

Chapter 84

Dutch Coastal Engineering Projects: Past Success and Future Challenges

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84.1 Introduction

The Dutch have a long history of executing massive engineering projects for the purpose of either flood protection or land reclamation. Flood protection includes the construction of seawalls, dikes and storm barriers to protect the low lying land along the coast. Reclamation projects involve draining previously submerged areas.

The primary focus of this chapter is two major 20th century projects, the Zuiderzee reclamation and the Delta Project. These are arguably two of the largest land reclamation and flood protection projects ever completed. This chapter also describes some of the plans that are in place to manage future climate change and sea level rise. Additional discussion on flood protection and land reclamation in the Netherlands can be found in *Designed for Dry Feet: Flood Protection and Land Reclamation in the Netherlands* (Hoeksema, 2006) and *Man-Made Lowlands: History of Water Management and Land Reclamation in the Netherlands* (van de Ven, 2004).

84.2 Background

Early in the Pleistocene epoch much of the present Netherlands was submerged. With time marine and fluvial deposits built up the land. Around 5000 years ago the coastline consisted of a sandy coastal zone, mud flats, salt marshes, and peat bogs. The subsequent formation of coastal dunes closed off the area of mud flats and salt marshes resulting in an increase of peat growth. Figure 84.1 shows the coastline around 800 A.D. when the shape was a result of natural forces only. Note Lake Almere in the center of the region.

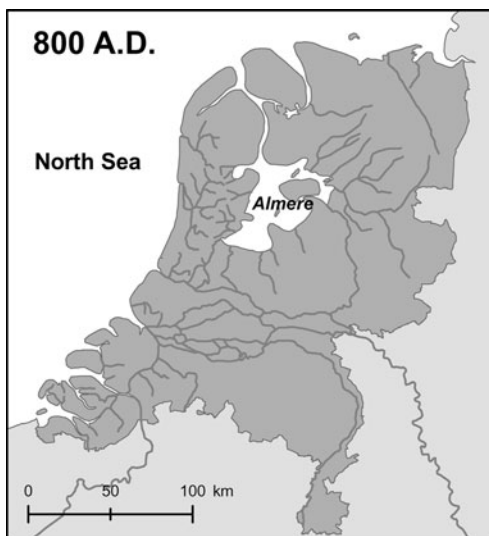
Increased settlement in the low-lying coastal areas during the Middle Ages resulted in significant change to the landscape. This, along with increased flooding frequency and gradual sea level rise, changed the shape of the coastline

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Fig. 84.1 The Netherlands coast – 800 A.D.



dramatically. Eleventh century inhabitants drained the peat swamps to transform them into agricultural land. As a result, the peat shrank, consolidated, and oxidized resulting in significant land subsidence. As the land subsided, marshes and lakes formed in the lowest areas. With time, these lakes grew ever larger threatening inhabitants of neighboring cities and villages. In some areas the problem was exacerbated by removal of peat for fuel.

The Dutch coastline was also threatened by North Sea flooding and the expansion of Lake Almere. Twelfth century storms destroyed some of the mud flats where Lake Almere drained into the sea. The resulting extensive growth turned it into a sea arm later named the Zuiderzee.

The Southwest delta region lies at the mouths of the Rhine, Maas, and Schelde Rivers. This area changed dramatically in Middle Ages. Increasing sea activity along with land subsidence and peat removal (for salt and fuel) resulted in the widening of existing sea arms and rivers as well as permanent loss of land. Figures 84.1, 84.2, 84.3, and 84.4 shows the transformation of the entire Dutch coastline between 800 and the present.

84.3 Developments Prior to the 20th Century

While the primary focus of this paper is the major 20th century projects, developments prior to the 20th century would lay the important groundwork for more recent activities. Specifically, land reclamation by pumping dry previously submerged lands started as early as the 16th century and developed to a high degree of sophistication in the 17th century. Coastal flood defenses also got an early start with later projects benefitting from centuries of experience. Prior to describing the 20th century projects some of these earlier activities will first be presented.

Fig. 84.2 The Netherlands coast – 1250 A.D.

