RESEARCH ON STRENGTHENING COOPERATION BETWEEN THE PORTS DURING LARGE-SCALE DISASTERS

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ABSTRACT**:** When the port facilities are damaged by the natural disaster such as large-scale earthquakes and a port function is paralyzed, the logistics base of the bulk cargo (crude oil, iron ore, coal etc.) which is not suitable for transport by land is more likely to suffer damage of the natural disaster because the logistics base is located near by the port. On the other hand, because the logistics base of the bulk cargo (cereals, car, etc.) and the marine container cargo which are suitable for long-distance transport by land is located in the distant place from the port, the port logistics can be restored early with non-damaged ports by the natural disaster.

In Japan, the outbreak of the large-scale earthquake of Level class two is expected in future. Then, the authors pinpointed the damaged ports by the natural disaster and the non-damaged ports, and simulated the change of the marine container cargo logistics by sacrifice model. As a result, the authors clarified the next points.

The volume of the cargo shifted from the damaged ports to the non-damaged ports exceeds the capacity of the non-damaged ports. The port facilities where the large vessels are going into service between Japan and the North America or Europe are in particular short.

The inflection of the overseas main ports such as Busan and Kaohsiung is indispensable. For the early recovery of the port logistics, plural ports should strengthen cooperation each other.

Finally, the authors will propose the reinforcement of the port facilities to realize these points and to prepare for large-scale natural disaster.

KEYWORDS: Large-scale Disaster, Cooperation between the ports, Early Recovery

1. INTRODUCTION

Of the major ports in Japan (Fig. 1), the Great East Japan Earthquake in 2011 destroyed 10 ports located on the Pacific side of Tohoku Region (Fig. 2) and left the port logistics paralyzed. The ports on the Sea of Japan side, shown in Fig. 3, then functioned as backup for port logistics on the Pacific side. In addition to being responsible for transporting the emergency supplies to the stricken areas, the ports on the side of Sea of Japan took on the necessary logistics for resuming the operations of private businesses. The Great East Japan Earthquake oddly made us realize the importance of healthy ports to back up the disaster-stricken ports.

