Advanced Sub-bottom Profiler Equipment for Soil Investigation Campaigns During Dredging Projects

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Abstract

Innomar's parametric sub-bottom profiler system SES-96 provides not only the exact water depth determination, but also gives detailed information about sediment layers and sub-bottom structures. The achievable high resolution and deep penetration with such a mobile system is unique on the international market. During several soil investigation campaigns in the Persian Gulf area, the system was used by Ballast Ham Dredging to search for sand dredging areas, to determine the bedrock layer and hidden rock outcrops and to detect the location of pipelines and other objects. Confirmed by vibrocores, the results were impressive and much time was saved by decreasing the number of borings.

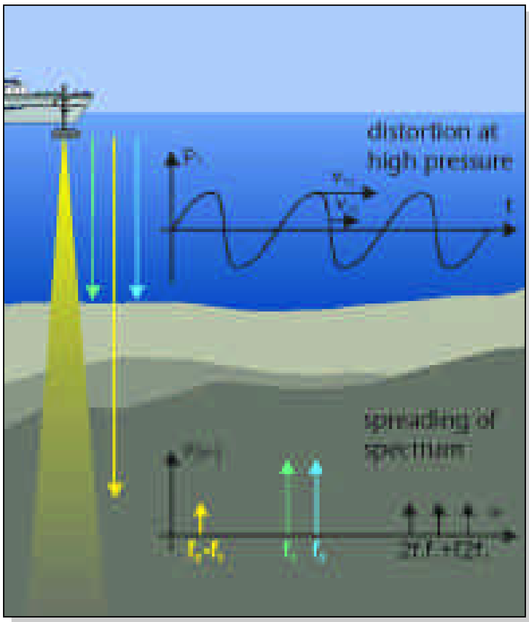


Figure 1
The parametric acoustical effect

PARAMETRIC SUB-BOTTOM PROFILER SYSTEM

Echo sounder systems are widely used by dredging and surveying companies for determining the exact water depth, but there is also a great interest in the sediment and sub-bottom structure. Due to physical limitations, common linear sub-bottom profilers are instruments that are difficult to operate and very often are not able to fulfill the expectations regarding the results. Disadvantages include big transducers together with towed systems, large beam width and large footprint with a resulting low horizontal resolution, long transmitting signals (caused by the ringing effects) with a resulting low vertical resolution and difficult and time consuming post-processing.

A new way to solve some of these problems with acoustical systems is the use of the parametric effect. Theoretically known for several years it was difficult to realise parametric systems in practice. A company in Germany, founded in 1997, has realised a complete product line of parametric sub-bottom profilers based on several years of formerly basic research at the University of Rostock. The product line SES-96 is still unique on the international market, with its compact design and mobility, easy operation combined with online digital processed results compared to linear acoustical systems.

The principle of the parametric acoustical effect is briefly described as follows. The transmission of two high frequencies with very high sound pressure, results in a non-linearity of the sound propagation. At high pressures the density of water and therefore the sound velocity is changing non-linearly. Higher sound amplitudes are moving faster than lower sound amplitudes. This results in a signal distortion and spreading of the spectrum. The two primary high frequency sound waves interact in the water column and the sum and differential frequencies result.

The resulting differential frequency has some very useful properties, such as the same small directivity as for the transmitted high frequency. The primary high frequency can be used to determine the exact water depth, the secondary low frequency is able to penetrate the bottom and can give information about the sediment layers and embedded objects and structures with very high resolution.

ADVANTAGES COMPARED WITH LINEAR SYSTEMS

Due to the parametric acoustical effect, the aperture angle of the low frequency is as small as for the primary high frequency, even with a small transducer comparable to a typical transducer size of a survey echo sounder.

The directivity is constant for all generated secondary frequencies and has no side lobes, which allows the survey in small and shallow waters. The quality of the data becomes much higher due to the smaller footprint and the signal-to-noise ratio increases dramatically due to less reverberation. This finally results in a higher penetration capability. The high system bandwidth, depending on the transducer quality, allows the transmission of very short pulses and gives a highly increased resolution. The transmitted signals have no ringing effect, which results in a higher resolution as well. The electronic beam stabilisation and beam steering becomes possible for low frequencies, even with such small transducer sizes. In combination with motion sensors not only can the heave movement be compensated, but also the roll and pitch movement of the vessels under bad survey conditions. Possible high ping rates of up to fifty pings per second can increase the efficiency to detect small embedded objects, such as pipelines and wrecks.

