Kees d'Angremond

From Disaster to Delta Project: The Storm Flood of 1953

Abstract

Fifty years ago the Netherlands experienced the country's worse flooding in modern times. The United Kingdom and Belgium were also inundated, but in the Netherlands the loss of life, livestock and destruction of land was enormous.

Facing this disaster, the first order of business was to rescue as many people as possible. The second step was to repair the breaches in the dikes, and the third was to take measures to make sure that such a disaster would not occur again. This last step resulted in the formation of the Delta Committee which subsequently created a plan known as the Delta Project. By the late 1950s and early 1960s a plan was in place that eventually resulted in the construction of an extensive storm-surge barrier.

The research that was conducted in this context transformed hydraulic engineering, including dredging, from a vocational profession into a science-based profession and laid the way for many of the projects executed today. It as well as gave us the tools for coping with a possible sea level rise which is predicted for the 21st century. In addition, during the 30-year span in which the work was conducted, the subject of the environment emerged as a dominant issue and the Delta Project marks the new age in which environmental impact assessments must be an integral part of any construction plans. What started as a response to disaster, turned into a monumental engineering feat.

After working for Delft Hydraulics (1963-75), Kees d'Angremond went to Volker Stevin (1975-1987) and then, after a short break as director of the Port of Amsterdam, to Delft University of Technology (1989-2001), where during his distinguished career as Professor of Coastal Engineering, he served as Head of the Hydraulic & Offshore Engineering Section, Chairman of the Department of Hydraulic & Geotechnical Engineering, and Dean of the Faculty of Civil Engineering. He recently became Professor Emeritus and is presently an independent consultant working as an advisor for, amongst other organisations, the Hanoi Water Resources University. He is also Chairman of the Foundation for the National Dredging Museum in Sliedrecht, The Netherlands.

Kees d'Angremond

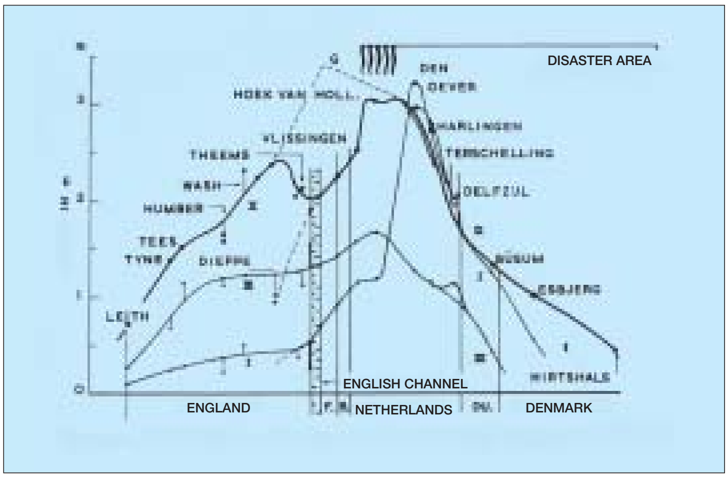
Introduction

On 1st February 1953, the coastlines of the southern North Sea were hit by a severe storm surge. Large parts of the United Kingdom, Belgium and the Netherlands were inundated. In the Netherlands alone, more than 1800 people drowned and 135,000 ha of land were flooded.

The first days after the event, the extent of the disaster was largely unknown. Rescue operations and initial repair activities took place in an improvised way. Thereafter, a more systematic approach was followed. The breaches in the dikes were all repaired before the end of the year. Already on February 18, the Delta Committee was established to advise the Government on measures to be taken to prevent such a disaster in the future. This Committee initiated projects of a to-then-unknown scale. The works became feasible as a result of an unprecedented research effort that lasted over 30 years and that turned the hydraulic engineering profession (including the dredging industry) from a largely vocational profession into a modern science-based enterprise. Without the experience gained during the execution of the Delta Project, many present-day projects would not have been feasible. As such, the disastrous flood of 1953 has provided us with the tools to cope with a potential sea level rise in the 21st century.

Figure 1. The path of the tidal wave into the southern North Sea with the times of high water (HW) indicated.

