

Paper:

Damage to Seisho Bypass due to Storm Waves During Typhoon 0709

Takaaki Uda*, Toshiro San-nami**, and Toshinori Ishikawa*

*Public Works Research Center

1-6-4 Taito, Taito, Tokyo 110-0016, Japan

E-mail: uda@pwrc.or.jp

**Coastal Engineering Laboratory Co., Ltd.

301, 1-22 Wakaba, Shinjuku, Tokyo 160-0011, Japan

E-mail: coastseri@nifty.com

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Some 1.1 km of the Seisho Bypass along the Seisho coast was severely damaged on September 7, 2007, due to Typhoon 0709 storm waves, closing the road to traffic for emergency repairs. Damage to the highway, caused primarily through wave impact and secondarily by long-term shoreline recession due to decreased fluvial sand supply from the Sakawa River and sand loss into a submarine canyon, was investigated through field observations. A factor contributing further to shoreline recession was the obstruction of eastward longshore sand transport by the Ninomiya fishing port breakwater. Storm waves hit the coastline counterclockwise to normal to the shoreline, causing offshore and westward longshore sand transport with part of the sand transported by the longshore sand transport flowing into the submarine canyon, causing a net sand loss.

Keywords: Seisho Bypass, damage, Typhoon 0709, offshore sand transport, longshore sand transport

1. Introduction

The ease of acquiring land for coastal development has led to public facilities such as highways being constructed along the Japanese coast. Given the wide sandy beaches existing nationwide in the past, the use of such land for highways was considered effective. As such sandy beaches have rapidly disappeared due to decreases in sediment supply from rivers and the effect of the construction of coastal facilities (Uda, 2007), maintaining the safety of such highways has become increasingly difficult due to shoreline recession. Future sea level rise is expected to worsen these problems.

The Seisho Bypass was built in the 1960s along the Seisho coast of a 17-km-long sandy beach extending from Ohiso Port and the Hayakawa River in Sagami Bay (Fig. 1). Storm waves from Typhoon 0709 on September 7, 2007, severely damaged the highway, forcing it to be closed for repairs.

Typhoon 0709 originated on August 28, 2007, near

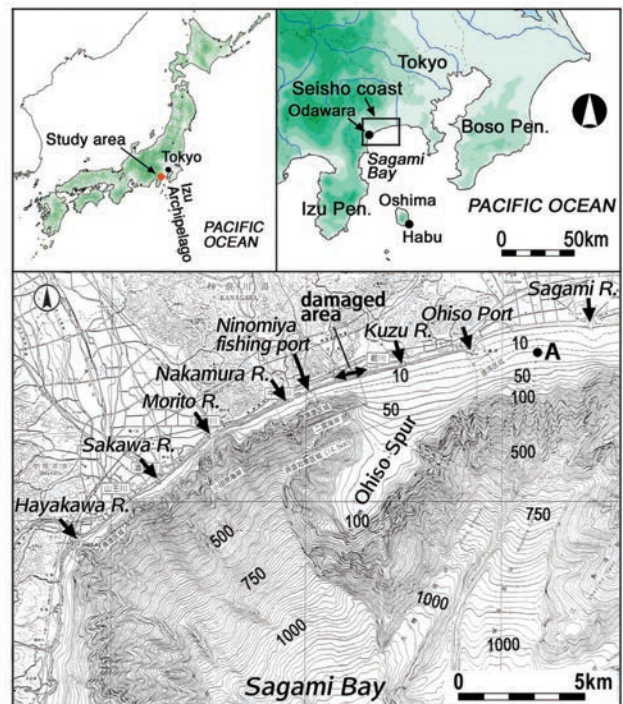


Fig. 1. Seisho coast in Sagami Bay.

Minami-tori Island 1,800 km southeast of Tokyo in the Pacific Ocean, and slowly moved northwestward, reaching the Chichijima Island on September 4 (Fig. 2). By September 5, the typhoon's central pressure had decreased to 965 hPa and the maximum wind speed was 35 m/s. On September 6 and 7, the typhoon moved northward at 20 km/h along the east coast of the Izu Peninsula to west of the Izu archipelago, but without losing strength. It reached land at Odawara City in Kanagawa Prefecture at 02:00 on September 7 where its storm waves damaged the Seisho coast, collapsing 1.1 km of the seawall protecting the highway near the Ohiso Interchange. In the most severely damaged area, two of the highway's four lanes were completely destroyed. A foreshore 20 m wide in front of the road before the typhoon was rapidly eroded by the storm waves, collapsing the highway.