THE SES-96 PRODUCT LINE

Innomar has four different system variants in the product line of their parametric sub-bottom profilers. The SES-96 light and SES-96 standard systems are used worldwide for a great variety of shallow water applications from 1 metre to 400 metres of water depth. The new variant SES-2000 medium is designed for a water depth down to 1,500 metres. With a bigger transducer it is still usable as a mobile system.

The SES-2000 compact model is the smallest sub-bottom profiler equipment, especially for the lower budget. It can be used even on the smallest boat, will be controlled by a notebook and gives the same high quality and reliable results, which one can expect from a parametric system.

The primary frequency for all SES systems is 100kHz and the generated secondary frequencies are between 4kHz and 12kHz. With a transducer size of only 20cm x 20cm the beam width for all frequencies is only +/–1.8 degrees. With the compact design, only the transducer and one water protected 50 cm unit is required, it allows very easy and mobile installations. The accuracy of the depth measurement fulfills the International Hydrographic Office (IHO) standard and the resolution of the low frequency channel is significantly higher than with any

Figure 2
Parametric transducer in a streamlined hull ready to mount over the side of the vessel

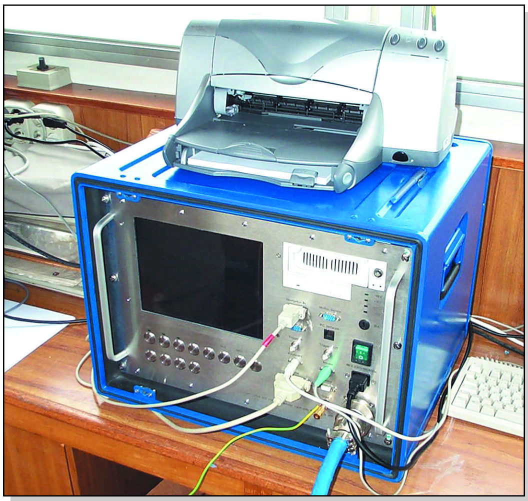


Figure 3
SES-96 light installed on board a survey vessel

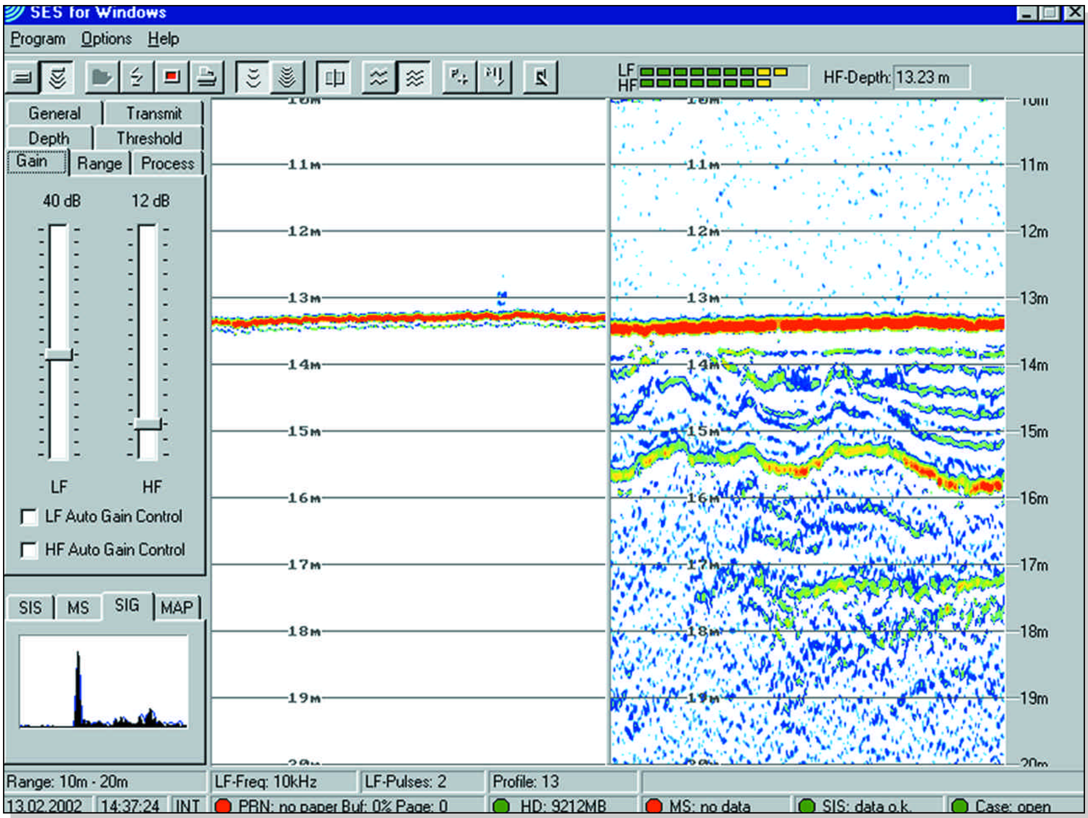


Figure 4
Screenshot of on-line control software with dual channel view (HF left, LF right)

linear system on the international market. The layer resolution goes down to 6cm depending on the frequency and pulse length. The SES-96 standard system has the ability for electronic beam stabilisation and beam steering. This might be useful especially for applications offshore and under rough survey conditions. Additionally, the search for embedded objects is more effective.

