Some recommendations to the ship master in order to evacuate a cruise ship due to tsunami arrival

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Abstract

Disaster mitigation is very important to minimize huge accidents which may occur due to the arrival of a tsunami. A possible way to minimize huge economic losses and to reduce the danger to human life is to have ships which are located in the port around Osaka Bay immediately evacuate to a safe area. The guidance for seafarer competency is regulated by the STCW (International Standard Training Certification and Watchkeeping) convention and STCW (Sea farer training certification and watchkeeping) Code. In relation to disaster mitigation, there are minimum-requirement capabilities which have to be achieved by the seafarer. However, there is no clear mention of any competencies required for the seafarer in case of a marine disaster, such as a tsunami arrival, since the tsunami case is considered very rare and it is difficult to predict when a tsunami might arrive in Osaka Bay. In this paper, some recommendations for masters to evacuate their ships in the case of a tsunami arrival is shown; the time evacuation of large passenger vessel is carried out and the initial position of the large passenger vessel is assumed and not changing based on data obtained from Automatic Identification System (AIS). The recommendations of ship evacuation shows where and how the ship has to evacuate from inside port in order to minimize a huge disaster.

1 Introduction

As of January 2008, the possibility of an occurrence of the Nankai and Tou-Nankai Earthquake as shown in Fig.1 in the next 30 years is estimated at 50% and 60% to 70% respectively. This condition causes not only the rise of free surface but also strong horizontal water movement in a bay. It also sets ships adrift and possibly destroys many parts of Osaka Bay, which would cause huge economic loss and endanger human lives. Moreover, in Osaka Bay, there are many cruise ships that carry many passengers and come in and out of Osaka Bay. Therefore, it could jeopardize any passenger inside a cruise ship, in the case of a tsunami arrival. However, there are problems which may be faced by ship masters, if they have not had any prior experience regarding tsunami disasters. Moreover, there are no specific procedures in STCW 1978/1995 as amended. Therefore, guidelines of disaster mitigation for ship masters are required. It should be available onboard any vessels which proceed to areas which are prone to tsunamis, such as Japan.

Basically, there are two risk control options, which are possible to be carried out by ship masters. First, a ship master may evacuate all passengers from on board to the port then evacuate the ship, if the initial position is alongside the port. Second, a ship master with passengers on board may evacuate his ship to shelter area. This paper describes an analysis of second risk control option as disaster mitigation which has been not investigated previously. During the conduct of a ship evacuation, the traffic density inside port area has to be taken into account. The traffic management is required in order to avoid collision disaster among vessels while proceeding to shelter areas.

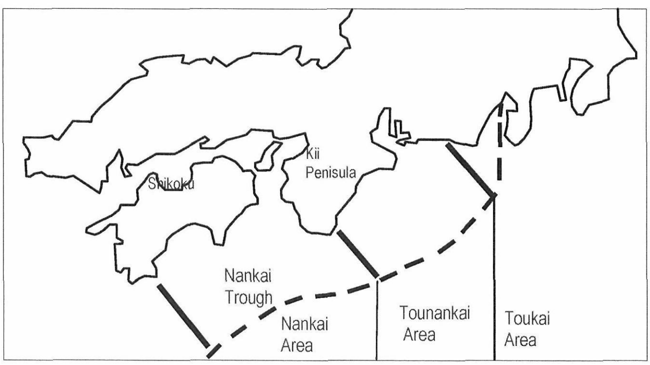


Fig. 1 Earthquake location in Nankai Trough

This paper is composed of three main sections. In the first section we give a brief introduction to the Automatic Identification Systems (AIS); how ship speed data can be taken from AIS and how AIS data is used in this paper by using the Geographic Information System (GIS). In the second section, a mathematical model of a tsunami is presented, showing the prediction for a tsunami arrival in a given spot; and general discrete event simulations for a cruise ship evacuation assessment as well as the result of time prediction are described. The clustered data of ship evacuation, which is input data for discrete event montecarlo simulation is also developed. Thirdly, the results between the tsunami arrival prediction and time evacuation of ships are evaluated and compared in order to investigate the time needed for cruise ships to evacuate to shelter areas. Then, the procedures of cruise ship evacuation as basic guidance of tsunami disaster mitigation are proposed.

