

Object Burial by Bedforms: Results from instrumented modules, new data analysis concepts

Th. Wever⁽¹⁾, and C. Jenkins⁽²⁾

1. WTD 71 / FWG, Kiel, D - thomaswever@bundeswehr.org
2. INSTAAR, Boulder, CO, USA - chris.jenkins@colorado.edu

Abstract

Results from deployments of burial-recording instrumented modules in the Jade area of the German Bight (North Sea) are reported. The time series show significantly changing patterns of burial activity under megaripples from quiescent periods to stages of repeated burial/unburial. The bedforms reached heights of 0.5 m and migrated past the modules on twice daily time scales. As an adjunct, a scanning sonar installation showed stages of quiescence and also stages of rapid (hourly) migration, splitting and merging activity for megaripple-scale bedforms.

The experiments are designed to help predict frequencies of seabed man-made object burial and unburial. They raise issues on the connection between data and models in this practical application. We review the nature of datasets dealing with the migration behavior of larger (megaripple, sandwave) bedforms and propose that some new approaches are needed. They include: (i) adoption of meta-analysis formalisms, (ii) invention of metrics for a bedform's stage of development; (iii) more use of larger experiment scales, manipulative experiments and instrumented modules; (iv) the gathering of a corpus of data on bedform migration. With these tools improved prediction of object burial by bedforms is feasible.

1. INTRODUCTION

The prediction of the presence and the properties of megaripples and higher sand dunes is of importance for many shipping routes, some of which require regular removal of the bedform tops. Similarly, for safety of navigation, objects at the seafloor under shipping routes need to be detected and perhaps removed despite patterns of burial and unburial. A high prediction accuracy for presence and evolution of active bedforms is a relevant cost factor in such situations.

2. BEDFORM ENVIRONMENTS

We focus on current-generated bedforms which are generated either by oscillating tidal currents, unidirectional flows, or a combination of those. These contrasting current regimes cause typical expressions of bedform features: under tidal influence a more regular back and forth movement ("swinging") of bedform crests is observed (Langhorne 1982), perhaps with some migration (Besio & others 2003). Under constant current influence a unidirectional migration is typical.

Subject to the combined action of tidal and unidirectional currents, bedforms show a characteristic unidirectional downstream progress and "swinging crests" (Wever & others 2008).

Tidally active bedforms composed of sand and capable of burying significantly sized objects are important seaward of many river mouths where unidirectional current impacts fade and marine influences such as tides become important.

One example of this situation is in the Jade area of the southern German Bight (North Sea) where our experiments were performed. Water depths there are 10-15 m. The area is protected against swell influence by the coast and a barrier system. The tidal flood and ebb currents have almost exactly opposite directions and peak tidal flows are up to 3 knots (1.5 m/s) at the surface. Occasionally tidal currents of 1 m/s have been observed 1 m above bottom at the site. There is no significant riverine outflow at the site. The megaripples of the area vary greatly in individual lengths and heights, even locally. Sediment character is medium-coarse sand with scattered shell remains.

3. VARIABILITY OF BEDFORM MOBILITY

A central difficulty in bedform research has been the position accuracy of repeated measurements. This inaccuracy can be overcome by using permanent burial recording modules on the seafloor. These modules mimic objects on the seafloor and have the approximate shape, size and weight distribution of the casings of naval mines. In the field experiments of Wever & Stender (2000) much was learnt from these modules about megaripple migration.

3.1 Burial recording module records

A many weeks long time series of bedform migration verified the high temporal variability of megaripple movement. Figure 1 displays a typical example that shows the irregularity of bedform migration.

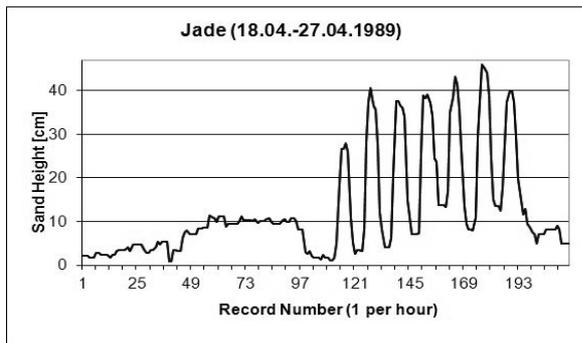


Figure 1. Recorded sand height around a burial recording module during nine days at the Jade site. Recording interval: 1 hour. Only moderate sand height changes around the burial recording module are observed for 4.5 days followed by 4 days of extreme sand height changes which are thought to be the passage of a megaripple.

