Analysing Subject Ship Behaviour Recorded by AIS to Extract Tsunami Effect - In Case of The 2011 Tohoku Earthquake and Tsunami -

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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 [1]. 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 [2]. 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. The author has done the investigation and research on a refuge situation of the vessel at the time of this Tsunami [3]. This study investigated the evacuation activities of the vessels at the Onahama Port in Iwaki-city, Fukushima Prefecture. 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 [4]. The coastal regions along the Pacific Ocean in Iwate, Miyagi, and Fukushima Prefectures received the major tsunami warning at 2:49 pm, 3 minutes 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 minutes after the earthquake as reported by Japan Meteorological Agency [5].

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 minutes 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. Figure 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.

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

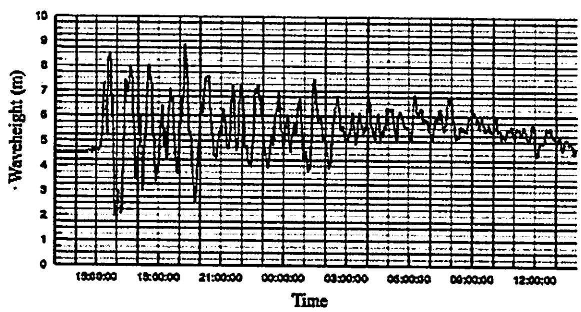

Fig. 1 Tsunami Observation Data from JMA

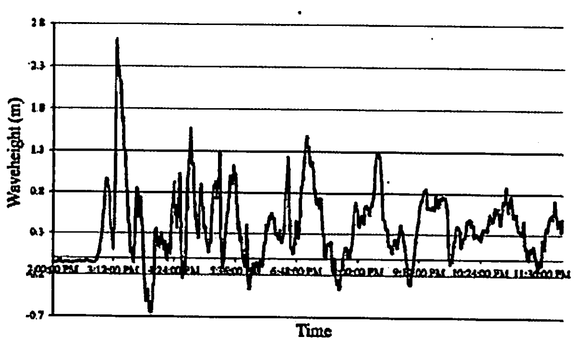

Fig.2 Tsunami Observation Data obtained from GPS Wave Recorders (Port and Airport Research Institute)

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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) [6] 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

At 3:29 pm, 40 minutes 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. Figure 3 shows the condition of the Onahama Port area at 4:49 pm, 2 hours after the major tsunami warning announcement and more than 1 hour after each vessel had started preparing for evacuation. In this figure, each arrow indicates a vessel (red: Cargo, green: Tug, blue: Tanker). The broken white lines show the paths of the vessels during a 60 min period. The solid white lines indicate the contour lines of sea depth. The figure also indicates the aforementioned example of several vessels drifting toward the same direction. The lower chart of Fig. 3 enlarges the red dots circle area in the upper chart. Subject ship A and subject ship B are different types of vessels and one is approximately twice as long as the other in length. The details of each vessel are shown in Table 2. 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 hours. Figure 4 shows the travel path. It is evident that both vessels moved offshore with time.

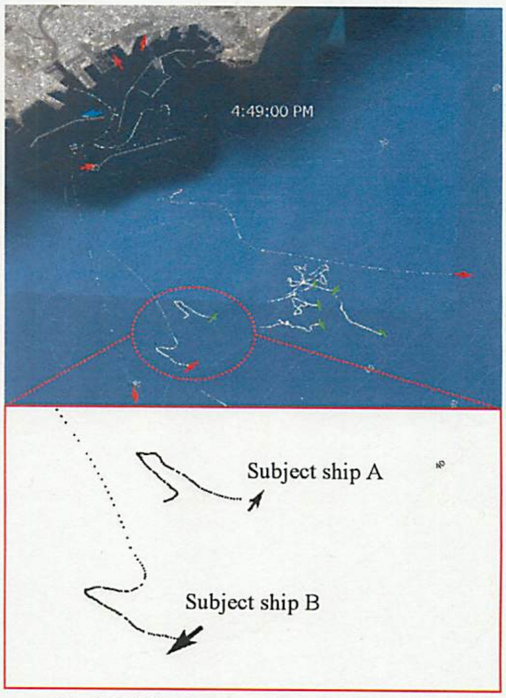

Fig.3 Drifting Status of Vessels Evacuated

Table 2 Principal particulars of subject ship A and subject ship B.

Item	Subject ship A	Subject ship B
Type of ship	Tug	Cargo
LOA (m)	34	83
Beam (m)	12	13
Draft (m)	4.9	4.6
DWT (ton)	319	1127
GT (ton)	492	1597