2 Investigation of a cruise ship

2.1 Installation of AIS

AIS is possible to recognize for any ships of 300 GT for an international voyage and more than 500 GT for domestic route now. Ship data can be obtained as static and dynamic information. Static information is included as following the vessel's maritime mobile service identity (MMSI), name of vessel, calling name, ship length, draught of ship, IMO number, ship width, type of ship, antenna position. However, dynamic information is as follows: longitude; latitude; time; course; rate of return; speed over ground; navigation information; draught ship; destination; and type of cargo (Leica Geosystems Inc 2001). The actual data of cruise ships are obtained from AIS (Automatic Identification System) equipment which is installed in Kobe University, Fukae, Japan. It is possible to record the time of large passenger vessels leaving and arriving in Tempozan Ferry Terminal in Osaka Bay. The principle of AIS installation is shown Fig. 2. Ship data is recorded by the AIS receiver and then transferred and saved to a laptop or a notebook computer. Those data, which are saved in a laptop, can be taken from other laboratories through a local area network (LAN).

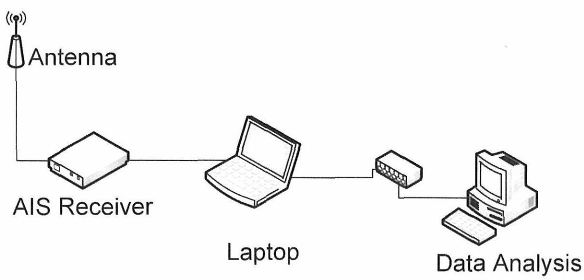


Fig. 2 The principle of AIS installation

2.2 AIS and GIS data analysis

There are several cruise ships which were in Tempozan Ferry Terminal as shown in Fig. 3 and which can be recorded by AIS receiver equipment.

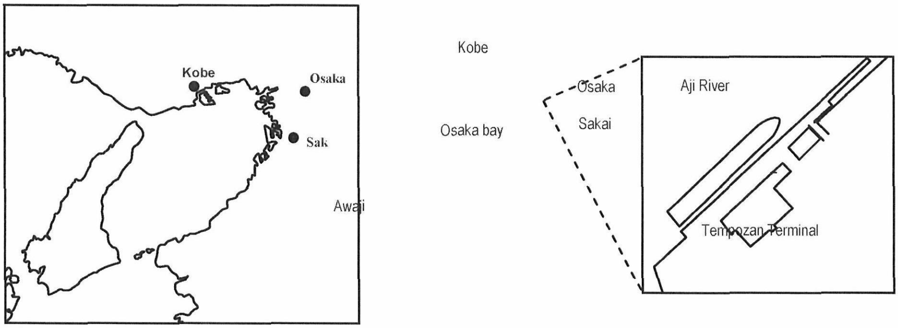


Fig.3 Location of cruise ships port

The cruise ship's data, which were collected in 2006 and 2007, are as shown in Table 1 below. It shows the principal dimension of cruise ships which were visiting in Tempozan Ferry Terminal.

Table 1 Cruise ships arriving at tempozan terminal

DATE	SHIPS	LOA(m)	B (m)	D(m)
18/3/2007	A	270	32.2	7.9
7/3/2007	B	293.5	32	9.8
14/10/2006	C	290	37.5	8.05
3/5/2007	D	219.5	30.78	-
16/4/2007	E	238	30.2	7.6
08/11/2006	F	241	29.6	7.5
20/10/2006	G	166.65	24	6.55
23/02/2007	H	162.3	21.34	7.9
10/03/2007	I	193	24.7	6.33
06/10/2006	J	167	24	6.33
16/12/2006	K	183.4	25	6.5
8/8/2006	L	102.9	15.4	4.3
22/2/2007	M	154.6	-	-

The largest one is "C" ship, which was 290 m in length (LOA), 37.5 m in beam (B) and 8.05 m in draft (D). The largest cruise ship (C) can accommodate a maximum of 4160 passengers (Onoguchi et al. 2004). It has 1339 passengers and 650 crew cabin respectively. The second largest one is B ship and the third one is A ship as shown in Table 1. From August – December 2006, it is shown that six (6) cruise ships are recognized by the AIS receiver. In 2007, it is shows that the number of vessels is seven (7) cruise ships.

Before carrying out an investigation of ship evacuation, it is very important to know the ship movement's behavior as shown in Fig. 4. It shows that from port the vessel speed rises gradually and the goes down, since the vessel is too large and cannot turn a circle in Tempozan Ferry Terminal. After she obtained space for turning back, the ship proceeded toward the outside Osaka of port and the ship speed is increased gradually. Then, the speed of vessel slowed again, since she was close to the harbor pilot station. Then, the pilot came on board as shown in Fig. 4. After that, the ship increased her speed toward Tomogashima channel. After passing that channel, the ship speed is constant and then reduced when she comes close to the bay pilot station.

