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The Japan Sea Central Region Tsunami of May 26, 1983

A Reconnaissance Report

Committee on Natural Disasters

Commission on Engineering and Technical Systems

National Research Council

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FOREWORD

The Committee on Natural Disasters was formed to study the impact of natural disasters such as earthquakes, floods, tornadoes, and hurricanes on engineered structures and systems. The objectives of the committee's work are to improve protection against disasters by providing factual reports of the consequences of these extreme events of nature and to stimulate research needed to understand the hazards posed by natural disasters.

The Japan Sea central region earthquake of May 26, 1983, provided a unique opportunity for a reconnaissance study of the effects of a moderate tsunami on engineered coastal works in northern Japan and Korea. A two-member team was therefore dispatched by the committee to document the effects of this tsunami for the benefit of researchers and designers of coastal protective works.

Anil K. Chopra, Chairman
Committee on Natural Disasters

ACKNOWLEDGMENTS

The authors wish to acknowledge the generous assistance and hospitality of individuals and agencies in Japan and South Korea who provided information essential for the preparation of this report. Kinjuro Kajiura of the University of Tokyo provided data on the earthquake and wave parameters. Nobuo Shuto of Tohoku University provided a file of data already distilled by himself and various colleagues on the coastal impact of the tsunami. Included in these data were original photographs, photographs from news magazines, and a videotape showing the real-time impingement of the tsunami at various locations along the Japan coast. These photographic and video data are an invaluable resource to U.S. engineers and scientists, and a special debt of gratitude is owed to Professor Shuto, his students, and his staff for their time and expense in making them available.

In South Korea we were ably assisted by Lang Choo Lee, Director of the Port Development Division of the Korea Maritime and Port Administration, and Jee-Yong Lee, Director-General of the Meteorological Observations Bureau, Central Meteorological Office. Both of these gentlemen provided their time and an organized collection of data on very short notice. The authors are extremely grateful for this assistance. In addition, we would like to thank Syng Ahn, former Director of the Port Development Division, for the general support he gave us during our stay in South Korea.

CONTENTS

INTRODUCTION

A few seconds after noon on May 26, 1983 (Japan Standard Time), a major earthquake occurred in the Japan Sea about 100 km off the coast of Akita Prefecture, which is located in northeast Honshu, Japan. The earthquake had a magnitude of 7.7 on the Richter scale, as measured by the Japan Meteorological Agency (JMA). Four individuals lost their lives directly from the earthquake, and considerable property damage occurred, primarily from foundation failure as a result of soil liquefaction.

The earthquake generated a tsunami that began striking the Japan coast approximately 12 minutes after the earthquake occurred. One hundred lives were lost as a consequence of the tsunami alone. The tsunami also caused significant flooding and property damage to coastal regions (Shuto, 1983b; Tanimoto et al., 1983).

The tsunami affected the entire Japan Sea, hitting the surrounding coastline of the Korean Peninsula and the USSR. Three lives were lost in South Korea, when the wave arrived there approximately 1-1/2 hours after the earthquake. At the time of this writing, no information is available on the impact of the tsunami in North Korea or the USSR.

This report focuses on the tsunami generated by the Japan Sea central region earthquake, as officially named by the JMA. The data presented herein were collected by the authors during site visits to Japan and South Korea approximately six weeks after the earthquake. Even though the recently acquired data are more reliable than those reported immediately after the earthquake, they must still be considered preliminary and subject to change as continuing studies in Japan are completed.

THE EARTHQUAKE AND THE TSUNAMI

The epicenter of the Japan Sea central region earthquake was located at 40.4°N latitude, 138.9°E longitude, approximately 100 km off the northwest coast of Honshu, Japan. The geographic location of the earthquake is shown in Figure 1. Figure 1 also shows the location of historical earthquakes that have occurred offshore of Japan in the Japan Sea. The Japan Sea central region earthquake is one of the largest earthquakes that have been recorded in that region.

The earthquake occurred at a focal depth of approximately 20 km along a fault line running north by northeast to south by southwest. The orientation of the fault line is indicated by the major axis of the aftershock ellipse, which is also shown in Figure 1. The measured area of the aftershock has a length of approximately 150 km along the major axis of the ellipse and a width of about 100 km. According to Kinjuro Kajiura of the University of Tokyo, the fault plane appears to dip to the east at an angle of about 20° to 30°.

The seismic moment (M_o) for this earthquake is estimated to be in the range 0.8 to 2.0 x 10^{28} dyne-cm. Assuming static and seismic

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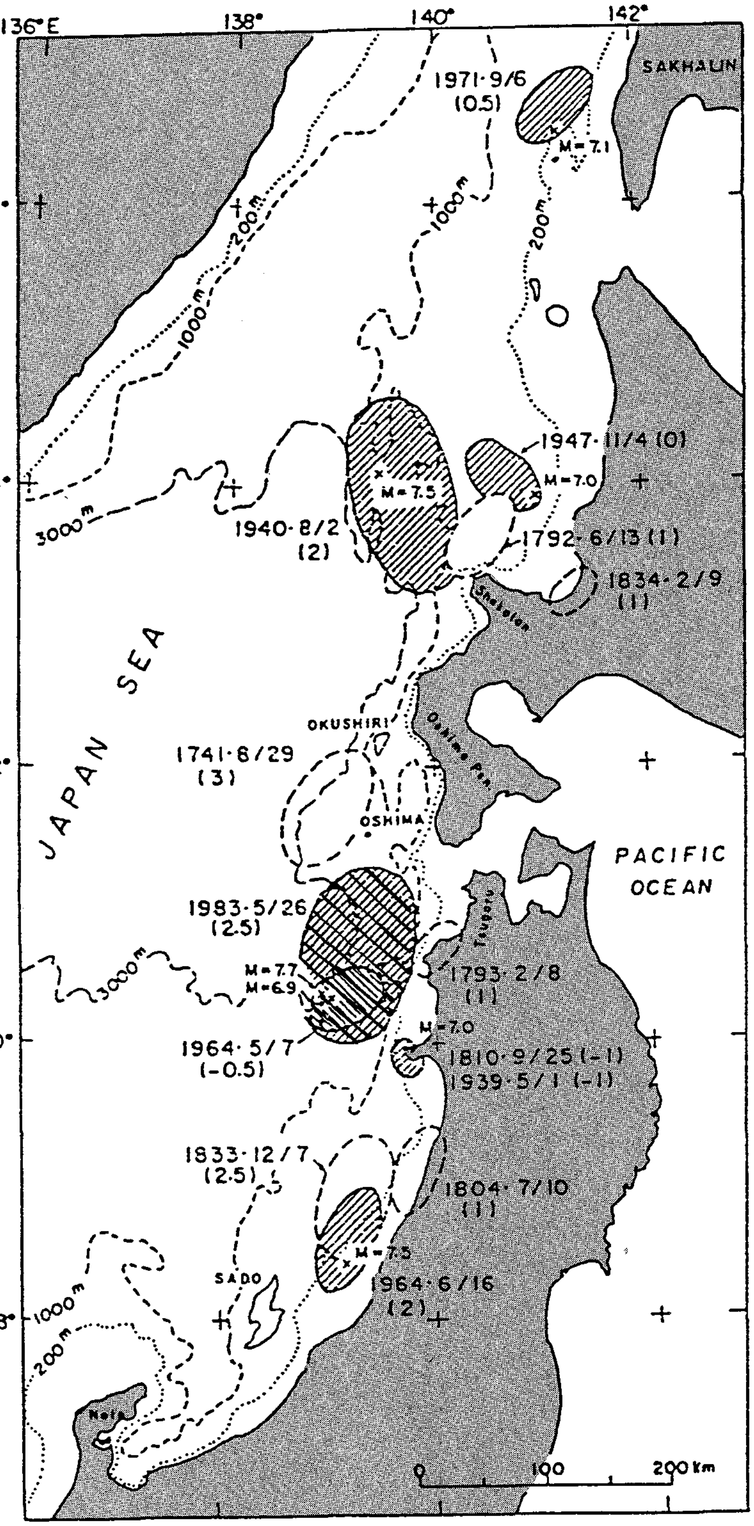
FIGURE 1 The epicenter and aftershock area of the Japan Sea central region earthquake are shown in cross-section area. Also shown are other historical earthquakes that have occurred in the region. The figures accompanying each earthquake give the year, the month, and the date, respectively. Recent earthquakes are also listed with their measured magnitude (M). Source: Japanese Tsunami Committee, 1983.

Longitude

Latitude



moments to be equal, a permanent seafloor offset, ζ_o, along the fault plane is found from

$$\zeta_o \sim M_o/\mu S$$

where S is the source area and μ is the shear modulus of the fractured material. With $S \sim 15{,}000\ km^2$ and $\mu = 5 \times 10^{11}$ dynes-cm^{-2}, we find the ground offset to be 5 to 10 m. For a fault plane inclination of 30^o, this yields a vertical offset component of 2 to 5 m.

The displacement was positive over most of the aftershock area, with slight subsidence occurring only in the eastern portions of the aftershock ellipse. At Kyuroku Island (Kyurokujima in Figure 2), the observed subsidence was approximately 30 cm. Figure 2 also shows the size of the earthquake's bottom displacement area. This area was delineated by reverse wave propagation based on records of wave arrival from surrounding tide gauge stations.