After a period of little change a set of strong (0.4 m; Figure 1: rec. no. 110-200) changes takes place. That set is interpreted as back and forth movement of a megaripple in response to the tidal current. The period of prominent changes is followed by another “quiet” phase. Weather conditions cannot explain this difference.

In a second phase of experiments arrays of burial recording modules were laid out to study the small-scale changes of bedform migration. Figure 2 displays the result of a typical experiment with

an array of six systems with separations of 48-53 m.

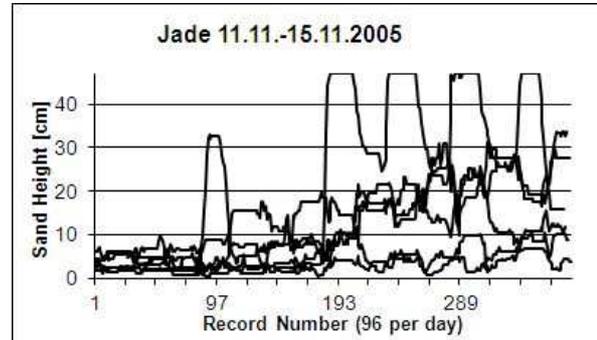


Figure 2. Six curves of recorded sand height around six burial recording modules (48-53 m distance) during a 4 day period at the Jade site. Recording interval: 15 min. The individual maximum sand heights observed by the six burial recording modules were 7, 11, 25, 25, 31, and 47 cm.

Such experiments with many systems were helpful to estimate small-scale variations among migrating bedforms. The repeated deployments of systems at close distance regularly showed similar time-series of burial due to bedforms at the recording modules. However, the observations pointed to new open questions which could not be answered solely by the point data at the recording modules.

3.2 Differential bedform movement

Accordingly, in a third series of experiments at the Jade site an area-covering rotating scanning-sonar was deployed. The 380 kHz frequency sonar was mounted at 4.8 m height on a tower which was positioned on the seafloor. Having a range of 50 m, the system covers a circular area of 7.850 m² (Wever & others 2008). Complete areal scans were obtained by the system each 3 minutes over a period of 25 hours, and at 10 minutes over periods of 7 and 9 days respectively. The recorded data showed for example: splittings of megaripples into segments; a sudden stopping of movement for such segments or whole bedforms; mergings with following bedforms. The 3 minute scans showed that these processes happen quickly - on scales of <60 minutes.

Another important aspect revealed by the rotating sonar is the three-dimensionality of bedform shapes and water flow. One short-interval, long-term scanning of an area with bedforms revealed

small sand ripples at the lee side foot of a steep sand dune. They indicated the action of crest-parallel currents. The water appeared to be moving in these cases at least partly on corkscrew-like paths first across and then parallel to sand dunes. Hence, even under purely reversed current situations without a tidal ellipse in the Jade area the bedforms had 3D characteristics as large-scale side scan sonar mappings ahead of sonar tower or burial recording module deployments showed.

4. SUBTIDAL DUNE MIGRATION

These experimental programs have raised important questions for those who are interested in the practical importance of subtidal dune migration. There is a need to understand the probabilities for burial (disappearance) of objects of ~1m size under megaripples and sandwaves, in different environments. Unburial is also of interest. Modeling of large-bedform migration offers one avenue for progress. Besio & others (2003) analysed the relation of sandwave migration to tidal constituents and bottom configurations and proposed morphodynamic scalings for sandwave migration. Now, most likely, further progress on the issue will be through closer data-model combination, especially if the model results (above) are to be applied to a wide set of areas and to the megaripples superimposed on the sandwaves.

4.1 Limiting Environmental conditions

A traditional approach to data on bedforms is the narrative form of analysis in which limiting conditions for presence of active bedforms are set out. This at least gives a highly useful 'epidemiological' view of the problem by defining the areas where burial of objects can be discounted.

For example, in sedimentology: (a) Fenster & others (1990) find no bedforms when the sediment's gravel content exceeds 12%, though (b) gravel bedforms are observed in the English Channel. Bokuniewicz & others (1977) (c) do not observe sand waves when >12% of the grains exceed 1 mm though (d) Harris (1989) reports sand waves composed of sediments with a d_{50} of 0.8 mm.

For the fine constituents of the sediments there is some agreement: (e) Fenster & others (1990),

report no sand wave development where silt exceeds 10%; (f) Terwindt (1971), finds no sand waves where mud content exceeds 15%; (g) Salsmann & others (1966), report megaripples with 6% of particles <0.062 mm; (h) Bokuniewicz & others (1977), absent sand waves where silt >10%, (i) Dalrymple & Rhodes (1995) put the limits for dune development at 0.13 mm, and for megaripple development at 10-15% silt/mud content.