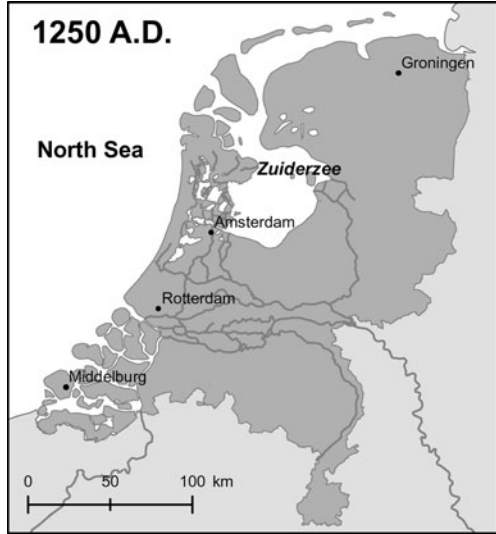
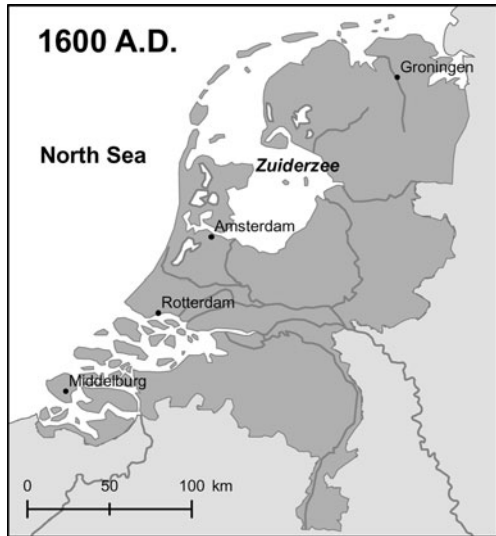


Fig. 84.3 The Netherlands coast – 1600 A.D.



84.3.1 Lake Draining

In the area north of the city of Amsterdam peat was drained as early as the 12th century to create agricultural lands. The drained soils consolidated and the land settled forming lakes. By the 16th century the lakes had grown to a point where region's safety was threatened. By draining the water from these lakes safety was improved and new agricultural lands were created.

Fig. 84.4 The Netherlands coast – Present



The process of draining a lake started with the construction of a ring canal around the lake to redirect existing streams and to provide a drainage path for the lake water. The spoils from the canal were used to create a dike between the lake and the canal. An outlet was then created to a receiving water body. The water from the lake was lifted into the ring canal with water pumping windmills. A single windmill could drain lakes smaller than 600 ha (1480 acre). Larger lakes required many more (Meijer, 1996). Finally, drainage ditches, dug inside the drained lake, conveyed water from the center to the perimeter. With lake bottoms well below sea level pumping (using modern pumps) continues to the present.

The windmills used to drain the lakes were adapted from corn mills used as early as the 14th century. An important technological innovation was the placement of multiple windmills in series allowing drainage of ever deeper lakes. Many lakes required groups of 3 to 4 windmills in series to keep the lowest areas dry.

In 1533 the 35 ha (86 acre) lake Achtermeer became one of the first ones drained (van de Ven, 2004). By the year 1600, 19 lakes comprising a total of 2,747 ha (6,790 acre) had been drained in the region north of Amsterdam. The 17th century saw a shift to draining ever larger lakes starting with 7,220 ha (17,800 acre) Lake Beemster. With capital acquired from the spice trade, Lake Beemster was drained in 1612 using 50 windmills (Meijer, 1996).

Lying south of Amsterdam, Lake Haarlem continued to grow into the 19th century. At 180 km² (70 mi²) it was more than twice the size of Lake Beemster. Lake Haarlem is distinguished as the first large lake drained using steam powered pumps alone.

Construction of the 60 km (37 mi) ring canal and ring dike started in 1840 and was finished in 1848. To remove the 800(10)⁶ m³ (28.3(10)⁹ ft³) of water from Lake Haarlem three pumping stations were built. Their pumps are considered to be the largest steam pumps ever built. Each station was designed with a single

steam engine driving multiple piston pumps. The pumps were arranged in a circular fashion around the steam engine. The first pumping station built had a steam cylinder with a bore of 3.66 m (12 ft) and a stroke of 3.05 m (10 ft). It powered 11 pumps, each with a bore of 1.6 m (5.25 ft) (van der Pols & Verbruggen, 1996). The other two pumping stations used 8 pumps instead of 11 but with larger bores. All three facilities were operational by the spring of 1848. It took 39 months of pumping to drain the former lake.

The draining of Lake Haarlem had a very significant impact on the 20th century projects. The Dutch realized that new technologies allowed them to successfully take on ever larger projects. Furthermore, draining Lake Haarlem was done as a public works project instead of with private investment. The major 20th century projects followed that pattern.

