



# INNOVATIVE DESIGN, TECHNIQUES AND EQUIPMENT AT MAASVLAKTE 2, PORT OF ROTTERDAM

## ABSTRACT

The Port of Rotterdam is currently undergoing a massive extension called Maasvlakte 2. During the first phase 700 hectares of new port area will be created. A combination of hard and soft sea defences in the North Sea will protect the new port from the elements.

To realise this massive project, innovative design, techniques and equipment were necessary. A design was developed to ensure that wherever possible the sea defence would be soft, since a hard seawall is more expensive. One of the innovative design features of the soft sea defence is the use of Pleistocene sand. In other areas a hard seawall was needed and large quantities of rock fill were necessary. This demanded other innovations and the development of specialised equipment. For instance, although the multi-beam system has been an accepted method of surveying rock layers for quite some years now, Project Organisatie Uitbreiding Maasvlakte (PUMA) and Port of Rotterdam agreed that new research was necessary to quantify the differences between conventional survey techniques and the multibeam. This article describes some innovative survey techniques and equipment used at the Maasvlakte 2.

## INTRODUCTION

The Port of Rotterdam is currently undergoing a massive extension called Maasvlakte 2. Between 2008 and 2013, 240 million cubic metres of sand have been deposited from which 210 million m<sup>3</sup> is dredged from a sand extraction area in the North Sea and around 30 million m<sup>3</sup> comes from dredging the port basins and the Yangtzehaven. During the first phase 700 hectares of new port area will be created (Figure 1). A combination of hard and soft sea defences in the North Sea will protect the new port from the elements.

Beach and dunes with a length of 7.3 km form the soft part of the sea defence. The 3.5-km-long hard sea defence comprises 7 million tonnes of rock and around 20,000 concrete blocks weighing 40 tonnes a piece. PUMA (Project Organisatie Uitbreiding Maasvlakte) formed by Netherlands-based dredging companies Van Oord and Boskalis are responsible for the design, construction and maintenance of this immense project.

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Above: Close up of the Blockbuster (Equilibrium Crane) which was custom built to meet the project's requirement: the ability to lift and place 40-tonne concrete blocks accurately at a distance of approximately 50 m.

The economic importance of the port extension is significant. The area added to the port in the 1970s, Maasvlakte 1, has virtually no room left for new companies and existing clients that wish to expand. The Maasvlakte 2 project will contribute to keeping the Port of Rotterdam in its current position as Europe's most important port. With the construction of the 20-m-deep harbour basins and access channel it will be ready for the container ships of the future.

## DESIGN

The design for the soft and hard sea defences was calculated to withstand a once-in-10,000-year storm with a wave height of 9 m coming from the north to north-west (348°) and duration of 12 hours (Figure 2). Wherever possible the sea defence would be soft, as the cost of a hard seawall is considerably higher. Still, during the execution of the project the design of the hard sea defence was further optimised, which resulted in lower construction costs. Model tests were carried out to verify the stability under various circumstances.

To prevent unsafe situations for shipping in the port entrance, criteria were set to the flow conditions for both the construction phase and the final layout. To analyse and quantify the effects, a current model was developed



#### ERIC PEETERS

received his Bachelor's degree in Hydrographic Surveying in 1998. He has been working as a project surveyor for Van Oord for over 14 years on projects such as Dubai World Island in the UAE and the Ras Laffan Port expansion project in Qatar where he gained experience with the Echoscope 3D sonar. From February 2009 he led the survey team for the rock installation on the hard seawall at Maasvlakte 2. He has also been involved in developing innovative survey techniques like the survey crane "Condor" and the research to determine rock quantities with various survey methods. In March 2012 he became the head of the survey department at Maasvlakte 2 where more than 12 surveyors of various nationalities are at work.



Figure 1. Sea defence, harbour basins and 700 hectares of new port area (Phase 1, in yellow). Grey area indicates Maasvlakte 1).

that can simulate the current in existing and future situations.

#### Soft sea defence

One of the innovative design features of the soft sea defence is the use of Pleistocene sand. By using this coarser grain of sand a steeper foreshore can be constructed, which requires less sand. The sand will be extracted till approximately  $-40$  m NAP which is around 20 m below the current seabed level. This deep extraction method will limit the area affected by the construction activities.

The row of dunes adjacent to the wide beach varies in height  $+10$  to  $+13$  m NAP. The new beach will provide room for recreation while the dunes will offer a lively habitat for nature.

#### Hard sea defence

The hard sea defence on the north side of Maasvlakte 2 was selected from a number of alternatives and comprises a so-called "stony dune with a reef of blocks" (block dam). The core consists of sand which is divided in two types. Finer sand (approximately 150  $\mu$ ) located in the deeper part is covered by coarse sand ( $> 370$   $\mu$ ) in the upper part. Under the reef the sand is covered with filter material (0.3-35 mm). Next a layer of cobbles (20-135 mm) is placed.

In the stony dune area the cobbles are placed directly on the sand creating a cobble beach with a 1:7 slope approximately 4 m thick. Under the concrete blocks two more quarry stone layers can be found: First 5-70 kg rock, secondly a top layer consisting of 150-800 kg armour rock.

A total of 7 million tonnes of quarry stone are required. Some 2 million tonnes of this rock are recycled from the existing block dam of Maasvlakte 1. In the surf zone 40-tonne concrete blocks are placed that measure 2.5 by 2.5 by 2.5 metres. In order to accurately place these blocks the development of a unique crane called the Blockbuster was required. To prevent the blocks from shifting, a toe construction of 1-10 tonne rock has been placed on both sides of the concrete block formation.

