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Clarification of Potential Risks in the Evacuation Process of Ships to Reduce the Risk of Maritime - NATECH

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ABSTRACT: This study aims to "reduce the risk of Natech (industrial disasters caused by natural disasters) in the maritime sector" and aims to develop a safe and optimal evacuation guidance method for ships that can be a source of risk, especially in coastal areas where large-scale industrial zones and important ports are located. In this paper, a time-series visualization analysis was performed based on data transmitted from automatic identification systems to grasp the overall picture of ship evacuation behaviour for ships in Osaka Bay when Typhoon No. 14 of 2022, which made landfall in Japan on September 18, 2022, approached Kansai. In addition, the "Crossing Point," which is a dangerous situation during navigation that can also be a factor in the collision risk of ships in usual situation, was calculated, and the potential risk factors in the process of evacuation behaviour outside the port were also analyzed.

1 INTRODUCTION

In recent years, there is a concern that Natech (Natural-hazard triggered technological accidents) risk may increase the damage not only from primary disasters such as frequent typhoons and tsunamis caused by major earthquakes, but also from secondary disasters caused by such natural disasters. Therefore, it is necessary to conduct research that comprehensively considers disaster prevention and mitigation against such risks. Although various factors can be taken into account for this Natech risk, one of its origins can be attributed to the evacuation of vessels if we focus on situations where large industrial areas and important ports are located. This is because vessels are responsible for transporting goods to industrial areas and port facilities, and a large number of vessels navigate in the waters surrounding these areas. In the event of a typhoon or tsunami, these vessels evacuate to ensure their own safety, but the evacuation depends on the judgment of individual vessels, and there is currently no controlled evacuation in the sea area.

Therefore, this research aims to create measures to reduce Natech risk in the maritime field by establishing a safe and optimal evacuation guidance method for ships in the event of a natural disaster and identifying potential risks that may cause secondary disasters.

This paper presents a time-series visualization analysis of the evacuation behaviour of a group of vessels in Osaka Bay when Typhoon No. 14 (Named: NANMADOL) of 2022 hit the Kansai region of Japan on September 18, 2022, using actual navigation record data. The existence of potential risks in ship evacuation was also clarified by extracting “crossing points,” which are dangerous situations during ship navigation, calculating the risk of collision between vessels, and identifying the sea area.

2 OUTLINE OF TYPHOON NO. 14 IN 2022 AND THE SURVEYED SEA AREA

2.1 *About Typhoon No. 14 of 2022[1]*

According to the Japan Meteorological Agency, Typhoon No. 14, which originated near the Ogasawara Islands at 3:00 a.m. on September 14, 2022, moved north-westward south of Japan, and by 3:00 a.m. on September 17, it had developed into a large typhoon of extreme strength. The typhoon made landfall in Kagoshima Prefecture at 19:00 on September 18 with large size and very strong force, and traversed Kyushu Island until the morning of September 19. After that, it changed its course to the east and moved over the Sea of Japan from the Chugoku region, making landfall again in Niigata Prefecture after 4:00 a.m. on the 20th, and then changed to an extratropical cyclone east of Japan at 9:00 a.m. on the 20th (Fig. 1). The approach, passage, and landfall of the typhoon caused stormy winds over a wide area from western Japan to northern Japan, centering on Kyushu, and caused severe droughts and heavy gales at sea. Storm surges exceeding the warning criteria were observed in some areas. Wind speeds reached a maximum of 50.4 meters per second in Saiki City, Oita Prefecture, and many locations in the Kyushu, Chugoku, and Kinki regions recorded the highest maximum wind speeds ever recorded. Heavy rainfall occurred in the Kyushu and Shikoku regions due to the long duration of rain clouds around the typhoon and its main body, and total precipitation from September 17 to 20 was about twice the normal for the month of September at several locations. The heavy rainfall caused landslides, swollen and overflowing rivers, inundation of low-lying areas, wind storms, and storm surges mainly in the Kyushu and Shikoku regions.

