Innovative Technique for Single Layer Armor Unit Placement

An example of Increased Production Efficiency while Improving Health and Safety

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Introduction

Innovation, in many cases, stems from analysing real and immediate complex engineering problems. One such example of the need for an innovative solution came from the breakwater armouring work being carried out at the new LNG terminal at Ras Laffan in Qatar. The Ras Laffan Northern Breakwater Contractors (RLNBC), Boskalis and Van Oord, was faced with the task of safely and accurately placing 37,000 single layer armour protection units, called Accropodes™, up to a depth of 11 metres below Chart Datum. The innovative solution adopted by RLNBC resulted in increased production efficiency whilst the health and safety was improved.

The Accropode is a single-layer artificial armour unit developed by Sogreah. In order to obtain the required interlocking between the units, Accropodes have to be placed accurately in a predefined grid. These Accropode placement grids are provided by CLI (Concrete Layer Innovations).

This paper will start with a short introduction of the Ras Laffan Northern Breakwater project. In order to demonstrate the benefits of the innovative technique, the conventional way of placing Accropodes is briefly discussed. Thereafter, the innovative technique will be discussed in more detail and the benefits on both production and safety will be considered.

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FIGURE 1: SATELLITE PHOTO AUGUST 2006 (LEFT) AND MARCH 2009 (RIGHT)

The Ras Laffan Northern Breakwater Project

The Ras Laffan Port Expansion Project concerns the expansion of the present LNG port of Ras Laffan in Qatar for the client "Qatar Petroleum". After the expansion the LNG port will be the largest in the world. Figure 1 shows the expansion plan.

The scope of the expansion works was:

- 20 million m^3 dredging
- 27 million m^3 reclamation
- 10 km northern breakwater
- 10 km southern breakwater
- 2 x 6km causeways

The total required quantity for the two breakwaters and causeways is 26 million tonnes of rock and 273,000 concrete elements (Antifers and Accropodes).

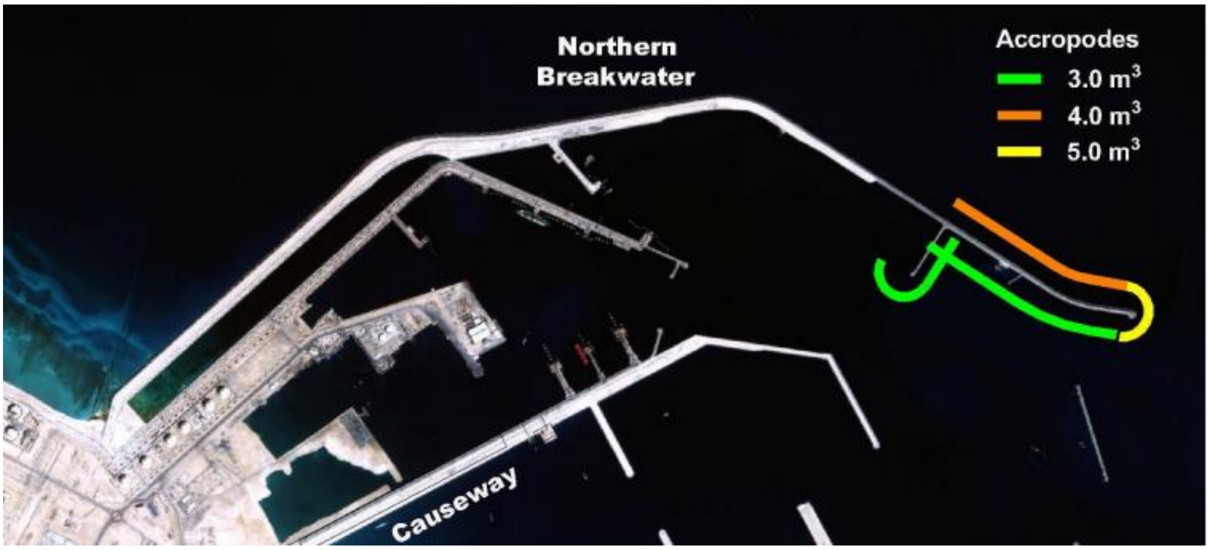

FIGURE 2: SECTIONS COVERED WITH ACCROPODES

The port expansion contract was divided into several sub-contracts. Construction of the northern breakwater and the two causeways was subcontracted to Ras Laffan Northern Breakwater Contractors (RLNBC). Construction of the northern breakwater had started early 2007 and was completed in April 2009.