We studied highway damage and the erosion mecha-

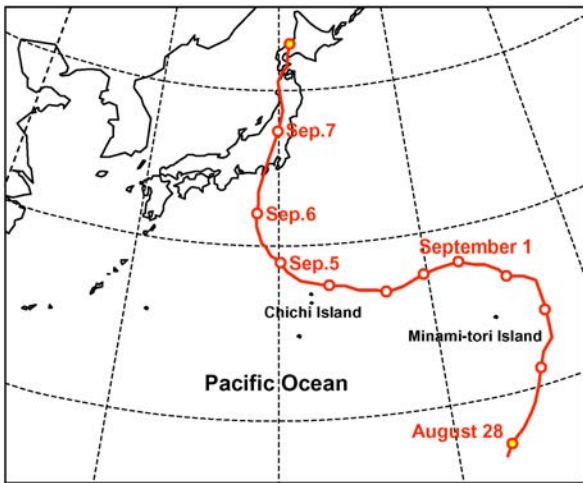


Fig. 2. Typhoon 0709 course.

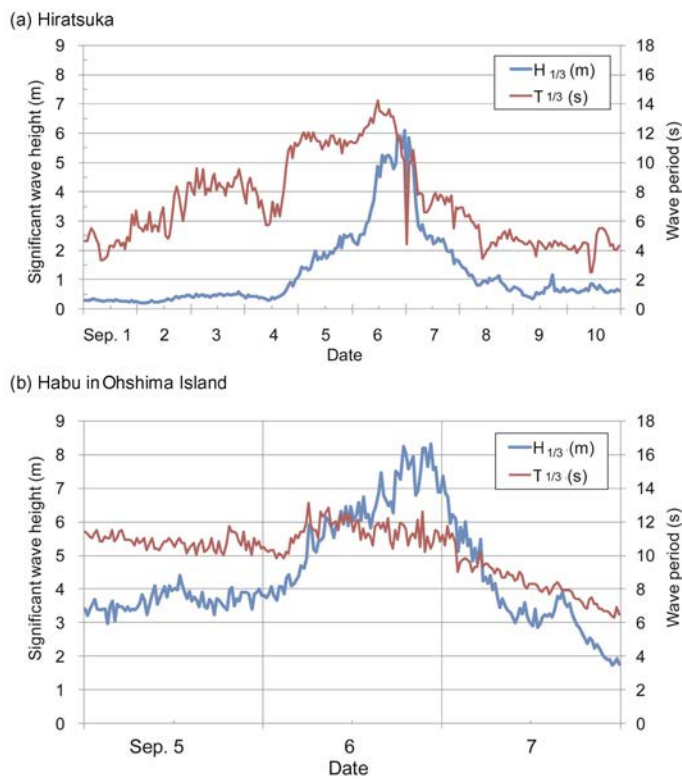


Fig. 3. Changes in significant wave height and period at Hiratsuka and at Habu on Oshima Island.

nism causing it, together with the importance of preserving beaches in protecting such facilities. In the wave observations during the typhoon, maximum significant wave height $H_{1/3}$ was 6.1 m ($T_{1/3}=14.2$ s) at Hiratsuka (Location A, Fig. 1) and 8.3 m ($T_{1/3}=13.1$ s, wave direction: SSE) at Habu on Oshima Island (Figs. 1 and 3). The maximum tide level at Shonan Port 15 km east of Ohiso Port rose to 1.27 m above mean sea level.



Fig. 4. Collapsed Seisho Bypass seawall, September 9, 2007.



Fig. 5. Damaged Ginpa Bridge footing and tilted seawall, September 9, 2007.

2. Post-Typhoon Seisho Bypass Damage

Off the Seisho coast extending from Ohiso Port and the Hayakawa River, the Ohiso spur, roughly 100 m deep and 9 km long, extends southwestward from Ohiso Port to off Ninomiya fishing port (Fig. 1) and continental shelf with a relatively gentle slope of 1/30 extends from the shoreline. A steep 1/3 slope extends offshore between 10 and 20 m west of the fishing port to the Hayakawa River. The main sediment source to the Seisho coast is the Sakawa River, from which fluvial sediment is carried by eastward long-shore sand transport (Uda, 1997). Seisho Bypass damage was located near the boundary where the offshore seabed topography changes markedly (Fig. 1).

We investigated highway damage and beach topography on September 9, 2007, immediately after the typhoon, and on October 8 (Fig. 4). The highway seawall was found to have tilted and collapsed and was being directly damaged by breaking waves. No beach was left in front of the collapsed seawall, which waves then traversed.

The seawall leaned against the scoured pier of the Ginpa Bridge, which connects the highway to the Ninomiya Interchange (Fig. 5). All filler inside the sea-



Fig. 6. Damaged highway and adjacent beach, October 8, 2007.