The large scale of rock and concrete blocks that have been reused from the Maasvlakte 1 block dam contributed to a cost reduction and made the design also sustainable.

#### DETERMINING ROCK QUANTITIES

For the Maasvlakte 2 project a large amount of rock fill is needed to be placed above and underwater within relatively thin layers and small tolerances. The standard method for surveying rock levels is described in the manual on the use of rock in coastal and shoreline engineering (CUR 154) and requires the use of a semi-spherical foot as a reference.

The greater part of the quality assurance on the sea defence works will be based on data acquired with a multibeam echosounder. The multi-beam system has been an accepted

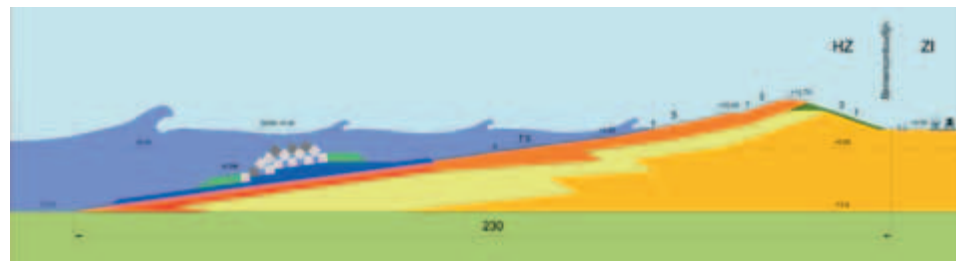


Figure 2. Design of the hard sea defence showing a once-in-10,000-year storm situation with 5.3 m NAP storm surge.

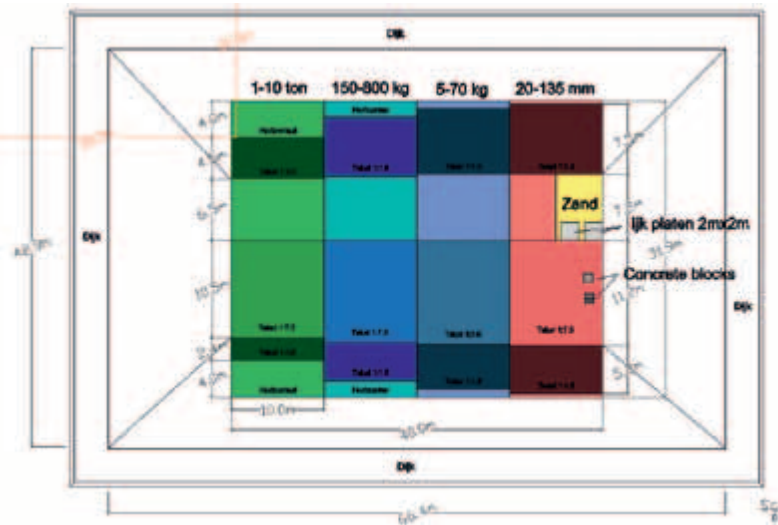


Figure 3. Design of the test pit showing different rock grades with corresponding slopes.



Figure 4. Test pit after dry sand excavation and filled with rock grades that will be used during construction of the hard sea wall. The flat sand area with concrete plates was used for calibration purposes.

method of surveying rock layers for quite some years now. Research in the past pointed towards lower volumes being detected using multibeam surveys as opposed to the semi-spherical foot.

PUMA and Port of Rotterdam agreed that new research was necessary to quantify these differences – in particular for the rock grades that will be used for the Maasvlakte 2 project.

### Test pit

For this purpose a test pit was dug out on a construction site near the Yangtzehaven. Layers of 20-135 mm, 5-70 kg, 150-800 kg and 1-10 t were placed in the test pit with a minimum thickness of 2 times the nominal stone diameter. A natural roughness of the bed was simulated.

The bottom of the pit consisted of a flat area and a 1:7 slope. Slopes on the side were respectively 1:2 and 1:1.5 (Figures 3 and 4).

First measurements were performed in a 1x1 m grid with a semi-spherical foot having a diameter of half the nominal average stone diameter ( $D_n/50$ ). This measurement gives a reference level of about 10-15% below the top of the rocks. With an ingenious design the point measurements were simultaneously carried out using the same rod with the semi-sphere on exactly the same geographical location (Figure 5).

In addition, measurements were performed using a square plate of 1 m<sup>2</sup> ( $\pm 4 \times D_n/50^2$ ). For the 1-10 tonne a 4 m<sup>2</sup> plate was used. During construction of the stony dune with block dam

it was the intention to also use measurements carried out by cranes using their bucket or grab. The position is calculated within the Crane Monitoring System (CMS) and thus can be used to log the level of the rock surface. This method was also tested in the pit (Figure 6).

Static and mobile laser measurements, including a helicopter using the FLI-MAP (airborne laser scanning system of Fugro) system, concluded the test.

After the dry measurements, the test pit was flooded and a small survey vessel (Figure 7) was used to perform test with 6 different types of multibeam systems, a single-beam system with a standard and narrow beam transducer and an Echoscope (Figure 8). Lines were sailed

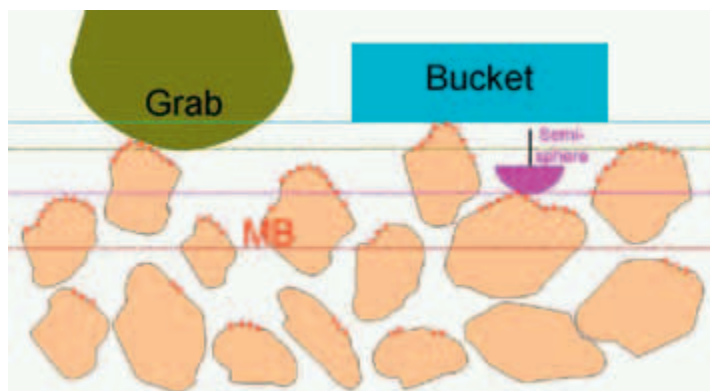


Figure 5. Level as registered by the different survey techniques.



