Storm Surge Damage caused by Typhoon No. 9918 in the Area of the Shiranui Sea

Lessons learned

Kiyoshi TAKIKAWA

Member of JSCE, Dr. of Eng., Professor, Research and Education Center of Coastal Environmental Science, Kumamoto University

Damage overview

Typhoon No. 18 of 1999 (Typhoon 9918) cut across the Kyushu and Chugoku regions on September 24, leaving widespread damage in its wake. The maximum instantaneous wind speed reached a record high of 66.2 meters per second at the Ushibuka Weather Station run by Kumamoto Meteorological Observatory. In Kumamoto Prefecture, the Matsuai District of Shiranui Town lies at the innermost extremity of an inlet in Shiranui (Yatsushiro) Bay. Here, storm-driven tides flooded over low-lying land and claimed 12 lives. These were the first victims of a storm surge in the country since the Ise Bay Typhoon of September 1959, so the loss of life was a shock to us all. The last such deaths in the prefecture also occurred in 1959, during Typhoon No. 14 in September of that year.

Damage in the vicinity can be characterized as follows. First, the typhoon, packing extremely strong winds at its core, took the worst possible course over the area. It moved northward along the west side of the bay, passing overhead between 4:00 a.m. and 6:00 a.m., coincident with a high autumn tide. Second, Shiranui Bay is a long, narrow sea inlet aligned in a southwesterly direction with extensive mud flats at its head. These geographical and topographical characteristics enhanced the storm and tidal surges. As a consequence, the tide rose beyond normal levels at various points around the head of the bay concurrently at about 6:00 a.m. about 2 hours before the tide was in.

The path of this typhoon almost matched that of Typhoon No. 9119 (popularly known as the Apple Typhoon) that tracked the length of Kyushu and Chugoku before moving north to hit Hokkaido in September 1991. Although stronger than this typhoon, and resulting in more overall damage, Typhoon No. 9119 caused little storm-surge and tidal-surge damage because it coincided with an ebb tide. In contrast, this typhoon inundated many houses to floor level and higher, and left heavy damage along the coast. Total damage was estimated at ¥100 billion, the worst ever in the prefecture.

Immediately after the event, Kumamoto University began a site survey, joining with the JSCE's coastal engineering research group to inspect the damage in detail. Information about the damage was collected on the following day, September 25.

The results of the survey were made public at the Coastal Engineering Symposium, held in Yonago City on November 15, 1999. On the day preceding the symposium, the JSCE's Coastal Engineering Committee held an emergency briefing and panel discussion, at which lively discussion of the academic challenges arising from studies of the damage and the technical focus of future studies took place. This preliminary report gives details of the damage as seen during the site survey.

