

ANALYSIS OF SHIP EVACUATION IN TSUNAMI USING AIS DATA

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ABSTRACT: This research investigated the evacuation behaviors of the vessels using the data obtained from AIS, during the major tsunami warning announcement. The result shows that most vessels in the port started evacuating approximately 30 min after the major tsunami warning announcement and completed evacuation 120 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.

Key Words: Great East Japan earthquake, Tsunami, AIS, Ship evacuation

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. 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 actions of the vessels at the Tokyo bay where major tsunami warnings were announced. The result shows behaviors unique to emergency evacuation situations. In addition, this study draws an inference on the local conditions of tsunamis by analyzing the evacuation status of the vessels.

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). Fig.1 shows a tsunami warning figure which JMA announced at 4:13 pm on March 11, 2011. In this figure, red lines indicate the major tsunami warning. This figure shows that major tsunami warning was issued almost all the area of the Pacific coast in Japan. About the tsunami in Tokyo Bay, the first wave was observed at the Yokohama observatory at 16:09. The wave height at this time was +0.8m. Moreover, the maximum wave was observed at 17:37. The wave height at this time was +1.5m.

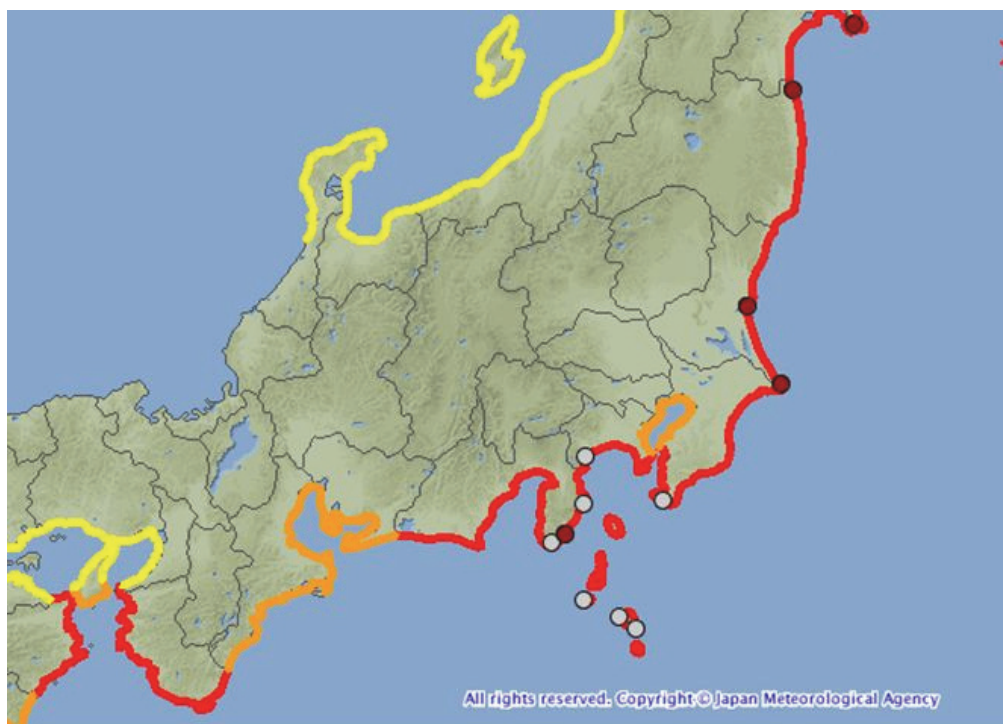


Fig. 1 Tsunami warning figure which JMA announced at 4:13 pm on March 11, 2011.

ANALYSIS OF SHIP EVACUATION USING 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 Tokyo bay, 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.