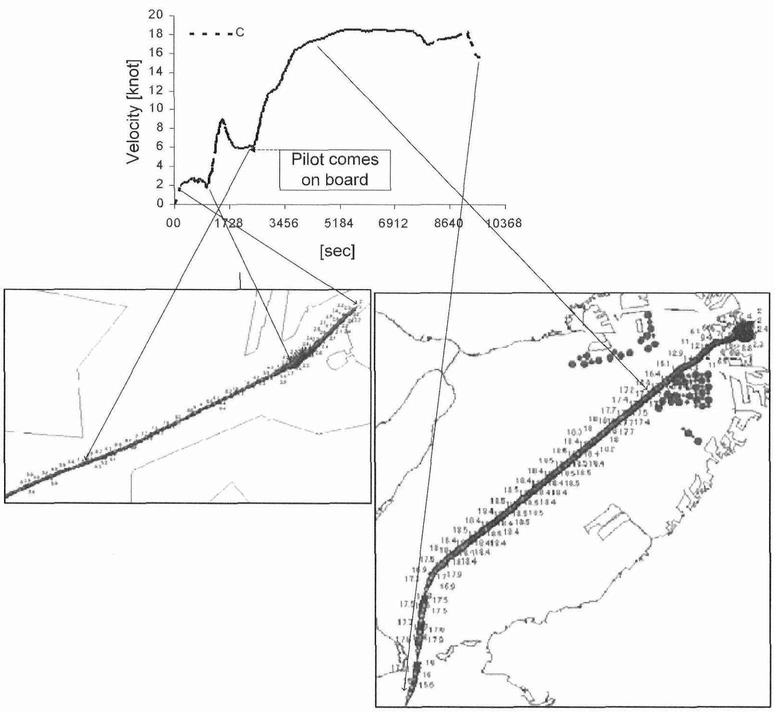


Fig. 4 a Cruise ship departure behaviors

2.3. Traffic density in berths

The number of ships in Osaka Port can be seen in Fig. 5. Those data were recorded on October 14 2006, when a large cruise ship arrived at Tempozan Ferry Terminal. The data shows there were around 10 ships along side the berth at 14.00-15.00. That number was considered the largest number in that day. In this simulation, the initial position of evaluated ships are along side berths, since that initial position is the most dangerous position in case of a tsunami arrival inside Osaka Port.

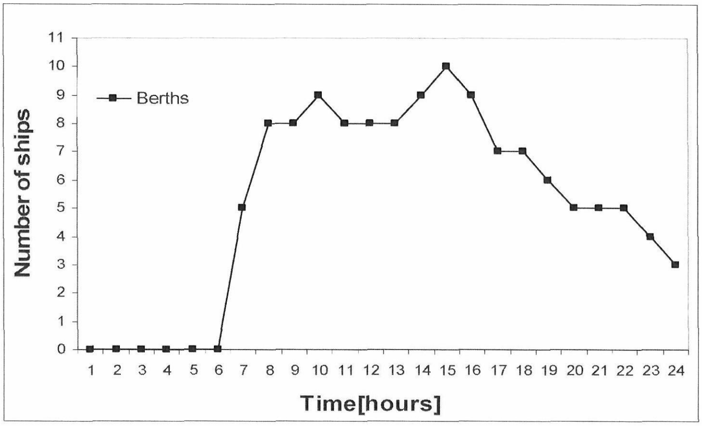


Fig. 5 Traffic density alongside berths

3 Mathematical model of tsunami

In order to predict a tsunami arrival in Osaka Bay, we used a mathematical model of a tsunami (Kobayashi et al. 2006). The characteristic of tsunami is expressed as the following form in the coordinate system shown in Fig.1. and formulated as following:

$$\left.\begin{aligned}
&\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x_0}+\frac{\partial N}{\partial y_0}=0\\
&\frac{\partial M}{\partial t}+\frac{\partial}{\partial x_0}\frac{M^2}{D}+\frac{\partial}{\partial y_0}\frac{MN}{D}+gD\frac{\partial \eta}{\partial x_0}+\frac{\tau_x}{\rho}=0\\
&\frac{\partial N}{\partial t}+\frac{\partial}{\partial x_0}\frac{MN}{D}+\frac{\partial}{\partial y_0}\frac{N^2}{D}+gD\frac{\partial \eta}{\partial y_0}+\frac{\tau_y}{\rho}=0
\end{aligned}\right\} \quad (1)$$

where :