The signal processing is completely digital and provides during the survey, a real time result with coloured echo plots and allows very quick adaptations of the survey. Operated via a graphical MS Windows application on the integrated industrial PC, the system has very short training requirements. The digital storage of the echo sounder data together with the data from attached positioning systems, like DGPS and from motion sensors, allows complete post-processing of the data. Innomar provides the user with a post-processing software package, mainly used for the extraction of the bathymetry, any sub-bottom layering and detected object positions in the form of compatible ASCII files for further visualisation, charting and volume calculations. The comparison with real probes, like from borings or from density measurements, is also possible during the post processing.

APPLICATIONS FOR THE PARAMETRIC SUB-BOTTOM PROFILER SYSTEM

Mainly used by dredging companies, general survey companies and waterway and shipping offices, the system is used for a great variety of applications in the marine field by customers worldwide. Some of the major applications are:

- determination of the water depth with high accuracy
- detection of fluid mud layers and dredging levels below siltation
- surveying of the morphology of the bottom surface and sediment structure
- determination of boring points during soil investigation campaigns
- search for mineral resources and sand dredging areas
- search for embedded pipelines, sea cables and stones and monitoring of their coverage
- marine archaeological investigations of wrecks, historical buildings and settlements.

SES-96 IN PRACTICE

In 2000, Ballast Nedam Dredging (BND) first used the Parametric Echo Sounder (SES-96) from Innomar. In the search for a suitable instrument to investigate the top-layer of the sub-bottom, several seismic systems proved unsatisfactory for the dredging industry, where a good resolution in the first metres is essential. After a trial in India with the SES-96, BND purchased the system later that year. Since 2000, the SES-96 has been implemented on various projects in different parts of the world and in many types and combination of soils. This leaves BND with a broad experience with the SES-96. In 2001 Ballast Nedam Dredging and HAM Dredging merged their companies in Ballast Ham Dredging (BHD).

