ANALYSIS OF SHIP BEHAVIOR IN TSUNAMI USING AIS DATA

Shigeaki Shiotani[1], Hidenari Makino[2] and Daisuke Terada[3]

[1]Organization of Advanced Science and Technology, Kobe University, shiotani@maritime.kobe-u.ac.jp
[2]Graduate School of Maritime Sciences Kobe University, makino@port.kobe-u.ac.jp
[3]National Research Institute of Fisheries Engineering., dterada@fra.affrc.go.jp

This research investigated the evacuation behaviors of the vessels using the data obtained from AIS, around the Onahama Port during the major tsunami warning announcement. The result shows that most vessels in the port started evacuating approximately 10 min after the major tsunami warning announcement and completed offshore evacuation 40 min after the announcement. This contributed in understanding the actual status of the vessel evacuation. In addition, the travel paths of each vessel revealed the influence of the tsunami on the vessels. Furthermore, the exceptional situation where several vessels moved in the same direction at the speed almost same for about 2 hours was confirmed. As a result, it can be estimated that the waves that affected both vessels were the drawback of the tsunamis

Key Words : *Ship evacuation, AIS, Tsunami, Ship behavior*

1. INTRODUCTION

The direction and velocity of vessels at sea change depending on external forces including wind waves, surges, and tides. The pre-eminent effect of these forces can result in disasters such as shipwrecks and collisions at coastal areas, according to Japan Coast Guard (2007). In particular, the submarine topography of the coastal areas of Japan, where earthquakes and tsunamis frequently occur, transforms tsunamis entering the bay from the ocean into large waves. This results in environmental destruction and enormous damage of vessels underway or at anchor, according to Y. Kugou (2011). A gigantic earthquake occurred in the Tohoku and Kanto areas on March 11, 2011 and is considered an event that occurs once in 1,000 years. Subsequently, the major tsunami warning and tsunami warning or advisory were announced to all coastal areas along the Pacific Ocean. This study investigated the evacuation activities of the vessels at the Onahama Port in Iwaki-city, Fukushima Prefecture, where major tsunami warnings were announced. The result shows behaviors unique to urgent evacuation situations. In addition, this study draws an inference on the local conditions of tsunamis by analyzing the evacuation status of the vessels.

2. STATUS OF THE TSUNAMI CAUSED BY THE GREAT EAST JAPAN EARTHQUAKE

The epicenter of the 9.0-magnitude earthquake on March 11, 2011 at 2:46 pm was off the Sanriku Coast. Accordingly, the coastal areas along the Pacific Ocean, especially the Hokkaido and Tohoku regions, experienced different sizes of tsunamis. At some locations, the tsunami reached a height of greater than 10 m as reported by T. Nagai (2011). The coastal regions along the Pacific Ocean in Iwate, Miyagi, and Fukushima Prefectures received the major tsunami warning at 2:49 pm, 3 min after the earthquake. In addition, all coastal areas along the Pacific Ocean received the major tsunami warning followed by the tsunami warning or advisory, 44 min after the earthquake as reported by Japan Meteorological Agency (2011).

The area around the Onahama Port, the survey area of this study, is located in Iwaki-city, Fukushima Prefecture. The port received the major tsunami warning at 2:49 pm, only 3 min after the earthquake. The first tsunami with height 1.0 m reached offshore Onahama at 2:52 pm. The largest tsunami with height 3.3 m was recorded at 3:39 pm as reported by Japan Meteorological Agency (2011). **Fig. 1** shows the tsunami observation results recorded at the Onahama observation point issued by the Japan Meteorological Agency. The Onahama observation point is located in the port.

Fig. 2 depicts the tsunami observation results obtained by the Port and Airport Research Institute using a GPS wave gauge. The device is located 1 miles off Onahama. The data also show the largest tsunami with height 2.6 m reaching offshore Onahama at 3:15 pm.

