A REPORT ON HYDROGRAPHIC ACTIVITIES FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE

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Abstract

The Great East Japan Earthquake (Mw9.0) on 11 March 2011 accompanied with a huge tsunami of more than 10 meters in height devastated many cities and ports along the Pacific coast of northeastern Japan, and claimed nearly 20,000 lives with many of them still missing. This report reviews actions taken by the Japan Hydrographic and Oceanographic Department (JHOD) after this unprecedented disaster.

Immediately after the earthquake, the JHOD carried out hydrographic surveys for the urgent need to help clear the passage in ports due to sunken debris swept away by the tsunami. These surveys have enabled the vessels with relief supplies on board for the affected areas to enter the ports.

The JHOD revisited the affected ports for the next stage of hydrographic surveys. These surveys will contribute to revised nautical charts based on new data collected after the earthquake, and includes the ongoing restoration and reconstruction work of quays and port facilities. This stage includes the re-determination of the datum level of the affected ports, which is necessary because of large subsidence being reported in the areas.

All of these efforts by the JHOD clearly demonstrate the significance of the hydrographic activities in case of the post-quake emergency situation, not only for the safety of navigation but also for economic recovery.

1. Introduction

An unprecedented huge earthquake (Mw=9.0) occurred on 11 March 2011, with the hypocenter located under the Pacific Ocean seafloor off the coast of eastern Japan. This resulted in a huge tsunami of more than 10 meters in height slamming into the Pacific coast along northeastern Japan. The earthquake and tsunami devastated many coastal cities and ports, and claimed nearly 20,000 lives with many, sadly still missing.

Immediately after the earthquake and tsunami, the Japan Hydrographic and Oceanographic Department (JHOD) of the Japan Coast Guard (JCG) dispatched all five survey vessels belonging to the JHOD to the affected areas, as part of emergency actions taken by the government of Japan (Sengoku and Saegusa, 2011). We carried out hydrographic surveys to help clear the passage in ports with sunken debris. These surveys have enabled the vessels with relief supplies on board for the affected areas to enter the ports. Our prompt dispatch of hydrographic survey vessels has been highly appreciated by local communities and pilots associations.

Significant subsidence of ground level caused by the earthquake was reported in the ports around the east coast of Japan. The tsunami surge was so powerful that water depth in the ports were changed. The JHOD has been revisiting the affected ports to carry out hydrographic surveys, including the observation of the datum level of the affected ports. The surveys identify progress of restoration and reconstruction work of quays and port facilities, and will enable new editions of nautical charts to be published. The JHOD has also made GPS/Acoustics seafloor geodetic observations near the hypocentral region.

This report describes work undertaken by the JHOD in response to the Great East Japan Earthquake. We hope that knowledge of our experience will be useful for other hydrographic offices to study and prepare for similar natural disasters in the future.

2. The Great East Japan Earthquake and Subsequent Tsunami

2.1 The Earthquake and Tsunami

The massive earthquake occurred at around 14:46 on 11 March 2011 (Japan Standard Time), with the hypocenter under the seafloor off the Pacific coast of Tohoku region of Japan. The magnitude of the earthquake (Mw) is estimated to be 9.0, which is the most powerful earthquake ever to hit Japan. This earthquake is typical of a plate boundary earthquake, which occurred on the upper boundary of the Pacific Plate subducting beneath northeastern Japan. Aftershocks followed subsequently. The hypocenters of these aftershocks have spread across a huge area with a length of 500 km and a width of 200 km (*Figure 1*).

Shortly after the main shock, a massive tsunami of more than 10 meters in height hit the Pacific coast of northeastern Japan. A second and third tsunami hit the coast, causing further devastation.

2.2 Damage due to the Earthquake and Tsunami

The earthquake and tsunami have claimed nearly 20,000 lives. Significant damage was experienced at logistically important ports such as the Port of Hachinohe, Port of Sendai-Shiogama, Port of Onahama, etc., and some of the largest fishing ports in Japan, such as the Port of Kesennuma, along the Pacific coast of eastern Japan (*Figure 1*). The tsunami not only damaged the facilities of these ports, but also mercilessly swept away parts of towns, the residential areas and factories.

The breakwaters protecting these ports, quays, and aids to navigation were destroyed. Cars, containers, port facilities and debris of destroyed houses were swept into ports and coastal areas, and the debris tore fishing equipment and nets in the bay into pieces. Obstructions, which are dangerous for navigation, were scattered on the seafloor, drifting underwater or on the surface in some ports and coastal areas. The earthquake caused significant change in ground level in several coastal areas of northeastern Japan. Some places saw the ground subside by more than 1m. The tsunami largely scraped away the coastline and seafloor in some areas, and conversely deposited a large amount of sand, mud and debris in other areas. Grave accidents occurred at the Fukushima Daiichi Nuclear Power Plant.