VALUABLE TOOL

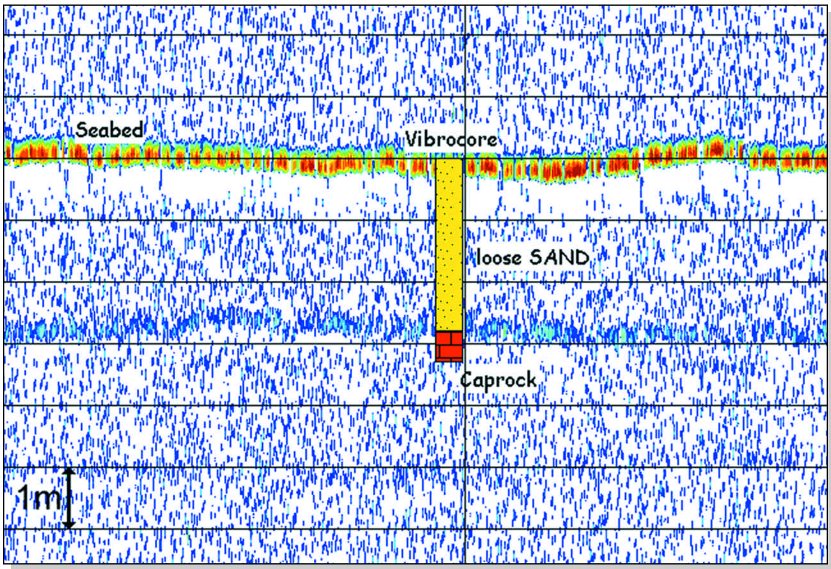
The SES-96 proved itself as being a valuable tool in predicting:

- the presence of hidden rock outcrops that can severely damage dredgers
- the dredging depth in soft soil for soil improvements of breakwater foundations
- the extension / volumes of a sand reserve on top of a lateritic clay layer
- the exact location of objects such as pipelines and ship wrecks.

These are all examples of where the SES-96 is used for dredging projects. The results of the SES-96 were correlated with existing or additional borings, vibrocores or Cone Penetration Testing (CPT).

The key question for every reclamation project is where to find suitable material. The client can considerably reduce development costs by choosing the location for a new reclamation project in the near vicinity of a dredging area. A thorough soil investigation in the study phase of any major development/reclamation project saves money in a later stage of the project.

At the moment, large reclamation projects are ongoing in the Persian Gulf area. The presence of cap-rock and coral makes seismic in the Gulf area a difficult task. The search for suitable sand is therefore a big challenge in which the SES-96 proved itself as a successful instrument. Granular material, i.e. sand and gravel size corals, overlying cap-rock forms a clear boundary that can be picked up easily by the SES-96. The amount of vibrocores can be severely reduced by plotting these after interpretations of the SES-96 results. The vibrocores should confirm the findings of the SES-96.



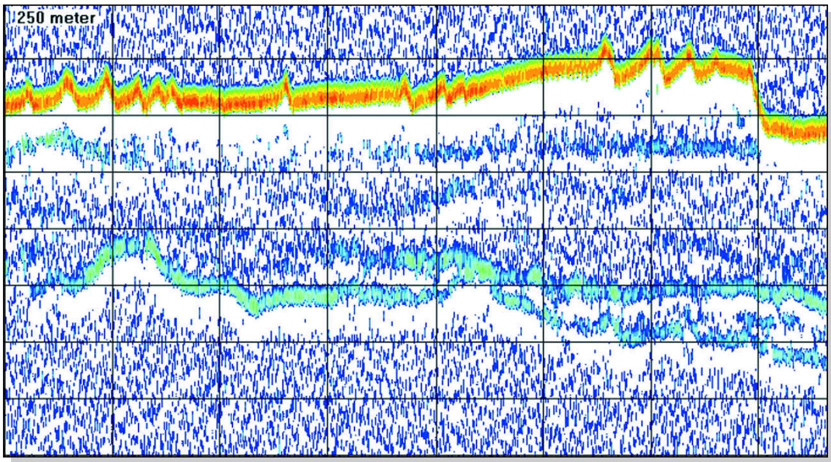
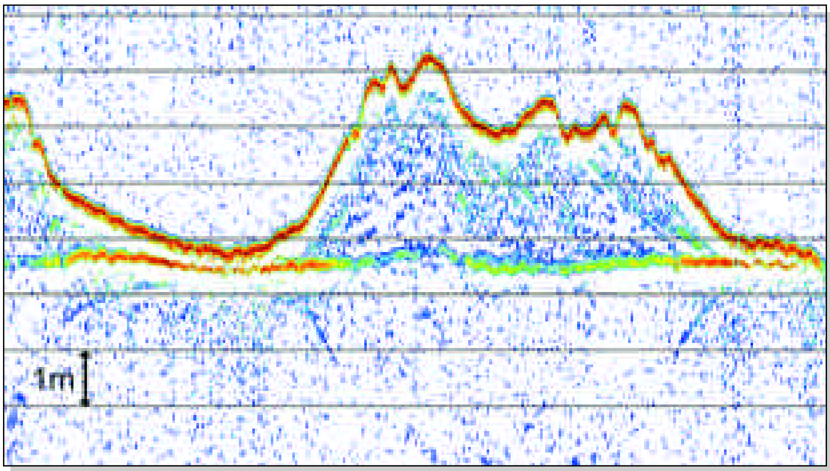