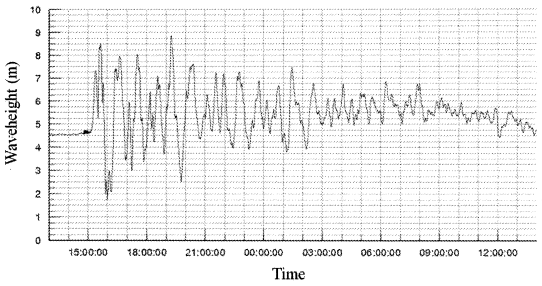


Fig.1 Tsunami Observation Data (Japan Meteorological Agency).

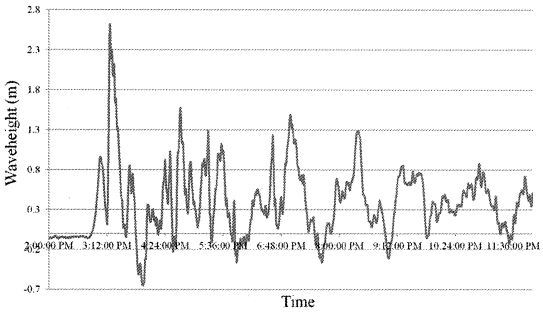


Fig.2 Tsunami Observation Data obtained from the GPS Wave Recorders (Port and Airport Research Institute)

3. ANALYSIS ON THE EVACUATION CONDITIONS OF VESSELS USING THE AIS DATA

Vessels are usually undocked and evacuated outside the port upon the arrival of tsunamis because anchoring inside the port is extremely dangerous. This study analyzes the movements of each vessel in the Onahama Port area, which received the major tsunami warning, by using the data obtained from the Automatic Identification System (AIS).

AIS is a type of automatic dependent surveillance-broadcast technology that provides useful information such as names of the vessels and call signs for distinguishing ships as well as locations, velocity, and directions of the vessels, as referred to at the literature of International Maritime Organization (2003) or others. The device automatically transmits information pertaining to destinations and loadings to the neighboring vessels. IMO (International Maritime Organization) mandates sequential loadings for target vessels (passenger ships and ships with a total of more than 300 tons for international voyages and vessels with a total of more than 500 tons for non-international voyages). The data received by AIS is broadly classified into static data (such as names of the vessels and the call signs), dynamic data (such as the current locations, navigation speed, and directions), and the voyage related data (such as the draft and destinations). **Table 1** shows the data contents of AIS. On the basis of the data, we depicted the conditions with the frequent changes in the motion of the vessels equipped with AIS. In addition, we selected the vessels that were evacuated because of the tsunami and analyzed the distribution of the areas and the distance to which they were evacuated.

Table 1 Contents of AIS data.

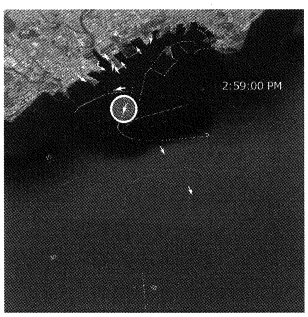
Kind	Contents
Static data	IMO number, call sign & name, length and beam, type of ship, location of antenna,
Dynamic data	Position, time in UTC(Universal Time, Coordinated), COG(course over ground), SOG(speed over ground), heading, navigation status(manual input), rate of turn(if available), angel of heel(optional, if available), pitch and roll(optional, if available)
Voyage related data	Draught, hazardous cargo type, destination and ETA, route plan(optional)

4. ANALYSIS RESULTS

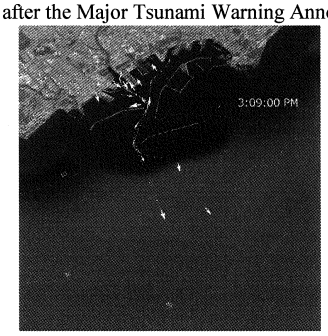
Fig. 3 shows an example that depicts the status of emergency evacuation of each vessel on the basis of the AIS data obtained from the Onahama Port areas. Each white arrow in the figure indicates a vessel. The broken white lines show the paths of the vessels during a 30-min period. The solid white lines indicate the contour lines. **Fig. 3(a)** shows the conditions around the port at 2:59 pm, 10 min after the major tsunami warning, and indicates that each vessel had started preparing for evacuation. The tanker white circled in the figure entered the port just before the announcement of the major tsunami warning. Upon the announcement, it hastily turned around and prepared for evacuation from the port. The figure also shows several vessels that were preparing for evacuation. **Fig. 3(b)** depicts the

