New strategy for predictions bedform migration

Th. Wever *WTD 71/ FWG, Berliner Str. 115, 24340 Eckernförde, Germany – ThomasWever@Bundeswehr.org*

S. Papili *Marinebasis Zeebrugge, Graaf Jansdijk 1, 8380 Zeebrugge, Belgium – Sonia.Papili@mil.be*

ABSTRACT: Since early reports of bedforms in rivers and the open sea large efforts were made to understand their formation and migration. Much is understood on their geometrical evolution as well as on the migration in response to hydro-meteorological forcing. The fast developments in positioning system technology and seafloor sensing methods in the last 15 years led to a focus on analyses of bathymetrical data and the quantification of individual bedform migration. Implying several initial assumptions these results are only locally valid and limited the portability to other areas. This too narrow perspective led to the loss of a general understanding. One proposed new strategy is based on simple experiments in which uncertainties are ruled out. Another strategy is proposed to make use of existing data and GIS systems. This can also account for uncertainty and variability in space and time.

1 BEDFORM RESEARCH

Although bedform dynamics is thoroughly investigated, the achieved knowledge is often only locally valid and cannot be generalized.

Moreover discrepancies between the bedform observations and the hydrodynamic predictions are commonly found (Duffy & Clarke, 2005) mostly due to simplifications in a pre-modelling phase.

Researchers try to predict bedform dimensions and evolution using mathematical equations. Those equations were derived from individual experiments in the last decades mostly trying to explain observed data sets and phenomena, see, e.g., previous MARID Conferences. They fail, however to predict properties correctly in other locations.

The actual need for better prediction capabilities of bedform evolution and movement on the seafloor in unmapped areas is an expression of the growing use of the seas for offshore engineering or installations. It is important for safety and environmental impact of drill rigs, wind farms and related pipelines or cables. Reliable predictions of seafloor stability are nowadays a necessity. New strategies are required to respond to permanently growing societal requirements.

1.1 Prediction difficulties

Bedforms are the equilibrium expression of physics controlled by water depth, water flow, and sediment properties. Early predictions of bedform properties used simple mathematical equations combining those parameters (e.g., Flemming, 2000, and references therein). The equations implicitly assumed ideal conditions. Especially variability and inhomogeneity were and still are not considered (Papili & others, 2013, Duffy & Clarke, 2012).

One simplification of this approach is the use of only one single sand grain size neglecting the spectrum or variability in space as, e.g., along sand dune flanks (for a summary see Wever, 2004).

A regular seasonal variability of sediment supply is not accounted for. This leads to imperfect bedform-related predictions, especially when measurements from different situations are used.

Borsje & others (2013) recently highlighted the problem of bedform stabilization and dimension changes due to a seasonal biological colonization. Also this factor demands time-dependent prediction models.

One of the unanswered questions relates to the problem of sufficient sediment supply which controls the development of bedforms reliefs. It remains unclear whether or not the observed bedforms achieved their equilibrium dimensions. Only in that case physics-based equations have relevance. Among the first to raise this problem were Anthony & Leth (2002). They assumed that a shortage of sand did not allow bedforms to reach optimum dimensions. An example for such a condition is shown in Figure 1. Nonetheless it is generally assumed that the condition of sufficient sediment supply is fulfilled. This opens the door for miscalculations in case that this assumption is not fulfilled by the nature.

Figure 1. Side scan sonar images from the Jade area (Germany). Individual (starving) megaripples are separated by large gaps in which underlying glacial till and coarse sediment shows a high backscatter due to a lack of sediment. In an area at 10 nm distance with sufficient sediment supply this is not observed.

Most modelling approaches assume for simplicity 2-D flows across 2-D bedforms. Currents in bedforms fields are, however, absolutely 3-D and turbulent and less stationary than mostly assumed. Figure 2 shows a rotary sonar scan during accelerating ebb current. At slow currents megaripples (marked by the ellipse) develop. At higher current speeds (1 kn) they are flattened. The circle of Figure 2 marks sand ripples, oriented perpendicular to the main current. They also change during the tidal phase, including temporary disappearance. They are a clear sign for a corkscrew-like 3-D water movement within the sand dune field.

To the standard simplifications mentioned so far other uncertainties have to be added. They are introduced by small-scale seafloor relief variations and by non-stationary water movement across bedform fields.

Examples for the impact of uncertain parameters on calculated results have been given by Wever & Stender (2000).

1.2 Technology developments

The technological development continuously supported progress in underwater bedform research. It allowed to map more details than before with a better resolution and accuracy.

Considerable progress was made first for position determination which started with bearings. Electronic navigation aids such as DECCA and nowadays satellite-based positioning almost eliminates position uncertainties and thus reduced error bars in calculations.

A second big step forward was made possible were acoustic devices (ADCPs and ADVs) to determine current–depth distributions. They operate for long periods and record current-depth profiles instead of current speed at one fixed depth. The results are necessary for an understanding of sediment transport.