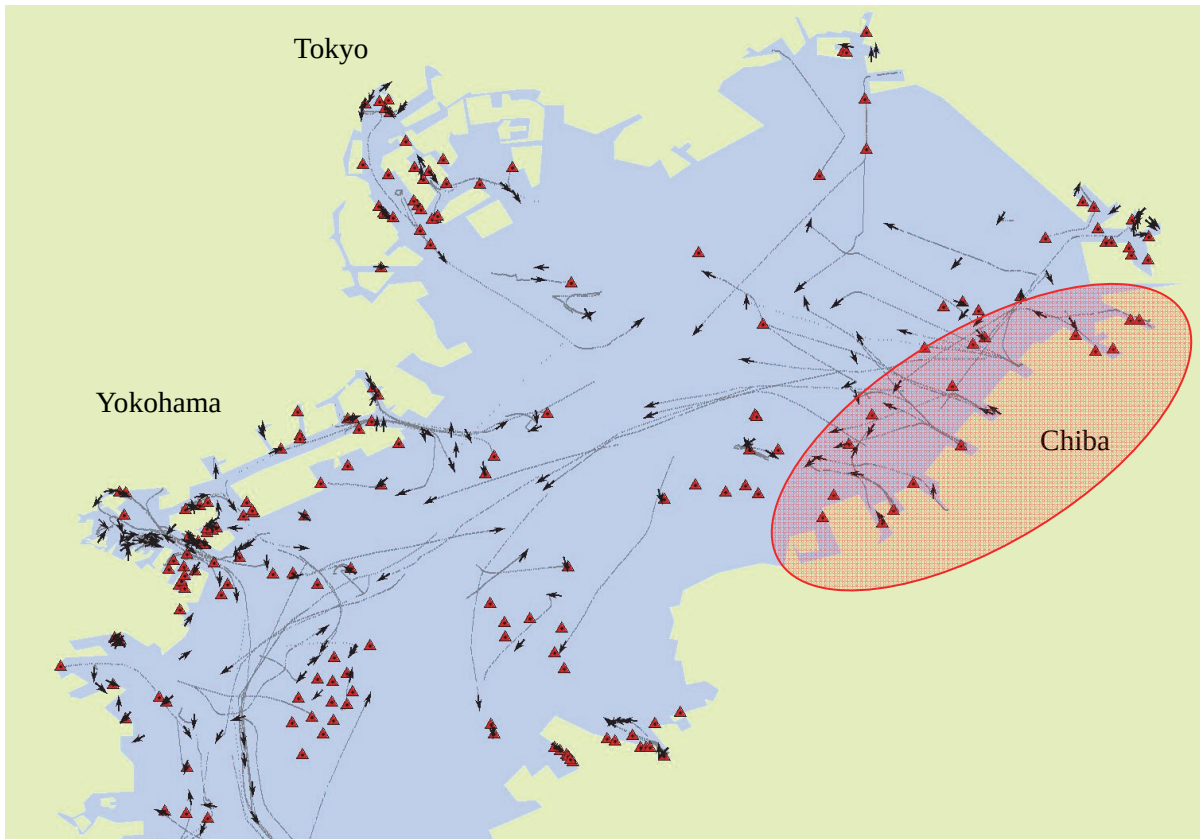
Table 1 Contents of AIS data

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)

