Determining rock quantities using swathe techniques on Maasvlakte 2

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INTRODUCTION

For the Maasvlakte 2 extension of the Port of Rotterdam a large amount of rock has to be placed underwater under tight specifications in relatively thin layers. The rock is placed both under water as well as above water. In general measurements above water are performed using land survey equipment and are relatively simple and reliable provided a clear reference level is used. The standard method for surveying rock levels is described in CUR 154 [1991] and requires the use of a semi-spherical foot as a reference.

As the semi-spherical foot staff is unusable under water or in the surf zone, echo-sounders are commonly used here. Experience from various projects has shown that the application of modern systems for monitoring dumped rock, however, can be accompanied by problems. Above water the application of laser-based techniques is now starting to be used whilst crane measurement systems are used as an on-the-spot alternative for more advanced survey systems. Each of these systems has its own specific advantages and disadvantages.

Errors in determining rock quantity

One of the most important factors in the construction at Maasvlakte 2 was the determination of the layer thickness. Possible errors in the surveyed thickness are determined by the following factors:

- Definition of the level of the upper surface of the bed / dumped rock to be surveyed in relation to the (mean) level as measured by the surveying system.
- Influence of settling and compression of the ground and penetration of the dumped materials into the ground.
- Inaccuracies in the surveying system.

It is important when discussing results to define a reference level to which the results obtained can be compared. Two (potential) reference levels can be defined: the plane passing through the tops of the stones and the level as obtained by a semi-sphere survey complying to CUR 154 [1991]. CUR 154 specifies a semi-sphere diameter of 0.5 Dn50 (nominal average stone diameter) and measurements in 1x1 m raster. In general the semi-spherical foot is stated to give a reference level of about 10-15% below the tops of the stones.

Available research

In an effort to find out more about the interaction between survey systems and the observed bottom, trials were held in 1999 in Dock VI of the Verolme company in the Botlek at Rotterdam. Initial conclusions pointed towards lower volumes being detected using multibeam surveys than with the semi-spherical foot [VBKO et al, 1999].

As the rock gradations tested in earlier studies were limited and survey techniques have advanced, it was deemed necessary for the Maasvlakte 2 project to extend these studies. Therefore a test-pit was constructed at the Maasvlakte 2 where various stone gradations were surveyed using a wide variety of survey methods [Lekkerkerk and Kol, 2011].

SET-UP OF TEST PIT TRIALS

The methodology used in the test-pit trials of 2010 was essentially the same as that of the dock trials from 1999. The main differences were the stone gradations, scale and survey systems used. The dumped rock in the dock trials consisted of a layer of 10 - 60 kg rock and a layer of40 -200 kg rock whereas in the test pit trials layers of 20-135 mm, 5-70 kg, 150-800 kg and 1-10 t of rock were surveyed.

Layers were applied in the dry to a minimum thickness of about 2- 2.5 times the nominal stone diameter of the gradation concerned. In the dock trials the layers were smoothed; in the test pit trials the roughness of the bed as expected from dumping (about 2 times the nominal stone diameter) was simulated using a crane. In both situations 'clean' rock (no foreign inclusions) was used. In the test-pit four different slopes were created (1:1.5; 1:2; 1:7.5 and 'flat' – i.e. < 1:10).

