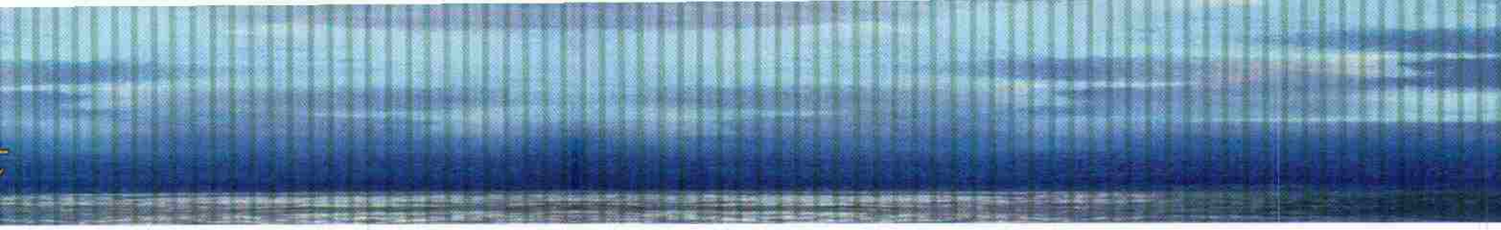

Offshore Sand Wave Dynamics, Engineering Problems And Future Solutions

By **A.A. Németh, S.J.M.H. Hulscher, University of Twente,** Civil Engineering, The Netherlands, and **H.J. de Vriend, University of Twente,** Civil Engineering and **WL|Delft Hydraulics,** The Netherlands

Figure 1: Observed sand wave occurrence in the southern part of the North Sea, (adapted after Hulscher & Van den Brink [2001]).

On the seabed of the North Sea, and many other shallow shelf seas, a variety of strikingly regular patterns can be found. These have different spatial and temporal scales, as shown in Table 1.

Sand waves (Fig. 1) are bed forms with wavelengths of about 500 meters and heights up to 10 meters in water depths of about 30 meters [Hulscher, 1996] and can migrate with velocities of about 10 meters/yr, (see also [Németh et al., 2002]). It is usually assumed that their crests are oriented perpendicular to the dominant current, Johnson et al., 1981].

Sand waves have a significant effect on the activities taking place in shallow shelf seas like the North Sea. Managers and engineers from several institutions in the Netherlands, all dealing with sand waves from a different point of view, have been interviewed to help address this question. Backed up with literature, this article provides an overview of the sand wave problems and the ways in which they are handled, and suggests possible improvements based on recent scientific progress, (see also [Németh, 2003]).

Seabed Topography Charts

Navigational charts are probably the most common seabed topography charts. For safe navigation, it is sufficient if nautical charts give minimum depths. As the seabed is likely to change over time, it is expected that the accuracy of a chart will decrease with time. Apart from long-term influences, such as sea level rise and overall sedimentation or erosion, the combined effects of moving sandbanks, sand waves and mega-ripples form the major source of change in the least depths.

Table 1:

QUANTITY	RIPPLES	SAND WAVES	SANDBANKS
Wavelength (m)	10-2	102	103
Wave height (m)	10-2	10	30
Timescale	Minutes	Years	Millennia

Echo Soundings

Nowadays, topographic data is mostly obtained using single-beam echo sounders, which are attached to ships sailing over the area to be charted. They measure the depth directly below the device, (Fig. 2). Recently, multi-beam echo sounders enable measurements not only directly under the ship, but also in a swath (strip) with a width of several times the water depth on either side of the ship. The error in the horizontal positioning lies currently in the order of magnitude of the distance over which sand waves migrate in a year. This margin makes it difficult to accurately determine the migration rates from data that are only a few years apart.

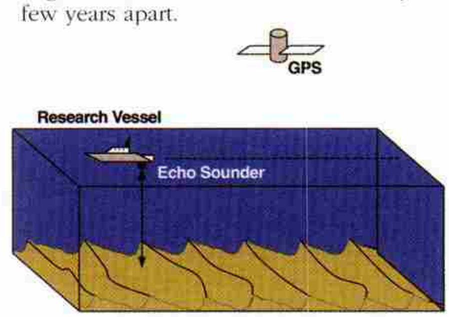

Figure 2: Echo soundings, satellite imagery and GPS.

Satellite Images

Remote sensing may be an alternative way of obtaining data on the seabed topography. Satellite images are inexpensive and provide snapshots of the sea-surface. Techniques to translate satellite images into seabed topography are being developed at this moment, [Calkoen et al., 2001].

