

VERIFICATION OF SHORE PROTECTION EFFECT OF BEACH NOURISHMENT ON CHIGASAKI COAST

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ABSTRACT: On a stretch of the Chigasaki coast of 1.4 km length extending between Chigasaki fishing port and Chigasaki artificial headland, beach nourishment using coarse materials has been carried out since 2006. Since the start of beach nourishment, various monitoring surveys have been carried out to investigate beach changes and verify the effect of beach nourishment. In this study, various monitoring data such as the narrow-multibeam survey and photographs of the shoreline taken from a fixed position were analyzed. It was found that the beach width of the coast was significantly increased by beach nourishment, and it was effective.

Keywords: Beach nourishment, coarse materials, chigasaki coast, narrow-multibeam survey, shoreline changes

INTRODUCTION

The Chigasaki coast is located in the central part of the Shonan coast of a 16 km length extending between Oiso Port and Enoshima Island, as shown in Fig. 1. This sandy beach has been formed by the fluvial sand supplied from the Sagami River located 1.6 km west of the coast. The sand supply from this river, however, has markedly decreased owing to the extensive riverbed mining before 1967 and the construction of the Sagami Dam in the upstream basin of the river. Furthermore, Chigasaki fishing port was constructed upcoast, obstructing eastward predominant longshore sand transport, and resulting in downcoast erosion of the Chigasaki fishing port. As a result, the shoreline retreated by 50 m between 1954 and 2005, and storm waves reached the promenade at the back of the shoreline and the seawall was severely damaged. To mitigate the beach erosion on the Chigasaki coast, beach

nourishment by which beach materials are supplied to the beach at a rate of 3.0×10^4 m³/yr for 10 years was planned in 2005 to recover a 50-m-wide sandy beach. After the experimental beach nourishment in 2006 and 2007, full-scale beach nourishment was begun in 2008. By March 2011, half of the planned volume of sand (1.62×10^5 m³/yr) had been applied. Figure 2 shows the

(a) August 29, 2005 before beach nourishment



(b) September 25, 2011 after beach nourishment



Fig. 2 Foreshore changes on Chigasaki coast between August 29, 2005 and September 25, 2011 before and after beach nourishment, respectively

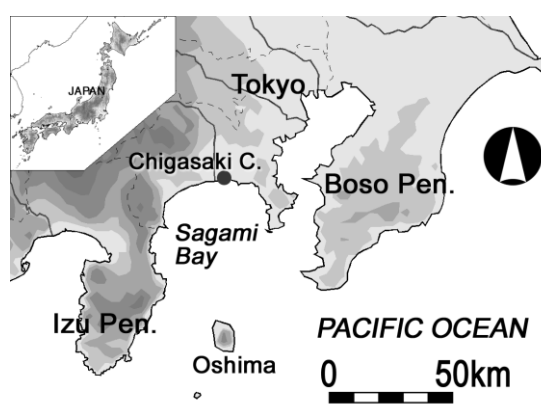


Fig. 1 Location of Chigasaki coast

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beach changes between August 29, 2005 and September 25, 2011 before and after the beach nourishment, respectively. It is seen that the sandy beach was markedly widened. In this beach nourishment, coarse materials containing up to 40% gravel were used, which were obtained by the dredging of materials deposited in the Sagami reservoir. We have already reported both the stability of the nourishment beach under the storm wave condition and the short-term changes in the nourishment beach (Ishikawa et al., 2008), but the overall effect of the beach nourishment between 2005 before the nourishment and the present has not yet been evaluated. Here, we investigated the monitoring data taken between 2005 and 2011 to study the effect of the beach nourishment on the Chigasaki coast.