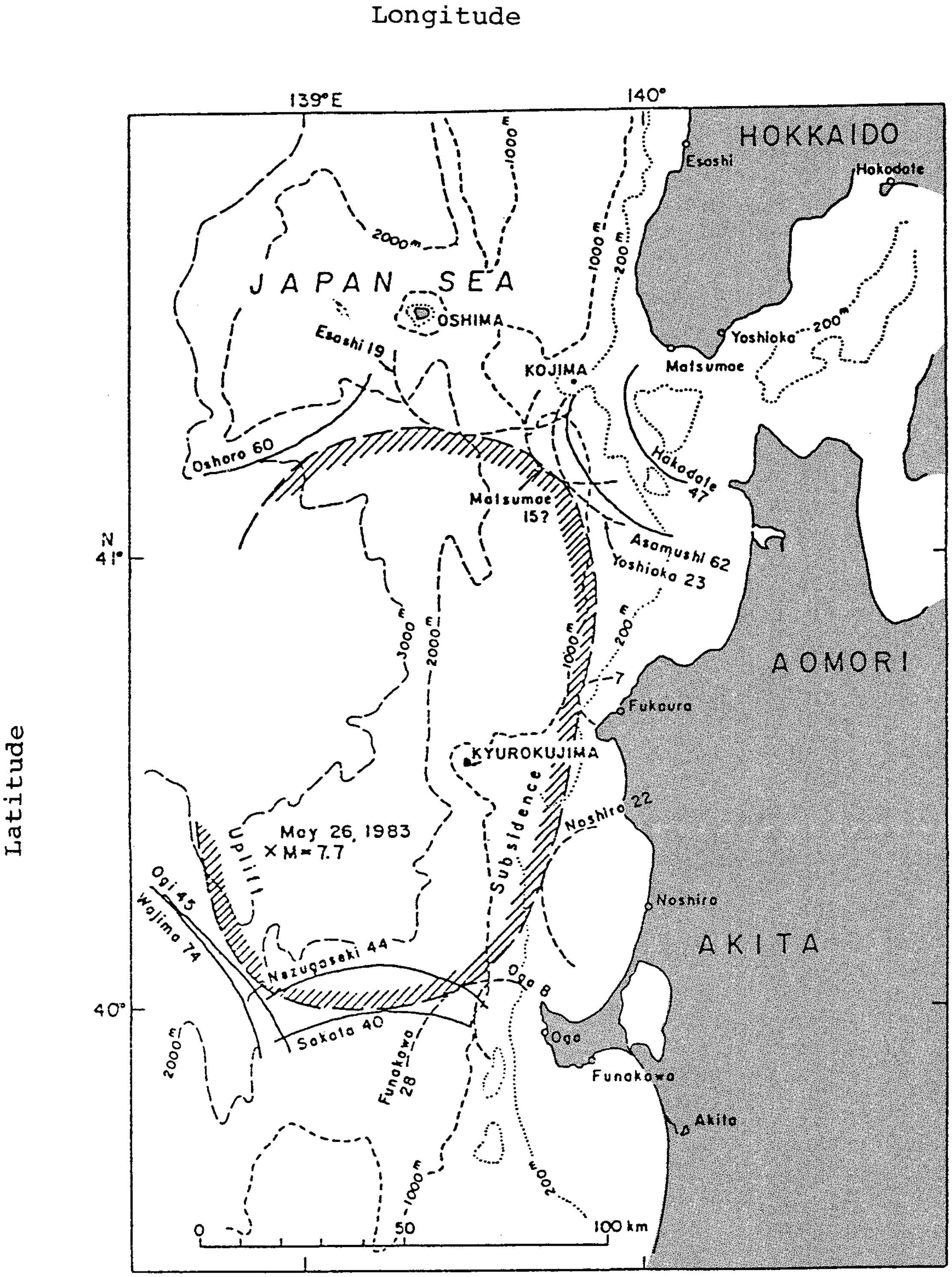


FIGURE 2 The earthquake area based on tsunami arrival times. Source: Shuto, 1983.

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TSUNAMI PROPAGATION AND COASTAL TRANSFORMATION

The major axis of the ellipse of the Japan Sea central region earthquake borders the deeper portion of the Japan Sea known as the Japan Basin. Water depths along the major axis and in the western portion of the ellipse are in the range of 2,500 to 3,000 m, as shown in Figure 2. East of the major axis and toward the coast of Honshu, Japan, the water depths decrease gradually to about 1,000 m before encountering the continental slope. At the continental slope the water depths decrease rapidly to approximately 200 m before encountering the continental shelf. From the shoreline the continental shelf varies in width from a few kilometers at Fukaura and Yatsumori to 30 km at Noshiro to a kilometer or so at the Oga Peninsula. Figure 3 shows the detailed bathymetry of the area. These large variations of bathymetry along the eastern Japanese coast profoundly affected the nearshore behavior of the tsunami.

The tsunami first arrived at the eastern Japan coast about 7 minutes after the earthquake occurred. The tsunami consisted of three to four main waves, of decreasing amplitude, each with a period of approximately 10 minutes. Figure 4 shows a photographic sequence of the first wave striking the shoreline in the Oga Peninsula area. These photographs also provide accurate time data because the camera that was used displayed the date and time at the bottom of each picture. The first photograph shows the wave as it was first seen offshore at 12:12 p.m. The remaining two photographs were taken at 12:13 and 12:17 p.m., respectively. During this 5-minute interval, the water rose and receded

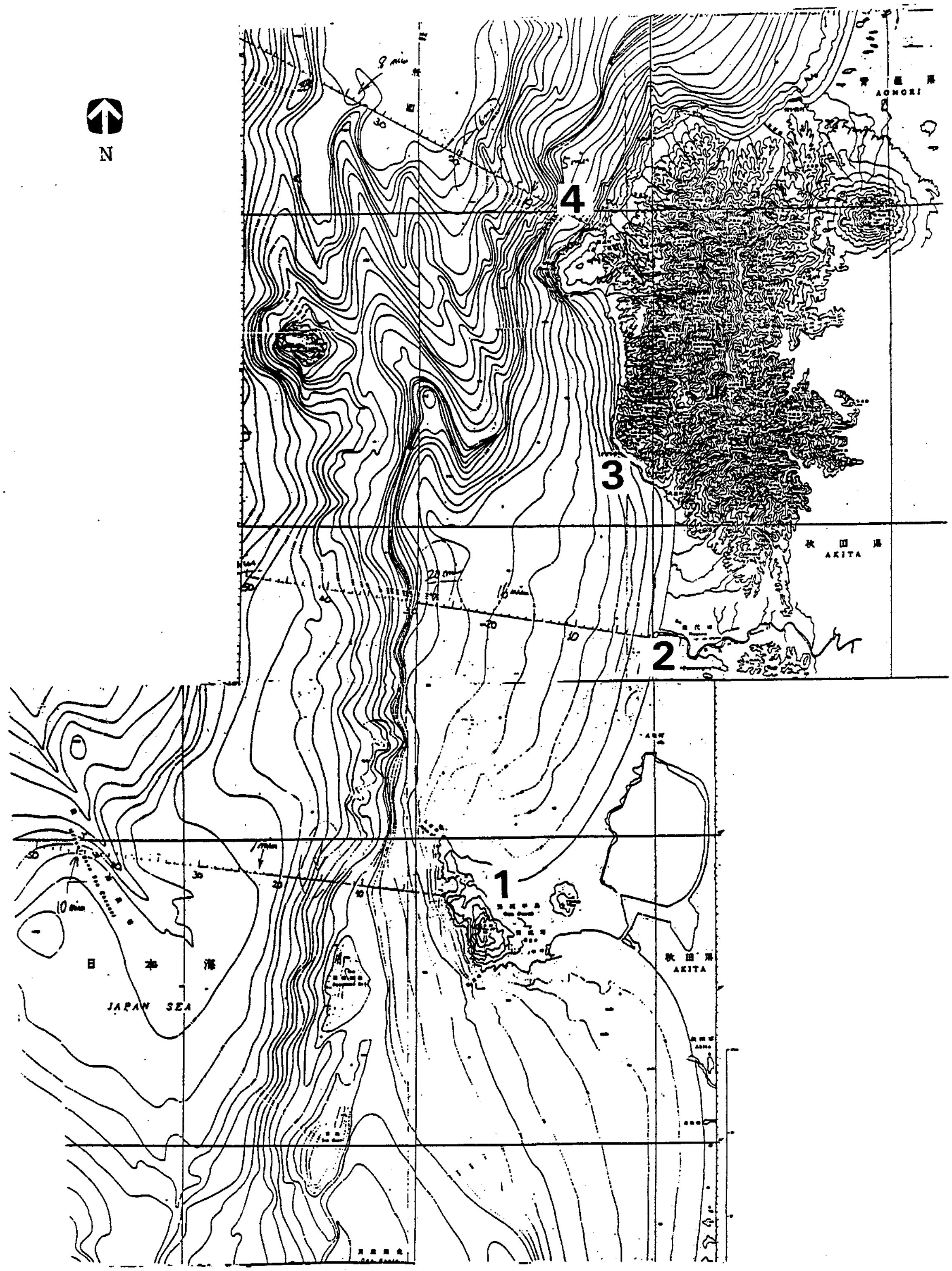

FIGURE 3 The detailed offshore bathymetry off the Oga Peninsula (1), Noshiro (2), Yatsumori (3), and Fukaura (4).

