SAND WAVE EVOLUTION MODEL FOR EFFICIENT CHANNEL DEPTH MANAGEMENT

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INTRODUCTION

Sand wave is a consecutive wavy bedform on seabed with several meters in wave height and several tens-hundreds of meters in wave length. If the crests of sand waves rise above the required channel depth, they often prevent vessels from safe navigation.

In this study, a prediction model of sand wave evolution is applied to predict depth change at the crest of sand waves in Kanmon route, Japan. Kanmon route is a long, narrow and winding channel where strong tidal currents take place due to large tidal difference between Japan sea and Seto-island sea. Figure 1 shows five areas where sand waves are typically formed in Kanmon route. In these area, a lot of bathymetric survey data have been collected to monitor the water depth. Also, channel deepening project up to -14 m is underway, and therefore reliable prediction model of sand wave evolution is needed for channel depth management in the future.

MODEL DESCRIPTION

Figure 2 shows a schematic diagram of bedform of sand waves, where two depths of averaged depth, h_{ave} and minimum depth, h_{min} are defined. The minimum depth corresponds to the depth at the crest of sand wave and is important for the practical purpose of channel depth management.

The prediction model in this study is an analytical model to calculate time development of wave height and wave length of sand wave. The model is based on the stability theory of bedform in river by Kennedy (1963). Nakamura (2015) extended the model for sand waves under tidal oscillatory currents by implementing several limitations of sediment transport rate proportional to the local slope, repose angle of sea bed material, and continuity of sand movement at the trough of sand waves.

The input parameters required to predict sand wave evolution are the averaged depth h_{ave}, sediment grain size d_{50}, and tidal current velocity U as shown in Figure 2.

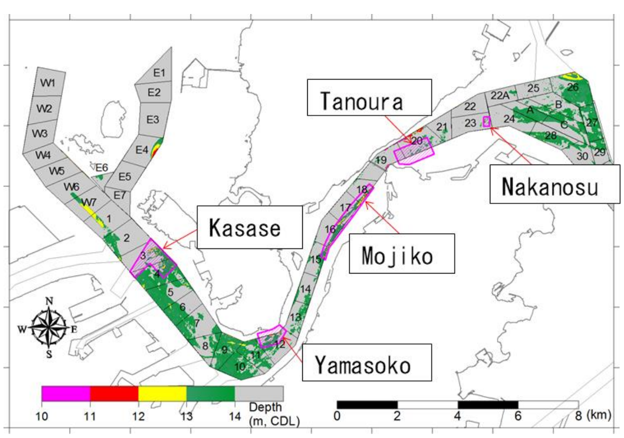

Figure 1 Typical five areas sand waves are formed in Kanmon route, Japan

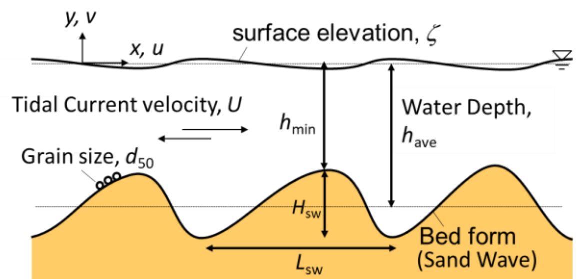

Figure 2 Definition of minimum depth, h_{min} and averaged depth, h_{ave} on sand waves

VERIFICATION OF THE MODEL

Applicability of the model has been verified by using bathymetric survey data. Figure 3 shows an example of comparison between predicted depth change at the crest of sand wave and measured one. Here, the depth at the crest of sand wave is estimated by sum of averaged depth and a half height of sand wave. Nakamura model can predict the half height of sand wave. From Figure 3, It is confirmed that the predicted depth at the crest well reproduces the measured one.

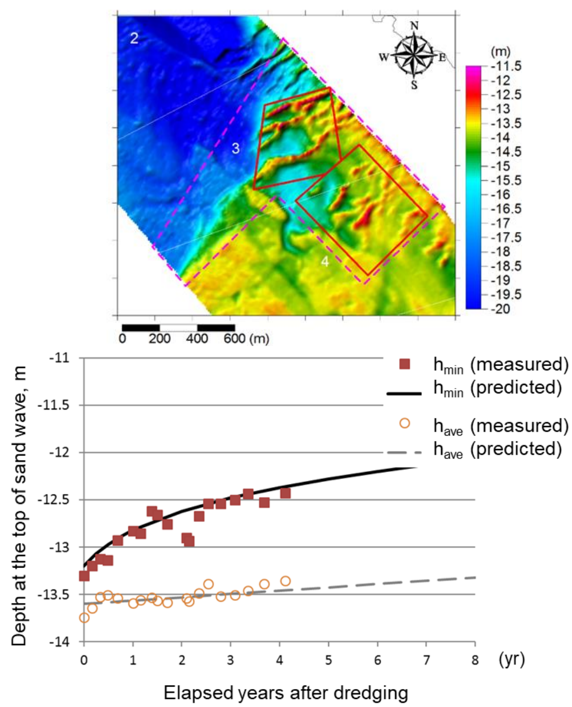

Figure 3 Sea bed topography of Kasase in Kanmon channel (top) and comparison between measured and predicted change in minimum depth (bottom)

The property of sand wave is usually site specific. Therefore, adjustment by using site specific parameters is needed to reproduce the sand wave evolution at each location accurately.
Through the verification described above, it has been confirmed that wave celerity of a sand wave, sediment grain size, and tidal current velocity are important as the site-specific parameter. In particular, representative sediment grain size of sand wave and asymmetry of tidal current velocity between ebb and flood tide are very sensitive for adjustment of the model.

