An Experimental Study of the Effect of Offshore Bar Sand Dredging on Beach Erosion

Duc Thang CHU 1, Gen HIMORI 2, Trong Vinh BUI 3 and Shin-ichi AOKI 4

1Dept. of Civil Eng., Osaka University
(2-1 Yamadaoka, Suita, Osaka 565-0871, Japan)
E-mail: duc_ct@civil.eng.osaka-u.ac.jp
2Student member of JSCE, Dept. of Civil Eng., Osaka University
(2-1 Yamadaoka, Suita, Osaka 565-0871, Japan)
E-mail: himori_g@civil.eng.osaka-u.ac.jp
3Dr., Faculty of Geology and Petroleum Engineering, University of HCMUT
(268, Ly Thuong Kiet, ward 14, Dist. 10, Ho Chi Minh, Vietnam)
E-mail: btvinh@hcmut.edu.vn
4Member of JSCE, Professor, Dept. of Civil Eng., Osaka University
(2-1 Yamadaoka, Suita, Osaka 565-0871, Japan)
E-mail: aoki@civil.eng.osaka-u.ac.jp

To evaluate the shoreline retreat caused by sand dredging at offshore bar, a series of experiments were conducted in a 2D wave flume. Various amounts of sand were dredged at an offshore bar model formed by regular waves and the change in the beach profile was observed under the same or different wave conditions. Different dredging methods, i.e. one-time and periodic dredging were also tested to observe the influence of the dredging method on the shoreline change. The results showed that the shoreline retreat increases as the dredging volume increases although the relationship between the two is not linear. The characteristics of shoreline retreat were investigated in terms of beach profile change, sediment transport rate, and wave height distribution. The applicability of Dean’s formula, used to estimate shoreline change by beach nourishment, is also discussed.

Key Words: offshore bar, offshore sand dredging, dredged sand volume, shoreline retreat

1. INTRODUCTION

Sand dredging at an offshore bar alters the wave transformation, leading to changes in the equilibrium beach profile and hence the shoreline. If the dredged area is close to the coastline, sand may be transported from the upper portion of the beach into the dredged area, causing erosion of the foreshore. A study in the Genkai Sea, Japan found that dredged holes in an area where the water depth is less than 30 m refilled with sand that was mainly transported from the onshore side. In our study, we examine the effect of offshore bar sand dredging on the intensity of beach erosion. We consider three factors: the volume of sand dredged, sand dredging time, and sand dredging methods. In the modelled offshore bar, different sand volumes were dredged to clarify how the volume of dredged sand affects the shoreline retreat. Additionally, sand was dredged under various wave conditions to find out the wave conditions in which dredging has the least impact on shoreline retreat. Finally, to see the effect of the dredging method on shoreline retreat, one-time and periodic dredging were tested and compared.

2. EXPERIMENTAL SETUP

Seven experiments were performed in a wave flume that was 30 m long, 0.7 m wide, and 0.7 m deep (Fig. 1 and Table 1). The initial slope of the beach was 1:10 in all the cases. To create equilibrium profiles that have a bar or berm, two different regular waves were generated by a piston-type wave generator. For the bar type profile, an incident wave with wave height H = 14 cm and wave period T = 1 s (wave-1) was used. For the berm type profile, an incident wave with H = 5 cm, T = 2 s (wave-2) was generated. The beach profile was measured at 2-cm intervals by an optical bottom profiler and the wave height was measured at 50 cm intervals along the profile by the first wave gauge. The measuring instruments were placed on a trolley car. At each position, the wave height was measured for 10 s before moving to the next position. The second wave gauge, which measured the offshore wave height, was...
set 7.3 m from the end of the slope.

To obtain an equilibrium barred profile from the initial slope, wave-1 was generated for 60 minutes. Then, an amount of sand was dredged using various methods. In the periodic dredging method, sand was dredged at the bar every hour during a 5-hour wave generation period and the total amount of sand dredged was 0.066 m$^3$/m. In the one-time dredging method, sand was dredged only once after 60 minutes of wave generation from the initial slope. After the sand dredging, wave-1 was generated again for 5 hours in all the cases except for experiment E5D where wave-2 was generated for 5 hours and then wave-1 was generated for 5 hours. The beach profile and wave height measurements were repeated every 15, 30, and 60 minutes every hour after the dredging.

3. RESULTS

Even in the case without sand dredging (E1), the shoreline still gradually retreated after 60 minutes of wave-1 generation. Thus, we define the additional shoreline retreat caused by sand dredging as the difference between the measured retreat and that of case E1.

