

Burial Recording Mines: a valid technique to study bedform migration and storm impact above the sea-floor

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Abstract

Initially, Burial Recording Mines (BRMs) were used to understand the sea mine burial. It was a technique predominantly related to military purpose. The first experiment was made 1974. Now a day, it is used as a valid tool for marine science. This methodology gives the rare opportunity to observe and analyze the processes acting on the seafloor directly, making the estimation closer to the reality.

During MARIDIV, we present the results of 3 months experiment using burial recording mines. The experiment was performed between September 2008 and January 2009. The Wandelaar region on the Belgian Continental Shelf was chosen as suitable test area. 10,000 measurements of the sediment height around the cylindrical object were recorded, each one of those every 15 minutes. The dataset collected, together with sediment characterization and hydrological and meteorological information, allowed the understanding of the bedform migration.

During the experiment, 2 storms passed the test area, in October and November 2008. Using Burial Recording Mines gave the rare opportunity to observe and analyze the storm impact directly on the sea-floor. Processes during and after the second storm will be revealed.

1. INTRODUCTION

Burial recording mines are instruments collecting data directly on the sea-floor. They perform a recording of the sand mobility in four dimensions. Due to their massive but smooth body they are not affected by heavy storms. Those objects were initially used for military purpose (Wever et al., 2004) for the understanding of the sea mine burial. The knowledge coming out from this methodology results valuable to figure local small scale scenario during bedforms migration (Wever et al., 2008). Moreover, it reveals mechanisms regarding the storm influences on man-made structures. Storms are uncontrollable and can be destructive. It is not always possible to get on-scene data measurements due to large involved forces. This technology gives possibilities in the understandings the storm impact on sediments surrounding objects laying on the sea-floor with a confidence level of centimeters in space and minutes in time.

2. STUDY AREA

2.1. Area of investigation

The Wandelaar region is located at 12 km distance from the port of Zeebrugge (fig.1) in the vicinity of the main navigation channels on the Belgian part of the North Sea. In these channels, every year about $1.4 \cdot 10^6$ T dry matters (TDM) of sand and mud are dredged to maintain the accessibility of the port (Lanckneus et al., 2001). Given the strategic position of the area, permanent stations for hydro-meteorological measurements are localized nearby. The tidal regime amplitude is between 3.5m and 5m producing strong rectilinear current ellipses prevail with the main axis oriented in a SW-NE direction (Lanckneus et al, 2001).

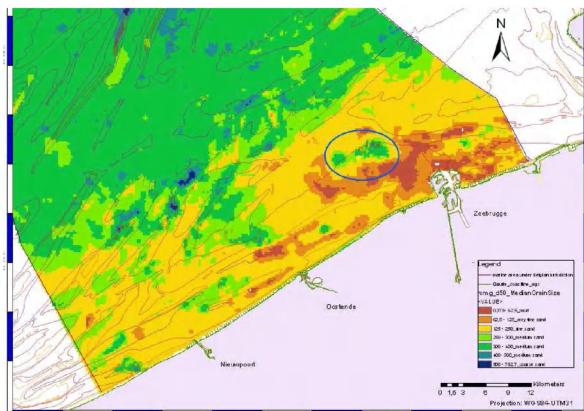


Figure 1. Extract from a grain size map of the Belgian continental shelf (Verfaillie et al., 2006). UTM coordinates. Sandy sediments are represented in green; the Wandelaar area is contoured in Blue.

The Wandelaar consists of a sandy bottom and is characterized by the presence of small to large dunes (*sensu* Ashley, 1990), of up to 2 meters in height.

Substrate characteristics and morphology, together with hydrological and meteorological conditions contribute to the dynamics and the evolution of the Wandelaar zone. Studies on the morphology of the large dunes revealed that in the near coastal zone the crests are dominantly oriented in a northeastern direction (Lanckneus et al., 2001). This is in agreement with the rectilinear current ellipses described above.