The ERS-1 (European Remote Sensing) satellite is equipped with a Synthetic Aperture Radar. The horizontal accuracy of its images is quite low, in the order of hundreds of meters, due to the lack of good landmarks. If good landmarks (characteristic features on land) are available, satellite images can be positioned more precisely in the horizontal. In practice, images taken near the coast are much more accurate than images taken farther offshore. The accuracy of the horizontal positioning can then be as good as +/- 25 meters.

Bathymetry Assessment System

The BAS (Bathymetry Assessment System) is based on the concept of combining the above optical sea surface measurements with a translation model. The model consisting of a flow, wave and radar-backscatter module, uses a known chart to create a simulated radar image. Comparing this simulated image with the observed one and adding data from traditional soundings, ultimately leads to a chart of the seabed topography.

This system, which is under development, is meant to produce charts at much lower costs than before. Theoretically, combining the satellite images with additional ship soundings and radar images taken from aircraft can improve the vertical and horizontal accuracy down to the order of meters or less. One may expect that, once the BAS technique is fully developed, it will reduce the number of soundings considerably, thus reducing the total production costs of charts.

Calkoen et al. [2001] observed sand wave patterns with the BAS-system. However, when exploring this technique in further detail, Middelkoop [1998] found sand waves with wavelengths significantly larger (900 to 1800 meters) than usually observed. Knaapen et al. [2001] suggest that what is seen on the SAR images are not sand waves, but another type of seabed feature, due to the interference of bed form modes.

The use of radar imagery for bathymetric mapping is under investigation. Because of the flow-dependence of the relationship between sea-surface patterns and seabed topography, we may not expect that this technique is accurate enough for investigating sand wave migration. On the other hand, sand waves influence processes, such as tidal motion, wave motion and sediment sorting. Insight into sand wave behavior and its relationships with these processes will enable better estimates of the unknowns in the BAS-system and improvement of the underlying model components.

Pipelines & Cables

Hundreds of kilometers of pipelines can be found in, for instance, the North Sea. Pipeline protection takes up a large part of the total costs of developing a new oil or gas field [Li & Cheng, 1999]. These pipelines sometimes have to cross a sand wave field. The sand waves can form a threat if they migrate and expose the

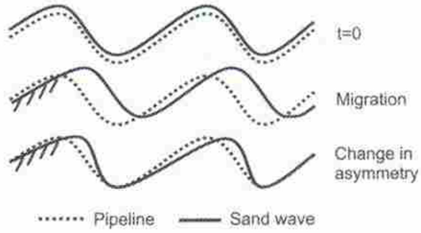

Figure 3: Illustration (free span) pipeline (dotted line), along a cross section of the seabed, due to the migration and change in asymmetry of sand waves (solid line).

pipelines, (Fig. 3). Free spans may develop, causing stresses due to gravity. Moreover, the pipelines can start vibrating, due to the turbulence generated under these free spans. The vibration also causes undesirable stresses, which may cause the pipeline to bend, break or buckle. Once exposed, a pipeline or cable can be damaged by ship anchors or fishing gear. The height and migration speed of sand waves are important design parameters for pipelines and cables. Mega-ripples are too small to create significant over-exertions.

Free spans may also be caused by changes in sand wave asymmetry, i.e. changes in the shape of the sand waves, irrespective of their migration, which may be caused by a change in the water movement across the sand wave field. Such a change in asymmetry may falsely be identified as migration, due to the large measuring errors. Hence, sand wave migration data in the literature are not always reliable.

The most straightforward solution is to lay the pipeline in a trench through the sand wave field. This solution is effective, but expensive. The main question is: what is the most efficient depth for a trench to place the pipeline in? This optimal depth depends on factors such as dredging costs, pipeline construction costs, monitoring costs and risk.

Furthermore, under certain conditions, the pipeline may have a 'burial potential' of its own, [Bos et al., 1996]. A pipeline laid on top of sand waves is curved, whence it will not sink as easily into the bed as it would in the case of a flat bed. Moreover, the current velocity varies along a sand wave, making it harder to predict the burial behavior of the pipeline.

Knowledge concerning the behavior of the seabed (especially the migration rate of sand waves) and its interaction with a pipeline can help optimize the design to minimize the total costs. Since the pipeline follows the contours of the bed, we also need to understand the behavior of the entire profile of sand waves and to what extent the pipeline works itself into the seabed.

Survey Before, During And After Use

Several bathymetric surveys are made in projects concerning pipelines. First, a reconnaissance survey is made. Next, the chosen route is measured more precisely. Before the pipeline is constructed, the route is surveyed once more to have the latest information about the condition of the seabed. After the pipeline has been placed, the whole pipeline and its surroundings are checked. During the entire life span of the pipeline, this area is monitored on a yearly basis.