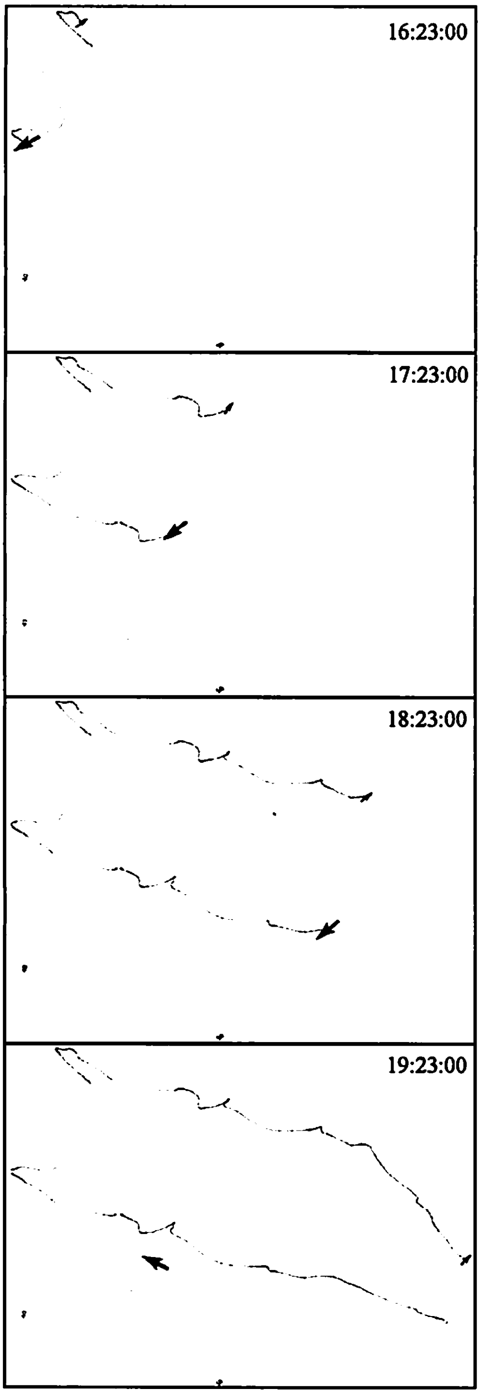

Fig.4 Travel Paths of subject ship A and subject ship B

The AIS data of both subject ship A and subject ship B were synchronized with the wave-height variation data considering a time step of 10 seconds. The results of the time-based synchronized data are shown in Fig. 5. Observing the variation of both ships speed with respect to time between 4:23 pm and 7:13pm, it can be said that they have a very similar variation pattern. The average speeds during that period of time for subject ship A and subject ship B are 0.96 kt and 0.97 kt, respectively. The wave height variation shows ten variation pick points which are simultaneously followed by ten speeds' variation pick points respectively for subject ship A and subject ship B. In addition, both ships seems to be drifting sidelong in opposite directions, as shown in Fig.4, with average drift angle values of -66.08° and 107.29° respectively for subject ship A and subject ship B.

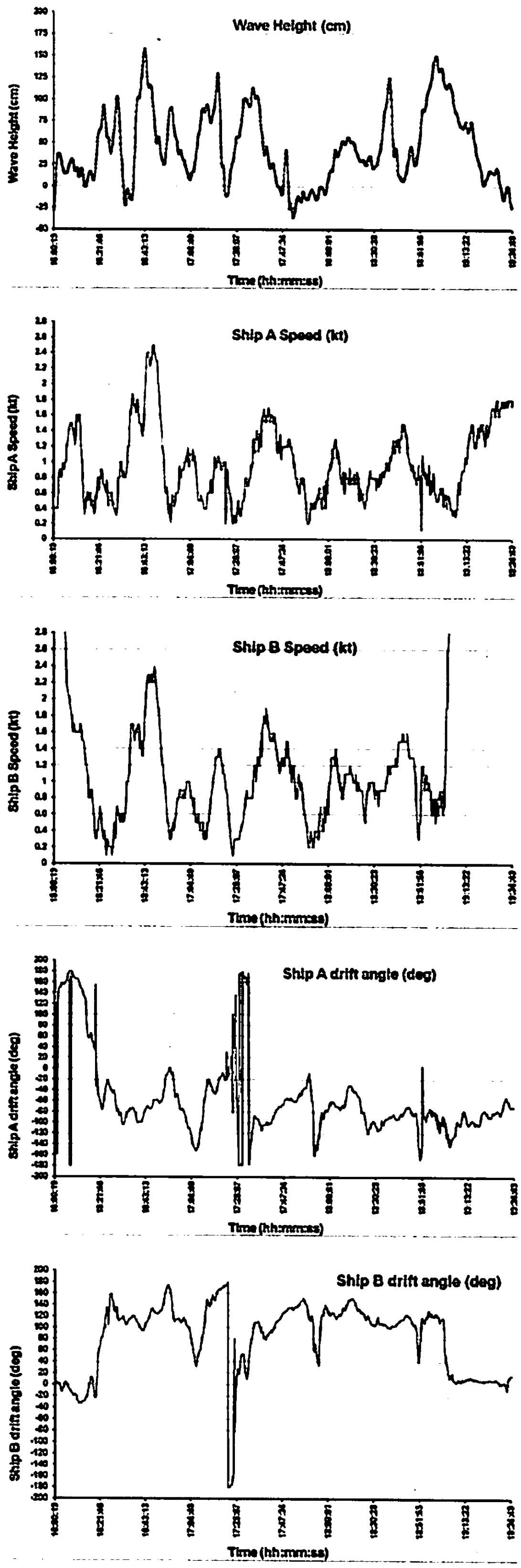

Fig.5 Time-synchronized AIS data for subject ship A and subject ship B with the wave height variation

As a result, it can be estimated that the waves that affected both vessels were the undertow of the tsunamis. Both vessels are drifting with same velocities and with opposite drift angles although they have different principal particulars. Therefore the two ships are behaving as floating objects under high energy incident tsunami waves. The drifting velocity seems to be also closely related to the wave height variation. 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.

5. 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 minutes after the major tsunami warning announcement and completed offshore evacuation 40 minutes 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.

It can be also concluded from this study that AIS is a very useful tool for analysing tsunami behaviours. In addition, it may help to assure the accuracy of tsunami simulation, which couldn't not be validated it yet by previous researches. AIS can be also useful for other kind of usage in the future, such as analysing ship accidents.

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.

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