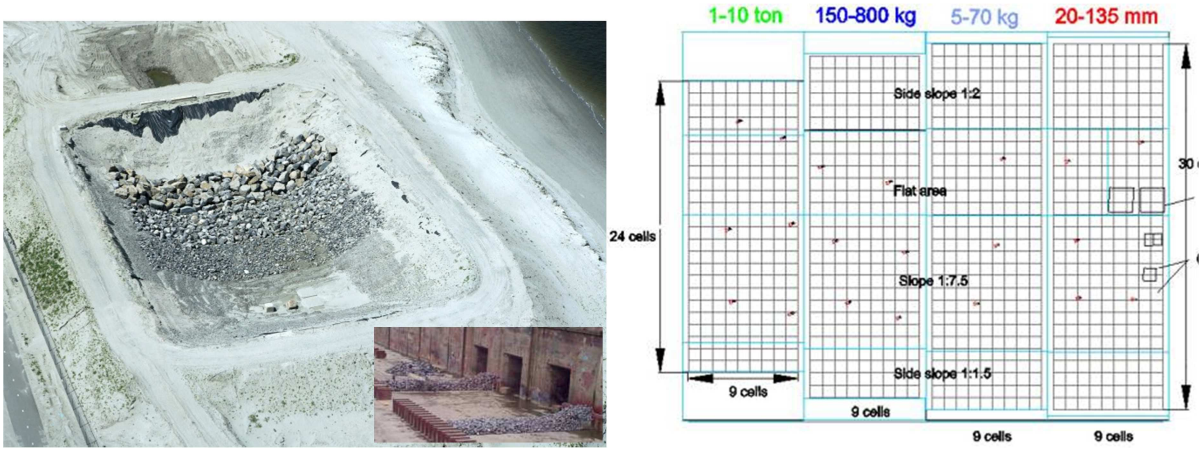

Figure 1: Trial set-up in the test-pit at the Maasvlakte port extension with 20-135 mm (including 4 objects), 5-70kg, 150-800 kg and 1-10t gradations. Inset: Trial set-up in the Verolme dock (1999).

<u>Survey systems used</u>

After construction, the stone layers were surveyed using a variety of dry survey techniques. The following survey systems were used for the dry surveys:

- land survey point measurements with level pole
- semi-spherical foot staff. Diameter calculated from CUR 154 [CUR/CIRIA, 1991] based on nominal stone gradation.
- plate measurements with a minimum dimension of around $4xDn50^2$ resulting in a 1x1 m plate for all gradations except 1-10 t and a 2x2 m plate for 1-10 t.
- crane monitoring measurements using a variety of grabs and buckets fitted to the crane
- static laser measurements (single system) from a total of six positions around the test pit
- mobile laser measurements from both a crane using an inexpensive type of industrial laser as well as from a helicopter using the Fli-map system

Subsequently the test-pit was flooded and surveyed using 'wet' equipment mounted on a small survey vessel. The wet surveys were performed with the equipment at a height of around 4 and 6 meters above the test beds. The following systems were tested:

- single-beam system with different beam angles. Long- and cross line pattern with line spacing of 5 meters.
- multi-beam with most common shallow water systems. Swath reduced to 45° either side of the normal (90° in total). Lines sailed with 100% overlap [Lekkerkerk and Theijs, 2011].
- echoscope with 50° x 50° swath angles at both normal and high frequency

<u>Processing</u>

The data from the swath systems (full coverage) was averaged in a regular 1x1 m grid aligned with the test pit. The resulting average is then compared with the point survey result taken at the centre of that same grid cell. This results in a deviation between the two survey results which is then statistically processed.

RESULTS

The results from the test pit surveys can be described in a qualitative as well as a quantitative manner. In practice the qualitative results need to be translated into survey procedures where the quantitative results result in corrections to the surveyed levels.

Quantitative results

Table 1 shows the results of the test pit trials in relation to the semi-spherical foot as reference. The results were surveyed and computed in 1x1 m^2 grid cells to allow for direct comparisons between the systems. The results shown are the average for those obtained from the horizontal and 1:7.5 slope.

Table 1: Results obtained in the test pit trials with the semi-sphere as reference (1x1 m grid)., All values in [m], a negative systematic error denotes that the measured value is below the reference level. Note 1: Values for 2x1.2 m bucket with bucket closed and edge parallel to plane of slope. Note 2: grab Ø 2.5 m and grab closed