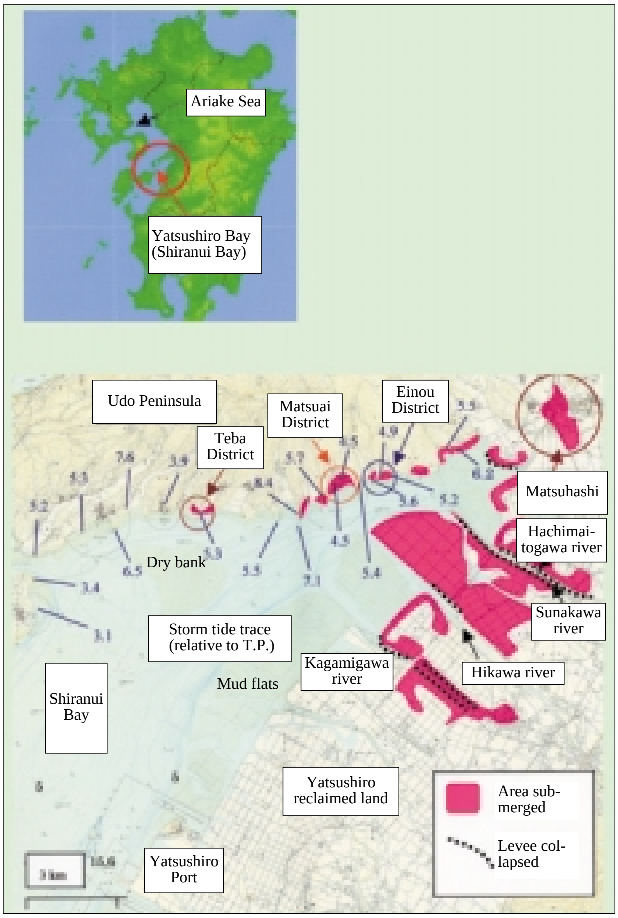

Fig. 1 Storm tide traces and areas submerged

Photo 1. Disaster-hit Einou District

Photo 2. Overturned torii at Einou Shrine (Source: Kumamoto Nichinichi Newspaper evening edition on September 28)

Details of damage in stricken area

Damage caused by storm and tidal surges around Shiranui Town

Figure 1 shows the tide levels (relative to T.P.) as measured by the university from water traces between September 28 and October 1. These tide heights were obtained by the leveling method using a leveling instrument and staff. Since waves have a greater influence near the shore as compared with areas within levees, some traces measured near the shore include the height of waves that traveled up local rivers. Limitations of space mean that this report covers damage in the Einou, Matsuai, and Teba Districts only, and these are marked with circles in the figure.

Damage in the Einou District

The Einou District of Shiranui Town lies at the head of Shiranui Bay. The storm became full-blown at about 4 a.m., and waves began washing over a coastal levee with a top height of T.P.+2.5 m at 5:30-6:00 a.m. Water

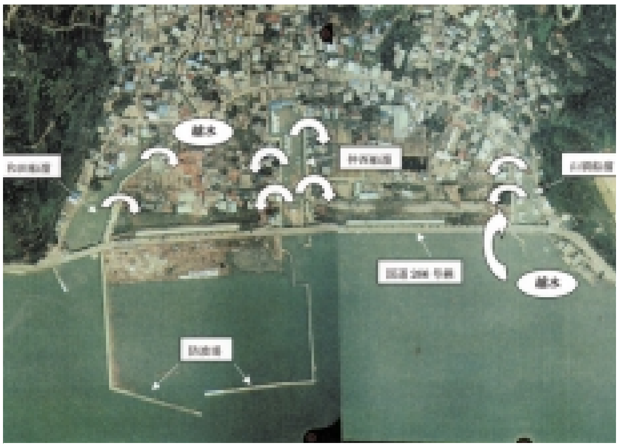

Photo 3. Aerial photo of Matsuai District

Photo 4. Disaster-hit Matsuai District (Source: Kumamoto Nichinichi Newspapers evening edition on September 25)

broke into the ground floor of a house in the vicinity of the levee; fortunately the residents had seen the danger and moved upstairs. The levee failed over a length of 137.0 m from a point near this inundated house up to the extremity of the bay (Photo 1). Other damage consisted of 13 houses inundated above floor level and 31 houses below floor level. National Highway 266 was also flooded. The peak of the storm tide in this area was T.P. +4.9-5.6 m.

The area is notable for its Einou Shrine, which is dedicated to a sea deity, and for the "sea fire," or mysterious lights, that can be seen out at sea. A concrete torii (shrine gate) measuring 5 m in height stood approxi-

Photo 5. Disaster-hit Teba District

Photo 6. Damaged banks of the river Sunakawa

mately 65 m out into the bay from the shrine. The storm tide snapped the 70-cm diameter torii foundations at a point 1.25 m above the seabed, and the structure fell in the direction of the shrine (Photo 2). The torii stood in approximately 2 m of water even at high tide and yet had never been knocked down by a typhoon before.