Figure 6. Measurement with semi-spherical foot and point measurement carried out on 150-800 kg rock grade.



Figure 7. Survey vessel Seapilot in the background carrying out a survey in the test pit. The Trimble SPS 930 Robotic total station was used to monitor possible variances in RTK height onboard the survey vessel.

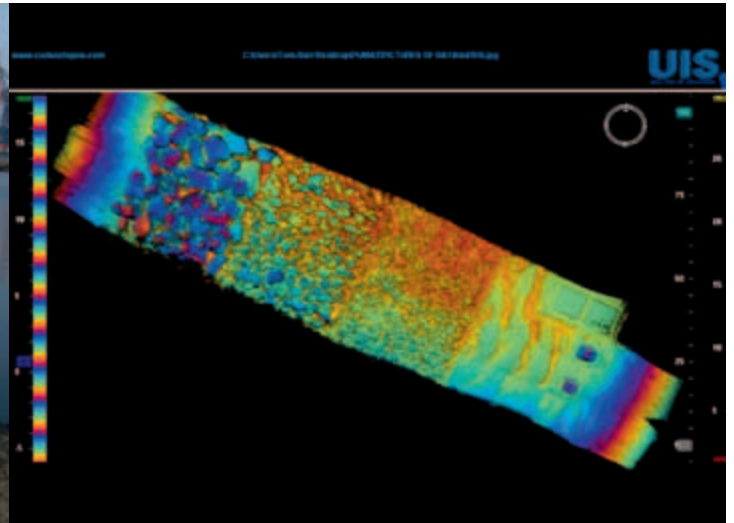


Figure 8. Results obtained from the CodaOctopus Echoscope 3D sonar.

with 100% overlap and the transducers mounted at a height of approximately 4 and 6 metres above the test bed. Swath width was reduced to 90°.

A 1x1 m grid was filled with multibeam data which had the same orientation and origin as the land survey data. The centre of the grid cells are corresponding to the topographical survey grid. A resulting correction table was established for each rock gradation with corrections for the various types of survey such as multibeam, single-beam, laser systems and CMS measurements. All correction values refer to the semi-sphere as a reference. When discussing results, it is important to define a reference level to which the results obtained can be compared.

### CHALLENGES

The construction of the hard seawall presented quite a few challenges for the PUMA team. One of PUMA's goals was to carry out as much work as possible with land-based machinery. This would have the advantages of working more accurately and almost continuously, whereas floating equipment is much more dependent on weather conditions (Figure 9).

### Blockbuster

The Blockbuster (Equilibrium Crane) has been custom built to meet the project requirements. One of the main design criteria for the Blockbuster was the necessity to place 40-tonne concrete blocks at a distance of approximately 50 m within 0.15 m accuracy

(Figure 10). Already at an early stage a team was formed to develop a unique Crane Monitoring System (CMS) that would provide the operator with all the information and tools needed to comply with the design criteria during construction. Because of the dimensions of the crane and the conditions in which it would work special care was taken in choosing reliable sensors that would feed the CMS system with all the information needed (Figure 11).

Above the king pin of the crane a survey mast was placed with a GNSS antenna exactly in the center. A second GNSS antenna was placed near the end of the boom. The second antenna was thought to provide a more accurate starting point of the bucket or block clamp position calculation.

Further on, the baseline between the two antennas supplies a heading which can be



Figure 9. Three specialised land-based machines used at Maasvlakte 2: Blockbuster, Hitachi 1200 and Condor.

Figure 10. The Blockbuster standing behind the temporary protection of the work road and placing a 40-tonne concrete block in the hard seawall.



used as a backup system. The main device that provides the heading, pitch and roll information is an Octans IV. The boom and stick angles are measured with rotation sensors. When the crane was assembled, a thorough survey was carried out to determine the geometry of the crane. After the first checks it appeared that the end of the stick could be positioned well within 0.10 m by using the main GNSS antenna in the center of the crane.

The next step was to accurately calculate and present the position of the block which is positioned in the clamp below the end of the stick. The additional computations needed were divided into the computation of the tilt angle of the clamp suspension, the attitude and position of the clamp, the translation offset for the position of the clamp from the taut wire system and the position of the block in the clamp. With these additional calculations

it was proved to position a block meticulously within the design criteria of 0.15 m (Figure 12).

Presentation of the blocks is done through the CMS system in a 2D and 3D environment. A target control system assists the operator during placement of the blocks.

To monitor any movement of the undercarriage while the crane is not driving, an

MRU was fitted. During the construction process both pitch and roll were constantly measured. Any sudden changes, or slow movement in a fixed direction over a longer period of time, trigger an alarm. The alarm may indicate the undercarriage is sliding away which can lead to an unsafe situation.

Although the as-placed position of a block is logged three dimensionally in the CMS system it was deemed necessary to register the as-built situation with a conventional survey method. In addition, the 150-800 kg armour layer which is partly placed by the Blockbuster needs to be surveyed before the blocks are positioned.