Figure 2. The surge resulting from the HW in the southern North Sea, going from left to right along the coast of the U.K. across the Channel to France, Belgium, The Netherlands, Germany and Denmark.



The Storm of 1953

From noon on 31st January 1953, a NW gale swept the water from the northern part of the North Sea (between Scotland and Norway) in a southerly direction towards the English Channel. Though part of the water was drained through the Channel, a major surge developed along the coasts of the UK, Belgium and the Netherlands. As a result of the wind direction and the coincidence of the surge with the astronomical tide, water levels exceeding any previously observed occurred in the early morning of Sunday, 1st February, 1953, specifically in the SW (Delta area) of the Netherlands. Conditions were worsened by the fact that the storm coincided with spring tide, though fortunately not the highest spring tide of the month.

The path of the disastrous tidal wave into the southern North Sea with the times of high water (HW) is indicated in Figure 1. The resulting surge (set-up above the astronomical HW) along the coast of the southern North Sea is given in Figure 2, starting at the left-hand side with the coast of the UK from N to S, then across the Channel, the French and Belgian coasts to the Netherlands, ending on the right-hand side in Denmark. The draining effect of the Channel can clearly be seen between the mouth of the River Thames and Flushing. Looking at this figure, it is no surprise that serious damage to the sea defenses occurred in the region where the surge reached levels of 3 m [1].

Flooding

The area that suffered the most direct hit was the Delta region, between Vlissingen and Hook of Holland. In total 187 km of sea defense was damaged, of which 48 km seriously. Most damage was caused by water flowing over the crest of the dikes and eroding the inner slope. Most breaches were found along the southern shores of the islands, where the freeboard of the dikes was less. (The dikes facing N and NW were designed higher so as to cope with wave run-up expected mainly from the NW.) Many deep polders were inundated to a depth of more than 5 m, most in the first night, but some later when sleeper dikes failed. In the meantime, the local people attempted to save their lives on roofs, in trees and on high spots. Others worked very hard to protect failing dikes and to repair breaches before they could grow into gullies. The Dutch journalist Cees Slager [2] has annotated numerous stories about the heroic efforts of the people in these first days.

Only by the morning of 3rd February, a few days later, did the full scope of the disaster become clear.
The extent of the flooding is shown in Figure 3.
In total, 1835 people died, 200,000 cattle were lost and over 135,000 ha of fertile land were inundated.

The first task of the authorities was to bring the survivors to safety. In total, 72,000 people were evacuated. Thereafter, the systematic repair of the sea defenses was begun.

Repair of Damage

Many of the smaller breaches could be repaired with simple means such as sandbags and locally available materials (sand, clay, rubble and quarry stone). In some places, inland barges were used by sinking them in the current to block gaps in dikes. In this way, 75% of the flooded area was recovered by 1st April.

Some of the breaches, however, specifically in the dikes around the Island of Schouwen Duiveland, had grown into deep gullies by backward erosion owing to the in- and outgoing tidal currents (Figure 4). These gaps could not be closed by traditional means. Fortunately, some experience had been gained in 1945, when similar gaps in the dike around the Island of Walcheren had to be closed following the bombing by the RAF for the opening of the Port of Antwerp during World War II. At that time, several caissons constructed for the artificial port of Arromanches were used to block the gaps. The famous novel by Den Doolaard gives an accurate account of the earlier experience [3]. Some of these Phoenix caissons were still available in the UK in 1953. They were towed to the Netherlands, and along with locally constructed smaller size caissons, they were used to block the final two gaps in Schelphoek and Ouwerkerk. Figure 5 gives an impression of the scale of these repair works. The last gap at Ouwerkerk was closed on November 6 and all flooded land was dry on 1st January 1954, less than a year after the flooding.

