Impacts on sandy beach and habitat of Japanese hard clams due to construction of port breakwater

Takaaki Uda

Public Works Research Center & Nihon University, 1-6-4 Taito, Taito, Tokyo, Japan
uda@pwrc.or.jp

The construction of a large-scale offshore breakwater often causes beach erosion on the nearby coast because it induces strong longshore sand transport from outside to inside the wave shelter zone. Despite the various erosion prevention measures taken, examples of such beach changes are numerous in Japan (Uda, 2009). One of the examples is the beach changes around Oharai Port located at the north end of the 97-km-long Kashimanada coast, which faces the Pacific Ocean. The construction of a 1297-m-long offshore breakwater began in 1979 at this port, resulting in the formation of a wide wave shelter zone in the lee of the breakwater, inducing longshore sand transport toward the wave shelter zone and causing severe beach erosion on a nearby coast.

Mimura and Kato (1991) studied the beach changes that occurred up to 1990, and Kumada et al. (2007) investigated the volume change in the accretion zone of this port. In these studies, however, the changes in longitudinal profiles and grain size were not investigated. Moreover, a quantitative analysis of the sand supply from the Naka River, one of the sand sources of the coast, has not been made. Here, the beach changes around Oharai Port and longshore sand transport toward the wave shelter zone are investigated in detail using field data. On the other hand, with the aggravation of beach erosion, the grain size changes in seabed materials may take place over an extensive area, affecting the habitat of benthos. The Japanese hard clam Meretrix lamarckii is a well-known species of shellfish living on sandy beaches composed of fine sand. This species lives along extensive areas of coasts with a gentle slope, such as the Kashimanada coast or Kujukuri Beach, facing the Pacific Ocean. On these beaches, the catch of clams has rapidly decreased with the erosion of the coast in recent years (Nihira et al., 2004).

Juvenile clams have been released to increase shellfish resources, but the evaluation of the effect of the release to determine the appropriate management of the shellfish resources was difficult, because a predictive method had not yet been established. It was difficult to predict how the grain size of the bed materials and the mud content would affect the survival of the clams, as well as how the change in the depth zone of the habitat would affect the growth or movement of the clams into a sand layer. Recently, Kumada et al. (2008) developed a model for predicting the extension of the habitat of this species, taking the life history of the clam between larva and adult into consideration. We can predict the habitat of Japanese hard clams using their model. However, in reality, regardless of whether or not we can predict the habitat of this species, the nearshore environment of the Kashimanada coast has been devastated by the selective accumulation of fine sand owing to the formation of a wave shelter zone, leaving coarser sand on the seabed in the extensive area outside the wave shelter zone. This causes degradation in the habitat because of the lack of fine sand appropriate for the habitat of Japanese hard clams. In this study, the relationship between beach changes and the change in habitat of Japanese hard clams is investigated, taking the Kashimanada coast as an example, while particularly focusing on the grain size of seabed sand.
Fig. 1. Bathymetry, bathymetric changes around Oharai Port, and arrangement of transects.

Figure 2. Change in longitudinal profile along transect A.

Figure 3. Depth change in median diameter of seabed materials along transect B.
BEACH CHANGES AROUND OHARAI PORT

(1) Survey method
Since 1979, bathymetric surveys have been carried out once a year around Oharai Port at 200 m intervals alongshore, as shown in Fig. 1. On the basis of these survey data, volume changes around the port since 1979 were calculated as well as the changes in longitudinal profiles between 1979 and 2004. The sampling of seabed materials was also carried out along two transects (B and D in Fig. 1) located in the accretion and erosion zones, respectively, and the depth distribution of the median diameter $d_{50}$ along each transect was determined.

(2) Bathymetry
Figure 1 shows the shape of the breakwaters of Oharai Port and the bathymetry in 2004 as well as bathymetric changes with reference to that in 1979. The contours south of the west jetty have a concave shape and a large amount of sand has been deposited in the wave shelter zone of the offshore breakwater, whereas the beach has eroded on the southern coast far from the wave shelter zone. The shoreline has advanced by 480 m since 1979 in the wave shelter zone. In addition, a slender deposition zone extends along the south breakwater to the offshore breakwater. This was caused by the trapping of sand supplied from the Naka River flowing into the sea 3 km north of the port.

