MONITORING OF GRAVEL NOURISHMENT ON MAKUHARI BEACH IN TOKYO BAY

Akio Kobayashi[1], Takaaki Uda[2] and Yasuhito Noshi[1]

On Makuhari Beach located in Tokyo Bay, an artificial beach was built in front of the reclaimed land in 1979, and this beach was widely used for recreation. However, the beach had gradually been eroded. In 2009, a jetty was extended in the middle of the beach, and 12,000 m^3 of gravel with the grain size of 4.2 mm was nourished on the beach between the south and the central jetties. Although an artificial beach was produced in parallel with the seawall line, the nourishment gravel was transported northward and was deposited to form a high berm in the northern part. This movement of the nourishment gravel was investigated by field observation.

Keywords: gravel nourishment; Makuhari Beach; Tokyo Bay; field observation; longshore sand transport

INTRODUCTION

In recent years, gravel nourishment has been widely carried out in Japan because of the high stability of the gravel beach against storm waves and its effectiveness as a measure against scouring as a result of the deposition of the gravel at the toe of the seawall. Kumada et al. (2010) investigated the effect of the beach nourishment using 87,000 m^3 of gravel with the grain size ranging between 2.5 and 13 mm at the Jinkoji coast originally composed of fine sand. They found by an excavation test that alternate layers of sand and gravel were formed instead of the uniform deposition of nourishment gravel, and they assumed that the deposition of fine sand over the gravel layer was caused by shoreward sand transport under calm wave conditions. Ishikawa et al. (2011) investigated beach changes after an extensive nourishment using 3.5×10^5 m^3 of a mixture of sand and gravel at the Hamamatsu-shinohara coast facing the Pacific Ocean, and they showed their effectiveness. Ishikawa et al. (2012) further proposed the moving gravel body method using the contour-line change model, in which the change in grain size is evaluated as the change in the equilibrium slope. They showed that when coarse material is nourished on sandy beaches with a predominant longshore sand transport, the downcoast of the nourishment area is eroded, because the movability of gravel is much smaller than that of sand, and gravel is preferentially deposited on the foreshore. However, the deposition of the gravel while maintaining the mixture conditions is still unknown and has not yet been sufficiently investigated. On Makuhari Beach located in Tokyo Bay, an artificial beach was built in front of reclaimed land in 1979, and this beach was widely used for recreation. However, the beach had gradually been eroded. In 2009, a jetty was extended in the middle of the beach and 12,000 m^3 of gravel of 4.2 mm grain size was added between the jetties. Although the artificial beach was widened particularly in the south part of the study area for the shoreline to be parallel to the seawall, the nourishment gravel was transported northward and was deposited to form a high berm in the north part of the study area. In this study, this movement of nourishment gravel was investigated by field observation.

METHOD OF FIELD OBSERVATION

The study area is Makuhari Beach located in Tokyo Bay, as shown in Figs. 1 and 2, where jetties were constructed at the south and north ends at 1,820 m intervals in front of the reclaimed land, and beach nourishment of 2.38×10^6 m^3 using fine sand of d = 0.184 mm, which was dredged from the offshore bottom in Tokyo Bay, was carried out between the jetties by 1979. Because the beach was gradually eroded after the construction of the original beach because of the predominant northward longshore sand transport generated by waves obliquely incident to the direction normal to the shoreline, another jetty of a 82 m length and with a crown height of +1.87 m above the mean sea level (MSL) was extended between the jetties by October 2009 as a measure against erosion, and gravel nourishment was carried out between the south and the central jetties.

First, the long-term changes in the shoreline position of Makuhari Beach between 1980 and 2012 were investigated using aerial photographs, and then the shoreline changes since the gravel nourishment were investigated in detail. Beach surveys were carried out along transects A, B, and C between the south and the central jetties, as shown in Fig. 2, and the foreshore material was sampled at 200 grams at each point on the beach surface along transects A, B, and C, on May 19, August 1, and October 31,

[1] Nihon University, 7-24-1 Narashinodai, Funabashi, Chiba 274-8501, Japan
[2] Head, Shore Protection Research, Public Works Research Center, 1-6-4 Taito, Taito, Tokyo 110-0016, Japan

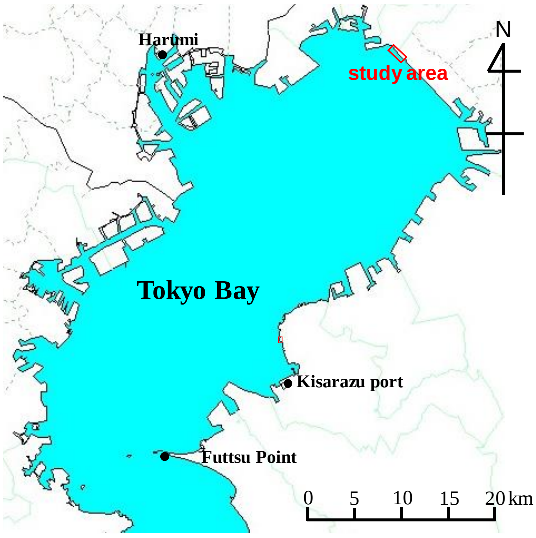

Figure 1. Location of Makuhari Beach in Tokyo Bay.