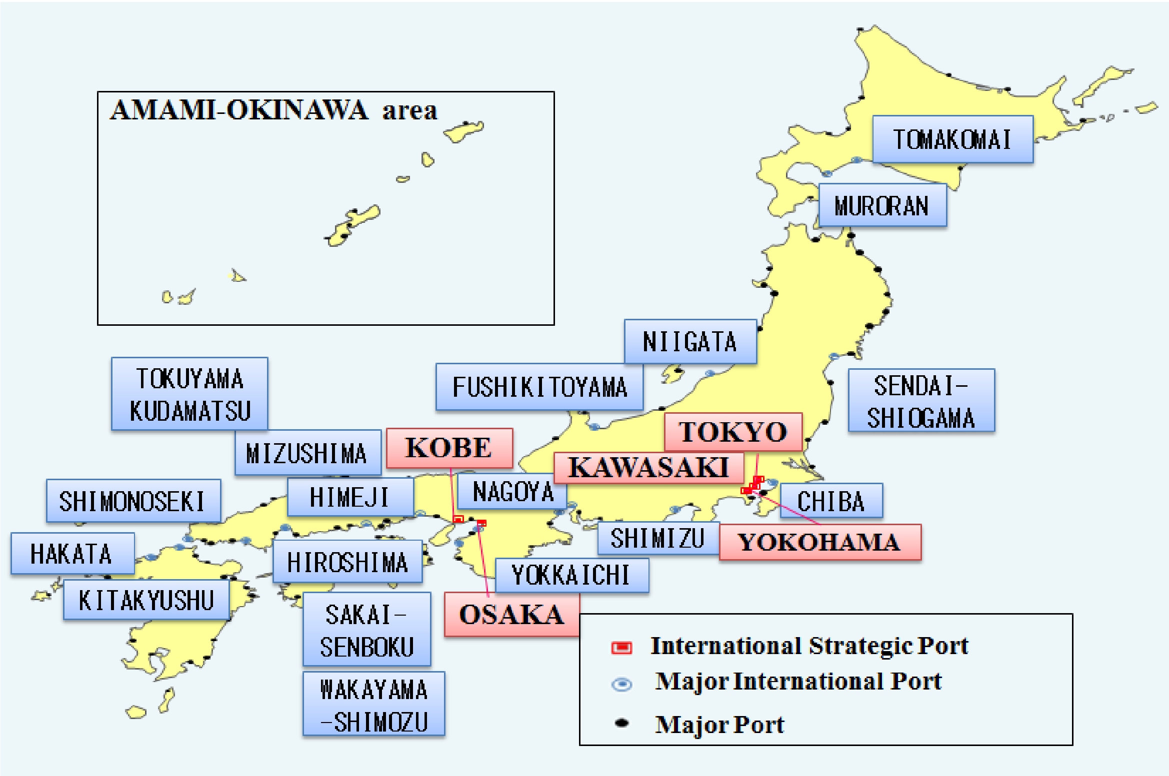

Fig.1 Locations of ports in Japan

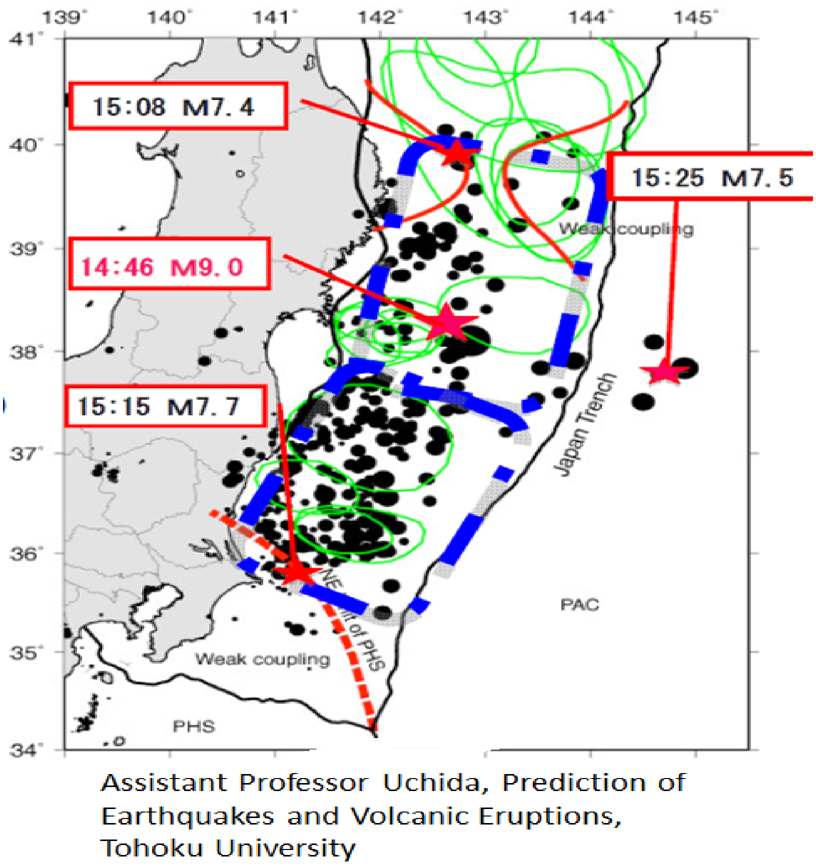

Fig. 2 Ports damaged in the Great East Japan Earthquake

Fig.3 Distribution of goods from ports on the Japan Sea side (left) to ports on the Pacific side (right)