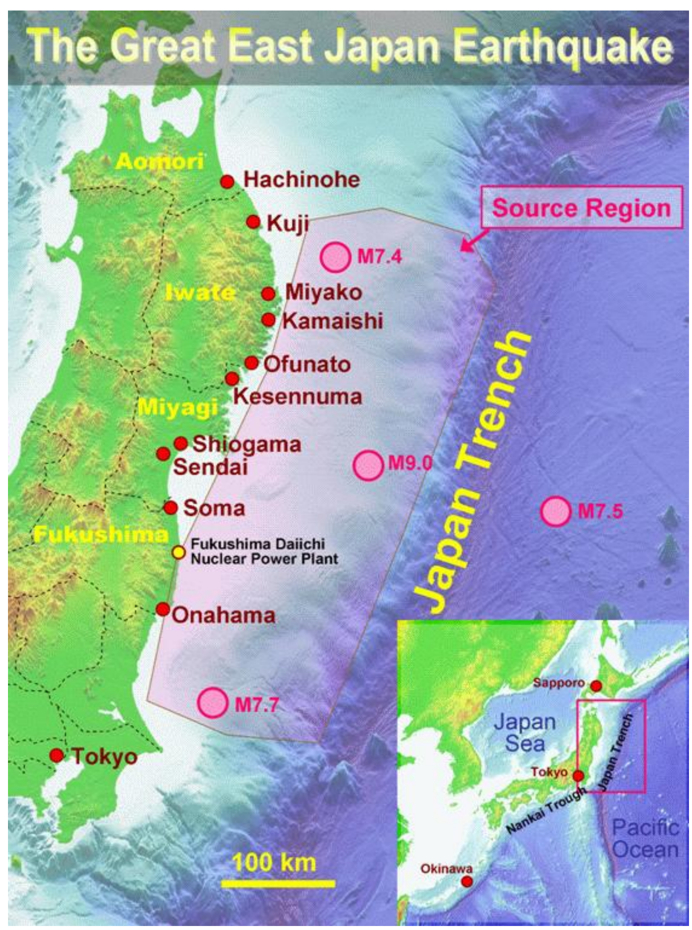

Figure 1 *The hypocenters of the Great East Japan Earthquake (large circles with magnitude) and major affected ports (small circles).*

3. Emergency Action Taken by the JHOD

3.1 Dispatch of All Survey Vessels

When the earthquake occurred on the Friday afternoon, most of our JHOD staff members were on duty. We set up the task force immediately both in the JCG Headquarters in Tokyo and in the second Regional Coast Guard Headquarters, which is in charge of the Tohoku Region, located in Shiogama City of Miyagi Prefecture and started to plan necessary emergency measures. After receiving information on the unprecedented magnitude of the disaster caused by the earthquake and tsunami, the JHOD issued an order to dispatch all five survey vessels belonging to the JHOD (***Figure 2***) to the affected areas. It is the first time in history since World War II that the JHOD issued the dispatch order for all of its survey vessels to the same region at the same time.

The survey vessel KAIYO had just arrived at the base close to the headquarters in Tokyo in the morning on the day of the earthquake after a 30-day voyage. It left the base on the following day on the emergency dispatch order, with supply of fuel, water, etc. The survey vessels SHOYO and TAKUYO were on other assignments in the Okinawa region, more than 1,500km southwesterly away from the affected areas. Both vessels immediately suspended their surveys and headed for the affected areas. In a couple of days, all five vessels arrived off the affected ports.

All the survey vessels carried out the surveys of passage obstructions in the ports as soon as they had arrived at the affected areas, as described in section 3.3. After the first phase, the survey vessel MEIYO proceeded to conduct GPS/Acoustic seafloor geodetic observations where a large crustal deformation caused by the earthquake was expected. MEIYO and KAIYO also collected seawater to monitor the radioactivity.

3.2 Issuing Navigational Warnings

Immediately after the earthquake, the JHOD issued navigational warnings on the earthquake occurrence and tsunami to ships in and around the region by NAVTEX and SafetyNet. The first warning was issued 15 minutes after the earthquake.

We continually issued navigational warnings on various subjects, *e.g.*, extinction of lights, dislocation of buoys, and floating debris and ships. As of Feb. 6, we had issued 730 warnings.

The number of warnings had greatly increased as compared with normal periods because of the magnitude of the damage. At users' requests, the JHOD posted a navigational warning map related to the Great East Japan Earthquake (***Figure 3***) on 17 March on its website, and have been posting it every day since then. The map contains all the NAVTEX navigational warnings related to the earthquake in one diagram which has been highly appreciated by the users, including the Japanese Ship-owners' Association.