Fig. 7. Damaged Seisho Bypass seen from the top of the Ginpa Bridge looking east, October 8, 2007.



Fig. 8. Damaged Seisho Bypass seen from the top of the Ginpa Bridge looking west, October 8, 2007.

wall had been removed by wave action and foundation piers under the bridge footing were exposed. Before the typhoon, this footing was buried under a sandy beach, which was eroded by at least 3 m during the typhoon, exposing the footing.

By October 8, 2007, (Fig. 6, east of damaged area) the seawall in front of the highway had collapsed and part of



Fig. 9. Oblique aerial photograph of the damaged highway, November 13, 2007.

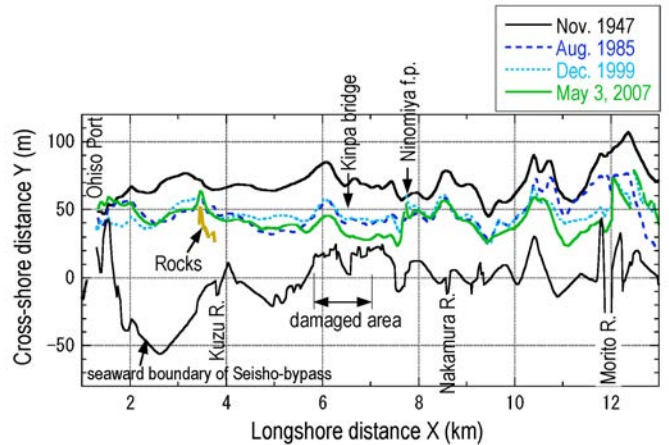


Fig. 10. Long-term pre-typhoon shoreline changes.

the debris was buried under the beach. Beyond this site, waves broke directly on the collapsed seawall, indicating that the site had been severely eroded. Damage to the highway was greatest there.

By October 8 (Fig. 7, top of the Ginpa Bridge looking east), the shoreline extending from Ohiso Port had retreated significantly landward east of the damaged area, resulting in seaward invasion of the damaged area (Fig. 8, west part of the damaged highway taken from the same location as Fig. 7. Circle: Kinpa Bridge). The beach under the bridge had been eroded entirely away. Riprap was temporarily placed along the coastline to rebuild the road.

Although emergency repairs had been made to the damaged area by November 13, 2007 (Fig. 9), the shoreline extending west from Ohiso Port was interrupted east of the damaged site, and the foreshore in front of the damaged highway had completely disappeared. The extrapolated shoreline extending from Ohiso Port intersects the damaged highway, indicating that the damaged highway functioned as a groin against the longshore sand transport.

3. Aerial Photographs and Shoreline Changes

3.1. Long-Term Pre-Typhoon Shoreline Changes

Long-term shoreline changes were studied based on aerial photographs taken in 1947, 1985, 1999 and 2007