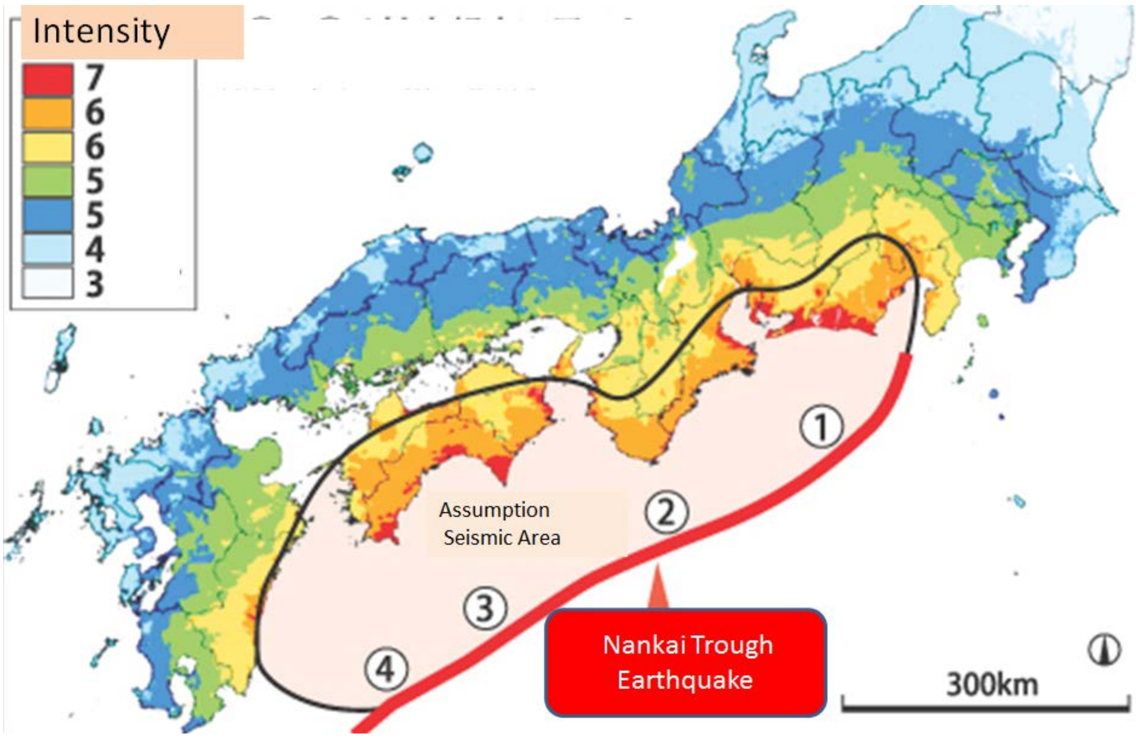

Fig.4 Distribution of the maximum of the seismic intensity

Meanwhile, the Nankai Trough Earthquake, which is expected to occur in the future, is predicted to cause damage concentrated in the Pacific side ports in the middle western part of Japan based on the expected point of origin, as shown in Fig. 4. The authors decided to verify which ports would function as backups for the stricken ports if several of the expected earthquakes do occur in the future, including the Nankai Trough Earthquake, in order to fully utilize the lessons learned from the Great East Japan Earthquake. In this verification, marine container shipments that can be horizontally transported on land over long distances were considered the subject cargo, and the Sacrifice Model was adopted as the model for estimation. Although bulk cargo such as completed automobiles can also be transported on land over long distances, this was not included in this estimation. It was supposed that the transport routes would be changed for these shipments in accordance with the container cargo.

Based on the estimation results, the authors declare that Japan should urgently establish its policy on whether to form domestic hub ports that large ships can call on the Sea of Japan side or to depend mainly on overseas ports with transshipment, utilizing the ports of other countries such as Busan, in order to deliver the backup functions.

2. OVERVIEW OF THE SACRIFICE MODEL

The sacrifice model is a type of decision-making model that digitizes behavior patterns to select the route that wastes the least time and cost (in other words, has the least sacrifice) for transport or movement when cargo is transported or a traveler moves. A characteristic of this model is that it simply digitizes the main two factors for route selection, which are time and cost.

2.1 Concept of the sacrifice model

Sacrifice is expressed by the following equation:

$$Sr = Cr + \alpha \cdot Tr \qquad (1)$$

Sr: total sacrifice, ***Cr***: cost, ***α***: time value,
Tr: time

The total sacrifice ***Sr*** for route ***r*** is expressed as the cost ***Cr*** required for each route including fares and transport expenses added with the product of the estimated time ***Tr*** required for the corresponding route and time value ***α,*** which is determined by the characteristics of the cargo or traveler.

Now, how is a route selected using sacrifice? The concept is shown in Fig. 5. In Fig. 5, the vertical axis plots the total sacrifice and the horizontal axis the time value. For example, supposing that there are three routes that can be selected to transport cargo from the place of departure to the destination, the three routes vary in transport expenses and required time and thus the sacrifices expressed by Equation (1) are calculated as S1, S2, and S3. S1 is a route whose transport expense is low but the time of transport is long, whereas S3 has high transport expense and short time of transport. S2 has intermediate transport expense and time between S1 and S3. On any of these routes, the total sacrifice S becomes larger in proportion to the time value.

Therefore, the route to be selected varies depending on the time value. In Fig. 5, Route 1 would be selected if the time value were smaller than α12, Route 2 if it were between α12 and α23, and Route 3 if it were α23 or larger.

Meanwhile, time value varies depending on whether it is cargo or a traveler, and each forms a point on a line when seen individually. It is thus