84.3.2 Coastal Flood Protection

Seventy-five percent of the outer Dutch coast is protected from flooding by sand dunes. The gaps in the dunes and the shorelines of the estuaries and islands are protected by hundreds of kilometers of dikes or seawalls that have been constructed over many centuries.

The early dikes were just mounds of tamped earth. Along the coast the dikes require a seaward face that can withstand wave forces and tidal currents. Several different types of sea dikes were developed for this purpose. In the 13th century the mud dike was constructed with pieces of sod covered by a layer of seaweed on the dike's steep seaward side (Lambert, 1971). Many of these dikes were still in use in the 17th century.

In the 15th century the mud dike was improved by placing a wall of seaweed sandwiched between wooden piles on the seaward side. Stone was also placed at the foot of the dike. The pile dike was a variation in which the outer wall consisted solely of 30 cm (12 in) square wooden piles. This type of dike was used extensively along the shore of the Zuiderzee.

In the southwest delta region the sea dikes were built differently because they experienced more direct attacks from the North Sea. These "Zeeland Dikes" were built with a gentle slope on the seaward side to dissipate the wave and tidal energy. They were constructed in layers using horses to compact each layer. Once the soil was in place the dike was covered with clay sod.

Around 1730 the pile dikes, used in the rest of the country, were being destroyed by the pileworm. This mollusk with a rasp-like mouth and a soft wormlike body bored holes in the exposed wood of sea dikes. Within a short time, the wooden piles began to crumble. By 1732, 50 km (31 mi) of the West-Friesland sea dike were destroyed (Lambert, 1971). These wooden dikes were finally replaced with new dikes fashioned after the Zeeland Dike.

By the 19th century sea dike design had advanced significantly. Dikes were constructed with a foreland for wave run-up. Their crest was placed up to 1.75 m (5.74 ft) above any previously known storm level. The crests were up to 6 m (19.7 ft)

wide and included roadways. The dike body was made of clay. The seaward side was protected with a layer of stones. Timber piles were placed into the dike at the toe to keep the protective revetments from sliding (van de Ven, 2004).

84.4 Zuiderzee Reclamation

While the transformation of Lake Almere into the sea arm called the Zuiderzee provided the opportunity for Amsterdam to develop in the 17th century as a world class port and trade center, it also presented a significant flooding risk for the region. To keep the Zuiderzee from expanding with each passing storm the entire coastline was protected with dikes. Plans for the reclamation of the Zuiderzee appeared as early as 1667, but this 6,700 km² (2,590 mi²) water body could never be drained with windmill technology. In 1886 the Zuiderzee Association was formed to make a serious effort to solve the Zuiderzee problem.

The Zuiderzee Association hired Conelis Lely who, in 1891, presented the first technically feasible plan to reclaim the Zuiderzee. His plan called for the closure of the Zuiderzee with a 30 km (19 mi) long barrier. The barrier would turn the sea arm into a freshwater lake fed by the River IJssel. Once the Zuiderzee was cut off from the North Sea, parts of it would be drained. This would be done by building dikes out into the water forming a closed ring. Once the dikes were constructed, pumps would remove water from the diked-in areas thereby creating new land from the sea bottom. Lely's 1891 plan, including four reclaimed areas or polders, was not immediately adopted. It took food shortage in World War I, floods, and Lely being appointed to the director of the national water management authority before the plan became law in 1918. Lely's 32-year construction schedule was never realized either. War, economic recession, and major project changes delayed completion of the reclamation. The completed project is shown in Fig. 84.5.

Construction began in 1920 on the 30 km (19 mi) long barrier dam designed to isolate the Zuiderzee from the North Sea. The barrier protected areas surrounding the Zuiderzee from flooding. It also provided a land transportation route between the North Holland and Friesland provinces. Additionally, it created a freshwater lake, called the IJsselmeer, which reduced salt water impacts on the surrounding agriculture.

Soundings, soil borings, and model studies preceded the construction of the barrier. The barrier was designed to withstand typical storms experienced in the previous 100-year period. The core of the barrier was constructed using locally available boulder clay. The rest of the dam was constructed from sand fill with submerged parts protected with mattresses constructed of osier fascines sunk with stones.

The lake that formed behind the new barrier dam was fed primarily by the river IJssel. Calculations showed that this lake had to be at least 800 km² (309 mi²) to provide enough storage to hold back fresh water during high tide periods on the North Sea (van de Ven, 2004). Two outlet sluices were needed with a discharge capacity of up to 5000 m³/s (177,000 ft³/s) (van Duin & de Kaste, 1990).