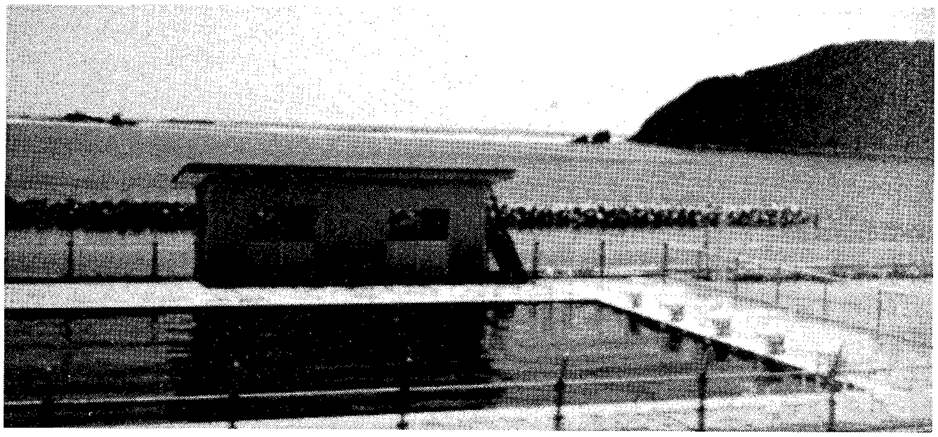

FIGURE 4A The first wave approaching the Oga Peninsula area at 12:12 p.m. Source: T. Sawaki.

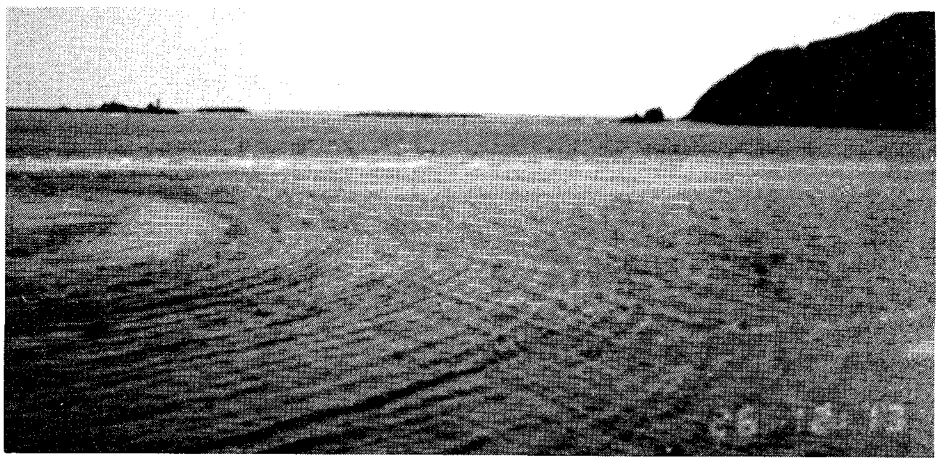

FIGURE 4B The same area at 12:13 p.m. Source: T. Sawaki.

FIGURE 4C The same area at 12:17 p.m. Source: T. Sawaki.

to approximately its initial level, corresponding to a complete wave period of about 10 minutes.

Offshore of Noshiro the first wave resembled an undular bore, with a short-period undulation of approximately 10 seconds superimposed on the leading portion of the main wave. At other coastal sites the character of the main waves varied, ranging from undular bores, spilling breakers, and plunging breakers to surges at a few locations. Schematic drawings of the observed waves at various coastal sites are shown in Figure 5.

Figure 6 presents evidence for the existence of several waves. This sequence of photographs was taken from an elevation of about 300 m on the Oga Peninsula looking north toward Noshiro. In the first photograph

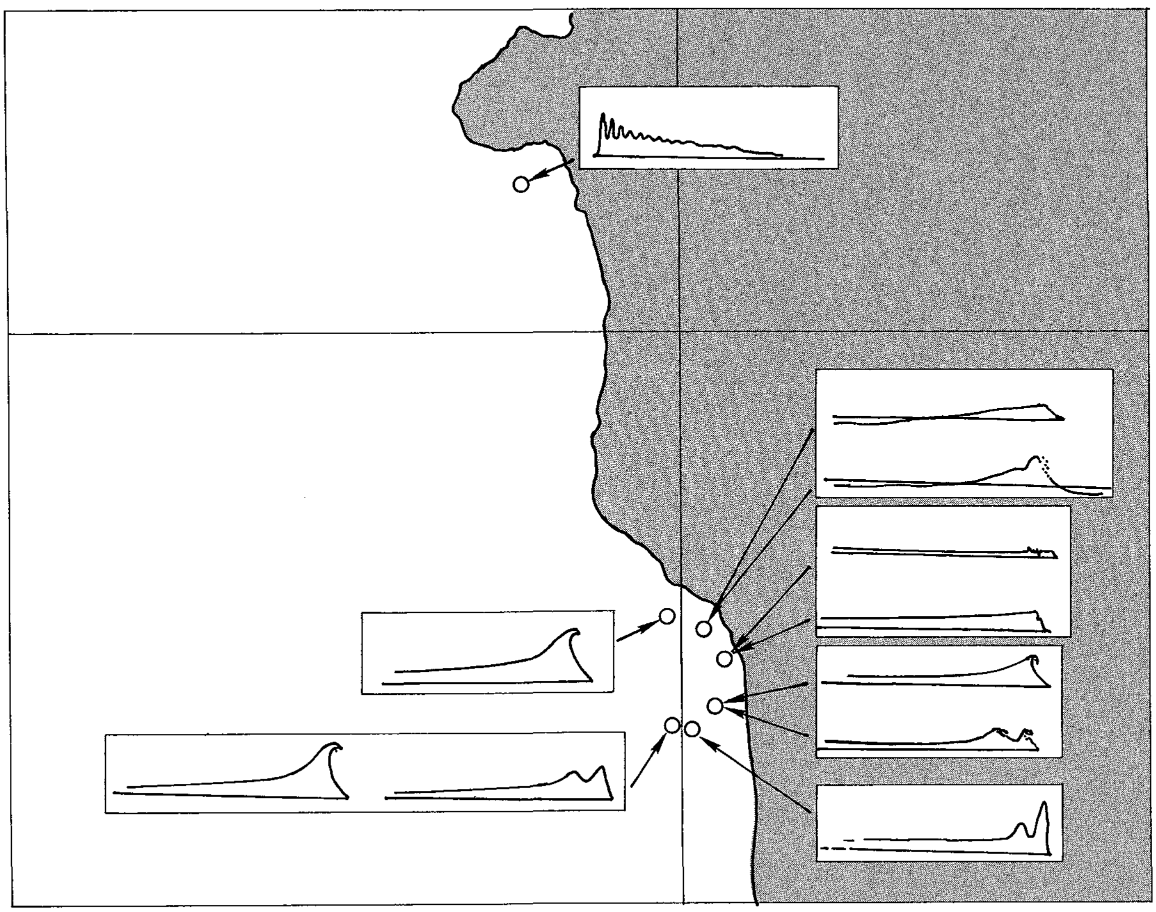

FIGURE 5 Schematic drawings of observed wave configurations. The top record is from Yatsumori. The bottom records are from near Iwadate (north of Noshiro). Source: N. Shuto., personal communication,