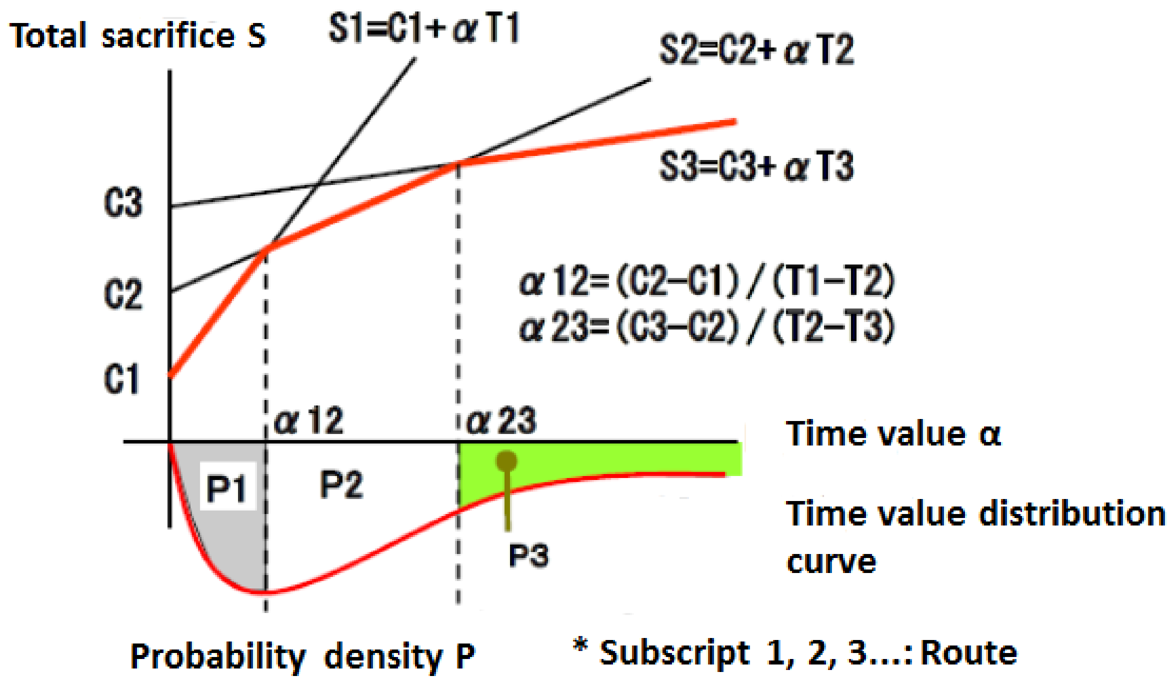

Fig. 5 Conceptual diagram of a sacrifice model

possible to express the time values as a collection by grasping how they are distributed when they are considered collections of shipments or travelers.

In general, there are practically no studies on shipping cargo, although research on estimating the time value for travelers has been more extensively conducted. It was therefore presumed that the time value for cargo would have logarithmic normal distribution pursuant to the estimation method for travelers. It was also presumed that the probability for the person making the choice to select the transport route would be the same as the actual measurement value for a container cargo flow survey.

2.2 Data used for analysis and assignment of ports

The data used for analysis were the results of a flow survey on marine container shipments conducted every 5 years jointly by the Ministry of Land, Infrastructure, Transport and Tourism of Japan and Japanese customs. The survey included minute items such as routes for marine container shipments; city, town, or village of production or consumption; container vanning and devanning locations; ports of loading and unloading; ports of exit and destination; and countries of origin and destination, as well as freight quantity transported (freight ton), list of articles, declared value (yen) and means of international transport; the survey had a large application range and high data reliability.

Because the ports used in the research are where marine container shipments pass in Japan, The authors represented all of Japan with 35 ports, by determining 1 representative port in each prefecture in addition to the 4 major areas (Tokyo Bay, Ise Bay, Osaka Bay, and Northern Kyushu).

As overseas ports, the authors selected the ports shown in Table 1 as representative ports in East Asia so that there would be no bias in distance. In addition, 5 ports (Busan, Hong Kong, Gaoxiong, Singapore, and Shanghai) show high transshipment rates as well as direct shipment between ports.

Based on these presumptions, and because the total number of routes subjected to this analysis was approximately 1,400 for export from Japan, the authors conclude that the routes in East Asia could be reproduced.

2.3 Reproducibility of the sacrifice model

The authors verified the reproducibility of the sacrifice model by utilizing the record values for flow survey on marine container shipments. Although they do not match completely, it is considered that reproducibility sufficient for verification is delivered. Reproducibility similar to the shipments exported to North America was also delivered for total cargo volume and the rate of transshipment cargo at overseas ports in the total cargo volume in other cases. Thus, the authors assumed that the sacrifice model had sufficient precision for making estimates.

Table 1 Settings of representative ports and harbors in East Asia

Country	Breakdown in region		Representative port
China	North	Liaoning, Jilin, Heliongjiang, Beijing, Tianjin, Hebei, Inner Shantung, Mongolia, Shaanxi, Gansu, Qinghai, Ningxia, Xingjiang	Dalian
	Middle	Shanghai, Jiangsu, Zhejiang, Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan	Shanghai
	South	Fujian, Guangdong, Hainan, Kwangsi, Chongqing, Sichuan, Guizhou, Yunnan, Tibet	Hong Kong
South Korea	-		Busan
Taiwan	-		Gaoxiong
Thailand/Myanmar	-		Laem Chabang Port
Singapore	-		Singapore
Indonesia/Malaysia/Brunei	-		Tanjun Priok
Vietnam/Laos/Cambodia/the Philippines	-		Ho Chi Minh

Table 2 Areas where port functions will become paralyzed in case of a future expected earthquake

Case		Hyuga -nada	Nankai	Tonankai	Tokai	The Metro -politan area	East Japan
1	Great East Japan Earthquake						✔
2	Earthquake that directly hits the Tokyo area					✔	
3	Tokai/Tonankai/Nankai Earthquake		✔	✔	✔		
4	Nankai Trough Earthquake	✔	✔	✔	✔		
5	Basic (Non-Disaster)						

3. ASSUMPTION FOLLOWING A NEW EARTHQUAKE

Table 2 shows the areas where earthquakes and their damage are expected for which simulations were made using the sacrifice model. Case 1 shows the Great East Japan Earthquake. Cases 2 to 4 show earthquakes that are feared to happen in the future. Simulations were conducted by supposing that the functions of the ports in the area where damages are expected would be paralyzed. In addition, the simulation results were compared with the results of Case 5, in which there is no earthquake, because the estimation errors would be reflected in the results if they were compared with actual results values.