η : elevation from still sea water, t :time

x, y : coordinate system, g :gravity acceleration

ρ : density of water, D :depth of water (η +h)

τ_x, τ_y : sea bottom friction in x,y direction

M, N : x,y direction flow volume flux

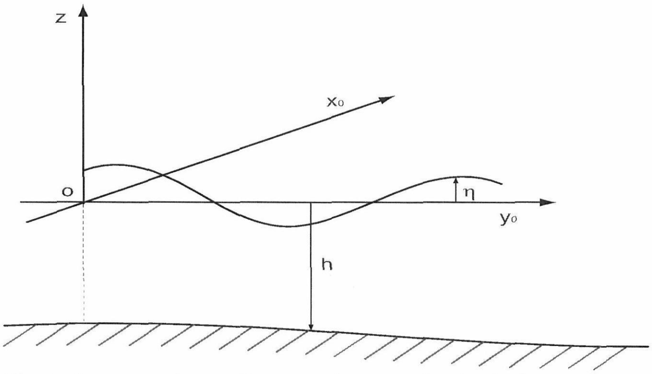


Fig.6. System of coordinates of tsunami calculation.

4 Tsunami arrival

From the mathematical model of the tsunami mentioned above, it generates a time prediction of a tsunami, which arrives in representative spots in the Osaka Bay area as shown in Fig. 7. The spots of tsunami arrival time prediction are evaluated in spot 1 and spot 2 as shown in Fig. 7 which are located in 135.43 longitude and 34.65 latitude as well as 135.39 longitude and 34.64 latitude respectively.

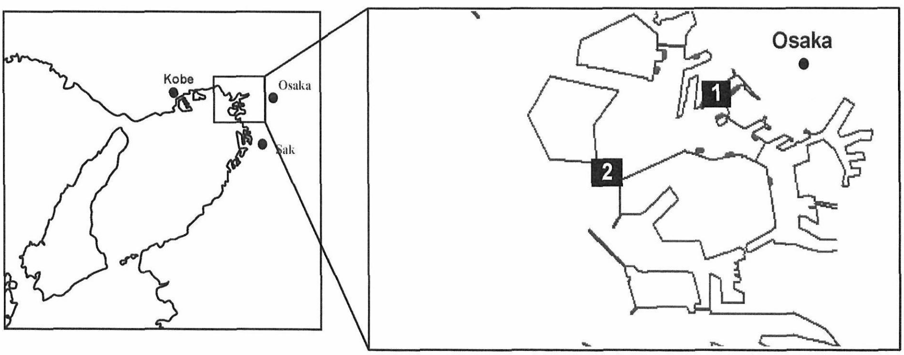


Fig.7 Tsunami arrival point assessments

Table 2 Coordinate of tsunami prediction assessments

Spots	Longitude	Latitude
1	135.43	34.657
2	135.395	34.64

The elevation and velocity time histories in one of the berths which is at point 1 are shown in Fig.8. It shows that the first tsunami arrival time is around 6810 sec and the first peak arrival time is around 8130 sec. Elevation and velocity in the first peak arrival time is around 1.5 meter and 0.55 m/s. The highest velocity is around 1.5 m/s and having elevation about 0.46 m. If it is observed that a vessel may destoy a berth and endanger the crew or passengers on board, since sea water is flowing and changing in different direction in finite different time during tsunami arrival, the immediate actions of evacuation may have to be taken in order to avoid huge disaster.

Fig. 9 shows the time histories of the elevation of the surface of the sea and velocity component in point 2, which is considered as narrow point in Osaka port area. The first time tsunami arrival is around 6410 sec and the first peak tsunami arrival time is around 7570 sec. Elevation and horizontal velocity in the first peak tsunami arrival become around 1.1 m and 2.1 m/s.