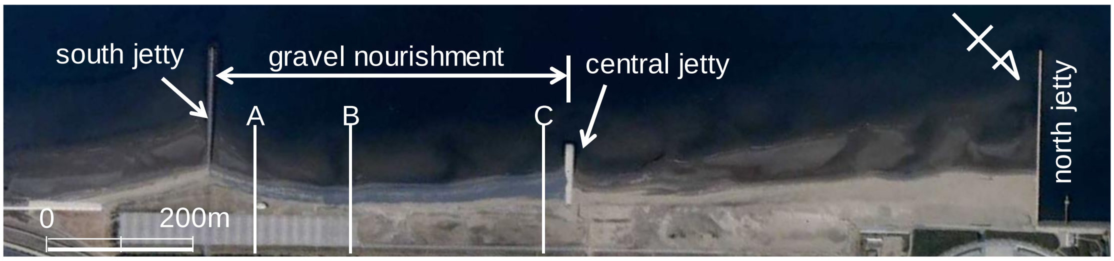

Figure 2. Aerial photograph of Makuhari Beach in 2010.

2012, and the distribution of the composition of grain size of the foreshore material was investigated. Holes were excavated near the shoreline along each transect on May 19 and October 31, 2012, and the depth change in the composition of the grain size was measured along with the measurement of the deposition zone of gravel on the beach surface using a GPS on June 17, August 5, and October 25, 2012. The wave rose during the observation period between April 1, 2010 and September 1, 2012 was obtained from the observation data at Chiba Port. As for the tide level of the study area, the high, mean, and low water level (HWL, MWL, and LWL) are +0.97, –0.13, and –1.13 m above MSL, respectively.

LONG-TERM SHORELINE CHANGES AFTER INITIAL NOURISHMENT

Figure 3 shows aerial photographs of Makuhari Beach taken in 1980, 1990, 2000, and 2012 to investigate the long-term shoreline changes. In 1980, an almost straight shoreline extended between the jetties with alongshore variations in shoreline position to some extent. Thereafter, additional nourishment using fine sand of 8.6×10^4 m^3 was carried out between 1983 and 1986, so that no large changes were observed in 1990. However, sand volume gradually decreased and additional nourishment was further required in 1994 and 1999. Despite such additional nourishment, the shoreline retreated north of the south jetty by 2000, while forming a concave shoreline, and sand was transported northward and the low-tide shoreline advanced south of the north jetty.

By 2012, the central jetty was extended 500 m north of the south jetty and gravel nourishment was carried out between the south and the central jetties. After the gravel nourishment, gravel was transported northward and was deposited on the south side of the central jetty. At the same time, on the north side of the central jetty, a concave shoreline was formed together with the advance of the low-tide shoreline south of the north jetty.

Figure 4 shows the shorelines in 1980 and 2012 and long-term shoreline changes between them with reference to that in 1980. The shoreline of this beach retreated in the entire area, implying loss of sand owing to the offshore sand transport, which was caused because the initial slope was as steep as 1/20 compared with the equilibrium slope of fine sand, which is milder than approximately 1/30. After the

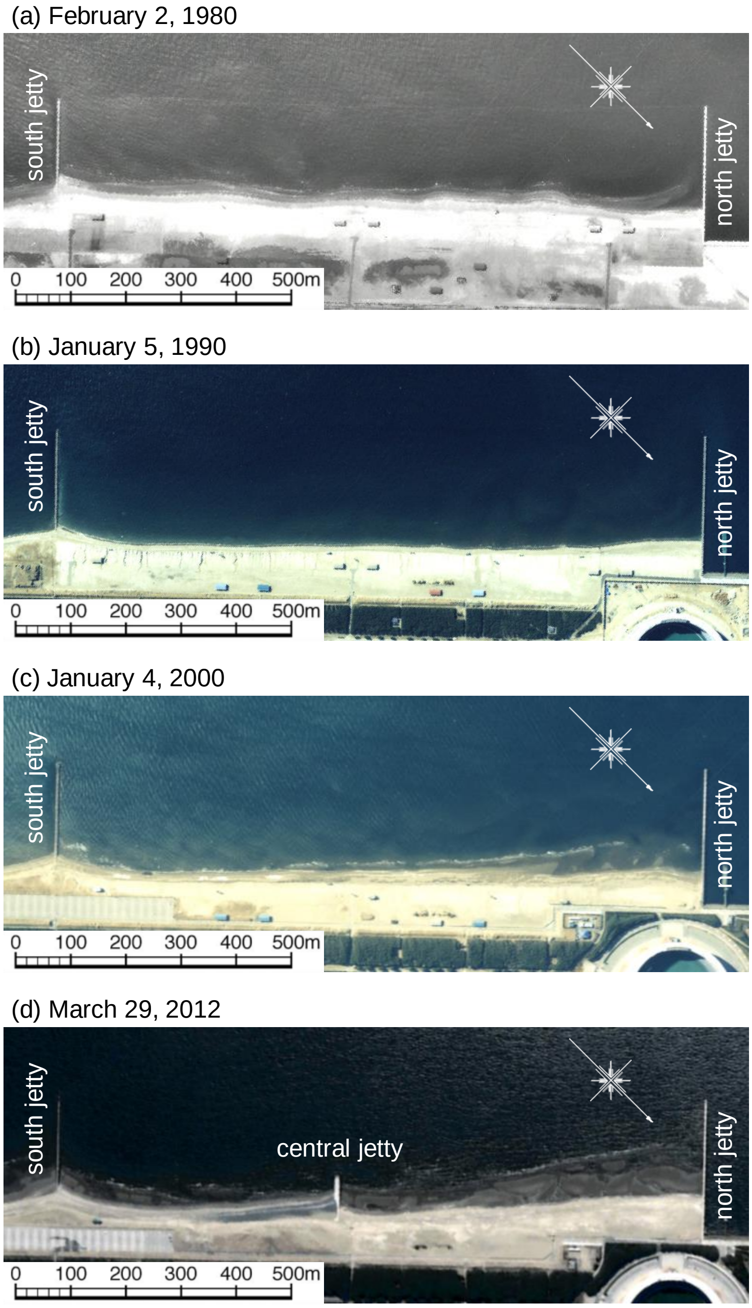

Figure 3. Aerial photographs of Makuhari Beach taken in 1980, 1990, 2000, and 2012.

