Extensive sheet pile wall inspection in the Port of Hamburg

An article by ISABELL MÜCKE

In spring 2014 a survey was conducted in the Port of Hamburg to examine the condition of a quay wall. For this purpose Kongsberg Maritime Embient GmbH (KMEMB) introduced a three-stage inspection concept, which provides, according to the current state-of-the-art sonar-techniques, best possible information and analysis of the inspected object, while significantly reducing survey time and costs related to the inspection. On basis of the survey data, a complete picture of the quay wall was created. Several areas of specific interest have been detected, such as bended sheet piles, scouring and distorted steel plates.

quay wall inspection | underwater inspection | MBES | multi-frequency scanning sonar | 3D modelling

Author

Isabell Mücke is Assistant Service Engineer for Kongsberg Maritime Embient GmbH in Halstenbek

isabell.mucke@km.kongsberg.com

1 Introduction

Three-dimensional inspections of underwater structures are a specific survey challenge, requiring specialised techniques and methods. In extreme environments, such as a basin in a port, optical sensors and divers might be limited due to a very high particle load in the water column. Divers also struggle with limitations of their working time under water. Acoustic methods are not affected by these issues, making them an effective, innovative approach for in-port surveys. Methods and techniques are generally customised, depending e.g. on the geometry, the desired resolution and the distance from the investigated object to the transducer. However, the acquisition of high-quality data covering large complex subsea structures in short order, remains a major challenge. Here, a combination of different inspection methods is essential to ensure an optimum coverage of the inspected subsea structure. For this purpose KMEMB introduced a three-stage inspection concept, which provides best possible information and analysis of the inspected object. The concept is based on a cost-efficient overview survey. This data is used to define specific locations of interest, where a more time-consuming high-resolution survey will be performed. The combination of these methods ensures that the most important areas are covered in fine detail, whilst achieving a full overview of the location. In this article, we present the results of a survey conducted by KMEMB in cooperation with Kongsberg Maritime in Germany and Kongsberg Mesotech Ltd., supported by Hamburg Port Authority.

2 Three-stage inspection concept of subsea structures

The three-stage inspection concept is based on a multibeam echo sounder survey. Multibeam systems provide coarse, but accurate point cloud data in relatively short time, which makes multibeam mapping an effective and fast method for an overview inspection of underwater structures. The recorded point cloud data delivers quantitative information and can be used in post-processing for three-dimensional measurements and volume calculations. Nevertheless, the method is subject to some limitations such as acoustic shadow zones, which appear at structures with a complex geometry. Furthermore, the minimum resolution of the systems is limited by the distance from the transducer to the object and the swath opening angle. Thus, the use of multibeam systems alone may not lead to the required resolution when mapping key subsea structures.

Hence, a scanning sonar is used for a more detailed examination of the subsea structure during the second stage of the inspection. Opposed to multibeam echo sounders, scanning sonars provide, depending on the mode settings, either high-resolution profiling data (profiling mode) or imaging data (imaging mode). Imaging data provides high-resolution qualitative information, which can be used for precise visual analysis and two-dimensional measurements. In contrast, high-resolution three-dimensional point cloud data, revealed in profiling mode, achieves better data precision and density, as well as reduced shadow zones in comparison to multibeam point cloud data. Furthermore, profiling data is very useful for modelling. Nevertheless, due to the high time expenditure of profiling measurements (one high-resolution scan can take up to several hours), it is only efficient and economical to conduct these measurements in specific locations of interest. These locations are defined after the analysis of the previously recorded multibeam and imaging data.

In the third stage of the inspection concept, quantitative (imaging data) and qualitative (multibeam and profiling data) information are processed and combined, before the data set is analysed and interpreted.

