hero during my Civil Engineering studies. Although Lely probably had no idea that the IJsselmeer (Lake IJssel) would play such a significant role as the Netherlands' rain barrel. These days, our approach is more holistic: we view the Afsluitdijk not just as a stand-alone structure but as part of our overall water system. Technology, organisation, collaboration and funding all play a crucial role in this. And the world keeps a close eye on us.

The Afsluitdijk was once a symbol of protection from the sea. We now recognise its multifaceted functions, from ecology to water management. My perception of the dike has also changed: from being in awe of it as an engineering achievement as a child, to appreciating its role in ecosystems and in our daily lives.

Over the course of years, we have learned that cooperation with nature is essential, an insight that resonates globally. Climate change reinforces this urgency. This requires international knowledge sharing and cooperation. Because we may know a lot about water, but not everything. Drought, for instance, now adds another dimension to our water management.

We are constantly learning and innovating and the Afsluitdijk remains a vivid example of our expertise. Because even though we are quick to note how long something takes and how expensive everything is, zooming out creates a different perspective: the perspective in which our achievements are reflected internationally. And only then does it become clear: time and again, the Dutch approach is monumental and pioneering, supported by the world's best hydraulic engineers and innovative technology.

“God created the world, but the Dutch created the Netherlands”. A tradition that has already lasted for 1,000 years and that will continue into the next millennium.'

Meike van Ginneken

Water Envoy and Programme Director for Climate Adaptation and Water International at the Ministry of Infrastructure and Water Management

“Good plans take root in the past and point to the future”

'A quote from Dutch engineer Ronald Waterman. As far as I'm concerned, this definitely applies to the Afsluitdijk and the way it is currently being addressed. The basis is the dike as it stands today. In terms of appearance, the current approach also preserves as much of this as possible. At the same time, many of the measures we are taking now point toward the future. The dike is being constructed with an eye on the changing climate, with the amount of water increasing from all sides. The installation of pumps and the dike's adaptive design are preparations for this new phase in the history of the Afsluitdijk.

Throughout the centuries, Dutch hydraulic engineering has undergone tremendous evolution: from a purely trial-and-error approach to one that makes extensive use of scientific insights, highly advanced equipment and state-of-the-art technology.

But almost always, a 'learning' approach has been applied. For example, the construction of the Amsteldiepdijk from North Holland to Wieringen yielded a wealth of experience which was drawn on in 1927 when construction started on the Afsluitdijk. The learning approach is still being used, although we can now do much more preliminary testing. Consider Deltares' Levvel-blocs in the wave flume test facility, for example. Nonetheless, every project remains unique and you need to allow leeway to make adjustments.

The Afsluitdijk is a living timeline showing how priorities change over time. In Lely's time, water safety and economic prosperity were paramount. So important even that an entire estuary was dammed, turning the inland sea called Zuiderzee ("Southern Sea") into a lake. These days, such a project would no longer be approached this way. Our current approach is more holistic. We take all aspects into consideration: from technical and ecological factors to cultural-historical significance. With that in mind, we are even building a fish migration river to make up for the damage caused back then.

Technically, ecologically and in terms of cultural history, the Afsluitdijk is an international icon of hydraulic engineering, with great significance for water management. But the world is also watching from a project-based perspective. How do you organise and commission such a big project? All in all, this is an exceptional project: a testing ground for innovative solutions and new technologies with an eye on sustainability. A hydraulic engineering icon that delivers on its promise and fame. "Yesterday, today and in the future!"

Bas Jonkman

Professor of Integral Hydraulic Engineering at TU Delft





The Afsluitdijk transforms

As early as the 17th century, there were plans to seal the Zuiderzee off from the North Sea with a dike. Not least because of the great danger posed by the sea and the massive floods that plagued the country. However, neither the resources nor the knowledge were at hand. The desire to construct a dam only grew stronger at the beginning of the 20th century. One of the reasons was the food shortage caused by World War I. Damming off the Zuiderzee and creating polders would make agricultural land available. The new polders should also alleviate the high population density in the Randstad region, which is the most densely populated area in the Netherlands.

New disaster, new law

The 1916 flood disaster that submerged large areas around the Zuiderzee - the water was up to the streets of Amersfoort - was a major reason to reconsider damming the Zuiderzee. The enactment of the Zuiderzee Act in 1918 gave the political green light for building the Zuiderzee Works; the construction of the Afsluitdijk was an essential first step.

First closure of the sea gap

The construction of the Afsluitdijk from 1927 to 1932 was a job done mostly with bare hands. For five years, over 4,500 workers worked continuously on its construction. The deployment of all those human hands may not seem very innovative, but closing a 30-kilometre long opening to the sea was. Nowhere in the world had such a feat ever been achieved.

Boulder clay and steam

The fact that Lely's plans could actually be carried out was due in part to the innovative use of steam-powered and specially-developed dredging and digging machines. These were used to extract boulder clay near Wieringen and on the island of Texel. This compact and erosion-resistant material was widely deposited in the northern Netherlands during the Saale glacial period. This was used to construct the embankment to above the waterline. This had never been done before either. Boulder clay and steam made the closure of the Zuiderzee possible.

Economic and spatial development

The Afsluitdijk enjoys worldwide fame, but the dike, or rather the dam, is much more than just a hydraulic icon. Engineer Lely's achievement marks a starting point for the economic and spatial development of the Netherlands. In addition to flood protection, the Afsluitdijk brought improved freshwater supplies, space for land reclamation, new cities and farmland and a better connection between North Holland and Friesland.

The Afsluitdijk in a new guise

Over the years, the dike has been raised and maintained here and there, but the Afsluitdijk has never been completely renovated. A higher and stronger hull to protect the Netherlands from sea level rise and superstorms. New structures provide greater discharge capacity from the IJsselmeer to the Wadden Sea whenever this is required. Additionally, we are restoring the natural migration route for migratory fish by creating an opening in the dike: the Fish Migration River. And all this with an eye to aesthetics, cultural history, ecology and the environment.



Afsluitdijk rejected after nearly 75 years

The Afsluitdijk is part of the primary flood defences: a dike that provides protection against flooding from the sea and major rivers. According to the Environment and Planning Act, primary flood defences must withstand superstorms that may occur once every 10,000 years. Almost 75 years after completion, the Afsluitdijk no longer satisfied the requirements of this Environment and Planning Act. This is due to changes in climate, technology and safety requirements.

Check and test every 6 years

Every six years, we test whether the dikes satisfy stringent hydraulic requirements. These requirements change regularly due to new insights and technologies. During the 2006 inspection, the Afsluitdijk was rejected as the dike proved unable to withstand extremely high water levels and powerful waves. The dike was too low and the revetment and lock structures were not stable enough.

Water safety and water management

The Afsluitdijk plays a crucial role in flood protection and water management. The dike not only has to provide water safety, but also efficiently regulate water draining and storage, taking sea level rise and increasing river discharge into account.

Reinforcement and renovation

The Afsluitdijk reinforcement and renovation project was preceded by a long period of preparation and theoretical research. That research focused on the question of the water levels that the Afsluitdijk should be able to withstand in view of rising sea levels, for example. The results of that research were then translated into principles and requirements for the design across the entire Afsluitdijk.

“Put the Netherlands back on the map!”