Damage in the Matsuai District

In the Matsuai District of Shiranui Town, about 60 houses huddled around Matsuai fishing port. Three fishing harbors (from the head of the bay, Yamasu, Nakanishi, and Wada), each with an entrance approximately 20-30 m wide to Shiranui Bay. None had a flood control gate. In spite of the presence of breakwaters between the Nakanishi and Wada harbors, sea water flooded through the harbor entrances at about 5:50 a.m. It rose to overwhelm the sea walls (T.P. +3.2 m in height) around the harbors by as much as 1.3 m, flooding the land beyond (T.P.+0.5 m) (Photo 4). Water crashed into single-storied houses up to ceiling level in a surge, leaving no time to escape. Many barely escaped with their lives by breaking windows and reaching the roof unaided, but twelve people failed to escape the waters and lost their lives. The results of interviews indicate that the outermost harbors (Yamasu and Wada) were overwhelmed earlier than the harbor in the middle (Nakanishi), and that the floodwater receded within approximately 30 minutes.

Immediately after the disaster, the storm tide traces were inspected and evidence, such as deposits left on crash barriers, marks on roadside vegetation, and landslides, was collected. At the same time, interviews relating to details of the damage were held. This survey was unable to locate traces of sea water that came over the sea wall (at approximately T.P. +4.9-6.5 m) along National Highway 266, although such evidence had been carried in the news.

The survey indicated that the storm tide level in the area reached T.P. +4.1-4.5 m. The results of a survey by the prefecture (as reported later) indicate that the rivers Sunakawa and Hikawa overflowed by T.P. +4.1-4.2 m, causing further damage. These measurements make it clear that the maximum flood level (T.P. +4.5 m) was the highest point of the storm tide.

Damage in the Teba District

In the Teba District of Misumi Town, located at the southern tip of the Udo Peninsula, sea water began to flow over coastal levees (T.P. +4.5 m) at about 5:30 a.m., causing the levees to collapse over a length of 245.0 m (Photo 5). Prawn farms in the hinterland were closed down and private houses were somewhat distant from the levees. Despite this, water damage was extensive, though there was no injury to humans. One house was inundated below floor level and strawberry farms were damaged. A few spans of a levee on the Matsuai side fell inward while others collapsed outward in the direction of the Shiranui Sea. Further, storm tide traces along the coast in this district showed peak levels of T.P. +4.6-5.7 m, indicating that waves were significant in this area.

Inundation of Yatsushiro reclaimed land by rivers

This section gives details of damage as compiled by the River Division of Kumamoto Prefectural Office as of October 1.

Damage caused by the rivers Hachimaitogawa and Sunakawa

The rivers Hachimaitogawa and Sunakawa are divid-

Photo 7. Flood damage caused by the river Hikawa

ed by a separation levee; on the right is the river Hachimaitogawa and on the left the river Sunakawa. The river Hachimaitogawa began to overflow its banks (T.P. +4.1 m) in the 2 km section from the Yatsushiro-Shiranui Road at the estuary to the Yatsushiro-Kagamiudo Road upstream at about 5:30 a.m. Water continued to flow over the banks until after 7 a.m. The overflow caused a collapse of the levee's rear slope over a length of 1,840 m, and water inundated 40 houses above floor level. The river Sunakawa began to overflow its banks (T.P. +4.1 m) over a 1,770 m-long section upstream from the Yatsushiro-Shiranui Road at the estuary at about 5:40 a.m., with the overflow continuing until after 7 a.m. Again, the rear slope of the levee collapsed, in this case over a length of 550 m (Photo 5). Twenty houses were inundated above floor level. The floodwaters from these two river overflows did not subside until after 2 p.m. on that day. About 70 residents took refuge in town offices and local elementary schools.

Damage caused by the river Hikawa

The river Hikawa began to overflow its right bank over a length of approximately 3 km upstream from the estuary (in the Wakasu, Tsunamichi, and Kano Districts of Ryuhoku Town) at about 5:30 a.m. The levee (T.P. +3.5 m) collapsed over a length of approximately 50 m directly below the Hikawa Bridge carrying the Yatsushiro-Shiranui Road 1 km upstream from the estuary at about 6-7 a.m. Combined with overflows from elsewhere, a massive amount of water flowed within the levee and caused flood damage (Photo 7). The construction of a temporary levee to replace the damaged section commenced the same day, and a 140 m temporary structure was in place by the time of the full tide at about 8 p.m. Other damage was as follows: the slope at the rear of the right levee collapsed over a length of 1,600 m and the slope at the rear of the left levee collapsed over a