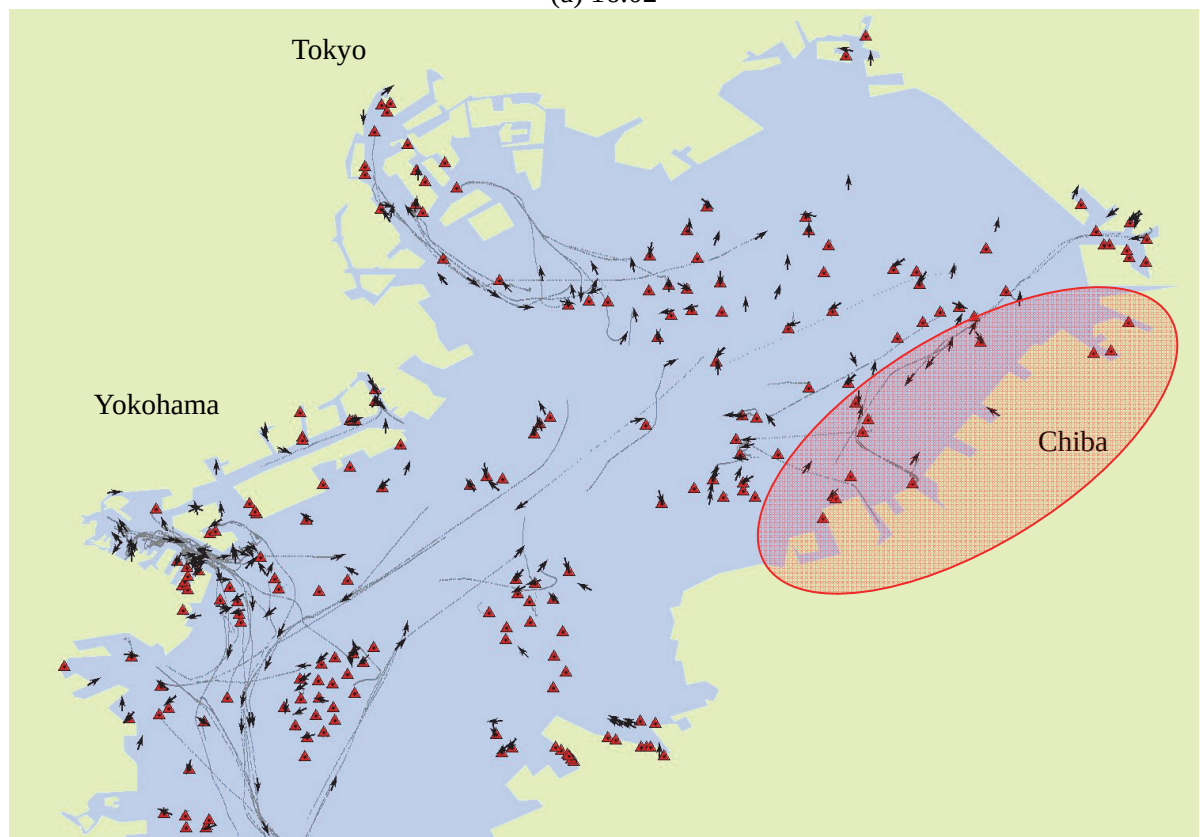
ANALYSIS RESULTS

Fig. 2 shows an example that depicts the status of emergency evacuation of each vessel on the basis of the AIS data obtained from the Tokyo bay. Each black arrow in these figures indicates a going vessel, and each red circle indicates anchor vessels, and also the broken lines show the paths of the vessels during a 30-min period. **Fig. 2(a)** shows the conditions around the port at 4:02 pm, 30 min after the major tsunami warning, and indicates that each vessel had started preparing for evacuation. This figure also shows several vessels that were preparing for evacuation. **Fig. 2(b)** depicts the condition at 5:32 pm, 120 min after the major tsunami announcement. In the region shown with the red circle in this figure, many oil industrial complexes exist and almost all the vessels of the neighborhood have completed evacuation to the outside of each harbor.

Fig. 3 shows the conditions around the closed-off section of Tokyo bay at 7:02 pm, 210 min after the major tsunami warning. In this figure, each black arrow indicates a going vessel, and each red circle indicates anchor vessels, and the broken lines show the paths of the vessels during a 30-min period. In Chiba port, all the vessels that can be confirmed from AIS data moved to the central part of closed-off of Tokyo bay. Furthermore, it is recognized that those vessels have completed evacuation. The numerousness of the vessels especially shown with the red triangle in this figure is remarkable. Since such a ship state cannot be seen probably at usually situation, it is thought that it is the feature of evacuation action of the vessel after a tsunami warning announcement. About the next situation from around 9:00 pm, almost all vessels were carrying out the anchoring. Therefore, the ship state where the flow of vessel traffic inside the Tokyo bay had almost stopped has been checked. This state continued till March 13 of which the tsunami warning was canceled.