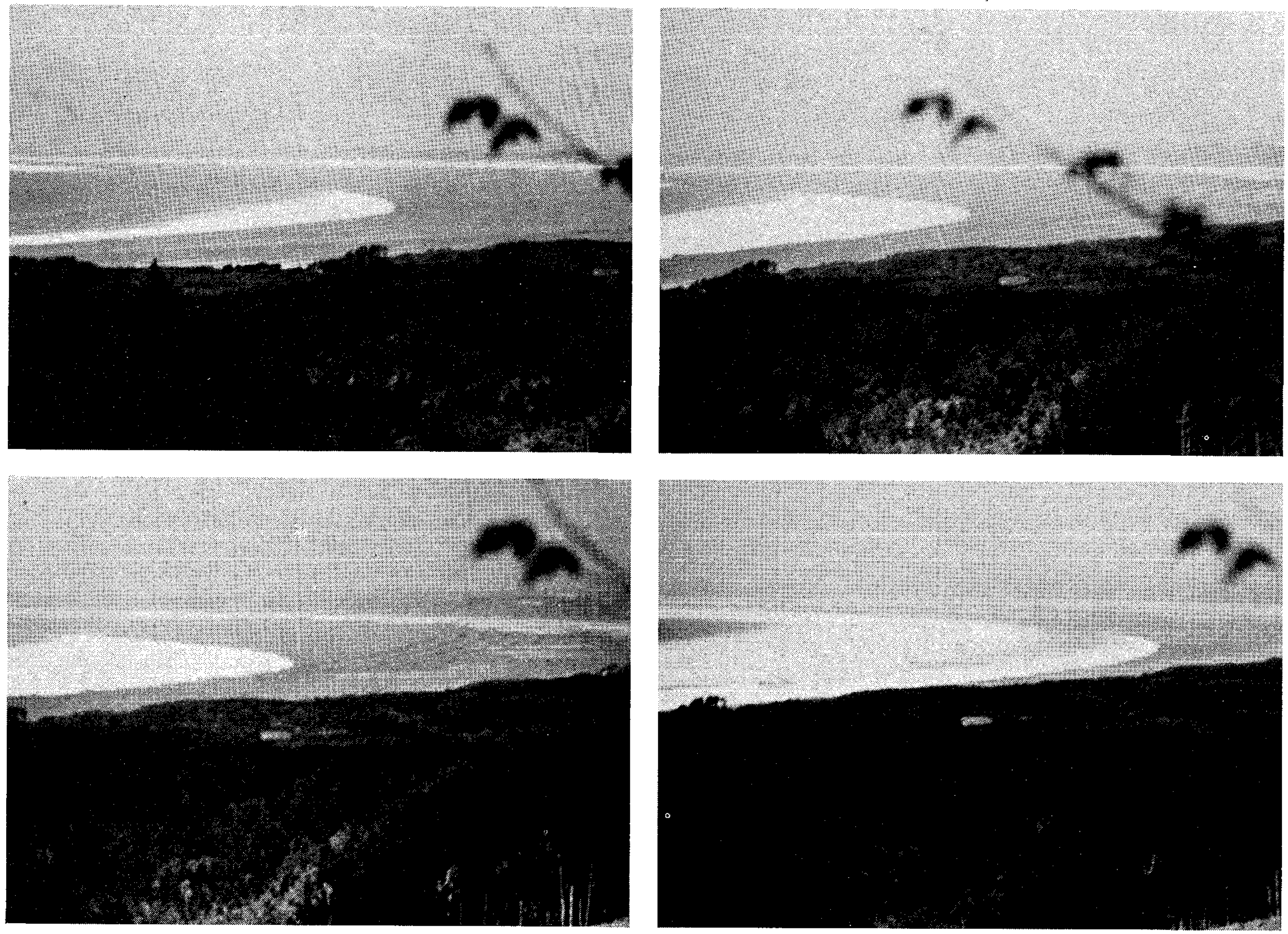

FIGURE 6 View of the tsunami offshore of the Oga Peninsula looking north. Source: N. Oba.

(upper left), three waves are visible: the first very near the shoreline, the second breaking offshore, and the crest of the third farther offshore. In the second and third photographs (upper right and bottom left, respectively), the first wave has reflected from the shoreline and dispersed into a train of undulations. At least 10 wave crests in the reflected wave can be detected in the third photograph. In the last photograph (bottom right), the reflected waves have collided with the incoming second wave to form a sea of "white water."

The formation of waves with a period of 10 seconds at the crest of a main wave with a period of approximately 10 minutes was not expected. The Port and Harbour Research Institute, Ministry of Transportation, has reproduced this phenomenon with experiments in a laboratory wave flume. The institute simulated the bathymetry offshore of Noshiro and generated appropriate incoming waves, as shown in Figure 7. The simulation demonstrated the formation of short-period waves on the leading edge of the main wave as the wave propagated over a steep continental slope and onto a gentle continental shelf. Analyzing the behavior of this transformation is crucial to understand tsunami transformation and to design practical coastal protection structures.

Another interesting feature observed was that once the bore formed at one location on the propagating wave, it tended to migrate across the entire wave crest. The wave crest was subsequently propagated with remarkable uniformity toward the shoreline. This phenomenon is shown in a photographic sequence of the incoming wave in Figure 8.

Another phenomenon that occurred during the tsunami was the creation of an edge bore that propagated along the shoreline and caused significant damage to shore structures. This edge bore is illustrated in Figure 9B.

The open-ocean propagation of tsunamis to Japan and other coastal sites bordering the Japan Sea can be accurately predicted by linear long-wave theory. Theoretical predictions for the May 26, 1983, tsunami are shown in the refraction diagram of Figure 10, which was prepared by

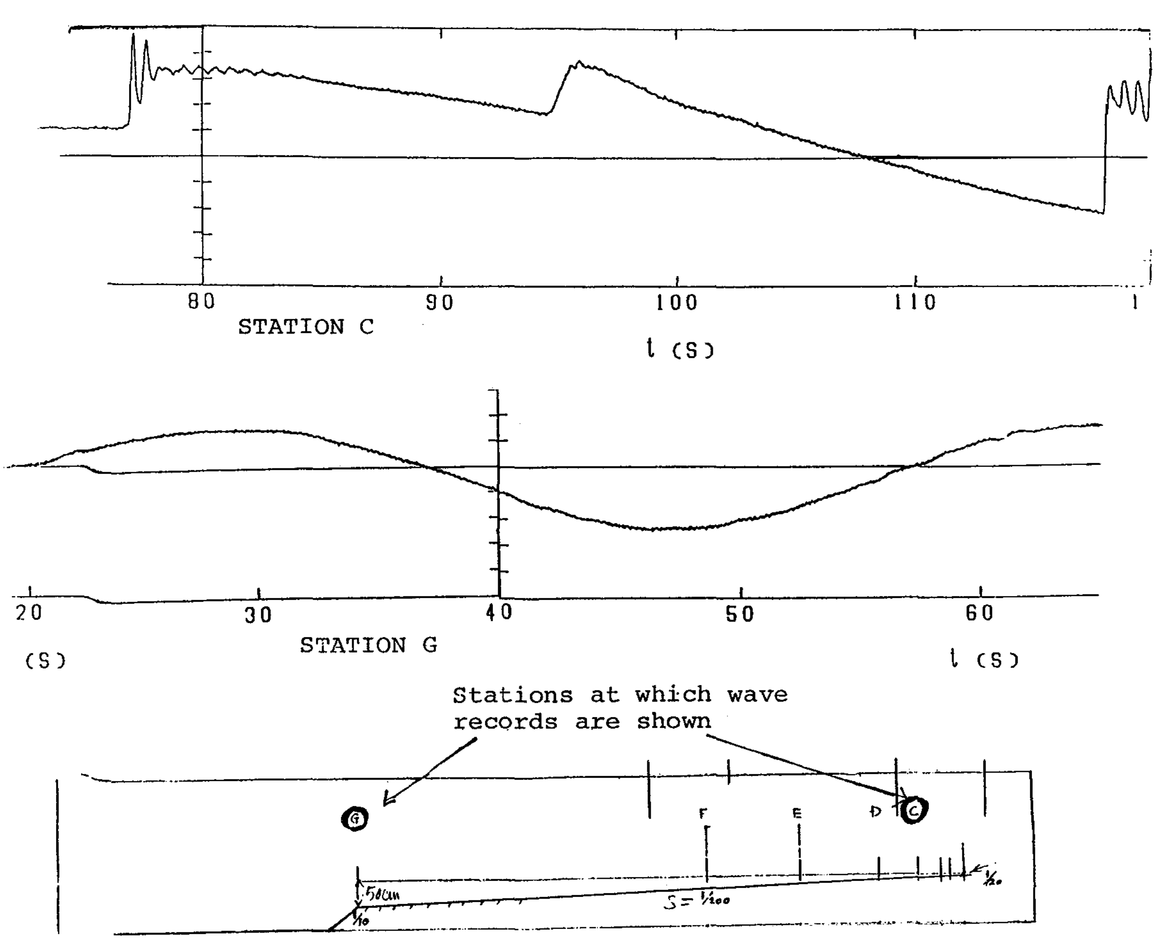

FIGURE 7 The experimental arrangement and a sample of the measurements at stations G (beginning of continental slope) and C (near shoreline). Source: Port and Harbour Research Institute, Ministry of Transportation.

T. Hatori. It should be noted that the Japan Sea remained disturbed by the tsunami for a period of about five hours, indicating multiple reflections of the wave. Wave trapping also occurred at some coastal sites. In particular, wave activity around Oki Island (see Figure 10) persisted for nearly 12 hours after the wave first arrived there, which was approximately 90 minutes after the earthquake occurred.

The extent of wave run-up along the Japan coast varied considerably with location. Figure 11 shows a bar graph of the run-up along the

FIGURE 8 Photographs of the bore crest propagating uniformly toward the shore north of the Oga Peninsula. Source: Akitakai Newspaper Publishing Company, 1983.