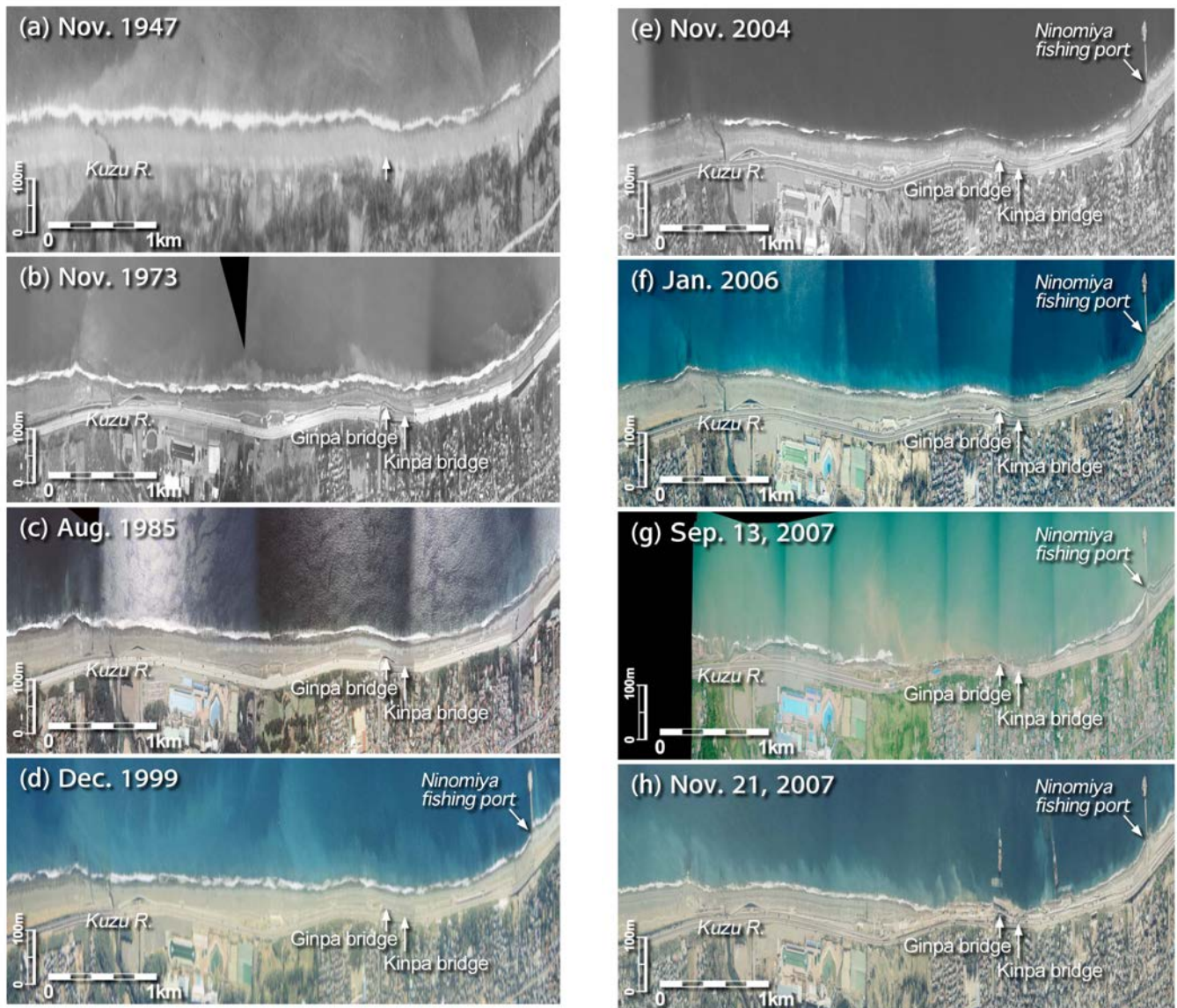


Fig. 11. Comparison of coastal changes in the damaged area using distorted aerial photographs.

(**Fig. 10**). The shoreline of the Seisho coast gradually bends alongshore (**Fig. 1**), so we used fixed curvilinear coordinates to follow the coastline smoothly in 1999, and measured cross-shore distances to the shoreline based on these coordinates. To clearly show longshore changes in shoreline positions, we show results using coordinates in which longshore and cross-shore distances are significantly distorted, together with the seaward boundary of the Seisho Bypass. Ohio Port is located at the east end of the coastline, providing a solid boundary for longshore sand transport, whereas offshore of the Morito River, a submarine canyon has developed (**Fig. 1**), where offshore sand loss has been reported (Uda, 1997).

The foreshore width in 1947 averaged at least 20 m wider than in the reference year of 1999. By 1985, the shoreline had receded over the entire area except near Ohio Port, decreasing the foreshore width from 60 m in 1947 to 20 m in 1985 in front of the damaged area of the Seisho Bypass, making it increasingly vulnerable to wave

attack.

Between 1985 and 1999, the shoreline receded dramatically between the Morito River and 1 km east of it. By May 3, 2007, this extended to where the highway was damaged, east of the Ninomiya fishing port breakwater and east of the Morito River, where the shoreline had receded significantly since 1985. The foreshore width in front of the damaged highway had thus been reduced to 10 m, accelerating highway collapse.

The longshore and cross-shore scale of aerial photographs taken between 1947 and 2007 was distorted to an aspect ratio of 1/5 (**Fig. 11**).

In 1947 (**Fig. 11(a)**), the shoreline extended smoothly with an 80-m-wide foreshore, and a small shoreline projection where the Ginpa Bridge of the Seisho Bypass was later constructed (arrow, **Fig. 11(a)**). In 1973 (**Fig. 11(b)**), when the Seisho Bypass was under construction, the highway protruded seaward at two locations near the Kuzu River and the Ginpa Bridge as construction proceeded

along the projecting coastline. Highway construction along the backshore narrowed the beach, which had been 80 m wide in 1947. The Seisho Bypass was nearly completed in 1985 (Fig. 11(c)) and the Ninomiya fishing port breakwater was extended in 1999 (Fig. 11(d)). Although shoreline changes between the Kinpa Bridge and port were small compared to those in 1985, the beach in front of the Kinpa and Ginpa Bridges was narrow because of the projection of the highway itself, producing weak points lacking a sufficient buffer zone against waves.

