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Simulation of the Evacuation of Ships Carrying Dangerous Goods from Tsunami

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***Abstract*—**The Great East Japan Earthquake occurred at 14:46 on Friday, March 11, 2011. It was the most powerful known earthquake to have hit Japan. The earthquake triggered extremely destructive tsunami waves of up to 40.5 meters in height. We focus on the ship's evacuation from tsunami. Then we analyze about ships evacuation from tsunami using multi-agent simulation and we want to prepare for a coming earthquake. We developed a simulation model of ships that set sail from the port in order to evacuate from the tsunami considering the ship carrying dangerous goods.

***Keywords*—**Multi-agent simulation, Ship's evacuation, Tsunami.

I. Introduction

THE Great East Japan Earthquake was a 9.0 magnitude undersea megathrust earthquake that occurred at 14:46 JST on Friday, March 11, 2011. The earthquake's epicenter was off the Pacific coast of the northeastern region of Japan. It was the most powerful earthquake to have hit Japan and one of the five most powerful earthquakes in the world since modern recordkeeping began in 1900. The earthquake triggered an extremely destructive tsunami with waves that reached 40.5 m in height in Miyako, Iwate Prefecture. In the Sendai region, waves traveled up to 10 km inland [1]. In the Great East Japan Earthquake, serious damage appeared in the many ships that were not able to evacuate from tsunami. Some ships were launched on land by the tsunami, caused serious damage to the facilities on land [2]. As we know that the uncontrolled ships are very dangerous [3]. In the earthquake, the uncontrollable ships broke many facilities. If large ships hit the port, go down or ride on land, they cause the delay of restoration or transport. The damage of ship is not only loss of property but also danger. In particular, the ship carrying dangerous goods gives serious damage to buildings on land. If the ships were carrying dangerous goods, for example LPG, crude oil, they cause environmental damage. Therefore, the evacuation of ships is very important.

In this paper we developed a simulation model of ships that set sail from the port in order to evacuate from the tsunami. Firstly, we implement simulation of the evacuation of the ship at Sendai-Shiogama port (Fig. 1) in Miyagi Prefecture of the Great East Japan Earthquake. Secondly, we compared the AIS data of ships that were evacuating from tsunami and the result of our simulation.

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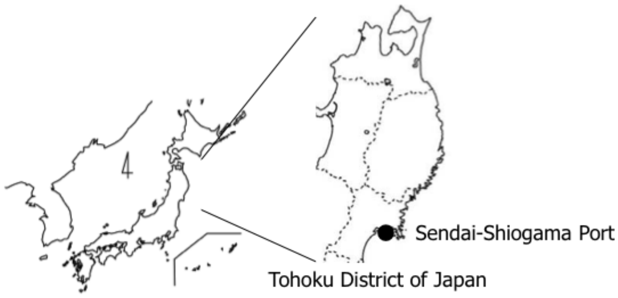

Fig. 1 Sendai-Shiogama Port

II. Evacuation of ships

As shown in Table I, Japan Coast Guard has issued the guideline to evacuate from tsunami. However, many ships could not evacuate by using the guidelines at the tsunami of the Great East Japan Earthquake. Japan Coast Guard indicates that ship carrying dangerous goods must evacuate from tsunami regardless of the arriving time.

On the other hand, if general ships (ships not carrying dangerous goods) are unable to evacuate from tsunami, Japan Coast Guard recommend that the crew of ship should moored their ship strongly and they should evacuate to a shelter.

We don't have a standard time to spare until tsunami arrival. So we would like to decide the time of standard of whether ships evacuate or not. For the purpose we have implemented a simulation model and we measured an evacuation time in the case of tsunami. We calculated relations of the tsunami arrival time and the ship evacuation time by multi-agent simulation when ships keep the Japan Coast Guard's guideline for tsunami.

We have used the AIS data which are real navigation data of Sendai-Shiogama port in Miyagi Pref. in the Great East Japan Earthquake. AIS is abbreviation of Automatic Identification System.

With the AIS installed, ships are able to monitor the movement of a multiple number of ships simultaneously regardless of visibility, thereby dramatically reducing the ship collision as shown Fig. 2. Furthermore, ground facilities can obtain the ship-specific information necessary for automatic, real-time maritime traffic control. AIS will play an important role in ensuring navigational and operational efficiency in congested waterways.

TABLE I
COPE WITH TSUNAMI WHEN TSUNAMI WARNING ALARMED IN THE PORT (CURRENT VERSION) [4]

TSUNAMI Warning	Time to Spare	Ships Getting Shore		
		Large or middle ship		*Small ship*
		Ship carrying Dangerous goods	*General Ship*	*Pleasure Boat, small fishing boat*
3m, 4m, 6m, 8m, Above 10m	No	SL, SW, EP in principle	SL, EL	EL
	Middle	SL, SW, EP in principle	SL, EP or EL	LT or EL (EP in some cases)
	Yes	SL, SW, EP	SL, EP	LT (EP in some cases)
1m, 2m	No	SL, SW, EP in principle	SL, EL or SM	EL
	Middle	SL, SW, EP in principle	SL, EP or EL or SM	LT or EL (EP in some cases)
	Yes	SL, SW, EP	SL, EP or SM	LT (EP in some cases)