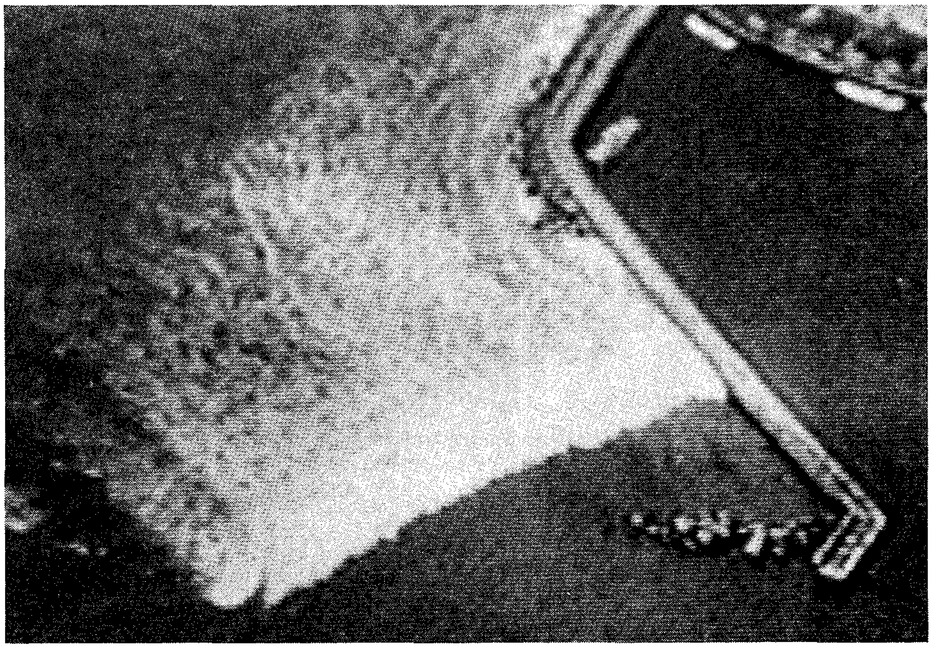

FIGURE 9A Edge bore sweeping along the riverbank at Oga City. Source: Asahi Newspaper Publishing Company, 1983.

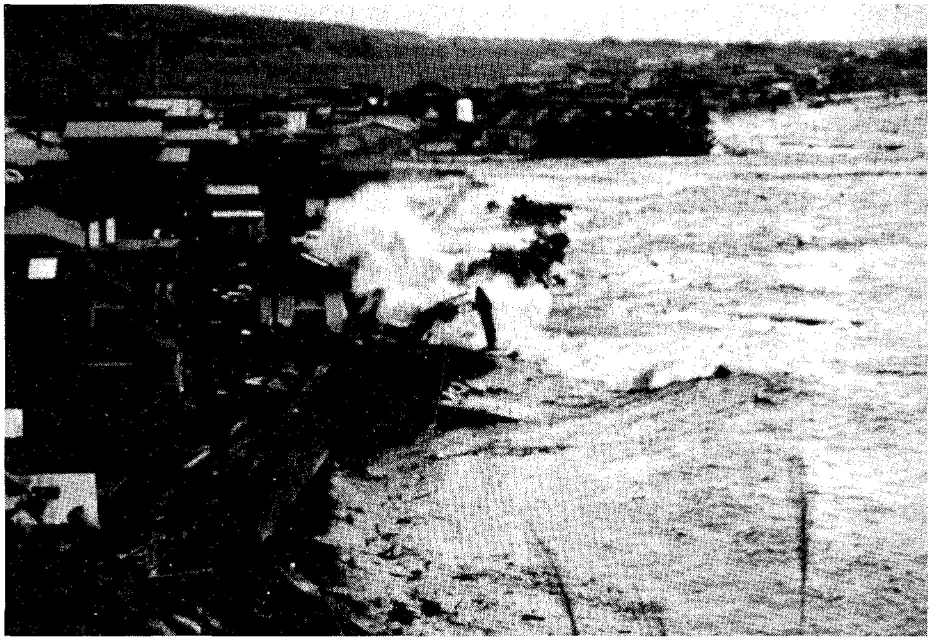

FIGURE 9B Edge bore along the coastline at Hachimori. Source: K. Yamanouchi.

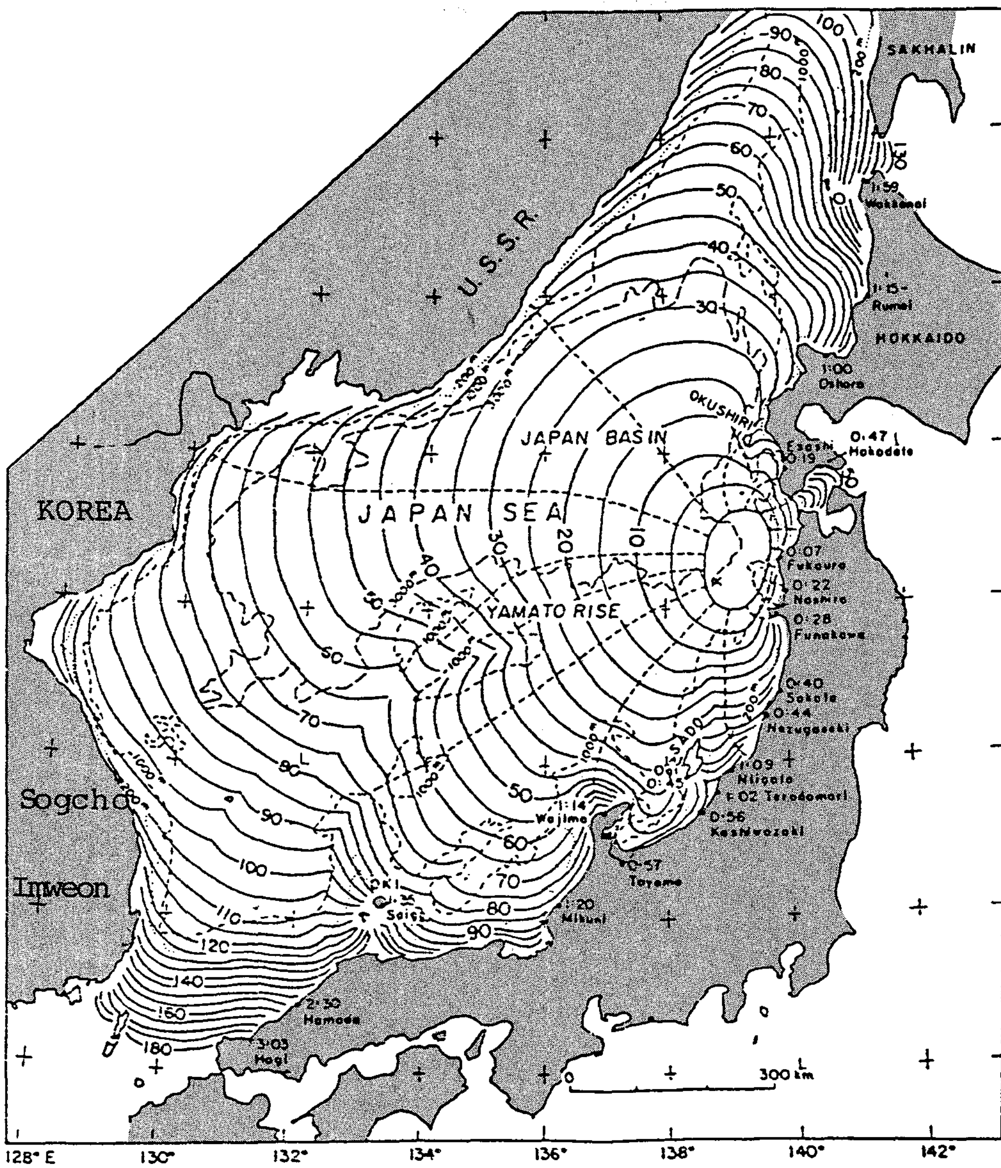

FIGURE 10 Refraction diagram for the May 26, 1983, tsunami.
Source: Japanese Tsunami Committee, 1983.

Japan coast and Sado Island. Clearly, most of the impact occurred north of the Oga Peninsula, where a maximum run-up of 14.9 m was recorded. More detailed results by Nobuo Shuto and his colleagues at Tohoku University demonstrated a significant reduction in run-up for areas protected by breakwaters. This effect is attributed to the presence of