The difference in the shoreline on both sides of the fishing port increased, and the foreshore on the east side was narrowed by 2004 (Fig. 11(e)), with the extension of the breakwater starting to block eastward longshore sand transport. The shoreline difference on both sides of the fishing port further increased, and the foreshore completely disappeared between the Ginpa Bridge and Ninomiya fishing port in 2006 (Fig. 11(f)).

On September 13, 2007, one week after the typhoon, the foreshore also disappeared around the Kuzu River and near the Ginpa and Kinpa Bridges, the debris of the collapsed highway was exposed to waves (Fig. 11(g)). In contrast, on the east side of the fishing port, the foreshore was wider and the shoreline had retreated on the west side compared to its location on January 7, 2006. These shoreline changes indicate that during Typhoon 0709, westward longshore sand transport was predominated, and part of shoreline changes was caused by the blockage of sand transport due to the breakwater. By November 2007, the foreshore had widened over an extensive area between the Kuzu River and the Ginpa Bridge (Fig. 11(h)), but the sandy beach in front of the Ginpa and Kinpa Bridges did not recover. With longshore sand transport blocked by the fishing port breakwater and no sandy beach left in front of the Ginpa and Kinpa Bridges, the only sand source for restoring the foreshore was from onshore sand transport, indicating that part of the sand was first transported offshore by storm waves, then transported to the foreshore by onshore sand transport during calm conditions. No sand remained in the damaged area and no sand source was left, preventing onshore sand transport.

3.2. Short-Term Shoreline Changes in Damaged Areas

In a study of short-term shoreline changes around the damaged highway shown through the comparison of aerial photographs taken before and after the typhoon (Fig. 12), we found that the shoreline had retreated until May 2007 (Fig. 10). By September 18, soon after the typhoon, significant shoreline recession had occurred east of the fishing port, exposing the seawall protecting the highway for 1.9 km, and the shoreline receded up to 40 m in the damaged area. The shoreline between Ohiso Port and the damaged highway eroded by storm waves had recovered in part by January 4, 2008, with sand accumulating on the foreshore, as confirmed by on-site inspection, due to onshore sand transport after rapid erosion of the berm by storm waves.

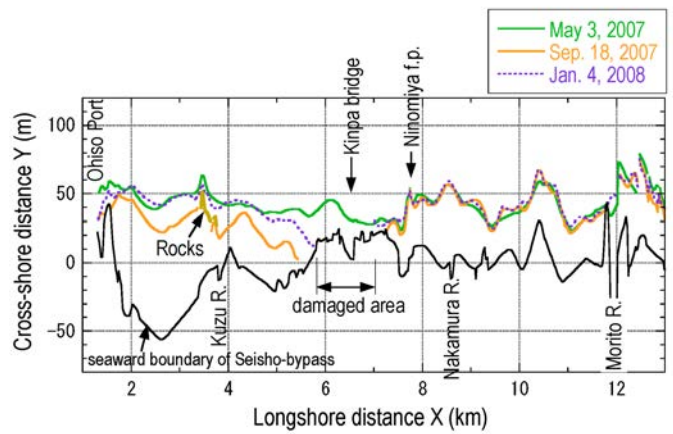


Fig. 12. Short-term pre- and post-typhoon shoreline changes.

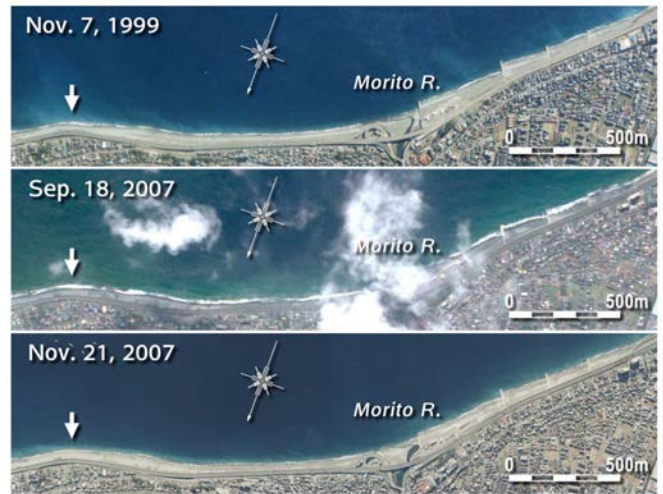


Fig. 13. Comparison of coastal changes around the Morito River.

The shoreline thus gradually retreated due to eastward longshore sand transport blockage by the fishing port breakwater, and damage caused by both offshore and westward longshore sand transport superimposed on the long-term shoreline recession.