After the offshore bar sand dredging, some sand was transported from the foreshore area and deposited in the dredged sand bar. To evaluate the relationship between the volume of the dredged sand and the shoreline retreat, four different volumes of sand were dredged once after 60 minutes of wave generation. The shoreline retreat of experiments E3D1–E3D4 was measured 5 hours after dredging (Fig. 2). The results show that immediately after dredging, sand was transported offshore, which caused an abrupt retreat of the shoreline; however, the effect subsided after about 2 hours in all the cases. The final shoreline retreat after 5 hours increased with increasing sand dredging volume; however, the ratio between the shoreline retreat and sand dredging volume was not constant.

In experiments E2D and E5D, the sand bar was dredged by different methods and in different wave conditions. The volume of dredged sand in these ex-

<table>
<thead>
<tr>
<th>No.</th>
<th>Case No.</th>
<th>Dredging method</th>
<th>Wave condition</th>
<th>Dredging volume (m$^3$/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>E1</td>
<td>Without dredging</td>
<td>wave-1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>E2D</td>
<td>Periodic dredging</td>
<td>wave-1</td>
<td>0.066</td>
</tr>
<tr>
<td>3</td>
<td>E3D1</td>
<td>One-time dredging</td>
<td>wave-1</td>
<td>0.02</td>
</tr>
<tr>
<td>4</td>
<td>E3D2</td>
<td>One-time dredging</td>
<td>wave-1</td>
<td>0.04</td>
</tr>
<tr>
<td>5</td>
<td>E3D3</td>
<td>One-time dredging</td>
<td>wave-1</td>
<td>0.06</td>
</tr>
<tr>
<td>6</td>
<td>E3D4</td>
<td>One-time dredging</td>
<td>wave-1</td>
<td>0.08</td>
</tr>
<tr>
<td>7</td>
<td>E5D</td>
<td>One-time dredging</td>
<td>wave-2 and wave-1</td>
<td>0.06</td>
</tr>
</tbody>
</table>
periments was very close to that of experiment E3D3. In experiment E2D, the sand bar was dredged periodically every hour in wave-1 conditions. The shoreline retreat gradually increased during the 5 hours of wave generation (Fig. 3). In experiment E5D, the sand bar was dredged by the one-time method. After dredging, wave-2 was generated for 5 hours and a local berm was formed in this period. Following that, wave-1 was generated for 5 hours. The shoreline retreat measured under the final wave-1 conditions is shown in Fig. 3. The shoreline retreat in experiment E5D gradually increased in the first 3 hours and then subsided in the subsequent 2 hours. Despite the equal volumes of dredged sand, the process of shoreline retreat in each experiment varied significantly. The speed of shoreline retreat in experiments E2D and E5D was slower than in experiment E3D3. The final shoreline retreat, however, was very similar.

4. DISCUSSION

(1) Sand dredging of different volumes

Immediately after sand dredging, the wave height distribution was changed by the increased water depth in the dredging area. The wave breaking location in cases E3D1–E3D4 shifted onshore compared with the case without sand dredging E1 (Fig. 4). The wave breaking points in experiments E3D1 and E3D2 were fairly close to each other; then, the wave height rapidly decreased in the dredging area. In experiments E3D3 and E3D4, the breaking points are further onshore and the wave height rapidly decreases beyond the dredging area. As the dredged sand volume increases (i.e., the depth of the dredging area increases) the energy flux in the dredging area also rises; therefore, more sand from the foreshore area will be eroded offshore.

As the beach profile approaches equilibrium, dictated by the incident waves, the net cross-shore sediment transport rate $q$ decreases to zero at all points $x$ along the profile. Thus, the shape of the transport rate distribution varies with time. The average absolute sediment transport rate $Q_a$ was used to indicate the measure of transport activity along the profile. The average absolute sediment transport rate was calculated as

$$Q_a = \frac{1}{x_f - x_i} \int_{x_i}^{x_f} |q| dx \quad (1)$$

where $x_f$ is the seaward limit of the profile change. In experiments E3D1–E3D4, after the sand dredging, the average absolute sediment transport rate quickly decayed in the first 2 hours and then stabilized in the subsequent 3 hours (Fig. 5). However, because the sand bar had been dredged, some sand from the foreshore was transported offshore, forming a new bar near the foreshore area. During the initial period of wave generation, this new sand bar moved either onshore or offshore (Fig. 6). As the sand bar moved onshore, the breaking point moved simultaneously closer onshore, causing the shoreline to retreat further. After 2 hours, the new sand bars tended to move to stable positions and the shoreline retreat subsided. Thus, the shoreline retreat was significantly affected by the movement of the new bar.