Knowledge about sand wave behavior can reduce the survey effort and the costs. It can improve the accuracy of the measurements and help their interpretation.

Channels, Navigational Routes & Sand Extraction

Access channels leading ports, such as Rotterdam harbor, have to be wide and deep enough for ships to pass safely, otherwise the channel needs to be dredged. Bathymetric information is provided to mariners so that they can navigate safely over the Netherlands' Continental Shelf. This is done by publishing nautical charts, depicting the least depths of the seabed together with information about wrecks and other obstructions.

Both migration and seasonal variations in height or asymmetry of sand waves change the topography and possibly affect the minimum water depth. The channel plus its surrounding area has to be monitored in order to decide where and when sediment has to be extracted.

Knowledge about the evolution of sand waves will make it possible to determine the depth to which they should be dredged if they form a hazard to navigation. If a sand wave is lowered only marginally, the dredging costs per operation will be relatively low, but the frequency of these operations and the monitoring afterwards are expected to be relatively high. Knowing the rate at which sand waves evolve will help determine the most efficient dredging strategy and monitoring interval to guarantee the least depths. Such a strategy can be set up using the empirical sand wave model developed by Knaapen & Hulscher [2001]. This model describes the evolution of sand waves in a certain area, based on measurements in time and space in that area. Lastly, instead of using the fictitious chart depth, a model can be used to decide whether or not to allow a ship into the channel. This will result in a combination of increased safety and a larger tidal window.

Burial Of Objects

Objects lying on the seabed can get buried, due to the migration and/or growth of sand waves, after which time they lie dormant in the seabed, (Fig. 4). Here one can think of objects such as shipwrecks, mines and containers possibly containing hazardous materials. However, they might become exposed again, forming a direct hazard to the environment (for example, leakage of chemical waste). These objects can get stuck in fishing gear.

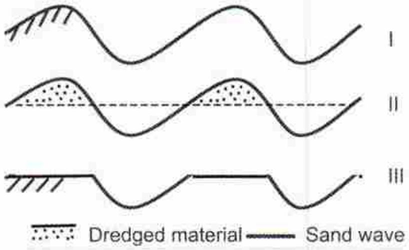

Figure 4: Sand mining from sand wave crests. (I) shows initial situation of a cross section of a sand wave pattern, (II) the cross-sectional area to be dredged and (III) the resulting bed profile after dredging.

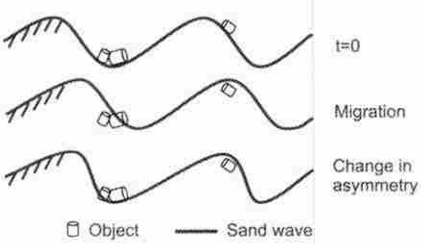

Figure 5: Burial of objects due to migration or a change in asymmetry.

Knowledge about the time between burial and exposure (residence time), can optimize the monitoring strategy and thus reduce the costs. There is little point in monitoring an area where the seabed hardly changes. Hereby, not only the horizontal displacement of bed forms plays a role in the residence time, but also the self-burial of the objects.

Discussion & Conclusions

Even though sand waves are not directly visible to the naked eye, they pose a threat to a range of offshore activities. The combination of their timescale (years), length scales (hundreds of meters) and height (meters) makes them bed features to be reckoned with.

The questions asked by the institutions and the industries involved in offshore activities can be summarized as: "Under which conditions are sand waves dynamic (horizontal and vertical movement) and what are the typical spatial and temporal scales?" At this moment, an estimate of the wavelength [Hulscher, 1996] together with the migration rate [Németh et al., 2002] can be described and obtained. Furthermore, if in a certain area, data are available over a period of years, the evolution of sand waves in that area can be described and the position of the seabed in the near future can be predicted ([Knaapen & Hulscher, 2001] and [Morelissen et al, 2002]). However, the latter technique is based on data assimilation, so that the results are only valid for the location from which the data originates. A model based on physical principles describing the nonlinear dynamics is not yet available, but is expected in the near future.

Insight into sand wave migration is important to estimate the optimal monitoring frequency for navigation channels, pipelines and buried objects. Greater insight into the height evolution of sand waves is required to determine when and how much should be dredged if sand waves get too high and form a threat to navigation together with the optimal monitoring frequency.

