Analysis of drifted drums of dangerous goods in Osaka Bay during the great Hanshin-Awaji earthquake

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Abstract

On January 17, 1995 the Great Hanshi-Awaji earthquake struck. 164 drums of dangerous goods stored in Karumo-island, to the west of central Kobe, were lost into the sea. A search was immediately executed. The purpose of this research is to examine why the drums drifted so far and to different coasts outside of the Karumo-island area, and much more quickly than predicted

The drums were not stored directly facing Osaka Bay. They had drifted out from the island into Osaka Bay, but not according to the current investigation by the tide table. There was a big low tide with 151cm difference on the night of the earthquake. Most of the floating drums had drifted out to Osaka-Bay during this time. 110 drums were recovered by 29th January. On the other hand, one drum was found at Izumiotsu port in Osaka Prefecture on January 27th and two drums were found on the coast of Wakayama Prefecture on the 31ST. Therefore, further search efforts focused on the further coasts, such as Wakayama Prefecture; these were executed from 2nd February. In total, 145 drums were recovered; search efforts came to a halt on 17th February with 19 drums notrecovered. The total recovery costs came to about US $140,000.

The factors affecting drift objects at sea are: Tidal currents (particularly the current at each sea) wind-driven currents, and leeway. As the length of each drum was from the surface of the seawater to the top cover was about 10cm, it was considered that leeway did not have a big effect on the drift route of the drum. By using the Oil-spill Prediction Model, it is possible to make the distribution chart of an oil slick when we consider factors such as place, tidal current and tide-induced residual current, etc. We predicted the drift routes of the drums by comparing the oil slick distribution chart made by this model with the places where the drums were found in reality. Moreover, we calculated without considering properties of the oil, such as surface tension, evaporation and so on. This, because a drift object in this research is a drum. According to the calculating results, wind-driven currents had the most effect on an object drifting on the surface of Osaka-Bay. Tidal currents and tide-induced residual

currents had a big effect on the drums which were found on the western coast of Awaji island.

1 Introduction

The recovery efforts of drift objects were executed under high risk. Those put into the sea by damage from the earthquake, flood or accidents at sea, are generally expected to be dealt with at an early stage to help prevent disasters from marine hazards. It is, therefore, necessary to establish a risk management strategy to reduce the initial damage and risk caused by such accidents.

On January 17, 1995 the great Hanshin-Awaji earthquake hit Kobe Port in Japan. 164 drums of dangerous goods stored in the Karumo-Warehouse in Kobe fell into the sea at the Karumo-Seawater area. It was expected that recovery efforts would retrieve them quickly. The contents of the drums were Alkyl methacrylate, Methyl methacrylate and Butyl methacrylate. These are considered dangerous as they would cause seawater pollution. Moreover, there was concern that the drifting drums might interfere with the safe passage of ships navigating in Osaka Bay. This was also a danger. Apart from Karumo-Seawater area, it was reported that drums had been found further along the coastline of Osaka-Prefecture. Partial recovery was from a wider range than had been expected. This took several days, despite recovery efforts being executed immediately after the earthquake.

The purpose of this research is to inspect the risk management system at that time, and to study why the drums drifted to different coasts outside of the Karumo-Seawater area so much more quickly than our prediction. We will propose a drift forecast and searching method for a drift object; such as a drum or lost object from a passing vessel, loss of a container along the sea route, etc. We will also analyze the drift behavior.

2 The drifting drums of Osaka Bay from the Karumo-Seawater area

2.1 Site of damage area

Fig.2.1 Damage situation of Karumo-Bridge

Fig.2.2 Damage situation of the drums[1, 2)]

Karumo-Shima was built on reclaimed land in 1931 □) Fig.2.1 and Fig.2.2 show the damage situation to the Karumo-Warehouse in pictures taken immediately after the earthquake.

There were two routes for the drums to drift out and towards Osaka Bay. One is the right-hand route, about 750 m from Karumo-Warehouse to Osaka Bay. The other is the left-hand route, under the bridge, about 1,300 m from Karumo-Warehouse to Osaka Bay.

2.2 Current investigation of Karumo-Shima by tide table

It turned out that the almost all floating drums in the Karumo-Seawater area had drifted out to Osaka Bay before the recovery efforts of the 17^{th}. The tide tables of Karumo-Shima for the two days before the earthquake occurred were retrieved from the tide record table of the Japanese Coast Guard□). From this we ascertained the time when the drums began drifting toward Osaka Bay by the ebb current. Karumo-Shima is not registered as a standard port in the tide record table. Tides and tidal heights of there are calculated by using the described correcting method in the table.