### Condor

Again the goal was to carry out these surveys from land which provided a new challenge for the PUMA team. As the production process was on a critical time path it was decided not to mount any survey equipment on the Blockbuster itself. Various options were considered taking into account that surveys partially had to be carried out in extreme shallow water with less than 2-m water depth. In addition surveys should possibly be carried out with current speeds up to 5 m/s and a significant wave height up to 2 m.

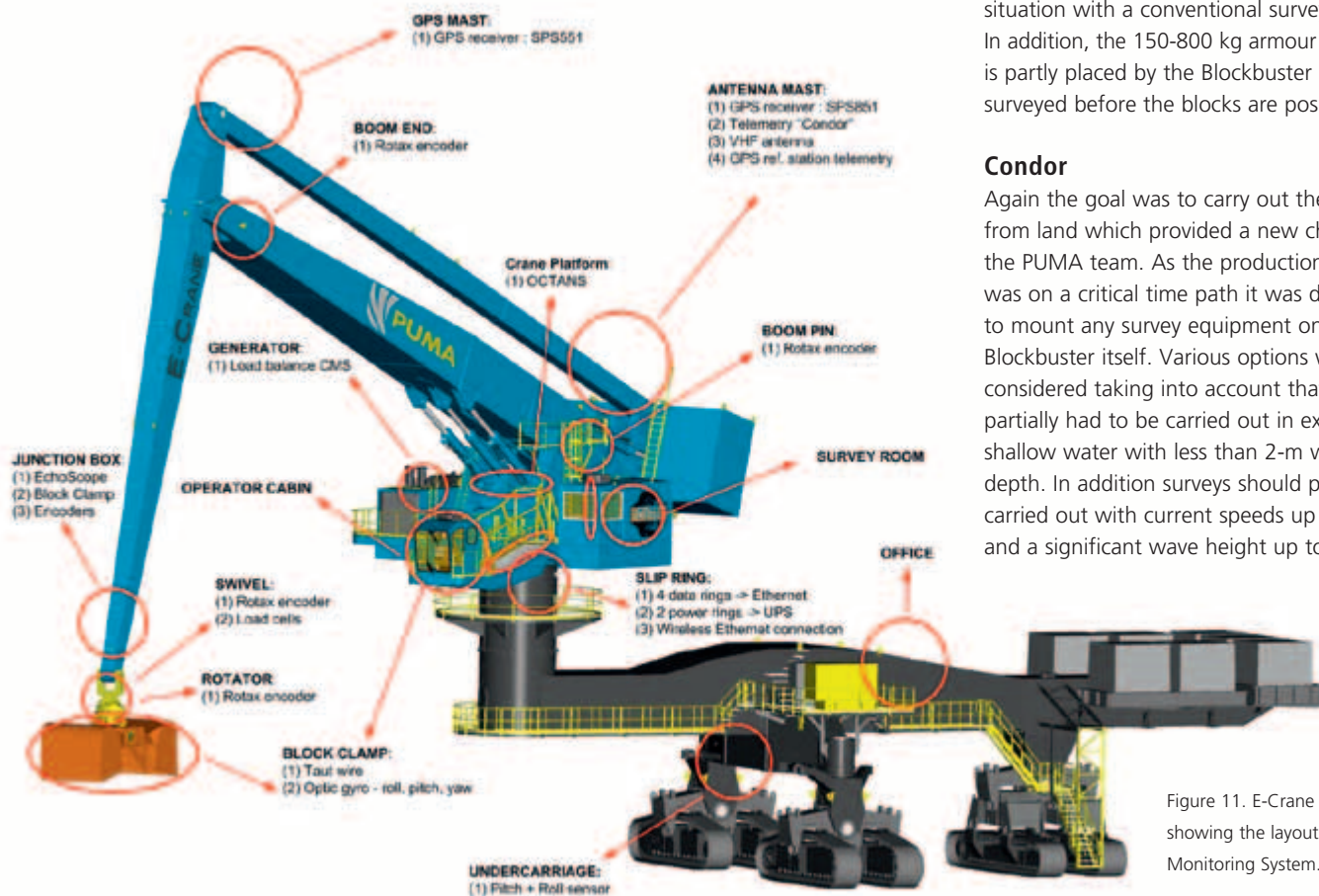


Figure 11. E-Crane "Blockbuster" showing the layout of the Crane Monitoring System.

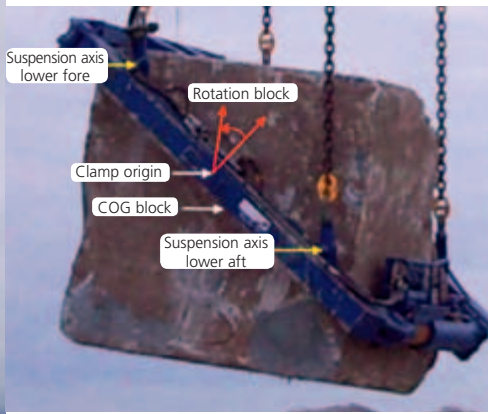


Figure 12. Left: The swivel axis below the end of the stick, pivot axis and taut wire system. The taut wire system measures by means of a wire the distance and angular offset to the block clamp from a fixed point located below the swivel. Above: Block clamp suspended by chains.