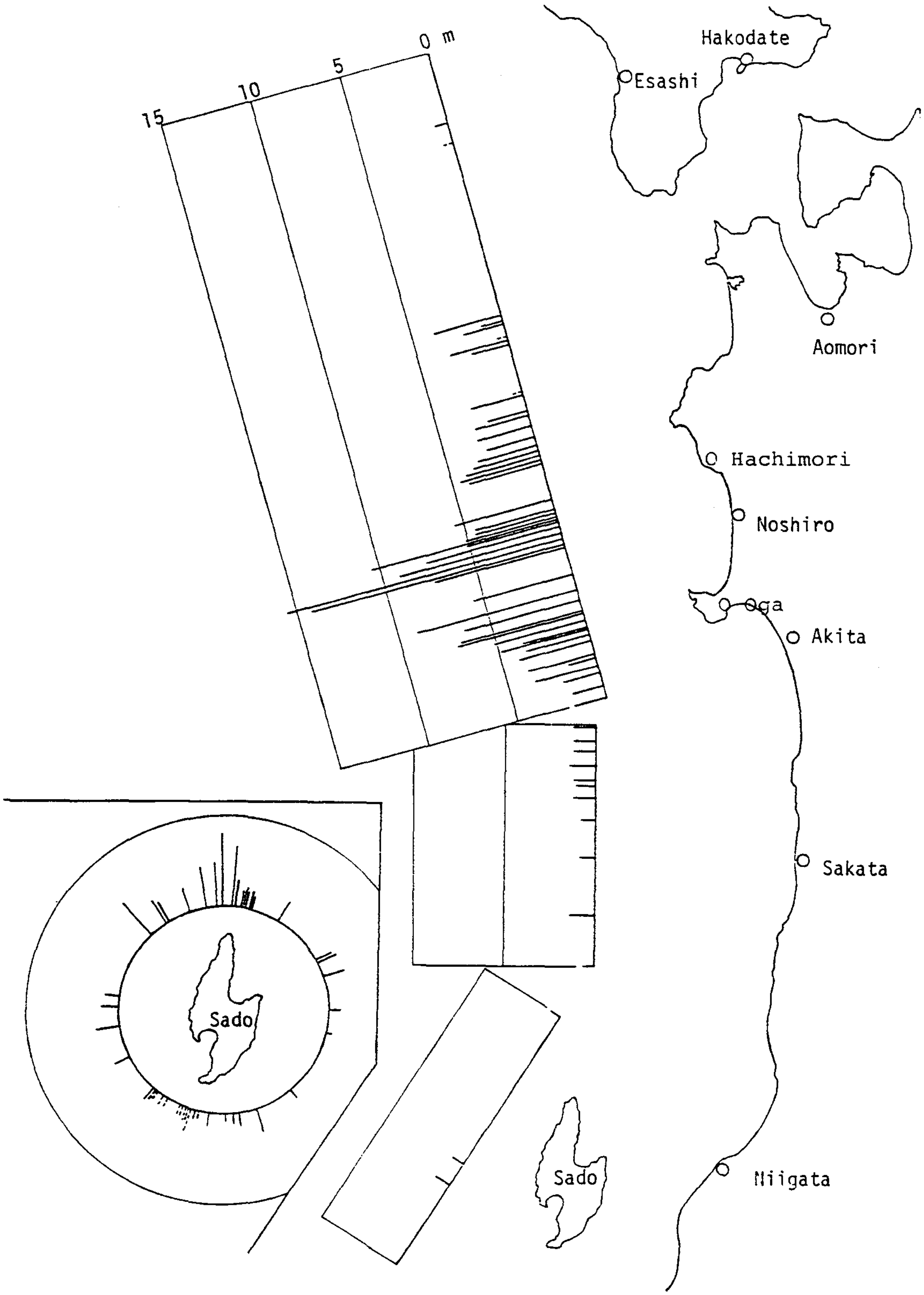

FIGURE 11 Run-up measurements along the Japan coast. Source: Shuto, 1983a.

the short-period 10-second waves that appear to have evolved on the main wave during propagation over the shelf. The breakwaters were designed for protection against storm waves and would have been totally ineffective for the tsunami's long-period waves had these short waves not evolved.

Significant wave run-up was also observed along the Korean coast. Figure 12 gives a visual recording of run-up and run-down elevations taken in the Port of Imweon by an observer from the Korea Maritime and Port Administration. A maximum run-up of 3.2 m was followed by a run-down of -5.6 m. Most of the impact of the tsunami in South Korea

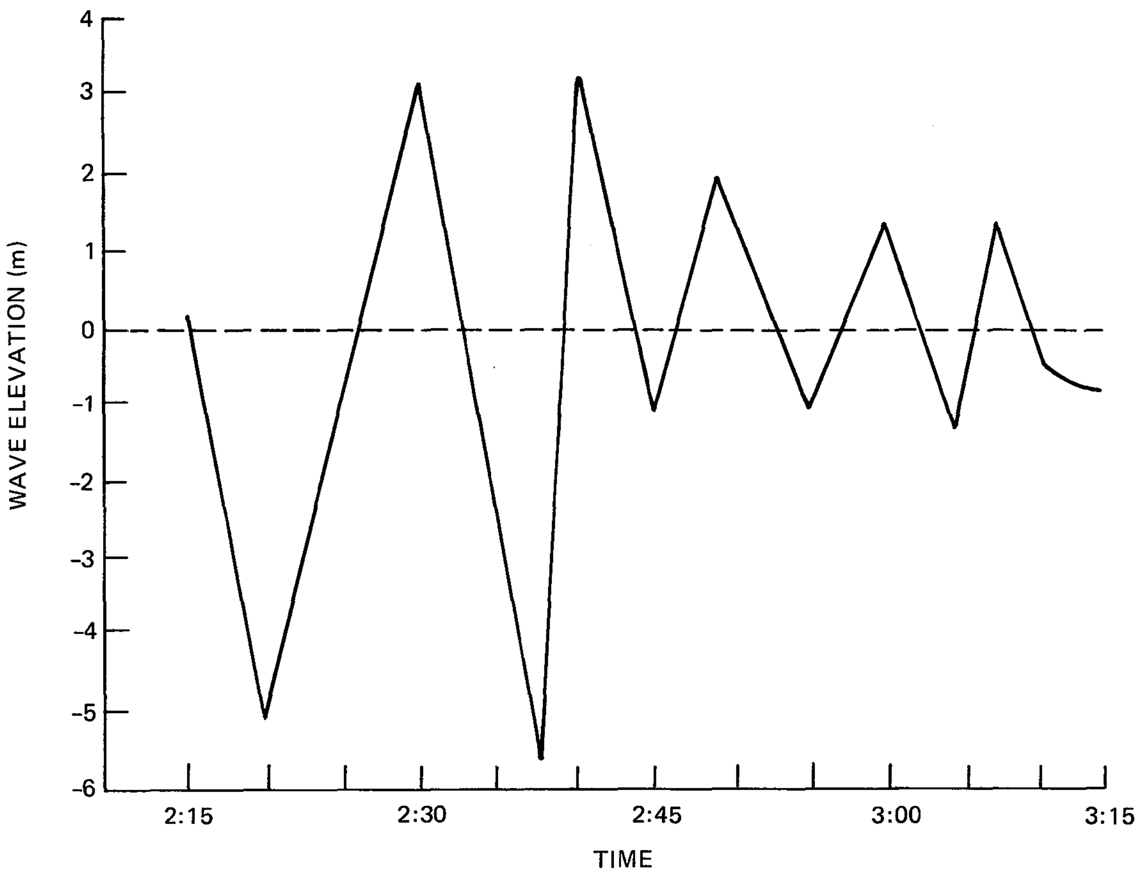

FIGURE 12 Visual observations of tsunami elevations at Imweon, South Korea. The run-ups were measured on the wall of a building; the run-downs were measured at the wall of a dock. Source: Korea Maritime and Port Administration.

occurred between Imweon and Sogcho (see Figure 10). The reason for the concentration of the impact in this area is not clear. It may be the result of the focusing of wave energy by refraction as the waves passed over the Yamato Rise.

There were many tide gauges in operation along the eastern coast of Japan that were available to record phenomena associated with the tsunami. However, due to the slow responses of the tide gauges, the slow chart speed of the recorders, and the relatively short wave period of 10 minutes, data from the tide gauges are not very reliable.

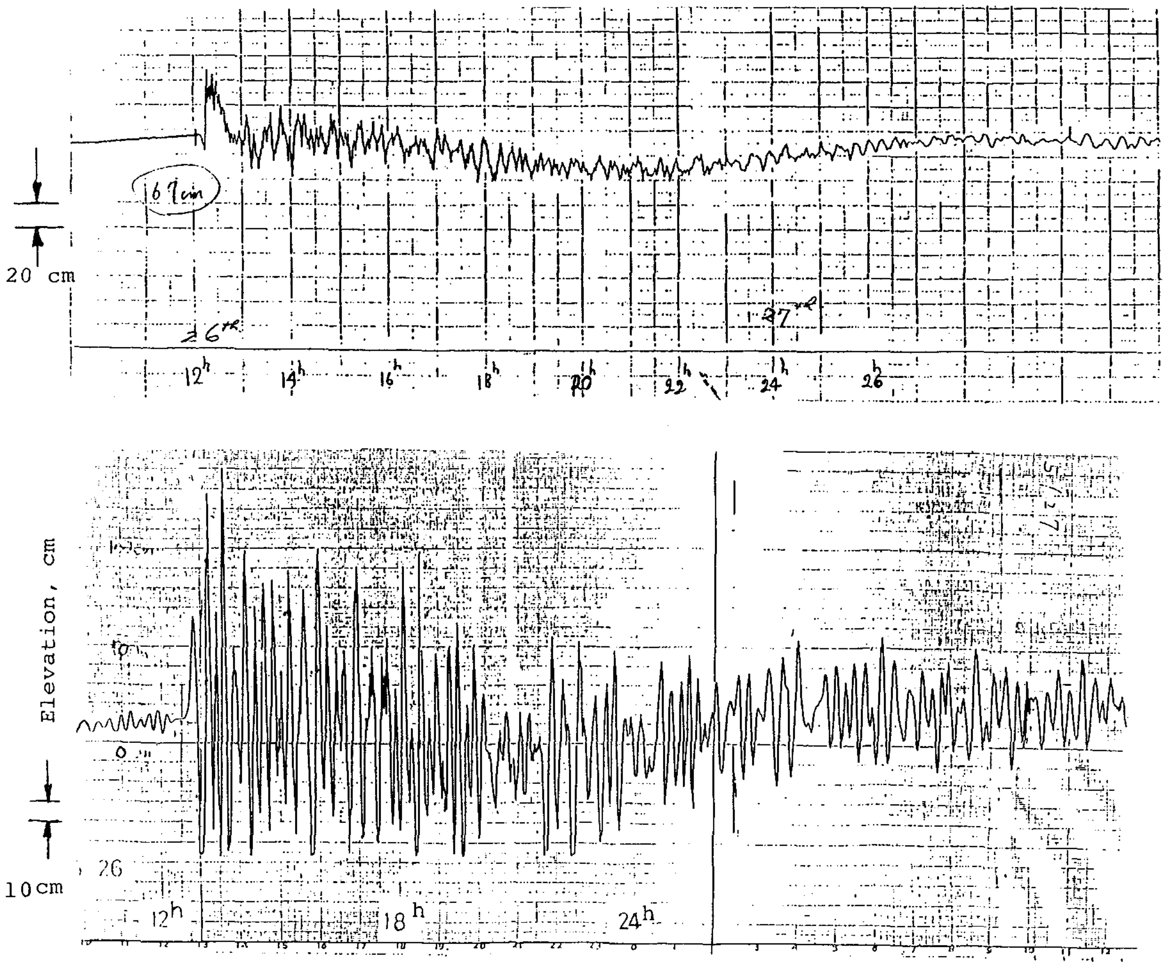

FIGURE 13 Tide gauge records. Top: Oga Aquarium. Bottom: Iwanai Harbor.