construction of the central jetty, the shoreline locally advanced on the south side, whereas it retreated on the north side. The fact that no large shoreline advance occurred near the north jetty, even though a large amount of sand was transported northward and it is blocked by the north jetty (impermeable), clearly shows that the sand transported northward discharged offshore along the north jetty. The shoreline change, as shown in Fig. 4(b), also shows that the shoreline recession is large in the entire beach with the loss of sand, and before the extension of the central jetty, the shoreline rotated counterclockwise with a pivot at the intersection between the shoreline and the north jetty. After the construction of the central jetty, the shoreline between the south and the central jetties and between the central and the north jetties individually rotated counterclockwise.

The shoreline changes between 2009 and 2012 in the same area are shown in Fig. 5. In 2009, the shoreline extended almost straight between the south and the north jetties except the vicinity of the south jetty, where the shoreline was locally of concave shape, whereas the shoreline extended straight to

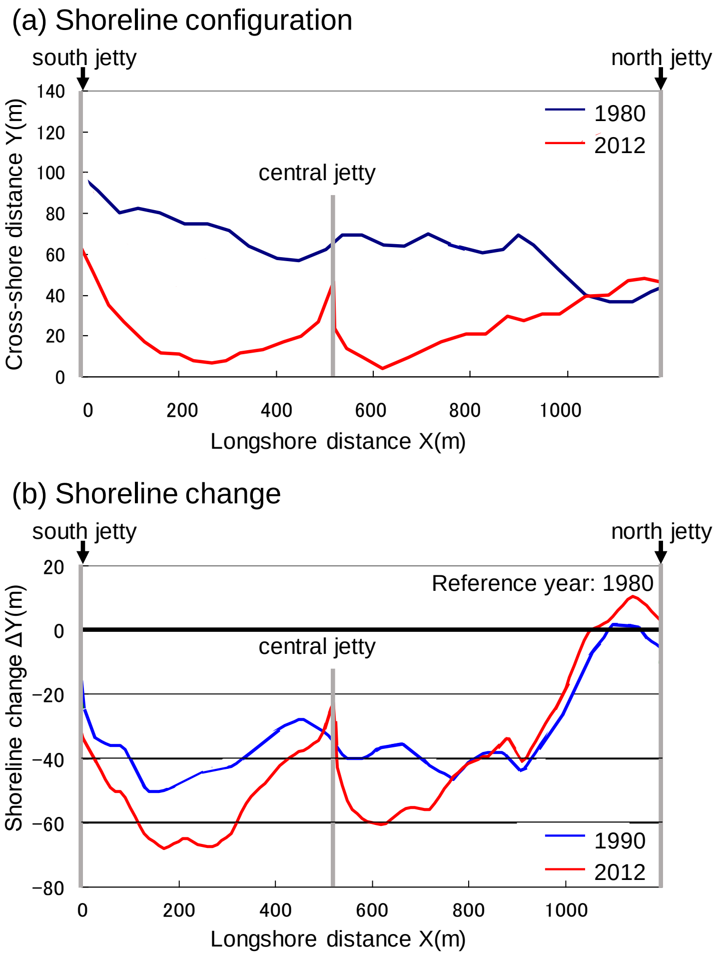

Figure 4. Shoreline in 1980 and 2012, and long-term shoreline changes relative to the shoreline in 1980.

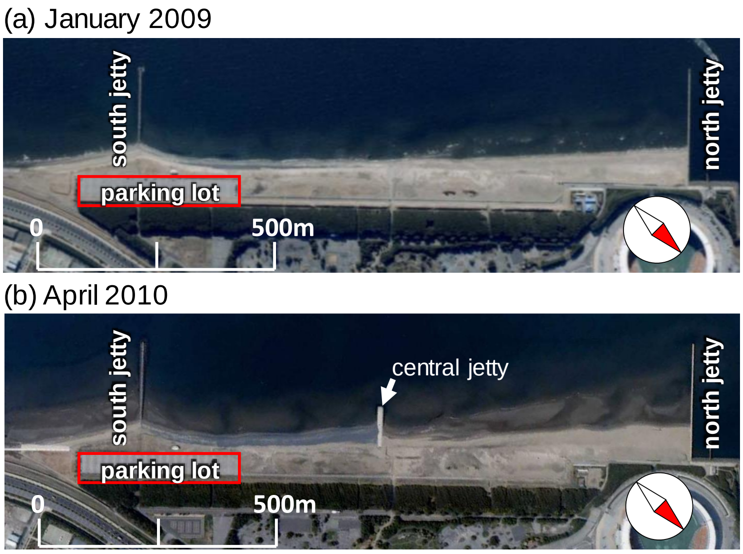

Figure 5. Shoreline changes on Makuhari Beach between 2009 and 2012.