(a) 16:02



(b) 17:32

Fig.2 Ship situation in Tokyo bay on March 11, 2011

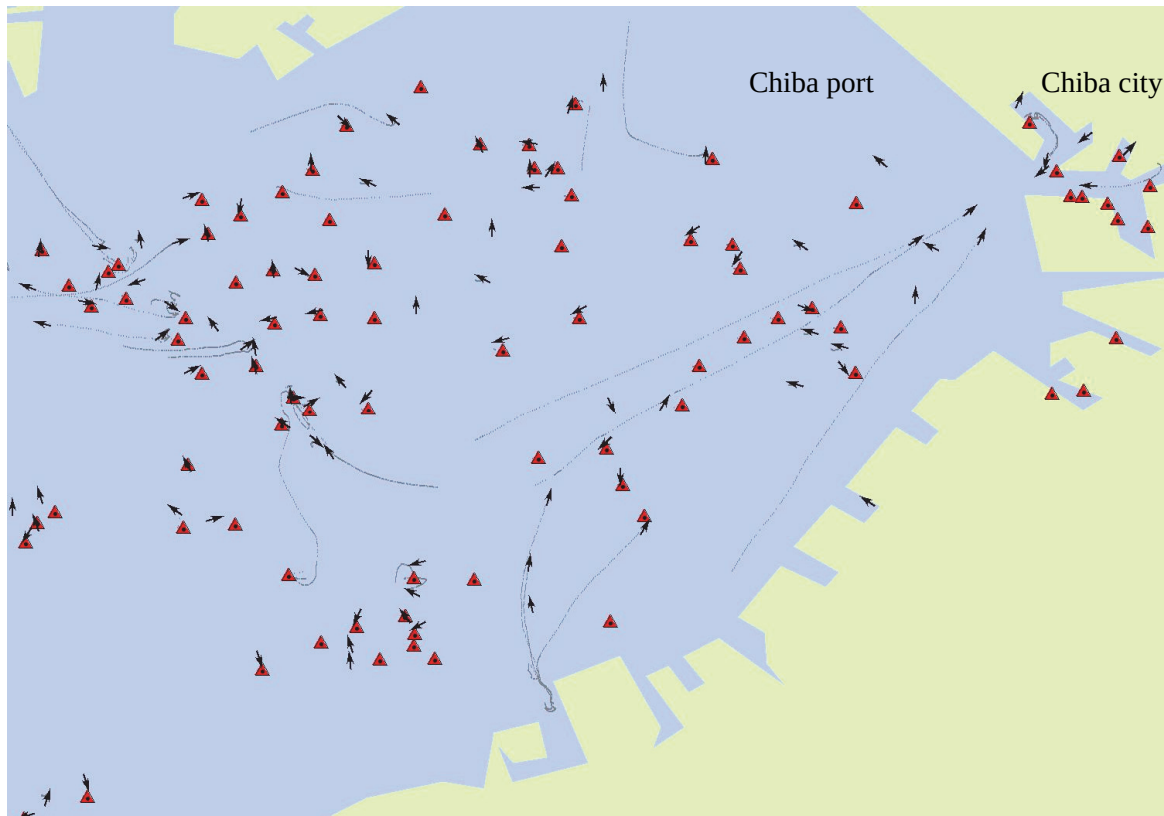
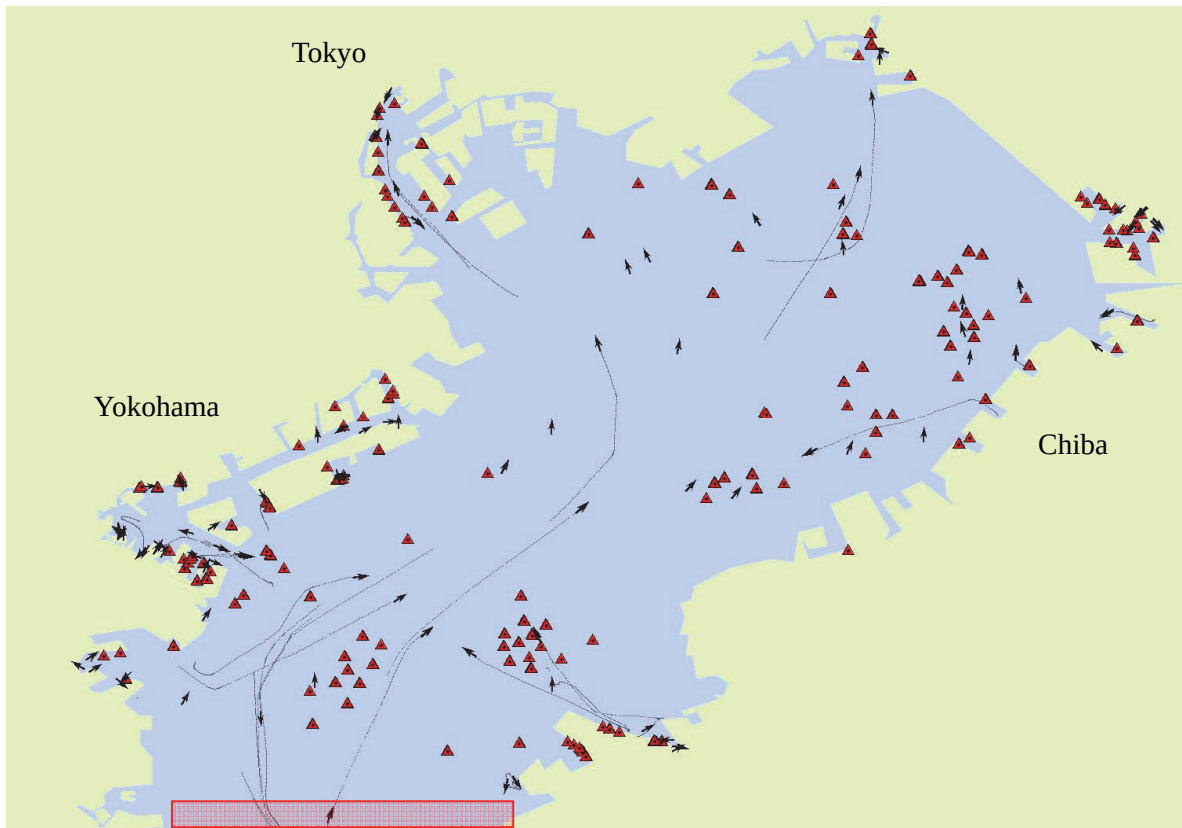