The preconditions of the damaged ports in these simulations are as follows;

a. Large vessels connected with North America or EU cannot use damaged ports.

b. Small vessels connected with overseas transshipment ports can use damaged ports.

For example, in the case 2, although the container vessels of 4000TEU for North America cannot use Tokyo Bay, the small vessels can be conveyed to Busan Port, etc. using Tokyo Bay.

4. SIMMULATUON RESULTS

The results of Cases 1, 2, 3, and 4 are shown in Figs. 6, 7, 8, and 9. Now let us see the simulation results.

Case1 (Great East Japan Earthquake) has a small difference with a basic case. This is because the cargo volume of a stricken area is small.

In Case 2 (an earthquake that directly hits the Tokyo area), 3.7 million tons per month of marine containers, which corresponds to 35% of the 10.5 million tons per month (2008) of marine containers for all of Japan, are diverted to other ports. The simulation results show that Shimizu Port, Ise Bay, Osaka Bay, and Kanazawa Port, Mizushima Port will function as backups for the 3.7 million tons of marine containers and that the transshipment containers would nearly double in number at the Shanghai, Singapore, Hong Kong and Busan Ports.

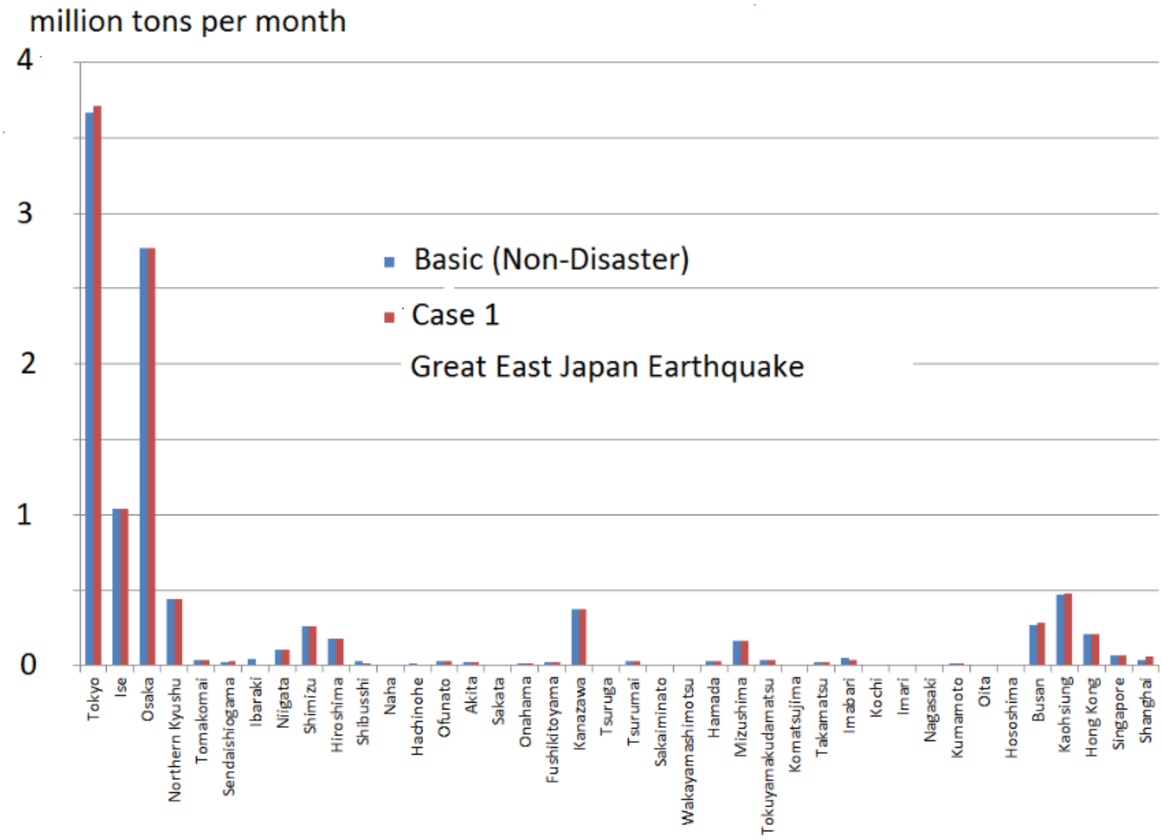

Fig. 6 Effects of the Great East Japan Earthquake (Case 1)