the north jetty with increasing beach width near the north jetty, implying the predominance of northward longshore sand transport under the obliquely incident waves counterclockwise relative to the direction normal to the shoreline. Furthermore, although a parking lot was constructed behind the south jetty in parallel with the shoreline, as shown in the aerial photograph taken in 2009, the distance between the north end of the parking lot and the shoreline was as narrow as 40 m, showing a high

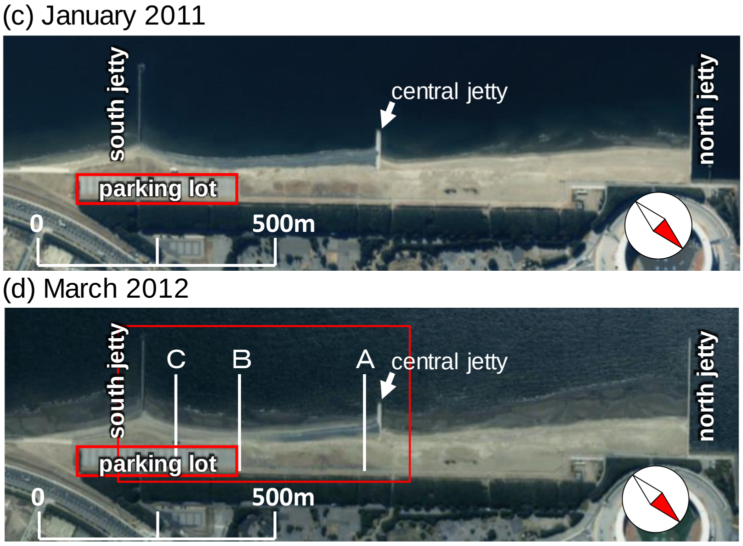

Figure 5. Shoreline changes on Makuhari Beach between 2009 and 2012 (continued).

possibility of wave overtopping to the parking lot. As a measure against the wave overtopping, a central jetty was constructed 500 m north of the south jetty, and gravel nourishment was carried out between the south and the central jetties by 2010. Because of the black color of the gravel, a band showing the deposition area of the gravel along the shoreline can be observed in the aerial photograph taken in April 26, 2010. Then, nourishment gravel in front of the parking lot was transported northward by January 27, 2011, and most gravel was deposited south of the central jetty and part of the gravel was deposited on the crown of the central jetty.

RESULTS OF FIELD OBSERVATIONS

Wave Rose during the Observation Period

Figure 6 shows the significant wave height and wave period at every hour between April 2010 and July 2012 measured off Chiba Port. The wave height is relatively low compared with that on beaches exposed to the open sea, because Makuhari Beach is located deep in Tokyo Bay. When selecting the significant wave height $H_{1/3}$ of 2.0 m as the lower limit of the extreme wave height in the observation period, a wave height larger than this critical wave height was observed only four times in 2010, but thereafter, the number of occasions increased by 16 and 27 times in 2011 and 2012, respectively. The

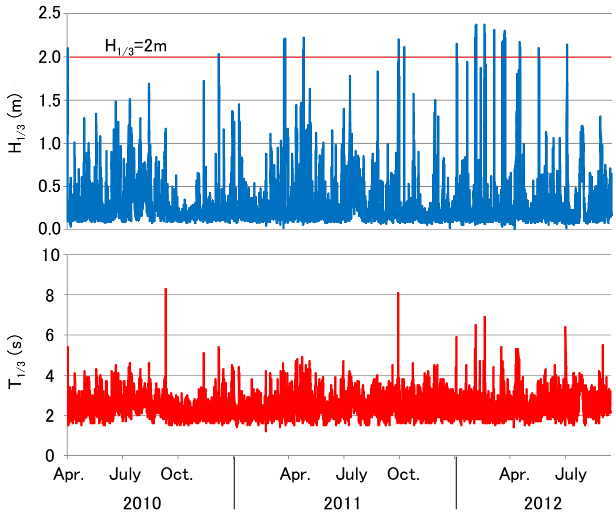

Figure 6. Wave rose between April 2010 and July 2012 measured off Chiba Port.

maximum value of $H_{1/3}$ in the observation period was 2.37 m, and the mean $H_{1/3}$ of waves with the significant wave height larger than 2 m was 2.18 m. The wave period varied between 2 and 4 s, with a rare case of a long period of 8 s corresponding to the occurrence of storm waves.

Deposition of Gravel and Profile Changes

Figure 7 shows the changes in beach condition in the area south of the central jetty between May 30 and October 8 in 2012, together with the shoreline on May 30 by the dotted line. It is seen that the shoreline markedly advanced immediately south of the central jetty, and a large amount of gravel (black

Figure 7. Changes in beach condition in area south of central jetty between May 30 and October 8 in 2012.

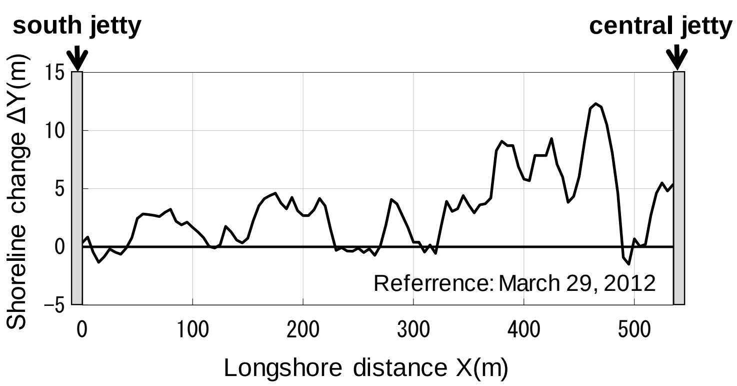

Figure 8. Change in shoreline position between March 29 and October 31, 2012.

color) was deposited on the beach surface near the jetty with berm formation. Figure 8 shows the change in shoreline position between March 29, 2012 and October 31, 2012. Although the shoreline had an irregular variation with a wave length of approximately 100 m, similarly to a large cusp, a large shoreline advance was observed on average in the north part between the south and the central jetties, implying the predominance of northward longshore sand transport.