This paper focuses on the placement of Accropodes on the northern breakwater. The sections involved are enlarged in Figure 2. The green sections on the harbour side consist of 3.0m^3 Accropodes, the orange section on the seaside consists of 4.0m^3 Accropodes and the yellow section on the roundhead consists of 5.0m^3 Accropodes. A typical cross section of the breakwater is given in Figure 3.

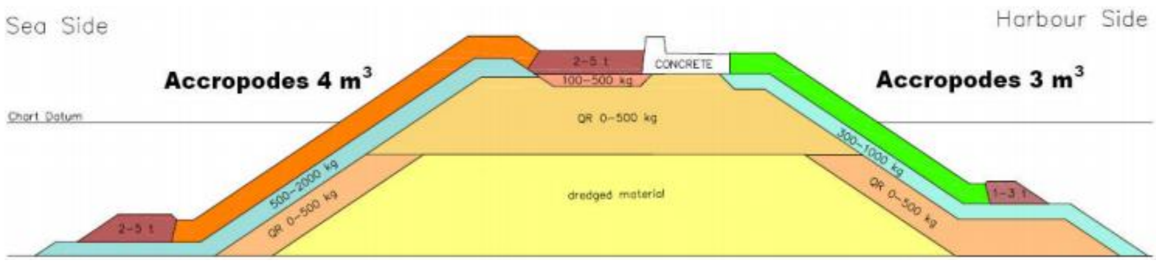

FIGURE 3: TYPICAL CROSS SECTION OF THE NORTHERN BREAKWATER

The length of the breakwater section covered with Accropodes is 1,760m and the spur perpendicular to it has a length of 500m. Table 1 gives the amounts of placed blocks per size. Placement of these 37,000 Accropodes started in January 2008 and was finalized in November 2008, utilizing a spread of 3 hydraulic excavators, of which two were utilized for placement below the water line and one for placement above the water line.

Accropode Size	**Number of Accropodes placed by RLNBC**	**Percentage of Total**
3 m^3	18,348	51%
4 m^3	16,271	44%
5 m^3	1,734	5%
Total	36,353	100%

TABLE 1: AMOUNT OF ACCROPODES AS PLACED PER SIZE

Conventional Ways of Placing Accropodes

The most common way of placing these kinds of concrete armour units is by using a crawler crane or hydraulic excavator provided with a sling or chain in which the armour unit can be lifted into place. The disadvantages of these placing methods are the:

- Relatively large motions of the armour unit in the horizontal plane
- Uncontrolled rotation of the unit when using a crawler crane
- Inability to rotate the unit when using a hydraulic excavator and
- Unsafe working situations due to direct human interaction during placing

FIGURE 4: CONVENTIONAL ACCROPODE PLACEMENT DUNG QUAT BREAKWATER, VIETNAM

Naturally, the integrity of the breakwater is dictated by the rules governing the accurate placement of the successive Accropodes in a predefined grid. Therefore, the decision to release and hence place an Accropode under water cannot be taken without the assistance of divers.

An example of a breakwater construction project with Accropodes placed in the conventional way is the Dung Quat project in Vietnam. The Accropode sizes used ranged from $2m^3$ to $12m^3$. All Accropode sizes were placed by crawler cranes. Figure 4 shows two pictures of the breakwater construction in Dung Quat in Vietnam. Some relevant characteristics of this project are:

- Many times the riggers helped the Accropode to rotate to the desired orientation by pushing against it. This is an operation with a high safety risk factor.
- A hook with latch was used to release the block by diver interaction after placing.
- The placement productions were disappointing and below the average placing rates as indicated by Sogreah. This might have been caused by the stringent safety standard which slowed down both placement during low visibility and the releasing of units.

Furthermore, it was recognised that good reliable communication between the divers and the crane operator was essential. Instead of training them as well as possible, it was recommended that a system for placing Accropodes without divers for both safety and cost reasons was developed.

Rotators

Since the start of the breakwater project, RLNBC has been focussing on a working method and placing system to increase the production rates whilst at the same time improving the safety environment by reducing the physical human interactions.