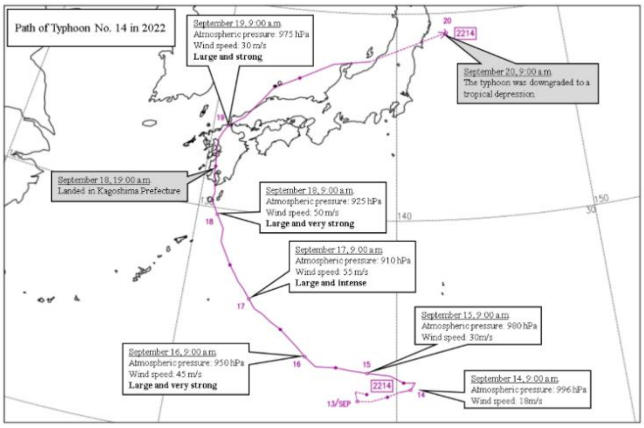


Figure 1. 2022 Typhoon No. 14 path map (JMA announcement)

2.2 *Outline of the surveyed sea area*

The survey area introduced in this paper is Osaka Bay, and Figure 2 shows Osaka Bay, each port, and each harbour area. The Hanshin Industrial Zone, one of Japan's three major industrial zones, is located within Osaka Bay. Heavy industries, particularly petrochemicals, are concentrated in the eastern part of the bay, which also covers a large area. In addition, there are several international strategic ports, so many large ships are constantly sailing through the bay. In addition, there are many fishing grounds, making it a congested sea area with a wide variety of ships coexisting. Furthermore, on September 4, 2018, Typhoon No.21 (Jebi) caused strong winds and high tides in the bay, damaging port facilities and disrupting industrial and economic activity in various ports, including the suspension of container terminals due to gantry cranes not functioning due to power supply being submerged. In addition, the disaster caused extensive damage in various locations, such as ships running aground and containers spilling out, disrupting ship navigation. In particular, at Kansai International Airport, in addition to damage such as the runway not functioning due to flooding and power outages at the passenger terminal, a ship that had been anchored for evacuation dragged its anchor due to strong winds and collided with the bridge connecting the airport to the opposite shore, resulting in the closure of the airport, leaving approximately 7,800 people inside the airport stranded for five days. In order to prevent the recurrence of large-scale disasters caused by such marine accidents, the 5th Regional Coast Guard Headquarters, which has jurisdiction over Osaka Bay, has issued a “recommendation to refrain from anchoring” for ships of 100 gross tons or more within 3 nautical miles from each of Kansai International Airport, Kobe Airport, and Sakai-Semboku Port Pier (shaded area in Figure 2) as a navigation rule to prevent evacuation vessels from dragging anchor during rough weather. In addition, if the typhoon is expected to reach the target sea area with a central wind speed of 40 m/s or more, (1) car carriers, container ships, gas tankers, tankers with a total length of 160 m or more, (2) passenger ships and ferry ships with a total length of 200 m or more. A system for out-of-bay evacuation recommendations and orders was established by the amendment to the Maritime Traffic Safety Act and came into effect on July 1, 2021, targeting ships such as ships, cargo ships, (3) dangerous goods ships with a gross tonnage of 50,000 tons or more, and (4) liquefied gas ships with a gross tonnage of 25,000 tons or more. In Osaka Bay, this evacuation recommendation outside the bay was first issued during Typhoon No. 14 in 2022. In the next chapter, we will introduce the results of an analysis of the evacuation situation of ships under such circumstances.