All bedforms are affected by hydro-meteorological factors (currents, waves), including occasional strong events and storms (Lanckneus et al., 2001). The superficial sand dune layers directly respond to these stresses (Van Lancker, 1999), but the residual effect on these bedforms can be evaluated only over a time scale of years (Wever, 2003). Different is the situation for smaller bedforms such as megaripples: they can be seriously affected by current, waves and current-wave interaction, on a time scale of hours. They can even be destroyed (Langhorne, 1976) to form again under normal conditions. Episodic strong storm effects dominate over processes related to current-induced bedform movement.

3. METHODS

3.1. Description of burial registration mine

(BRM)

Four burial registration mines (BRMs) of FWG (Forschungsanstalt der Bundeswehr für Wasserschall und Geophysik, now Forschungsbereich für Wasserschall und Geophysik of WTD 71) were deployed to study sediment dynamics in the Wandelaar area.

The BRM (fig.2) has a cylindrical shape, is 1.70 m long and has a diameter of 0.47 m. The weight in air is 500 kg. BRMs were built to determine the sediment height surrounding the object as function of time. For this purpose BRMs are equipped with three rings of 24 led bridges ("sensors") equally spaced around the object at 15°. All electronics and energy supply is installed within the BRM. Up to 10,000 measurements of all 72 sensors can be recorded. The sensors emit light at pre-set intervals. The light bridges (light emitter and receiver) are in small housings at a distance of 4 cm. The light sensors detect the presence of sediment by recording the value "1" if sediment occludes the space between emitter and receiver (the led bridges are blocked) otherwise they record "0". The led bridges of each ring are numbered from 1 to 24. The rings are located on both ends and the centre of the BRM at a distance of 60 cm (fig.2). The rings are named "Stern", "Centre" and "Bow". The bow ring is at the truncated side.



Figure 2. BRM, length: 1.70m, diameter: 47cm, weight: 5.0 kg. Bow ring at the right side (Wever et al. 2004).

In addition to the burial status, accelerometers inside monitor the movement of the object and allow to calculate the Pitch and the Roll of the object and its variation in time. Figure 3 shows the used convention defining the positive and the negative side for both Pitch and Roll. The magnetic steel casing does not permit to monitor of the BRMs heading with a compass.

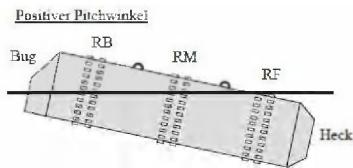


Figure 1: Side view of a BRM with positive pitch angle. The bow (Bug) is the tapered end of the mine, the stern (Heck) is symmetrical. The three rings are named RB, RM, and RF.

Figure 2 gives a cross section through the BRM and explains how the numbering is defined.

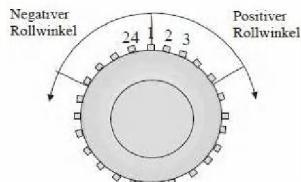


Figure 2: Cross section of a BRM and indication of positive and negative roll when looking from the stern (RF) of the mine to the bow. ("Rollwinkel": angle of roll)

Figure 3. Used convention defining the positive and negative position for pitch and roll measurement.

The Pitch has positive values when the Bow side is up with respect to the horizontal position. Watching from Stern towards Bow the roll has positive values when the object rotates to the right side.

It is important to underline that the geometry of the object produces, at a small scale, different modalities of sedimentation of the sand. Both end rings are around 25 cm from the ends. The Bow and Stern rings are exposed to stronger water acceleration and consequently stronger erosion than the Centre ring. On the contrary, the sediment deposits behind the Centre ring are in a “current shadow”.

3.2. Experiment

Four BRMs were deployed on 25th September 2008 in the Wandelaar region (fig.1).

Always two instruments are deployed together, one having 15 minutes and one having 60 minutes recording intervals. Figure 4 gives a sonar image of one pair of BRMs after deployment. The BRM called “Seestern” was recovered from the seafloor on 15th January 2009. It recorded the sediment height every 15 minutes. With this setting the Seestern had a maximum recording time of 104 days until 6th January 2009. The other instruments were buried and could not be recovered yet.

Initially, a quality control for the elimination of obviously wrong recordings was performed; subsequently, data were analyzed and interpreted. Only very few records had the necessity to be corrected showing that the measurements were achieved in optimal conditions.