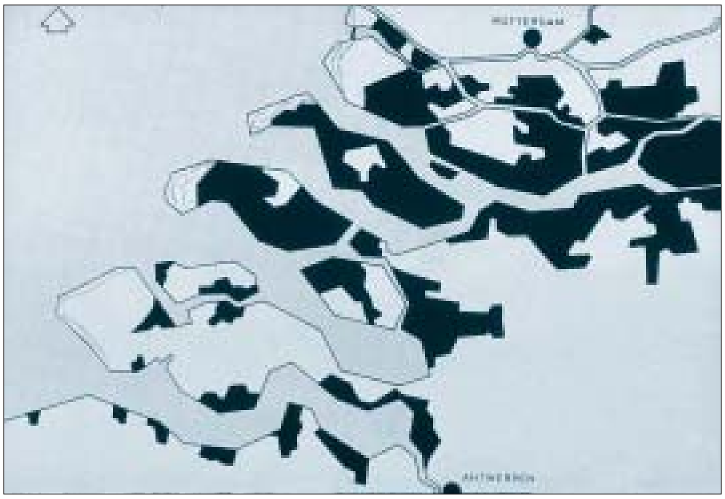


Figure 3. Areas of flooding in The Netherlands,1953.

The Disaster in Hindsight

In hindsight, it is amazing that the storm of 1st February 1953 could have such a disastrous effect.

Figure 4. In some cases the streaming water through the breaches in the dikes caused deep gullies and waterfalls to form, which were difficult to close.

Figure 5. Caissons being used to close the gap at Ouwerkerk. The extent of the repair work was enormous.

As early as 1939, an engineer from Rijkswaterstaat (the Dutch Ministry of Waterways and Public Works) P.J. Wemelsfelder published an article in *De Ingenieur* [4] in which he indicated that the occurrence of extreme water levels along the Dutch coast followed a logarithmic probability distribution. On the basis of this work, he indicated that the crest levels of many dikes, in particular in the SW part of the country, were too low. Afterwards, it could be derived that the water level that caused the 1953 disaster had a probability of exceedance of about 3*10-3 per annum, or on the average, only once in 300 years.

Though the damage was extensive, it could have been much worse. A breach in the river dike between Rotterdam and Gouda was prevented by a major effort in the early morning of 1st February, probably thanks to the fact that HW occurred here close to sunrise. If this dike had failed, the densely inhabited (and well-developed) area between Rotterdam, The Hague and Amsterdam would have been flooded as well.

The Delta Committee: Long-term Solutions

Given the magnitude of the disaster and the economic consequences, it is no surprise that the Government wanted answers to various questions, of which the most important were:

- which storm surge levels could be expected along the Dutch coast; and
- is the safety against flooding along the Dutch coast sufficient, and if not, what measures should be taken.

In order to answer these questions, the Delta Committee was formed on 18th February 1953, just two and a half weeks after the disaster. It took the Committee almost 8 years to complete its task.
The final report covers six volumes, most of them the result of comprehensive research by a multi-disciplinary team of experts. Five interim reports were published to enable the Government to make an early start with the most urgent works [5].

The final report of the Delta Committee is a landmark in coastal engineering design. For the first time, the required safety level was based on a comparison between the economic damage owing to failure of seawalls and the cost of strengthening the coastal defense works. It was established that the sea defenses around the most densely populated part of the country should be able to withstand surge levels with a probability of exceedance of 10-4 per year (average once in 10,000 years).

To achieve this kind of safety, a major renovation programme for the existing dikes needed to be carried out. The Committee indicated, however, that it would be an advantage to close the estuaries in the SW part of the country instead of raising the crest of many dikes around the existing islands. Before the Committee arrived at this conclusion, due attention was paid to secondary advantages and disadvantages, such as salt intrusion, enhancement of land transportation and inland navigation, recreation, and social and environmental issues. The proposals of the Committee became known as the Delta Project.

Although the final report did not appear until after 1960, several interim reports formed the basis for the legislation comprising the closure of the inlets in the SW part of the country. The Delta Law passed through the Dutch Parliament (Tweede Kamer) on November 5, 1957, and was published on May 8, 1958.

Delta Project

In concrete terms, the Committee recommended the closure of the primary inlets (from N to S) Haringvliet, Brouwershavense Gat, Oosterschelde (Eastern Scheldt) and Veerse Gat. The latter closure had already been mentioned in an interim report. Since there would be a considerable time gap between closures of the inlets, secondary dams would have to be built to avoid shortcuts through the channels at the upstream end. This required secondary dams in the Volkerak, Grevelingen and Zandkreek. The closure dam in the Haringvliet had to be equipped with a discharge sluice of sufficient capacity to cope with the discharge of the River Rhine. Remaining dikes that would not be protected by the closure works were to be strengthened to the required level.