3 The Amsterdamer quay wall survey

For running the three-stage inspection concept, the Amsterdamer Kai, located in the Dradenauhafen in the Port of Hamburg, was selected as the survey site in spring 2014. The investigated quay wall is about 500 m in length and is used as a docking place for freighters and barges. The main task of the project was to examine the condition of the quay wall, which is made up of several fixed sheet piles. Particular attention was paid to the steel plates, which were welded on the sheet pile wall to repair former damage. The shape of the investigated sheet wall is an isosceles trapezoid, with the wide side facing outwards, which makes it susceptible to the formation of shadow zones in sonar data. This had to be considered during planning and measuring. Furthermore, KMEMB had to deliver precise, high-resolution data to determine possible areas of interest (e.g. deformations) and the corresponding location (exact position and depth). In order to meet these requirements, KMEMB used the three-stage inspection concept as a guideline for the survey.

3.1 Method

Following the three-stage inspection concept, a multibeam overview survey was conducted, followed by a high-resolution survey and the final processing, analysis and interpretation of the combined data set.

Project phase I: Overview measurement and extensive recording of qualitative data

During the first phase an overview measurement of the sheet pile wall and the adjacent sea-floor was conducted using a Kongsberg EM2040 multibeam system. The system operates at a frequency of 400 kHz with a beam width of 0.4° × 0.7°. During survey the transducer was mounted at a pole on the side of the survey vessel and orientated towards the quay wall. Motion data was acquired by a Kongsberg Seapath 330 Inertial Navigation System, and VRS (Virtual Reference Station) corrections were received via GSM modem. The measurement was repeated several times. During the individual measurements, the vessel was sailing along various profiles with respect to the quay wall, which resulted into varying positions and sizes of shadow zones in the multibeam data. Through the combination of these individual data sets, the shadow zones could be reduced during post-processing.

Project phase II: High-resolution survey

The multibeam survey was followed by a high-resolution survey, conducted with a Kongsberg Mesotech 1171-Series high-resolution, multi-frequency, Fan/Conical Beam Transducer Scanning Sonar (MS 1171). This sonar supports two different modes of operation. It was first used in imaging mode and then in profiling mode. During imaging survey, a fan-shaped acoustic beam is produced to scan a specified area or feature, while during profiling survey a narrow, conically shaped beam generates a single point for each ping.

Project phase II: Imaging survey

For imaging survey, the scanning sonar was deployed on a pole, which was adapted to a mobile working platform (man lift). The platform was operated on shore, illustrated in Fig. 1. The sonar head was in approximately 1 m water depth during measurement. The sonar was operated with linear frequency modulated (LFM) pulses using a frequency of 1,100 kHz and producing a beam width of 0.6° × 45°. Every ten metres, scans with range settings of 15 m were performed to ensure good overlap coverage between scans (Fig. 2), whereby the scanning time was approximately 1 minute per scan. The whole quay wall was recorded this way. A data example (screenshot) during imaging survey is shown in Fig. 3. The distances between the individual scans were selected deliberately, in order to produce an image overlap to eliminate in later processing the typical data gaps in the centre of rotation of the sonar head (Fig. 1 and Fig. 2).

Project phase II: Profiling survey

After a short data analysis of the recorded multibeam and imaging data, a profiling survey was per-