(3) Depth distribution of $d_{50}$
Along transect A across the sand accumulation zone in Fig. 1, the shoreline advanced by 400 m between 1984 and 2004, as shown in Fig. 2, and a gentle slope was formed owing to sand deposition in the offshore zone. Sand was deposited up to a depth of -9 m, suggesting that the depth of closure of this coast is approximately 9 m, within which sand movement due to waves is predominant. Figures 3 and 4, respectively, show the depth distribution of $d_{50}$ along transects B and D. $d_{50}$ near the shoreline of transect B in the sand accumulation zone is 0.2-0.3 mm, but it converges to approximately 0.1 mm with increasing depth. On the other hand, $d_{50}$ near the shoreline of transect D in the erosion zone has become coarser with time and reached 20 mm, approximately hundred times larger than the initial grain size, whereas the grain size in the offshore zone remained constant at 0.1 mm, similar to that along transect B. These results imply that fine sand was selectively transported away by the northward longshore sand transport in the vicinity of transect D, resulting in the formation of the seabed covered with coarser material and the steepening of the beach slope. In contrast, fine sand selectively accumulated in the wave shelter zone. These beach changes along with the change in grain size can be predicted using the contour line change model considering the grain size (Kumada et al., 2006).

(4) Change in volume of accumulated sand
By setting regions I and II, as shown in Fig. 1, the accumulated volumes of sand in these regions since 1979 were investigated (Fig. 5). The sand volume in region I south of the west jetty increased with time, reaching $7 \times 10^5$ m$^3$ in total between 1979 and 2004, a rate of $2.5 \times 10^5$ m$^3$/yr. The rate of increase has been approximately constant; thus, the beach erosion south of the port and accretion inside the wave shelter zone of the port are expected to continue. This is because the offshore breakwater was gradually extended until 1979.
Figure 4. Depth change in median depth of seabed materials along Transect D.

Figure 5. Volume change in sand accumulated in Oharai Port.

Figure 6. Life history of Japanese hard clam (Nihira et al., 2004).

Figure 7. Relationship between density of Japanese hard clams per square meter of seabed and $d_{50}$ of seabed materials.

Figure 8. Depth distribution of $d_{50}$ measured offshore of Jinkoji and Daishoshizaki coasts in 2004.
B-1

In region II east of the south breakwater, a total of $1.5 \times 10^6 \, m^3$ of sand was deposited between 1979 and 2004, a rate of $6.0 \times 10^4 \, m^3/yr$. Southward longshore sand transport prevails under the predominant wave direction from the northeast on the coast north of Oharai Port, and the Naka River flows into the Pacific Ocean 3 km north of the port, implying that the source of the sand that accumulated in region II is the fluvial sand supplied by this river. Owing to the depth distribution of $d_{50}$ along transect B, sand that deposited in the zone deeper than -5 m is mainly composed of fine sand with a grain size of 0.12 mm, and therefore, fine sand with approximately the same grain size is assumed to deposit in the deep zone between the south and offshore breakwaters. This sand accumulation zone between the south and offshore breakwater gradually extends to the navigation channel, and siltation in the navigation channel is of concern.

PREVIOUS STUDIES ON JAPANESE HARD CLAM

The Japanese hard clam is a well-known species of shellfish living on exposed sandy beaches. These clams living on exposed beaches spawn in the depth zone between 2 and 6 m in summer, as shown in Fig. 6. The planktonic larvae fall to the seabed in the same depth zone during a suspension period when the shell size ranges between 125 and 200 µm. They then arrive at the sandy seabed near the shoreline, at which point their shell size is between 2 and 5 mm, where they start their growth from juvenile to adult clams. As they mature and their shell size reaches 55 mm, they move offshore. Most of the juvenile clams with shell size smaller than 55 mm live along the seabed between the top of the longshore sand bar and the gentle slope shoreward of the bar, and the adult clams with shell size larger than 55 mm live on the seabed with a gentle slope offshore of the longshore sand bar (Nihira et al., 2004). They prefer to live on the sandy beach around the longshore sand bar, where well-sorted fine sand accumulates. Fine organic matter tends to accumulate on seabeds covered with fine sand, resulting in an appropriate environment for the clams. However, when the silt content becomes excessive, the gills of the clams are blocked by fine materials, breathing becomes difficult, and they die of oxygen starvation (Fukuda, 1976).