BEACH NOURISHMENT AND WAVE CONDITIONS

On the Chigasaki coast, beach nourishment with a total volume of $1.62 \times 10^5 \text{ m}^3/\text{yr}$ of coarse materials containing gravel has been carried out since 2006: $10,392 \text{ m}^3$ (2006), $21,650 \text{ m}^3$ (2007), $31,655 \text{ m}^3$ (2008), $30,000 \text{ m}^3$ (2009), $37,535 \text{ m}^3$ (2010), and $30,971 \text{ m}^3$ (2011). As the nourishment materials, the material dredged from the reservoir upstream of the Sagami Dam and beach materials deposited west of the Chigasaki fishing port were used. Figure 3 shows the composition of nourishment materials. Nourishment materials were placed on the revetment forming a mound of 400 m length alongshore in the central part of the Chigasaki coast, where the beach width was most narrowed as a result of beach erosion, and the discharge of the material of the mound to the nearby coast by run-up waves was planned.

The wave characteristics between 2005 and 2011 were measured at the Hiratsuka wave observatory 4 km west of the study site. During the observation period, five extreme storm events occurred. Figure 4 summarizes the results: (1) storm waves with a significant wave height of $H_{1/3} = 6.1 \text{ m}$ ($T_{1/3} = 10.1 \text{ s}$) during Typhoon 0709, which had the longest 17-hour duration of storm waves with a significant wave height larger than the annual mean maximum wave height of $H_{1/3} = 4.5 \text{ m}$, (2) those with $H_{1/3} = 6.5 \text{ m}$ ($T_{1/3} = 10.4 \text{ s}$) during Typhoon 0918, which recorded the maximum wave height in observation history, (3) those with $H_{1/3} = 4.5 \text{ m}$ ($T_{1/3} = 12.4 \text{ s}$) during Typhoon 1106, (4) those with $H_{1/3} = 3.6 \text{ m}$ ($T_{1/3} = 11.0 \text{ s}$) during Typhoon 1112, and (5) storm waves during Typhoon 1115. Although the wave height of storm waves during Typhoon 1115 failed to be observed at the Hiratsuka observatory because of the shutdown of the electricity, the wave height of $H_{1/3} = 10.6 \text{ m}$ ($T_{1/3} = 12.8 \text{ s}$) was measured at NOWPHAS

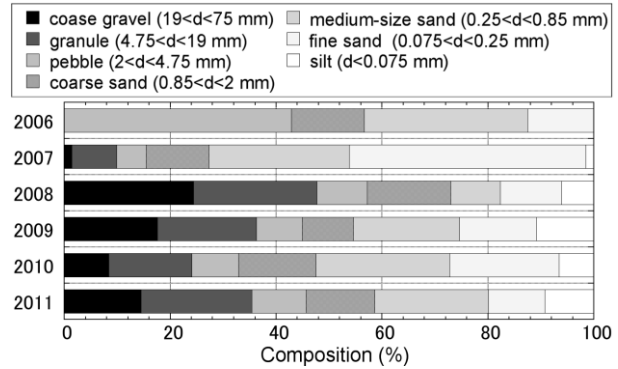


Fig. 3 Composition of nourishment materials

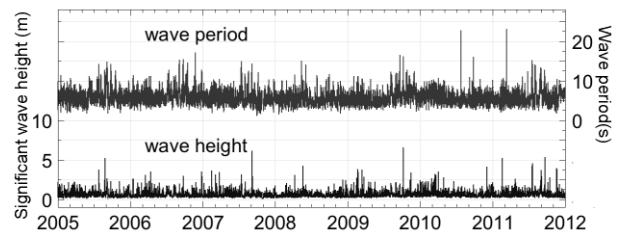


Fig. 4 Wave conditions between 2005 and 2011 measured at Hiratsuka wave observatory

Irozaki located at the tip of the Izu Peninsula, and severe erosion occurred on the Odawara coast, resulting in the decrease in the backshore elevation by 3.5 m during this typhoon.