Nevertheless, for purposes of information two tide gauge records have been included (see Figure 13). The 10-minute wave period can be seen in the top chart of Figure 13. The bottom chart, however, indicates that there were approximately 20 waves within a six-hour interval, which implies periods of about 18 minutes. This longer wave period could be due to the effects of the harbor's response.

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COASTAL DAMAGE

The coastal damage produced by the tsunami can be grouped into three main classifications: (1) damage from flooding; (2) damage to and caused by floating structures and damage caused by floating debris; and (3) damage to protective structures.

DAMAGE FROM FLOODING

As the tsunami, which was generated in relatively deep water, approached the coast and entered shallow water, the wave amplitude increased and was then transformed, mostly into bores. These bores rushed up the beach and entered harbors and rivers. Even though many areas were flooded, damage to houses was minor because few structures were located in low coastal areas.

During the tsunami, 100 individuals were drowned, most of them at Noshiro, Hachimori, and the Oga Peninsula. These individuals were caught on the shoreline or on offshore construction sites. Tsunami warnings were issued approximately 14 minutes after the earthquake occurred; however, the leading wave reached the shoreline at these locations at approximately the same time.

In Korea, three deaths were attributed to the tsunami. Since the tsunami reached the Korean shoreline approximately 1-1/2 hours after the earthquake occurred, these deaths could have been prevented. A tsunami warning was issued by the Central Meteorological Office in Korea, providing ample time for proper evacuation. Part of the Korean people's response to the tsunami, however, is indicative of the general lack of understanding concerning the dangers of tsunamis. Figure 14 shows Korean spectators following and watching the receding tsunami as it spills from a dock. Minutes before the photograph in Figure 14 was taken, this area was flooded to the top level of the tetrapods resting on the dock. This action by the spectators reveals a lack of understanding of tsunami dangers, in general, and of the possibility of subsequent waves, in particular.

FLOATING STRUCTURES AND DEBRIS DAMAGE

As the tsunami approached the shoreline and entered shallow waters, it created high water levels and strong currents. These caused mooring lines to break and ships to capsize. Most damage to floating structures resulted when they were carried by the high water levels and strong currents toward land, where they collided with other fixed structures. During the tsunami, significant numbers of boats were damaged when they collided with piles. Sometimes, these piles were designed to keep boats out and let water flow through. This type of damage is illustrated in Figure 15.

In Korea, over 70 ships were damaged by the tsunami. The two photographs in Figure 16 graphically illustrate the destructive damage to boats and floating structures that can occur from the waves and currents produced by a tsunami. Figure 16A shows the tides rushing over a breakwater and inundating low-lying portions of a harbor. Figure 16B shows large ships being thrust onto and into the city. These ships received and caused significant damage during their movement. Experience from these localities suggests that damage from tsunamis could be significantly reduced if ships could be moved in time to deeper water, where both the waves and currents would be smaller.

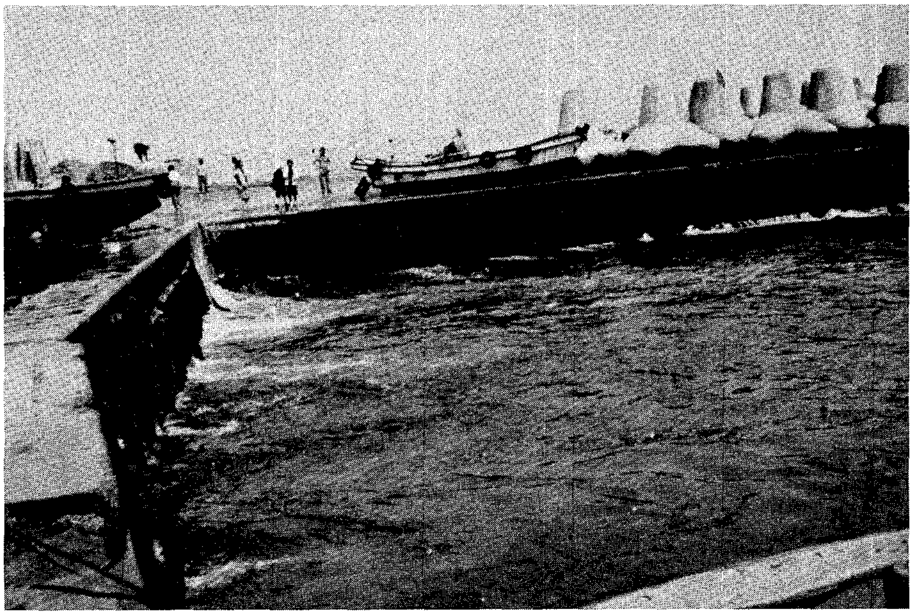

FIGURE 14 Sightseers observing tsunami action in Imweon, Korea. Source: Korea Maritime and Port Administration.

DAMAGE TO PROTECTIVE STRUCTURES

Many coastal flood protective structures were severely damaged during the tsunami. For example, concrete armor units weighing 4 metric tons were moved hundreds of feet inland near the area of maximum run-up (see Figure 17). In addition, many levees and seawalls were overtopped and damaged. These protective structures were designed for storm waves and were unable to accommodate the waves produced by the tsunami. However, the nature of the damage observed could be useful in improving the future design of protective structures for tsunamis.

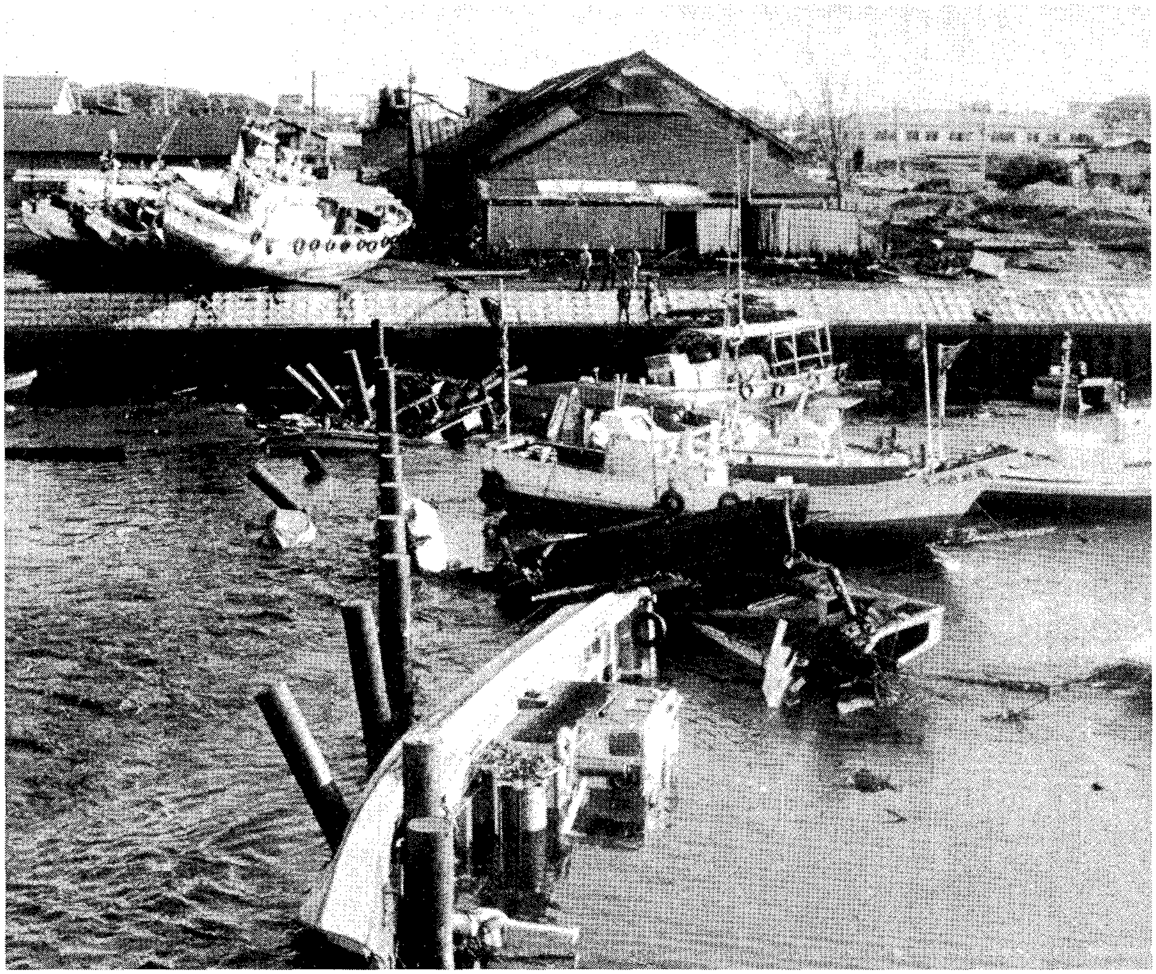

FIGURE 15 Damage in Noshiro, Japan. Note the large ship lodged on the pile. Source: Akitakai Newspaper Publishing Company, 1983.