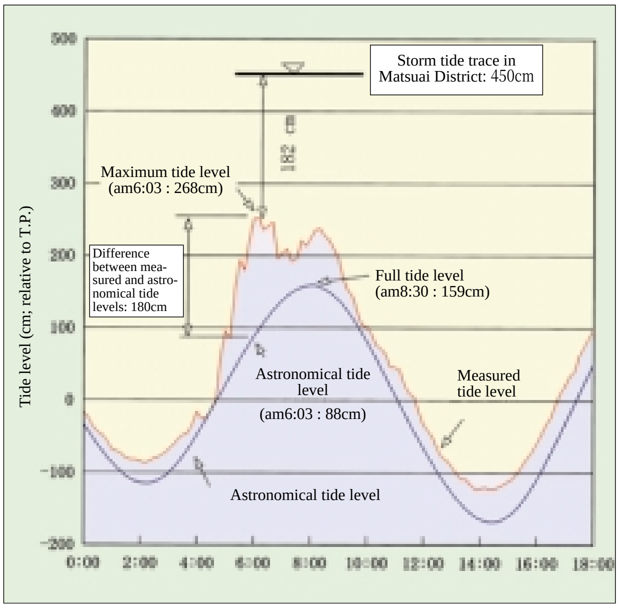

Fig. 2   Changes in tide level at Yatsushiro Port

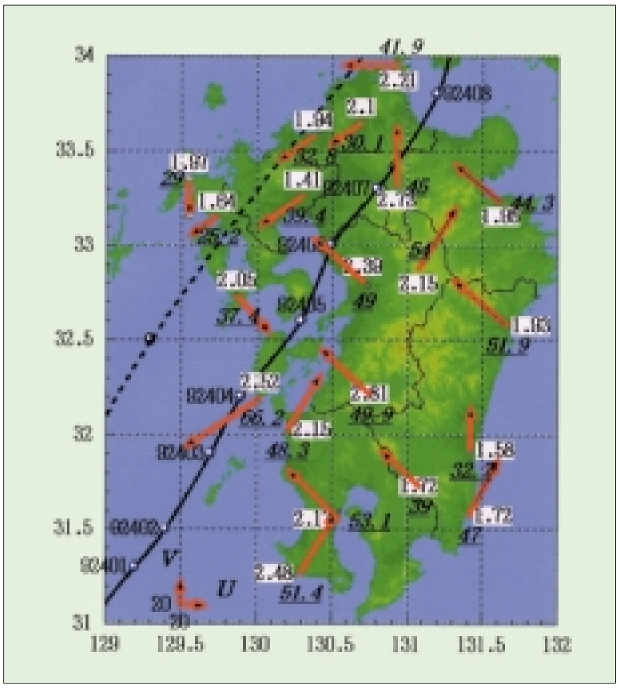

Fig. 3   Maximum instantaneous wind velocity driven by Typhoon No. 9918 (with direction and magnitude indicated by arrow and underline, respectively) and gust factor (ratio of maximum instantaneous wind velocity to maximum wind velocity averaged over 10 minutes; shown by open rectangles) The solid line indicates the track of Typhoon No. 9918. (In this figure, 92403 means 03:00 hours on September 24.) The broken line indicates the track of Typhoon No. 9119.

length of 400 m. In addition, 15 houses were inundated above floor level, 270 below floor level, 592.4 hectares of land was submerged, about 800 residents fled to safety.

Characteristics of Typhoon No. 9918 and accompanying storm surge

Tide level records at Yatsushiro Port

Figure 2 shows the changing tide level at Yatsushiro Port (relative to T.P.) on September 24. The solid and dotted lines indicate measured and astronomical tide levels, respectively. The former were read at intervals of 10 minutes from recorder charts at Yatsushiro Port Office of the No. 4 Port and Harbor Construction Bureau, and the latter estimated by calculation using a harmonic constant for 40-minute sea levels at the port. The estimated astronomical tide levels are less than the measurements for September 22 and 23, just before the typhoon struck, by 15-30 cm. (It was through this survey that the difference was made clear. Similar differences had been observed on the coast of northern Kyushu before and after Typhoon No. 5 of the same year. The discrepancy is thought to be associated with recent abnormal weather phenomena, although no definite conclusion has yet been drawn, and the question is now under study.)