AERIAL PHOTOGRAPHS AND SHORELINE CHANGES

Aerial photographs of the Chigasaki coast between 2005 and 2011 before and after the beach nourishment, respectively, are shown in Fig. 5. The foreshore width was extremely narrow and the location of the seawall coincided with the shoreline in the central part of the coast bounded by the artificial headland and Chigasaki fishing port in October 2005. In 2006, the beach nourishment was begun and $3.2 \times 10^4 \text{ m}^3/\text{yr}$ of sand was applied. By November 2007, two months after Typhoon 0709, the shoreline in the central part had advanced compared with that in 2005, even though storm waves hit the coast. By August 2008, the foreshore was markedly widened in the central part compared with the condition in October 2005. In particular, the foreshore in front of the seawall was recovered in the central part owing to the beach nourishment, in good contrast to the condition that the seawall was exposed to waves in October 2005, suggesting the effectiveness of the beach nourishment.

By May 2010 after almost half ($1.31 \times 10^5 \text{ m}^3$) of the planned volume of the beach nourishment was applied, the recovery of sandy beach became more dominant. Then, by March 2011 after the nourishment of 1.62×10^5

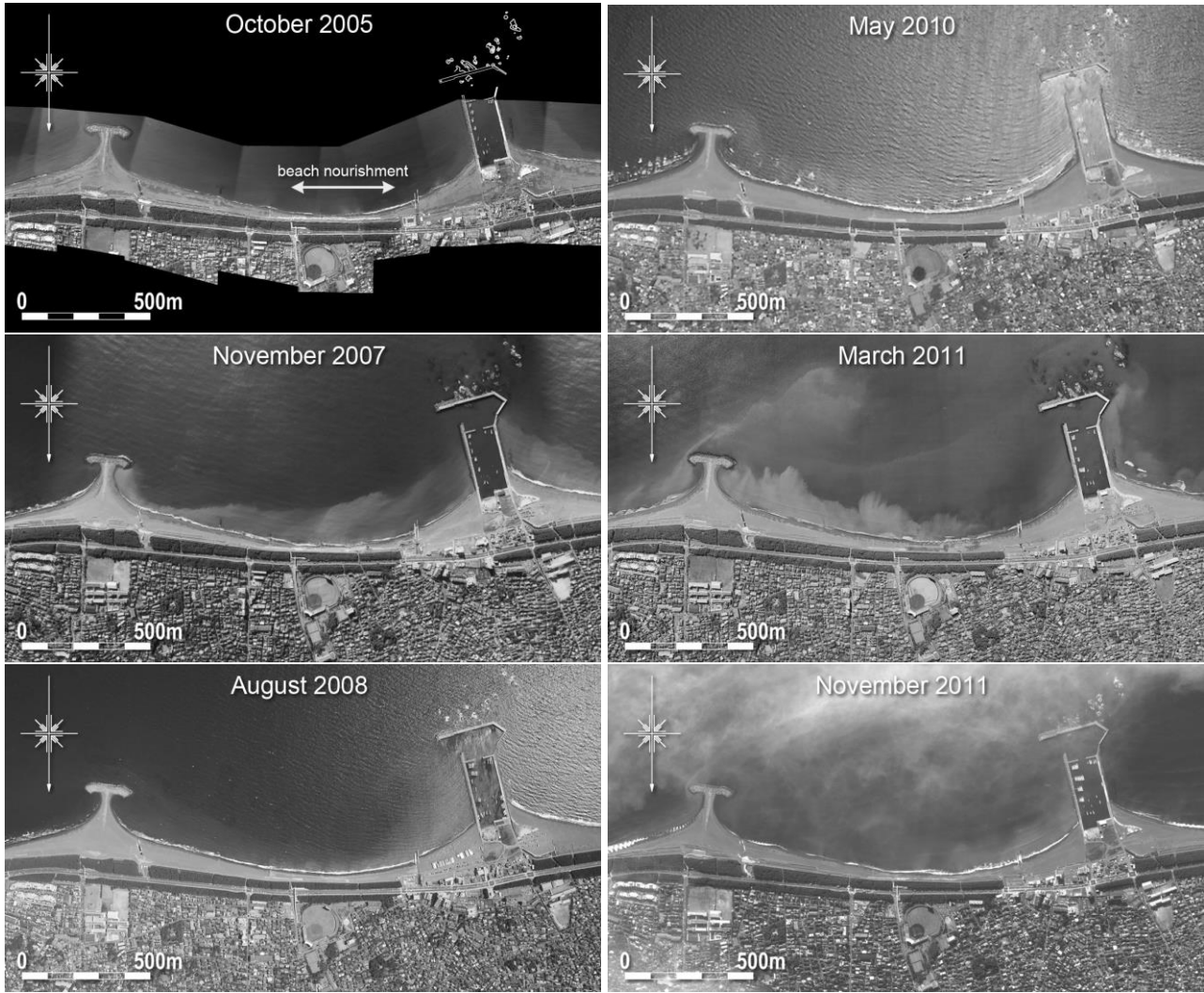


Fig. 5 Aerial photographs of Chigasaki coast taken between 2005 and 2011

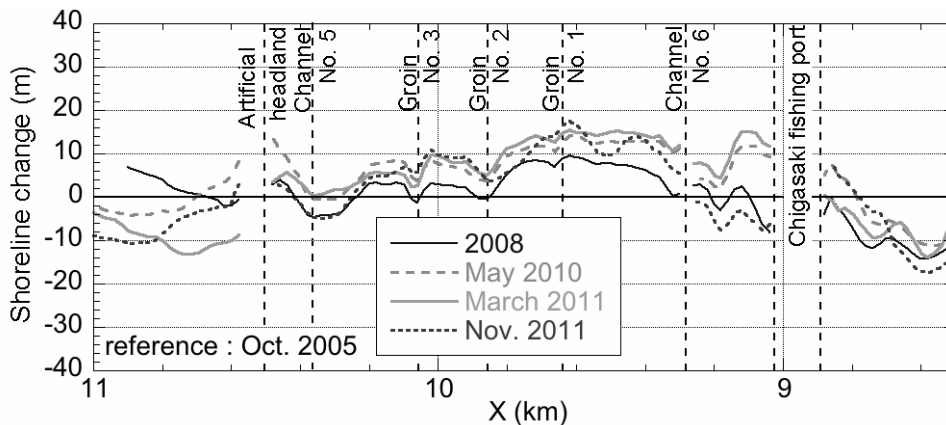


Fig. 6 Shoreline changes with reference to shoreline in October 2005