FIGURE 5: ROTATOR SYSTEM WITH DETAIL OF RELEASING SYSTEM (RIGHT)

The two basic starting points resulted in the development of an unconventional and innovative placing system. The innovative solution developed by Van Oord was threefold:

- Considering the overall production schedule of the project, the choice was made to use hydraulic excavators to obtain higher production rates and accuracy compared to crawler cranes, conventionally used for the placement of Accropodes under water.
- A "Rotator System" was developed to be able to rig and rotate the Accropode in multiple ways and to have it released by the operator. This way the need for divers and riggers to assist with rotating and releasing the Accropode during placement was avoided. Whilst it is normal practice for divers and riggers to assist in the placement of Accropodes with crawler cranes, this inevitably increases the safety risks.
- Based on experience during previous projects and the dangers involved, the use of divers for placement and inspection below the waterline was to be minimised. Hereto the excavators were equipped with an Echoscope system and underwater cameras to provide the crane operator with a subsea view of the unit and the breakwater section under construction.

The patented "Rotator System" is installed at the end of the excavator arm and is a hydraulic device allowing the rotation of the units, that enables the operator to change the orientation of the block without having to remove the chain. The releasing system is activated from the hydraulic excavator with a hydraulic cylinder that simplifies remote release of units below the water. The Rotator System and the releasing system are shown in Figure 5.

Object Tracking System

Several object tracking systems were considered but were deemed inappropriate due to factors such as poor to zero visibility, inadequate field of view, 2D representation of a 3D space and the inability to accurately place and rotate an Accropode with respect to its neighbours. Finally these trials resulted in using a combination of an Echoscope® system and under water cameras.

Echoscope® 3D Imaging Sonar

Introduction

The Echoscope sonar can generate a real time three dimensional image from one acoustic transmission, or ping. Unlike the single beam echosounder, which has one returning range and bearing point, or the 2D multibeam echosounders, with which circa 150 returning range and bearing points are calculated, the Echoscope can generate over 16,000 range and bearing points per acoustic ping. This is diagrammatically shown in Figure 6. The actual sonar will return a footprint containing 128x128 points or 16,384 beams per ping. The Echoscope insonifies a volume which measures 50˚ x 50˚. Within this acoustic volume an instantaneous 3D image is generated from just one ping of data. The image is constructed from 16,384 sonar returns.

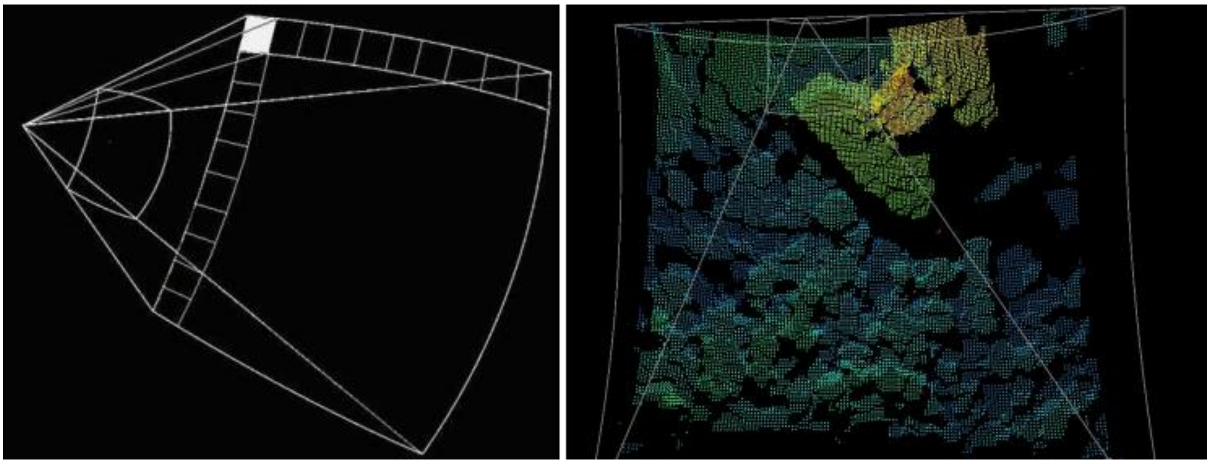

FIGURE 6: SONAR HEAD CENTRE POINT AND ONE WHTIE BOX SHOWING AN INSONIFICATION POINT (LEFT PICTURE) AND FIRST IMAGE OF THE SUBSURFACE ACCROPODE USING THE ECHOSCOPE SONAR (RIGHT PICTURE)

The fact that these 3D images can be generated instantaneously and without the need of positioning, heading or motion reference sensors was seen as an advantage for the RLNBC project.