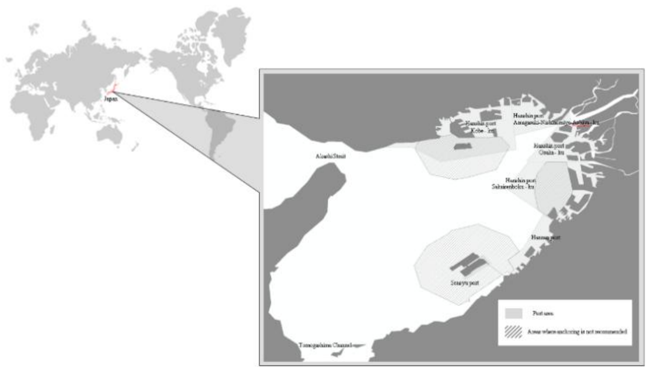


Figure 2. Major ports in Osaka Bay and areas where anchoring is not recommended

3 ANALYSIS OF ACTUAL EVACUATION BEHAVIOUR OF SHIPS AND IDENTIFICATION OF POTENTIAL RISKS

3.1 *Time series visualization analysis using actual navigation record data*

In this study, we used data transmitted from the Automatic Identification System (AIS) installed on ships as the actual navigation record data used in the evacuation behaviour analysis. AIS is a type of broadcast-type automatic dependent surveillance, and is required by the International Maritime Organization (IMO) to be installed on target ships (passenger ships and ships of 300 gross tons or more on international voyages, and ships of 500 gross tons or more on non-international voyages) [3]. The transmitted data can be broadly divided into 1) static information (IMO number, call number, ship name, captain, overall width, ship type, etc.), 2) dynamic information (time, ship position, ship speed, relative position, heading, navigation status, etc.), and 3) navigation-related information (draft, destination, estimated time of arrival, cargo, etc.). Figure 3 shows a map of the tracks of ships in Osaka Bay during normal times using this AIS data. The yellow dashed lines in this figure show the ship tracks. The main routes for maritime traffic within Osaka Bay are: (1) the route connecting A-B in this figure from the Seto Inland Sea through the Akashi Strait to Osaka Port, Kobe Port, and Sakai-Senboku Port (or vice versa), and (2) the route connecting B-C in the figure passing from the Pacific Ocean through Tomogashima Channel and entering the bay to Osaka Port, Kobe Port, and Sakai-Senboku Port. (or the reverse route), (3) A route connecting A-C in this figure from the Seto Inland Sea, passing through the Akashi Strait, navigating within the bay, passing through the Tomogashima Suido to the Pacific Ocean (or the reverse route), and it can be confirmed from the track map that there are especially many ships navigating the route connecting A-B as explained in (1).

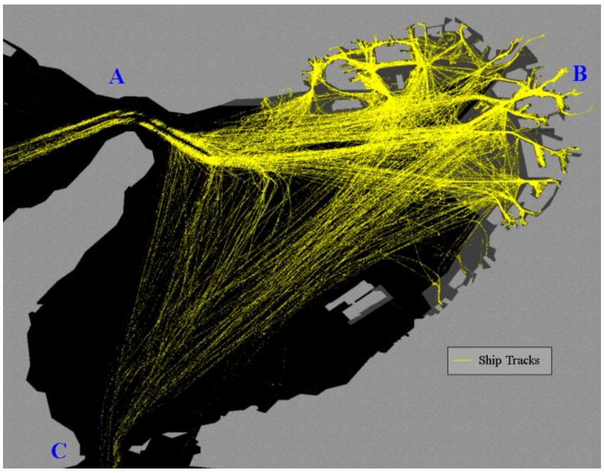
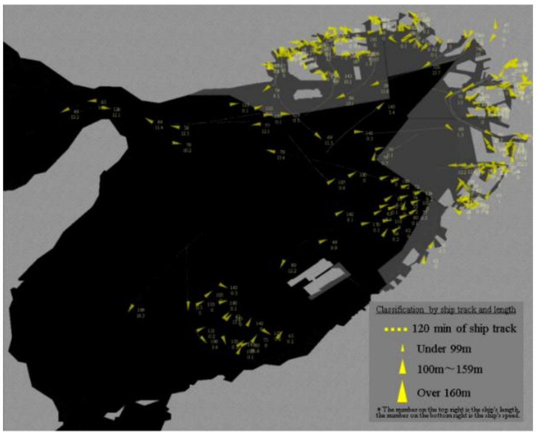
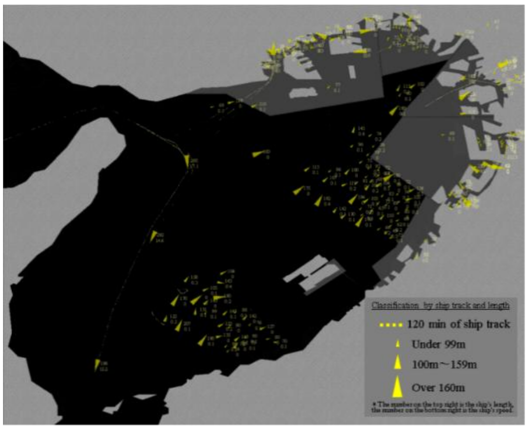