Survey System	Sand		20-135 mm		5 - 70 kg		150 - 800 kg		1 - 10 t	
	Systematic Error	Precision	Systematic Error	Precision	Systematic Error	Precision	Systematic Error	Precision	Systematic Error	Precision
Total station – plate	n.a.	n.a.	0.07	0.08	0.12	0.09	0.14	0.15	0.11	0.17
Total station – point	n.a.	n.a.	n.a.	n.a.	-0.07	0.07	-0.13	0.19	-0.27	0.51
Excavator – bucket[1]	n.a.	n.a.	0.17	0.13	0.14	0.15	0.34	0.27	0.32	0.40
Excavator - orange peel[2]	n.a.	n.a.	0.17	n.a.	0.08	0.11	0.18	0.21	0.20	0.36
Excavator – sorting	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0.14	0.22	0.18	0.32
Single-beam	0.01	0.03	0.08	0.08	0.08	0.11	0.09	0.18	0.06	0.26
Multi-beam / Echo-scope	-0.01	0.02	-0.03	0.06	-0.11	0.09	-0.19	0.15	-0.38	0.26
Static laser	-0.01	0.05	-0.01	0.06	-0.04	0.10	-0.05	0.15	-0.18	0.23
Crane based laser	0.02	0.05	0.04	0.07	-0.01	0.10	-0.08	0.15	-0.25	0.24
Fli-map laser	0.00	0.06	-0.06	0.09	-0.12	0.10	-0.17	0.18	-0.36	0.27

The measurements as presented in Table 1 were also computed with a 1x1 plate as reference. Figure 2 allows the determination of the systematic error for the plate as well as for the semi-spherical foot. Standard deviation when using the plate as reference was found to be smaller than with the semi-spherical foot.

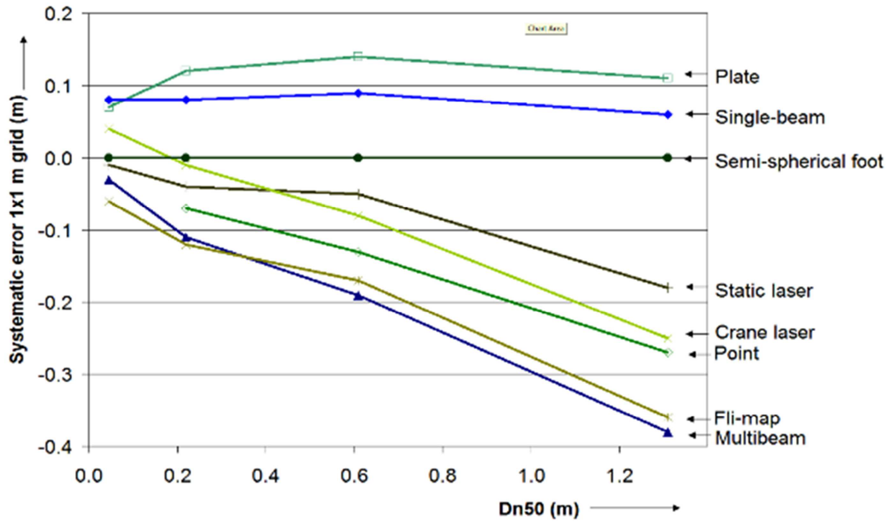

Figure 2: Systematic errors for the non-excavator systems based on Table 1.

Qualitative results

Besides the quantitative results from the table, the following qualitative results were also found and need to be taken into account when surveying stones:

- When using a crane monitoring system, special attention should be given to bucket size and shape as well as to a well-defined measurement protocol resulting in the bucket / grab always being placed in the same orientation (longest dimension transverse to average slope direction) and in the same condition (opened / closed)
- Surveys on the stones done using either multibeam or laser systems require a certain degree of (manual) editing and filtering as a high number of spikes may exist in the data when compared to surveys on sand / filter layers
- The precision of some multibeam systems degrades in very shallow water (< 2 meter below the transducer); it is suggested that this is a result of the beam forming processes which requires a minimum water depth to take place fully. The effect becomes more pronounced with a greater stone diameter
- Surveys with the crane monitoring system produced each time the largest mean layer thickness as well as the largest values for the precision. The mean bed level surveyed by this system lies above both references when using a bucket as crane tool. Results vary with the size and type of bucket / grab used.
- Surveys with the multibeam and laser systems, on average, produced the lowest layer thicknesses.