Initial Tests at the Ras Laffan Northern Breakwater

The Echoscope 3D imaging sonar was first introduced to RLNBC in January 2008. As with any such innovative approach to problem solving the initial deployment methodology was a quick interim measure to gauge the suitability of the sonar.

Even from the early images captured from these initial results, as shown in Figure 6, the benefits to the excavator operator were clear. The front face image of the Accropode was now visible within the insonification (50˚ x 50˚) volume. The position and orientation of the currently hanging block was seen directly from the acoustic returns and not inferred from other types of motion sensor. The background breakwater and any other previously laid blocks could now be seen instantly. This could all be achieved even in zero visibility conditions, which would have rendered cameras unusable. In short, a greater detail of information was being presented to the operator in order for him to make the block release decision.

Advancement in Visualization Techniques

The early results were very promising, but improvements needed to be made. Firstly, sonars are designed to work underwater, where surrounding sea water provides cooling, and not above water and certainly not in the heat of the summer periods of Ras Laffan. Therefore, mechanical shading techniques were introduced on the excavator mounting along with software changes to reduce the current drawn by the sonar, and hence reduce heat, when the sonar came out of the water. Additionally the operators were not sonar experts, so the imagery had to be made even clearer.

As an extension of another development program within Coda Octopus a new version of the software was provided to the operator that contained new sonar rendering techniques, which it was hoped would make the view of the Accropode clearer.