m^3 , the sandy beach was significantly expanded, recovering a 40-m-wide sandy beach in the central part of the coast where the beach width was most narrowed in 2005.

The shoreline positions were read from these aerial photographs, and the shoreline position corresponding to the mean sea level was determined using the foreshore

slope of 1/10 and the tide level when each photograph was taken. Then, the shoreline change with reference to that in October 2005 was calculated, as shown in Fig. 6. Although the shoreline advanced only in the central part until 2008, the foreshore had been widened in the entire zone between the artificial headland and Chigasaki fishing port until 2009. Furthermore, the shoreline



Fig. 7 Gravel deposited immediately east of Channel No. 6

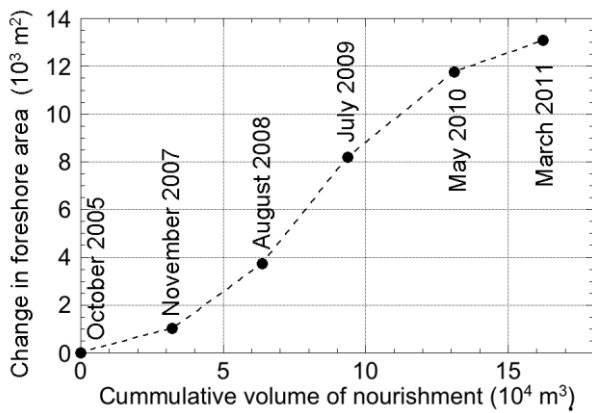


Fig. 8 Relationship between beach nourishment volume and change in foreshore area in study area between artificial headland and Chigasaki fishing port

advance reached up to 15 m in the central part by March 2011, resulting in the longshore expansion of wide foreshore. In November 2011, immediately after Typhoon 1115, the shoreline in the central part barely changed east of Channel No. 6, even though the shoreline retreated in the vicinity of the artificial headland and Chigasaki fishing port. Because coarse materials mainly composed of gravel are generally transported along the foreshore, Channel No. 6 blocked the movement of coarse materials so that much coarse material was considered to be left east of the channel, as shown in Fig. 7.