2.3 Tidal record at Karumo area

Tides and tidal heights (except high and low tide from 17^{th} to 18^{th} January 1996) were also required and Fig.2.3shows the results.

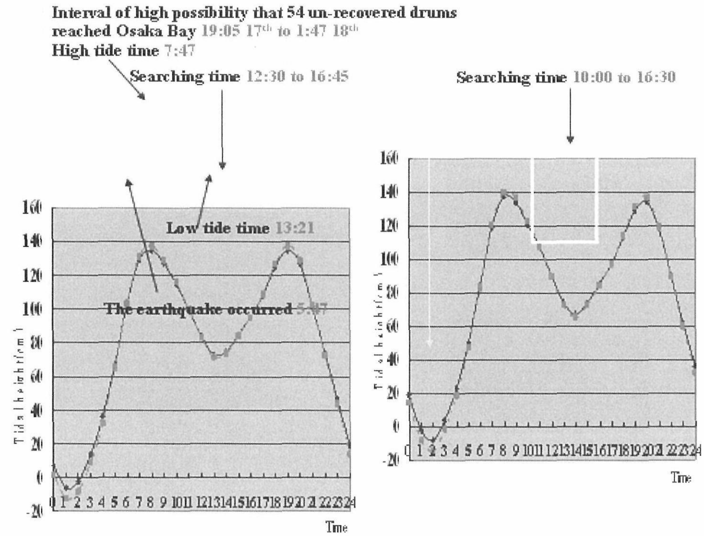

Fig.2.3 Tide records of Karumo-Shima from 17th to 18th January[3)]

According to Fig.2.3, the high tide of the 17th was at 7:47 am, about 2 hours after the earthquake. Therefore, the possibility that the drums began drifting toward Osaka Bay during this high tide period is low. After 7:47 am, it is estimated that the drums began drifting out on the low tide at 13:21 am. 164 drums were eventually lost into Osaka bay. 30 drums were recovered drums by the 17th between12:30 pm and 16:45 pm. It is considered that these recovery efforts were not so successful, because during the day of the earthquake the workers might have thought that it would be no great problem to leave the drums because the current speed of the seawater area was so slow. However, there was a big low tide from 19:05 pm on the 17th to 1:47 am of the18th, as shown in Fig.2.3. The tide difference at this low tide time was 151 cm and was over the prediction. On the other hand, the unrecovered drums had already drifted out to Osaka Bay before the beginning time of the recovery efforts on the 18th. Therefore, it was considered that most floating drums had drifted out to Osaka Bay during the low tide time.

3 Details of the drums drifting to each sea area

3.1 Detail of found drums in each coast

Fig.3.1 shows the found places of the drums on map From January 27th to February 17th