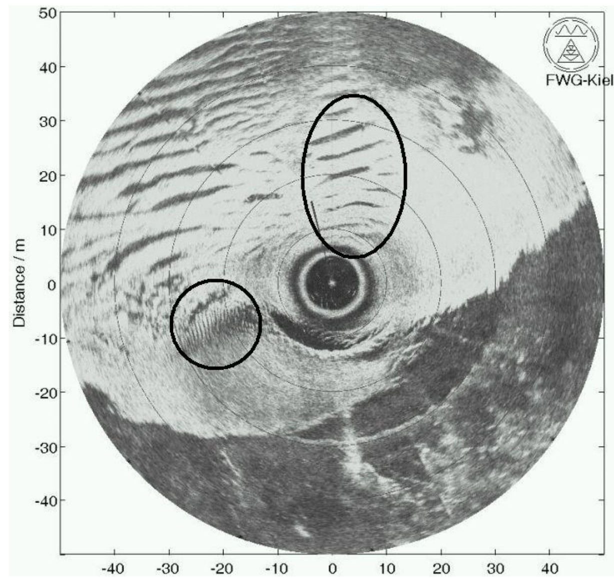

Figure 2. Rotary sonar image during ebb current, shortly after ebb slack water. The radius of the circle is 50 m, every 10 m a marker ring is shown. The dark area in the lower part represents the shadow zone of a sand dune with a curved crest. The light patches within this area result from backscatter from suspended sediment. The tidal currents move up and down the displayed area (no tidal ellipse). For more explanations see text.

The third important technological advance is the development of acoustic systems for mapping the seafloor and bedforms (side scan sonars and multibeam echo sounders). They replaced simple depth echosounder recordings along profiles with considerable spacing. The implementation of such sonars on Autonomous Underwater Vehicles diminishes the impact of wave motion on the sonars.

The improved technologies revealed more details. The concentration on explaining those details reduced the efforts for a general understanding of bedforms.

1.3 Prediction Capability

The recently increased data quantity and detail of single mappings led scientists to focus on explaining the observed data. This de-focused from the necessary predictive capability of where, when and what kind of bedforms will develop.

This disappointing situation was noticed by offshore engineers during the actual planning for offshore wind farms and cable routes to land.

Equations derived from experiments often require an additional adjustment of parameters to local conditions. This restricts the general use and transportability to other areas.

We see a central difficulty in the voluntary concentration on single data sets and subsequent limitation of results.

Assumptions and simplifications are necessary for modelling the complex seafloor. However, they come along with a reduction of available information and an increase of uncertainty in the results.

1.4 New Strategy

In view of these limitations, a new strategy is needed to answer the recurrent questions and societal needs. The goal must be the development of a general concept for the prediction of (a) bedform existence in unmapped areas, and (b) their dimensions and behavior. Lessons learned for different local conditions are an important supplement. The aim is a more general vision and treatment of seafloor bedform dynamics.

Different approaches are needed to reach the goal of a universal reliable bedform prediction based on validated equations.

As important obligatory step is a mathematic description of fully developed bedforms. This must be achieved for different combinations of the easily observable parameters depth, current, grain size under sufficient sediment supply.

A supplementary thrust should be the mapping of bedforms and correlation with other data using GIS (Geographical Information System) technology to integrate different information layers. They can and should include statistical information instead of only one single value.

We think, e.g., not of only a grain size layer but also a grain size spectrum layer in a GIS. Other layers can display sample density and related uncertainty, and many similar parameters as variability of bedform migration speed or give information about flow conditions (direction, turbulence, 3-D flow, interaction with waves) and variability (tidal and non-tidal).

2 DISCUSSION

In view of the disappointment of civil engineers involved in offshore engineering as soon as information about bedforms is needed in unmapped areas, new approaches are necessary. This is especially true for their distribution, dimensions or behavior.

Experiments can be designed to analyze bedform dimensions under ideal conditions, i.e., when they reach their (site dependent) equilibrium dimensions. Nasner (1983) made such observations in Elbe river. He determined the time for restoration of original bedform dimension after crest-capping. Additional upstream sediment supply could be used to rule out sediment shortage. In a different approach filling the upstream trough of a bedform with sediment could be used to monitor the bedform's response. A rotating sonar with regular scanning intervals installed on a small tower (Wever et al., 2008) can resolve changes in time, even in intervals of a few minutes.

On a larger scale experiments based on regular bedform mapping and monitoring of the water climate (waves, currents, tides) could help to understand controlling processes and factors.

The intense mapping of shelves and rivers for navigational purposes has led to the accumulation of large data sets. Their synoptic analyses should offer insight into the long-term development and help to distinguish those from short-term reactions to changes of forcing parameters. GIS technology offers very good tools to implement that. Additional ADCPs within the research area would be a useful addition for understanding processes.