We conveyed news of the emergency events such as the serious accident at Fukushima Daiichi nuclear power plant to the vessels at sea by issuing navigational warnings. When we received the instruction from the government to take shelter inside or to avoid navigating in the cautionary zone due to the released radioactive materials from the nuclear power plant, we also conveyed the same information to the vessels at sea.

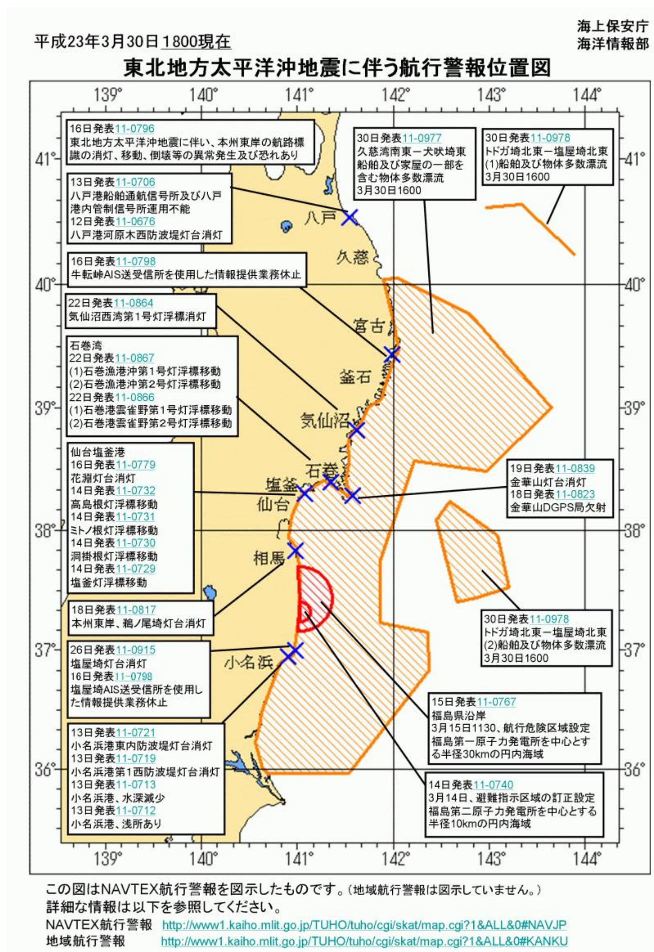

Figure 3 *A navigational warning map related to the Great East Japan Earthquake issued on 30 March 2011.*

Shoyo	Completed : 1998	Gross tonnage : 3,000 t
	Length, Beam, Depth : 98.0m x 15.2m x 7.8m	
Echo sounder : SEABEAM 2112 (mother vessel) PDR-601, SEABAT 9001 (onboard craft) Side scan sonar : SYSTEM 3000, SYSTEM 3900		
Survey assigned : Hachinohe, Kuji, Ofunato, etc.		

Takuyo	Completed : 1983	Gross tonnage : 2,400 t
	Length, Beam, Depth : 96.0m x 14.2m x 7.3m	
Echo sounder : EM 122, EM 710S (mother vessel) PDR-601 (onboard craft) Side scan sonar : SYSTEM 3900		
Survey assigned : Kesennuma, Shiogama, etc.		

Meiyo	Completed : 1990	Gross tonnage : 550 t
	Length, Beam, Depth : 60.0m x 10.5m x 5.0m	
Echo sounder : EM 302 (mother vessel) PDR-601, PDR-8000, C3D (onboard craft) Side scan sonar : SYSTEM 3000, CM2		
Survey assigned : Sendai, Onahama, etc.		

Tenyo	Completed : 1986	Gross tonnage : 430 t
	Length, Beam, Depth : 56.0m x 9.8m x 4.8m	
Echo sounder : SEABEAM 1180 (mother vessel) SEABAT 8125, PDR-601 (onboard craft) Side scan sonar : SYSTEM 3900		
Survey assigned : Miyako, Ishinomaki, Soma, etc.		

Kaiyo	Completed : 1993	Gross tonnage : 550 t
	Length, Beam, Depth : 60.0m x 10.5m x 5.0m	
Echo sounder : EM 302 (mother vessel) PDR-601, C3D (onboard craft) Side scan sonar : CM2		
Survey assigned : Kamaishi, Sendai, etc.		

Figure 2 *Specifications of the dispatched survey vessels.*

3.3 Sea-bottom Obstruction Surveys Performed by Survey Vessels

After the earthquake and tsunami, delivering necessary relief supplies to the affected areas was required to support the afflicted people. The number of evacuees, who had lost their houses or been evacuated and stayed at schools or public facilities, exceeded 400,000.
It was necessary to enable emergency transport vessels with relief supplies on board to enter the affected ports as well as to restore the damaged roads connected to the affected areas. More than 15 ports suffered damage due to the earthquake and tsunami.