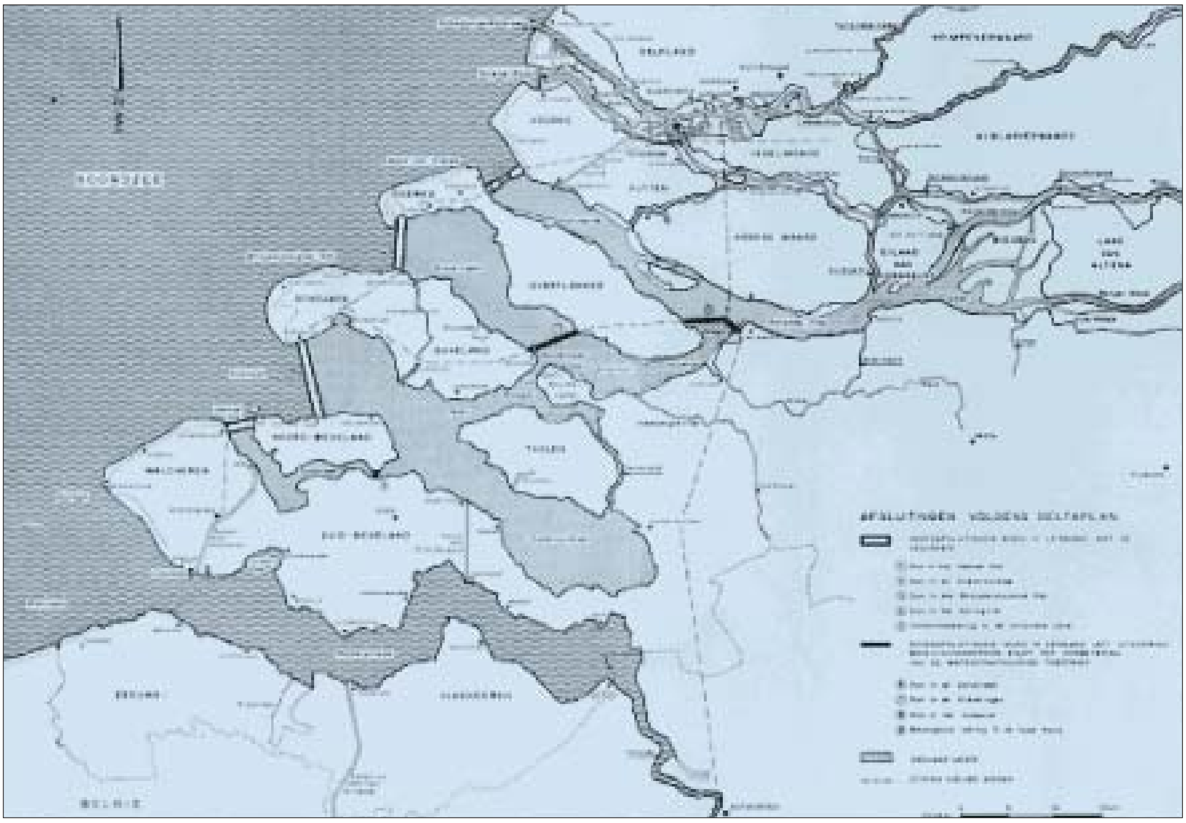
The report also pays attention to the possibilities of improved management of the fresh water resources in the SW part of the country. Control of the Haringvliet sluices would give the possibility to increase the discharge via the Rotterdam Waterway, reducing the salt intrusion caused by the continuous deepening of this channel for navigational purposes. A network of inlet sluices was designed to flush the reservoirs of Grevelingen and Oosterschelde with fresh (Rhine) water. Last but not least, new lock complexes in the Volkerak Dam and at the Kreekrak would facilitate the inland fairway from Rotterdam to Antwerp, honouring an already long overdue commitment to Belgium.