‘In this project, we asked companies very explicitly to deploy their innovative powers. The message was: ‘Put the Netherlands back on the map.’ ‘Think outside the box’. All of the innovations now being deployed at the Afsluitdijk also offer perspective for other works. In the Netherlands, but also globally. ‘Now and in the future.’ We imposed only a limited number of preconditions: the dike must be able to withstand storms that may occur once every 10,000 years, and it must be able to discharge water into the sea so that the water level in the IJsselmeer is maintained. Within those limits, we gave market players every opportunity to come up with innovative and sustainable solutions. The demand we did place, however, was that the solution actually works and meets the preconditions and that this be demonstrated in a manner we prescribed.’

Emiel Boerma

Hydraulic Engineering Consultant at Rijkswaterstaat



Water safety

Since 1932, the Afsluitdijk has provided protection against flooding from the sea. To keep doing this for the next 100 years, taking current water safety standards and future developments into account, the Afsluitdijk must be higher and stronger.

The water safety task for the Afsluitdijk: reinforcing and renewing the dike and all its components, along its entire length.

The Netherlands on the map

The Level building consortium surprised Rijkswaterstaat (the executive agency of the Ministry of Infrastructure and Water Management, dedicated to promote safety, mobility and the quality of life in the Netherlands) with an innovative and sustainable design. This consortium consists of the companies BAM, Van Oord, Rebel and Invesis. Together, they delivered a solution with new discharge sluices for more passive water drainage, while Rijkswaterstaat had called for a less sustainable solution by requesting a pumping station. And spectacular simplicity is maintained in the complete reinforcement and renovation with the specially designed Level-blocs. Level is responsible for the design, construction and 25-year maintenance of the Afsluitdijk.



Quattroblock

- Ridges slow down high waves
- 6 to 9-sided concrete block
- Up to 700,000 m² on the dike



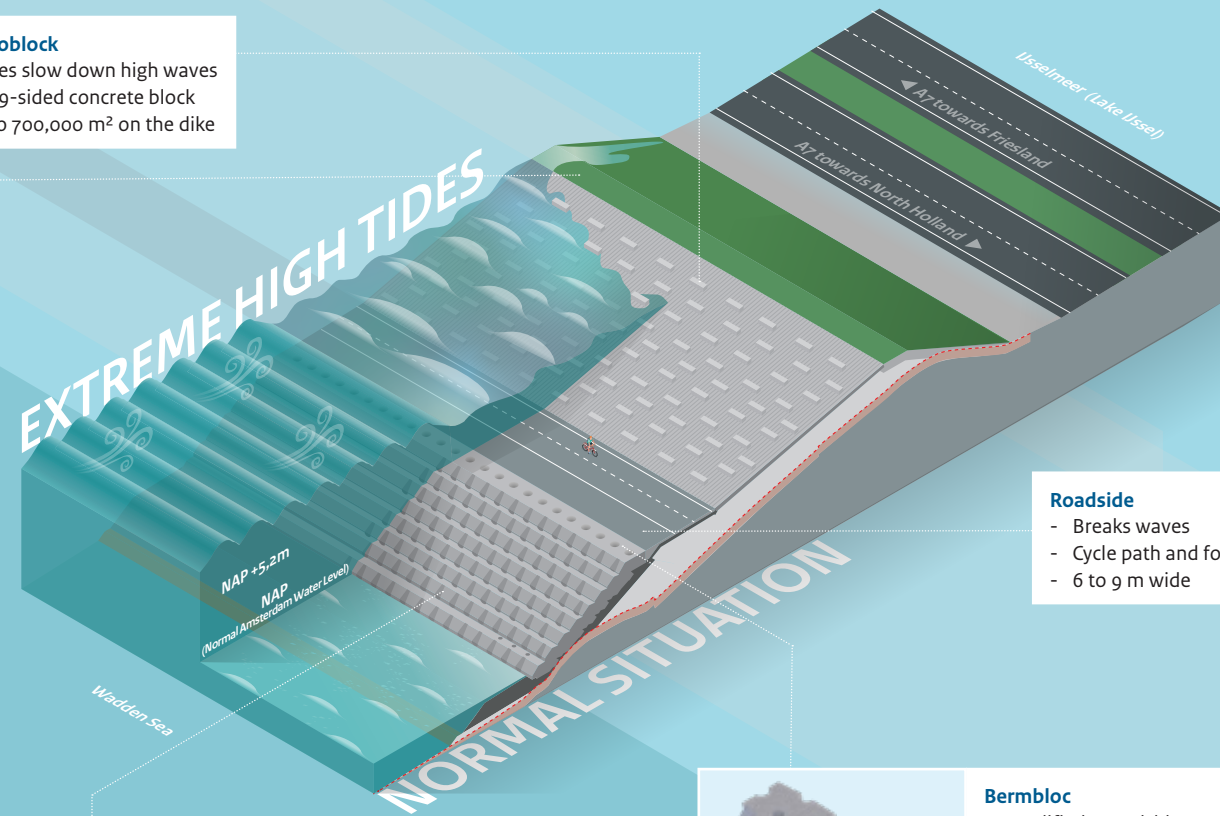
Crown

- Circa 2 m higher
- Enables surge overflows
- Can drain 10 litres of water per second per metre
- The water first flows over the dike. Once this is saturated, the water flows over the road.



Level-bloc

- Breaks waves
- 70,000 units
- 6,500 kg per block
- 2.3 m x 2.8 m x 1.1 m



Roadside

- Breaks waves
- Cycle path and footpath
- 6 to 9 m wide



Bermbloc

- Modified Level-bloc
- Keeps the Level-blocs in place
- With openings for optimal water drainage
- 11,000 kg per block
- 4.77 m³

Dike reinforcement

The original Afsluitdijk was 'only' able to handle water levels and wave heights associated with a 1:100 storm. According to the Environment and Planning Act, the Afsluitdijk must be able to withstand a 1:10,000 storm. To withstand such superstorms, the dike had to be stronger and higher and the lock complexes had to be better protected.

Theoretical models

How much higher and stronger? We use models to determine height much more accurately and efficiently. Water levels and wave heights are not the same along the entire length of the Afsluitdijk. And that's also why the dike doesn't have to be the same height everywhere. Moreover, we opt for a dike that is able to withstand surge overflows. A dike where water is allowed to flow over the crown. This is possible here since it poses no immediate safety risks to the IJsselmeer behind it.

Adaptive Delta Management

Adaptive Delta Management is leading in the project. This means that we do what is necessary, and that we create latitude for future needs and choices. For example, the robust revetment on the outer slope, the Wadden Sea side, has a lifespan extending until the year 2100. For overflow, we don't look quite as far ahead. In this regard, the Afsluitdijk meets the legislated water safety standards until at least 2050.

Smart measures allow the dike to be raised further in the future with relatively simple interventions. And if we want to protect the dike from more wave overtopping in the future? Then the design allows for raising the dike and strengthening the crest or slope on the inside of the dike (the inner embankment, on the A7 side). Or maybe we will allow more overflow then based on new insights.

Cooperation with Deltares

Innovation means investing in all phases of a project. Because, as a client, how do you maintain sufficient solution space in the contract to call for innovations? How do you check whether a design from a market party meets your requirements? And in the implementation phase, how do you investigate whether built-up areas of the Netherlands will really remain safe until 2100? For the answers, we collaborated with independent knowledge institute Deltares.

Theory versus practice

Intensive preparation and precise execution mean that the probability of the Afsluitdijk breaching during a superstorm is low. Low, but not zero. In theory, the reinforced dike can withstand a 1:10,000 storm. Through testing, incorporating certainties and applying safety margins, we are confident that the dike will also withstand these conditions in practice. The only question is whether and when this superstorm will hit the Netherlands.