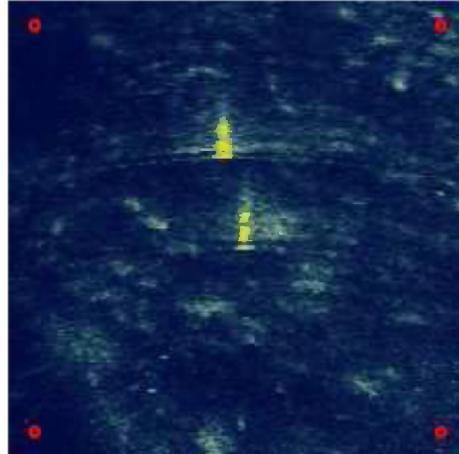


Figure 4. Hull-mounted sonar image of two BRMs directly after deployment. The three rings with the sensors are perfect sonar reflectors and allow identifying the systems.

3.3. Hydrometeorological datasets

Hydrological and meteorological data were recorded at different monitoring stations in the vicinity of the Wandelaar. They included wind measurements, velocity and direction, recorded by the *Wandelaar* waverider (Fig.5), ca. 3 km southwest of the Seesterns’s position.

Wave height and period were recorded by the *A2* buoy (Fig.5), ca. 6 km southeast of Seestern. The direction of high and low frequency waves was observed at the *Bol van Heist* waverider (Fig.5), ca. 11 km to the southeast. All of these data originated from the Flemish Hydrography, Flemish Authorities.

Current data are recorded at the measuring pile MOWO (Fig.5) located ca. 2 km north of the BRM. The data give information about speed and direction of the current at different water depths. Starting at the surface there is a measure of current velocity and direction every 2 meters of depth.

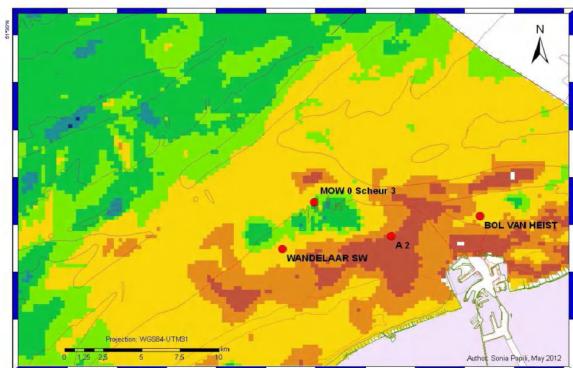


Figure 5. Hydrological and meteorological monitoring stations in the vicinity of the Wandelaar area.

3.4. Time references

The time references (local time and UTC) were a parameter that asked some recalculation. The current and the hydro-meteorological data were recorded in UTC time, the tide data were recorded in local time: UTC time+1h during winter and UTC time+2 during summer period; the "Seestern" recording were in Central European Time (CET): UTC time+2. To facilitate the interpretation all data were reconverted in UTC time. In addition, data were recorded at different time intervals, for instance, current data every 10 minutes, mine burial and wave height every 15 minute, wave direction every 30 minutes. Only simultaneous measurements were correlated and compared.

4. RESULTS

4.1. Interaction sediments-object.

The recordings made by the BRM are visualized on figure 9 at the end of the present document. They show the sediment displacement around a cylindrical object in a shallow dynamic environment. Remembering that the instrument was programmed measuring every 15 minutes, the picture we got is close by to an on-scene scenario. Figure 9 is a composite figure where 3 different diagrams are displayed.

The first one indicates the variation during the 3 months experiment for pitch and roll values. The second one shows the BRM burial volume in percentage and the third one is the combination of both.

Watching the burial curve (b) we can identify 3 significant stages in the recording.

The first one, with values less than 20% burial; the second one with a medium burial oscillating between values of 60-70% and the third one with a medium value oscillating around the value 80-90%.

Two crucial moments delimiting the three stages are visible in the recordings, they correspond to storm events. Storm events represent the only circumstances where the object reaches minimum value of burial and has the possibility to roll. We will go deeper into this matter in the next paragraph.