The report then discusses the technical feasibility of the works. A comprehensive comparison was made with similar earlier works. It was concluded that the works would be feasible, but that they so greatly exceeded the existing experience that only a phased approach could be successful, starting with the smaller inlets, and gradually tackling the larger inlets, based on experience gained during the project itself.

Finally, the Committee stressed the need to apply new technology and to carry out research by using all modern means.

The works proposed by the Delta Committee have been indicated in Figure 6. The suggested time schedule anticipated a construction period of 25 years is given in Figure 7. Three major works determined the total time schedule: the closings of Veerse Gat, Brouwershavense Gat and Oosterschelde. Other elements, such as the closure of the Grevelingen, the Volkerak and the Haringvliet, had to be fitted in between.

Figure 6. Delta area with major works.



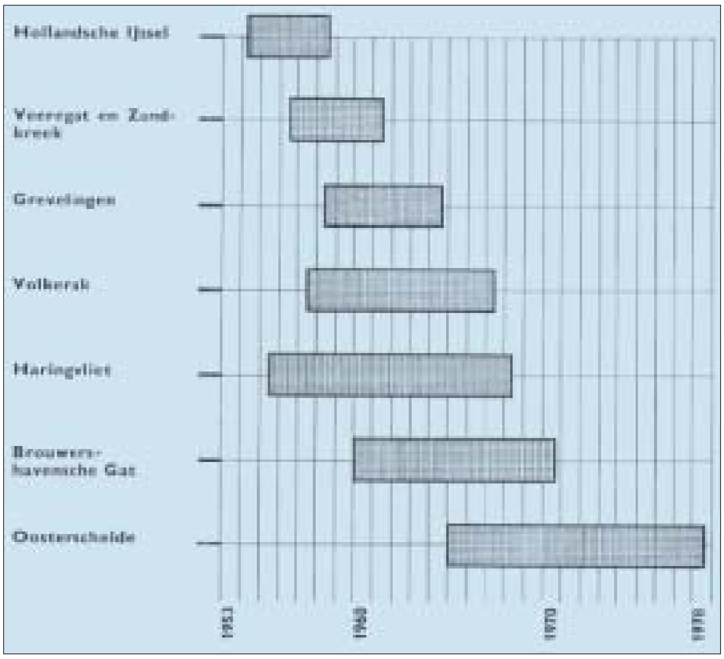


Figure 7. Time schedule of construction at the Delta Works.

Management

For the management of the Delta Project, a separate entity the Deltadienst within Rijkswaterstaat was formed: Within this department, units were established for the design and supervision of the works, and for the research that had to be carried out to make the works feasible. For many years, the "Waterloopkundige Afdeling" (Hydraulic Department) guided the long-term research, varying from field observations to all kinds of model tests and calculations. This Department formed the liaison between research and practical engineering for over 25 years.

The sequence of the works was partly designed to create a learning curve. Since it would be necessary to develop and test new techniques, a variety of working methods was used to provide experience and to make the appropriate choices for the most difficult closure – the Eastern Scheldt. A good insight in the execution of the works can be obtained from the series *Driemaandelijkse Berichten Deltawerken* edited by the "Deltadienst"[6].

In this way, in 1969, the formal decision to close the Oosterschelde could be taken. After careful consideration, the decision was taken to use the technique of gradual vertical closure by cable car. This method was preferred to the use of caissons to avoid the inherent risks of placing the caissons. The works on the Oosterschelde started with the construction of work harbours and dam sections over the shoals. A huge factory was constructed for pre-fabricated geotextile mats to be used as scour protection. The works were well underway, but in the public opinion there was a growing concern about the environmental effects of the large stagnant water basins. The potential loss of the oyster beds near Yerseke also continued to cause concern. Closure of the Oosterschelde even became an issue in the parliamentary elections of 1973. After the formation of a new coalition cabinet, it was decided to re-consider the continuation of the Delta Project.

Environmental Concerns

After ample consideration, a compromise was achieved: instead of completely closing the Oosterschelde Estuary, a storm-surge barrier would be constructed in the mouth. During normal tidal conditions this barrier would reduce the tidal amplitude to a level that was considered adequate for the oyster cultures. During storms the barrier could be closed to provide the desired safety. In the upper reaches of the estuary, some compartment dams would be built to separate the Rhine-Scheldt canal from the now tidal Oosterschelde, and to reduce high current velocities in the Krammer. Although the new plan was far more costly than the old one, the idea was received favorably. This marked the dawn of a new age in which environmental impact assessments would become an integral part of any construction and dredging projects.