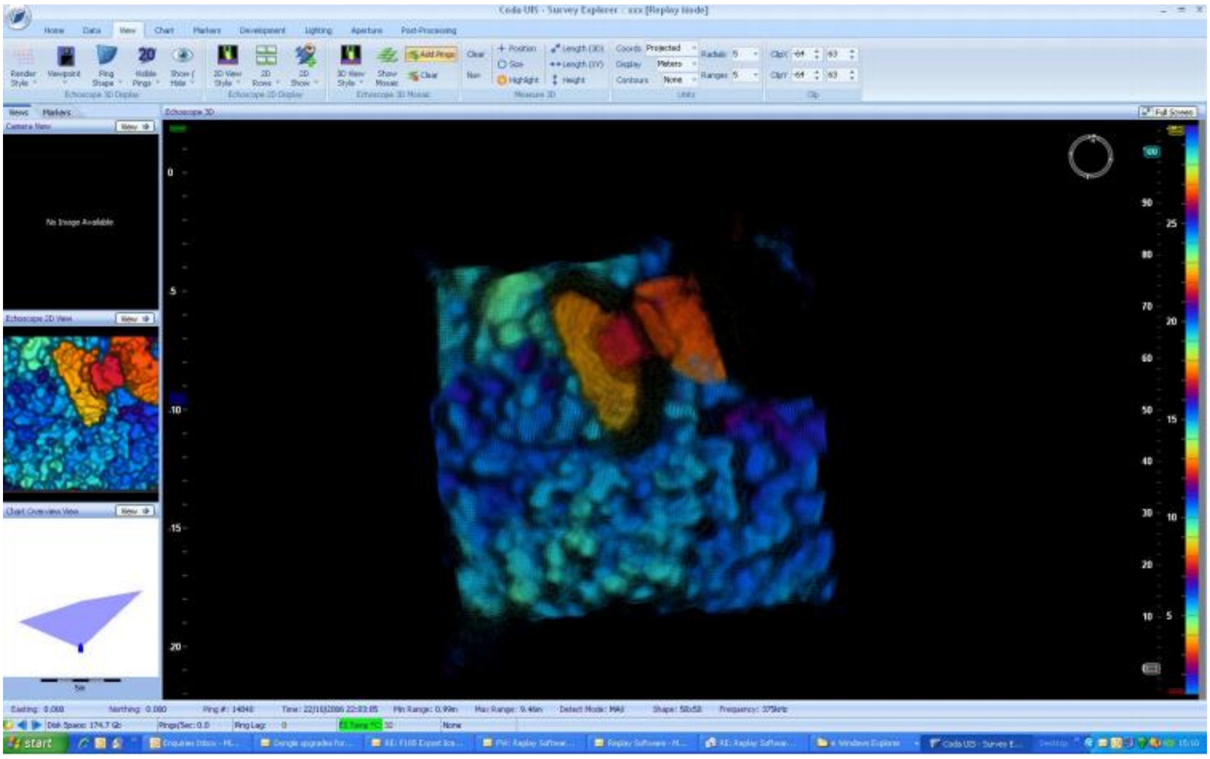

FIGURE 7: NEW STYLE SOFTWARE SHOWING BETTER VISUALIZATION OF 2D EDGE DETECTION

In Figure 7 the real-time 3D sonar data is shown in the main data view window. This 3D view can be rotated by the operator in real-time so that he can visualise from any field of view. Alongside and to the middle is a 2D edge detection view of the same image, but with a static field of view i.e. that of the sonar in relation to the Accropode. This view aims to accentuate manmade shapes by highlighting corners such as those on the Accropodes, when compared to the background seabed or breakwater returns.

As reported later in this document, the step-change improvement in productivity was almost immediate.

Echoscope Construction Monitoring System

Through collaboration between Van Oord and Coda Octopus, it was concluded that far more could be obtained from the interaction between the excavator, the rotator system and the Echoscope.

Firstly, combining the high precision RTK positioning and Van Oord Survey Software (WinCrane) used on the excavator with the sonar returns would enable the operator to locate all blocks, whether currently hanging or previously laid, in their true real-world coordinates.

Secondly, given both the regular shape of the Accropodes and the high resolution imagery from the Echoscope, it was considered that a mathematical algorithm could be developed that could track the Accropode sonar returns in real-time. Were the software able to perform this tracking, then a computer generated model (CGM) could then either be superimposed onto, or replace altogether, the sonar imagery. The advantage of using a CGM would mean the operator could see all sides of the Accropode, with no side being masked by acoustic shadowing. Figure 8 shows the sonar image of a hanging Accropode with superimposed the computer generated model in the figure on the left (note the acoustic shadow on the breakwater background). The figure on the right side is the identical image, but with the sonar returns from the Accropode completely removed. The Accropode is now being tracked in real-time with a CGM.

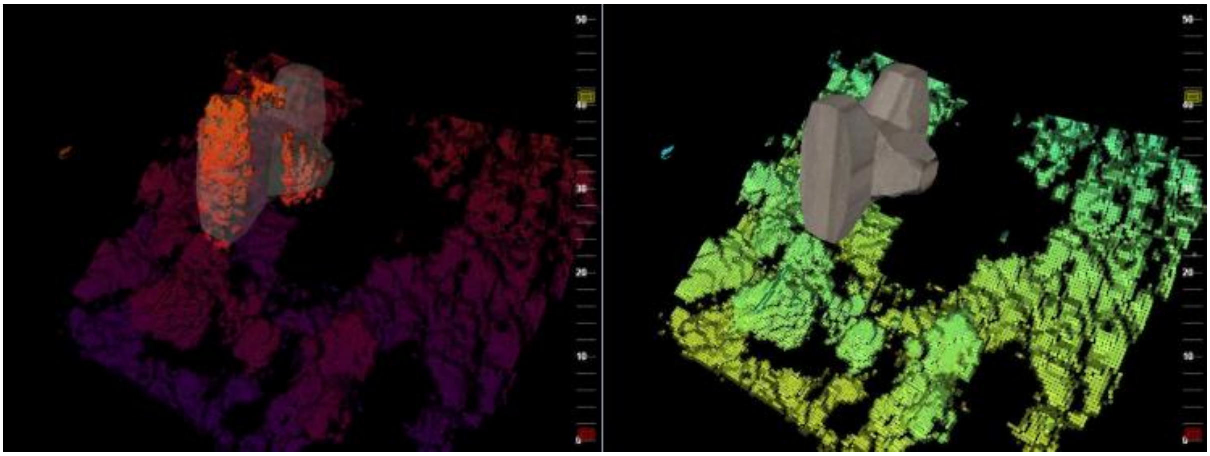

FIGURE 8: SONAR IMAGE AND CGM OF HANGING ACCROPODE

Thirdly, by merging together the automated tracking with the high precision positioning inputs, a full real-time Geographical Information System (GIS) based package could be made. This GIS-based system could then 'save' the CGM of an as-laid Accropode, along with other information such as position, orientation, block serial number, date, time, etc. Furthermore, when the operator came to position the next Accropode he would be able to co-locate the currently hanging Accropode with the previously laid Accropodes, all being done with computer generated models.