Figure 9 shows the distribution of the deposition area of gravel on the beach surface measured using a GPS. The deposition area of gravel was narrow in the south part, and the cross-shore width of the deposition zone of gravel increased with the proximity of the central jetty, and gravel was deposited up to the crown of the groin from the south side. Furthermore, the south end of the slender deposition zone of gravel expanded southward between June 17 and August 5, but then it retreated northward on October 25 with a variation, resulting in the narrowness of the deposition zone of gravel in the south part. In contrast, the deposition zone of gravel monotonically expanded over time in the vicinity of the central jetty.

Figure 10 shows the superimposed profiles along transects A, B, and C in each observation. Along transect A near the south jetty, although a scarp with a steep slope was formed near an elevation of 2 m above MSL on May 19, 2012, sand was deposited to form a uniform slope by August 1, and the same

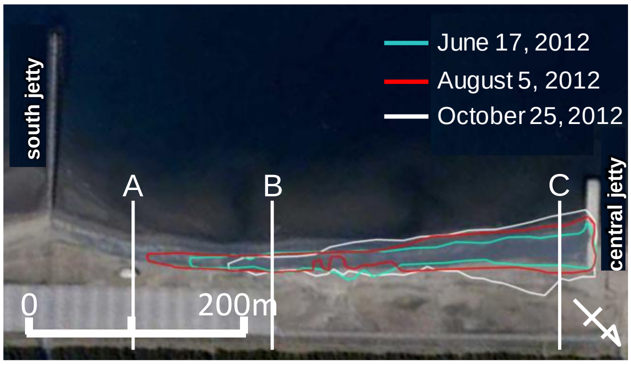

Figure 9. Distribution of deposition area of gravel on beach surface.

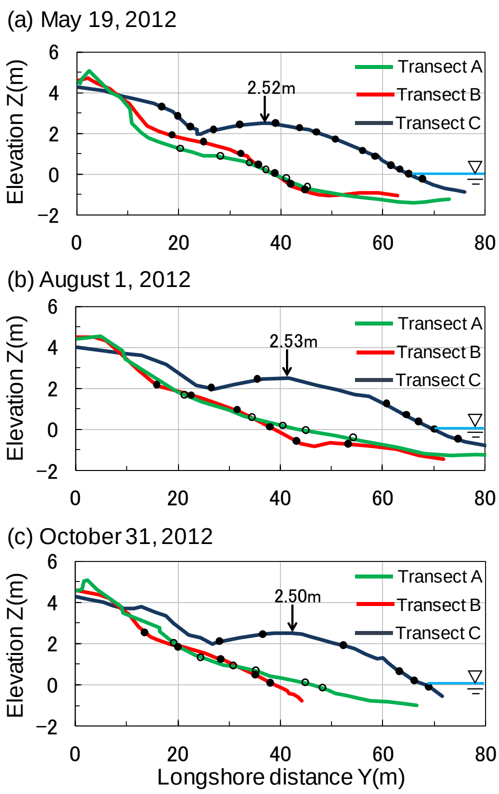

Figure 10. Temporal changes in longitudinal profiles along transects A, B, and C between May 19, 2012 and October 31. 2012.

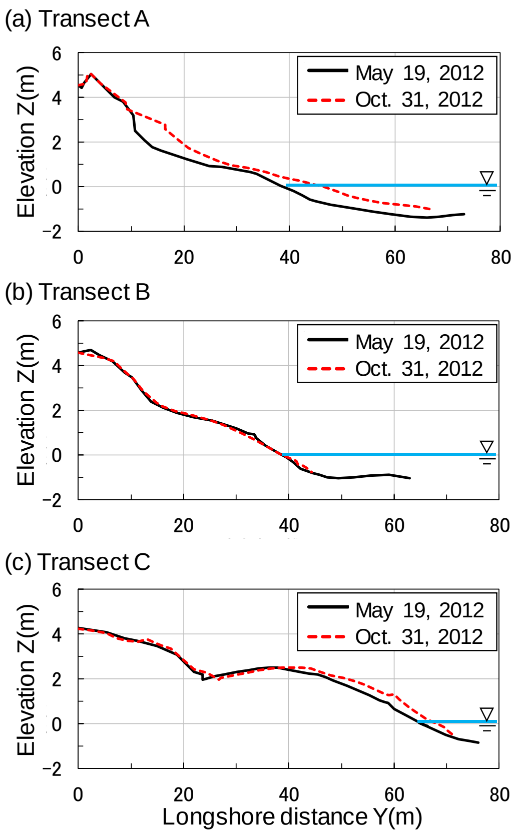

Figure 11. Temporal changes in longitudinal profiles along transects A, B, and C (May 19 vs October 31, 2012).

uniform slope was maintained until October 31. Along transect B, a uniform slope was formed in every occasion. The foreshore slope measured between Y = 20 and 40 m was constant: 1/10 (May 19), 1/10 (August 1), and 1/10 (October 31). Along transect C immediately south of the central jetty a wide berm was formed with an upward convex profile. The berm height was constant: +2.52 m on May 19, 2.53 m on August 1, and 2.50 m on October 31. The berm top moved seaward over time owing to the successive deposition of gravel, as shown by arrows in Fig. 10, at Y = 16.8 m on May 19, 21.3 m on August 1, and 22.5 m on October 31. The measured berm height was approximately 2.5 m, which was close to the mean value of $H_{1/3}$ (2.18 m) averaged over the observation period regarding the waves with $H_{1/3}$ larger than 2 m, as shown in Fig. 6.

