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Impact of groyne fields on the littoral drift: A hybrid morphological modelling study

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ABSTRACT

This paper concerns numerical modelling of the impact on the littoral drift and the shoreline from groynes forming a field of equidistant and identical groynes. The most important effect of a groyne on the shoreline morphology is that the littoral drift is blocked completely or partially. A local reduction in the littoral drift around the groyne introduces alongshore gradients in the alongshore sediment transport and sedimentation and erosion around the groyne which will cause re-orientation of the bed contours towards the prevailing wave direction until an equilibrium is reached. A discussion of this mechanism is presented including effects of scales, e.g. the effect of the relative length of the groynes (compared to the width of the surf zone).

The model results indicate a strong dependency of the reduction in littoral drift on the initial geometric bypass ratio (Q_{geo}^*), which is defined from the groyne length and the littoral transport on the undisturbed coastline; Q_{geo}^* is the transport occurring outside the tip of the groynes divided by the total transport. It is found that the sensitivity of the littoral drift to variations in groyne spacing and the angle, of the approaching waves, is inversely proportional to Q_{geo}^*.

1. Introduction

Single groynes are structures typically normal to the shoreline, which block the littoral drift partially or completely. In modern beach management strategies, single groynes are used to create smaller sediment cells in which the beach can turn against the locally predominant wave direction (e.g. the Danish Amager Beach Park described in Mangor et al., 2008). Single groynes are also often used as terminal structures (jetties) which limit the amount of sediment deposited in tidal inlets and navigation channels, Basco and Pope (2004); and Grunnet et al. (2009). The qualitative functionality of a groyne system has been described by French (2001).

Groyne fields (a series of groynes) are typically constructed on shorelines where erosion problems are generated by gradients in the longshore transport (in contrast to erosion problems caused by cross-shore transport). The groynes act by partially blocking the longshore sediment transport and as a result the bed contours landward of the groyne tip tend to turn against the predominant waves. Examples of this are shown in Fig. 1 where a series of channel groynes in the entrance to the Limfjord at Thyborøn in Denmark, has caused the beach to turn approximately 40°.

In areas where the predominant waves approach more perpendicularly to the coast, as in the case along the Agger barrier, Denmark (Fig. 2) the shoreline response is more subtle. In both cases the groynes act to fixate the shoreline and the bed contours landward of the groyne tip. The groynes have therefore mitigated beach erosion, DCA (2008). Seaward of the groynes at the Agger barrier (Fig. 2), erosion continues, and this is remedied by the use of nourishment.

Shoreline erosion will occur downstream of the single groyne or the groyne field because the supply of sediment is reduced by the structures. The downstream erosion is often emphasized as one of the major shortcomings of groyne fields (Kraus et al., 1994; Basco and Pope, 2004) and this problem should always be addressed in any new designs. In order to quantify the magnitude of downstream erosion it is necessary to estimate the bypass rate of sediment from the groyne field (after the transient redistribution of sediment within the groyne compartments).

Estimation of the bypass rate is not trivial. Reliable quantitative field data are not available due to difficulties in estimating the change in the littoral transport in a groyne field. The groynes will normally be constructed on a coast, which is under erosion and therefore experiences significant gradients in the longshore transport from the start. If effective the groynes will increase the erosional pressure on the downdrift coastline. The blocking effect will be strongest immediately after the construction and remedial action (such as nourishment or construction of more groynes) to reduce the downdrift effects will often be required before the bypass rate of the groyne field has reached an equilibrium.

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Fig. 1. Example of a groyne field where the shoreline is turned against the prevailing wave direction. Photo is from: Thyborøn Channel at the West Coast of Denmark.

The time varying wave conditions combined with the above mentioned time varying conditions within the groyne field makes a comparison, based on field data, of the net transport before and after construction of the groyne field questionable.