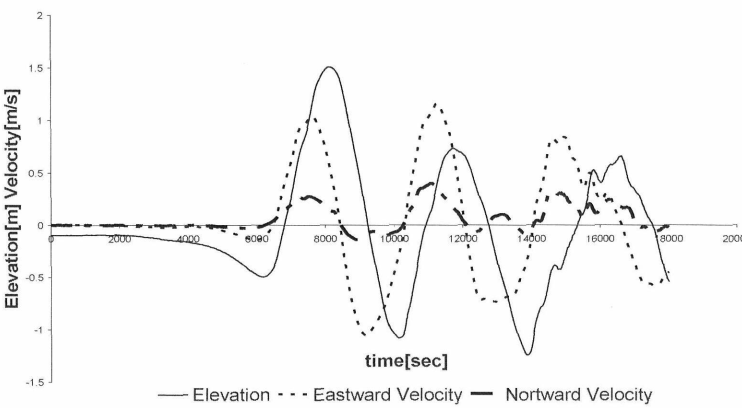


Fig. 8 Tsunami arrival in point 1 of Osaka Port

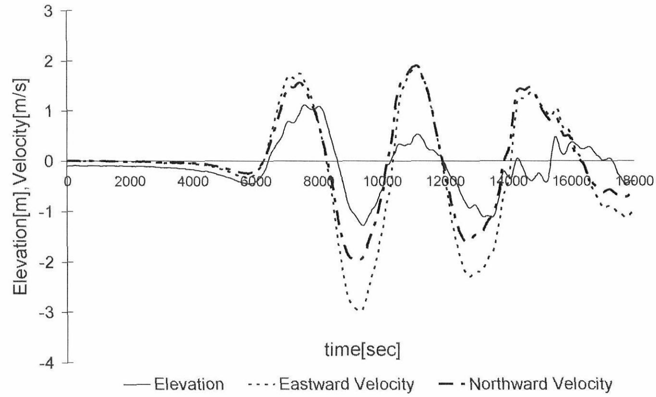


Fig.9 Tsunami arrival in point 2 of Osaka Port

5 Ship evacuation simulation

Ship evacuation simulation is conducted based on a discrete event montecarlo simulation, which is usually only called a discrete event simulation. It can develop a model with the assumption that the state variable changes instantaneously at separated points of time (Law 2007). The DSS characteristics also regard an individual entity as more important than aggregate entities. It means that each passenger ship is assumed to alter instantaneously at specific time. Moreover, the simulations do not assume that each entity is as group of movement, but individual movement is more the important aspect (Law 2007). The authors use this approach, since there is uncertainty about ship speeds during departure to outside the port area. Therefore, the authors note that this approach can predict the time needed for a ship to proceed from one point to another point.

If DES is compared with the analytical approach, it shows that DES have stochastic and uncertainty characteristics. However, analytical have opposite characteristics such as deterministic and certainty. It means that the result of the assessment has exact value. The calculation of the total time needed for each vessel for evacuation generally can be expressed as follows:

$$\left.\begin{aligned} T_{total} &= t_1 + t_2 \\ t_2 &= \sum_{i=1}^{n} T_i \end{aligned}\right\} \quad (2)$$

$$T_i = \frac{dS_i}{\overline{V_i}}$$

where:
T_{total} = total time needed of each vessel to spend in all nodes.
t_1 = response time of the captain to realize the existence of disaster
t_2= time for each ship to reach the end of its destination, which are divided by n cluster,
T_i = time needed of each vessel in node i
dS_i = distance spent by each vessel in each node i
$\overline{V}_i$= average speed in node i, which is obtained from AIS data and then generated by using pseudorandom number generator.

Each speed data of a ship obtained from AIS is analyzed by a goodness of fit test to ensure the specific probability distribution of velocity data. After that, it is known the type of distribution and then new data are randomly generated using random generator. Then, the average speed of each speed in each node is calculated. From the average speed, the time needed of each node can be calculated.

5.1 Modeling

Evacuation simulation in this paper is modeled as shown in Fig. 10. The time needed by each vessel is divided by several clusters e.g, Leaving 1; Leaving 1B; Leaving 2; Arrival 1; Arrival 2A and Arrival 2B, since the character of each speed of vessel is different. Each vessel has to spend its time in each node, which is assumed to follow a specific probability distribution.

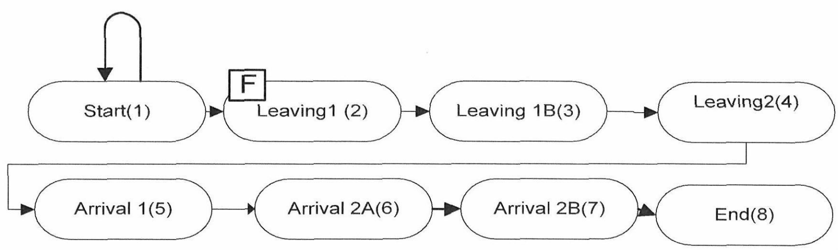


Fig. 10 Modeling of evacuation simulation

Leaving 1; Leaving 1B; and Leaving 2 time nodes are assumed to follow a normal probability distribution. The Arrival 1 time node is assumed to follow log logistic probability distribution and the rest e.g. Arrival 2A and Arrival 2B nodes are assumed to follow logistic probability distribution.

