Chapter

Introductory Chapter: Morphodynamic Model for Predicting Beach Changes Based on Bagnold's Concept and Its Applications

Takaaki Uda, Masumi Serizawa and Shiho Miyahara

1. Introduction

Beach erosion is caused by an imbalance in the sediment budget of a coast, with the exception of ground subsidence associated with the excessive extraction of groundwater or sea level rise. Seasonal variations on beaches due to the occurrence of storms and calm waves are commonly observed, but the long-term stability of a beach is governed by longshore sand transport [1]. When the amount of sand supplied from rivers and sea cliffs decreases compared with the longshore sand transport of a coast, the inevitable result is beach erosion. Similarly, artificial removal of coastal sediment by dredging or mining results in beach erosion on neighboring coasts. The anthropogenic causes of beach erosion could be mainly classified into four types: (1) obstruction of longshore sand transport, (2) beach changes associated with the formation of wave-shelter zones, (3) decreased fluvial sediment supply, and (4) offshore sand mining or dredging [2]. When a breakwater, jetty, or groyne is extended offshore on a coast with predominant longshore sand transport, part or all of the longshore sand transport is obstructed, causing erosion downcoast and accretion upcoast. Even if waves are incident from the direction normal to the shoreline, longshore sand transport is induced from outside to inside the wave-shelter zone near a large port breakwater, resulting in erosion outside the wave-shelter zone and accretion inside. The dredging of sand deposited behind an oblique breakwater soon induces longshore sand transport from outside to inside the wave-shelter zone, resulting in erosion in the adjacent area. The effect of offshore mining may be extensive, depending on wave conditions, even though sand is not removed directly from the shoreline. Sand movement due to longshore sand transport occurs at depths less than the depth of closure, h_c, which is roughly equal to 10 m on well-exposed beaches. Since sand is continually being exchanged up to this depth, the removal of sand from a depth less than h_c leads to the same results as sand mining near the shoreline.

To solve these erosion problems or prevent the shoreline of a coast from receding earlier, it is important to predict beach changes. In the prediction of beach changes triggered by the imbalance in longshore sand transport, a long-term prediction in an extensive area is often required. The time scale changes yearly to decadal time scales, and the calculation domain reaches even up to 10–100 km. The One-line model is the most popular tool to predict such beach changes, which represents beach topography by the shoreline position, and beach changes are solved using the total longshore sand transport formula [3–5] described by wave parameters at the breaking point, and the continuity equation of sand [6–9]. This has been applied to many problems with small computational load. The N-line model is an improvement over the One-line model, and beach topography is represented by multiple contour lines. The change in successive locations of each contour line is calculated using longshore and cross-shore sand transport formulae, and the continuity equation of sand [9–15].

Recently, further advanced 3D beach change models, so-called process-based models, have been developed [16–26]. Furthermore, Nam et al. [26] reviewed the previous studies, which included the application of the model for predicting the beach changes around coastal structures. In these models, the depth changes on 2D horizontal grids are predicted using the sand transport formulae expressed by local hydrodynamic parameters, i.e., oscillatory velocity due to waves, nearshore current velocity, and tidal current velocity.

Regarding the sand transport formulae in the process-based models, a number of formulae have been proposed [17, 27–39]. Since recurrent calculations of not only wave field but also nearshore current are required in these process-based models, computational load is much larger than that of the One-line or N-line model, so that application to the long-term prediction in an extensive calculation domain is difficult.

On the basis of these previous studies, the authors have developed models for predicting beach changes applicable to various problems on real coasts [2]. One of them is the contour-line-change model [40] to predict long-term beach changes caused by the imbalance in longshore sand transport, which is a kind of N-line model, and in this model a sand transport equation similar to that by Hanson and Larson [14] is employed. Because the calculation of the nearshore current is not needed in this model as in 3D process-based models, and the computational load is small, it has an advantage in the prediction of long-term topographic changes in an extensive coast where many coastal structures have been constructed. This model then was improved to predict the temporal and spatial changes in the grain size of bed material [41–43]. The authors applied this model to many coasts in Japan to work out the countermeasures against beach erosion [2, 44–51]. However, this model has weak points.

First, in this model, the handling of boundary conditions becomes difficult when offshore coastal structures are constructed in a complicated manner, because tracking the subsequent positions of the contour lines is needed. In this regard, the so-called 3D model has an advantage. Taking this point into account, the authors developed a morphodynamic model (hereafter, "the BG model" named after Bagnold [52, 53]) by applying the concept of the equilibrium slope and the energetics approach, in which depth changes on 2D horizontal grids are calculated instead of tracking the subsequent positions of the contour lines [54, 55]. Second, the application of the contour-line-model to the prediction of topographic changes on a coast with a large shoreline curvature, such as a sand spit, was difficult.

In several previous studies, prediction of the deformation of a sand spit was tried by introducing the curvilinear coordinates along the curved shoreline in the One-line model [56–58], but their application to the prediction of topographic changes around a sand spit with a complicated form was limited. Taking this into account, the BG model was further improved to predict the 3D topographic changes around a sand spit or an isolated sand bar. Ashton et al. [59, 60] showed that sand spits may develop from infinitesimal perturbations on the shoreline under the conditions that the incident wave angle exceeds approximately 45° relative to the direction normal to the shoreline. The BG model could be applied to these phenomena. In this book, the BG model is introduced with its applications.

In this book, however, we have not introduced the applications of the BG model to the prediction of beach changes on a coast with sand of mixed grain size because of the limits of space. On real coasts, spatial changes in the longitudinal profile associated with changes in the composition of each grain size may occur. The longitudinal slope gradually becomes gentle with increasing content of fine sand, for example, in the wave-shelter zone. These changes in the local slope in and around the wave-shelter zone can also be predicted [61, 62], taking the equilibrium slope corresponding to each grain size and its composition into account. Their applications are shown in [63–65].

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