Enhanced Role for Construction Industry

Preparation of the new design was not a task of Rijkswaterstaat alone; a design team was established with strong participation of the contractor. During the design phase, serious problems were encountered that forced the designers to a make radical change several times. First, the idea of using the caissons was abandoned to make place for a design with piers cast in situ and a foundation deep in the Pleistocene deposits, with the aid of cellular rings. Construction of the piers and their foundation would take place in separate steel cofferdams. This idea was also abandoned, and eventually the choice fell on pre-fabricated concrete piers that would be placed on mattresses consisting of a granular filter (Figure 8).

In between the piers, a sill was to be constructed consisting of a sill beam and heavy quarry stone. The sill beam would be the lower support for the steel gates that would move in between the piers. In total, 66 piers had to be placed with a heart-to-heart distance of 45 m, distributed over 3 main channels, thus forming 63 openings. The soil, consisting of loosely packed, fine sand had to be densified before the foundation mattresses could be placed. Accuracy was essential while working under extremely difficult conditions in

Figure 9. One of the spin-offs of the Delta Project: discharge caissons at the Oosterschelde, being built in 1976.

water depths up to 35 m and current velocities of over 4 m/s.

Part of the already completed works had to be demolished including part of the scour protection and the piles for the cableway. Therefore the conditions set by the Government with respect to cost and time of completion could not be met. The barrier was completed in 1986 instead of 1985, and the budget was also exceeded even after correction for inflation. This could not be a real surprise since the original idea was abandoned to carefully build up experience during construction working from smaller to larger closures. The work methods required for the Oosterschelde barrier were a completely new challenge to the engineering community.

Figure 8. Concrete piers at the Oosterschelde works.

Innovations and Spin-offs

The emphasis on research and innovation was not restricted to only Government Agencies.
Private enterprise, including the dredging industry, was challenged and sometimes urged to participate in this process. As such, the Delta Project has contributed significantly to the evolution of the hydraulic engineering profession in general and the dredging industry in particular from a vocational profession into a modern science-based industry.

With so much emphasis on innovation, there must have been a tremendous spin-off. At present, it is difficult to recognise the origin of present-day working methods. Nevertheless an attempt has been made to list at least some of the achievements including:

- Quantitative insight in scour
- Extensive study of wave impact forces
- Large-scale application of geotextile and asphalt mats for scour protection
- Closure of tidal channels by dumping material from cable cars
- Application of geocontainers
- Use of discharge caissons (Figure 9)
- Large-scale use of asphalt and sand asphalt for slope protection instead of labour-intensive stone revetments
- High capacity dredging of sand;
- Extensive use of pre-stressed concrete in the marine environment
- Compaction of sand by vibration to a depth of NAP –60 m
- Placement of foundation mattresses consisting of 3 layers of granular material

Figure 10. Aerial view of the completed Oosterschelde Storm-Surge Barrier.

- Lifting and accurate positioning of extremely heavy elements in water depth of 35 m and velocities up to 4m/s
- Closing tidal channels with sand only
- Development of probabilistic design methods
- Technology of granular filters
- Accuracy of dredging and providing foundation layers for caissons.

The Delta Project in Hindsight

The Delta Project was originally designed in a period when awareness of the environment and of the ecological effects of civil engineering works scarcely existed. Moreover, the decisions to carry out the project were taken in an emotional context immediately after a major disaster that took over 1800 lives. It is therefore not surprising that during the execution of the project priorities changed. The growing level of prosperity and the growing attention for the quality of life strengthened the concern for the environments.

Conclusions

Looking back 50 years, it is clear the Delta Project has certainly been very effective in reducing the risk of inundation. With the growing concern about the rise in sea level, this aspect is gaining emphasis.
Also, the side effects of the project have been positive for the economic and social development of the region, including the opportunities for tourism and recreation. This is due not only to the better wet and dry traffic infrastructure, but also to the creation of the water basins. The effect on the national water management must be rated as positive. With the aid of the Haringvliet Sluice it has become possible to control the Rhine discharge, to reduce salt intrusion, and to safeguard drinking water resources.