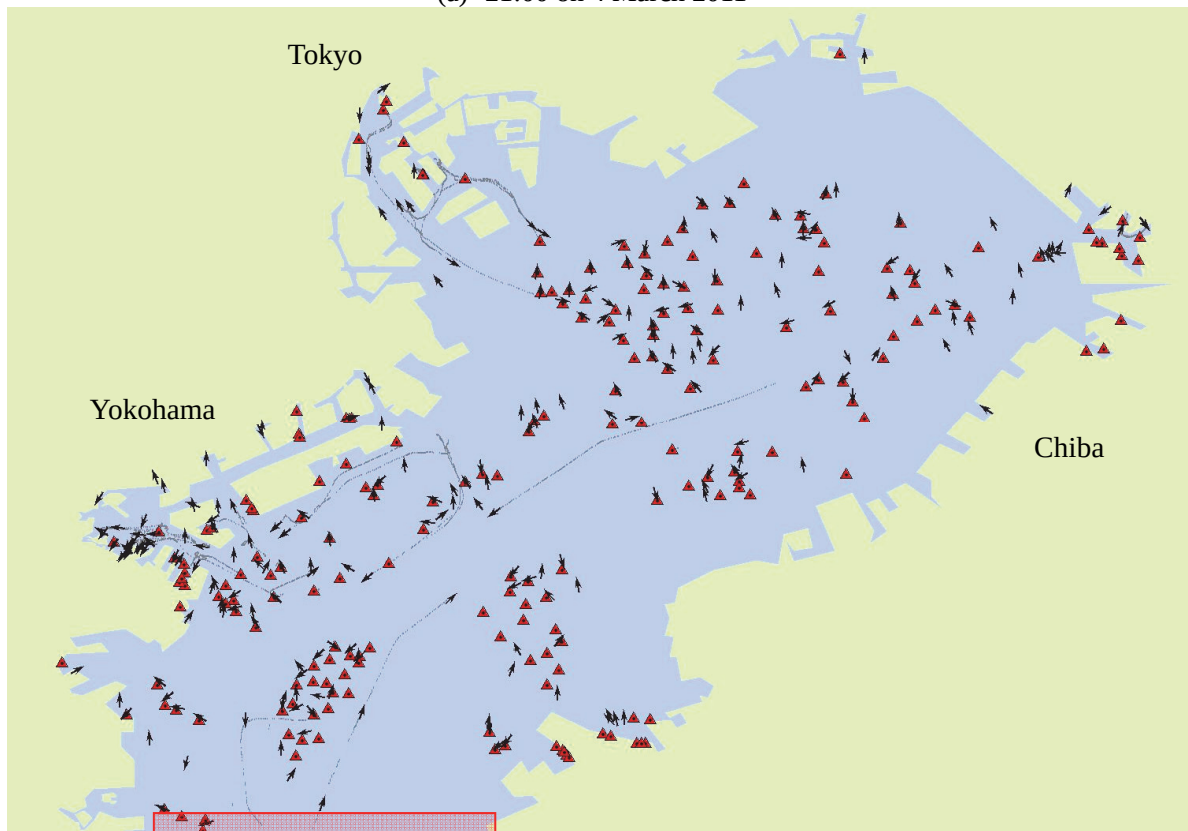
Fig.3 Ship Evacuation situation in closed-off section of Tokyo bay