6 Ship evacuation study

6.1 Restriction of Passage

In normal conditions, there are several restrictions for any vessels departing from their berth (Port & Harbour Bureau City of Osaka 2005). For any vessels which have size more than 10000 GT, it is mandatory for that vessel to have a pilot on board. They have to proceed in that area with moderate speed and should not go through the navigation route standing side by side with each other in order to avoid danger to other ships as shown in Fig. 11(b). A ship also is not allowed to go ahead of another ship in the navigation route as shown in Fig. 11(a). In case there are several vessels wanting to depart to outside of the harbor area, the larger ship has the first priority to evacuate. In this assessment, the author also evaluates the possibility of evacuating one by one as the applicable regulation in Osaka Port.

No passing (a)

No Side by side (b)

Fig.11 Restriction of navigation passage

6.2. Distance between vessels

The distance between vessels during departure from inside to outside of the harbor is assumed around 8L + 2 L1 as shown in Fig. 6 (Yoneda et al. 2006). L means length of vessel behind fore vessel and L1 mean length of fore vessel.

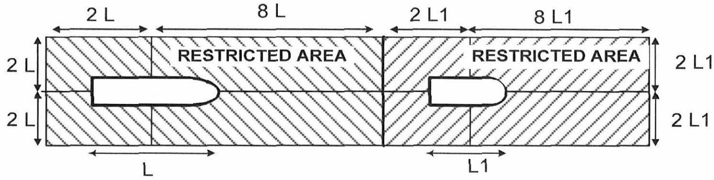


Fig.12 Distances between vessels

The distance between those ships as shown in Fig.12 is assumed as a safe area, which is considered by several captains (Yoneda et al 2006). They have to keep that distance in order to avoid a collision condition. In case of a tsunami arrival, all ships which are moored in berths have to evacuate immediately (Port of Kobe-Harbor Manager 2006). However, there are no specific areas which are used as a shelter area. In this simulation, it is assumed that ships have to evacuate to the anchorage area.

6.3 Initial position

The positions of ships which are along side berths are considered the most dangerous position. It may destroy the port and endanger people on board when a tsunami arrives. Therefore, the initial positions of ships are assumed along side of berth, which was recognized by AIS receiver. It was recognized that the maximum number of ships was around 10 (ten) which were located alongside the berths.

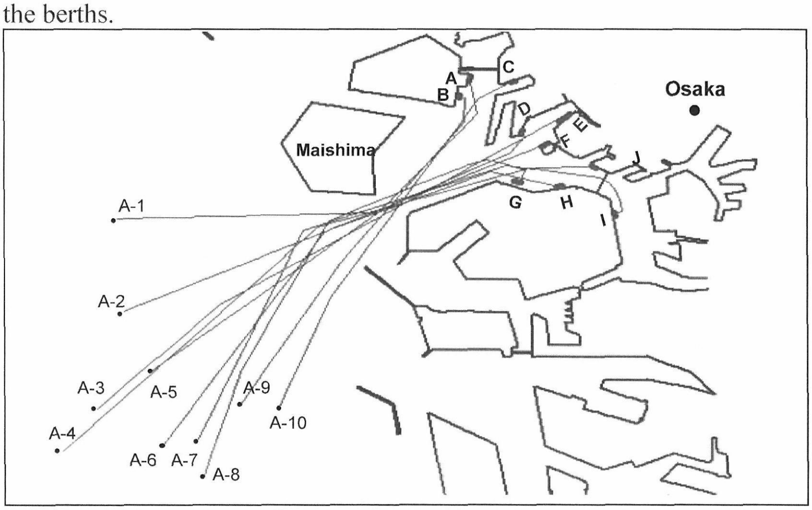


Fig.13 Initial position and anchorage location of vessels

The detail type and location are shown in Table 2. It shows that there are various types of vessels which are located along side in berths. A till J are the name of berths, where vessels are anchored.