3.3. Comparison of Aerial Photographs at Submarine Canyon off the Morito River

Aerial photographs of the area around the Morito River in 1999 and 2007 (Fig. 13) shows how the shoreline extended smoothly alongshore in 1999, but had receded between the Morito River and the shoreline projection located 1.3 km east of the river by September 18, 2007, shortly after the storm (arrow, Fig. 13). The shoreline did not recover until November 21, 2007. Around the three groins located west of the Morito River, eastward longshore sand transport continued to predominate, since the shoreline advanced on the west side of the groins. Taking these facts into account, westward and eastward longshore sand transport must meet at the mouth of the Morito River, which should result in the shoreline advancing. In fact, however, this did not happen, indicating the possi-



Fig. 14. 20-m-wide foreshore left under the Kinpa Bridge, September 4, 2007.



Fig. 15. Beach under the Ginpa Bridge, December 1, 2006.

bility of offshore sand loss through the submarine canyon off the mouth of the Morito River.

4. Comparison of Pre- and Post-Typhoon Photographs

Near the Kinpa and Ginpa Bridges, which were both severely damaged, photographs of coastal conditions before the typhoon showed a 20-m-wide foreshore under the Kinpa Bridge on September 4, 2007, two days before the typhoon (**Fig. 14**). Similarly, on December 1, 2006 (**Fig. 15**), the base of the Ginpa Bridge was protected by concrete blocks on the shoreface, so the 20-m-wide foreshore in front of the bridge eroded after that time (pier denoted by an arrow, **Fig. 15**, the same as in **Fig. 5**).

Studies of beach changes before and after damage on the west side of the Ohiso Port breakwater, considered a fixed boundary for longshore sand transport, showed on July 2, 2007, that a salient had formed behind reefs next to the breakwater due to the deposition of gravel (**Fig. 16(a)**). By September 12 after the typhoon, gravel had been transported away, exposing the base of the rocks

(a) July 2, 2007



(b) September 12, 2007



Fig. 16. Comparison of beach conditions immediately west of Ohiso Port on July 2 and on September 12, 2007, after the typhoon.

(**Fig. 16(b)**). The base of the rocks was white in front of the berm, meaning that part of rocks had been buried under the gravel layer without exposure to ultraviolet light and wave action (Uda and Ishikawa, 2007), and black further seaward. This rock exposure was considered due to the movement of gravel by westward (rightward in the figure) longshore sand transport, because a long impermeable breakwater extends immediately east of this site.

The base of rocks, which had long been buried under the sand layer, was exposed 270 m east of the Kuzu River. On the east side of these rocks, a berm had formed by October 8 due to sand deposition (**Fig. 17(a)**). On the west side, however, ground elevation was significantly lower, isolating individual rocks (**Fig. 17(b)**). Such asymmetrical beach changes, with sand accumulating on the east side and beach erosion on the west side, imply that westward longshore sand transport prevailed during the storm. Field observation on November 20 showed that sand reacumulated and buried the rocks (**Figs. 18(a)** and **18(b)**) suggesting that rapid landward sand transport occurred between October 8 and November 20 under calm wave conditions.

5. Changes in Longitudinal Profiles

We studied changes in longitudinal profiles using seabed-sounding data taken before and after the typhoon (**Fig. 19(a)**, change in the longitudinal profile along survey line X=3.2 km near rocks east of the Kuzu River). The



Fig. 17. Exposure of rocks east of the Kuzu River on October 8, 2007: (a) east of rocks and (b) west of rocks.



Fig. 18. Rocks recovered by sand accumulation on November 20, 2007: (a) east of rocks and (b) west of rocks.

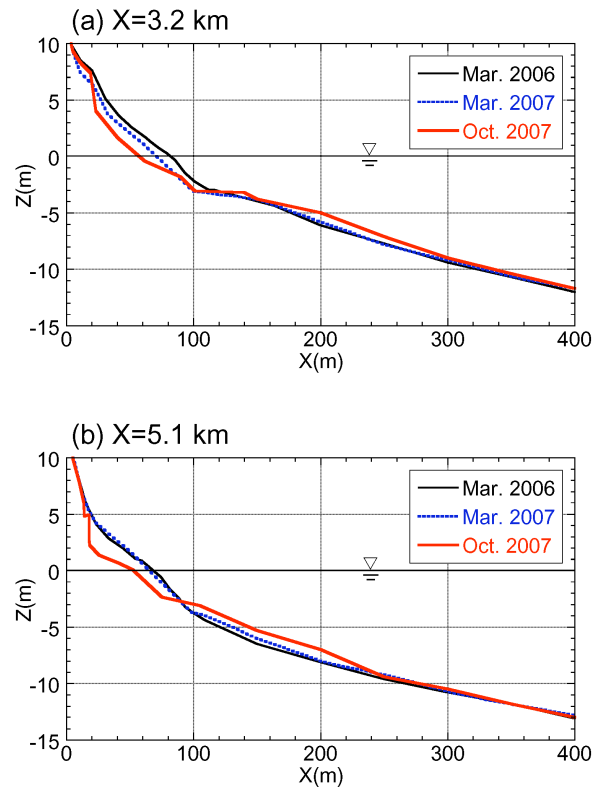


Fig. 19. Change in longitudinal profiles along survey lines X=3.2 km and X=5.1 km.