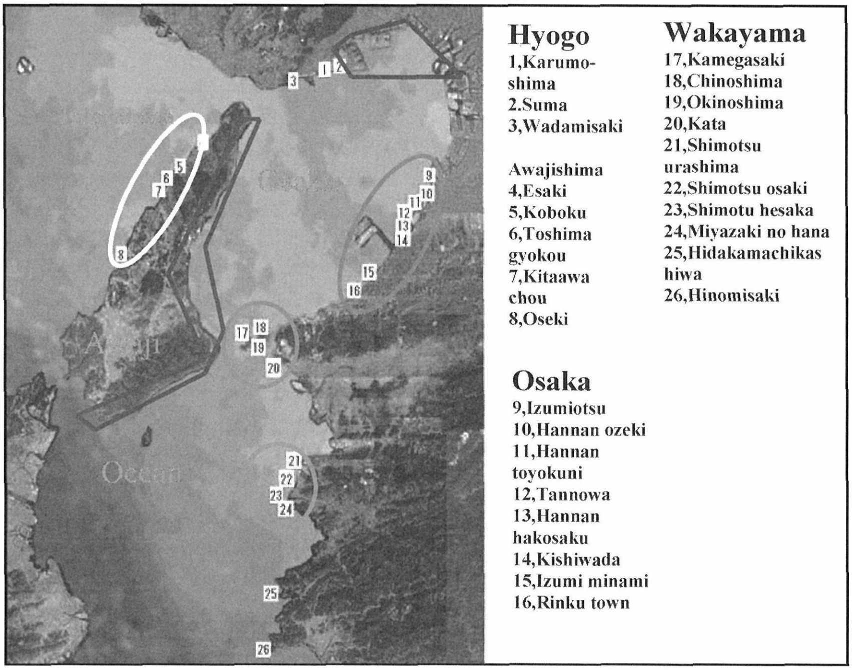

Fig.3.1 Places where drums were found

In Fig.3.1, it can be seen that the drums had drifted much beyond Karumo-Shima. The furthest was to Hinomisaki as shown by the number 26 in Fig.3.1. All of the drums located outside of the Karumo-Seawater area were found to have drifted ashore on the coasts, and were not drifting in the sea. In addition the drums which had drifted ashore were found almost in the same areas as shown at the frames red, yellow, pink and orange in Fig.3.1. On the other hand, there were areas (shown at the blue frame in Fig.3.1) where no drums were found at all, even as recovery efforts were enacted.

According to these results, it may be considered that the places where the drums drifted, or not, depends on, and is connected to, the currents of Osaka Bay. However, the total number of drums found was 35. Recovery efforts were discontinued on 17th February. A total of 19 drums were never seen again. It was thought that the unrecovered drums had sunk somewhere beneath the surface of Osaka Bay.

3.2 Prediction of the drift routes of the drums to the coastal parts around Osaka Bay

The factors influencing drift objects at sea are mainly ocean currents and tidal currents. Additionally, the shape of a drift object influences the drift route [5]. For instance, even if the place of a departure point and the weather are the same, driftwood which has sunk almost under the sea and a sailor of the same weight as the driftwood will have greatly different drift paths. This is because the influence of the wind on each is different. It is almost possible to guess drift routes if the factors mentioned above are grasped with accuracy. When guessing a drift route of some drift object in the ocean, such as the Pacific or Atlantic Ocean, then the main factors which makes drift objects flow "away" are the ocean currents, and not the tidal currents. But in this research, the seawater area into which the drums had been flowing was Osaka Bay, which can be considered an "Enclosed Coastal Sea" from the Pacific Ocean by the Kii Channel and from the neighboring western part of the Inland Sea by the Akashi Strait. In an enclosed coastal sea like Osaka Bay, there are no ocean currents, such as the Tsushima current which flows in the Japan Sea. Instead the influence of the tidal currents is large.

By using the Oil-spill Prediction Model developed by the Petroleum Association of Japan, it is indeed possible to make a distribution chart of an oil slick with consideration given to: the point of departure, tidal currents, tide-induced residual currents, river-water driven flow, the influence of sea wind, the kind of oil, and the outflow form of oil moment within Osaka Bay. The drift process of the drums is then analyzed by using the Prediction Model. [5]

3.3 Influence of leeway on the drums

As mentioned above, the sea wind is the prime factor which influences drift objects. The influences of the sea wind are leeway, when the sea wind sweeps drifting objects away directly, and the wind-driven current, which occurs when wind blows over the sea. In this section, we consider the influences of leeway on the drums. The ratio of volume of the floating drum on the sea surface is calculated by considering the different demystification of the packing situation on the drum and seawater.

3.3.1 Detail of the drum

The drifting drum has a capacity of 200 L and is called "H class". Fig.3.1 shows the side and upper view of the drum and with the name of each part listed.

□Numerical values of the drum
D (Diameter): 567 mm
D1 (Diameter of Rolling Hoop and Chime): 584 mm
H (Height): 890 mm
h (Height of chime) 7 mm
a (Height of Rolling hoop) 7 mm
W_d (Weight of the drum) 27.5 kg

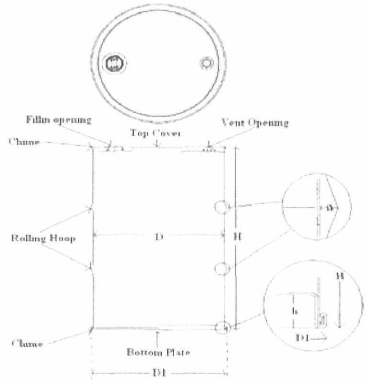

Fig.3.2 Detail of the drum

3.3.2 Calculation result

The drum is not the exact shape of a column due to the two rolling hoops 7mm high. It is considered to be small. Therefore, the volume of the drum is calculated without considering the volumes of the two rolling hoops. The ratio of the volume of the floating drum on the sea surface is calculated by considering the different density of seawater and the packing state of the drum containing Alkyl methacrylate.