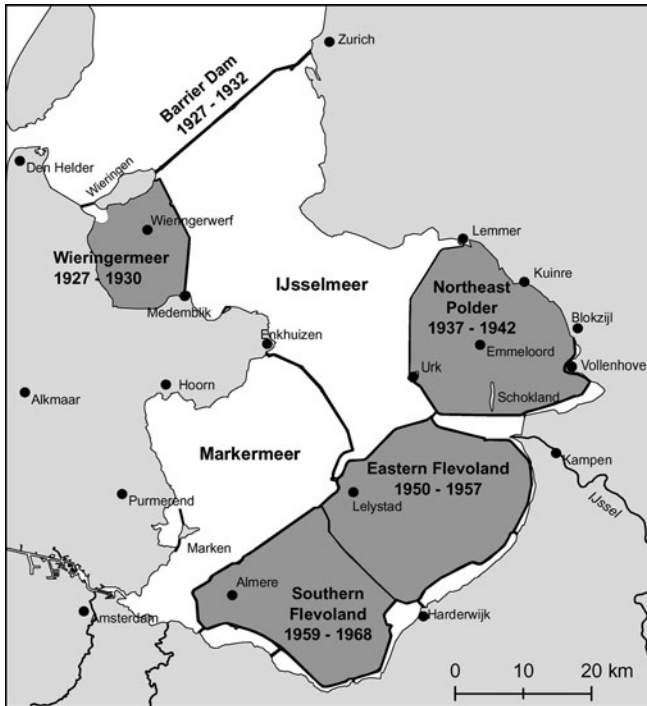


Fig. 84.5 Map of the Zuiderzee reclamation

Even before the barrier dam was finished work started on the first polder. Before the polder dikes could be built unstable foundation soils were removed and replaced with compacted sand fill. The dike was constructed using a double boulder clay core and sand fill. Riprap, asphalt, and basalt revetments were placed on the dike body to protect against wave action. The pumping stations were constructed in the dike at locations where the primary discharge channels were planned.

Before the diked-in areas were pumped dry the primary drainage canals were dredged to allow water to continue to drain to the pumping stations as the water level was lowered to that of the former sea bottom. To make the new land usable the water levels needed to be lowered to 1.5 m (4.9 ft) below the new ground surface. This was done with drainage canals as well as transpiration through reeds sown by airplane. The reeds extracted water as well as improved the bearing capacity of the soil. When the ground was stable enough for heavy equipment to move around, additional field ditches were dug. Finally, after the soil was matured through a series of different plant types, the field ditches were replaced with field tiles.

Wieringermeer was the first large polder created from the Zuiderzee (see Fig. 84.5). The dike from the tip of Wieringen Island to the mainland at Medemblik was constructed between 1927 and 1929. After removing around $700(10)^6 \text{ m}^3$ ($24.7(10)^9 \text{ ft}^3$) of water the polder came dry on August 11, 1930 creating 200 km^2

(77 mi²) of new land. The deepest portion of this polder is 6 m (20 ft) below the IJsselmeer water surface.

Wieringermeer was designed to be almost entirely agricultural. Each plot was 20 ha (49 acre) in size with a road in front and a canal, large enough to transport agricultural products, in back. Most farms, leased to the framers, encompassed one to three of these plots. Very little planning was done for the towns needed to support the agricultural community. It was assumed that they would just appear spontaneously. When this did not happen, the planners realized that the development of new towns was going to be as important as the physical design of the polders.

The second large polder created in the Zuiderzee reclamation was the 480 km² (185 mi²) Northeast Polder (see Fig. 84.5). The polder dike runs from Blokzijl on the east to Lemmer on the north. The drained land included two islands, Schokland and Urk. Two rivers in the old land had to be dammed and diverted to drain into the water surrounding the new polder. Construction started in 1937 and the 1.5(10)⁹ m³ (53(10)⁹ ft³) of water was removed by 1942. The deepest canals lie 5.5 m (18 ft) below the outside IJsselmeer water (van Duin & de Kaste, 1990).

After this area was pumped dry it was discovered that the groundwater levels in the old land around the perimeter of the newly created polder were much lower. This resulted in a drying out of the old land. They concluded that a peripheral lake between the polder and the old land would have kept this from occurring.

Town planning was more deliberate in the Northeast Polder. A single central city, Emmeloord, was constructed at the center of the polder. Ten small villages were constructed in a ring surrounding Emmeloord. The island of Urk, which had been occupied since the 17th century, was incorporated into this new polder as an additional town. Town spacing was set at 5 km (3.1 mi), appropriate assuming that the bicycle would be the primary mode of transportation. After World War II fewer people remained on the farm and agricultural activities became complex enough that the small villages could not provide the required level of support. Automobiles became more common reducing the need for such tight town spacing. As a result the 10 small villages did not develop as planned.