If quantified through numerical modelling, analysis of the bypass process should be made by the use of process based 2D or 3D coastal area models rather than by the use of 1D coastal models. Differences in the orientation of bed contours landward and seaward of the groyne tip make it difficult to define the orientation of the shore normal to be used in 1D littoral transport models and the bypass transport is complicated further by a number of processes which are not inherently included in the 1D models. One commonly known process is the local increase in sediment transport due to the contraction of streamlines around the tip of the groyne which causes local erosion, seen in lab experiments of e.g. Hulsberg et al. (1976); Badiei et al. (1994) and in the field e.g. in Grunnet et al. (2009). Furthermore as described in Pattiaratchi et al. (2009) alongshore differences in wave set-up downstream the groyne creates a horizontal circulation current. These circulation currents may cause the redistribution of sediment in the coastal profile and can cause the shoreline immediate downdrift of the groyne to advance. Finally, upstream rip currents caused by the blocking of the groyne may, according to Kraus et al. (1994) and Hanson and Larson (2004), cause offshore loss of sediment. These processes have previously been shown to be resolved by coastal area models, see e.g. Walker et al. (1991); Roelvink and Walstra (2004); Johnson (2004); and Nam et al. (2011). Van Koningsveld et al. (2005) made a numerical model study of the sediment transport in a groyne field; by varying the angle of wave incidence, the sensitivity of the transport along the shoreline was determined. On the basis of the simulations for the undisturbed morphology in a coastal area model, the shoreline evolution was predicted by the use of a shoreline model to form realistic sedimentation/erosion patterns.

For the model predictions of the coastal area models to be accurate a good description of the bathymetry around the structures is also required. For existing groyne fields, surveys can be performed to obtain a bathymetry, while for groyne fields which have not yet been built; it will be the modeller who is required to construct a realistic bathymetry. One approach to construct a realistic bathymetry; is to allow the process based coastal area model to evolve the bathymetry under typical wave conditions as shown in Roelvink and Reniers (2012). Assuming that the model is capable of reaching equilibrium conditions, where the littoral transport is more or less constant along the coastline, it is simply a matter of extracting the littoral transport from the model.

The focus of the present study is to describe the impact of groyne fields on the littoral drift during equilibrium conditions, i.e. quantify the reduction of the littoral drift after the transient redistribution of sediment has occurred. The reduction in the littoral transport will be quantified by the use of a process based 2D morphological model for a number of different groyne dimensions and wave climates. The morphological response is modelled using a hybrid approach where the results from the 2D coastal model are used to update the coastal profiles rather than the bed level in the individual mesh elements. The extracted bypass rates are compiled into a simple formulation which, combined with a 1D littoral drift model, can be used to estimate the bypass transport of a groyne field. The results can be used to estimate bypass transport for a given groyne field without setting up a new 2D or 3D morphological model.

1.1. Morphological modelling concept

The hybrid morphological modelling concept is used because important, large scale and medium scale hydrodynamic processes around coastal structures are inherently included in such a model i.e. effects such as streamline contraction and development of 2DH circulation currents. The simplified morphological scheme allows the model to use large morphological time steps and it reduces degeneration of the

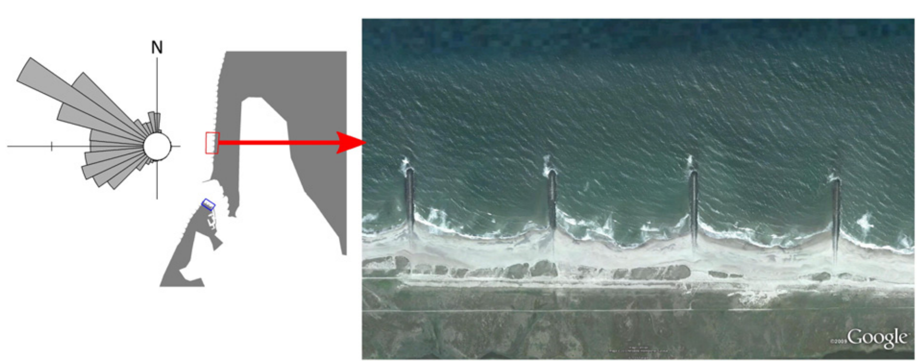

Fig. 2. Example of a groyne field where the angle between the prevailing wave direction and the overall coastline normal is small. Photo is from the Agger barrier at the West Coast of Denmark.