Dean (2003) showed that during the process of beach nourishment, it is reasonable to assume that the profile after nourishment is similar to the original profile. The shoreline advance $\Delta y_0$ in response to the beach nourishment is expressed as

\[ \Delta y_0 = \int_{x_i}^{x_f} q dx \]
\[ \Delta y_0 = \frac{V_s}{h_* + B} \]  

where \( V_s \) is the sand nourishment volume per unit length, \( h_* \) is the closure depth, and \( B \) is the berm height. In this formula, the relationship between the shoreline change and sand nourishment volume is linear because the wave and berm height is constant. Here, we examine whether Dean’s formula can be applied for offshore bar sand dredging by using the dredged sand volume \( V_d \) instead of \( V_n \).

The final shoreline retreat in experiments E3D1–E3D4 and E1 are plotted in Fig. 7. The shoreline retreat increases as the dredged sand volume increases; however, the ratio between the shoreline retreat and sand volume is not constant and tends to be small for larger volumes of sand. That is, the relationship between shoreline retreat and dredged sand volume is nonlinear (solid curve in Fig. 7). Fig. 8 shows the sediment transport rate distribution. In the region seaward of the dredged bar (indicated by the dashed circle), the sediment transport rate for experiments E3D1 and E3D2 is larger than for experiments E3D3 and E3D4. In this region, the amount of sand transported offshore due to the dredging was large for the small volume of dredged sand. This amount of sand is named volume loss (Fig. 9). Thus, the sand eroded from the foreshore was deposited on the dredged sand bar but was also used to replenish the lost sand that was transported further offshore. As the volume of dredged sand increased, the volume loss decreased (Fig. 10). Moreover, during the experiments we found that the ratio of shoreline retreat to dredged sand volume depends also on the actual berm height rather than on a constant berm height as in Dean’s formula. The larger the dredged sand volume the higher the actual berm height, hence the reduction of shoreline retreat (Fig. 7).

To apply Dean’s formula to offshore bar sand dredging, we must assume that the translation profile is equal to the pre-existing profile\(^4\), whereas in our experiments, the final beach profiles after sand
dredging are different from the original profile because of the volume loss (Fig. 9).

Dean’s formula underestimates the shoreline retreat (Fig. 7) and cannot express exactly the relationship between the shoreline retreat and the sand dredging volume. The actual berm height and the volume loss are both dependent on the volume of dredged sand. Thus, we introduce the factor $\alpha(v)$ to Dean’s formula to obtain the modified formula

$$\Delta y_0 = \alpha(v) \frac{V_v}{h_v + B}$$

(3)

where $\alpha(v)$ can be derived from the experimental data of E3D1–E3D4 (Fig. 11). The coefficient $\alpha(v)$ is larger than 1 when the sand dredging volume is small and approaches 1 as the sand dredging volume increases.

(2) Sand dredging using different methods

In experiment E2D, small volumes were dredged from the sand bar every hour. After 5 hours of wave generation, a large volume loss was observed (Fig. 10). Although the sand was dredged regularly, there is little difference in the final shoreline retreat between experiments E2D and E3D3; however, the shoreline retreat in experiment E2D was slower than in E3D3.

In experiment E5D, because of the formation of the local berm and the shoreline advance during the wave-2 period, after shifting back to wave-1 conditions the shoreline retreat was small and slower than in experiment E3D3 during the first 3 hours (Fig. 3). In the following 2 hours, the shoreline was stable because of the small volume loss (Fig. 10). Thus, sand dredging in wave-2 conditions has a smaller effect on beach erosion than in wave-1 conditions.

5. CONCLUSIONS

The shoreline retreat increases with increasing volume of dredged sand; however, the ratio between the shoreline retreat and the dredged sand volume is not constant and shows a decreasing trend as the volume increases.

Dean’s formula underestimates the shoreline retreat caused by offshore bar sand dredging. In addition, it cannot express exactly the relationship between the shoreline retreat and the volume of dredged sand.

Different methods of sand dredging have a significant effect on the speed of the shoreline retreat. Sand dredging in wave-1 conditions causes fast and large shoreline retreat. To mitigate or delay coastal erosion, sand should be dredged periodically during wave-2 conditions.

ACKNOWLEDGMENTS: The authors would like to thank Emeritus Prof. Ichiro Deguchi, Assoc. Prof. Susumu Araki and the laboratory members for their valuable contribution to this study.

REFERENCES