A further set of limitations can be imposed based on near-bottom current speeds. Salsman & others (1966) (a) observed megaripple height reduction with increasing current speed; (b) Terwindt & Brouwer (1986) reported that sand wave height increases around the times of spring tide, and decreases around neap tide. Langhorne & Malcolm (1979) (c) found highest bedforms during lowest current velocities and a flattening during higher currents of spring tide. Support comes (d) from observations of Nasner (1975) in Elbe river where he found an inverse correlation of ebb current speed and sand dune height. Idier & others (2002) (e) reported height increases during quiet weather conditions. The rotating sonar records (f) show a flattening of megaripples when current speed at 1 m above seafloor exceeds 0.6 m/s (Wever & others 2008), height determinations are not possible.

Controversially, Soulsby (1997) (g) sees bed shear stress as well as water depth determining the dimensions ("rough guide ... wavelength is 6 times water depth"). Bartholdy & others (2004) (h) argue against this and refer to reports where flow depth did not control dune dimensions (see, for example Flemming 1978) (i).

Extraneous factors such as irregularly occurring major storms also affect bedform heights: (j) Langhorne (1976) and Houthuys & others (1994) observed the storm-induced disappearance of megaripples, Houthuys & others (1997) (k) reported a flattening of sand dunes by 1.2 m during storms.

Conflicting reports in the literature of both crestwards sediment fining on large bedforms (Harvey 1966; Anthony & Leth 2002) and a coarsening (Terwindt 1970; Stolk 1996; Wells & Ludwick 1974; Fenster & others 1990; Chakhotin 1977) may be due to the action of waves (Perillo & Ludwick 1984). The same may apply for conflicting observations on the heights of megaripples on large sand dunes. Some authors

(Terwindt 1971; Stender 1996) report higher megaripples near the crests of sand dunes. Others (Langhorne, 1977) report the opposite.

4.2 Synthesizing the data

It goes without saying that a better understanding of the entire matrix of environmental controls on bedforms is needed. First, narrative forms of synthesis should be replaced with more formalized methods. We envision a systematic meta-analysis of that corpus as is done in medical sciences and ecology (Stewart 2010). This would enlarge the available pool of data and overcome the heterogeneities between individual, small and local studies. Plus, importantly for practical burial problems, a large-as-possible corpus of data on bedform mobilities and dimensions versus key environmental controls is needed.

In terms of modeling, successful models should be able to explain the collated data on environmental controls, not just implement them *ab initio* in code.

4.3 Dune development

Allowance will have to be made in data syntheses on whether the subject dunes are fully developed, of composite structure, and in equilibrium with surrounding environment. Much existing data is likely to refer to non-ideal states of dune development. It would help to have metrics for stages of bedform completeness of development so that their attending data can be assessed. To an extent this is a matter of the scales of dune dimensions and longevities versus stability of their environment.

The sensitivity of subtidal dune development to sediment supply is well known (Dalrymple & Rhodes 1995). Laboratory work such as by Tuijnder & others (2009) quantitatively addresses ripple scale phenomena, but the excursion paths for the building and migration of megaripples and sandwaves appear to scale over distances and durations well beyond flume scales. To examine the issues of sediment supply controls at appropriate scales, large-scale long-term experiments are needed – including manipulative experiments like trenching into dunes or changing sediment loads (see Nasner 1983; Wienberg & Hebbeln 2005). There may be a role for the instrumented burial recording modules in such experiments.

The simplicity of bedforms is also an issue for rating the reliability of existing data in formal data synthesis. Many large subtidal bedforms have sub-structure that involves layering from alterations in the prevailing flow patterns (e.g., Berne & others 1993), storm induced layering, and varied patterns for their smaller surficial (superimposed) bedforms and sediment textures.

5. CONCLUSIONS

For practical applications such as safe navigation and object burial a knowledge of bedform occurrence and movement is of highest relevance. The immense costs of dredging puts pressure on responsible agencies and bureaux to reduce such operations to a safe minimum. To attain that goal reliable prediction models are desirable which can cope with varying environmental conditions.

Those models could be of the numerical-process type, morphodynamic, expert system, or geographic information system (GIS). In all these cases a good connection between models and data must be a high priority and we advocate a new approach with that in several ways: (i) more systematic meta-analysis of existing data, especially in terms of bedform dynamics; (ii) construction of a corpus of reliable data; (iii) rating that data in terms of bedform development stage; (iv) renewed effort with larger-scale, perhaps manipulative, experiments that use instrumented modules.

From our perspective existing combinations of data and model do not yet provide sufficient predictive capability for practical problems of object burial under bedforms.

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