condition at 3:09 pm, 20 min after the announcement. We confirmed that most vessels in the port were prepared for evacuation, while several ships had already moved out of the port. The tugboats (indicated by the small arrow) in the port were prepared and had already started evacuating 20 min after the major tsunami warning announcement. **Fig. 3(c)** shows the condition of the port at 3:19 pm, 30 min after the major tsunami warning announcement. It indicates that the cargo ships and tankers that can independently leave the port initiated emergency evacuation. The vessel white circled in the figure evacuated the port via a different route than usual, suggesting the state of emergency of this event. **Fig. 3(d)** depicts the condition of the vessels around the port at 3:29 pm, 40 min after the major tsunami warning announcement. At this point, most vessels that left the port had already evacuated to approximately 4.5 miles (approximately 7.2 km) off the coast, which is indicated by the white circle, an area with water depth of 40–50 m. As explained in Chapter 2, this was an extreme state of emergency and the first wave of tsunami (height of 1.0 m) arrived 3 min after the major tsunami warning announcement. Even in this dire situation, the vessels took a prompt and appropriate action after the announcement, leaving the port within 30 min and completing the evacuation in about 40 min.

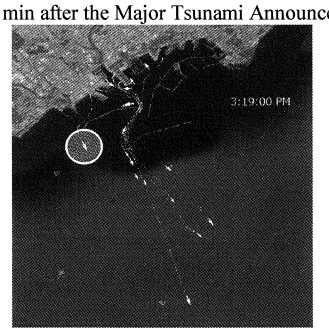
However, we confirmed that some vessels went aground owing to the major tsunami. **Fig. 4** indicates a part of the travel paths of these vessels. The arrows in the figure show the direction of the bow and the broken lines show the travel paths. This vessel started evacuating at 3:39 pm and left the coast in about 5 min. However, the wave with height 3.3 m, the largest tsunami, had already reached the Onahama Port; this probably made it very difficult to control the vessel. **Fig. 5** is a graph comparing the velocity of this vessel upon leaving the Onahama Port with that of the vessel that completed evacuation. The vertical grey lines in the figure indicate the velocity of both vessels at point A. Most vessels that completed evacuation passed point A at a speed of approximately 10 kt, whereas the ship that went aground traveled through point A at a speed of 16.5 kt. This is an unusual speed for traveling inside the port and an uncommon measure even for a pressing need to evacuate the port. The effects of the tsunami can be considered the reason for such high vessel speed. The highest wave was on its way to the Onahama Port at 3:39 pm, and it is appropriate to speculate that the drawback of the tsunami had an impact on the increase in velocity. This sudden increase in velocity made it difficult to control the vessel and resulted in opting for a different course than the normal departing route. A vessel normally travels on the right side facing the breakwaters. Instead, this particular vessel traveled along the breakwaters. It is unclear whether the vessel intentionally chose to assume a different



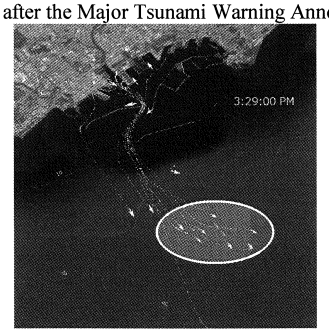
(a) 10 min after the Major Tsunami Warning Announcement



(b) 20 min after the Major Tsunami Announcement



(c) 30 min after the Major Tsunami Warning Announcement



(d) 40 min after the Major Tsunami Warning Announcement

Fig.3 Evacuation Status of Vessels after the Major Tsunami Warning Announcement

direction than usual or whether it became impossible to control. Subsequently, this vessel completely lost control and became adrift because of the approaching tsunami and drawback waves. The travel paths in **Fig. 4** clearly indicate this condition.