At the initial stage, we deployed the five survey vessels at the ports with top priority that had urgent need of supplies, and started obstruction surveys to secure the safe passages to the berths so that the emergency transport vessels could come alongside. The task force in the JHOD determined the priority of ports to be cleared and issued appropriate orders to each survey vessel. The task force also received detailed updates of survey status and survey results from each vessel.

We identified passage obstructions on the seafloor using echo sounders and side scan sonars on survey vessels or onboard survey craft (***Figures 4a and 4b***). The most annoying obstacle during these surveys was nets and ropes drifting in the seawater. The survey vessels were repeatedly tangled up in these nets and ropes. These problems interrupted our surveys several times a day. At some ports, however, a diving unit of the Japan Maritime Self-Defense Force assigned to the areas supported our work by watching for obstructions around our survey vessels and craft with their rubber boats, or by removing tangled nets and ropes. This support helped us carry out the surveys without trouble. The port authorities removed the spotted large obstructions that could impede safe navigation of the vessels.


Figure 4a

Figure 4a and 4b
The survey crafts engaged in the passage obstruction survey. a) Survey in Port of Ofunato, b) Survey in Shiogama Section of Port of Sendai-Shiogama. Maritime Self-Defense Force (rubber boat) supported our obstruction survey.

The joint effort by the JHOD that performed obstruction surveys by the survey vessel Kaiyo and port authorities that removed the obstructions cleared the passage to the usable quays in the Port of Kamaishi on 15 March, four days after the earthquake and tsunami (***Figure 5***). Joint efforts also cleared the passages in the affected Ports of Miyako on 17 March and Sendai-Shiogama on 18 March.

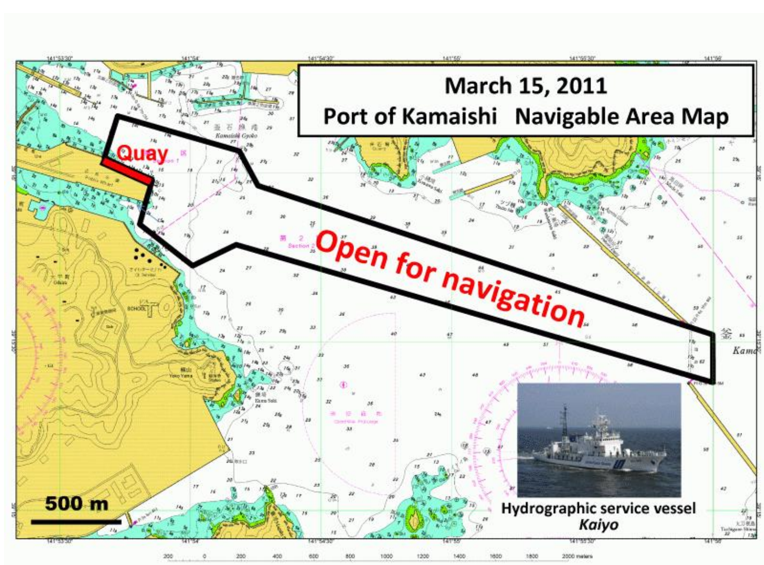

Figure 5
The schematic diagram showing the clearance of Port of Kamaishi provided to the port authority four days after the earthquake.

These surveys enabled transport vessels to enter the ports full of relief supplies onboard. The long-awaited relief supplies were finally delivered to the evacuees. We continued the sea-bottom obstruction surveys for about a month until most affected ports were re-opened.

The JHOD has learnt that from the experience of past disasters such as the 1993 Southwest-off Hokkaido Earthquake and the Great Hanshin Earthquake in 1995, what we had to do immediately after the earthquake or tsunami was to conduct hydrographic surveys that would help transport vessels enter the affected ports. In these hydrographic surveys, we decided to dispatch all available resources as quickly as possible, considering the damage of affected ports. These experiences facilitated our prompt action this time.

The captains of the survey vessels, when they returned to the base in Tokyo, told us that their crews immediately recognized the magnitude of the damage after having seen the devastated towns and undertook their assignments eagerly in the severe environment where dangerous obstructions were drifting. We have received gratitude from the mayors of local municipalities and pilots engaged in port entry for our contribution. Our dispatched survey vessels cleared the passages one after another through the sea-bottom obstruction surveys.

3.4 Details of the Sea-bottom Obstruction Surveys

Five survey vessels and their respective 10m-type onboard survey craft carried out the passage obstruction surveys in the affected ports. The onboard survey craft carried out surveys mainly inside the ports whilst the mother survey ships conducted surveys outside of the ports.