According to wind velocity data measured by Yatsushiro Fire Department, stormy winds exceeding 30 m/s in velocity began at about 4:00 a.m., and a maximum wind velocity of 56.5 m/s (southerly) was recorded in Yatsushiro at 4:47 a.m. At the same time, the tide level rose sharply after 4:00 a.m. Although high tide at Yatsushiro Port on that day was 8:03 a.m., the maximum surge level of 268 cm was recorded at 6:03 a.m., two hours earlier. The maximum tide level exceeded the previous record of 249 cm (recorded on September 6, 1971). The difference between measured and astronomical tide levels at this time is estimated to be 180 cm, although fluctuations in sea level due to long-period waves are not taken into account in this estimation. Storm traces observed in the Matsuai District are also plotted in this figure. Sea water had already flowed over the levees in the Matsuai District when the maximum surge level was recorded at Yatsushiro Port. So, although the distance between these two areas is only about 13 km, there was a big surge level difference of about 2.0 m between them.

Typhoon No. 9918 in weather observation data

The author consulted the records of meteorological observatories and weather stations in the Kyushu region and Yamaguchi Prefecture to examine the characteristic features of the winds driven by Typhoon No. 9918. Figure 3 shows the maximum instantaneous wind velocities driven by the typhoon. As can be seen from the figure, the velocity was not less than 40 m/s northwest of the typhoon's track, while it exceeded 50 m/s over a wide area to the southeast of the track.

The gust factor, defined as the ratio of maximum instantaneous wind velocity to wind velocity averaged over 10 minutes, is commonly used as a measure of sudden strong winds caused by typhoons. The ratio of maximum instantaneous wind velocity to maximum wind velocity (averaged over 10 minutes) can be treated much like the gust factor, and this is plotted in Figure 3 by open rectangles. Whereas the gust factor is typically about 1.5, this measure averaged over the Kyushu region was approximately 2.08. It has previously been reported that when Typhoon No. 9119 hit Kyushu, the gust factor exceeded 2.0 at many observation points. The true gust factor would probably be larger than the factor shown in the figure. This high gust factor is one of the characteristic features of Typhoon No. 9918.

Table 1 compares Typhoon No. 9918 with Typhoon No. 9119. Although Typhoon No. 9119 was greater in terms of force at the time it hit Kyushu, Typhoon No. 9918 followed a track 50 km or more to the southwest of that of Typhoon No. 9119. It is thought that this difference resulted in a considerably lower atmospheric pressure at sea level, leading to sudden wind gusts and the devastating storm surge damage.

Lessons learned from the storm surge damage

The author rushed to the area hardly able to believe early reports of storm tides flowing over sea walls, washing away a fishing village, and the loss of as many as 12 lives. How could such a thing happen in this small, quiet fishing village with a warm climate, and where damage from storm surges and floods was previously unknown? This question wouldn't go away during the drive to the area, which was disrupted in many places by fallen utility poles and trees.

Coastal engineers from universities in Kyushu had begun drawing up maps of areas in danger from flood tides and tsunami around each Kyushu prefecture the previous year, and as a result the author had visited the