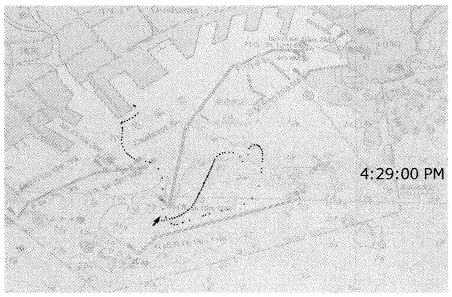


Fig.4 Travel Paths of Vessels Aground

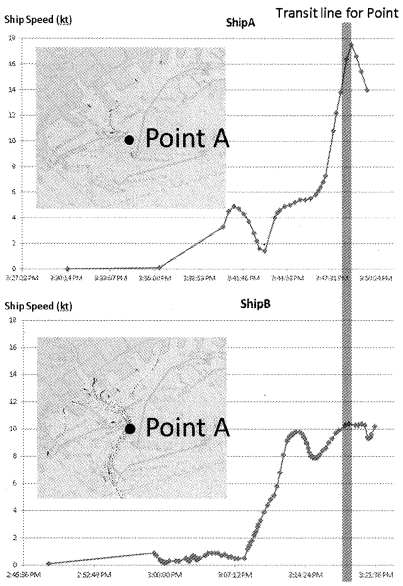


Fig.5 Velocity Comparison between Vessel Aground and Vessels Evacuated

5. TSUNAMI ESTIMATION BASED ON THE STATUS OF VESSEL EVACUATION

As discussed in Chapter 4, at 3:29 pm, 40 min after the major tsunami warning announcement, the vessels that safely left the port evacuated to approximately 4.5 miles (approximately 7.2 km) off the Onahama Port, an area with a 40–50 m water depth level. The AIS analysis confirms that these vessels also became adrift owing to the effects of the tsunami. The most significant finding is that several vessels simultaneously took identical travel routes despite the difference in their sizes and bow directions. This implies that an extraordinarily powerful external force, i.e., the major tsunami, was acting at the same location, causing such a phenomenon. Using the AIS data analysis, the following section attempts to elucidate the major tsunamis, which are difficult to examine. **Fig. 6** shows the condition of the Onahama Port area at 4:49 pm, 2 hour after the major tsunami warning announcement and more than 1 hour after each vessel had started preparing for evacuation. The figure also indicates the aforementioned example of several vessels drifting toward the same direction. The lower chart of **Fig. 6** enlarges the black dots circle area in the upper chart. Ship A and Ship B are different types of vessels and one is approximately twice as long as the other in length. Both vessels exhibited different whirling movements prior to becoming adrift. However, they suddenly started drifting and took the same travel path at 4:23 pm. At this time, the distance between the two vessels was 0.95 miles (approximately 1.5 km), and they maintained the same distance and continued drifting in the same travel path for 2 hour. **Fig. 7** shows the travel path. It is evident that both vessels moved offshore with time. The AIS data indicate that the average speeds for Ship A and Ship B are 0.96 kt and 0.97 kt, respectively. In addition, the average course over ground are 114.9° and 115.3° for Ship A and Ship B, respectively. As a result, it can be estimated that the waves that affected both vessels were the undertow of the tsunamis with an average speed of 0.97 kt and a course over ground of 115.1°. Other regions and time zones also experienced this rare phenomenon in which several vessels became adrift, while assuming the same travel path. It is expected that the analysis of this phenomenon will help in understanding the situation of this tsunami.