It is perhaps some small solace to those who lived through the disaster and grief of the storm flood of 1953, that without it and the Delta Project as its logical consequence, hydraulic engineering and dredging would not have advanced as dramatically as they have, preventing similar disasters since and providing us with solutions for the impending problems of the 21st century.

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Special IADC Award: "On the Sedimentation Process in a Trailing Suction Hopper Dredger"

The Trailing Suction Hopper Dredger (TSHD) is very often used for large-scale land reclamation works. During dredging the TSHD lowers one or two suction pipes to the seabed. From the bed a sand-water mixture is sucked up and discharged into a large cargo hold, the so-called hopper. In the hopper sand settles and the excess water flows overboard. A part of the inflowing sand may not settle during loading into the hopper, but flows back overboard with the excess water. Therefore, the VBKO (Vereniging van waterbouwers in Bagger-, Kust- en Oeverwerken) initiated a research programme to improve knowledge on the subject of hopper sedimentation.

Different models were developed in the past to estimate the amount of material lost overboard and the particle size distribution of the sediment in the hopper and in the overflow mixture. These models were based on relative simple models developed for the field of sewage water treatment (Camp, 1946) and were based on an idealised inflow and outflow configuration and a prescribed velocity distribution in the hopper. Because the velocity distribution is prescribed, its relation with the inflow and outflow structures is absent. The second effect is that the concentration distribution does not influence the velocity distribution in these simple models.
With the increase in scale of the TSHDs, the validity of these simple models became questionable.

The research programme started in 1997 with a literature survey from which it was concluded that knowledge about the physical process inside the hopper was lacking and the existing models were too simple. The second step was the execution of laboratory hopper sedimentation tests with the smallest length scale possible (hence geometry as large as possible to minimise scale effects) at WL|Delft Hydraulics. Based on the improved phenomenological description that resulted from the laboratory tests, a one-dimensional vertical (1DV) model was developed. The difference between the earlier models and this new model with its (mostly one-dimensional) predecessors is that the dimension is in vertical direction instead of horizontal. The 1DV model proved capable of simulating the model hopper sedimentation tests quite well. It was however unsure if the model could simulate the process on prototype scale equally well since the horizontal transport in the hopper was not included owing to the one-dimensional character.

It was therefore decided to extend the one-dimensional model to two dimensions (two-dimensional-vertical: 2DV). At the same time it was recognised that quantitative information on the influence of the bed shear stress on sedimentation was missing for the conditions present in a hopper (large concentration and velocities below the deposition limit).
Consequently special sedimentation tests were carried out in a closed flume. With these tests the sedimentation-erosion processes close to the bed could be examined. The developed two-dimensional model is compared with benchmark situations and with the model hopper sedimentation tests. To validate the models prototype measurements were executed onboard the *TSHD Cornelia*. These measurements were used to validate both the 1DV and the 2DV model. The agreement between the 2DV model, based on the Reynolds-Averaged Navier-Stokes equations and the measurements is good.

Cees van Rhee, during his promotion ceremony, flanked by his advisors, left, Professor Wim Vlasblom, and right, Professor Emeritus Kees D'Angremond.

Presented on December 3 2002 at Delft University of Technology

For almost twenty years, Cees van Rhee has been engaged in research for the dredging industry. From 1985 to 1990, he was at WL|Delft Hydraulics, and from 1990 to the present at Ballast HAM Dredging. At Ballast HAM he was employed in the Research Department, Estimating Department and worked for two years in Hong Kong where he was responsible for the Production and Planning of one of the large land reclamation projects that were executed at that time. From 1997–2001 he was posted for two days per week at Delft University of Technology in a PhD research programme, sponsored by major Dutch dredging contractors. In December 2002 Mr van Rhee received his degree and was awarded a special IADC Award for his research paper. A summary of this is published here.
A more extensive article based on his thesis can be found in *Terra et Aqua*, nr. 86, March 2002.