foreshore was significantly eroded until October 2007 after the storm, and sand accumulated in the depth zone between -4 and -9 m. No beach changes were observed in the depth zone deeper than -9 m, however, implying that the depth of closure, h_c , of this coast is roughly -9 m. In the change in the longitudinal profile along survey line X=5.1 km, 700 m east of the damaged area (Fig. 19(b)), ground elevation was lowered 2.5 m on the foreshore, and eroded sand was transported offshore and deposited up to a depth of -9 m during the storm. These beach changes clearly show the occurrence of rapid seaward sand transport under storm conditions.

6. Mechanism Behind Beach Changes

A high gravel berm existed west side of Ohiso Port preceding the typhoon was washed away, rocks were exposed near the Kuzu River, and ground elevation markedly decreased west of the rocks. Other evidence showing the predominance of westward longshore sand transport was also observed at some sites.

We looked into the possibility of predominant westward longshore sand transport in wave propagation. Assuming the deep-water wave height as the offshore boundary condition, wave propagation was numerically solved using the energy balance equation (Mase, 2001). Since the wave direction measured at Habu Port on Oshima Island was SSE, the wave direction from SSE was first

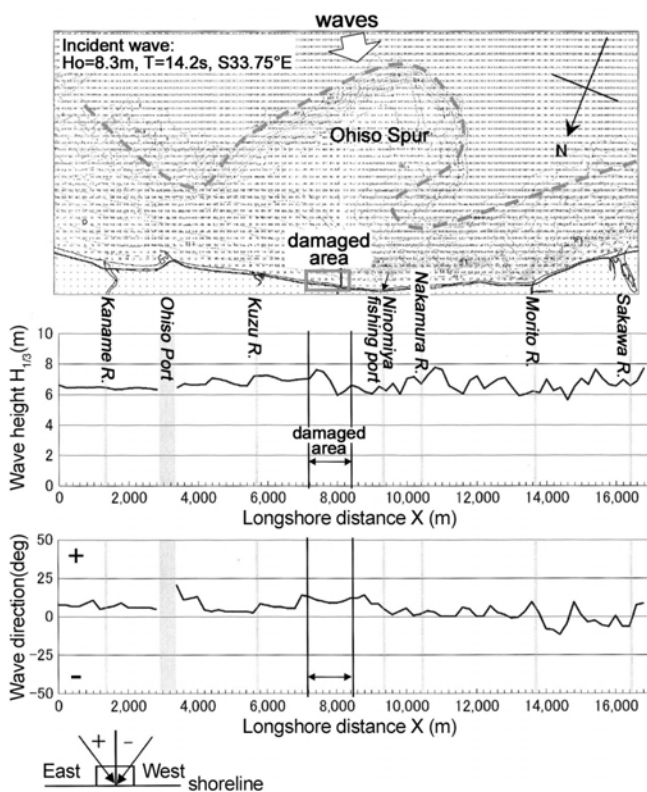


Fig. 20. Longshore distribution of predicted significant wave height and angle of incident waves.

assumed in the calculation, making westward longshore sand transport predominant in the area where the highway was damaged. In other areas, the wave direction varied resulting in spatial changes in the direction of longshore sand transport that differed with local conditions.

According to aerial photography of the Seisho coast on December 22, 2005, the mean direction normal to the coastline was $S15\text{degE}$ between Ohiso Port and Ninomiya fishing port, and $S28\text{degE}$ between Ninomiya fishing port and the shoreline projection east of the Morito River (arrow, **Fig. 13**), shifting the direction of the coastline by 13 deg. The fact that the shoreline west of the structures and rocks receded between Ohiso Port and the Morito River shows that westward longshore sand transport was predominated in this area. The direction of incident waves was not SSE, but is assumed to be counterclockwise relative to $S28\text{degE}$. Since wave direction is given by one of 32 points on the compass, SSE includes all the directions between $S11.25\text{degE}$ and $S33.75\text{E}$. Taking this into account, we assumed that wave incidence was further inclined to the east and that waves incident from $S33.75\text{degE}$. We then calculated the breaker angle along the coastline (**Fig. 20**). The significant wave height was assumed to be 8.3 m, the wave period 14.2 s, and the tide level 1.27 m above mean sea level.