Figure 8 shows the relationship between the cumulative volume of the beach nourishment materials and the change in foreshore area with reference to that in 2005 in the area between the artificial headland and Chigasaki fishing port. The foreshore area increased to $1.3 \times 10^4 \text{ m}^2$ by March 2011 before Typhoon 1115 with the increase in the volume of the beach nourishment. Because the characteristic height of beach changes of this coast, which can be derived by dividing the change

in the cross-shore area of the beach changes by the shoreline change, is 10 m (Ishikawa et al., 2009), the increase in the foreshore area can be transformed into the volume change of the beach when multiplied by this characteristic height of beach changes, and this becomes $1.3 \times 10^5 \text{ m}^3$. Because the eastward longshore sand transport turning around the tip of the artificial headland was estimated to be $5 \times 10^3 \text{ m}^3/\text{yr}$ on the basis of beach changes (Ishikawa et al., 2009), the total amount of sand transported eastward during the observation period of 5.4 years becomes $2.7 \times 10^4 \text{ m}^3$. Thus, the net increase in the volume left in the study area is assumed to be $1.35 \times 10^5 \text{ m}^3$, which can be obtained from the total nourishment volume of $1.62 \times 10^5 \text{ m}^3$ minus $2.7 \times 10^4 \text{ m}^3$, and they are in good agreement.

ANALYSIS OF NARROW-MULTIBEAM SURVEY DATA

The bathymetric changes after the beach nourishment in the study area were investigated using the narrow-multibeam survey data taken since 2005. Figure 9 shows the bathymetries of the study area including the downcoast of the artificial headland in 2007, 2008, 2010 and 2011 along with the bathymetric changes with reference to the bathymetry in 2005. In the central part of the study area, the sand deposition zone gradually expanded owing to the beach nourishment over time. By January 2008, the nearshore zone in the central part was eroded by the offshore sand transport associated with the storm waves during Typhoon 0709, which hit the coast on September 6, 2007, and sand eroded from the vicinity of the shoreline was deposited near 4 m depth, forming a bar and trough topography. Then, sand markedly deposited near the shoreline due to both the effect of the beach nourishment and the shoreward movement of sand composing the offshore bar by October 2010. However, by November 2011, a bar and trough were formed again around the depths of 2 and 3 m owing to the action of storm waves associated with Typhoon 1115. The scale of the bar and trough formed in November 2011 was smaller than that of the bar and trough formed during Typhoon 0709, and the offshore sand movement only occurred in a shallow water zone.

Figure 10 shows the changes in longitudinal profile along transect No. 18 in the central part of the study area where severe beach erosion occurred and the seawall was exposed to waves by 2005. In January 2008 after Typhoon 0709, the nearshore zone shallower than 4 m depth was eroded and the eroded sand was transported offshore, resulting in the formation of a bar with a relative height of 1 m. This offshore sand movement was observed up to 8 m depth. By January 2011, the elevation of the foreshore had increased and the