SL: Stop Loading or unloading; SW: Stop Working; EP: Evacuation from the Port; EL: Evacuation for Land; LT: Landing and Tie the ship ; SM: Strengthen Mooring

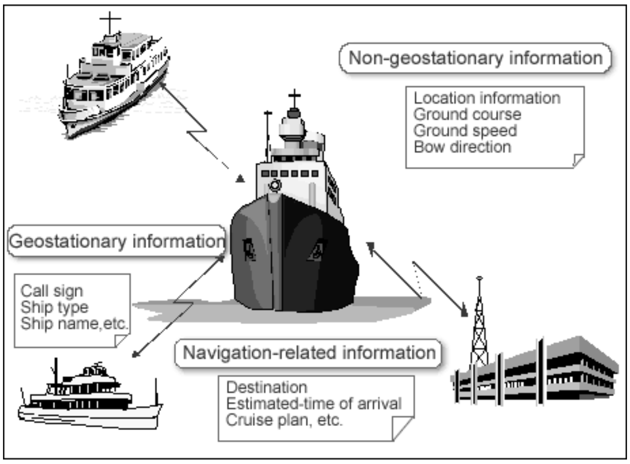

Fig. 2 Functions of AIS [5]

Fig. 3 At 30 minutes after the earthquake (AIS data)

Fig. 3 shows the tracks of the ships 30 minutes after the earthquake. According to AIS data, 15 large ships had moored at each pier in the port when earthquake occurred. In this area, big tsunami warning announced at 14:49 and tsunami attacked the port at 15:49. Five ships have evacuated to safety position out of the port in about 30 minutes after the earthquake. On the other hand, five ships still have been sailing to evacuate in the port, the rest five ships still have not left from the pier in this port. About one hour after the earthquake, tsunami reached the breakwater. Five ships still have been in the port and ships near the breakwater were involved in tsunami. Even after the tsunami, three ships were able to sail out of the port, but the two ships remained in the port.

III. SIMULATION MODEL

We implemented a simulation model by using the multi-agent simulator Artisoc [6]. We set the mooring position, departure time, and speed of the ship for the model by AIS data. By executing this simulation, we can predict whether ships can evacuate from the tsunami or not.

In this model, agents stand for ships and nodes. The link of each node represents sailing courses. The composition of this simulation model is as follows.

A. Sailing Course

To establish the route of the ship, we connect the mooring points, veering points and the evacuation point by links, respectively. We set the veering points on the route in order to change direction of ships. The mooring points, veering points and the evacuation point are nodes.

B. Input

Ships are expressed as agents having move position, speed and departure time, respectively.

C. Evacuation

Ships in the port begin the preparation of departure after the earthquake. A ship will sail to the evacuation point, immediately after preparation to depart is completed.

D. Preparation Time For Departure

In order to prepare for departure, large ship spends much time to start and warm-up operation of her engine. If ships finished preparing for departure before the earthquake, could sail immediately after the earthquake occurs.

IV. SIMULATION RESULTS OF THE MODEL

We have used the AIS data of Sendai-Shiogama port in Miyagi Prefecture at the Great East Japan Earthquake. We implemented a simulation model on multi-agent simulator. We set the initial position, departure time, and speed for each ship. We could simulate the evacuation of 12 ships, which didn’t ride on land, of the 15 ships. The relative error of the AIS data and the simulation result are 14.3 percent for 10 ships that could evacuate from tsunami. Fig. 4 shows the result of this simulation at 30 minutes after the earthquake.

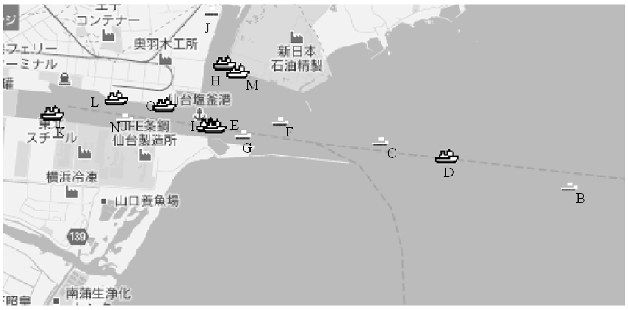

Fig. 4 At 30 minutes after the earthquake (Simulation)

Fig. 5 shows the evacuation time of AIS data and the simulation result of 15 ships at the Great East Japan Earthquake. According to AIS data, after the ship L and M were involved in tsunami, they couldn't evacuate to the offing. The ship K, N and the O stranded and they became impossible to cruise. 10 ships A-J that could evacuate before tsunami attacked the port, also could evacuate to the offing in this simulation result.