Table 1 Comparison between Typhoon Nos. 9918 and 9119

		Typhoon No. 9119	Typhoon No. 9918	
Landfall in Kyushu region	Location	Sasebo City	Arao City	Amakusa City
	Time	16:00	6:00	4:00
	Radius of storm	300 km	150 km	190 km
	Central atmospheric pressure	940 hPa	950 hPa	945 hPa
	Wind velocity	50 m/s	40 m/s	40 m/s
	Speed	50 km/h	45 km/h	35 km/h
Max. instantaneous wind velocity	At Hitoyoshi	48.8 m/s	49.9 m/s	
	At Ushifuka	52.1 m/s	66.2 m/s	
	At Kumamoto	52.6 m/s	49.0 m/s	
	At Aso	60.9 m/s	54.0 m/s	
Period of storm winds (in Kumamoto)	At 10 m/s or more	14:00 - 20:00 (approx. 6 h)	3:00 - 10:00 (approx. 7 h)	
	At 25 m/s or more	16:40-16:50 (approx. 10 min)	5:20 - 5:40 (approx. 20 min)	
Closest approach of typhoon to Kumamoto City		Approx. 80 km	Approx. 30 km	

area for a coastal environment survey no more than two weeks previously. Upon arrival, the scars left by the typhoon were still visible, and it was immediately clear that the damage was caused by a worst possible combination of circumstances. This strong typhoon had taken the worst possible course at a time that coincided with a rising tide. It hit land at the deepest part of a bay open to the southeast, and where mud flats accounting for 7.3% of Japan's total stretch out toward the sea. To make matters worse, the area had never been hit by a major disaster and was defenseless, both physically and otherwise, against storm and tidal surges. As one of those working on the disaster maps, the author very much regrets having to reach this conclusion after disaster. The damage clearly presents us with many important scientific and technological questions.

Scientifically, is it possible to explain the difference of about 3.5 m in tide levels in the Matsuai District and the difference of about 2.0 m between the Yatsushiro and Matsuai Districts? It is questionable as to what extent such differences can be explained by the conventional method of estimating static high sea levels. Going back to the basic fact that a storm surge is an interaction between the atmosphere, sea water, and natural topography, research needs to focus on a storm surge as a dynamically interactive system, taking into account the deformation of waves. A scientific study of the social and economic background of the disaster-stricken areas will also be necessary. Further, studies of low and aging embankments are necessary, along with investigations of living conditions on low-lying land from the viewpoint of the regional environment, including details of past regional development and past relations with administrative bodies.

Technologically, the first issue is how design standards should be established. The storm surge peak during this typhoon exceeded the maximum recorded tide level by 2.2 m. In other words, to ensure complete safety, the area should be protected against a worst-conceivable disaster. Meticulous attention will be necessary in first assuming a hypothetical worst disaster, and then establishing design standards according to local geographical and topographical restraints and taking into account the social and economical background.

The second technological issue is how to improve the accuracy of tide level forecasts and, from a non-engineering point of view, how to issue suitable evacuation orders. Tide level records are available only at Yatsushiro Port and Misumi Town, both at least 10 km distant from Shiranui Town. Yet it is clear that abnormal rises in sea level should be detected as early as possible so that evacuation orders can be issued in good time. Further, the mistaken assumption that a storm surge is not a danger unless it occurs at high tide must be dropped.

To make these improvements, correct information needs to be provided, and this means the installation of more measuring equipment. An information network should be set up for disaster prevention and environmental protection, bringing together the meteorological observation systems of related government bodies, such as prefectural offices, the Fire Defense Agency, the Meteorological Agency, and the Ministries of Transport and Construction.

The third technological issue is the unification of coastal administration roles. While storm damage can extend over wide tracts of coastline, responsibility for damage management is divided into individual administrative offices. Fortunately, the River Division of Kumamoto Prefectural Office took the initiative in making emergency repairs after the flood damage, but faced difficulties in keeping step with central government. The division of a continuous coastline into convenient administrative units is nothing but selfish. The Seacoast Law, as amended this year, needs to take on board the opinion of people with experience and of academic standing when a coastal construction project is planned. Taking this as a good opportunity, the author proposes an administrative system under which one or more coastal "doctors" are stationed in every local administrative office or regional coast administration to manage the coast on a unified basis.

In Japan, there are many lengths of coastline similar to the Matsuai District. They exist in every corner of the country. To prevent a recurrence of storm surge damage like that experienced in the Shiranui Sea, we must absorb the lessons taught to us by this natural disaster and work to promptly solve these issues.