Figure 3. Map of ship tracks in Osaka Bay

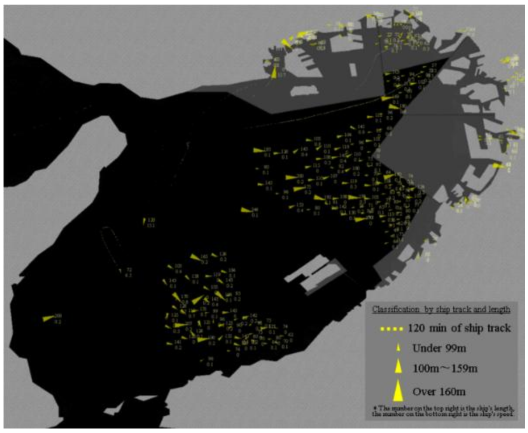
Next, a time-series visualization analysis was conducted on the behaviour of ships in Osaka Bay using AIS data from September 17th to September 20th, 2022, the day Typhoon No. 14 of 2022 came closest to Osaka Bay, focusing on that day and the period before and after (September 17th to September 20th). The results are shown in Figure 4. Each black triangle in the figure indicates a ship and the accompanying numbers indicate the ship's overall length. Figure 4 (a) shows the status of ships in Osaka Bay at 15:00 on September 17th, 2022, when a "Bay Evacuation Advisory" was issued by the Chief of the 5th Regional Coast Guard Headquarters, which has jurisdiction over Osaka Bay. At this point, it was confirmed that many ships had already taken refuge at anchor in the southwest and northeast of Kansai International Airport. Regarding ships within the bay that were recommended to evacuate outside the bay, 12 ships were identified within Osaka Bay. Among them, it was confirmed that there were 10 ships anchored within each port area and one ship outside the port area. Figure 4(b) shows the status of ships in the bay at 0:00 on September 18, 9 hours after the "Out of Bay Evacuation Advisory" was issued. The number of ships anchored for evacuation had increased since Figure 4 (a), and it was confirmed that the area northeast of Kansai International Airport was in a state of congestion. Ships anchored for evacuation were also confirmed within each port district. Furthermore, five large ships were confirmed to be anchored within the berths, and three outside the port districts. Figure 4 (c) shows the status of ships in the bay at midnight on September 19th, 36 hours after the issuance of the "Evacuation Advisory for Outside the Bay." At this point, it was confirmed that port district or outside Osaka Bay (there were six ships subject to the evacuation advisory that had anchored in the bay). However, it was confirmed that the ships that had anchored in the bay were overcrowded, as they were anchored in limited waters outside the port districts and outside the areas where anchoring was recommended to be avoided. In Osaka Bay, a maximum instantaneous wind speed of 25 m/s was observed at the Japan Meteorological Agency's Kansai Airport Island Observatory at around 8:20 p.m. on the same day, but the wind gradually weakened thereafter as the typhoon passed. Figure 4 (d) shows the status of ships in Osaka Bay at 0:00 on September 20th, after the typhoon had passed through the bay. At this point, several ships were observed drifting and taking refuge in the deep waters of the central-western part of Osaka Bay. It was also confirmed that the number of ships anchored for evacuation had further increased. The "advisory to evacuate outside the bay" was lifted at 6:00 the same day. Figure 4 (e) shows the status of ships in the bay at 7:00, one hour later. At this point, many of the ships that had anchored for evacuation within the bay were observed to have completed their evacuation actions and were sailing out of the bay.