The 300-metre long, 9.5-metre deep and 5-metre wide Delta Flume in Delft is a unique test facility that generates the world's largest artificial waves. That length is required to mimic wave formation in progressively shallower coastal waters. The Delta Flume lends itself perfectly to studying the effects of wave heights, wave forces, flow velocities and wave overtopping on structures, for example.





INTERVIEW

“Small-scale simulation doesn’t work in practice”

‘Looking out over the Afsluitdijk, the motto of “spectacular simplicity” really evokes a sense of pride in me. Because the apparent simple and sleek revetment of Levvel-blocs camouflages impressive feats of engineering and verification.

Combining engineering, aesthetics, sustainability and ecology, the design task for the dike reinforcement was challenging. This is the reason Rijkswaterstaat chose to encourage innovation and prescribed Delta Flume tests as verification in tendering process. Since innovative design means you are going to achieve something that has not been done before, you have to work with trials.

The design was extensively tested and fine-tuned in the Delta Flume at a scale of 1:3 with a 10% higher wave load and a 10% weaker built-in structure than required. Actually verifying of the design, which also had to take inaccuracies into account during execution outside, required a stretch of almost 2 years of testing in the Delta Flume.

For example, during this period, the design of the bermbloc - the top row of Levvel-blocs - was modified and additional tests were carried out on deviations, or imperfections. It's easy to build a perfect model on a small scale, but in practice you are faced with larger and heavier material and equipment, and factors such as wind, high water levels and waves. So the level of accuracy of ‘building on your knees into the Delta Flume’ is not feasible. Certainly not over a length of more than 30 km. If you don't test structures including inaccuracies in advance, this will always remain an additional uncertainty during implementation.

The Quattroblocks on the upper slope were also tested extensively in the Delta Flume. Every possible variant, from checkerboard to ridges, was reviewed at the design table. In this project, the challenge was to find the best technical solution for limiting wave run-up on the one hand, and the most beautiful solution for preserving the aesthetic value and clean lines of the ‘old’ Afsluitdijk on the other.

Ultimately, the primary flood defence's technical functioning is determinant and this is reflected in staggered ridges halfway up the upper slope. On the lower half you see low ridges, tightly wedged in to absorb wave impacts and, on the upper half, high ridges to minimise wave run-up. This transition is necessary to clamp the high ridges in sufficiently. This is technically necessary, but from an aesthetic standpoint, this was the subject of much debate since it deviates from simple, clean lines.

Constantly balancing between aesthetics and engineering and opting for innovative solutions was not exactly conducive to the project's progress. But when I look at the result, the interplay between technology and design and the collaboration between client and contractor, then I'm extremely proud of what was achieved!’

Rolf Bruins

Hydraulic Engineer and Object Leader for Dike Reinforcement at Rijkswaterstaat





Levvel-bloc

- Height: 1.13 m
- Width: 2.3 m
- Length: 2.8 m
- Weight: 6,500 kg

Revetment

Spectacular in its simplicity - that is what the original Afsluitdijk was and how it should be preserved. The dike was raised and widened on top of the existing embankment, retaining the classic 1:3 sea dike profile. A classic sea dike profile is characterised by a narrow top (crest), a gentle slope on the outside (outer slope) and grass on the inside of the dike (inner slope).

Levvel-blocs on the lower slope

The Levvel building consortium breathed new life into the iconic appearance of the Afsluitdijk with its Levvel-blocs. Driven by the requirements for aesthetics, climate resilience, innovation and sustainability, Levvel developed the blocks specifically for this project. On the Wadden Sea side, the lower slope of the embankment consists of a total of 70,000 Levvel-blocs. With their symmetry and regular placement, the blocks create a calm impression that reinforces the austere, autonomous character of the dike. The Levvel-blocs provide a technically powerful front against the highest wave loads.

Sustainable in all respects

Since Levvel-blocs require much less concrete, they deliver CO₂ savings of as much as 56% compared to comparable dike reinforcement materials. The top layer of the blocks is roughened and has two tidal pools where seawater stays behind. A beautiful new habitat for flora and fauna, contributing to the development of bio-diverse marine life.

Pop-up factory

A specially built circular factory was erected in Harlingen for the production of Level-blocs. Some 100 blocks per day were produced in a fully automated process. The Level-blocs were taken from the conveyor belt by water, then placed on the dike by the 'Titan' - a crane barge. This kept road traffic disruption to a minimum. The circular production facility has now been dismantled and parts of the factory are being used elsewhere.



IJsselmeer side revetment up to date

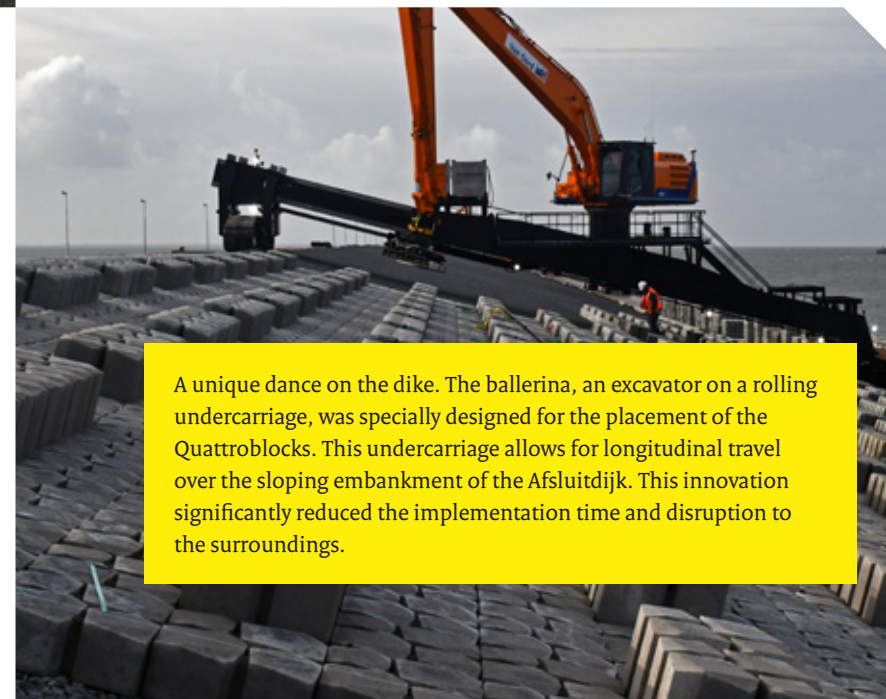
Less stringent requirements apply to the revetment on the IJsselmeer side, as the dike has no flood defence function from this side. For this side, a water safety level was chosen for storms that may occur once every 1,000 years. Half of the revetment satisfied this requirement. In those areas where the cladding did not comply, the embankment was rebuilt with Quattroblocks.



An RFID chip was embedded in each element. Using this chip, the product specifications and exact position of the block can be retrieved. And if a block gets damaged relatively quickly? Then the chip will tell you which batch the block comes from and where the other blocks from that batch are located.

Quattroblocks on the upper slope

The Level-bloc is not the only novelty: the Quattroblocks that adorn the upper slope were also used for the first time on the Afsluitdijk. The Quattroblock is a further development of the original basalt stone as revetment. The ridged pattern ensures maximum wave arrest, meeting the wave overtopping requirement of up to 10 l/s/m in the event of a superstorm. The ridges on the lower half of the upper slope are lower than those on the upper half. This is necessary to maintain the stability of the revetment. A total of 700,000 m² of Quattroblocks cover the Afsluitdijk.