During the 3 months experiments, 7 cycles of neap-spring tide are counted. This alternation is reflected in the measured data. Under stronger tidal neap and spring currents the megaripples show an enhanced mobility (back-and-forth movement) which is easily recognized in the recordings by 6-hour peaks in response to a changing current direction. This has been shown for wider areas by Wever et al. (2008). During neap tide, the environment is less subject to turbulences; as a consequence the sediment mobilization around the object is minimal not exceeding 5% of burial variation.

On the contrary, during spring tide the sediments are affected by increased local turbulence producing short moments of complete burial (peaks). Both periods are recognizable in the burial volume curve (b).

4.2. Storms

Storms along the Belgian coast are caused by a low pressure system over Scandinavia associated with reinforced Azores high pressure systems. The atmospheric pattern leads to a strong Southwest-Northeast pressure gradient associated with onshore winds blowing from the western sector in the southern part of the North Sea (Ullmann et al., 2009).

Two storms passed the experiment site off the Belgian coast in October and in November 2008. The effects of both storm passages are well documented in recordings. The second storm is discussed in the following.

4.2.1. Storm 21st-24th November 2008

On Thursday 20th November 2008 a high pressure system developed on the Atlantic Ocean together

with a low pressure above the Baltic Sea. As a consequence a cold front passed along the Northern coasts around the midday of the 20th November 2008; from Friday the 21st, winds blew from northerly direction and affected the Belgian coast and inland. The combination of cold arctic airs with relatively warm water from the sea started an instable situation with the beginning of a storm. (Storm archive, Royal Meteorological Institute, 2008).

Meteorological measurements show a wind blowing from WNW-NWN during the 20th, 21st and 22nd November with 10 to 22 m/s (5 to 8 Bft), with gusts of 28 m/s (10Bft) at 22:10 h on the 21st November and 33 m/s (12 Bft) at 04:50h on 22nd November (fig.6).

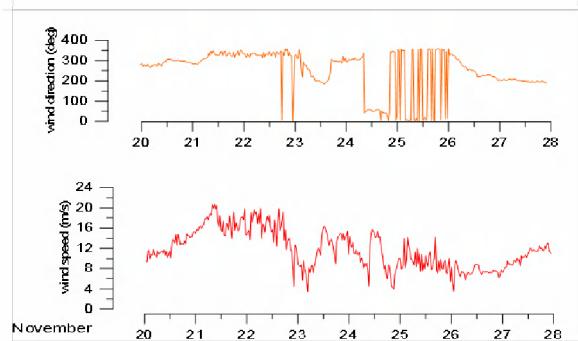


Figure 6. Wind direction (a) and wind speed (b) between the 20th and the 28th November 2008. The graph illustrates only measurements recorded every 30 minute. Therefore, the maximum values discussed on the results section are not visible.

The significant wave height increases during this period reaching almost 3.50 m. Peaks of maximum wave height of 6 m were measured during the 21st and the 22nd (fig.7).

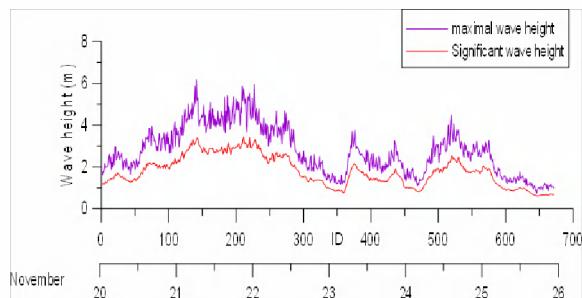


Figure 7. Maximum (blue curve) and significant (red curve) wave heights measured between 20th and 26th November 2008.

The tidal cycle was during 21st and 22nd November in neap tide regime with a maximum water depth variation of 3.47 meters.

Before the storm, the BRM lay almost horizontally on the sea floor with the Bow side (pitch value -2) oriented slightly downwards. At that time it was partially buried for 60% of its volume. A flattening of megaripples already during the rise of the storm is clearly visible as reported by Langhorne (1976). Between the 20th November at 10:45h and the 23rd November at 09:15h the significant wave height recorded at sea (red on fig.8a) was much higher than the calculated critical wave heights for sediment mobilization (gray on fig.8a). The storm caused forces at the seafloor that were able to move easily the sediments in the main phase of the storm. On 21st November at 11:00h the storm has a peak water height of 6.17 m of producing energy of 48,000 J/m² in an estimated water depth of 9.5 m. The wind blew with 18.5 m/s from NNW (337.4°) whereas the tidal current at a depth of 10 m had a direction of 275°. The combined action at the seafloor is scouring around the mine leaving only 4.8 % of the total mines volume buried (fig.8b). During this phase the sediment cone underneath the BRM collapsed and the mine rolled 97° towards NW and 26° back in the following 30 minutes (Table 1). The burial increased to more than 80% in the following hours.