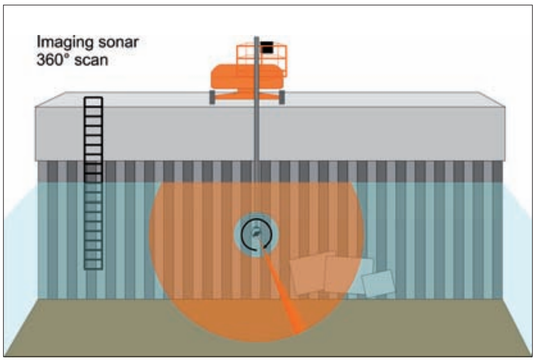

Fig. 1: Survey configuration in imaging mode

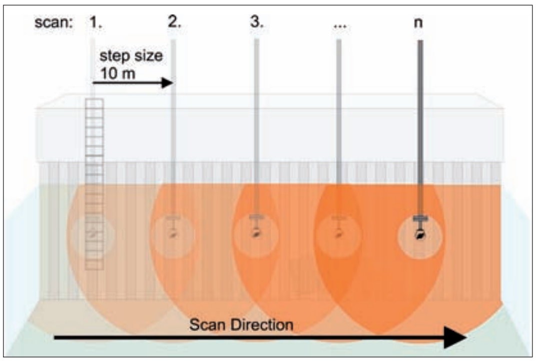

Fig. 2: Scanning positions and procedure in imaging mode

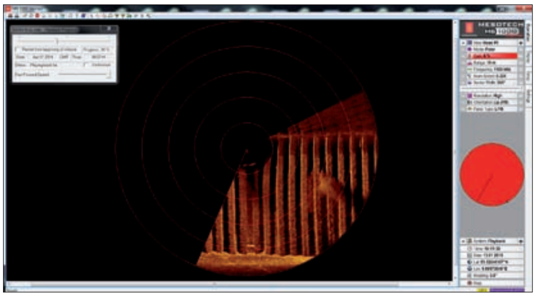

Fig. 3: Screenshot of a data example during imaging survey

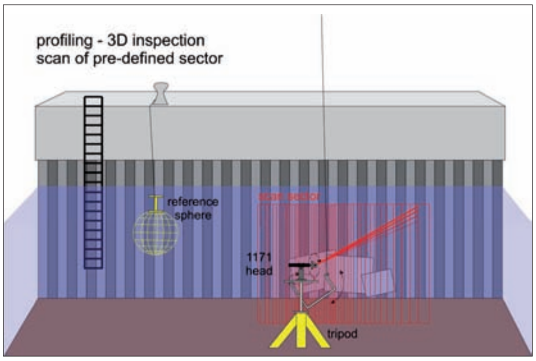

Fig. 4: Survey configuration and procedure in profiling mode

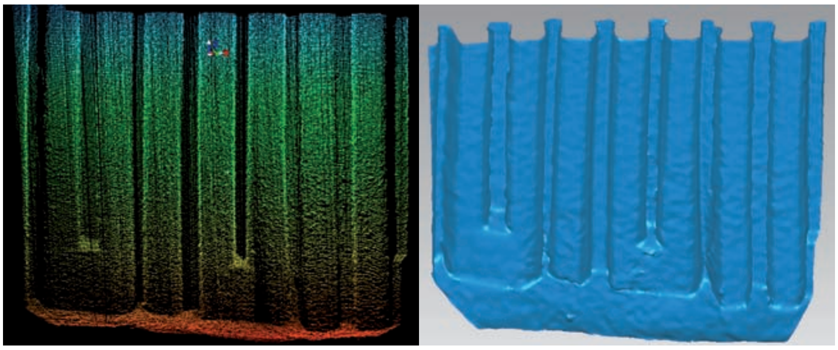

Fig. 5: Data example of high-resolution profiling data (left), and a 3D-model based on high-resolution profiling data

formed in areas where features (e.g. welded steel plates) were identified. For this purpose the single-axis profiling head was integrated with a Kongsberg Mesotech Heavy Duty Rotator (mechanical second axis drive), which was mounted on a tripod assembly. The tripod was placed on the sea-floor with the sonar adjusted parallel to the quay wall, displayed in Fig. 4. This method provides high-resolution three-dimensional profiles. After collecting the single axis profile, the head rotates by the second axis drive through preset increments and the scan process repeats. This generates a grid of profile points from a single position, after which the processed data generates a three-dimensional point cloud. During measurement the operating frequency of the sonar was set to 1,100 kHz with beam width of 1° × 1° and the pulse type to LFM. The step size of the rotator was set to maximum resolution (0.225°). Thereby a point resolution of 1–2 cm was achieved. The time needed for one 45° scan was approximately two hours, whereby about 130,000 data points were collected. Due to the tripod deployment method, the survey was conducted using relative positioning. The resulting point cloud data was co-registered and geo-referenced in the post-processing phase, using the multibeam data from project phase I.