A unique dance on the dike. The ballerina, an excavator on a rolling undercarriage, was specially designed for the placement of the Quattroblocks. This undercarriage allows for longitudinal travel over the sloping embankment of the Afsluitdijk. This innovation significantly reduced the implementation time and disruption to the surroundings.

Placed by hand

Set stone cladding is a Dutch invention! In the 20th century, Dutch engineers could draw on the world's only manual on stone setting: the Stone Setting Handbook. From basalt to Basalton (a concrete version of natural stone basalt) and now Quattroblocks: the further development of stone linings remains in Dutch hands.

In Den Oever's outer harbour, this piece of cultural history has been honoured with an embankment of basalt stone. Stone setters from the Netherlands and neighbouring countries revived the old craft here. The Netherlands has about 20 stone setters, a dying profession. It is hard, labour-intensive work and requires skill.



INTERVIEW

“Innovating under intense pressure”

‘Come up with an innovative solution for the revetment so that the sleek line is maintained, so that wave overtopping is minimised and the dike can once again last until the year 2100,’ was the message from Rijkswaterstaat at the 2015 Water Construction Day. On a large screen, it became clear that our rugged Xbloc would not successfully pass the tendering phase due to the required sleek lines.

With the prospect of the Afsluitdijk tender and market demand for regularly placed blocks, we began further development of the Xbloc at lightning speed. In 2017, we came up with the final form of the Level-bloc. But a design is only the first step; the real work starts with testing.

During these tests, we noticed that some blocks were lifted by the upward wave pressure of tall waves. So one of the things we added was the hole in the block. This hole prevents lifting and also allows precise placement with a special gripper.

When we submitted the offer to Rijkswaterstaat in 2018, the blocks had withstood both 2D and 3D tests in the test flume well, but we had not yet completed any projects with Level-blocs. By way of comparison: our first project with the Xbloc involved 1,000 blocks. But the Afsluitdijk project involved as many as 70,000 Level-blocs! It's admirable that a client asks for and takes on innovations on such a large scale as this.

The development and verification of the Level-bloc was an intensive process, ultimately resulting in a robust, durable and sleek block. And while I was critical of the emphasis on aesthetics in 2015, I now have to admit that the landscape architects were right. Our Level-bloc safeguards Lely's heritage both technically and aesthetically."

Bas Reedijk

Inventor of the Level-blocs at BAM

Storm surge barriers

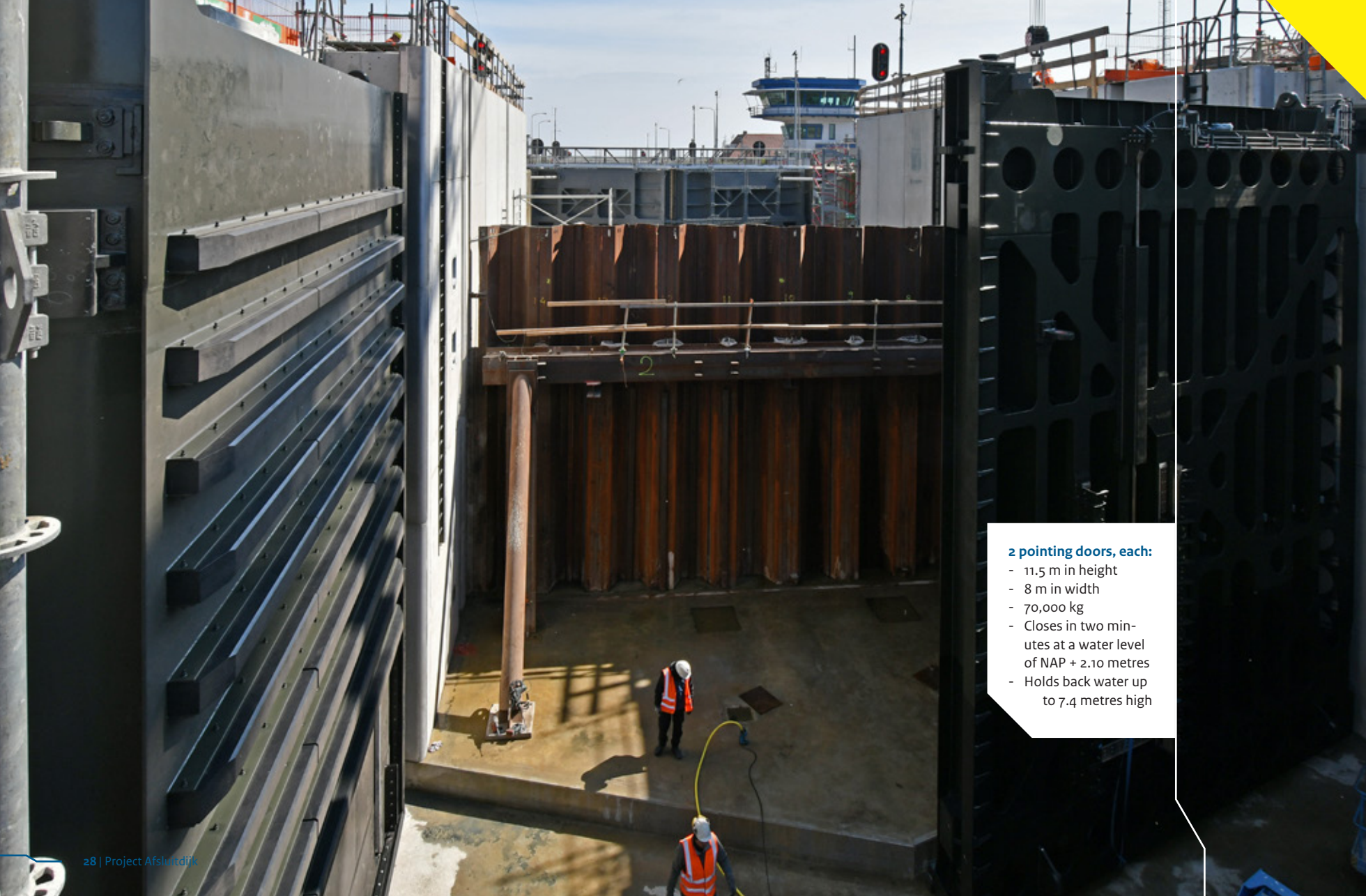
The navigation locks at Den Oever and Kornwerderzand are part of the primary flood defence system and date from the time of the Afsluitdijk's construction. The locks were built so robustly at that time that they have lasted a very long time. By building two new storm surge barriers in front of the monumental locks, we protect the hinterland from extremely high water levels. This is because the storm surge barriers close when the water level in the Wadden Sea gets too high.

At Den Oever in North Holland, we built a storm surge barrier directly in front of the navigation lock. Under normal conditions this storm surge barrier is open, allowing ships to pass. This storm surge barrier has pointing gates that close in 2 minutes if necessary.

At the Frisian town of Kornwerderzand, we built a storm surge barrier on the Wadden Sea side of the swing bridges. By building the storm surge barrier on the sea side, we minimise damage to this culturally valuable historic area and don't need to raise the dam in front of the houses, for example.



Does the storm surge barrier take over the flood control function completely? No. In practice, we assume separate functions for the storm surge barrier and for the navigation lock. But in theory, the storm surge barrier has a probability of failure of 1:1,000. And if the storm surge barrier fails? Then the navigation lock temporarily takes over this barrier function.