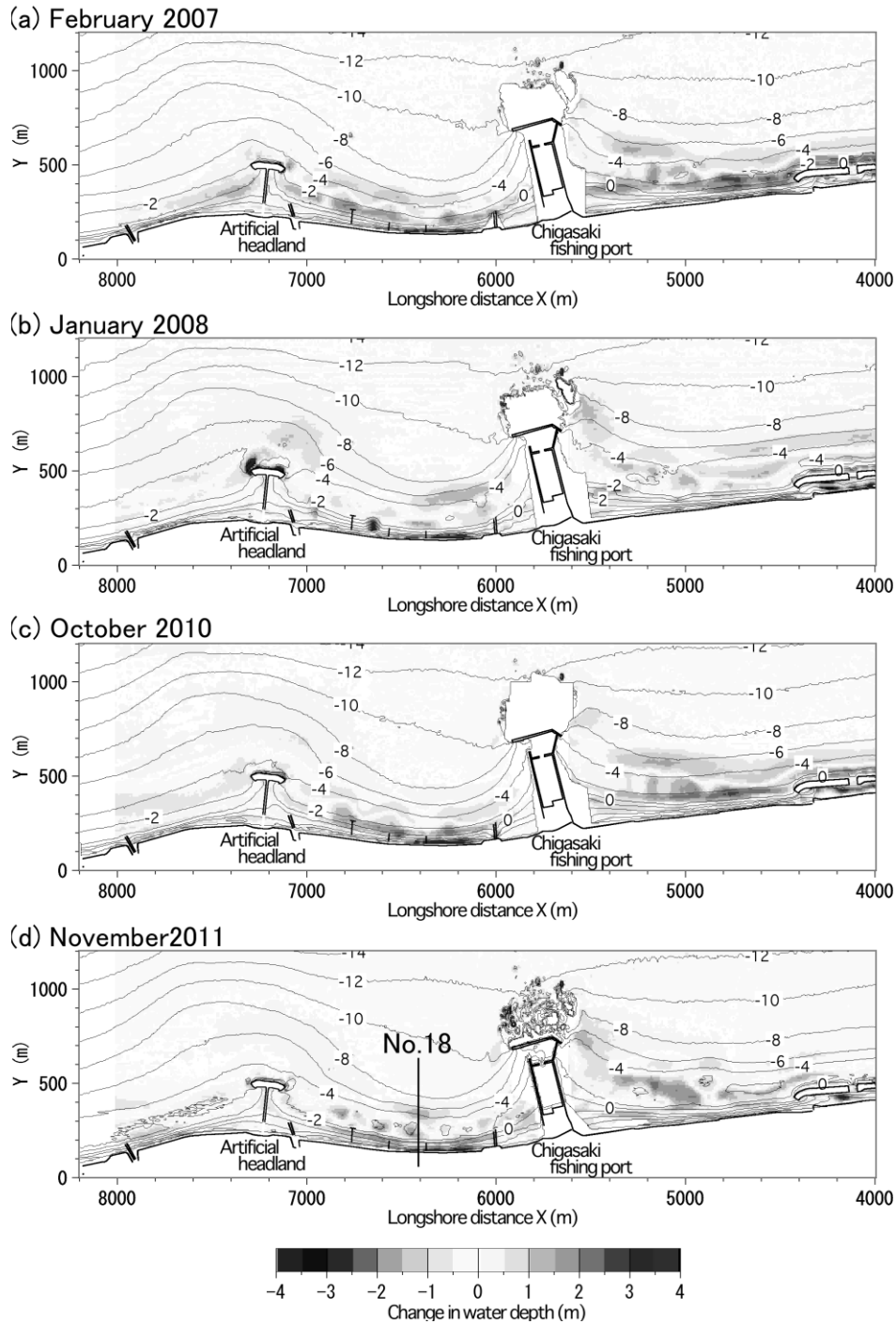


Fig. 9 Bathymetric changes between February 2007 and November 2011 with reference to bathymetry in 2005

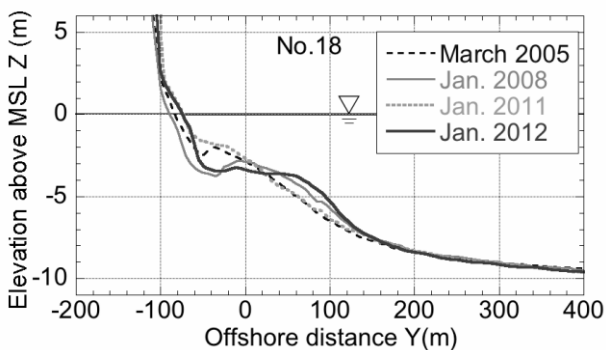


Fig.10 Longitudinal profile along transect No. 18

shoreline advanced owing to the beach nourishment, and a smooth profile of a gentle slope was formed because the trough was filled with sand. The shoreline advanced by 12 m compared with that in 2005, resulting in the foreshore width of 40 m. Then, until January 2011, a bar and trough topography similar to that immediately after Typhoon 0709 was formed again owing to the storm waves associated with Typhoon 1115.