Date	Time (UTC)	Significant wave height(cm)	Relative buried volume (%)	Roll
20/11/08	11:01	330,570007	4	+39
21/11/08	11:16	339,890015	15	-58
21/11/08	11:31	335,670013	31	-47
21/11/08	11:46	325,26001	45	-32

Table 1: comparison between significant wave height, relative mine buried volume and roll on 21st November 2008

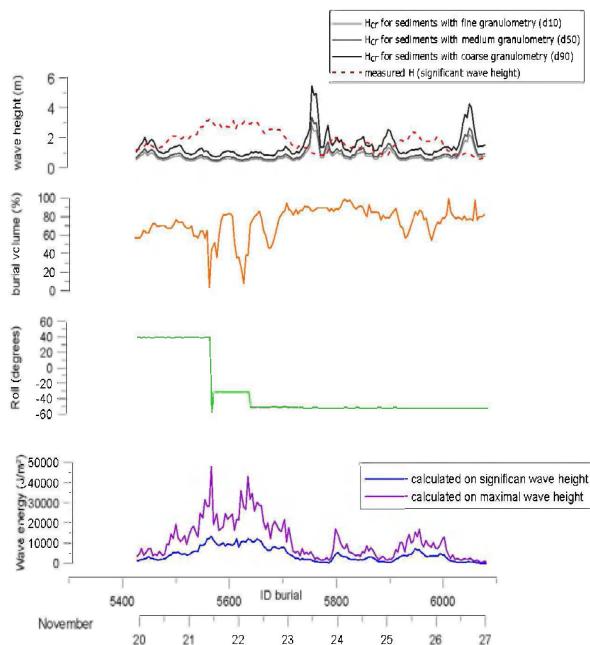


Fig. 8. Storm in November 2008. (a): comparison between measured curve of real wave height (red-dashed) and calculated curves of critical wave height (different tone of grey); (b): curve of burial volume; (c): curve of roll measurements; (d): curve of wave energy.

On 22nd at 04:00h a second minimum burial of 9.5% was recorded (Table 2). The estimated water depth was 8.7 m. During this minimum of water depth a wave height peak of 5.8 m is measured producing wave energy of 43.200 J/m². The tidal current had a direction of around 250°. The combined action of wave and current caused scouring around the mine. This allowed an additional roll of 20° towards W.

Date	Time (UTC)	Significant wave height(cm)	Relative buried volume (%)	Roll
22/11/08	3:31	297,329987	26	-31
22/11/08	3:46	302,73999	9	-30
22/11/08	4:01	313,01001	10	-32
22/11/08	4:16	335,140015	24	-52
22/11/08	4:30	344,779999	27	-52

Table 2: comparison between significant wave height, relative mine buried volume, and roll on 22nd November 2008.

The sediment deposition phase started in the evening of the 22nd November. It is characterized by a fast drop in wave energy (fig.8d). The sediment settling around the object covered it to about 90% of its total volume during the next day. On 23rd November at 17:45h the minimum value of wave energy (2,024 J/m²) is recorded.

5. CONCLUSIONS

Through the use of the burial recording mines (BRM) seabed processes could be studied; also during storms. Especially the flattening of megaripples under high-energetic conditions could be proven.

In shallow water, both current and waves affect the sea-floor and are able to mobilize fine to medium sands. The tidal variation during neap and spring period produces different scenarios, respectively steady or turbulent. During storms, a rapid erosion of sand around the object is observed. It starts with scouring at both BRM ends. The scour holes eventually merge leaving the BRM almost uncovered. At this stage it rolls to a deeper level within the merged scour pits. The subsequent sedimentation phase favours reaching a higher percentage of burial volume. More in detail, the BRM data showed during the experimental period, a burial of 60% after the first storm (October 2008) and 80% after the second storm (November 2008). It remained in this condition until the end of the 3 months experiment.