Eastern Flevoland and Southern Flevoland were the third and fourth large polders constructed (see Fig. 84.5). They were built at different times but share a common dike boundary. These polders included a marginal lake to eliminate any problems with lowered water tables in the surrounding old land. These lakes provided additional recreational benefits.

National reconstruction after World War II delayed the start of work on these final polders. Eastern Flevoland construction started in 1950 and Southern Flevoland in 1959. These two polders became dry in 1957 and 1968 respectively. A total of 3(10)⁹ m³ (106(10)⁹ ft³) of water was removed creating 970 km² (375 mi²) of new land (van Duin & de Kaste, 1990). The total amount of new land created between 1930 and 1968 added up to 1650 km² (637 mi²). On a national scale this was equal to a 5 % increase in total land mass.

Four towns were constructed in Eastern Flevoland. The largest of these was Lelystad, named after Cornelis Lely. In 1986 the Dutch government established a new province consisting of the last three polders. Lelystad is the capital city of the

Flevoland Province. Two towns were constructed in Southern Flevoland, Almere and Zeewolde.

Over the years since Lely's first work on the Zuiderzee project the needs of the Netherlands changed considerably. Technological advances in farming reduced the need for new agricultural land. With Southern Flevoland being so close to the Amsterdam metropolitan region the new focus became housing and recreation. Agricultural allocations in Wieringermeer and Northeast Polders were 87% as compared to 50% in Southern Flevoland.

The city of Almere is around 20 km (12.4 mi) from the center of Amsterdam and is the largest and newest of the new cities developed in the Zuiderzee reclamation. It is still, in effect, under construction today. It represents the ultimate dream for any city planner: to design a new major city starting with only dry ground. Almere is being constructed as a polynuclear city. The larger Almere is really a number of smaller cities held together by green space. Each nucleus has its own neighborhoods, central business district and unique character. The entire area has a well planned public transportation system. Almere Stad is the central nucleus. When completed in 2025, Almere is expected to have 350,000 to 400,000 inhabitants.

84.5 The Delta Project

The Zuiderzee reclamation was easily the largest effort by the Dutch to reclaim lost land. The Delta Project was the largest coastal flood protection project ever attempted by the Dutch. These two projects are similar in many ways. Both were initially planned without any urgency until a flood event sent the plans into action. Both projects were developed in stages allowing new developments to alter the plans as time went by. And, both projects took longer to complete than originally planned.

Most of the islands in the Southwest delta region lay between -2 and $+5$ m (-6.6 and $+16.4$ ft) elevation and were protected by dikes, some dating as far back as the 12th century. This, along with neglect during the World War II years, left the region in a vulnerable state.

Prior to 1953 plans were already in place to close off much of the Southwest delta coastline to protect the region from storms and to protect the agricultural lands from salt water intrusion. By 1950 dams were already constructed closing the Brielse Maas. Then the storm of the century hit.

On the morning of January 31 the Royal Netherlands Meteorological Institute issued the first warnings about the impending storm. By early evening distress signals were being received by ships at sea. Around midnight dikes began to fail. The storm was characterized by a deadly combination of high winds, high spring tides, unfavorable wind direction, and long duration. With wind velocities exceeding 100 km/h (62 mi/h) from the northeast the North Sea was pushed into the funnel shaped by the Dutch and British coasts causing unusually high surge levels. At the town of Hoek van Holland water levels reached 3.85 m (12.6 ft) above sea level. This was 0.57 m (1.87 ft) higher than the previously measured high in 1894.