Figure 11 shows the depth distributions of the grain size composition of bed materials measured in October

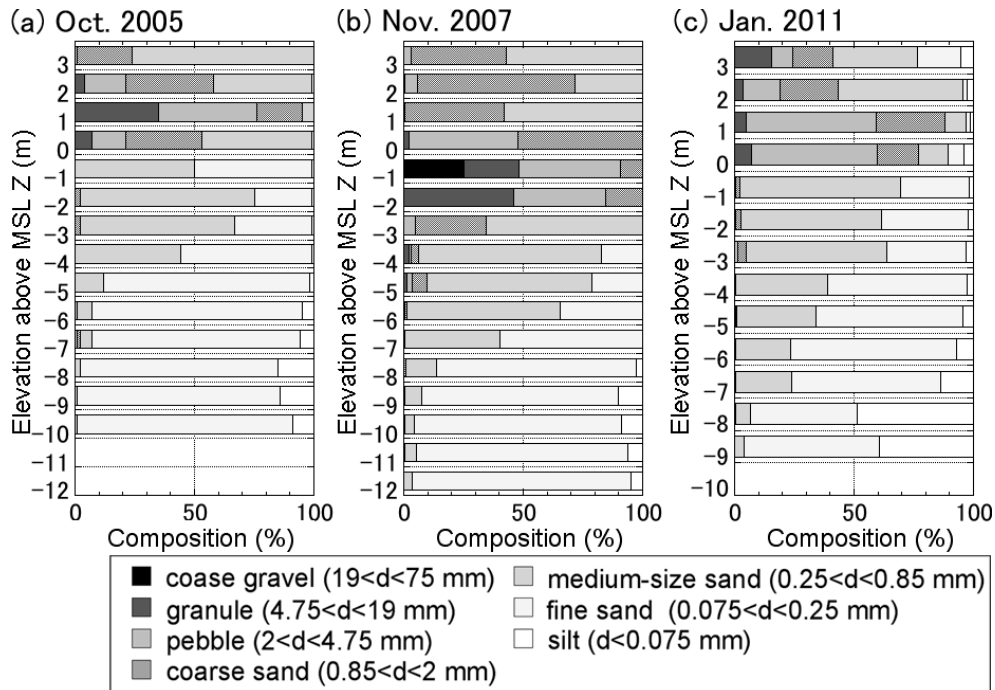


Fig. 11 Depth distribution of composition of bed materials along transect No. 18



Fig. 12 Time-averaged images of shoreline before and after Typhoon No. 6

2005, November 2007 and January 2011 along transect No. 18. The content of medium-size sand in the offshore zone decreases with depth and it becomes less than 13% at 8 m depth in all the observations, which approximately equals the depth of closure of this coast (Ishikawa et al., 2009), whereas the gravel content is high near the shoreline. Although the foreshore slope was constant at 1/10 in March 2005 and January 2008 in Fig. 10, gravel is mainly deposited near the shoreline in Fig. 11, so that a steep slope is considered to be maintained. In addition, the elevation of the foreshore increased with the deposition of gravel until January 2011. In contrast, a gentle slope was formed between 1 and 3 m depth because the content of medium-size sand increased to 65% in this depth zone. Thus, it is seen that beach nourishment using materials of mixed grain size is effective in protecting not only the foreshore but also the nearshore zone.