2 pointing doors, each:

- 11.5 m in height
- 8 m in width
- 70,000 kg
- Closes in two minutes at a water level of NAP + 2.10 metres
- Holds back water up to 7.4 metres high

The Den Oever storm surge barrier

The locks of the Stevin sluizencomplex are located on the western side of the Afsluitdijk. In this monumental lock complex, every square centimetre has been used to fulfil the functions of flood protection and discharge, as well as those of shipping and road traffic. The Stevin sluizen locks are part of the lock complex.

More than 2.5 metres higher

Until 2021, the original navigation lock, with a height of 4.88 metres, was the flood barrier against high water. The storm surge barrier has now taken over this task. This new lock has gates that can hold back water up to a height of 7.4 metres. Although this storm surge barrier increases the overall length of the lock structure by 36 metres, the length, width and depth of the Stevin sluizen lock remain the same. Both the old and the new locks use pointing gates only, creating coherence between the new and the old.

Pointing gates weighing 70 tonnes

The pointing gates, built to the highest standards, are impressive: 11.5 m in height, 8 m wide, each weighing 70,000 kg. In the normal situation, the gates are open. The gates close when water levels are expected to be at NAP + 2.1 m or higher, a situation that is estimated to occur 3-5 times a year.

An eye for cultural history

The storm surge barrier connects to the reinforced embankments of the outer harbour. The basalt revetment on the Wadden Sea side is unique. This revetment is not only functional but also has historical value. Because even though many Dutch dike bodies are still lined with basalt, the traditional craft of 'stone setting' is practised these days only by a group of about 20 Dutch people. To honour this craft, a statue depicting 'the stone setter' stands at the Vlieter Monument, a silent witness to a rich water-building tradition.

The Kornwerderzand storm surge barrier

The Lorentzsluizen locks complex is located on the eastern side of the Afsluitdijk. The Lorentz locks and surrounding buildings were designed in coherence and boast a rich history. For this reason, the area was designated as a protected village in 2007. A higher storm surge barrier with pointing gates, like those at Den Oever, would detract from the area's protected views of the village. But how do you protect this area from a 1:10,000 storm, while also honouring this protected cultural historical area?

Protecting without compromising

By building the storm surge barrier with roller door on the Wadden Sea side, we minimise the impact on this culturally valuable area. In the normal situation, the roller door is completely hidden in the door casing. And when the water is high? Then the door closes off the waterway in 6 minutes. This is expected to happen 3 to 5 times a year at predicted water levels of NAP + 1.80 m or higher.

The roller door

The roller door consists of a plate with a trellis structure, which ensures sufficient strength. This design ensures sustainable use of materials and the lowest possible weight in order to get the huge door moving. Water pressure pushes the door into the concrete cavity, thereby blocking the water.

Prepared for the future

Taking future widening and deepening of the navigation lock into account, the threshold of the storm surge barrier lies at NAP -6.0 m, lower than the threshold of the historical navigation lock. This difference in threshold height now leads to the deposition of silt in the shipping channel. A jet system at the front of the roller door ensures a clean channel, driving the roller door into the channel at high tide without any problems.

The reinforcement and renovation of the Afsluitdijk provides opportunities to look at local issues integrally. One of those issues is the future widening and deepening of the navigation lock at Kornwerderzand. Although this project is not part of the Afsluitdijk project, the principles for this project are indeed determinant for the storm surge barrier at Kornwerderzand. Because even though the threshold depth of the current navigation lock is even higher now, the threshold of the storm surge barrier has now been set to NAP -6.0 m in order to enable future passage of luxury super-yachts and larger freighters. In addition to the widening, work is also underway to replace the swing bridges in the A7 and to deepen some 20 kilometres of the shipping channels in the IJsselmeer.



Roller door:

- 58 m in length
- 8 m wide
- 14 m high
- Weighing 960 tonnes
- Closes in six minutes at a water level of NAP + 1.80 metres
- Holds back water up to 7.4 metres high
- Maximum driving force 125 tonnes

“With full confidence to the finish line”

The Afsluitdijk is iconic; and so is this project. Because this is so much more than just a dike. The reinforcement and renovation of the Afsluitdijk includes 32 km of dike, 32 km of motorway, two unique storm surge barriers, one of Europe's largest pumping stations, two new discharge sluices and a fish migration passage. Such a complex and massive project should receive proper attention. Technical managers Ruud Hendriks (Level) and Herald Vervoorn (Rijkswaterstaat) tell how they are working confidently toward the finish line.

Complexity difficult to grasp

"Because even though our focus is on implementing the technical challenge, the processes, environmental concerns and organisation make such a large project difficult to fathom beforehand," Herald explains. "Furthermore, all kinds of disciplines converge and they all need to show ownership," says Ruud. "Ultimately, we were able to combine the technical knowledge from different areas of expertise quite well by working with equally formed technical teams at Rijkswaterstaat and at Level. This resulted in considerable impact, which we are working with collectively toward the finish line."

Cooperation and trust crucial

Cooperation and trust are two factors that have a big impact on the project's progress. Because even if you think carefully about the design latitude, priorities and hard preconditions during preparations, only during implementation do you really see whether everything is feasible and practicable. Without good cooperation and mutual trust, you adhere rigidly to contractual frameworks but sometimes miss the mark.

One good example of this is the stretch of dike on the IJsselmeer side at Kornwerderzand. At first, replacement seemed the only option. But as completion of the project came into view, doubts arose. "To prevent inconvenience to residents and to counter logistical challenges, we decided together to reassess. The result? Most of the original revetment was retained. Pure profit in terms of the surroundings, cultural history and aesthetics. And we achieved our goal technically as well."

Level in the lead, Rijkswaterstaat responsible party

"Level is in the lead for implementation, but Rijkswaterstaat is just as much in the lead as the responsible party for ensuring water safety in the Netherlands in 2100, says Herald. "You can carry that responsibility only with mutual trust and with an understanding of each other's role."

A good example is validation, or checks and balances. You also want to ascertain that the revetment is constructed correctly. Once things are finished, only the top is visible. By being sufficiently involved as a client during the work, checking things during testing and beyond, confidence builds that the work is properly constructed, and that the processes will help demonstrate this afterwards. A body of work with such an important function for the Netherlands, which will only prove itself in extreme situations, should be given proper attention."

Both technically and organisationally sound

Because even though the Afsluitdijk is designed to withstand a superstorm that we will hopefully never experience, it can indeed be done! And that requires an approach that is both technically and organisationally sound. This way, future generations 100 years from now will still be able to affirm the iconic status of this dike.

Ruud Hendriks (left on the photo)

Technical Manager at Level

Herald Vervoorn (right on the photo)

Technical Manager at Rijkswaterstaat



Water discharge

The Afsluitdijk provides flood protection from the Wadden Sea and has an important water management function for the Netherlands. The Afsluitdijk provides:

- water draining whenever inflow into the IJsselmeer is too great;
- retention of water to enable shipping, the availability of drinking water and responding to dry spells.

Additional discharge capacity is needed to manage water in the IJsselmeer today and in the future.

The assignment for the Afsluitdijk is to create additional discharge capacity. At least 235 m³/s capacity is needed to fulfil the dike's water management function. We achieve this by building new discharge sluices and a pumping station.

The monumental discharge sluices no longer comply with the mandatory water safety level and require thorough renovation and reinforcement. The work activities required for this are being prepared at this time. These activities are not within the scope of the Afsluitdijk project and are being prepared in parallel.