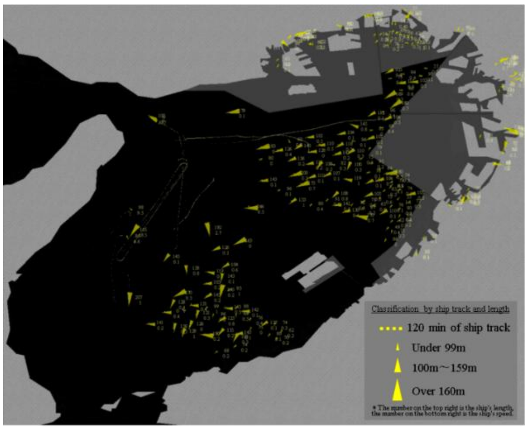
(a) Status of ships in Osaka Bay at 15:00 on September 17th, 2022



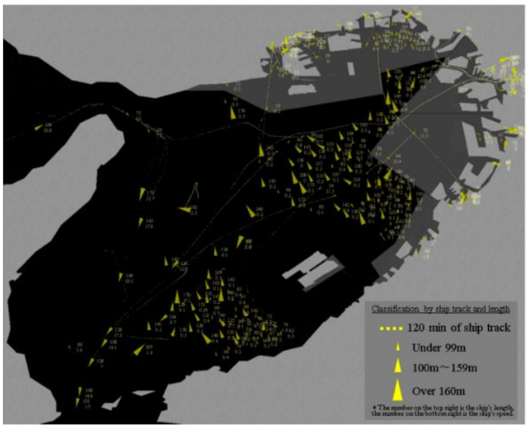
(b) Status of ships in the bay at 0:00 on September 18th, 2022



(c) Status of ships in the bay at midnight on September 19th, 2022



(d) Status of ships in Osaka Bay at 0:00 on September 20t, 2022



(e) Status of ships in the bay at 7:00 on September 20t, 2022

Figure 4.Transition in ship evacuation behaviour in Osaka Bay

3.2 *Understanding potential risks in ship evacuation*

In order for ships to evacuate more safely, it is necessary to avoid any maritime accidents such as collisions during the evacuation process. Especially during an emergency evacuation, even experienced ship operators may find it difficult to judge the situation appropriately and may not be able to perform the same actions as normal ship operations [4]. Therefore, in this paper, we extracted the "Crossing Point", which is the intersection of the course with other nearby ships, which is a dangerous situation during navigation that is a factor in the risk of ship collision during normal times, and analyzed the potential risk factors in the process of evacuation action outside the port.

This Crossing Point indicates a dangerous situation where there is a possibility of a collision because the vessel that is obliged to give way has not taken any action to give way, even though the ships are in a position to avoid collision. The procedure for extracting crossing points is as follows. First, it is determined whether the ship is underway based on dynamic data contained in AIS data. The determining factor for this judgment is whether the ship's speed is 2 knots or more and continues for 30 seconds or more. Next, for each extracted ship underway, the predicted navigation line 5 minutes later from the latest ship position was calculated, and any intersections with other predicted navigation lines that continued for more than 1 minute were extracted as crossing points. The reasons for extracting crossing points using the predicted navigation line for 5 minutes at this ship speed are as follows. If a ship with a ship speed of 12 knots sails for 5 minutes, it will travel a distance of 1 nautical mile, and depending on the positional relationship, there will be two ships within a range of 2 nautical miles at the farthest distance, considering other ships around. At that point, it can be determined that some time has passed since the two vessels were in an arranged relationship, and that they are not taking any action to avoid danger, so the closer the distance between the two vessels becomes, the more abrupt a change of course is required to avoid the danger. In addition, such a situation could create a dangerous situation in the surrounding sea area, as the vessel suddenly forms an arranged relationship with other ships that do not have an arranged relationship. In other words, the crossing point extracted this time is an extremely dangerous situation that poses danger not only to the two ships that created the situation, but also to other ships sailing in the vicinity. Regarding this Crossing Point extraction, we analyzed the period from 15:00 on September 17, 2022, when the "Out of Bay Evacuation Advisory" was issued, when many evacuation vessels were navigating, to 23:59 on the same day. Figure 5 shows the crossing points calculated at 15:02:56, about three minutes after the issuance of the "Evacuation Advisory Outside the Bay." The yellow triangles in the figure indicate ships that were in Osaka Bay. Also, the upper number indicates the total length of the ship, and the lower number indicates the ship's speed. In addition, the straight line extending from the tip of each triangle represents the predicted 5-minute navigation line. Furthermore, the red stars in the figure indicate the crossing points.