Figure 11 shows the temporal change in longitudinal profiles along transects A, B, and C between May 19 and October 31, 2012. Along transect A, the beach was eroded owing to the storm waves that occurred in April and a scarp was formed at an elevation of +2 m, but sand was deposited, while forming a foreshore of a uniform slope of 1/12 by October 31. Along transect B, located at the central part, no profile changes occurred, while maintaining the same profile over time. Along transect C near the central jetty, the longitudinal profile moved in parallel with each other, while maintaining a constant berm height of 2.3 m, and beach material was deposited only in the area seaward of the berm top.

Change in Composition of Beach Material on Surface

As the results of the sieve analysis of the beach material sampled along transects A, B, and C, as shown in Fig. 9, Fig. 12 shows the cross-shore distribution of the composition of the grain size of the foreshore material sampled along transect A with the location of the sampling point of the beach material. Along transect A, there existed a small-scale berm near Y = 37 m on May 19, 2012, and the gravel content was relatively high at 35% near the berm top. However, the berm was eroded and a uniform foreshore slope of approximately 1/12 was formed until August 1, resulting in a marked decrease in the content of the gravel. Along transect A, the beach material is mainly composed of medium-size sand, as shown in Fig. 12, and therefore shoreward sand transport is considered to occur during storm waves in April 2012, and a concave profile was formed, as shown in Fig. 12. In contrast, such profile changes did not occur along transects B and C because the beach face was covered with gravel and offshore sand transport was difficult to occur, while maintaining upward convex profiles owing to the deposition of gravel. The same condition continued on October 31, and the shoreline advanced compared with that on May 19 owing to the deposition of medium-size sand with decreasing volume of gravel. This means that gravel was transported away from the vicinity of transect A by northward longshore sand transport.

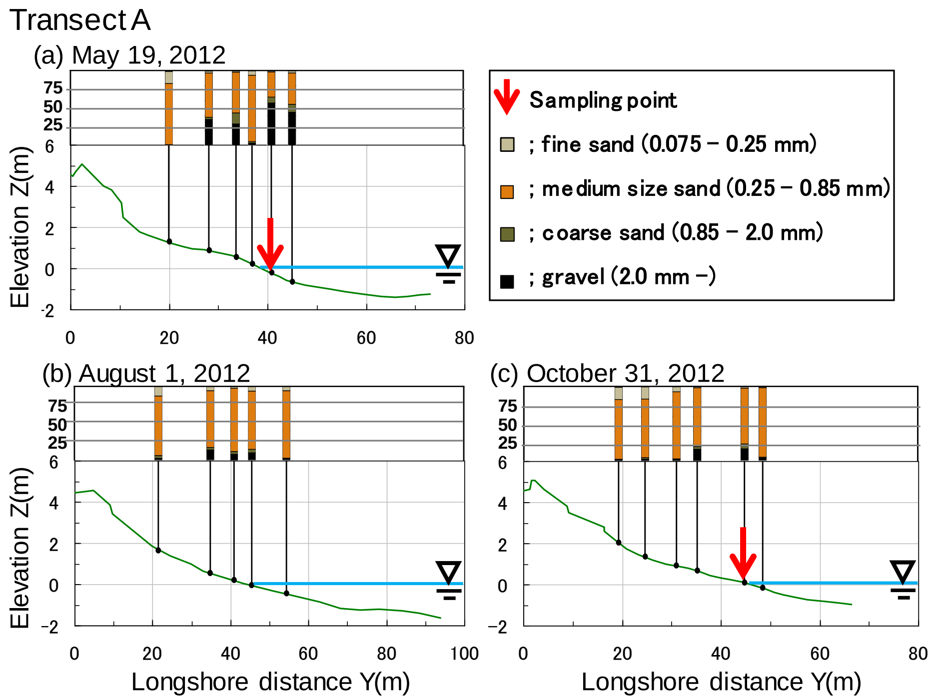

Figure 12. Cross-shore distribution of composition of grain size of foreshore material sampled along transect A.