Other benefits of the GIS-based approach were to import the breakwater slope model (also known as the TIN or triangular irregular network) which could then act as the backdrop to the laying operation. Additionally, the pre-lay database showing the centre points for all of the

Accropodes could be shown in a chart overview window. This is shown in Figure 9 in which a run-time image showing CGMs of previously laid Accropodes and the currently hanging Accropode is given in the figure on the left (the slope and the pre-lay centre points, circular blobs, are also shown). In the figure on the right, the chart overview image is given showing the centre points of where each Accropode should be laid.

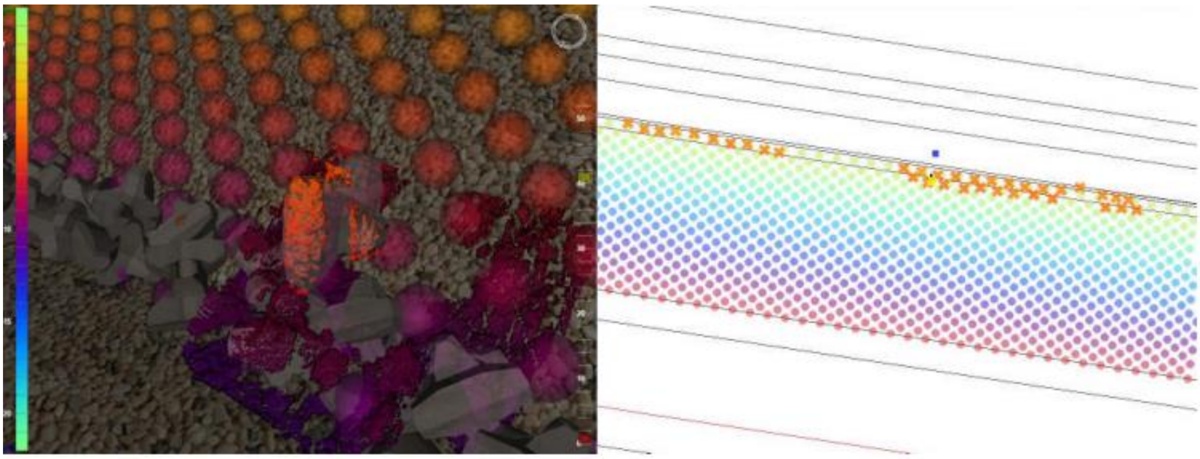

FIGURE 9: RUN-TIME IMAGE (LEFT) AND CHART OVERVIEW (RIGHT)

Underwater Cameras

With the initial software packages for the Echoscope, underwater cameras were required to be used in comparison with Echoscope systems because the view of cameras is easier to interpret. With the software updates the need for the cameras was reduced. However, since some excavator operators had difficulty in understanding the sonar and CGM images and in working with the software package, the use of underwater cameras was still needed and was continued in combination with the Echoscope. One camera was attached to the Echoscope frame the same distance as the Echoscope. The other camera was attached half way. Figure 10 shows a camera image and the Echoscope frame with the mounted cameras.

Placing Method

General

After a block is placed in reach of the excavator by the wheel loader, the block is rigged in one of the 6 different ways according to the CLI documentation. The operator uses his GPS system in combination with the Van Oord Survey Software (WinCrane) to navigate the Accropode to its location in the placement grid. By using the rotator the operator can rotate the block in the preferred orientation. When the block is placed and appears to be in a good position according to the Echoscope/camera information or inspection by diver, the block is 'fixed' by the operator. Next the chain is disconnected by releasing a locking pin on the rotator. The coordinates of the centre of gravity of the block and other relevant data, such as time of placement, are registered within WinCrane.

FIGURE 10: VIEW OF UNDERWATER CAMERA (LEFT) AND ECHOSCOPE FRAME (RIGHT)

Placement Underwater

Placement under water is carried out with an adapted Hitachi 1200 hydraulic excavator with a custom made exceptionally long stick of 14m in order to reach the flatbed level (-11.10m CD) and up to about -3m CD.

FIGURE 11: PLACEMENT UNDERWATER

For the first row placed on the flatberm the correct spacing between two units is of major importance to provide proper space for units to be placed in the rows above. Therefore, a dive inspection is preferable after placement of the first two rows. Afterwards the slope can ideally be built up without intermediate dive inspection until about 5m below the waterline. On the Echoscope screen, the operator can see the Accropode to be placed as well as parts of some previously placed Accropodes, so he can determine the preferred position of the block. If the visibility is sufficient, underwater cameras can help to determine the configuration of placed blocks and slope. Echoscope and cameras can be used up to a level of about 3m below the waterline. When visibility of the camera and Echoscope are not sufficient, diving assistance is needed to provide the operator with “eyes”. Due to the Rotator System the diver does not need to touch the block and can stay at a safe distance during placement.