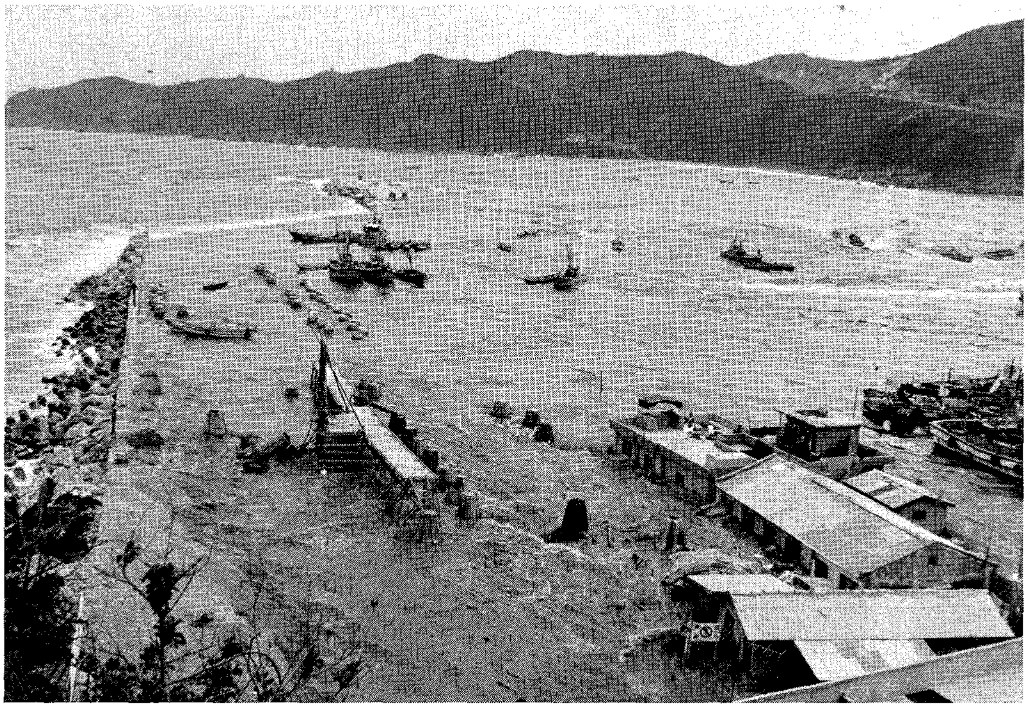

FIGURE 16A Coastal inundation in Imweon, Korea. Source: Korea Maritime and Port Administration.

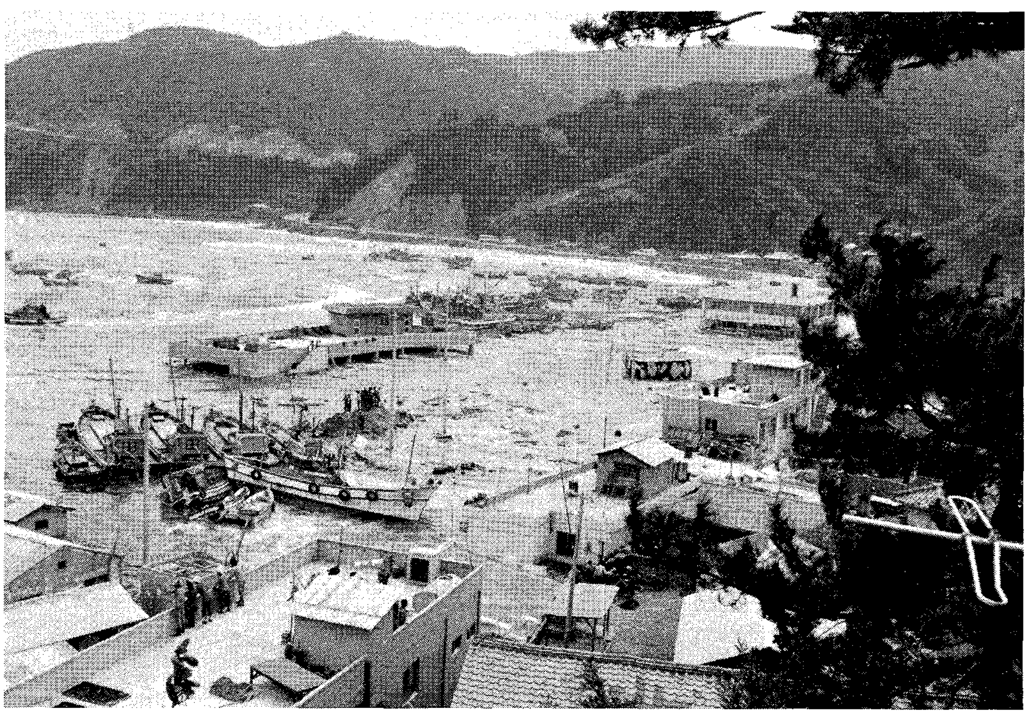

FIGURE 16B Damage to floating structures in Imweon, Korea. Source: Korea Maritime and Port Administration.

FIGURE 17 Protective concrete units weighing 4 metric tons were scattered by the tsunami at Mizusawa Beach near Minehama Village in Akita Prefecture. Source: Akitakai Newspaper Publishing Company, 1983.

5

SUMMARY AND RECOMMENDATIONS

In the past few years, significant advances have been made in tsunami research (Hwang and Lee, 1979). There is considerably greater understanding now of wave generation, transoceanic propagation, and coastal transformation than there was just a few years ago. Many computer models have been developed to calculate wave transformation in specific coastal environments. However, most of this progress has been limited to incoming waves from large and distant sources. Waves of intermediate size generated locally, such as the Japan Sea central region tsunami, have received only limited attention. The occurrence of the May 26, 1983, tsunami provided new information for scientists and engineers working to understand the tsunami phenomenon and created new challenges in finding ways to reduce tsunami damage.

Based on this reconnaissance study, there are a number of areas in which further research is needed to help solve engineering and social problems.

TSUNAMI THEORIES

There are four main aspects of the May 26, 1983, tsunami that appear to warrant further investigation. First, current theories of tsunami generation predict that a tsunami for this earthquake should have consisted of a single wave with an amplitude of about 1 m and a period of 10 minutes. This prediction is consistent with the observed height and length of the first wave of the tsunami. However, there were three to four main waves in the tsunami with periods of about 10 minutes.

Since the ground motion is related to the response time of the overlying waters, and since the distance from the source of the tsunami to the shore was less than one wavelength, it is not clear how several waves with 10-minute periods could have been generated.

Second, the evolution of short-period waves on the long main wave is both surprising and fortunate. It is surprising because the appearance of these waves would not have been predicted based on previous experience. It is fortunate because without the appearance of these waves the energy contained in them would not have been dissipated by early breaking, and damage would have been more severe.

Third, the conditions under which bores begin to form and migrate across the entire wave crest deserve further study. Fourth, the propagation of "edge" bores also deserves more study.

COASTAL PROTECTION

Coastal protection structures designed for storm waves can provide some protection against tsunamis when short-period waves evolve. But aside from extensive seawalls or "set-back" lines for coastal development, there appears to be little that can be done to avoid coastal flooding by waves with periods of 10 minutes or more.

It should be emphasized that most of the damage from this tsunami was caused by floating structures colliding with other structures. In areas with ample tsunami warning, a management scheme for the orderly removal of ships and floating structures to offshore areas would be very useful. There were many sites in Japan and Korea that would have benefited from such efforts during this tsunami.

WARNING AND PUBLIC EDUCATION

The tsunami warning service of the Japan Meteorological Agency functioned properly by issuing a warning from Tokyo within 14 minutes of the earthquake. However, the nearness of the source of the tsunami to the Japan coast negated the utility of this warning in many localities. In other areas local agencies failed to broadcast the warning promptly. In still other areas people responded to the warning by rushing to the shore to see the wave.

Figure 14 shows docks in Korea lined with people during the tsunami inflow. Apparently, to people who do not respect the danger of tsunamis, a warning can be an enticement to travel to the endangered area.

A similar lack of public education is revealed by the fact that most of the 100 people killed by the tsunami could have been saved had they left the coastal area immediately after the earthquake occurred. Effective warnings must be coupled with more public education about the dangers of tsunamis.

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