□Volume of the drum (V_d)

$$V_d = \frac{D}{2} \times \frac{D}{2} \times \pi \times H$$
(3.1)

$$= \frac{567}{2}\ mm^3 \times \frac{567}{2}\ mm^3 \times \pi \times 890\ mm^3 \quad 224722214.4\ mm^3 \quad 0.2247\ m^3$$

□Weight of the packing drum (W_p)
Weight of Alkyl methacrylate (W_m)
W_m = Density of Alkyl methacrylate (D_a) × Volume of Alkyl methacrylate (V_a) (3.2)
$D_a \times V_a$

$= 0.87\ Kg/l \times 200\ \ell = 174\ Kg$

$W_p = W_m + W_d = 174\ Kg + 27.5\ Kg = 201.5\ Kg$

Density of the packing drum (D_p)

$$D_p = \frac{W_p}{V_d} = \frac{201.5Kg}{0.2247m^3} = 896.7512\ Kg/m^3 \quad 0.8967\ g/cm^3 \qquad (3.3)$$

According to these results, the ratio of volume of the floating drum is calculated by using the formula below.

$$\frac{\text{Density of the packing drum}}{\text{Density of the seawater}} = \frac{D_p}{D_s} = \frac{0.8967 g/cm^3}{1.025 g/cm^3} \times 100 \quad 87\ \% \qquad (3.4)$$

Therefore, ratio of volume of the floating drum on the surface of the sea is 13 %.

3.3.3 Discussion on forces moving the drums

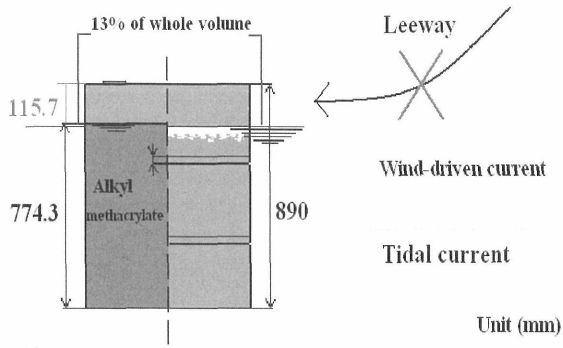

Figure 3.3 Floating Drum at Sea

Since it turned out that the ratio of the floating drum on the sea surface is 13 % according to the calculation result, the length of the drum from the surface to the top cover is about 115 mm, as shown in Fig.3.3

Moreover, the other contents were Methyl methacrylate and Butyl methacrylate. The calculation result of Methyl methacrylate was only 7 % and that of Butyl methacrylate was 11%. The weight of packing state of the drum is about 200 Kg each and it is too heavy. The side of the drum is spherical in shape which can be influenced by sea wind and is quite different from the shape of a sailboat, which is of course easiest to be influenced by sea wind. Therefore, it is considered that sea wind influencing the floating drums are low in potential.

Therefore the factors most influencing the drums are tidal currents and wind-driven currents.

3.4 Distribution chart of the oil made by using the Oil-spill Prediction Model

The Oil-Spill Prediction Model developed by the Petroleum Association of Japan enables us to investigate the oil slick distribution chart when considering point of departure, tidal currents, tide-induced residual currents, river-water driven flow, the influence of sea wind, the kind of oil, and the outflow form of oil (discrete or continuous) in Osaka Bay. Based on these calculated conditions, the drifting tracks and the distribution chart of the drifted drums can be predicted by adapting the real conditions while they were drifting in Osaka Bay. According to the discussion in section 3.3, the factors influencing drifting objects at sea were tidal currents, tide-induced residual currents, and wind driven currents. However, there are also compounded currents: such as tidal current and tide-induced residual current, tidal current and wind driven current, which compound the factors at sea. Therefore, the combinations of the factors influencing drifting objects at sea are shown in the following.

① Tidal current □ Wind driven current

② Wind driven current □ Tide-induced residual current

③ Tidal current □ Tide-induced residual current □ Wind driven current

The drifting tracks and distribution chart of the drifting drums are predicted by comparing where the drums actually drifted ashore and the results of the drifting tracks and distribution chart of oil, calculated by adjusting each of the calculating conditions above, along with the combinations of the factors influencing drifting objects at sea.