Table 2 Initial position of vessels

Ships type	**Number**	**Location**
General cargo	1	D
Container	2	H,1
Ferry	1	G
Cruise	1	E
Refrigerated cargo	1	A
Vehicle carrier	1	B
General cargo	1	C
Bulk carrier	1	F
General cargo	1	J

6.4 Scenarios

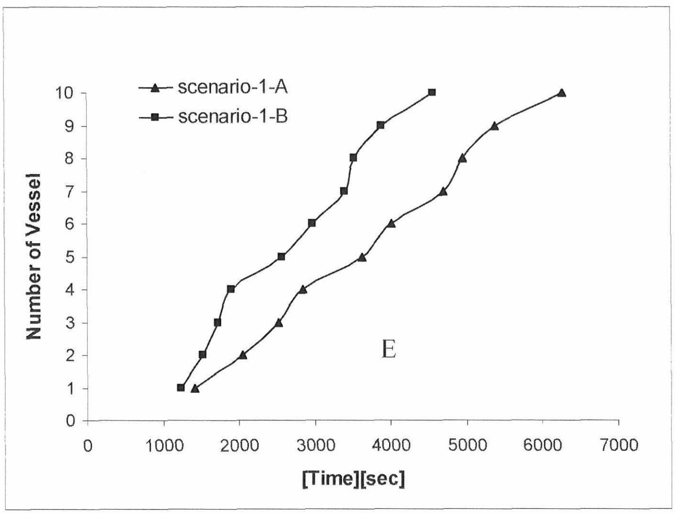
All vessels are initially assumed to anchor alongside in port, which was previously explained. When the information regarding a tsunami is announced, ships are to evacuate immediately to anchorage areas such as A-1; A-2 till A-10 as shown in Fig. 13. The largest passenger vessel is assumed to evacuate first in all scenarios, since it carries many passengers and it will be jeopardized if it is not evacuated immediately. Moreover, ships are assumed to follow normal Port of Osaka regulations. They cannot pass each other due to the narrow channel and area. They are assumed to proceed at a moderate speed, which is around 3–5 m/s. In case a tsunami arrives, all ships inside Osaka port area have to evacuate to the anchorage area, which have a depth of 15-16 m. For cruise ships, the foreside faces in bound, therefore, the ship has to move back and look for room to turn back. The pilot also is assumed to have come on board before the ship proceeds to anchorage area.

The scenarios are basically divided by 2 clusters as following: scenario 1 and scenario 2. Scenario 1 (one) consist of scenario 1-A and 1-B. Both scenarios 1-A and 1-B assume that the largest vessel, which are based on Gross Tonnage (GT) have to evacuate first. Moreover, in scenario 1-A, each vessel has to keep distance as shown in Fig. 12 However, in scenario 1-B, the distance between two vessels are half of scenario 1-A distance or 8L+2L1 as shown in Fig. 12. The order of vessel for conducting emergency evacuation is as following: E-F-B-A-G-I-C-D-H-J as shown in Fig. 13. It means that ship "E" evacuate first, then it is followed F till J.

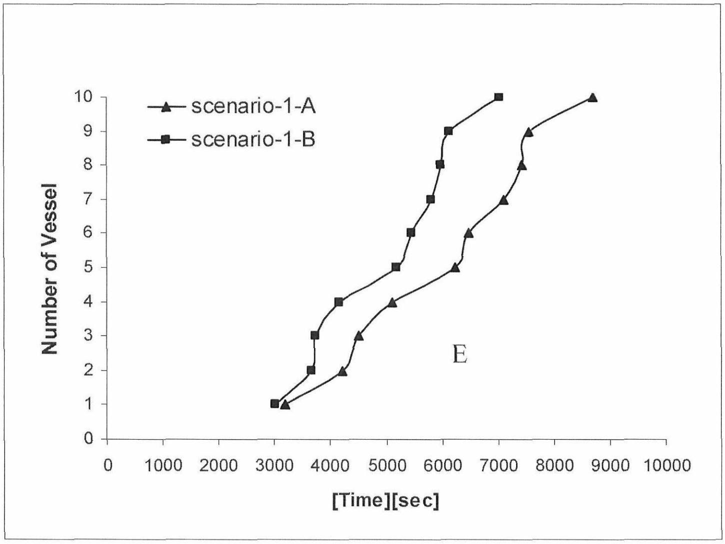
As same as scenario 1, Scenario 2 is also divided by two scenarios as following: Scenario 2-A and Scenario 2-B. In this scenario, the closest distance of vessels from the bottleneck evacuate first, then it is followed by those farther from the bottleneck evacuating to the shelter area. The distances between two vessels are shown in Fig. 12. In Scenario 2-B, the Scenario is similar to Scenario 2-A, however, the distance of the vessel is half of the distance of Scenario 2-A. In both of those scenarios, the order to evacuate vessels are as following: E-D-G-F-B-A-C-H-J-I as shown in Fig. 13. The distance of the anchorage port to the bottleneck is measured based on ship tracking line, which is recorded by AIS.