Fig. 4 shows the condition of vessels at the time of usual, and the time of emergency in Tokyo Bay. In each figure, each black arrow indicates a going vessel, and each red circle indicates anchor vessels and the broken lines show the paths of the vessels during a 30-min period. Fig. 4 (a) shows the cruise situation of the vessel on March 4 which one week before the earthquake disasters. Both Fig. 4(a) and Fig. 4(b) are in the situation of the vessel at 9:00 pm. Both figures are compared and a difference clear about the number of anchoring vessels and its anchorage area is distinguished. As Fig. 4(a) showing, anchoring vessels are the anchor stay aiming at entry into the port near harbor boundary of each harbor. On the other hand, vessels are the anchor stay aiming at the evacuation as Fig. 4(b) showing. Moreover, 289 vessels were checked from AIS data about the number of vessels in Tokyo Bay at 9:00 pm on March 4. Meanwhile, no less than 331 vessels were checked at 9:00 pm on March 11 at the time of emergency situation.

The result of having investigated the number of vessels which goes in and out into Tokyo Bay of both days using AIS data is shown in Fig.5. This investigation was conducted by statistics comparison of the passage vessel of the entrance of Nakanose route shown in the red square region of Fig. 4 in 3:00 pm to 23:59 pm of both days. Fig. 5(a) shows the number of vessels entered in Tokyo Bay. It turns out that there are many vessels included in Tokyo Bay from 6:00 pm to 10:00 pm as a feature on March 11 which it was under the emergency situation. In it, the vessel which was cruising towards each harbor of the Tohoku district as a destination existed. This means that the vessel from which it was departing towards the Tohoku district as a destination got to know the earthquake and the situation of tsunami, changed the destination, and went into Tokyo Bay. Moreover, Fig. 5(b) shows the number of vessels left from Tokyo Bay. As this result, it turns out that March 4 was 92 boats and March 11 was only 39 boats. From this result, it is guessed that the vessel usually left towards the outside of Tokyo Bay as that cause had stayed and taken evacuation in the inside of the bay.