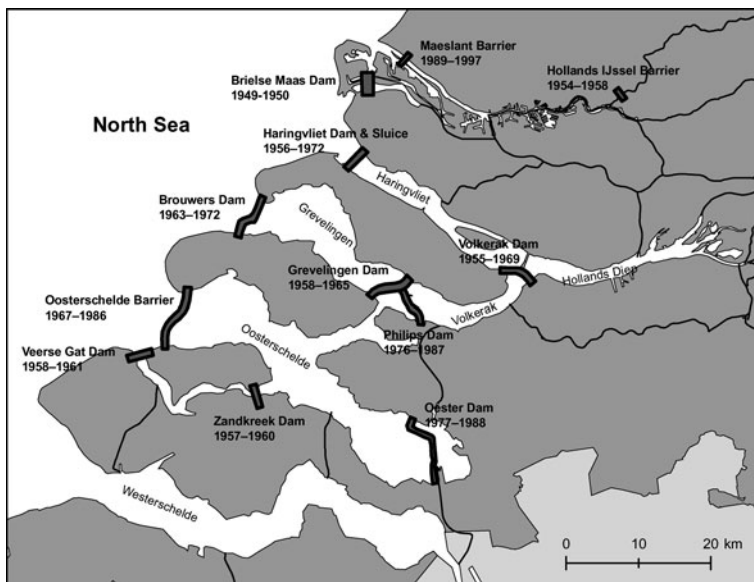


Fig. 84.6 Map of the Delta project

By the time the storm was over 800 km (497 mi) of dikes were severely damaged and 2000 km² (772 mi²) of land flooded. Over 3000 homes were destroyed, 1835 people drowned and 72,000 were evacuated. In 67 locations there were large enough gaps in the dikes to allow tidal flows to pass through. The tidal flows scoured the gaps, some to a depth of 40 m (131 ft). Many dikes failed simply because they were not high enough. They were overtopped and scoured on the inside slope. It took around 9 months to close all of the major gaps.

In response to this flood disaster the Minister of Transport and Public Works instituted the Delta Commission. This group was assigned the task of finding ways to make sure that a flood disaster of this magnitude would never occur again. Two clear options emerged. One was to raise the level of approximately 700 km (435 mi) of sea walls and dikes throughout the Delta region. The other option was to dam most of the tidal inlets and raise dikes only along the open shipping routes. Previous studies that had proposed closing the tidal inlets for flood protection and salt exclusion heavily influenced the approach taken by the Delta Commission. The main advantage was clear: a shorter coastline would be much easier to defend from future storm events. The plan developed by the commission was approved by parliament in May 1958. The finished plan, which differed somewhat from the 1958 version, is shown in Fig. 84.6.

The dams and barriers constructed consisted of primary barriers along the coast and secondary barriers further inland. The secondary barriers were generally located at tidal divides between two neighboring inlets thereby isolating one inlet from the influence of its neighbor. The primary barriers could not be constructed until the

secondary barriers were in place. The following sections cover some of the more significant structures completed in the Delta Project.

84.5.1 Hollandse IJssel Barrier

The Hollandse IJssel River, east of Rotterdam, was one of the most critical locations in need of flood protection. It passes through some of the lowest land in the entire country. A major disaster was averted during the 1953 flood when a ship was purposely sunk in a developing dike breach along this river. Had this dike failed a large part of the region between Rotterdam and Amsterdam would have been flooded affecting millions of people.

The construction of this barrier began even before the Delta Commission issued its final recommendations. It consists of two movable gates each 80 m (262 ft) long and 11.5 m (37.7 ft) high (Lingsma, 1966). These gates are held above the river by two 45 m (148 ft) tall towers. When a flood threatens they can be lowered down to the river with the aid of two 19 kw (25 hp) motors and counterweights. Once in place ships can still travel through a ship lock next to the barrier.

84.5.2 Veerse Gat

Veerse Gat was the first primary closure along the North Sea. Not only was this location exposed to direct wave attack but it experienced a twice daily tidal flow volume of $70(10)^6 \text{ m}^3$ ($2.5(10)^9 \text{ ft}^3$) (Lingsma 1966). Standard dike construction methods would never work. As the size of the opening gets progressively smaller the tidal flow velocities increase to the point where any new materials placed would simply be swept away. The solution involved the use of the sluice caissons. This is a large concrete box with removable sides. The caissons used in Veerse Gat measured 45 m (148 ft) long, 20.5 m (67.3 ft) wide, and 20.5 m (67.3 ft) high (Lingsma 1966). The caissons were built off-site then floated into place at the closure location. The caissons were sunk onto a prepared sea bed with the sides left open to allow tidal flows to continue through the caisson. Once all caissons were in place the sides were closed at once at the turning of the tide. With this method they completely eliminated the tidal flows in the Zandkreek inlet all on a single day. After the caissons were closed, they were covered with sand, forming the rest of the dam body.

84.5.3 Haringvliet Dam and Sluice

The Haringvliet estuary was, at one time, the outlet of the Rhine River. The tidal volume here was $260(10)^6 \text{ m}^3$ ($9.2(10)^9 \text{ ft}^3$) passing through an opening 4.5 km (2.8 mi) wide. The dam constructed here had to allow excess water and ice to discharge into the North Sea so it was built with a 1 km (0.6 mi) long discharge sluice.