Figure 5 (top)
Two metres of sand on top of cap-rock after noise reduction

Figure 6 (above)
Two kilometre track in the borrow area with layers of cemented sand on top of cap-rock



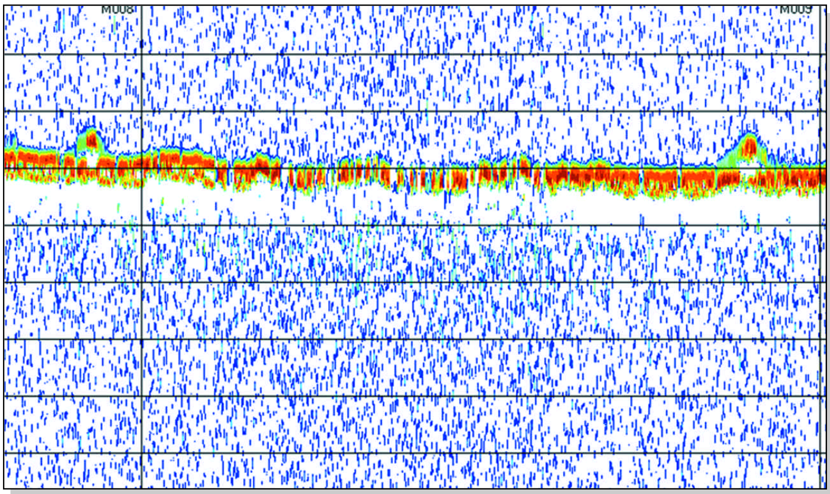


Figure 7 (top)
Dumped sand on top of hard sea bed

Figure 8 (above)
Two pipeline marks on hard seabed

WORK METHOD

A combination of different types of soil investigation techniques gives an optimal result. In general, the work method for a sand search is as follows:

- study available soil information
- determine line spacing for SES-96
- SES-96 survey
- study SES-96 results
- plot and execute vibrocores/borings
- combine results of vibrocores/borings with SES-96 results.

When a SES-96 survey is started, first the optimal settings need to be found. This is determined by the water depth, the soil properties and is subject to the nature of the campaign. Available soil information can be a big help by calibrating the SES-96 settings and correlating the SES-96 results in an early stage.

EXAMPLES AND RESULTS FROM THE GULF

Sand on top of cap-rock (Figure 5 and 6) as well as dumped sand on top of the original seabed could be easily detected.

The system penetrated up to 5 metres of coarse sand with gravel size pieces of coral down to the cap-rock layer. Layers (±10cm thickness) of cemented sand underlain by sand were identified by the SES-96.

The shape of dumped sand by way of opening the dredger,s bottom doors is clearly visible in Figure 7.

In search for it,s exact location, a pipeline had been mapped by zigzagging across the pipeline over a distance of 25 km resulting in more than 60 marks. Figure 8 shows two marks of this pipeline.

By use of the ISE software from Innomar, the vibrocores can be implemented in a later stage into the echo plots (Figure 5). By use of the same software package, profiles can be generated that can be used in various in-house volume calculation programmes.

ABOUT THE AUTHORS

Marcel van den Heuvel MSc, graduated from the Faculty of Mining and Petroleum Engineering of Delft University of Technology. From 1996–1999 he worked offshore with Neddrill and Noble Drilling before joining Ballast Nedam Dredging in 2000 as a soil engineer in the production and estimate department.

Jens Lowag has been involved in software engineering and software development. From 1995–1997 he worked within a research group for underwater acoustics at the University of Rostock. He then joined Innomar Technologie GmbH where he is currently Project Manager.

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