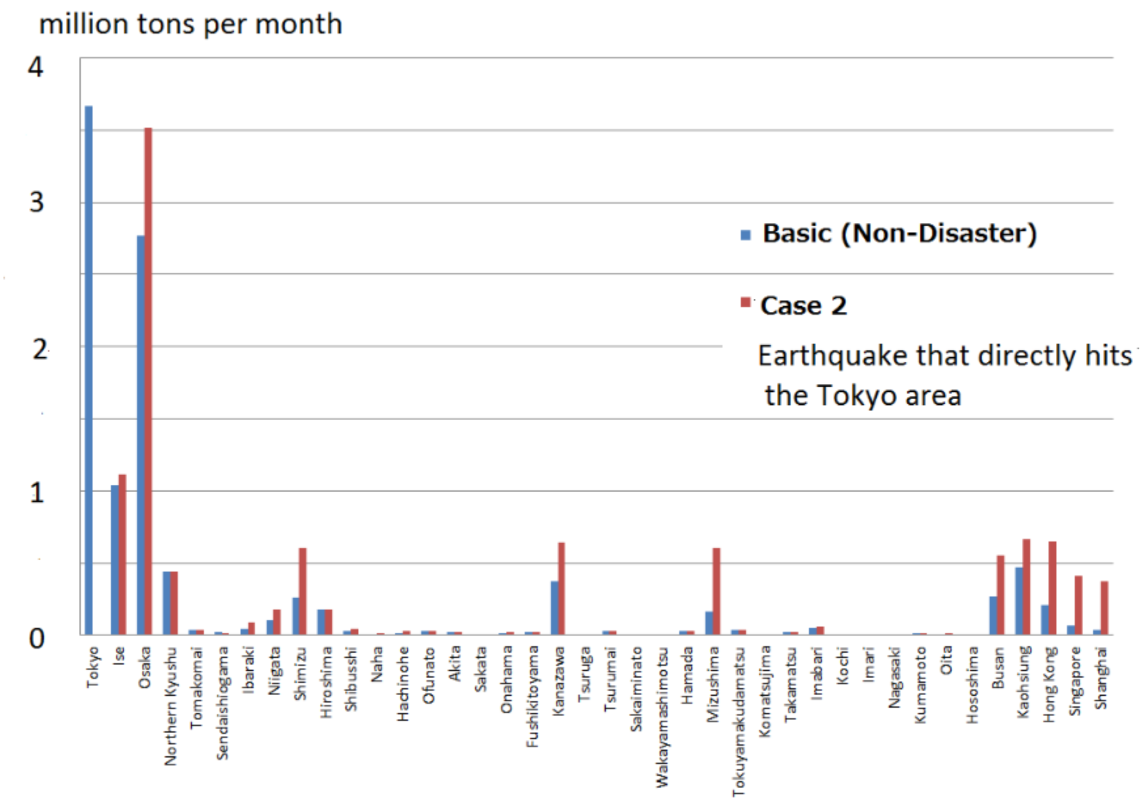

Fig. 7 Effects of an earthquake that directly hits the Tokyo area (Case 2)