Bedform research seemingly remains anchored on a hindcast level without making the appropriate advancement into predictive applied science. The reasons are multifold. They arise from the topic's complexity and the need of simplifications. The topic's complexity is illustrated by the discussion about the value of bedform classification schemes in contrast to continuous dimensions (e.g., Flemming, 2000 and references therin).

The proposed practical approaches can help to tackle the actual difficulties and find answers.

Difficulties arising from contrasting observations (e.g., grain size distributions along bedforms) leave scientists puzzled with the escape route to concentrate on and deliver the best possible explanation of measured data sets.

Baas & Malarkey (2013) analyzed the grain size distribution's impact and biological factors that influence sediment transport, thus making steps in the direction of a wider understanding.

Any new approach should be planned to understand the general picture first and then to explore and explain details within the broad picture. Necessary simplifications can be carefully chosen and kept under control.

3 CONCLUSIONS

The results of bedform research are not successfully applied in offshore engineering.

A strong focus on the explanation of existing observations led to a loss of the general picture. This, however, needs to be understood before the details can be predicted (top-down approach).

Simplifying assumptions and lacking information limit the value of data-derived solutions in terms of their transportability to other locations.

We propose as one step towards a better bedform related predictions dedicated and well planned experiments to achieve a basic understanding of how the controlling forces interact to form bedforms and how they control their dimensions.

A different proposed tactic makes use of existing data is the summary and integration of all data and their variations. GIS-based approaches offer the necessary tools.

We propose the identification of a suitable bedform dominated area which is thoroughly analyzed. This includes dense sediment sampling, wave/ current climate monitoring, and repeated bathymetric surveys in a joint effort of different labs and various nations. Such a test field will offer ideal conditions to test and validate concepts, especially when displayed with a GIS.

It is important to switch from a focus on explaining existing (historic) data to a "forward looking" prediction of future data.

4 REFERENCES

Anthony, D. & Leth, J.O. 2002. Large-scale bedforms, sediment distribution and sand mobility in the Eastern North Sea off the Danish west coast, Marine Geology 182, 247-263.

Baas, J. & Malarkey, J. 2013. Physical and Biological Cohesion Within Mixed Sand-Mud Beds: Implications for Erosion and Bedform Development, Marine and River Dune Dynamics – MARID IV, 15-17 April 2013, Bruges, V. Van Lancker & T. Garlan (eds.), 23.

Borsje, B.W., Hulscher, S.J.M.H., Herman, P.M.J. & Degraer, S., 2013. Biogeomorphological self-organization in sandy shelf seas. Marine and River Dune Dynamics – MARID IV, 15-17 April 2013, Bruges, V. Van Lancker & T. Garlan (eds.), 53-58.

Duffy, G.P. & Clarke, J.E.H., 2005. Application of spatial cross correlation to detection of migration of submarine sand dunes. Journal of Geophysical Research. V.110, F04S12. 1-11.

Duffy, G.P. & Clarke, J.E.H., 2012. Measurement of bedload transport in a coastal sea using repeat swath bathymetry surveys: assessing bedload formulae using sand dune migration. International Association of Sedimentologists. Special Publication. V.44, 249-272.

Flemming, B.W. 2000. The role of grain size, water depth and flow velocity as scaling factors controllling the size of subaqueous dunes, , Marine Sandwave Dynamics, International Workshop, March 23-24, 2000, University of Lille 1, Proceedings, A. Trentesaux & T.E. Garlan, (eds.), 55-61.

Nasner, H. (1983). Dredging of tidal dunes, International Harbour Conference, Antwerp, Belgium.

Papili S., Baeye M. & Van Lancker V.2013. Decifering Mega-Ripple variability in an anthropogenically-steered environment: implications for mine burial studies. Marine and River Dune Dynamics – MARID IV, 15-17 April 2013, Bruges, V. Van Lancker & T. Garlan (eds.), 207-208

Wever, Th.F. 2004. Bedforms and Bedform Migration: A Data Review, Marine Sandwave & River Dune Dynamics II, 1-2 April 2004, Enschede, S.J. M.H. Hulscher, T. Garlan & D. Idier (eds.), 330-338.

Wever, Th.F. & Stender, I.H. 2000. Strategies for and results from the investigation of migrating bedforms in the German Bight, Marine Sandwave Dynamics, International Workshop, March 23-24, 2000, University of Lille 1, Proceedings, A. Trentesaux & T.E. Garlan, (eds.), 221-226.

Wever, Th., Voß, H., & Lühder, R. (2008). High-resolution observation of small-scale variability in a bedform field, Marine Sandwaves and River Dynamics III , International Workshop, April 1-3, 2008, Leeds University, Proceedings, D. Parsons, T. Garlan, & J. Best (eds), 331-335.