Obstruction surveys were carried out using 4-channel single beam echo sounders together with side scan sonars. These survey instruments were urgently transported from many other regional headquarters all around Japan except those in the affected area. Only the survey craft of the survey vessel “Tenyo” had a multibeam echo sounder for shallow waters. In addition, we deployed an interferometric sonar that we had introduced and tested. These swath-type sonars turned out to be quite powerful and efficient in survey operations. Missions would have been completed in shorter times if all the vessels had been equipped with such modern instruments. Following is a list of survey instruments deployed for the initial stage of the obstruction surveys.

List of the survey instruments and the software deployed

- **Single Beam Echo Sounders**
  PDR-601 (SENBON DENKI)
- **Multibeam Echo Sounders**
  SEABAT8125 (RESON)
  SEABAT9001(RESON)
  EM302 (KONGSBERG)
  SEABEAM1180 (L-3 ELAC Nautik)
- **Side Scan Sonars**
  SYSTEM-3900 (L-3 KLEIN)
  SYSTEM-3000 (L-3 KLEIN)
  CM2(C-MAX)
- **Interferometric Sonar**
  C3D-LPM (Teledyne BENTHOS)
- **Software**
  HYPACK (HYPACK)
- **Bathy Pro (Triton Elics International)**
- **SonarPro (L-3 KLEIN)**
- ***SIS (KONGSBERG)***
- **TNTmips (Microimages)**

The task force drew up a data processing flow to ensure access to the survey results as quickly as possible. Survey data was processed on board and summarized results such as the position and the size of the obstacles were reported to the task force. Subsequently the task force produced charts (***Figure 6***) to show the obstruction survey results in an illustrated manner. The established data flow enabled prompt notifications to the port authorities within the day of each survey, which contributed to the quick reopening of the ports.

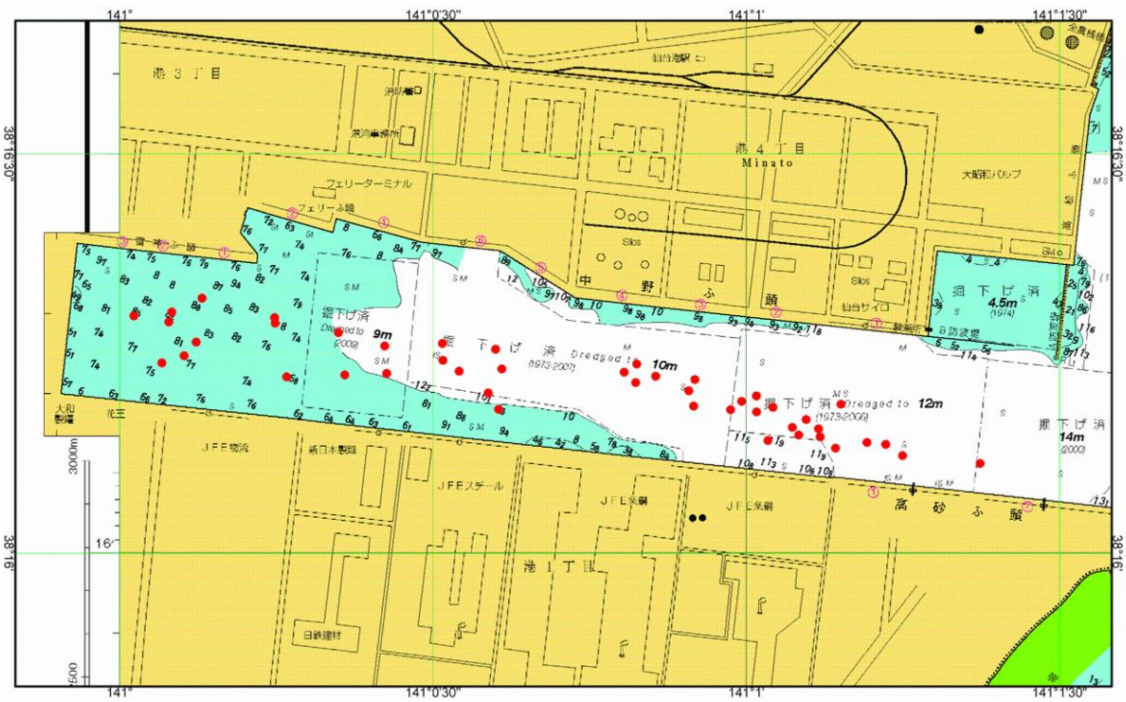

Figure 6 *Sample of daily survey results for port authorities. Red circles indicate detected obstructions.*

The multibeam/singlebeam echo sounders and side scan sonars had an indispensable function to visualize the collected data immediately on site. This provided convincing information to the port authorities, who were then able to remove the detected obstructions. We realized that the onboard survey instruments to be used after the disaster must have a function of fast data processing speed as well as effective survey capacity. ***Figures 7a and 7b*** show sample records of a sunken ship on the seafloor and ***Figure 8*** shows a fallen crane from a quay.