PREDICTION OF REFORMATION OF SAND WAVE

After the verification, the model has been applied for prediction in case of channel deepening in the area where sand waves form.
Figure 4 shows an example of predicted changes in minimum depth at the crest of sand wave for Kasase area. The predicted curves in Figure 4 show reformation process of sand wave after dredging with 0.4m of over excavation. The legend in the figure shows the plan depth and initial depth including over excavation, respectively.
The predicted results indicate that channel deepening decreases growth rate of the sand wave. It is considered that the channel deepening decreases tidal current velocity and therefore growth rate of sand wave also decrease.

MINIMIZING DREDGING VOLUME

The bottom in Figure 4 shows estimated total dredging volume for maintenance period of 50 years. The total dredging volume is calculated by sum of initial dredging volume for the first time and maintenance dredging volume repeatedly conducted during 50 years after the initial dredging. From the figure, the interesting result has been obtained that the total dredging volume is estimated the minimum when the plan depth is set as -14 m corresponding initial depth of -14.4 m.
The result indicates that the shallower plan depth, the more maintenance dredging volume is estimated because of faster growth rate of sand wave. On the other hand, the deeper plan depth, the more initial dredging volume is estimated although the maintenance dredging volume is getting smaller. Therefore, the total dredging volume is minimized on the condition that both of them balance.

APPROPRIATE DREDGING FREQUENCY

The example of Figure 4 shows that the dredging volume is minimized if the plan depth set -14 m. In this case, maintenance dredging frequency is estimated every 3 years as shown in the top of Figure 4. Also, because the growth rate of sand wave is different every place, there are some cases that dredging frequency is estimated unrealistically short, within one year, under the condition to minimize the total dredging volume.
Figure 5 shows the predicted change in depth at the crest of sand wave from critical condition of sand wave formation. In Figure 5, the lowest red line shows change in averaged depth which changes linearly and curves on the red line represent development of sand wave. Consequently, the black dashed line, the envelope of the curves, is considered as the realistic change in minimum depth. From the diagram, therefore, the realistic dredging frequency can be estimated. The example in Figure 5 indicates that the required depth for maintenance dredging once in ten years is -14.7m.
Thus, it is confirmed that the present model can be applied for estimation of minimizing dredging volume and setting appropriate dredging frequency for the efficient management of sand waves.

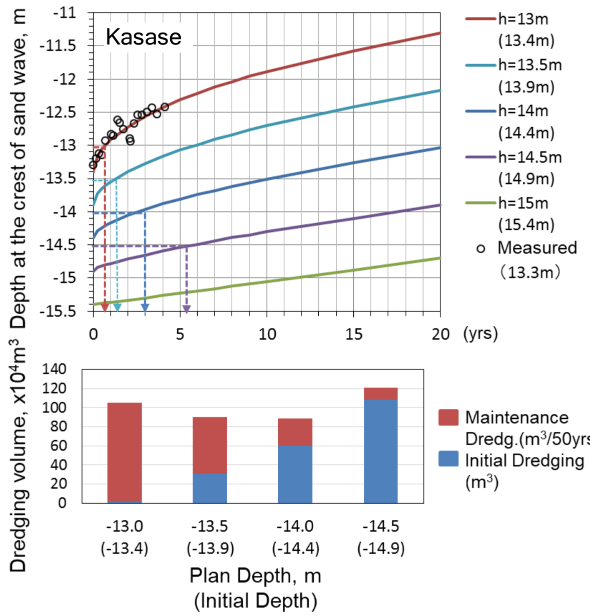

Figure 4 Predicted changes in minimum depth at the crest of sand wave for each plan depth (top), and totally required dredging volume (bottom)

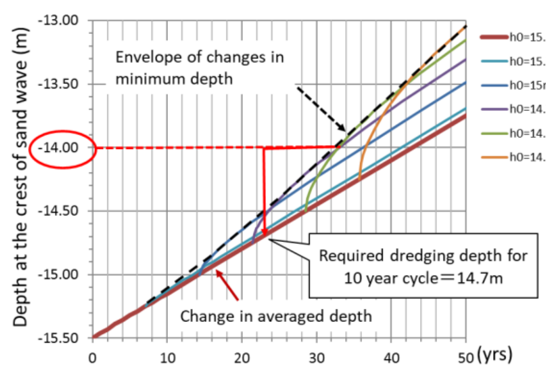

Figure 5 Depth change at the crest of sand wave predicted from critical condition of sand wave formation

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Nakamura, S, K. Toyama, A. Hirata (2015): Development of numerical prediction model for sand wave evolution, Journal of JSCE, B3 (Civil Engineering in the Ocean), Vol. 71, No. 2, I_281-I_286, (in Japanese)