The discharge sluice was built in a dry construction pit on-site. This was, in essence, a polder in the middle of the Haringvliet inlet. When most of the ring dike



Fig. 84.7 Haringvliet sluice

was constructed suction dredgers entered and excavated the pit down to the desired level. After the dredgers left the dike was completed and pumps drew the water down to the sea bottom.

Pile drivers next entered the site placing over 20,000 piles for the foundation of the structure. The structure included 17 sluices each 56.5 m (185 ft) wide with a total flow area of 6,000 m² (65,000 ft²). Two radial gates were installed in each sluice opening. The gates were supported by 25 m (82 ft) long steel arms pivoting on a massive beam. The 22 m (72 ft) wide upper surface of the support beam carried a roadway.

After the sluice complex was completed, the dike surrounding it was removed and the remainder of the closure dam was completed. Throughout construction of the closure dam the sluice remained open. Once the dam was completed the sluice could finally be closed eliminating tidal flows into the Haringvliet. The completed sluice complex is shown in Fig. 84.7.

84.5.4 The Brouwers Dam

The Brouwers Dam crossed the 6.5 km (4.0 mi) wide and 30 m (98 ft) deep Brouwershavense Gat between the islands of Goeree and Schouwen-Duiveland. After expanding the size of several natural sand banks two tidal gaps were left to be closed. One gap was closed using sluice caissons. The other gap was closed by

dropping 240,000, 15 metric ton (16.5 ton) concrete blocks from cable cars that traveled across the gap (Lingsma, 1966).

84.5.5 The Oosterschelde Barrier

At 9 km (5.6 mi) wide the Oosterschelde was the largest estuary to be closed in the Delta Project. The opening passed a tidal volume of $1.1(10)^9 \text{ m}^3$ ($39(10)^9 \text{ ft}^3$) and included gullies up to 35 m (115 ft) deep. The original plan called for a closure similar to the Brouwers Dam. The first step, commencing in 1967, was to construct three islands in the middle of the estuary creating four gaps to be closed.

Until the construction of the Oosterschelde Dam there were no serious concerns raised about the impact that the closures would have on the environment of these salt water tidal estuaries. The Oosterschelde estuary supported abundant sea life including mussels and oysters. Its impending closure sparked a national debate about the direction taken by the Delta Commission. Should safety be regarded above all other concerns or should the design incorporate the environmental concerns as well. The debate resulted in a complete redesign of the Oosterschelde barrier. An open barrier was to be built. The redesigned barrier would allow tidal flows to continue into the Oosterschelde estuary. Only when a storm threatens would the barrier be closed. The new design incorporated 62 large steel gates supported by massive concrete piers. Because of the size and depth of this estuary it would not be possible to construct this barrier in place like Haringvliet. Instead, the concrete piers that form the framework of this barrier would be constructed off-site and floated into place.

The first step was to create a foundation for the concrete support piers. Poor soils from the sea bottom were removed and replaced with sand fill. This was then compacted using vibrating needles. Next, foundation mattresses were assembled in a specially designed factory and rolled onto a gigantic spool to be spread out on the sea bottom.

Polders were built at the sand bank islands in the middle of the estuary opening for the construction of the piers. Once construction of the piers was complete, the polder could be filled and the dikes breached to allow a special ship to lift and carry off the completed piers to the barrier site.

A total of 65 piers were constructed. They varied in height from 30 to 39 m (98 to 128 ft) or about the height of a 10-storey building. The largest weighed 18,000 metric tons (19,800 tons) (DOSBOUW, 1983; van de Ven, 2004). Each pier took a year and a half to construct and a new one was started every two weeks.

The last step involved placing the various components between the piers. These included a sill beam and upper beam that together with the piers formed the rectangular opening through which the tide would flow. In addition the gates and a roadway were placed between the piers. The steel gates had a span of 42 m (138 ft) and ranged in height from 5.9 to 11.9 m (19.4–39.0 ft) depending on the depth of



Fig. 84.8 Oosterschelde barrier

the water at the particular location. One section of the completed barrier is shown in Fig. 84.8.

84.5.6 The Maeslant Barrier

Because of the need to maintain shipping routes, the original 1958 Delta Plan did not include any barriers to protect the entrances to Antwerp or Rotterdam harbor areas. The entrance to Antwerp was through the wide Westerschelde, but ships heading to Rotterdam used the man-made Nieuwe Waterweg canal. A decision was made to provide additional flood protection to this economically important region by building a storm barrier at the entrance to the Nieuwe Waterweg. The primary restriction was that the barrier would not hinder ship traffic.