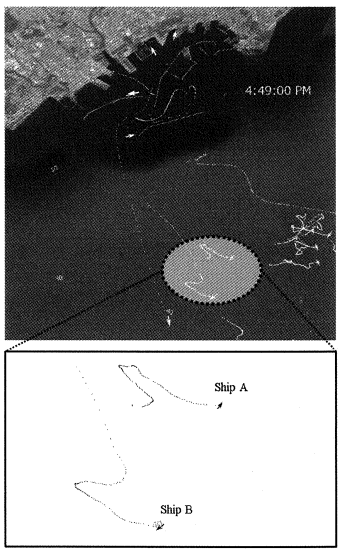


Fig.6 Drifting Status of Vessels Evacuated

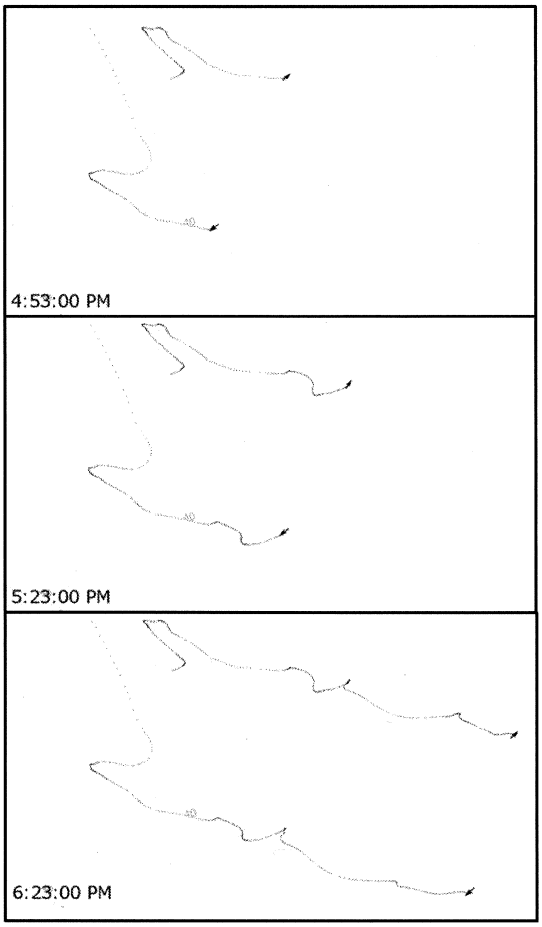


Fig.7 Travel Paths of Ship A and Ship B

6. CONCLUSION

Using the data obtained from AIS, this study investigated the evacuation behaviors of the vessels equipped with AIS around the Onahama Port during the major tsunami warning announcement. The result shows that most vessels in the port started evacuating approximately 10 min after the major tsunami warning announcement and completed offshore evacuation 40 min after the announcement. This contributed in understanding the actual status of the vessel evacuation. In addition, the travel paths of each vessel revealed the influence of the tsunami on the vessels. It is considered that analysis of such phenomena could enable forecasting the direction of tsunami diffusion.

Based on the results obtained in this study, our future study will conduct further analysis for preparing a manual that provides appropriate evacuation instructions during a tsunami. The analysis will provide more comprehensive perspectives including evacuation behaviors of all vessels.

ACKNOWLEDGMENT: We express our deepest gratitude to all those who gave us valuable data during this research. We are especially indebted to AIS live Japan.

REFERENCES

International Maritime Organization (2003): Guidelines for The Installation of A Shipborne Automatic Identification System (AIS), http://www.imo.org/OurWork/Safety/Navigation/Documents/227.pdf

Japan Coast Guard (2007): The Occurrence of Disasters and Accidents Causing Injury or Death at Sea and Rescue Status, pp.16-19.

Japan Meteorological Agency (2011): Tsunami Information, http://www.jma.go.jp/jp/tsunami/.

T. Nagai (2011): The History and Current Status of Tsunami Observation by the NOWPHAS and Tsunami Wave Formation Related to the Great East Japan Earthquake in 2011 Captured by the NOWPHAS, *Lecture Document Collection of Review Meeting on the Great East Japan Earthquake*, pp. 9-17.

Y. Kugou (2011): Disaster Conditions in the Pilot Areas in the Tohoku Region, *Lecture Document Collection of Review Meeting on the Great East Japan Earthquake*, pp. 49-56.

(Received June 24, 2011)