The monumental discharge sluices

The monumental discharge sluices at Den Oever and Kornwerderzand form the gateway to the Afsluitdijk. With their distinctive symmetry, these discharge sluices are both technically and culture-historically important. Technically, since its completion in 1932, it has all been about holding back and draining the water.

5 sluice groups, each with 5 spouts

The discharge sluices are divided into sluice groups, each consisting of 5 spouts. Den Oever has three sluice groups (15 spouts) and Kornwerderzand has two (10 spouts).

The foundations of the two complexes differ: Den Oever is built on a shallow foundation since there is a load-bearing layer of boulder clay here. Kornwerderzand was built on a foundation of wooden pilings because there was no load-bearing subsoil here. The superstructures of both complexes are identical.

Water management and flood defence

The discharge sluices' primary function is to provide water draining. Their secondary function is flood control. For the water management functions, Rijkswaterstaat regulates the water level in the IJsselmeer according to the water level ordinance. This stipulates how high the water is allowed to be in a given area. The national government and water boards determine the level.

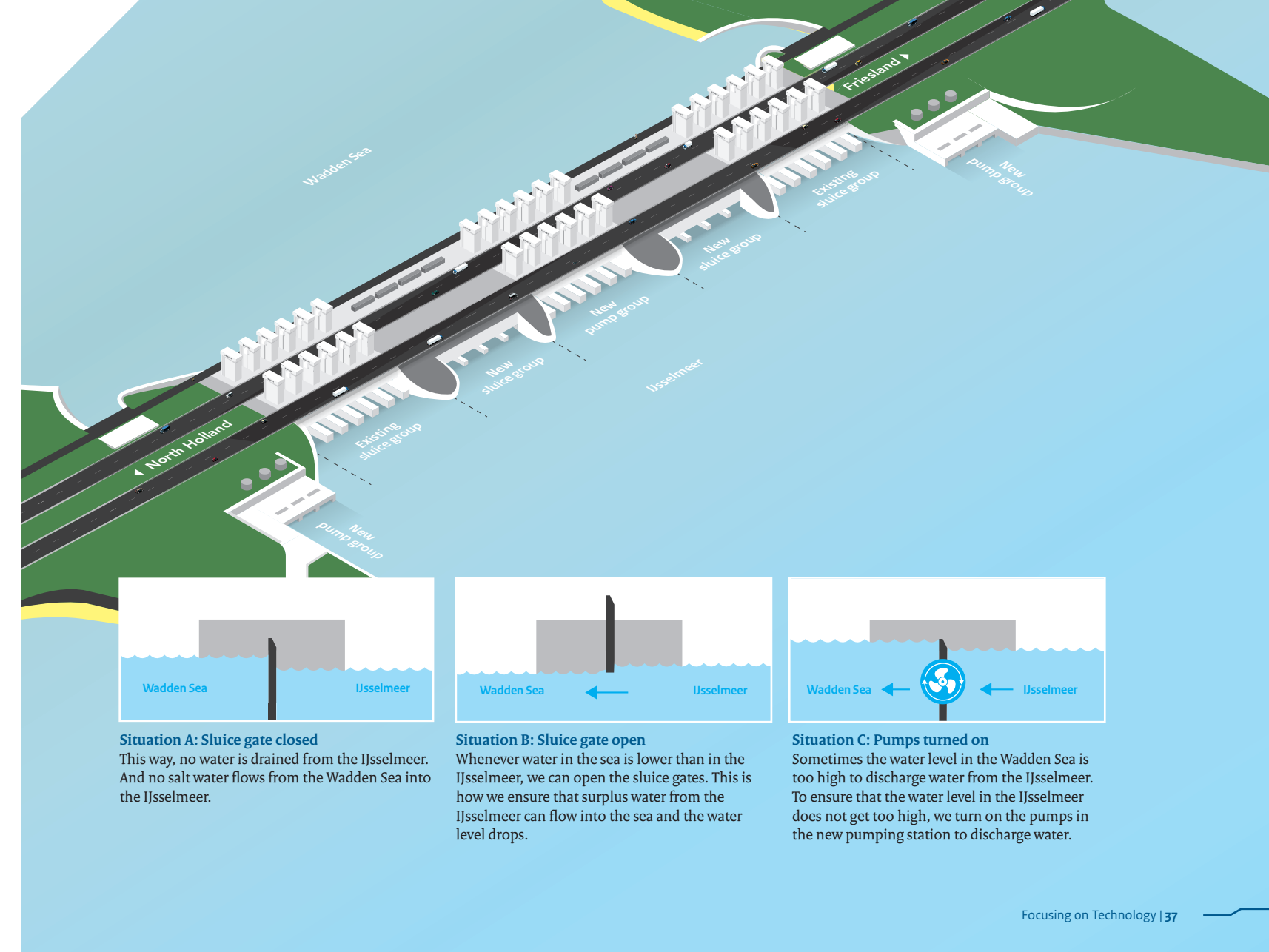
Discharging water

If the supply of water exceeds the capacity to manage the water levels according to the level decree, water is then discharged into the Wadden Sea. Discharge occurs by free flow and can take place only when the water level in the Wadden Sea is lower than that in the IJsselmeer. So theoretically, discharge can take place only twice a day, during low tide. Collectively, the monumental discharge sluices can manage an average volume of 4,000 m³/s. This is comparable to emptying 1.6 Olympic-size swimming pools every second.

Discharge windows are decreasing systematically

Climate change affects how well the existing discharge sluices can discharge surplus water. Discharge, the process of draining water by free flow, is done mainly in winter. This means that a limited number of days are available for this task, about 180 days each year. In the 1970s, discharging averaged 120 to 130 days per winter. But over the past 50 years, this has increased to around 150 to 160 days.

The reason? Sea level rise. Higher sea levels mean less time is available to effectively purge water, a period we call the 'discharge window'. Moreover, sea level rise causes the difference in height between the inland water and the sea, called head or gradient, to decrease. This means less water can be discharged at a time. So more and more days are needed to discharge water into the Wadden Sea. In the long term, there won't be enough time to drain all the water by means of discharging.



Situation A: Sluice gate closed

This way, no water is drained from the IJsselmeer. And no salt water flows from the Wadden Sea into the IJsselmeer.

Situation B: Sluice gate open

Whenever water in the sea is lower than in the IJsselmeer, we can open the sluice gates. This is how we ensure that surplus water from the IJsselmeer can flow into the sea and the water level drops.

Situation C: Pumps turned on

Sometimes the water level in the Wadden Sea is too high to discharge water from the IJsselmeer. To ensure that the water level in the IJsselmeer does not get too high, we turn on the pumps in the new pumping station to discharge water.



INTERVIEW

“A hydraulic engineering icon in a complex water management system”

“The Afsluitdijk keeps the Netherlands dry. But the dike also plays a vital role in keeping the Netherlands ‘wet’ - to provide sufficient drinking water, buffer water for dry periods, limit salinisation and facilitate shipping. So the project is much more than just a water safety task. The Afsluitdijk is a hydraulic engineering icon in a complex water management system!”

For centuries, we have fought against water in our Dutch delta. But the realisation that we also need sufficient water to keep the delta liveable has come about only in recent decades. And this need is also becoming increasingly apparent with the extreme summer droughts we are experiencing more and more often.

The water management system is a complex puzzle in which all the pieces have to fit together precisely. We used to build dikes based on the highest surge we knew. And when one breached? Then we just made it higher, but actually without knowing exactly how much higher it should be. These days, we have the knowledge and tools to model all kinds of scenarios; from river discharges to the effects of peak downpours. In this manner, we make informed choices about what we build today, with an eye on what the future may bring.