3.5 Calculated results and discussion

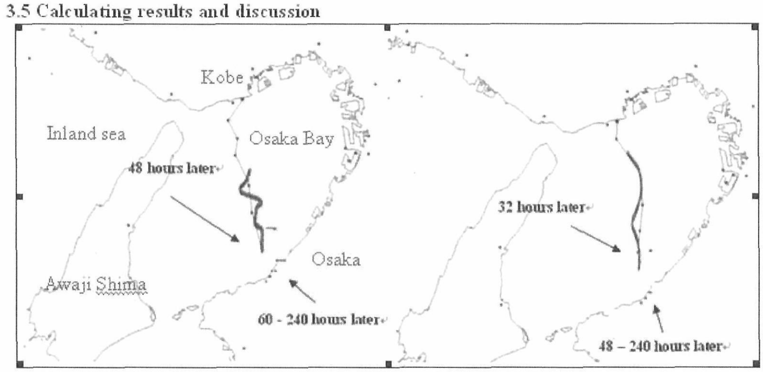

Fig.3.4 Calculating result of Tidal current+ Wind driven current

Fig.3.5 Calculating result of Tide-induced residual current + Wind driven current

The oil track in Fig.3.4 shows the top of the oil slick. Here, all of the oil slick shown as being below are on top of the oil slick. As shown in Fig.3.5, the top of oil slick drifts toward the coastal parts of Osaka Prefecture; though near the center of Osaka Bay. The top of the oil slick got into the coastal part of Osaka Prefecture 60 hours from the start time of the calculation. The rest of the oil slick got into the coastal parts of Osaka Prefecture, as shown in Fig.3.4 one after another. Moreover, the oil slicks that drifted ashore in the coastal parts of Osaka Prefecture never moved until 24 hours later. As shown in Fig.3.5, the calculated result was similar to the calculating result of Fig.3.4: The top of the oil slick got into the coastal parts of Osaka Prefecture 48 hours later. Moreover the rest of the oil slicks never moved until 24 hours later, after reaching the coastal part of Osaka Prefecture. This is shown as the calculated result of Fig.3.4. According to Fig. 3.4 these results, by exchanging the calculating condition, such as tidal current or tide-induced residual current, the difference of speed of oil slick can be seen, while the different landing place of the oil slick could not be seen. Therefore, it turned out that the influence of wind driven current on the drifting route of the oil slick was bigger than the influence of the tidal current or the tide-induced residual current.

3.6 Tidal current + Tide-induced residual current + Wind driven current

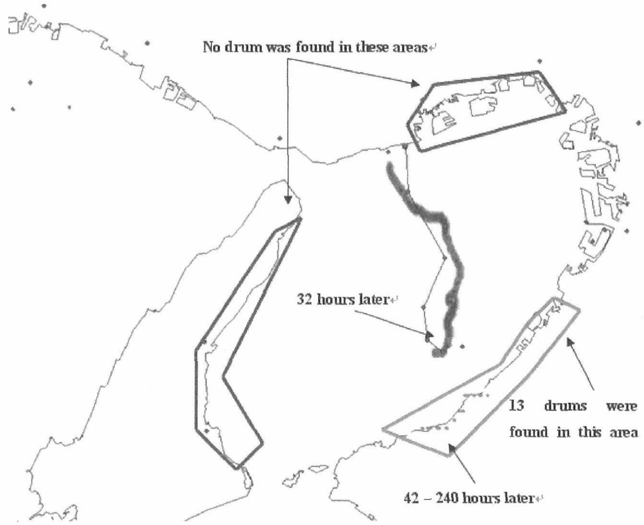

Fig.3.6 Calculated result of tidal current + tide-induced residual current + wind driven current

The top of oil slick arrived at the coastline of Osaka Prefecture 42 hours after the earthquake first struck. This was the fastest of all the results. The oil slicks didn't move until 240 hours later, after they had drifted ashore into the coastal parts of Osaka Prefecture. According to the result, it also turned out that the influence of wind driven current on the oil slick was the biggest even when the compounded current of tidal current and tide-induced residual current were considered in the calculation.