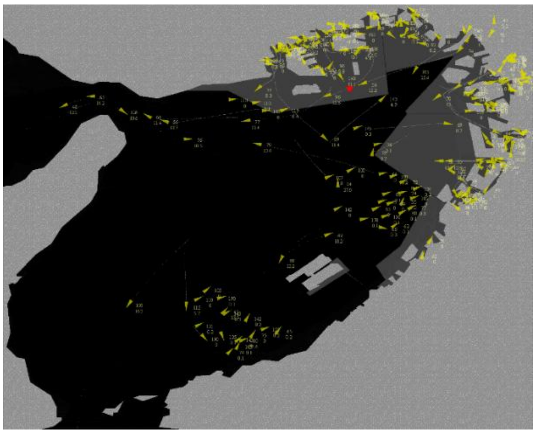
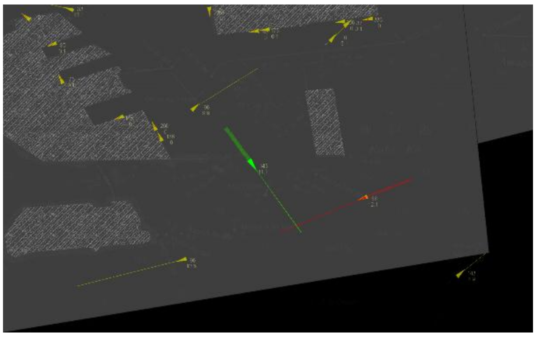
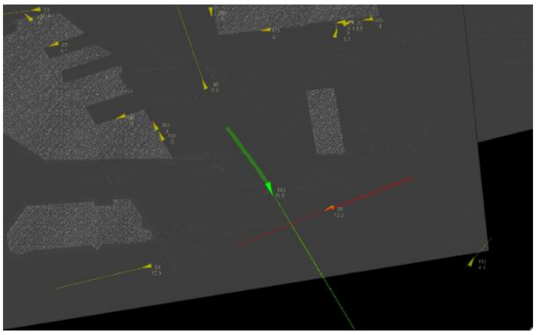


Figure 5. The crossing points calculated at 15:03 on September 17

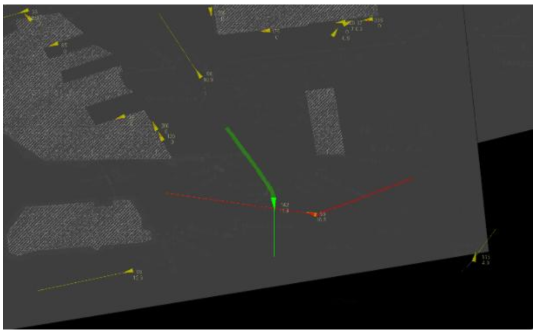
Figure 6 shows the results of a detailed analysis of the movements of both ships at this crossing point. This Crossing Point was caused by an arrangement between a 143m long cargo ship (green triangle in the diagram) that departed from Kobe Port and a 56m domestic tanker (red triangle in the diagram) that sailed westward from Hanshin Port's Amagasaki. Figure 6 (a) shows the situation when the crossing point was first calculated. At this point, the distance from each ship to the crossing point was about 0.8 miles. In this situation, the ship that must give way is the ship indicated by the red triangle. However, at this stage, no avoiding action was taken, and three minutes later, as shown in Figure 6 (b), both ships began sudden manoeuvring to avoid a collision. At this point, the distance between the two ships and the crossing point was 0.45 miles for the vessel shown in red and 0.4 miles for the ship shown in green. Figure 6 (c) shows the situation one minute later, when both ships took action to avoid a collision and the crossing point disappeared. Both ships then attempted to correct their course and return to their original course, but this resulted in both ships creating a Crossing Point with another ship. This situation is shown in Figure 6 (d). It is predicted that these two secondary crossing points would not have occurred if the ship had taken early avoidance action when the crossing point occurred as shown in Figure 6(a). In this way, it was confirmed that one dangerous event has the possibility of leading to a later, larger danger. The first crossing point occurred near the entrance to the main sea route of Kobe Port, which has one of the largest container terminals in Osaka Bay, and if a marine accident occurred at this point, it is possible that entry and exit would be blocked, affecting the evacuation of many ships. It was also revealed that the ship that was at risk at this time was a high-speed passenger ship, and that even more serious damage was expected. Figure 7 shows a map of the crossing points calculated as above that occurred during the target period. It was confirmed that multiple crossing points have occurred in the sea areas indicated by A to D in the figure. Sea area A is near the main sea route entrance to the main container terminal of Kobe Port, as explained above. Sea area B is near the entrance/exit of the main shipping route to Osaka Port, and area C is near the main shipping route entrance/exit to the large passenger ship terminal at Kobe Port. Sea area D is the eastern entrance to the navigational route of Akashi straight, which connects Osaka Bay and the Seto Inland Sea. Both points are very busy, with many ships passing through. If a marine accident occurs even in one place in such a sea area, it will have a huge impact on maritime traffic within Osaka Bay even in normal times, but during evacuation situations such as this one during a natural disaster, it is a risk factor that must be prevented, as it not only obstructs the safe evacuation of ships in the bay, but can also be a factor that directly leads to secondary disasters. The results of this analysis have identified these potential risks in the bay and identified the process by which they occur, so these results must be utilized for the safe and smooth evacuation of ships in the bay in the event of a natural disaster.