Multibeam reults in more detail

The results of both the dock and test pit trials for the multibeam system in a 1x1 meter cell size are displayed in Figure 3 and show a good comparison between both trials. The graphs for the dock trials and test pit trials show a deviation from the trend line established at around a Dn50 of 0.25 meter.

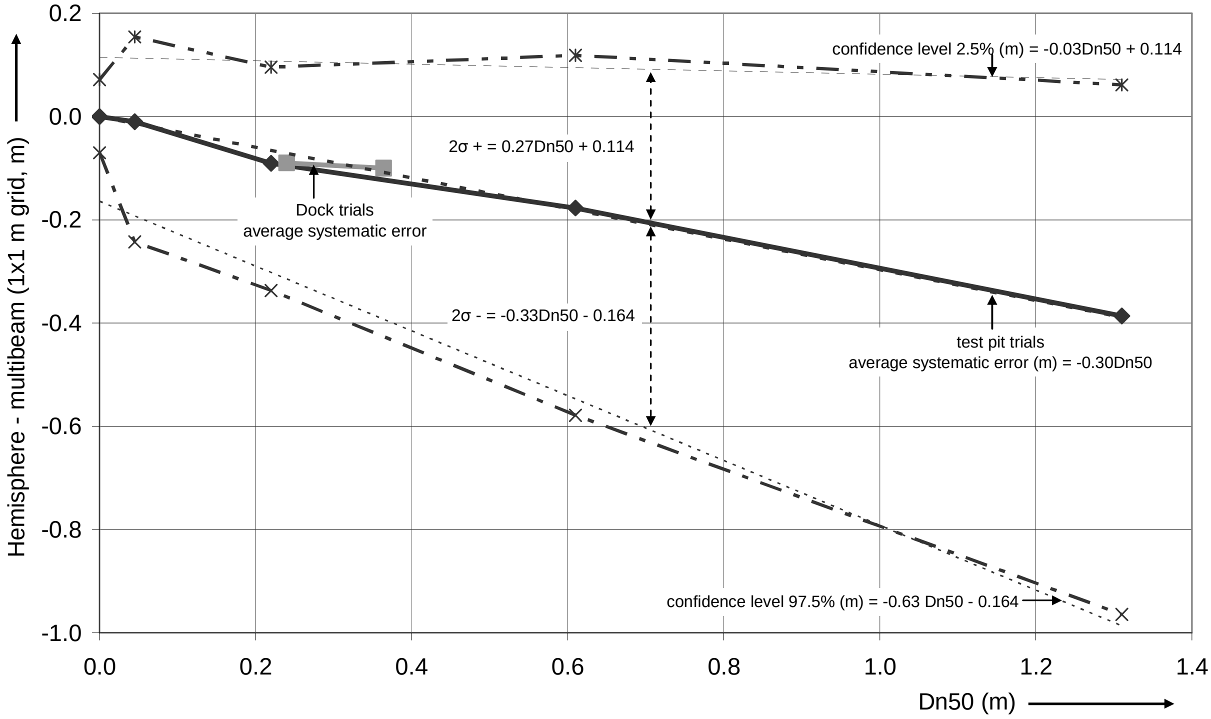

Figure 3: Results of systematic error and precision resulting from both dock and test pit trials in a 1x1 m grid.

DISCUSSION OF RESULTS

Based on the accumulated data both systematic error and precision for a multi-beam system seem to behave according to a common formula which depends on the stone diameter, slope and reference method. It should be specifically noted that the formula's given below are only valid for surveys with a high quality survey system (both good quality for the sounding system as well as good quality of operations) and are valid for clean stone (no foreign inclusions). In the situation where different conditions are found, additional tests are required to establish the correct values.