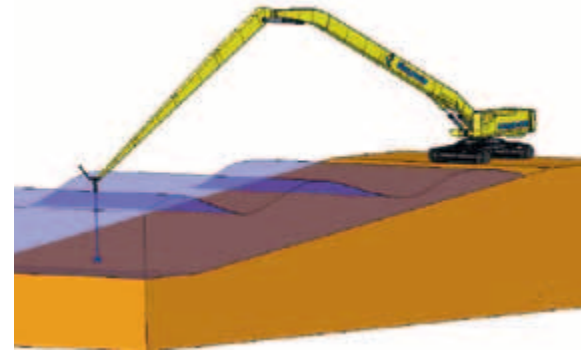


Figure 13. The Condor survey crane has an unusually long 46.5-metre reach.

Tower cranes and crawler cranes were first considered. Hydraulic excavators were ruled out at first because they would be more expensive and could not have the reach that was necessary. On the other hand, a hydraulic excavator would provide a sturdy platform which could withstand the hostile environment of the North Sea. Engineering was pushed to the limits which led to the construction of a specialised survey crane called Condor with a massive 46.5-m reach. The basis is a Cat 385C with a widened undercarriage. A double cabin was fitted to provide ample workspace for the surveyor (Figure 13).

One of the limitations of the Condor is its reduced lifting power of only 750 kg. Hence a 7-m-long lightweight frame was designed which consists out of a 5.5-m-long lightweight aluminum middle section, a stainless steel cage at the bottom to fit the

survey equipment and a coupling piece at the top of the frame (Figure 14).

Accurate positioning proved to be the next challenge. To rule out any loss in accuracy caused by angle sensors on the boom and stick the antenna was placed on top of the survey frame. This way all sensors would be fitted on one frame, with relatively small lever arms, which would be beneficial for the overall accuracy of the system (Figure 15).

After having studied the behaviour of various kinds of multibeam systems on rubble mound structures in a purpose-built test facility, the choice was made for an R2Sonic 2022 multibeam (Figure 16). Alternatively, a CodaOctopus Echoscope system for underwater inspection purposes can be installed in the protective cage.

The compact multibeam has “on the fly” selectable swath coverage from 10° to 160° and focuses 1° x 1° beam widths. A mini sound velocity probe is mounted next to the transducer to do the receive beam steering, which is required for all flat array sonars. Near the end of the stick a small winch is mounted to lower a sound velocity profiler. The profile is used to compensate for any ray-bending effects through the water column.

As the Maasvlakte 2 construction site is located next to the shipping channel Nieuwe Waterweg, the artificial mouth of the river Rhine, changes can be expected in the sound velocity profile caused by temperature variations in the water column or a mixture between fresh and salt water. Heading and motion data are provided by an Octans 3000 which is mounted directly above the R2Sonic.



Figure 14. Protective stainless steel cage with on top the Octans 3000 subsea gyrocompass and motion sensor.

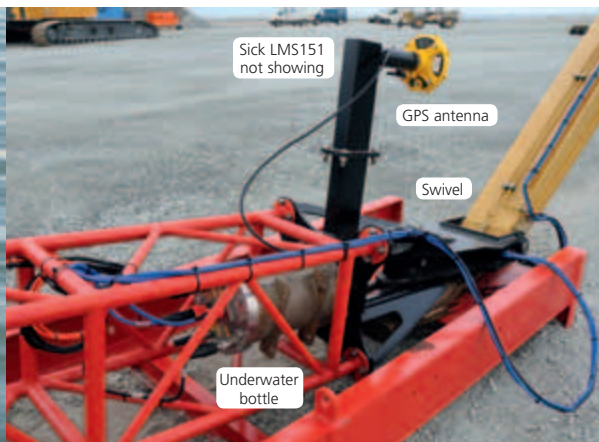


Figure 15. The top part of the measuring pole: A custom-built underwater bottle providing power and communication to all equipment is mounted on the frame. The SICK LMS151 laser scanner is not visible here.

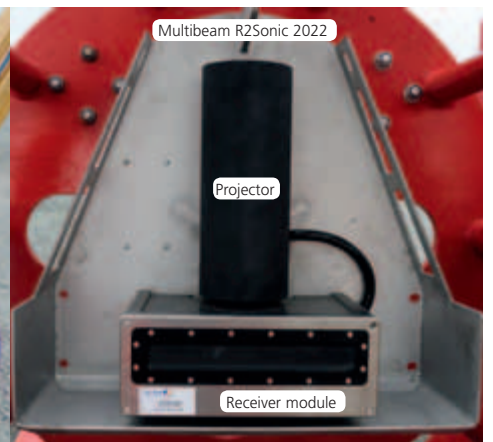


Figure 16. The multibeam R2Sonic 2022 is mounted on the lower part of the measuring pole inside the protective cage.



Figure 17. Image from the frame-mounted camera.

Next to underwater bathymetric measurements, surveying the part of the block dam that is lying above water was also required. For this purpose a SICK LMS151 laser scanner was mounted directly below the GNSS antenna pointing vertically downwards. The scanner works with a class I infrared laser (905 nm) and has an opening angle of 270° and 0.25° beams.

In some situations the crane operator could not see the location of the protective cage with reference to the underlying area. A camera was placed to provide the operator with visual information so any contact between the frame and the blocks could be avoided (Figure 17).

During the construction of the block dam various situations were recorded. Before placing blocks 1, 2 and 3, the underlying 150-800 kg was surveyed including part of the 1-10 tonne toe construction (Figure 18). Because the work front was kept relatively small such a survey was generally performed, processed and verified within less than 1 to 2 hours. If the construction was within tolerance the blocks were placed into position. Afterwards the as-built situation was registered by the Condor.