Because of the longshore distribution of the breaker angle, westward longshore sand transport generally predominated between Ohiso Port and the Morito River, whereas eastward longshore sand transport predominated west of

the Morito River. These features agree with results of shoreline change analysis. A larger wave incident angle causing large longshore sand transport was predicted in the damaged area. From this fact, the damaged area was considered to be significantly eroded, and around the Morito River where eastward and westward longshore sand transport meet, part of sand was considered to be transported offshore through the submarine canyon, causing a net sand loss.

7. Conclusions

The most important cause of damage to the Seisho Bypass was storm wave impact, but a secondary factor was long-term shoreline recession due to partly decreased fluvial sand supply from the Sakawa River and sand loss into the submarine canyon and partly the Ninomiya fishing port breakwater obstructing eastward longshore sand transport. Long-term shoreline changes and wave impact on highway structures must therefore be carefully studied if both the beach and the highway are to be protected.

Our case study of the Seisho Bypass shows that the shore must be sufficiently wide to operate as a buffer zone to preventing wave damage (Uda et al., 2007). Although constructing the highway on the Seisho coast was originally considered as using land effectively, the shoreline has gradually receded, increasing the danger to the highway.

Based on laboratory and field studies on the physical effects of seawalls and revetments, Komar (1998) concluded that they can have adversely impact on both front and adjacent beaches, and that the presence of such a structure can impound sand, particularly when it is used to protect foredunes that would normally be eroded during a storms and supply sand to the beach in front. This results in greater erosion of adjacent, unprotected foredunes and properties, in effect acquiring an equivalent volume of sand denied by the area protected by the seawall. On the Seisho coast, the extension of the exposed seawall without the sufficient buffer zone of a sandy beach caused the same results.

Had the buffer zone in front of the seawall been wide enough, shoreline recession due to offshore sand transport during storms would have been allowable to some extent, but the foreshore in front of the seawall had become too narrow. In determining the location of public facilities, the buffer zone in front of the seawall must be wide enough to prevent wave damage, and the prediction of long-term shoreline changes is important in reducing potential damage to facilities.

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Name:
Takaaki Uda, Dr. Eng.

Affiliation:
Head, Shore Protection Research, Executive Director, Public Works Research Center

Address:

1-6-4 Taito, Taito-ku, Tokyo 110-0016, Japan

Brief Career:

1973- Research Engineer, Coastal Eng. Division, Public Works Research Institute, Ministry of Construction
1997- Director of River Department, Public Works Research Institute, Ministry of Construction
2001- General Coordinator of Research, National Institute for Land, Infrastructure and Management, Ministry of Land, Traffic and Infrastructure
2002- Executive Director, Public Works Research Center

Selected Publications:

- "Improvement of contour line change model in terms of stabilization mechanism of longitudinal profile," Coastal Sediments '03, pp. 1-5, 2003.
- "Predictive model of change in longitudinal profile in beach nourishment using sand of mixed grain size," Proc. 29th ICCE, pp. 3378-3390, 2004.

Academic Societies & Scientific Organizations:

- The Japan Society of Civil Engineers (JSCE)
- The Japanese Geomorphological Union (JGU)



Name:
Toshinori Ishikawa

Affiliation:
Senior Research Engineer, Shore Protection Research, River and Coastal Engineering Dept., Public Works Research Center

Address:

1-6-4 Taito, Taito-ku, Tokyo 110-0016, Japan

Brief Career:

1997 Pacific Consultants Co., Ltd.
2005 Coastal Engineering Laboratory Co., Ltd.
2005- Public Works Research Center

Selected Publications:

- "Effect of Typhoon 0709 to Shonan Coast in Terms of Coastal Protection and Surfing," JSCE Annual Journal of Civil Engineering in the Ocean, Vol.24, pp. 441-446, 2008.

Academic Societies & Scientific Organizations:

- Japan Society of Civil Engineers (JSCE)
- Japanese Association for Coastal Zone Studies (JACZS)
- Japanese Geomorphological Union (JGU)



Name:
Toshiro San-nami

Affiliation:
Research Engineer, Coastal Engineering Laboratory Co., Ltd.

Address:

1-22-301 Wakaba, Shinjuku-ku, Tokyo 160-0011, Japan

Brief Career:

1981 Sanyo Hydrographic Survey Co., Ltd.
1989 Pacific Consultants International Co., Ltd.
1995 Coastal Engineering Laboratory Co., Ltd.

Selected Publications:

- "Investigation of Evolution of Lowland in Mekong Delta Using Satellite and Aerial Images," Proc. 4th Int. Conf. on Asian and Pacific Coasts, pp. 509-512, 2007.