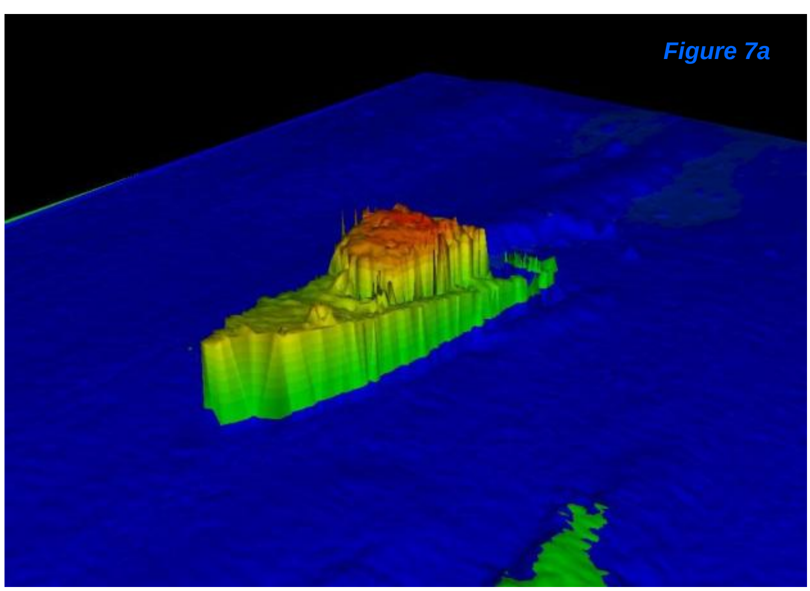

Figure 7a and 7b *The record of a sunken pleasure boat on the seafloor measured by multibeam echo sounder (left panel) and the picture when it was salvaged (right panel).*