3.7 Discussion on the current

The places where the oil slick drifted ashore in the calculating results were almost identical. Moreover, it is almost the same when compared with the pink frame shown in Fig.3.6, where the most drums were found in reality. As these results demonstrate, what most influenced the routes of the oil slick was the wind driven current. However, the data of wind used in this calculating was not that of real time. Moreover, only the drift behavior of Fig.3.6 was different. However, five drums were found in the coastal parts of West Awajishima. It was considered that the influence of the tidal current and tide-induced residual current was greater on the drums toward Akashi Strait. It was reported by the Kobe Maritime Safety Agency that one drum was found along the coast of Osaka Prefecture on 27th January, ten days after the earthquake. On the other hand, the calculated result of Fig.3.6 shows that the top of the oil slick arrived at the coastline of Osaka Prefecture 60 hours later. This was the slowest. The volume of the oil slick or the drum under the surface of sea is completely different. This means that the ratio of the influence on drifting objects under surface of sea is different. Given this consideration, it is hard to consider that the drift behavior of the oil slick and the drum is quite same, even if the weights are the same in the calculation. And the drum arrived at the coastline of Osaka Prefecture faster than did the oil slick. Therefore, it is predicted that the drum got there between 42 to 240 hours. The problem with this drift calculation is that no oil slick drifted toward the coast of Wakayama Prefecture. It is considered that the reason for the difference between the drift behavior of the oil slick and the drum is because the wind data was the average data, not real data. There might be a problem in the accuracy after five days from some accident happening though this drift calculation is probably effective within five days.

4 Conclusion

The drums were stored along the coastline, even though they were well known as dangerous goods. This meant that they would fall into the sea if stored in that manner. The recovery efforts commenced within seven hours of the great Hanshin-Awaji earthquake. But there was some ineptitude in the execution of the recovery efforts. Moreover, it was believed the drums would not drift into Osaka Bay, even if not immediately recovered. However, an extremely low tide had occurred that day, until nightfall.. This caused the majority of the floating drums to float away into Osaka Bay. It was hard for the risk management system, according to these facts, to consider other countermeasures to prepare for such an occurrence. The recovery efforts were executed in the coastal parts of Osaka Prefecture, Wakayama Prefecture and West Awajishima. They were continued for one month after the earthquake. They discontinued on 17th February, even though 19 drums still had not been found. It was estimated that the unrecovered drums had sunk underneath the surface of Osaka Bay or may have drifted to areas outside the recovery area. The recovery efforts costs exceeding some 10 million yen or $100,000 US as the search area was expanded. By comparing the calculated results with those drums found in reality, it turned out that there was a similarity of drift behavior with that of the drift objects. That is without the influence of leeway and oil, though each shape is different. However, it also turned out that the drift route changed greatly because of the influence of factors on the drifting objects in the sea, such as in Osaka Bay in which the tide-induced residual current had a major effect.

According to the research results, we conclude that the drums would not drift out from the Karumo Seawater area to Osaka Bay, and the search ranges of the drums in Osaka Bay were different from the area where the drums had actually drifted. Dangerous goods should not be stored along the coastline, even if the storage system of the dangerous goods is well maintained. Sometimes a large-scale disaster causes damage greater than our expectation. Therefore, it is necessary to establish countermeasures, such as drift prediction. It is proven that if the drift prediction was accurately done before, then that would lead to the reduction of the damage caused by drifting objects once they began to move. Finally, this thesis concludes that effective method of drift prediction is accurately to know the properties of likely drift objects, the conditions at the starting point, the currents of the sea, and real time data of wind in each area throughout the year.

References

[1] Private contact to Chikko Co.,Ltd.

[2] Onohama shipyard of Kobe, History of Kobe Port, Web site of Onohama shipyard of Kobe http://209.85.175.104/search?q=cache:t6WMPlNyS2kJ:homepage3.nifty.com/rekick/rcent/portofkobe/portofkobe.htm+%E5%92%8C%E7%94%B0%E5%B2%AC%E3%80%80%E9%95%B7%E7%94%B0%E6%B8%AF&hl=ja&ct=clnk&cd=1&gl=jp.

[3] Hashimura, M., et al. Drifted drums of Dangerous Goods in Osaka Bay at the Great Hanshin-Awaji Earthquake in 21st The Institute of Social Safety Science, (Nov. 2007).

[4] Petroleum Association of Japan, Users manual of the Oil-spill Prediction Mode, Petroleum Association of Japan, (Jun. 2003).

[5] Hashimura, M., Research on drifted drums of Dangerous Goods in Osaka Bay at the Great Hanshin-Awaji Earthquake, Master Thesis, (Jan.2008).