The burial recordings display a rapid (within two days) generation of megaripples after the decay of the storm thus proving a quick adjustment to normal hydrodynamic conditions.

Burial recording mines are reliable tools to investigate local phenomena in 4 dimensions. They can be a supporting method for analyzing small scale scenarios and they are perfect for in situ measurements during storm events.

6. ACKNOWLEDGMENT

The author is grateful to the Belgian Navy founder of this project and to Ghent University, particularly to RCMG (Renard Centre of Marine Geology) for the facilities and the precious intellectual support; to Forschungsanstalt der Bundeswehr für

Wasserschall und Geophysik, now Forschungsbereich für Wasserschall und Geophysik of WTD 71, owner of the BRMs kindly supporting this experiment. The author is also grateful to the crew of the MH vessel Lobelia especially the diving team that deployed and recovered the BRM Seestern.

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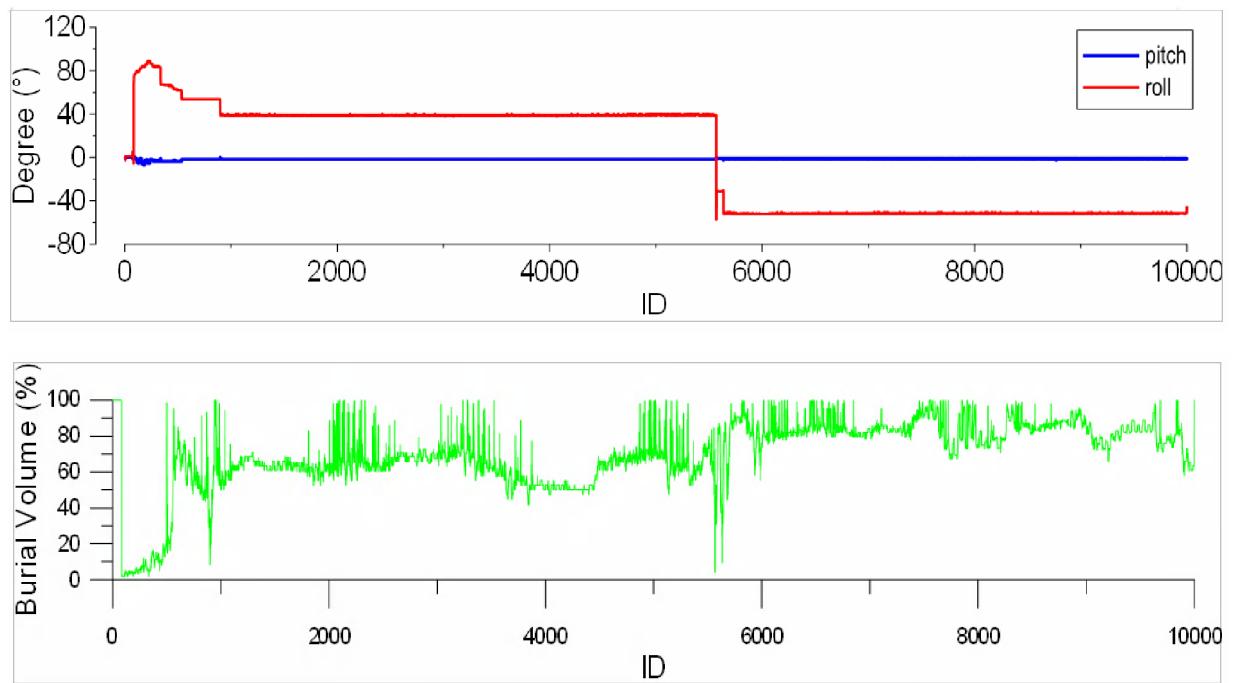


Figure 9. Pitch and roll measurements during the all experiment, (a). Mine burial volume during the all experiment. 2 storm events are recognizable: lowest values at around 1000 and 5500 recording number, (b). combination pitch-roll and burial volume. Roll events are encountered during storm events.