ANALYSIS OF PHOTOGRAPHS TAKEN FROM FIXED POSITION

A monitoring survey has been carried out using the photographs from a fixed position since May 2007. For this purpose, the time-averaged images using oblique photographs taken at 50 s intervals every hour were compared to investigate the shoreline and beach changes (Lippmann and Holman, 1989). Figure 12 shows the time-averaged images taken on July 10 and 23, 2011, before and after the storm waves, respectively, with a significant wave height of $H_{1/3} = 4.5$ m ($T = 12.4$ s) associated with Typhoon 1106, which hit the coast on



Fig. 13 Time-averaged images of shoreline before and after Typhoon No. 15

July 19, 2011. Because storm waves with a period longer than 10 s were incident for 76 h, as shown in Fig. 4, a large amount of gravel was deposited on the foreshore, forming the berms and cusps by July 23, 2011 and debris was scattered on the backshore.

Figure 13 shows the photographs taken on September 12 and 27 in 2011 before and after Typhoon 1115 hit the coast on September 21, 2011, respectively. Although sand was deposited on the backshore on September 12 before the storm, debris was transported by the run-up waves and left on the backshore in front of the fence preventing windblown sand on September 23. However, no beach changes occurred except for a slight shoreline recession. The same situation was observed in the case of the storm waves associated with Typhoons 0709 and 0918. Taking these facts into account, it is concluded that the sandy beach recovered by beach nourishment using coarse materials has a high stability against storm waves. Also, in this case, a large amount of gravel was not deposited on the foreshore as in the case after the storm associated with Typhoon 1106. This is because the duration of storm waves with a period longer than 10 s



Fig. 14 Time-averaged images in May 2007 and December 2011

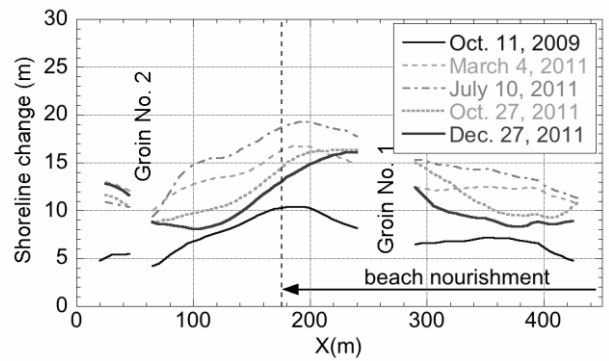


Fig.15 Shoreline changes determined from image after geometrical correction with reference to that in March 2007

was as short as 40 h, which was half of that during Typhoon 1106.

Figure 14 shows the time-averaged images taken on May 12, 2007 in the beginning of the observation and on December 27, 2011. The shoreline on May 12, 2007 is also shown in Fig. 14(b). It is clearly understood that the shoreline advanced in parallel each other and a continuous shoreline was formed with no obstruction at

Groin No. 2 owing to the beach nourishment. In addition, the shoreline positions were determined from the vertical images transformed from the oblique photographs using the geometrical transformation method, and the shoreline change after the beach nourishment with reference to that on March 16, 2007 was obtained, as shown in Fig. 15. The maximum and mean shoreline advances until July 10, 2011 were 19 and 8 m, respectively. In addition, it was found that the short-period shoreline variation owing to the storm waves was less than 5 m, as shown in the shoreline changes immediately after Typhoon 1115.

CONCLUSION

The monitoring survey data taken since 2005 on the recovery of sandy beaches on the Chigasaki coast were analyzed and the following results were obtained:

- (1) As a result of beach nourishment since January 2006 using coarse materials of $1.62 \times 10^5 \text{ m}^3$, the shoreline advanced by 15 m at maximum and the foreshore was widened in the overall study area.
- (2) In the central part of the study area where the beach width was most narrowed, the beach width of approximately 40 m was recovered, which satisfied the beach width in the plan of this coast.
- (3) Gravel was deposited on the foreshore, and the foreshore composed of gravel was stable against storm waves.
- (4) The volume change of the study area corresponded to the volume of beach nourishment, taking into account the loss of the materials by longshore sand transport.
- (5) When long-period waves with a large significant wave height were incident for a long time, gravel was exposed on the foreshore and cusps were formed. However, sand was deposited again under the calm wave condition and gravel was buried under the sand layer.

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