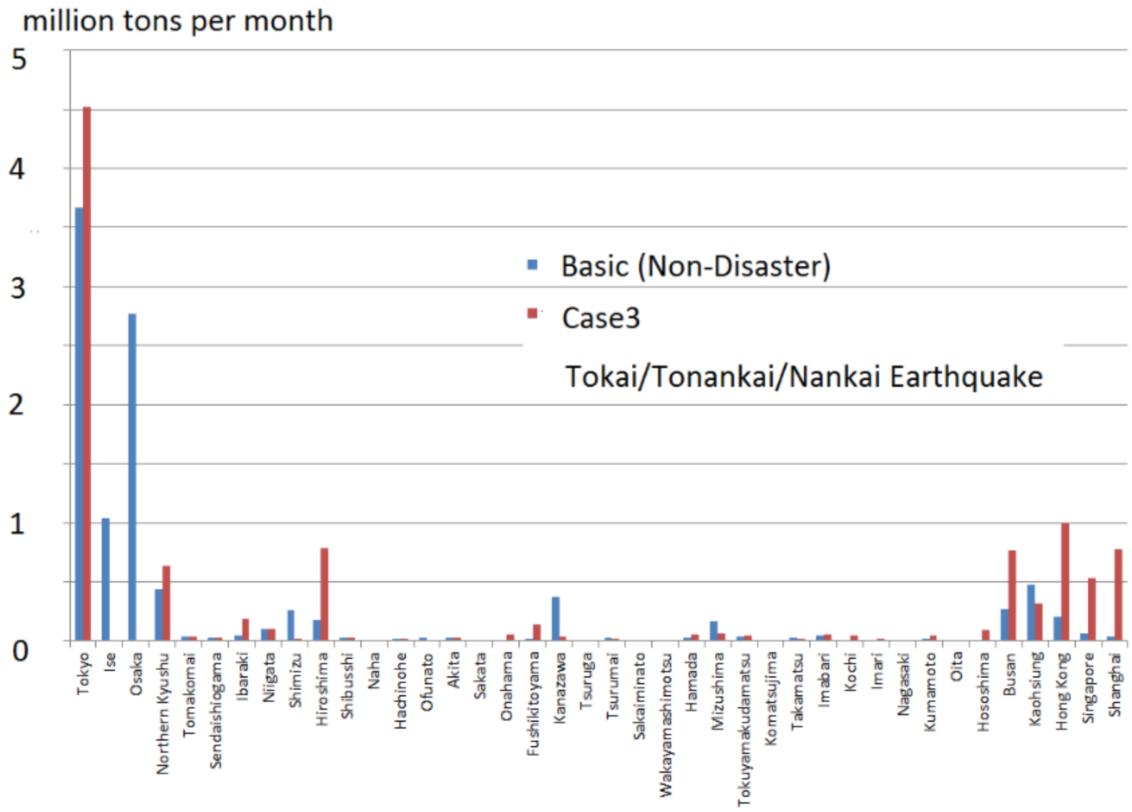

Fig. 8 Effects of a Tokai/Tonankai/Nankai earthquake (Case 3)

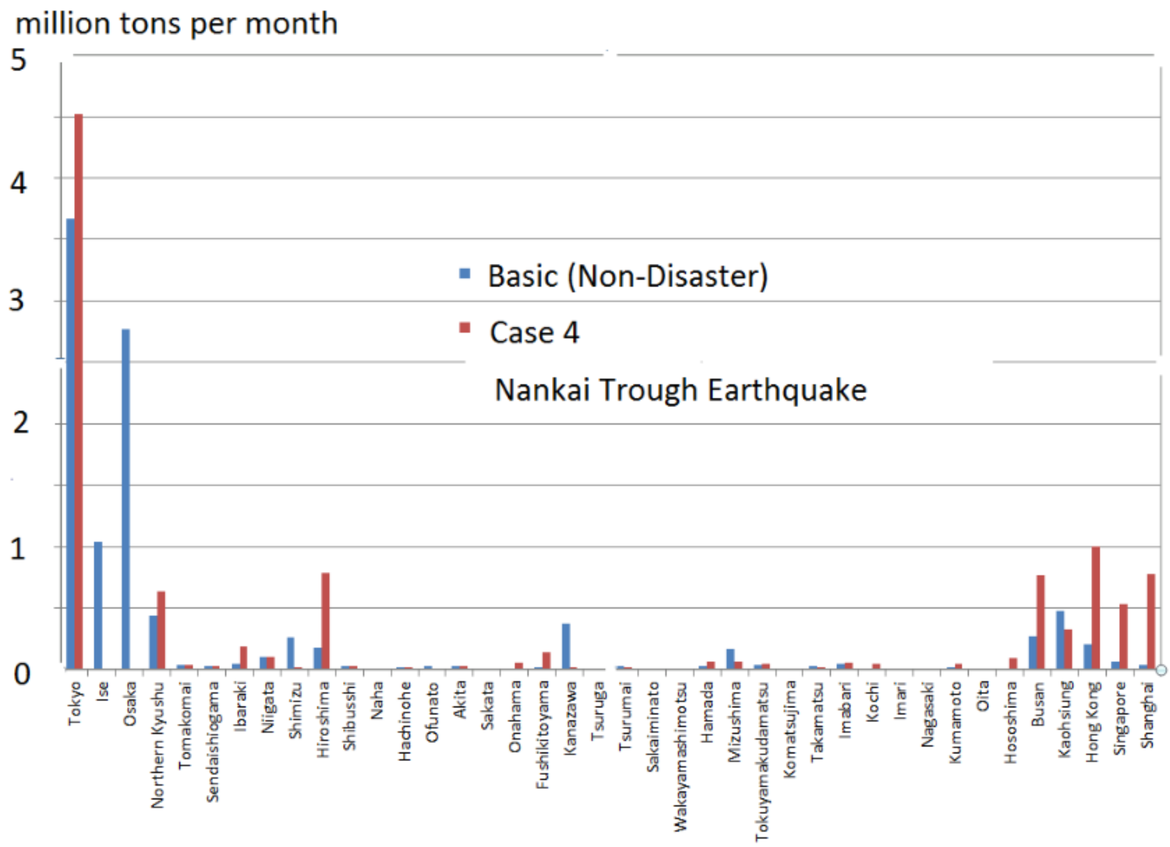

Fig. 9 Effects of a Nankai Trough Earthquake (Case 4)

In Case 3 (Tokai/Tonankai/Nankai Earthquake), Tokyo Bay, Hiroshima Port and the ports on the Northern Kyushu would function as backups for 4.1 million tons per month of marine containers, which corresponds to 39% of Japan's total container cargo, and the transshipment containers would nearly double in number at Busan Port, Hong Kong Port and Shanghai Port.

