HOW RIPPLES AND WAVES DETERMINE SAND-GRAIN MOVEMENT

Seabed in Motion

Despite its great practical importance, we still have much to learn about the transport of sand grains in the coastal environment. This mainly due to the complexity of sand transportation processes influenced by both waves and net currents like the tide. Here an overview of recently completed PhD research that yielded new insights into, and predictive models for, wave-induced sand transport over rippled beds.

Coastal regions and shallow shelf seas like the North Sea are increasingly subjected to human activity. Cities, harbours and industry are situated near the coastline, and farther offshore the seabed is used for the construction of windmill parks and the extraction of sand. Therefore it is important to understand the morphological behaviour of the coastal system and to be able to predict future changes as a result of natural processes and human interventions. For this, knowledge of sand transport processes induced by waves and currents is of crucial importance. However, little is known about wave-induced sand transport in cases where the sandy seabed is covered with ripples.

Ripples

Walking along a sandy beach you may wonder how the seabed beneath the water surface might appear. You can get an impression of this by looking at the part of the beach that falls dry at low tide. You will find that it is generally covered with a rhythmic pattern. The distance between two consecutive crests is a few decimetres and the bedforms are some centimetres high. These 'ripples' can also be found on large parts of the bed of shallow shelf seas like the North Sea. The near-bed oscillatory (to-and-fro) motion of waves generates ripples. When this so-called orbital motion is great enough near the seabed, sand grains are mobilised and begin to roll back and forth on top of the flat bed. Grains of sand accumulate to form small ridges, which grow in size. After some minutes, equilibrium geometry is attained. Equilibrium ripples typically have a height of 0.01-0.1m and length of 0.1-1m.

Sand Transport

Ripples strongly influence wave-induced oscillatory flow near the seabed and therefore also have a great influence on sand transport. If ripple steepness, the ratio of ripple height to length, exceeds 0.1, the oscillatory flow is no longer able to follow the ripple contour and separates from the surface. As a result, a vortex, or whirling water mass, is generated on the lee-side of the ripple. When oscillatory flow changes direction this vortex is ejected into the flow and at the same time a new vortex is generated on the other flank of the ripple. This vortex process is highly effective in picking up sand from the bed into suspension and carrying it along.

Span class="art_subkop">Lab Studies

A new experimental study was carried out at two large-scale laboratory facilities: the Aberdeen oscillatory flow tunnel at the University of Aberdeen (UK) and the large oscillating water tunnel at WL|Delft Hydraulics (The Netherlands). At these facilities, oscillatory near-bed flow conditions as in-duced by moderate (non-breaking) waves can be simulated at full-scale for a wide range of relevant coastal conditions. Using state-of-the-art measuring techniques, ripple dimensions, flow velocities, suspended sand concentrations and net sand-transport rates were measured for different sand and flow conditions. For example, flow velocities over the ripples were measured using a cross-correlation Particle Image Velocimetry (PIV) system. PIV is a planar measurement technique wherein a pulsed laser light sheet is used to illuminate a flow field seeded with tracer particles small enough to accurately follow the flow.

New Insights

The new data shows that net (time-averaged) transport over rippled beds in asymmetric oscillatory flows (where onshore orbital velocity peaks are larger than offshore orbital velocity peaks) is determined by the ratio of bedload to suspended load transport. Bedload transport is the transport of sand grains by means of sliding, rolling and saltating, frequently in contact with the bed. The suspended load consists of grains in suspension, that is grains that follow long paths within the water and seldom come in contact with the bed. Due to flow asymmetry, more sand is entrained and transported as bedload during the onshore half wave-cycle, and therefore net bedload transport is in the onshore direction. However, if suspended sand transport becomes dominant, the total net transport rate can become offshore directed due to phase lags between flow and sand concentration induced by lee-side vortices in combination with flow asymmetry.

At times of maximum onshore flow there is a strong vortex filled with sand present on the lee-side of the ripple. When the direction of oscillatory flow changes from onshore to offshore, this sand cloud is ejected into the flow and transported in the offshore direction. Then a new vortex is generated on the other flank of the ripple. This vortex is weaker and smaller and contains less suspended sand than the vortex gener-ated at times of onshore flow. This is the result of flow asymmetry: the maximum offshore velocity is lower than the maximum onshore velocity. The sand cloud is ejected at times of flow reversal from offshore to on-shore and transported in the onshore direction. As a result, the net (time-averaged) suspended sand transport is in the offshore direction.

Practical Model

The new experimental data was combined with existing full-scale data to make a large dataset of sand transport processes over rippled beds in oscillatory flows. With this combined dataset we validated and further developed various types of models to predict ripple dimensions, suspended concentration profiles and net sand transport rates. For practical purposes, accurate prediction of net sand transport rates is of the greatest importance, since spatial gradients in sand transport lead to either erosion or deposition, thereby changing coastal and seabed topography.

At low orbital velocity measured net sand transport is positive (onshore), because bedload is the dominant transport mode. However, for larger orbital velocities, net sand transport changes direction and becomes increasingly negative (offshore). This is due to the vortices generated at the lee-side of the ripple and associated sand transport processes, as discussed in preceding sections. Existing models (red line) always predict positive (onshore) net sand transport, while the measurements show that this is not the case for high orbital velocities. A new model (blue line) has therefore been devel-oped capable of predicting the right order of magnitude and direction of wave-induced sand transport over rippled beds.

Relevance

The Dutch coast, like other sandy coastal zones, is subject to erosion. Historically, protection against flooding of the lowland area behind the coastline was achieved by constructing groynes, dikes, dunes and seawalls. In 1990, a coastal policy was adopted to maintain the Dutch coastline of that date by applying beach nourishment. Such nourishment has been regularly applied to erosive stretches. Since 1999 sand nourishment has also been applied at the shore-face, aimed at preventing the coastline from moving landward. In planning an effective nourishment scheme it is important to have insight into the relationship between transport of nourished sand and design variables like location of nourishment and characteristics of the nourished sand. More generally, coastal profile models and coastal morphological models used for designing sand nourishment, coastal defence schemes and coastal reclamation require accurate description of wave-induced sand transport.