The next step was again to survey and verify a part of the 150-800 kg layer. If within tolerance the blocks 4 to 7 were placed into position. High tide was used to perform the as-built survey of the blocks (Figure 19). The crest of the block dam is surveyed with the laser scanner (Figure 20).

Every 50-m section of the breakwater was handed over to the client including a

combined 3D model of the multibeam and laser scan data (Figure 21).

During the execution phase of the project the design of the survey frame was optimised by adding a rotator between the stick pin and the upper part of the survey frame. This makes it possible to survey not only perpendicular lines to the coast, by moving the boom and stick, but also parallel lines can be surveyed by swinging the crane from left to right.

The survey crane proved to be a valuable tool during the construction of the stony dune with block dam. By providing almost instant survey results to the operators and engineers the efficiency of the Blockbuster was improved. From August 2010 through January 2012 the Condor worked almost continuously, 24 hours a day, 7 days a week.

Significant wave heights encountered during operational hours:

Hs < 0.5m	40%
Hs > 0.5 & < 1.0m	27%
Hs > 1.0 & < 1.5m	15%
Hs > 1.5 & < 2.0m	11%
Hs > 2.0m	7%

The SICK LMS 151 laser scanner turned out to be a helpful survey tool. Besides surveying the crest of the block dam it was also used to measure stockpile quantities. Owing to the size of some rock gradations measuring these piles on foot is unsafe. With the Condor survey crane these surveys could be carried out accurately and within a relative short time.

Because the Condor could only move at a pace of approximately 2.5 km/h, travel time to the stockpile area became an issue and an



Figure 18. Multibeam survey after the placement of the first 3 blocks.



Figure 19. Multibeam survey on the 1-10 tonne toe structure and the second layer of blocks below the waterline.



Figure 20. Laser scan survey of the crest blocks. Additionally the survey vessel will survey the remaining part of the 1-10 tonne toe structure.

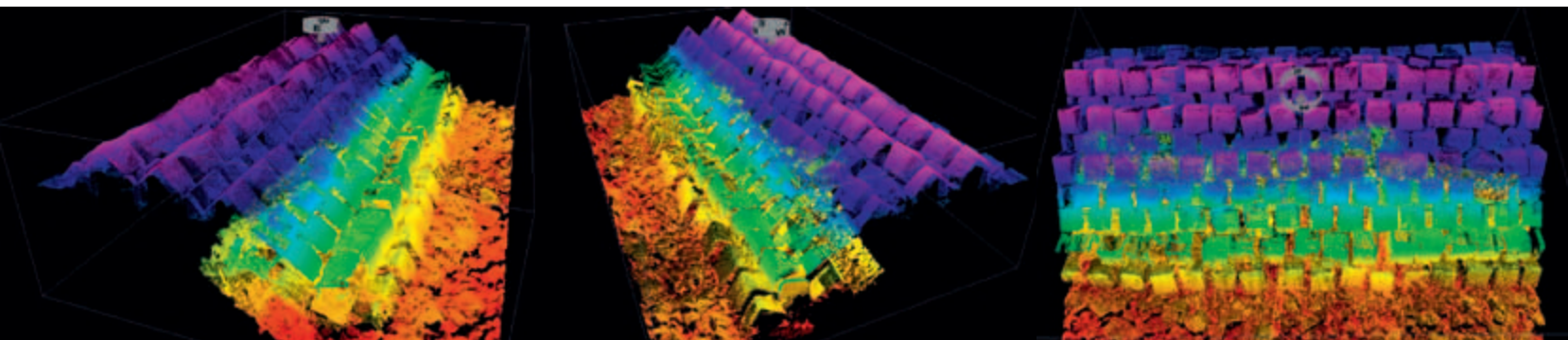


Figure 21. From left to right, side views east and west and front view from the combined multibeam and laser scan surveys.

alternative was sought. All the components needed for a laser scan survey were built into a small aluminum box that was mounted on various equipment, such as the CAT980 Wheel loader and Manitou MT1440 telescopic forklift (Figure 22). Via a WiFi connection the computer in the box was controlled by a surveyor.

After gaining experience with this method, the project bought a John Deere 6200 tractor that was only used for survey purposes (Figure 23). Nowadays the tractor is still used on a daily basis to cover large terrains in a short time and with full coverage. To indicate, an area of 20 hectares can be measured within 30 to 60 minutes.

### Recycling of the block dam

Some 20,000 blocks are reused from the existing Maasvlakte 1 block dam. The backhoes *Nordic Giant* and *Wodan* were mobilised to the Maasvlakte 2 project to remove the 40-tonne blocks and 2 million tonnes of rock fill. A special ripper tool was developed by PUMA so each block could be carefully extracted (Figure 24).

Above water this was already quite some challenge. If the correct pressure was not applied at the correct place the possibility that the block would fall during the extraction process, causing damage to the backhoe or transport barge, was significant. Along the way modifications were performed to optimise grip on the blocks.