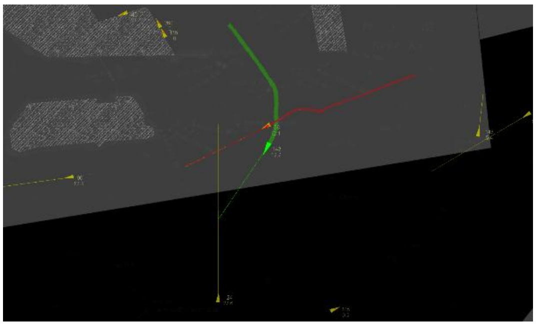
(a) Situation when the crossing point was first calculated.



(b) Status of both ships 3 minutes after Crossing point was calculated



(c) Both ships took action to avoid a collision



(d) Emergence of new Crossing points

Figure 6. Analysis results of Cross Point occurrence

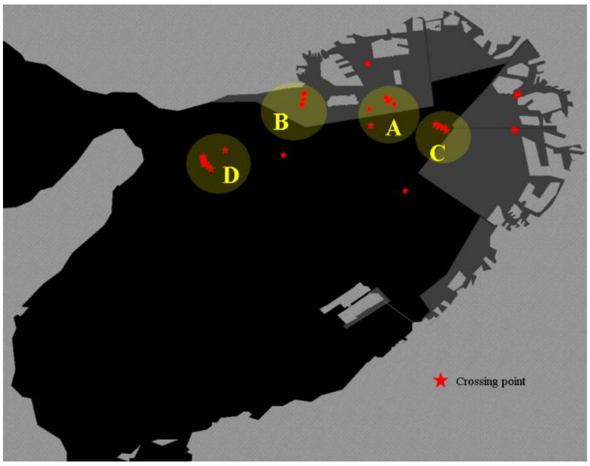


Figure 7. Occurrence of multiple cross points

4 CONCLUSION

In this paper, for the purpose of disaster prevention and mitigation in ports in the event of a super-large natural disaster, we focused on evacuation behaviour analysis of a group of ships responsible for maritime transportation, which is the main function of a port, and introduced the results of understanding the details of the evacuation situation of ships through a ship evacuation behaviour analysis using actual navigation data of a group of ships when Typhoon No. 14 of 2020 passed through. It was also confirmed that the occurrence of the Crossing Point was ascertained and that its continued existence included secondary dangers to other ships navigating around it. The results of this investigation showed that there were no reported cases of serious accidents resulting in loss of life as a result of the evacuation actions taken by each vessel, and as a result, it can be said that there were no major problems with the evacuation response of most vessels. However, these are all cases in which the evacuation was possible within the expected range of each ship operator and those involved in the operation, and if an unexpected situation such as dragging anchor or drifting occurs after berthing, it could not only be dangerous for the ship itself, but could easily cause harm to other ships and damage to nearby port facilities. Therefore, in the future, it will be necessary to clarify these situations and consider measures for vessel evacuation that can ensure not only the safety of one's own vessel, but also the safety of the entire sea area.

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