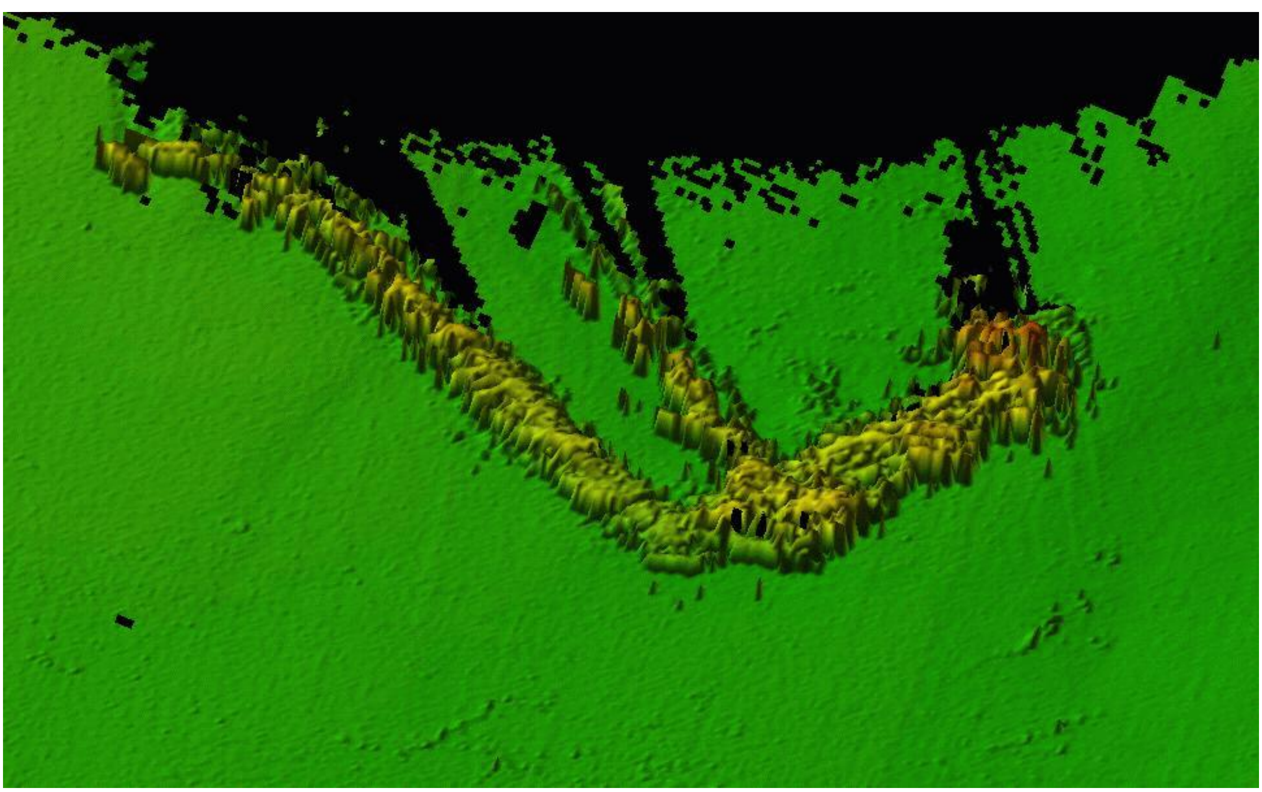

Figure 8 *The multibeam echo sounder record of a fallen crane from a quay.*

3.5 Seafloor Geodetic Observation

The JHOD has been developing precise seafloor positioning systems using the GPS/acoustic combination technique (***Figure 9***) and carrying out campaign observations along the major trenches on the side of the Pacific Ocean. The primary purpose of these observations is to detect and monitor the crustal movements caused by the subduction of the oceanic plate near the plate boundary where huge earthquakes have repeatedly occurred. In this observation, two different techniques are combined using a survey vessel. One is kinematic GPS to determine the position of the on-board GPS antenna. The other is acoustic ranging to measure the round-trip travel time between the on-board transducer and the acoustic mirror-type transponder installed on the seafloor. By combining these techniques, we get the position of the seafloor reference point with centimeters precision. From past observations, we have succeeded in detecting intraplate crustal movements and co-seismic movements at seafloor reference points with centimeter resolution.