Project Phase III: Processing

After finishing the data recording, the third stage was devoted to several processing steps to combine the recorded quantitative (imaging data) and qualitative (multibeam and profiling data) information. The single imaging scans on the one side and the multibeam profiles on the other side were merged to overview pictures and geo-referenced in relation to the quay wall. In addition, the multibeam data were supplemented by laserscan data, which were provided by the Hamburg Port Authority and show the part of the quay wall that is above sea level. Besides that, 3D models were generated using both multibeam data and point cloud data from the high-resolution profiling survey (for high-resolution model see Fig. 5). On this data basis, a complete picture was created and the condition of the quay wall could be analysed.

3.2 Result

The full picture of the quay wall after data processing is illustrated in Fig. 6. Several features have been detected, such as bended sheet piles, scouring and distorted steel plates. Larger features were identified in the multibeam data, while smaller features were identified in the imaging data. For instance, after analysing the imaging data, small deformations (2–10 cm) have been detected on the lower part of the sheet piles, which have not been

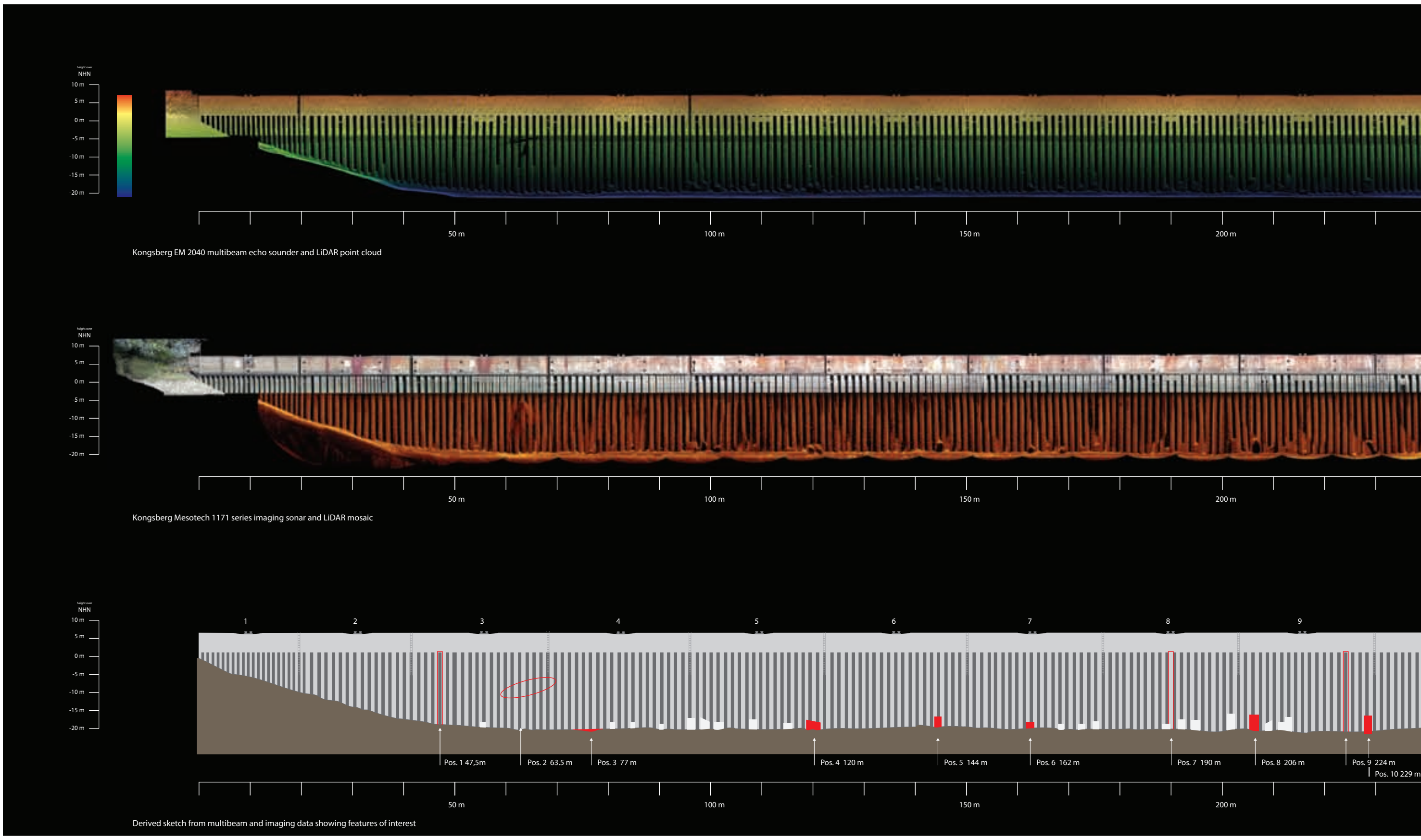

Fig. 6: Result of the Amsterdamer quay wall survey: imaging data of the wall (upper panel); multibeam and laserscan data of the wall (centre panel); 2D-model of the wall, showing identified features (lower panel)

Multibeam survey

Pro	Con
Good survey coverage in short time, providing a geo-referenced overview for future detail scans (profiling) Good positioning accuracy	Small anomalies cannot be identified Shadows due to the shape of the structure

Imaging survey

Pro	Con
Very short timed survey per single scan location Small anomalies can be resolved	Scan results are very dependent of scanning head stability (mounting is important) Only 2D measurements are possible Slant range distortion

Profiling survey

Pro	Con
Best achievable resolution Minimal development of shadow zones Generation of exact 3D model possible	Scan results are very dependent of scanning head stability (mounting is important) Scan duration may be very time consuming

Fig. 7: Summary of the three inspection methods with pros and cons