Regarding their rate of growth, the length of the clam is about 1 cm after one year, 3-4 cm after two years, and 5-6 cm after three years, at which point it is a fully developed adult clam (Marine Ecology Research Institute, 1991). The clam is forced to always move along the sea bottom owing to the wave action once it arrives at the sandy seabed (Kuwabara and Higano, 1994). It resists the wave action by burrowing into the sand layer. Higano et al. (1993) pointed out that in the determination of the distribution of this species, the physical effects of waves and particle size are more important than the chemical effects of fine organic matter. Maoka et al. (1978) pointed out that juvenile clams, which have poor burrowing capability compared with adults, tend to be distributed in wave shelter zones, where fine materials accumulate, suggesting that juvenile clams are transported in the same manner as sand particles by longshore sand transport towards the wave shelter zone. The seabed in the wave shelter zone is generally covered with fine materials, and this contributes to the formation of an appropriate environment for the clams, resulting in their dense distribution. Kumada et al. (2008) developed a model for predicting the distribution of the habitat of Japanese hard clams *Mertrix lamarckii*, taking into account the life history of the clam from larva to adult. The model was based on the contour line change model proposed by Kumada et al. (2006), which considers the sorting effect of sand particles due to changes in grain size. They successfully predicted the change in habitat of the clams as they develop from larvae to adults as well as the planar change in habitat.
RELATIONSHIP BETWEEN DENSITY OF JAPANESE HARD CLAMS AND MEDIAN DIAMETER OF SEABED MATERIALS

Figure 7 shows the relationship between the density of Japanese hard clams per square meter of seabed and $d_{50}$, measured on the Kashimanada coast by field observations since 1999. The Japanese hard clams live on the seabed with the grain size ranging between $d_{50}=0.1$ and $0.35$ mm (fine and medium sand), in particular, many clams can be found in sand with grain size between $0.1$ and $0.2$ mm. Figure 8 shows the depth distribution of $d_{50}$ measured in 2004 offshore of the Jinkoji and Daishoshizaki coasts (Uda et al., 2009). The seabed of these coasts is mainly composed of sand with the same grain size range as shown in Fig. 7. Maoka et al. (1978) and Nihira et al. (2004) showed that the catch of juvenile clams is large at Oharai Beach and the Hirai coast next to Oharai and Kashima Ports, respectively, where fine sand accumulated forming a wide sandy beach, whereas outside the wave shelter zone the size of the catch is diminishing, suggesting that fine sand is vital for preserving a suitable habitat for Japanese hard clams.

Sand supply from the Naka River is now obstructed by the Oharai Port breakwater, and the northward longshore transport of sand supplied from the Tone River is also obstructed by the long breakwater of Kashima Port that extends up to a depth of 24 m, which is deeper than the depth of closure. At present, there is no supply of new sand to the Kashimanada coast, and the total volume of fine sand is not increasing. Under these conditions, much fine sand with a grain size ranging between $0.1$ and $0.2$ mm has accumulated in the wave shelter zone of Oharai Port, as shown in Fig. 5, and similarly, the selective accumulation of fine sand has occurred on the Hirai coast next to Kashima Port. This means that a large amount of fine sand, which is vital for the habitat of Japanese hard clams, was transported away from an extensive offshore area and selectively accumulated only in the wave shelter zone, leaving the coarser sand in the remaining area. This causes the gradual deepening of the offshore seabed, resulting in the difficulty in coastal protection, as well as the degradation of the habitat of shellfish. Studies on beach erosion and the habitat of benthos, such as the Japanese hard clam have been carried out from the viewpoint of different engineering sciences, but it should be noted that the ultimate objective of all studies is the same: preservation of a sound coastal environment with a sandy beach and rich shellfish resources. Collaborative studies are strongly required.

CONCLUSIONS

1. In region I south of the west jetty of Oharai Port, $7\times10^6$ m$^3$ of sand was deposited between 1979 and 2004 after the construction of the offshore breakwater. The average rate of accumulation was $2.5\times10^5$ m$^3$/yr. This sand transport is attributable to the northward longshore sand transport induced by the formation of the wave shelter zone.

2. In region II east of the south breakwater, a total of $1.5\times10^6$ m$^3$ of sand was deposited between 1979 and 2004, an average rate of $6.0\times10^4$ m$^3$/yr, which is equal to the sand supply from the Naka River, one of the sand sources of the Kashimanada coast.

3. It was shown that fine sand is selectively deposited in the wave shelter zone, leaving coarse material in the erosion zone.

4. The distribution of the habitat of Japanese hard clams *Meretrix lamarckii* can be predicted using Kumada et al.’s (2008) model. However, a more important issue is the decrease in the amount of fine sand itself, which is vital for the habitat of Japanese hard clams, deposited over an extensive offshore zone, resulting in the reduction of the effect of shore protection structures and reduced shellfish resources.
B-1

5. Comprehensive management in terms of the overall preservation of the volume and quality of fine sand in the vast offshore area is required.

REFERENCES