Case 4 (Nankai Trough Earthquake) was very similar to Case 3. Because the volume of marine container cargo presumed in Case 4 for Miyazaki and Kagoshima Prefectures was not large compared with the overall volume, the simulation results did not vary considerably from Case 3.

5. SCENARIO FOR ESTABLISHING A BACKUP SYSTEM

What can be commonly said about all cases is that the handled volume for each port that functions as a backup for ports destroyed by earthquakes would double or more than double. Because shipments exceeding the capacities would be concentrated on the backup ports, these ports' limits for handling shipments would be practically exceeded. It is also expected that a concentration of transshipments would occur at Busan Port, Shanghai Port, Kaohsiung Port, Hong Kong Port, and Singapore Port, where an increase in transshipment containers is predicted. Table 3 shows the increase in transshipment cargo volume at overseas ports. On the whole, at overseas ports, the volume of cargo handled would increase to 3 or more times. In particular, in the rate of increase, Shanghai, Singapore, Hong Kong and Busan are high.

Thus, the authors believe that it is necessary for Japan to consider the following scenarios when they develop a backup system in case of earthquakes:

5.1 Scenario 1: Provide full support with backup ports

In this case, expansion in capacity will be necessary in terms of facilities, including capacity to allow the docking of large ships and handling capacity for marine container shipments. It is difficult to handle 40% of the marine container shipments for the entire country of Japan in terms of the scale of facility capacity and the size of investment, and it is not easy to change the ports of call for large ships that make

Table 3 Increase in transshipment cargo volume at overseas ports

	Non-Disaster	Case 1	Case 2	Case 3	Case 4
Busan	0.27 (1.00)	0.29 (1.07)	0.55 (2.08)	0.76 (2.86)	0.77 (2.88)
Kaohsiung	0.47 (1.00)	0.48 (1.00)	0.67 (1.41)	0.32 (0.67)	0.32 (0.68)
Hong Kong	0.21 (1.00)	0.21 (1.00)	0.65 (3.12)	1.00 (4.75)	1.00 (4.75)
Singapore	0.07 (1.00)	0.03 (0.39)	0.41 (5.87)	0.53 (7.59)	0.53 (7.59)
Shanghai	0.04 (1.00)	0.06 (1.57)	0.38 (10.29)	0.78 (21.25)	0.78 (21.25)
Total	1.06 (1.00)	1.06 (1.00)	2.66 (2.52)	3.38 (3.20)	3.39 (3.21)

Unit: million tons per month (ratio)

tours around the world.

5.2 Scenario 2: Set up domestic hub ports for backup and coordinate by feeder transport

Because shipments were concentrated at Northern Kyushu, Niigata Port, and others in Cases 3 and 4, this scenario tries to position these ports as the hub ports for backup and to establish coordination with other healthy ports through feeder transport.

Although it is difficult to change the trunk routes for large ships, because the service patterns for the large ships all over the world would be affected, it is possible to change the service patterns for collection at ports where they already regularly dock or in concurrence with reducing the number of the ports of call. On this point, Northern Kyushu, Shimizu, Mizushima, Hiroshima, Kanazawa, etc. would play the important role of backup hub ports.

5.3 Scenario 3: International coordination with foreign ports such as Busan Port and Shanghai Port

This is the scenario for using transshipment of Japanese cargo at Busan Port, Shanghai Port, and others through international coordination. There has already been a case of international port integration between Copenhagen Port in Denmark and Malmö Port in Sweden. In this scenario, the national government of Japan would adopt a policy to promote the international coordination of ports. However, concluding an international agreement in case of disasters with Busan Port, which is a rival port to those of Japan, would inevitably force Japan to change its policy on international coordination.

6. CONCLUSION

To fully utilize the lessons we learned in the Great East Japan Earthquake, the authors verified the changes in logistics for marine container shipments through a simulation using a sacrifice model by presuming damages from earthquakes that are expected to occur in the future. As a consequence, it was found that approximately 40% of all the marine container shipments in Japan would need to be handled by healthy ports as backup, and that the volume of marine container shipments to be handled by the backup ports would nearly double or more than double.

It was also clearly shown that the ports of the three largest bays would back up one another, and that the ports on the Sea of Japan side would also play important roles as backups for stricken ports.
However, in reality, the backup ports are not capable of accepting that much cargo volume, nor are they large enough to allow the docking of large ships. Therefore, the authors proposed three possible scenarios. The first scenario was to improve the capacity of each backup port, the second was to improve the capacities of several backup ports to form domestic hub ports while conducting feeder transport with other ports, and the third was to promote international coordination with Busan Port, Shanghai Port, and others.

In light of the port arrangement theory from the viewpoint of physical geography, the authors believe that the second scenario is the most practical. Japan needs to urgently decide which ports should be developed as backup hub ports and have the system for port logistic backup established before another large earthquake occurs.

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