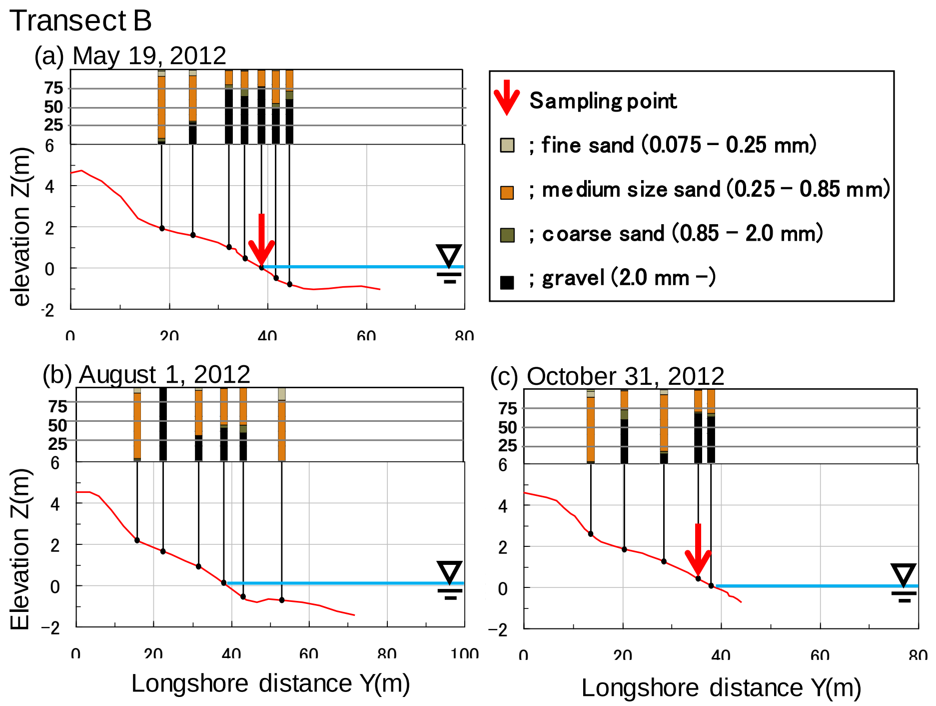

Figure 13. Cross-shore distribution of composition of grain size of foreshore material sampled along transect B.

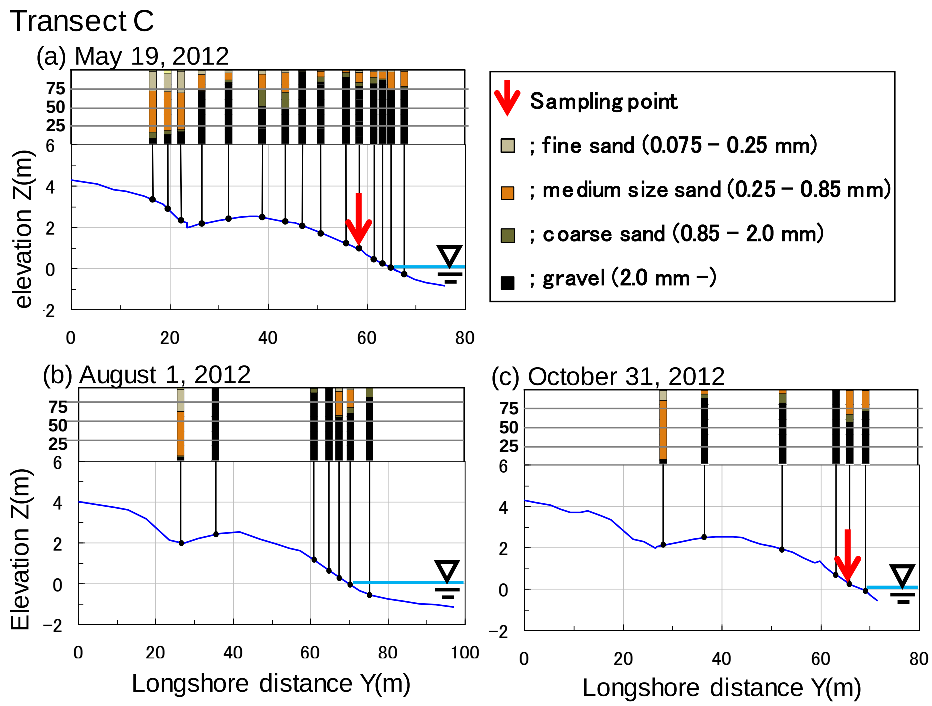

Figure 14. Cross-shore distribution of composition of grain size of foreshore material sampled along transect C.

Along transect B, as shown in Fig. 13, the foreshore slope was as steep as 1/8 in a zone with the elevation lower than 1 m above MSL on May 19, whereas a gentle slope of 1/10 was formed in the area higher than 1 m above MSL. The composition of grain size corresponded well to the change in beach slope, and the gravel content is high on the foreshore of the steep slope. Furthermore, gravel was deposited only in the area with the elevation lower than 2 m above MSL along this transect.

Similarly, the longitudinal profile along transect C, where a large amount of gravel was deposited, and the cross-shore distribution of the composition of foreshore material are shown in Fig. 14. Although an upward convex profile had already formed with a berm of 2.52 m height by May 19 in the zone seaward of Y = 24 m, the gravel content was less than 20% landward of this berm, whereas the gravel content markedly increased over 60% seaward of this berm, suggesting that this berm was formed mainly by the deposition of gravel, which was transported from the south part of the study area. The same characteristics can be seen in the results on August 1 and October 31, showing that the gravel that was transported by northward sand transport was successively deposited by the blockage by the central jetty.