To build something that works now and in the future, you have to take an integral look at the system. Everything is interconnected. And then you have to deal with climatic developments and changing needs as well. Because the future situation was calculated based on a probabilistic approach. There remains a chance that this situation will be very different in 30 years' time.

Growing from ‘simple’ dike builders to experts in complex water management systems, the Netherlands has been a frontrunner in the water sector for centuries. We cherish the lessons of the past, look to the future and adapt to new challenges, but we are never finished. “And therein lies a fantastic mission for engineers!”

Lukas Meursing

IJsselmeer Area Programme Manager at Rijkswaterstaat



Draining versus pumping

In addition to sea level rise, more frequent periods of high water input from the rivers flowing into the IJsselmeer are expected. Furthermore, sometimes no discharge can take place at all because wind loads drive the seawater up too high. And although the monumental discharge sluices remain essential for maintaining level dynamics, additional pumping capacity is needed to make sure that discharge capacity is always available: 'draining if possible, pumping when necessary'.

More discharge sluices!

Rijkswaterstaat had set its sights on increasing discharge capacity using pumps. But Level building consortium came up with a more sustainable alternative: more discharge sluices combined with pumping capacity. In this design, two new sluice complexes, each with four spouts, were added on the islands between the monumental discharge sluices at Den Oever. The distinctive appearance of the monumental complex is preserved since these complexes are not visible above ground level.

45% more discharge capacity

Each spout houses double sliding valves, which are closed in average weather conditions. Spouts measure 7.75 x 12.65 m and run under the A7. With these additional discharge options, even if the discharge window does not expand, the discharge capacity does. In total, nearly 45% more discharge capacity will be achieved. This way, we can better anticipate high peaks in discharge.

Wave impact

The forces released when a wave hits a dike, rock or breakwater are great. Without space to release this energy, as is often the case in structures, these wave impacts can be immense. This also proved to be the case in the design of the discharge sluices. At certain water levels, wave impacts of more than 4,000 kN/m would occur in the structure. This is comparable to the combined weight of 300 passenger cars per linear metre! Even science hadn't done sufficient research in this field of work. Rijkswaterstaat, Level and TU Delft finally arrived at a new scientific theory. The design of the discharge sluices was then modified to include a venting shaft and a large open space in front of the gate on the IJsselmeer side to allow energy to be released.



Craftsmanship still relevant

The profession of hydraulic engineering is evolving, but some techniques have not changed throughout the years. This also applies to the sinkers with 'cradles' (lashed bundles of willow twigs and boughs), which protect the bottom at the outflow opening of both the discharge sluices and the pumping station from washout. The sinker places geo-textile (permeable textile) in the proper place that is then submerged and anchored with rip-rap. A centuries-old archetypal Dutch technique that is still relevant today.



INTERVIEW

“Beyond the fringes of science”

Applying innovations on a large scale, building adaptively and working beyond the fringes of science: Dutch hydraulic engineering expertise is highly regarded internationally, and for good reason. The world is watching what happens next on the Afsluitdijk. And this goes beyond ‘just’ the technology. Because building is and remains a people business. “Without good cooperation, common sense and intuition, the Afsluitdijk would never have become such a hydraulic icon,” says Hans Ramler, design manager at Level.

“You can prepare the most detailed plans, but in the end, the translation from paper to reality really remains a human effort. This also became apparent during the design of the new discharge sluices. A plan that has long substantiated the credo ‘draining if possible, pumping when necessary’.”

During the design process, it turned out that the set of hydraulic constraints on which the plan was based was incomplete. Based on the incomplete hydraulic preconditions, the conceived structure would be unable to withstand the enormous wave impacts and would eventually collapse as a result.

Together with experts from Rijkswaterstaat and a research team from TU Delft, we worked together to devise a solution beyond the fringes of science. In addition to an improved discharge sluice structure, this also resulted in an improvement in wave impact loading theory.

So a project is not just about technical competence. You never create a hydro-engineering icon all alone. You need each other. This necessitates an environment in which you can call on each other, where you can look through each other's eyes and realise what else is going on besides technology. The real craftsmanship in a project such as the Afsluitdijk lies in the balance between technical innovation and human connection. This is how Lely put the Afsluitdijk on the map back in 1932. And this is how we're doing it again decades later.’

Hans Ramler

Design Manager at Level

One of Europe's largest pumping stations

During a high tide on the Wadden Sea with strong north-westerly winds, we cannot use the discharge sluices. In order to still be able to release water in such an event, a pumping station was built in Den Oever. The pumping station has two pumping groups, each with three pumps with heights of about 12 metres and impellers of 4.60 metres in diameter. This construction takes water from a lower to a higher level. We can discharge large quantities of water under all weather conditions: together, the pumps have a capacity of up to 275 m³ of water per second. Installing pumping capacity marks a transition point in the Afsluitdijk's new life phase.

3,400 operating hours in 2050

The pumping station is energy-efficient. For example, the energy used by the discharge sluices and the sizeable new pumps at Den Oever will be generated from solar energy on and around the Afsluitdijk. To further limit energy consumption, the underlying principle is: 'We drain if we can, pump if we must'.

By 2050, the pumps are expected to operate an average of 140 days a year. Up to 4,800 hours in 'wet' years and 1,800 hours in 'drier' years. These operating hours are needed especially in the winter months.

Attention to surroundings

In addition to having the largest discharge capacity in Europe, the pumping station also has the largest fish-friendly pumps. 99% of the fish can reach the Wadden Sea safely through the pumps. Besides ecology, considerable attention has been paid to aesthetics. Only the red engines under the glass domes on the dike reveal the presence of the massive structure. And in doing so, the domes mark a new era without compromising the historically austere sightlines.



The pumping station is energy-neutral! In addition to optimised energy consumption, a 2.7-hectare solar farm will deliver enough energy to offset the pumping station's average energy consumption until 2050.



INTERVIEW

“More than anything, you have to keep thinking logically”

"Europe's biggest pumps, a design and implementation duration of more than a decade and its crucial role in the Netherlands' water safety and water management task: when I think of the Afsluitdijk, 'big' is the first thing that comes to mind. And that makes such a project hugely challenging.

The technical uncertainties are also relatively large when compared with dry infrastructure projects. A motorway is much more straightforward and formalised. This also yields a certain degree of objectivity, whereas in wet engineering we rely more on experience, models and progressive insights. So it also requires extra time to gather the proper underlying principles and make decisions.

Concerning the new discharge sluices and pumping station, we are talking about a 5-year period of preparations by Rijkswaterstaat, followed by a design and implementation phase of about 7 years by Levvel. A total of 12 years! Over such a long timespan, you go through tremendous development, but so do the specialists and the world around you. So it's crucial to implement the lessons learned over such a long period of time throughout the duration of the project. Because you design and implement with a set of preconditions and principles that you are given at the very beginning. You all pursue a goal together, with the frameworks changing over the course of time. The trick is to immediately

reapply what is learned in the rest of the project. Rijkswaterstaat uses a learning approach for this, and Levvel is also improving its implementation process this way. Start with the implementation of a single pump first and apply the lessons learned to the implementation of the next pump, so that you can draw conclusions from this. Even if this approach doesn't always prove practical due to delays or other external factors.

Another lesson I take away from the project is that, above all, you have to keep thinking logically and dare to look beyond the contractual frameworks. A prime example is the implementation of the storm surge barrier at Kornwerderzand. At the recommendation of Rijkswaterstaat, this construction was eventually performed over the course of two storm seasons, allowing us to work more safely and under less pressure than the planned implementation within a single storm season.