Several companies formed a partnership to win the contract to design and build this barrier. The selected design used two hollow, semicircular gates as the main element of the barrier. The gates normally sit in a dry dock on the side of the canal. When a storm threatens the dry dock is filled with water and the gates are pushed out to the center of the canal. Once in place they are filled with water and sink to a concrete sill.

Each gate is 210 m (689 ft) long and 22 m (72 ft) high. It pivots on a 10 m (33 ft) diameter ball joint via 237 m (778 ft) long steel space trusses. The ball joints were 3 times larger than any previously constructed. As built, the Maeslant Barrier (Fig. 84.9) is considered to be the largest man-made moving object on earth.

At the time of its construction, it was anticipated that this barrier would close, on average, once every 10 years. The barrier was completed in the spring of 1997. In November 2007, with sea levels at 2.84 m (9.32 ft), the barrier closed for the first time under storm conditions.



Fig. 84.9 Maeslant barrier

84.6 The New Delta Plan

The original Delta Commission was given the task of finding a way to keep a flood disaster like that of 1953 from ever happening again. The result is a system of strengthened dikes and structures that have successfully protected the southwest delta area up to the present. Along the way, maintaining the environmental condition of this area was added as an additional constraint. Recently, a new commission was established to look further into the future. The effects of climate change and associated sea level rise could undo all of the progress made in the past. The new commission was asked to provide recommendations to parliament that would make the country “climate proof” and yet remain an attractive place to live and work.

The new Delta Commission presented its initial recommendations to parliament in September 2008. The advice emphasized the need for both water security and sustainability. The recommendations are based on an assumption that relative sea level rise (including land subsidence) will be somewhere between 0.65 and 1.3 m (2.1–4.3 ft) by the year 2100 and between 2 and 4 m (6.6–13.1 ft) by the year 2200. Increased flows from the rivers Maas and Rhine are also included in the recommendations.

The Delta Commission report includes a set of 12 recommendations for the future. These recommendations are to be the foundation for the “Delta Program” to be made law in the new “Delta Act.” The following are the recommendations that relate to the coastal defenses and reclamations described in this chapter (Deltacommissie, 2008).

Recommendation 1: Between the present and 2050 the protection level of all diked areas must be improved by a factor of 10. This would increase the standard for high value areas along the coast to protection for up to the

100,000 year storm event. To do this might require the construction of a so called “Delta Dike” which is so high or so wide and massive that there is virtually zero probability of a sudden failure. After 2050 the protection standards must be updated regularly.

Recommendation 2: Detailed cost benefit analysis will be required for any construction in low lying areas. All costs, including those for flood protection, for new construction must be covered by those benefiting.

Recommendation 4: Flood protection along the entire North Sea coast will be provided by beach nourishment gradually moving the coast seaward in the next century.

Recommendation 5: The Wadden Sea islands will be maintained.

Recommendation 6: Through 2050 the Eastern Schelde barrier should be able to function in its present condition. After 2050 its life will be extended by technical interventions up to a sea level rise of 1 m (3.3 ft). Once this level is attained a new solution to protection of the Eastern Schelde estuary will be found that restores all of the tidal dynamics while still providing safety against flooding.

Recommendation 7: The Western Schelde must remain open for navigation to Antwerp. Flood protection will be maintained by strengthening the existing dikes.

Recommendation 8: The former sea inlets now closed off by the Delta barriers must be able to provide temporary storage of river water (Rhine and Maas) during periods where the sea barriers are closed.

Recommendation 11: Between the present and 2050 the level of the IJsselmeer will be raised by a maximum of 1.5 m (4.9 ft) to allow gravity drainage to the higher Wadden Sea. The challenges will be to protect the lower reaches of river IJssel. After 2050 even higher levels may be required.

Recommendation 12: The political administration of water safety must be strengthened. Funding of projects must be guaranteed. The Delta Act must be approved by parliament.

84.7 Conclusions

The Dutch have a long history of water management. Living in a low lying coastal area has forced them to continually find ways to protect themselves from flooding. They have also perfected the art of reclaiming land that was previously lost. The two major projects of the 20th century, the Zuderzee reclamation and the Delta Project, are proof that they can take on flood protection and land reclamation challenges on the grandest scale. Unfortunately the battle is not over. Climate change and sea level rise threaten to undo the progress made in the past. Instead of giving in to future threats, the Dutch have taken the path of flood proofing their country. Only time will tell if this can be done successfully and sustainably, while maintaining the natural and cultural resources that exist today.

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