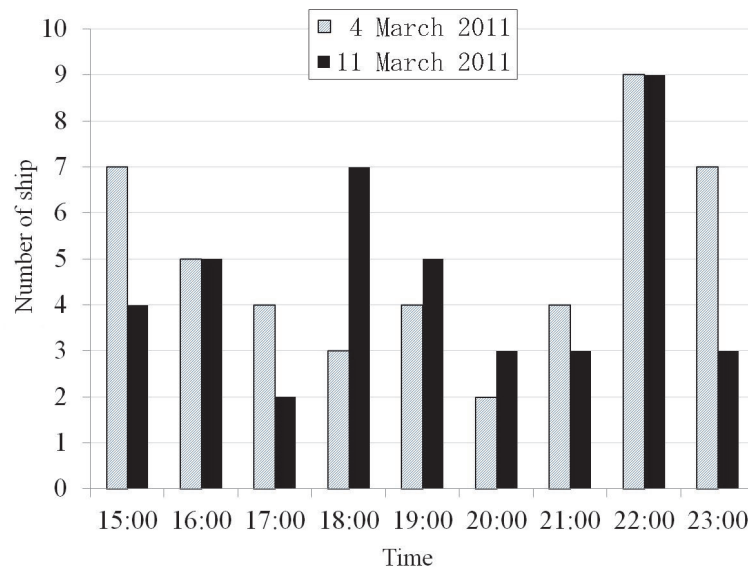


(a) 21:00 on 4 March 2011

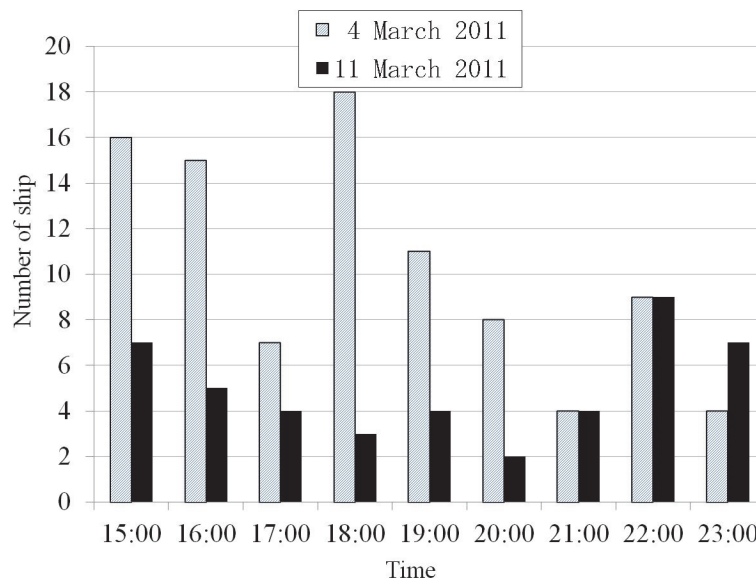


(b) 21:00 on March 11, 2011

Fig.4 Comparison of ship traffic flows in Tokyo bay of emergency and usual time



(a) A number of entered ship to Tokyo bay



(b) A number of left ship from Tokyo bay

Fig.5 Comparison of number of ship on March 4, 2011 and March 11, 2011

CONCLUSIONS

Using the data obtained from AIS, this study investigated the evacuation behaviors of the vessels equipped with AIS in Tokyo bay during the major tsunami warning announcement. The result shows that most vessels started evacuating approximately 30 min after the major tsunami warning announcement and completed evacuation 120 min after the announcement. This contributed in understanding the actual status of the vessel evacuation.

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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