Below the water surface, where the majority of the blocks are located, the operators had no visual information which made it extremely difficult to position the ripper tool correctly around the block. In particular the danger was that the ripper tool would be damaged by moving blocks. From the start it was clear that a normal underwater camera system would not be a solution in the murky waters that surround the breakwater and that an acoustic viewing system would be necessary. At the Ras Laffan Northern Breakwater project both Boskalis and Van Oord had gained experience in safely and accurately placing 37,000 single layer armour protection units, called Accropodes™, with help of a Coda Octopus 3D Echoscope system. This innovative solution

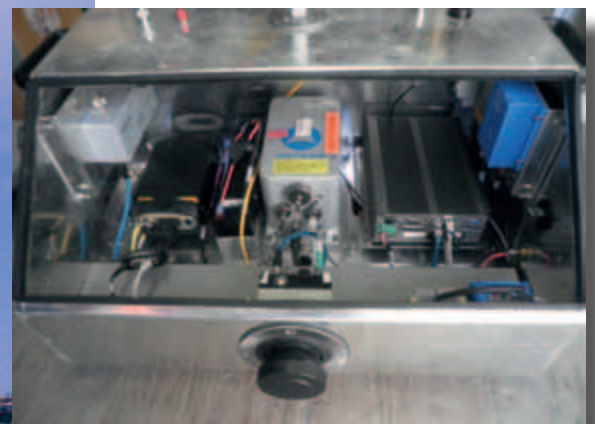


Figure 22. From left to right: The Trimble SPS851 GNSS RTK receiver, Octans surface gyrocompass and motion sensor, SICK LMS151 laser scanner and ruggedised computer.

Figure 23. John Deere 6200 tractor lifting the aluminum box which contains the laser scanner.





Figure 24. Left: Backhoe Wodan extracting a block from the Maasvlakte 1 block dam. Middle: Close up of the Wodan’s ripper tool holding firmly to a 40-tonne concrete block. Right: A 40-tonne block is safely released on to the transport barge.

resulted in increased production efficiency while at the same time safety was improved. The same technique was adopted on the Maasvlakte 2 project.

The Echoscope generates over 16,000 beams and has an opening angle of 50° (375 kHz) in both horizontal and vertical directions producing instantaneous three-dimensional sonar images of both moving and stationary objects. The Echoscope is mounted in a frame that is attached to the front of the pontoon of the backhoe. The frame is equipped with two electrical servo motors which can follow the position of the ripper tool in the horizontal plane (yaw) and vertical plane (pitch). The automated tracking of the ripper tool is controlled from the Crane Monitoring System (CMS).

Within the system certain parameters can be set to prevent the frame tracking the ripper tool when it only moves a few degrees or is lifted out of the water. For this specific job a new feature was added – the Echoscope-UIS™ software – to present the stick and ripper tool as 3D models with information from the CMS. This additional information was especially useful to the operators of the backhoe as it gives a clear picture of the position of the ripper tool with reference to the acoustic presentation of underwater objects (Figure 25).

**Airborne systems**

Because of the vast area covered by the project PUMA has always looked at new survey techniques that could improve the way the daily surveys are conducted. Quantity,

quality and safety are some of the parameters that play an important roll in this matter. Updates of the reclamation areas, stockpile quantities, location on objects such as roads and pipelines should preferably be carried out on a daily basis but given the enormous size of the project this is not always possible.

The pre-survey covering the beach and dunes of Maasvlakte 1 and the old block dam was carried out with Fugro’s airborne laser scanning system (FLI-MAP). Point density at an average flight speed of 35 knots and 100 m above ground level will be 74 points per square metre with an absolute accuracy of around 2.5 cm. During the course of the project several other FLI-MAP surveys have been carried out to monitor the behaviour of the block dam and stony dune.

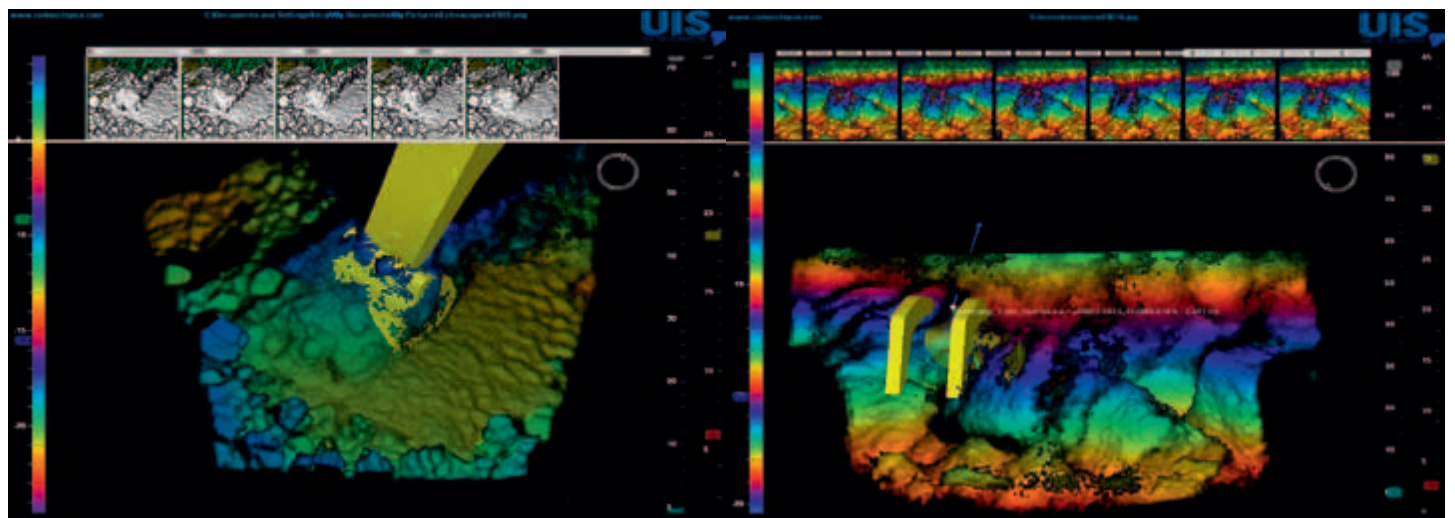


Figure 25. Left: 3D model presentation of the stick and bucket while removing riprap. Right: 3D model presentation of the ripper tool while removing a 40-tonne block.