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Placement Around the Waterline

To place blocks in the area from about -3m CD up to the waterline an adapted Hitachi 1200 with a shorter stick is used. It reaches down to about -5m CD. The area around the waterline is most critical. At the same time placement of the Accropodes just below the waterline is most difficult. The Echoscope and underwater cameras can only be properly used for placement up to 3m below the waterline. When the Accropode to be placed is just under the waterline the Echoscope is protruding out of the water.

FIGURE 12: PLACEMENT AROUND THE WATERLINE

The units just below the waterline need to be placed with the assistance of divers. As with placement under water, the diver only provides "eyes" to the operator.

Placement Above the Waterline

For this placement an adapted Hitachi 870 is used. Placement is visually by the operator and a rigger, whilst placement above the waterline is done without physical interaction between the rigger and the Accropode.

FIGURE 13: PLACEMENT ABOVE THE WATERLINE

Replacing Accropodes

When Accropodes have to be replaced, firstly the chain of the rotator will be replaced by a longer wire rope. The rope has to be put around the Accropode and choked. Underwater this is done by divers; above water a rigger can install the chain. Removing an Accropode from below the waterline takes up to 5 times longer than placing a block.

Production and Health & Safety

The placing production of Accropodes depends on many factors beside the technique or system used, e.g. the feeder supply of the Accropode units, skill of the operators and divers and the capacity of the crane/excavator.

It is therefore difficult to compare production figures for different projects. However, a comparison of average production figures for the complete construction of breakwaters is considered to provide an objective indication of achieved placing productions. In Table 2 these average placing productions are given for various projects and the CLI brochure:

Project	Placing Method	Accropode Size	Avg Production (units/hour)	Max. Production (units/hour)
Dung Quat, Vietnam	Crawler Cranese	$2m^3$ – $12m^3$	2.0	5.0
Scarborough, UK	Crawler Cranes	$6.3m^3$ + $9m^3$	3.5	5.2
CLI Accropode brochure	Crawler Cranes	$4m^3$ – $9m^3$	6.6 ($4m^3$) 5.0 ($9m^3$)	
RLNB, Qatar	Rotator System with Echoscope	$3m^3$, $4m^3$, 5m+	6.0	8.3

TABLE 2: AVERAGE PLACING PRODUCTIONS

From comparison it can be concluded that significantly higher production rates are achieved with the innovative technique.

During the course of placing the Accropode units, the Echoscope software was updated twice and both updates resulted in an increased placing production. In Figure 14, this is visualized for the placing production below the waterline of the $4m^3$ Accropode units on the sea side of the breakwater. This shows that the average placing production increased from 36 to 97, then to 147 Accropode units per day placed by two excavators equipped with the rotator and Echoscope system. It also shows that the wave conditions have a significant influence on the placing production. This is not caused by excavator limitations, but fully by the increased difficulty or even impossibility for the divers to carry out their inspection activities in a safe manner. Taking into account the average operational hours of 43% per week, an average 7.2 units per hour per excavator in the final stage of the project have been placed. This is a placing production which far exceeds the rates achieved on other projects.

Some general remarks about the placement of Accropodes as experienced during the construction of the northern breakwater in Ras Laffan are:

- The placing production is strongly dependent on the skills of the excavator operator, who needs a feeling for placing, needs to understand the principles of Accropode placement and has to be able to interpret the data from Echoscope and video camera. This, for most operators, is a rare combination of skills.

- Placing Accropodes at a roundhead is more time consuming than placing in straight areas. Production losses at the roundhead are up to 50%.
- Even with additional visual equipment for the operator (Echoscope, video cameras) divers are still necessary for verification purposes, for placing around the waterline and for remedial works.

More importantly, the health and safety environment for divers has been improved as the crane operator relies less on the diver's advice during the actual placement process. At the Accropode installation works of RLNBC there were no injuries or casualties at all. The diver's expertise however is still used to finally confirm correct placing of the Accropode. After placing of the Accropode and when the operator believes that, based on the information from the Echoscope and camera, the Accropode is placed correctly, then a diver will inspect the Accropode. After inspection the diver moves away and the Accropode will be released from the supporting sling. This procedure is completed in far safer conditions then when a diver is needed to rotate and release the Accropode, as is the case when placing with a crawler crane.