Looking at the impact of a large-scale intervention in space and time, such as the construction of an island in the sea or large-scale windmill parks, evolution and migration are both important. This also holds for the further development of sand wave observations by the Bathymetry Assessment System combining satellite images with ship soundings.

Finally, bed level statistics, and especially extreme value statistics of the seabed, are indispensable information for dealing with the natural dynamics of the seabed. ***P&GJ***

REFERENCES:

- Bos, K.J., Chen, Z. and Bijker, R. 1996, Interactie tussen zandgolven en pijpleidingen, WL|Delft Hydraulics, prepared for the North Sea Directorate, Directorate-General for Public Works and Water Management, Report H3016, the Netherlands.
- Calkoen, C.J., Hesselmans, G.H.F.M, Wensink, G.J., Vogelzang, J., 2001, The Bathymetry Assessment System, Efficient depth mapping in shallow seas using radar images, International Journal of Remote Sensing, Vol. 22, Nr. 15, pp. 2973-2998.
- Hulscher, S.J.M.H. and Van den Brink, G.M., 2001, Comparison between predicted and observed sand waves and sand banks in the North Sea, Journal of Geophysical Research, Vol. 106, No. C5, pp. 9327-9338.
- Hulscher, S.J.M.H., 1996, Tidal-induced large-scale regular bed form patterns in a three-dimensional shallow water model, Journal of Geophysical Research, Vol. 101, pp. 20727-20744.
- Johnson, M.A., Stride, A.H., Belderson, R.H. and Kenyon, N.H., 1981, Predicted sand-wave formation and decay on a large offshore tidal-current sand-sheet, Spec. Publs. Int. Ass. Sediment, Vol. 5, pp. 247-256.
- Knaapen, M.A.F., and Hulscher, S.J.M.H., 2001, Regeneration of dredged sand waves, Coastal Engineering, Vol. 46 (4), pp. 277-289.
- Knaapen, M.A.F., Hulscher, S.J.M.H., and De Vriend, H.J., and Stolk, A., 2001, A new type of bedwaves. Geophysical Research Letters, Vol. 28 (7), pp. 1323-1326.
- Li, F. and Cheng, L., 1999, Numerical model for local scour under offshore pipelines, Journal of Hydraulic Engineering, Vol. 125, No. 4, pp. 400-406.
- Middelkoop, I., 1998, Large scale bed pattern recognition by means of remote sensing, ARGOSS, University of Twente, The Netherlands.
- Morelissen, R. Hulscher, S.J.M.H., Knaapen, M.A.F., Németh, A.A., and Bijker, R., 2002, Interacting sand waves and pipelines: a data-assimilation based mathematical model, Coastal Engineering, submitted.
- Németh, A.A., 2003, Modelling offshore sand waves, PhD-thesis, in preparation.
- Németh, A.A., Hulscher, S.J.M.H. and Vriend, H.J. de, 2002, Modelling sand wave migration in shallow shelf seas, Continental Shelf Research, Vol. 22/18-19, pp. 2798-2806.

ACKNOWLEDGEMENTS:

This work is performed within the EU-sponsored project HUMOR (HUman interaction with large-scale coastal MORphologic evolution; EVK3-CT-2000-00037) and supported by Technology Foundation STW, the applied science division of NWO and the technology programme of the Ministry of Economic Affairs. Furthermore, we would like to thank M.A.F. Knaapen and P.C. Roos (University of Twente); C.J. Calkoen and G.J. Wensink (ARGOSS); S.L. Bicknese A.M. Haksteen, H. Keyser, R.C. Lambij, A. Stolk and W. Verhagen (North Sea Directorate); C. Laban (TNO - National Geological Survey); J. Appelman, M.R. Gerding and W. Korbijn (The Hydrographic Service of the Royal Netherlands Navy) and R. Bijker.

Dresser-Rand to Provide Power For Bass Strait Platform

Under a contract agreement with Origin Energy, Dresser-Rand will provide power generation equipment for the BassGas Project offshore platform in Bass Strait, Australia. The contract was awarded by Origin Energy through its engineering, procurement and construction contractor, Clough Engineering Limited, and includes two Dresser-Rand KG2-3E gas turbine generator packages that will generate base-load power on the unmanned platform.

The Dresser-Rand KG2 units will be manufactured at the company's facility in Kongsberg, Norway. Shipment is slated in June. Plans call for the offshore platform to be positioned above the Yolla gas field, 91 miles (147 km) off the Victorian coast of Australia, in Bass Strait. Origin Energy estimates that the field contains up to 256 petajoules of sales gas, 1 million metric tons of liquid petroleum gas and 14 million barrels of condensate (light oil). ***P&GJ***