For the day-to-day surveys this method is relatively expensive and results are not available instantaneously as the technique relies on GPS post-processing techniques.

Early in 2010 a test was performed with a Gatewing unmanned aircraft. Unfortunately the prototype crashed near the Maasvlakte 1 block dam. Two years later a new test was performed by Geo Infra with a production model called X100 (Figure 26). The 2-kg system with a shock-absorbing structure is powered by electric propulsion and carries a calibrated camera. Flights and landings are conducted in a fully automated manner and according to a pre-programmed flight plan.

No piloting skills are required to fly the Gatewing X100. The obtained accuracy with this system is within 5 cm (x,y) and 10 cm (z). For the PUMA project this new technology came too late but it would certainly be an alternative to carry out daily surveys over the immense area of Maasvlakte 2 (Figure 27).

## MILESTONES

### Closure soft sea defence

On July 11, 2012 a major accomplishment occurred when the last gap in the soft sea defence was closed in the presence of Her Majesty Queen Beatrix of The Netherlands. Since the construction of the Philipsdam 25 years ago this was the first large sand closure and unique in its kind.



Figure 26. The Gatewing X100 ready for takeoff.

A thorough study preceded the closure in which all aspects were analysed. During the course of June 2012 a “spoiler” was constructed on the north side of the closure area to divert the current and provide the lee side for the trailing suction hopper dredgers while discharging. Throughout the week before the closure an underwater bund was constructed by placing sand to about  $-8$  m NAP. Next the bund was made higher till a level of approximately  $-1.5$  m NAP.

This was done with a process in which the sand mixture is discharged as close as possible over the bow coupling (as opposed for instance to rainbowing in which sand is spouted in an arc as far as possible). The TSHD discharges and spreads the sand mixture as slowly as possible at a low speed and the material is thus deposited right in front of the bow. In this way the material can be accurately spread within the design tolerances.

Next the bund was widened to 300 m. On the day of the closure the seaside part of the underwater bund was raised to  $+2.0$  m NAP with a combination of cutter suction dredger Edax discharging by landline from the north side and TSHD *Vox Maxima* and *Prins der Nederlanden* discharging by landline from the south side (Figure 28).

Despite the difficult circumstances the survey department managed to provide the operation and engineering department with vital information on seabed changes and current profiles on a day-to-day basis.

### Opening passage to Maasvlakte 2 from Yangtzehaven

On November 25, 2012 another milestone was achieved when access to the Maasvlakte 2 was created from the Yangtzehaven. After closing the sea defence on July 11, a lake was



Figure 27. Two views of the Gatewing X100 results displayed with Autodesk Infrastructure Modeler. Left: Part of the block dam and stony dune. Right: The stony dune with sand core and clay protection.



Figure 28. Closure of the soft sea defence on July 11, 2012. TSHDs from far left to right: *Vox Maxima*, *Prins der Nederlanden*, *Crestway* and *Ham 317*. Insert: Closing the gap, the land-based equipment spreading sand.

created which had no tidal influences. In the Yangtzehaven the tide varies in-between  $-1$  and  $+1$  m NAP. Because of the size of the interior lake significant flow rates can be expected during the first stage of the breach. During slack tide the remaining

piece of land separating Maasvlakte 2 from the Yangtzehaven was excavated down to  $+0.40$  m NAP, the same as the level in the interior lake.

After the tide started to rise again and the flow increased, sand was washed away from

the dam making it wider and deeper. Cutter suction dredgers *Edax* and *Zeeland II* (Figure 29) kept on dredging continuously on both sides of the opening to increase its size. During the next days the opening was made wider and the rates of the water flow reverted to normal.



Figure 29. Top: CSDs *Edax* and *Zeeland II* at work while creating the passage to Maasvlakte 2 from the Yangtzehaven. Below: Stormy weather conditions at the stony dune and block dam, November 25, 2012.

## CONCLUSIONS

The Maasvlakte 2 expansion project is extensive and presented a number of challenges which were met by innovative design, survey techniques and equipment. These included:

- The use of Pleistocene sand which is a coarser grain of sand and allowed a steeper foreshore to be constructed which therefore needed less sand.
- A large scale of rock and concrete blocks were reused from the Maasvlakte 1 block dam which contributed to a cost reduction and made the design sustainable.
- One of PUMA's goals was to carry out as much work as possible with land-based machinery, which has the advantage of working more accurately and almost continuously, as compared to floating equipment which is much more dependant on weather conditions: the results was the Blockbuster able to lift 40-tonne concrete blocks.
- The development of a unique Crane Monitoring System (CMS) that provides the operator with all the information and tools

needed to comply with the design criteria during construction.

- A new feature was added to the Echoscope – the Echoscope-UIS™ software – to present the stick and ripper tool as 3D models with information from the CMS.
- Engineering was pushed to the limits when a specialised survey crane called Condor with a massive 46.5 m reach was constructed.
- Recycling the block dam from Maasvlakte 1 required improving the grip of the backhoes and special acoustic viewing systems as underwater cameras were not useful in the murky waters.
- An airborne system called the Gatewing was tested during the start of the project, but was not ready for use until the last construction phase of Maasvlakte 2. The later model Gatewing X100 does however represent a breakthrough which can clearly be applied to future projects.

On July 11, 2012 the soft sea defence was closed and on November 25 access to Maasvlakte 2 through the Yangtzehaven was achieved.