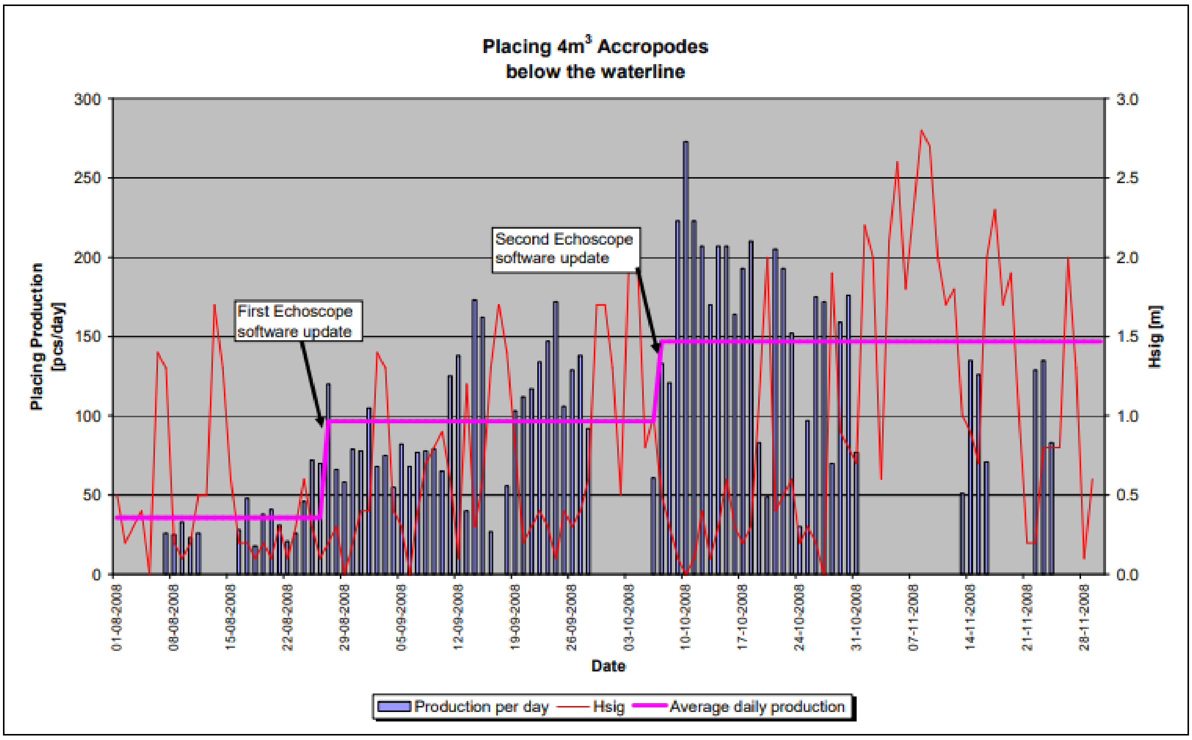

FIGURE 14: INFLUENCE SOFTWARE UPDATES ON PLACING PRODUCTION

Future Developments

Following the successful application of the Rotator System developed by Van Oord in combination with the real-time Echoscope 3D imaging sonar, Van Oord and CodaOctopus are working together on future developments of placing other single layer armour units like CORE-LOC™, Xbloc™, gravitational quay wall blocks and the like, in combination with this sonar imaging technology. A further challenge will be to create a complete system suitable for use on other construction vehicles such as crawler cranes, whilst future plans for the sonar are envisaged to include improvement on range resolution and new rendering techniques for even clearer visualisation of the sonar returns.

Conclusion

Driven by experiences gained using conventional techniques for placing Accropodes on other projects, Van Oord has developed a placing system utilizing a hydraulic excavator. The utilisation of the excavator minimized the uncontrolled large motions in the horizontal plane. Furthermore, on the end of the excavator arm a Rotator System with a hydraulic release system was installed enabling the operator to rotate the Accropode in a controllable manner and to release the supporting sling without the assistance of divers below the water or riggers above water.

The advantages gained by RLNBC from this new and innovative approach to breakwater single layer armour protection construction techniques have led to the realisation of the twin goals of increasing production efficiency whilst improving safety for riggers and especially for divers. An innovative thought indeed.