7 Results of simulation

The result of the simulation can be seen in Fig. 14 and 15. Those figures represent the result of Scenario 1 including Scenario 1-A and 1-B and Scenario 2 including Scenario 2-A and 2-B respectively. Fig. 14(a) shows the time needed for any vessel passing the bottleneck of the channel. By using scenario 1-A, it shows that the last ship that evacuates may face the first tsunami arrival. However, in scenario 1-B, all ships avoid the first tsunami arrival, since the time needed to proceed to the bottleneck of the channel is below 6000 seconds. However, Fig.14 (b) shows that several vessels may face the first tsunami arrival, when they arrive in their anchorage point. However, large passenger vessel, which are represented by "E" and carry many passengers may be able to proceed to her anchorage point before tsunami arrival as shown in Fig. 14(b).



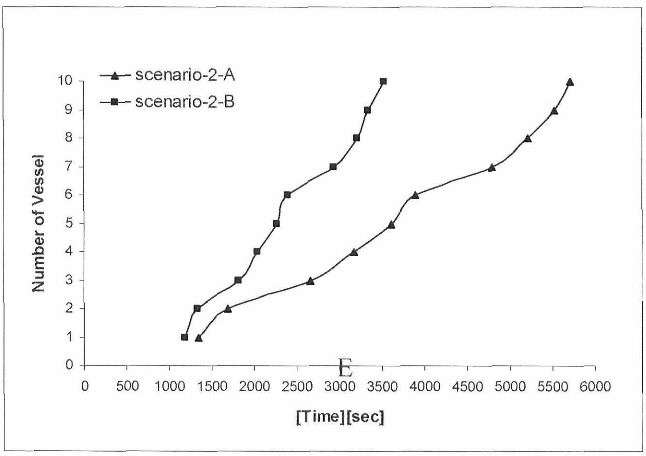
(a)



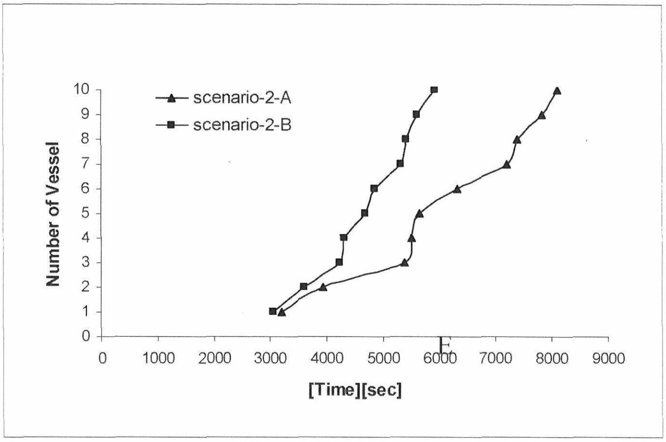
(b)

Fig. 14 Results of scenario 1 simulation

By using this scenario, Fig. 15(a) shows that all vessels may not face the first tsunami arrival at the bottleneck. However, from Fig. 15(b), it shows that by using scenario 2-A, around 5 (five) ships will probably face the first tsunami arrival. However, by using scenario 2-B, it is possible for all vessels to carry out emergency anchoring in anchorage area before the tsunami arrival.



(a)



(b)
Fig. 15 Results of scenario 2 simulation

From all scenarios, if this ship evacuates first, it seems that it is possible for a large passenger vessel which is in anchorage in Tempozan Terminal to evacuate safely, since average time needed is around 3200 seconds which is far below from the first tsunami arrival time.

8 Conclusion

In this study, several considerations have to be taken into account by the ship master, who may be piloting a cruise ship in Osaka Bay and use the largest passengers vessel as a representative of cruise ships. It shows that if the cruise ship is evacuated first, a cruise ship may be able proceed to the anchorage safely. However, if port authority decides for a large passenger vessel not to proceed first; it is not recommended for ship master to keep distance as normal distance condition, since it will spend a longer time to evacuate to the anchorage area. It is possible for the ship master to use moderate speed in order to avoid a collision in case of a tsunami arrival. Even if the fore side of ship faces inward of the port, it is possible for a cruise ship to evacuate from inside the port area. Moreover, the ship master must conduct immediate emergency anchorage in shelter area by following port authority instructions, if any, since the initial position of the vessel is not spacious enough and it may destoy the berth and any facility along side the berth. Moreover, it will be better for any ships which carry many passengers or dangerous goods to evacuate first.

Ship masters have to communicate with the Port Authority regarding a tsunami arrival. Moreover, they have to follow the instruction from the Port Authority, if any, since the traffic density inside the port also has to be taken into account.

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