noticed in the multibeam data. In contrast, the recorded point cloud multibeam data allowed the identification of the direction and shape of the deformation of sheet piles, which cannot be derived from the imaging data. As a final result, the quay wall is illustrated as a 2D-model (see Fig. 6, lower panel) with all identified features. This is used as the basis for the required upcoming work, where for instance divers can be sent directly to the surveyed features. Finally, the high-resolution point cloud, derived from the profiling survey, as well as the multibeam data were used for the generation of 3D-models. Due to the limited point cloud density and accuracy, the multibeam data model shows different artefacts and uncertainties. Compared to that, the high-resolution profiling model, displayed in Fig. 5, shows significantly less shadow zones and fewer distortions.

4 Conclusion

The three-stage inspection concept offers a wide range of information that is crucial for a complete analysis of an investigated subsea structure. The combination of individual data sets of different sonar systems involving differing time commitments and different resolutions make it possible to ensure an optimum coverage of the investigated subsea structure in the shortest time possible. The concept has been structured in such a way that the different restrictions of the individual devices are neutralised when applying these in the overall concept, which is demonstrated in Fig. 7. The final result exhibits both qualitative and quantitative information. The quantitative information is provided by high-resolution imaging data, while qualitative information is provided by multibeam and high-resolution profiling data. The initial inspection of a quay wall in size of the conducted survey, including the baseline survey with post-processing and identification of features, the detailed high-resolution survey with post-processing, and the final reporting and documentation, will last about 20 days. The final result will be an illustration like in Fig. 6, without being at risk to miss any feature. Based on this full picture baseline survey, repeated surveys of the identified critical features only utilising the scanning sonar, can be conducted at longer intervals. A repeated survey is estimated to be in the area of 2–3 days only, including post-processing and documentation. ⚓