There was very good cooperation between Rijkswaterstaat and Levvel, I think, to devise a good solution for technology and the environment. I'm really proud of being able to make a difference through my role in this project.

Bram Beijer

Hydraulic Engineer and Assistant Technical Manager at Rijkswaterstaat



Fish migration river

We are reinforcing and renewing a hydraulic icon to keep the Netherlands liveable, now and in the future. Liveability goes hand in hand with strengthening and regenerating ecological and cultural-historical values. This is about building for the future while preserving accessibility, cultural landmarks and historical and ecological values.

World's first fish migration river

A hole in the dike, in the primary flood defence system that protects the Netherlands from high water! A hole that restores the Doove Balg, the channel once so brutally cut off from the sea. Migratory fish can once again continue their migration routes.

From concept to feasible design

The idea for this innovative fish migration river arose during the preparations for the dike reinforcement. Scientists from around the world joined forces to create a technically feasible and ecological design - the world's largest saltwater-to-freshwater connection with a 20-metre-wide culvert in the flood barrier.

The location right next to the Kornwerderzand lock complex proved ideal due to the presence of the original channel and freshwater flow luring migratory fish. The new connection will ensure that at least 12 target species beyond the luring flow actually find fresh water and thus expand their growing, spawning and habitat areas.

Passageway with two tubes

The passageway in the Afsluitdijk consists of an open structure with a main tube for the strong swimmers and a tube equipped with vertical slots for the weaker species. A 4 km long tidal river on the IJsselmeer side keeps salt water within the river's boundaries; this already takes sea level rise into account.

Monitoring and steering

Water flows in the tidal river at an average rate of 0.3 m per second. This low speed and sufficient lee areas give fish time to make the transition from salt water to fresh water at their own pace. Using sensors, the province of Friesland monitors whether salinity, flow velocity and migrating fish species meet expectations and design principles. If necessary, we make course corrections using three small gates in the passageway and a gate at the mouth of the tidal river.

Flood barrier with composite door

The passageway is open by default unless a water level of 1.5 m +NAP or higher is predicted. The Fish Migration River is then closed with two gates. Safety first, but with sustainability in mind. This makes the Fish Migration River a state-of-the-art, world-class engineering masterpiece.

The five gates are made of fibre-reinforced plastic. A first! For the first time anywhere in the world, composite material is being used here as a storm surge barrier. The big advantage of composite? Long lifespan and low weight.

“From building against nature, to building with nature”

‘From initiative to implementation, building the Fish Migration River is pioneering work! There is no handbook anywhere on how to make a fish migration river. Nothing is standard, so you have to discover everything as you go. Where there's a will, there's a way. And that mentality characterises the entire Afsluitdijk project.

Without flexibility and good cooperation among all parties involved, this project would never have been completed. We make work of work by connecting independent projects and by working as circularly as possible, using area-specific materials. This requires patience, coordination and choices in planning and budget. On the western flank, for example, reeds were transplanted from the Makkumer Noordwaard area. This does create challenges in terms of planning and budget. But for both projects, this transplantation yields considerable natural benefits.

In 1928, we built against nature; now we build with nature. A freshwater-saltwater connection on such a large scale - and that in a primary flood defence - is a Dutch first. Such an innovative project is a huge puzzle, but each small victory brought us one step closer to reality. The experiences gained here can be applied in about 200 comparable situations for migratory fish around the world.

Still, it's remarkable that we created a hole in the primary water barrier to create a passage for migratory fish. And once you stand in that passageway, you see how grand it really is. It truly is an experience and everyone can enjoy it, as the Fish Migration River will be open to the public in the future. Walk through the passageway, look out over the IJsselmeer and visit the Fish Migration River!’

Wiepkje Elsinga

Project Manager, Province of Fryslân

The Province of Friesland is running this project on behalf of the Waddenvereniging, It Fryske Gea, Sportvisserij Nederland, NetVISwerk and Coalitie Blauwe Hart Natuurlijk. Close collaboration among Rijkswaterstaat, Province of Friesland and the contractors made it possible to implement the project as nearly 100% circular.





The iconic 1932 Vlieter Monument is also in need of extensive renovation and expansion. The monumental building, designed by the architect Dudok, will retain its former glory and then be better equipped for the many visitors.

Retaining accessibility, culture and history

Cycling along the outer dike and a safer A7

In reinforcing and renovating the Afsluitdijk, two major traffic optimisations were made. One of these is the widening of the A7's emergency lanes. In the existing space, this was made possible by introducing a narrow crash barrier, bringing the lanes closer together without compromising safety. Another highlight is the bike lane along the outer dike, created at the region's initiative. Along this bike lane from North Holland to Friesland and back, you have views of the UNESCO nature reserves in the Wadden Sea.

Vlieter Monument

The Vlieter Monument is located where the Vlieter gap was closed on 28 May 1932. This monument is visited each year by more than a hundred thousand people. To better facilitate these numbers, the service area has been expanded toward the Wadden Sea. A crest wall at a height of NAP +9.15 m provides flood protection. In total, over a length of some 750 metres, more than 210 concrete blocks measuring 2.5 metres high and 3.29 metres wide were placed. The crest wall, including anchoring in the embankment, consists of some 3,000 tonnes of reinforced concrete.

Next to the Vlieter Monument, the statue of Cornelis Lely towers over the dike. Lely looks out across the IJsselmeer, which was formed by his plans. The statue of the Stone Setter can also be found at the Vlieter Monument.

Casemates (the barracks)

The islands of barracks at Den Oever and Kornwerderzand recall the military function the Afsluitdijk had after its completion in 1932. These islands, which include barracks, bunkers and trenches - military positions - are of great historical value. And these were preserved in their original state as much as possible during the dike reinforcement project. A few of the military positions are integrated into the embankment.

The primary flood defence on the islands consists of a sheet piling wall, an asphalt berm and an upper slope of Quattroblocks. The barracks are now partly outside the flood barrier, but can indeed be visited via the cycle and foot path on the outside of the dike. And if you come by bike, you might just notice the intermittent ridge pattern in the Quattroblocks. This spot marks the location of the former tank barricade.

The work on water safety is never finished

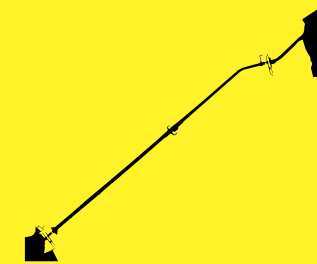
Due to climate change and sea level rise, extreme high water levels will occur more often. So working on water safety in the Netherlands is never finished.





The Afsluitdijk Facts & figures

The Afsluitdijk



2 metres

height by which the Afsluitdijk
has been raised

Discharge sluices



45%

more discharge capacity due to
the new discharge sluices at Den Oever

Levvel-blocs



70,000

Levvel-blocs jointly
reinforce the Afsluitdijk

Pumping station



275 m³ of water

per second is the combined pumping
capacity of the 2 pumping stations,
each with 3 pumps

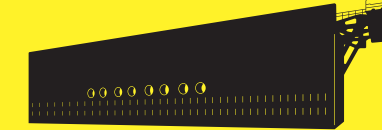
Fish migration river



20-metre

wide culvert
in the water barrier

Storm surge barrier



1 million kilos

is the weight of the roller door
in the storm surge barrier
at Kornwerderzand

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