Systematic error

Based on the results from both the test-pit and the dock trials formula 1 is proposed for the computation of the systematic error of multi beam swathe systems.

$$Esyst = -s1 * D_{N50} - 0.01 * (10 - sg) * D_{N50} \qquad (1)$$

with:

- Esyst Systematic error between average level as determined by reference survey and multi beam echo-sounder survey [m]
- D_{N50} Nominal stone diameter for the 50% mass fraction [m]
- s1 Error factor.
- sg Slope gradient (e.g. 2 in a 1 vertical :2 horizontal slope) for slopes steeper than 1:10

The error factor depends on reference level and survey system used; as a rule of thumb, for multi beam systems this varies between 0.29 and 0.33 for the semi-sphere as reference and around 0.52 for a plate reference as derived from the tests. Based on these results the systematic error is relatively large in comparison to generally accepted construction accuracies for the placement rock under water.

Around a Dn50 of 0.25 meter (10 - 60 / 5 - 70 kg) an interaction between the multi beam and the stone layer seems to be occurring which has not yet been explained but could be the result of an interaction with the beam angle of the systems.

Precision

The precision expressed as the standard deviation of the layer thicknesses measured with the various survey systems appears to show a linear relationship with the D_{N50} of the sounded crushed stone. Formula 2 is proposed as a generic formula for computing the precision.

$$\sigma_N = \pm 1/\sqrt{N} . (p1_1 + p2_1 * D_{N50}) \qquad (2)$$

with:

- σ_N precision at 68% confidence limits in a N m^2 gridcell [m]
- $p1_1$ basic precision of the survey system in a 1x1 meter grid [m]
- $p2_1$ precision influence due to roughness of the bed in a 1x1 m grid [m]
- D_{N50} Nominal stone diameter for the 50% mass fraction [m]
- N number of 1x1 m^2 cells in a N m^2 grid cell (i.e. 4 for a 2x2 m grid cell)

For multibeam systems p1 can be determined during calibration measurements on a flat, smooth bottom such as a dock floor or flat sandy bottom. For various multibeam systems this constant was found to be around 0.03 m. For laser systems the results can, in general, be expected to be better. The value p2 was derived in the tests and was found to be between 0.26 and 0.33 for multibeam systems when using the semi-sphere as a reference level.

The values of p2 are relatively large compared to generally accepted construction accuracies. During surveys with multibeam systems not only the systematic survey error, but also the random survey error can have a role of great significance upon the determination of rock levels.

CONCLUSION

It may be deduced from the results of both trials that the use of echo-sounding systems when surveying underwater dumped stone areas will be accompanied by relatively large systematic and random survey errors. This applies particularly to surveys with multi beam systems. The errors can be so large that actual construction inaccuracies on the micro level cannot be directly shown and that corrections need to be applied for showing construction inaccuracies on the macro level.

In general it can be said that the errors will increase with increasing nominal stone diameter. The systematic error when using the top of the stones (plate) is larger than when using the semi-sphere as a reference. The precision of plate measurements was however found to be better when using the plate as reference.

More background as well as the results presented in this article as well as more details on the surveying of rock quantities in general is to be published as a CUR / CIRIA report.

REFERENCES

CUR/CIRIA. 1991. Manual on Use of Rock in Coastal Engineering. Gouda: CUR / CIRIA.

Lekkerkerk, H-J., and M.J.Theijs. 2011. Handbook of Offshore Surveying volumes 1-3. Voorschoten: Skilltrade.

Lekkerkerk, H-J., and M. Kol. 2011. Onderzoeksrapport testgoot MV2. Rotterdam: Port of Rotterdam / PUMA.

VBKO et al. 1999. Een onderzoek naar hoogteligging breuksteen met multi- en singlebeam echo-sounders. Gemeentewerken Rotterdam / Baggermaatschappij Boskalis / Rijkswaterstaat / Vereniging van waterbouwers in bagger-, kust- en oeverwerken.

BIOGRAPHIES

Marnix Kol received his degree in Hydrography (A) from the Nautical College in Amsterdam. He has worked van Oord on various international projects as a hydrographic surveyor.

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