Results of Excavation Study

To investigate the deposition of gravel, vertical holes were excavated on May 19 and October 31, 2012 near the shoreline, as shown by arrows in Figs. 12–14, and beach material was sampled vertically. Figure 15 shows the depth distribution of composition of the beach material obtained by the excavation test along transects A, B, and C on May 19, 2012. The grain size composition of the materials sampled on the surface and at depths below the surface is shown. It is seen that the contents of gravel and coarse sand on the surface increase from 65, 76, and 84% in the order of transects A, B, and C, respectively, implying that coarse material was selectively transported northward and deposited near the shoreline. The content of coarse material below the surface is small at transect A, whereas the content at transect C is as large as 60%, while decreasing with depth. The decrease in the content of the coarse material means that medium-size sand, which has a larger movability than gravel, was transported at the first stage, and then the gravel content increased over time. Similarly, Fig. 16 shows the results of the excavation study along transects A, B, and C on October 31, 2012. Because gravel was transported away from transect A, the gravel content markedly decreased along this transect, whereas the content of the coarse material is high owing to the successive deposition of the coarse material along transect C.

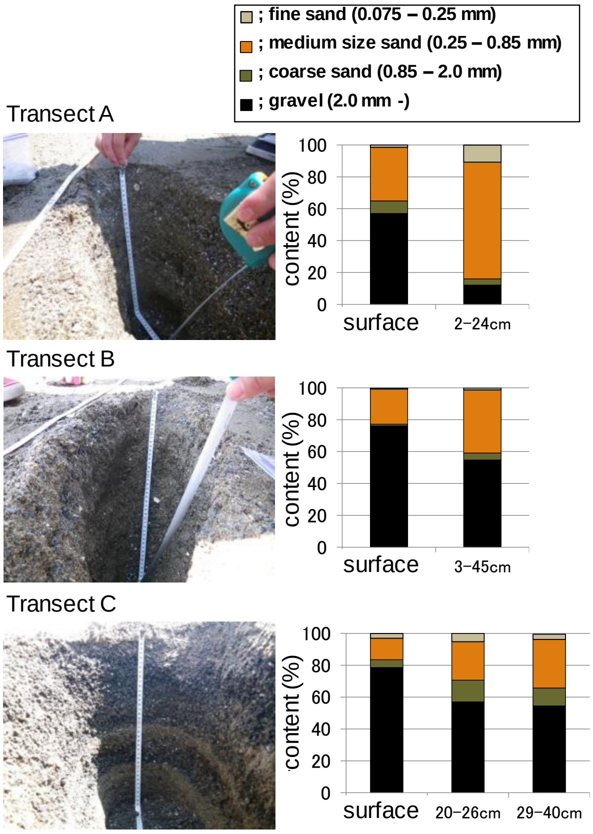

Figure 15. Depth distribution of composition of beach material along transects A, B, and C on May 19, 2012.

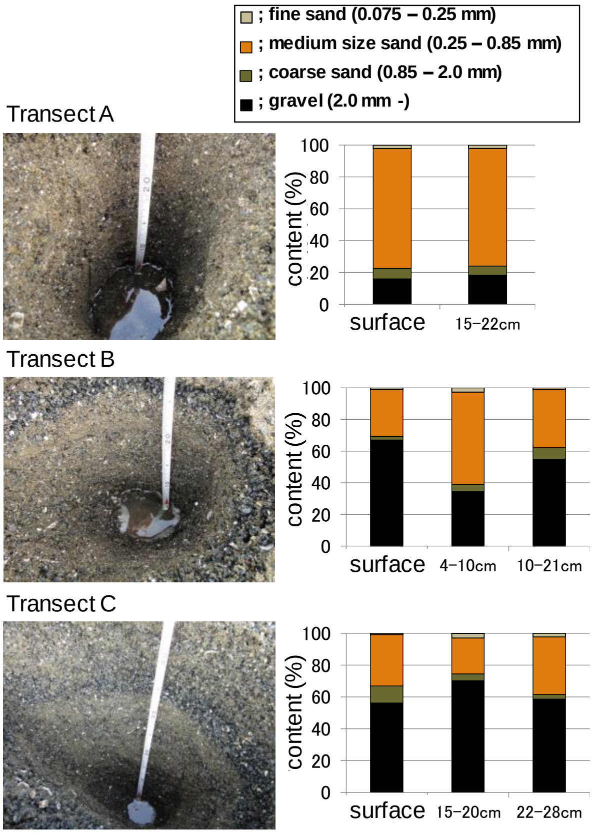

Figure 16. Depth distribution of composition of beach material along transects A, B, and C on October 31, 2012.

CONCLUSIONS

A monitoring survey after a gravel nourishment at Makuhari Beach showed that nourishment gravel moved along the shoreline and was deposited on the foreshore, while forming a thick gravel layer south of the central jetty and a berm of 2.5 m height above MSL. Ishikawa et al. (2011) investigated the effect of beach nourishment using gravel by tracking the movement of gravel on the Hamamatsu-shinohara coast, which is composed of fine and medium-size sand and that westward longshore sand transport prevails. Because this coast had an open boundary on the west side of the study area, the coarse material was transported westward with the gradual mixing with fine and medium-size sand, and the thickness of the mixing layer decreased with the westward distance. Makuhari Beach is separated by the south and central jetties, and has a closed system of sand movement, although originally northward longshore sand transport prevails. After the gravel nourishment, nourishment gravel was transported northward, and gravel was successively deposited on the beach surface south of the central jetty, forming a thick gravel layer. The gravel nourishment on this coast was carried out as a measure against erosion in front of the parking lot where the foreshore width was narrowed by the successive erosion immediately north of the south jetty, while anticipating the stability of gravel. However, even though the diameter of the nourishment material is large, such material could be transported by longshore sand transport particularly under the storm wave conditions, and it was ineffective in widening the narrow foreshore, although the beach nourishment itself was useful for increasing the entire volume of the beach.

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