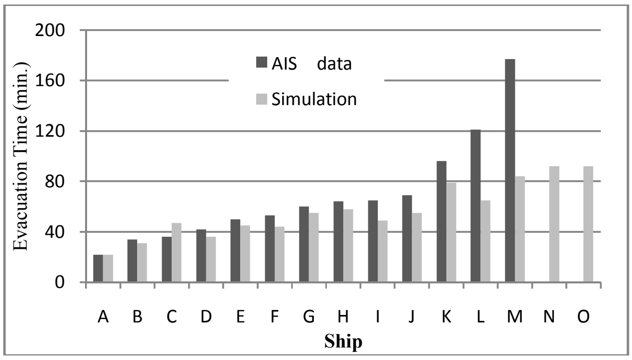

Fig. 5 Evacuation times of AIS data and the simulation results

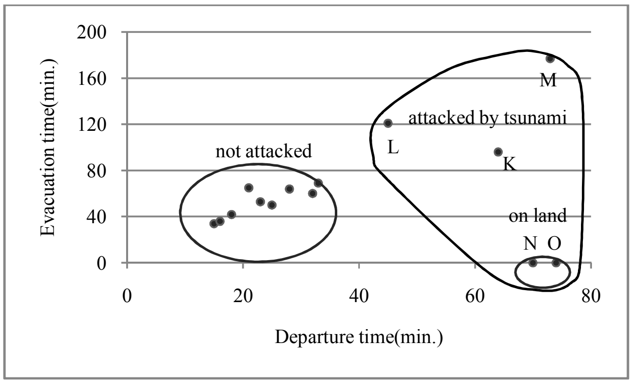

Fig. 6 Correlation between Departure time and evacuation time

Fig. 6 stands for a correlation between departure time for evacuation point and arrival time at the evacuation point. The x-axis represents the set sail time of ships after the earthquake. The y-axis represents the arrival time of ships at the evacuation point. These Ships that left for the evacuation point in 33 minutes from the earthquake were not attacked by tsunami. Tsunami which brought about serious damage arrived at the Sendai-Shiogama port about 1 hour after the earthquake. These Ships that left for the evacuation point after 45 minutes from the earthquake, were attacked or stranded by tsunami.

V. Results of the Simulation of Evacuation Ships Carrying Dangerous Goods

We simulated the evacuation rate of each ship classification based on the kinds of cargo at the Sendai-Shiogama port. Fig. 7 represents the simulation results of the ship's evacuation rate from tsunami considering the ship carrying dangerous goods. We assumed that all ships carrying dangerous goods must evacuate from the port in order to prevent huge damage to facilities on land. And we assumed the general ships (without dangerous goods) that are unable to evacuate from the port before tsunami arrived, need to be moored strongly. In Fig. 7, the x-axis represents the time to spare until tsunami arrived at Sendai-Shiogama port and the y-axis stands for evacuation rate of each ship classification based on their cargo in the port. The evacuation rate R_d of carrying dangerous goods is shown as follows.

$$R_d = E_d / A_d \tag{1}$$

where E_d stands for the number of general ships could evacuate and A_d stands for the number of all general ships, respectively. The evacuation rate R_g of general ships is shown as follows.

$$R_g = \frac{M_g + E_g}{A_g} \tag{2}$$

where M_g stands for the number of the mooring ships, E_g stands for the number of ships could evacuate and A_g stands for the number of all general ships, respectively. The evacuation rate R_w of whole ships is shown as follows.

$$R_w = \frac{E_d + M_g + E_g}{A_d + A_g}. \tag{3}$$

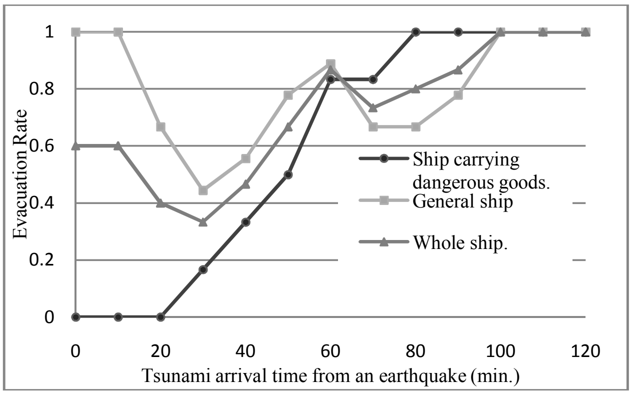

Fig. 7 Relation between the tsunami arrival time and the evacuation rate

Firstly we consider that there is no time to spare until tsunami arrival. The evacuation rate of general ships is high because the ships moored strongly by their crew. However, we defined that the ship moored strongly has been able to evacuate completely. The evacuation rate of carrying dangerous goods, on the other hand, is low because they could not depart from the port. Secondly we consider that there is 30 minutes until tsunami arrived. The evacuation rate of general ships is down because they depart from the port but they did not arrive at the evacuation point. But the evacuation rate of carrying dangerous goods is up because they were able to prepare to depart.

VI. Conclusion

We simulated the ship's evacuation from tsunami with considering the ship carrying dangerous goods. By the result of this simulation, all ships in the port should depart for the evacuation point for their safety within 30 minutes after earthquake. For keeping the safety of the port, all ships carrying dangerous goods in the port should depart for the evacuation point regardless of the arrival time for tsunami. We want to all ships carrying dangerous goods to depart within 30 minutes after the earthquake. Our future work is to propose the guideline for evacuation from tsunami considering the ship carrying dangerous goods.

Acknowledgment

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