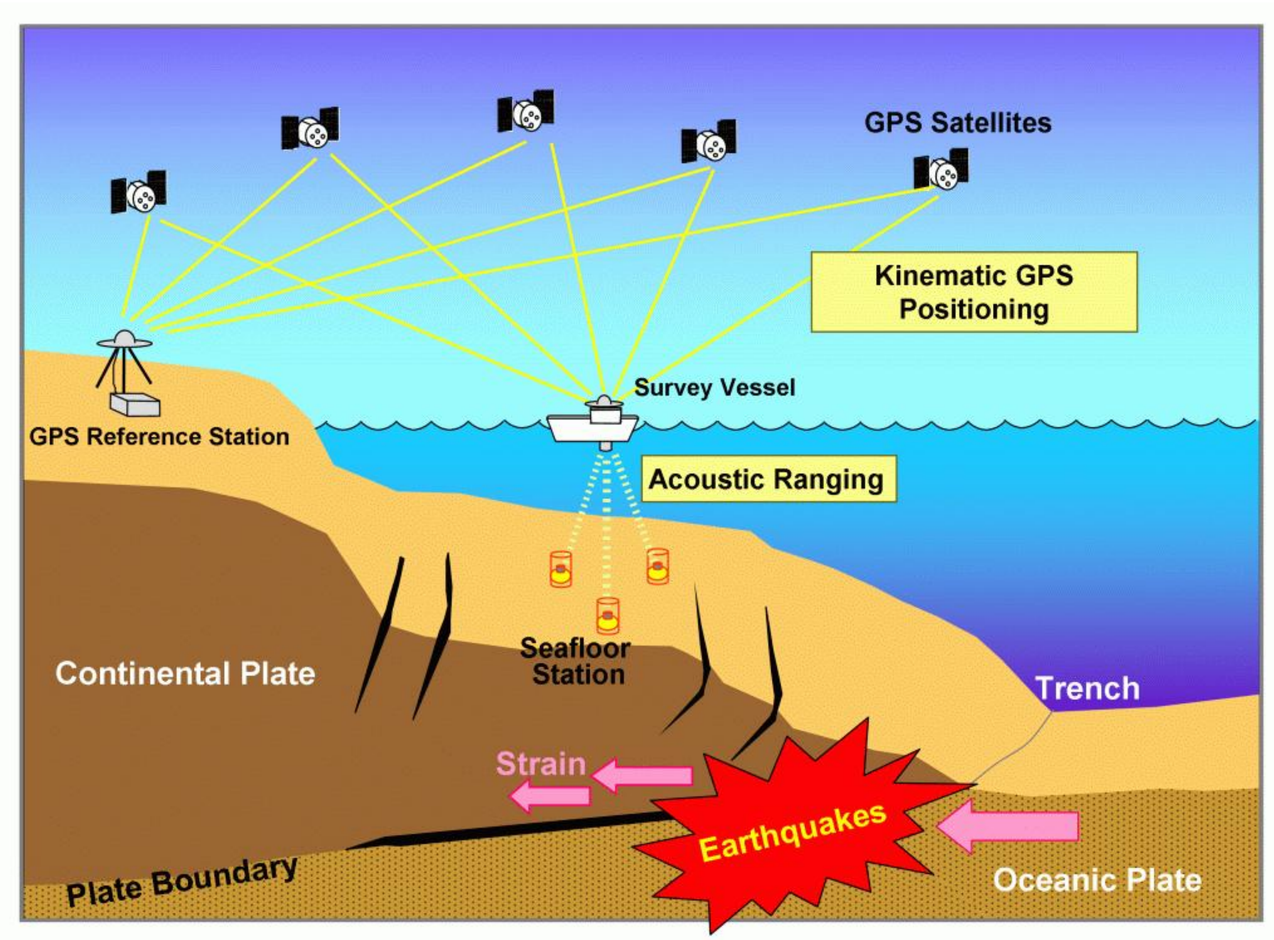

Figure 9 *The GPS/acoustic combined method of seafloor geodetic observation*

We have five sea-floor reference points in the focal region of the 2011 Great East Japan earthquake with campaign observations carried out three times a year on average. After the earthquake, we conducted observations at these sites for the period from 28 March to 5 April.

Comparison between before and after the event, yielded co-seismic displacements of 5 to 24m toward ESE and –0.8 to 3m upward (***Figure 10***, Sato *et al*., 2011). In particular, at the reference point near the epicenter, we detected a huge co-seismic displacement of about 24m toward ESE and about 3m upward. The horizontal displacement is more than four times larger than that detected on land. These displacements detected on the seafloor indicate that a huge slip generated on the plate boundary near the trench.

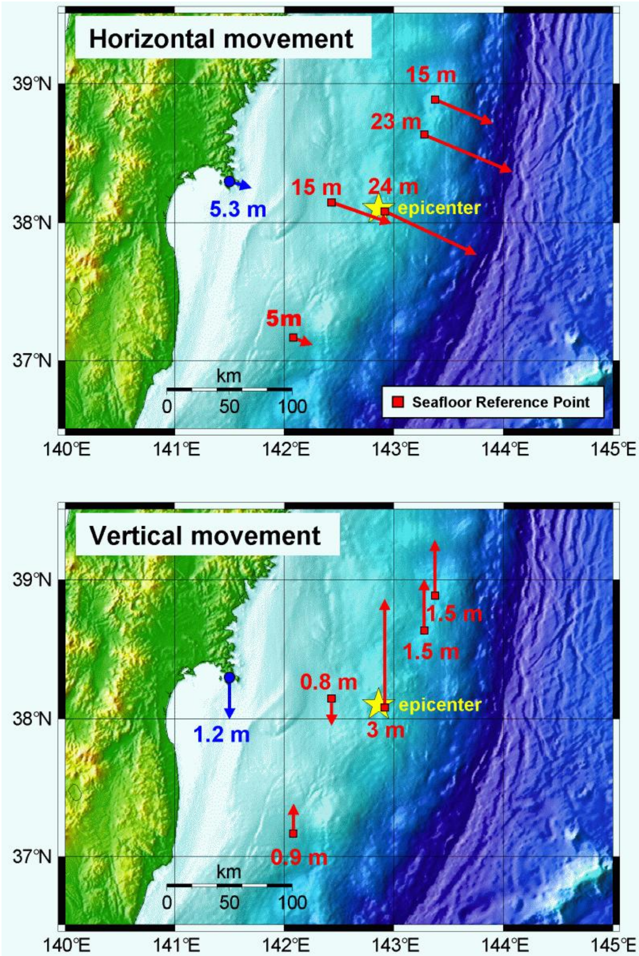

Figure 10 *Horizontal (upper panel) and vertical (lower panel) displacement at the seafloor reference points and the GPS station, associated with the earthquake. Red squares and blue dots show locations of seafloor reference points and the GPS station respectively.*

Observed seafloor displacements by seafloor geodesy have contributed to the estimation of the coseismic slip distribution on the plate boundary by combining crustal movements revealed from on-land GPS stations. While the slip estimated using only on-land GPS data was about 30 m at the maximum, the one estimated using both on-land and seafloor data was 50-60 m at the maximum and the location of the peak moved toward the trench (Geospatial Information Authority of Japan, 2011). This result shows that a huge slip occurred near the trench axis, and it provides valuable information to understand the mechanism of the huge tsunamis caused by the earthquake.

3.6 Airborne LIDAR Bathymetry of Coastal Region

The JHOD has been carrying out airborne LIDAR bathymetry in order to measure the depth of shallow waters, natural coastline and coral reefs, safely and efficiently.

After the earthquake, the Water and Disaster Management Bureau (WDMB) of the Ministry of Land, Infrastructure, Transport and Tourism of Japan (MLIT) requested the JHOD obtain bathymetric data in the very-shallow coastal water regions as soon as possible in order to support local governments to carry out the precise tsunami simulations needed for the future re-design of ravaged towns.

The JHOD, in collaboration with the WDMB, urgently carried out the airborne LIDAR bathymetry (***Figure 11***) along natural coastlines n June 2011.

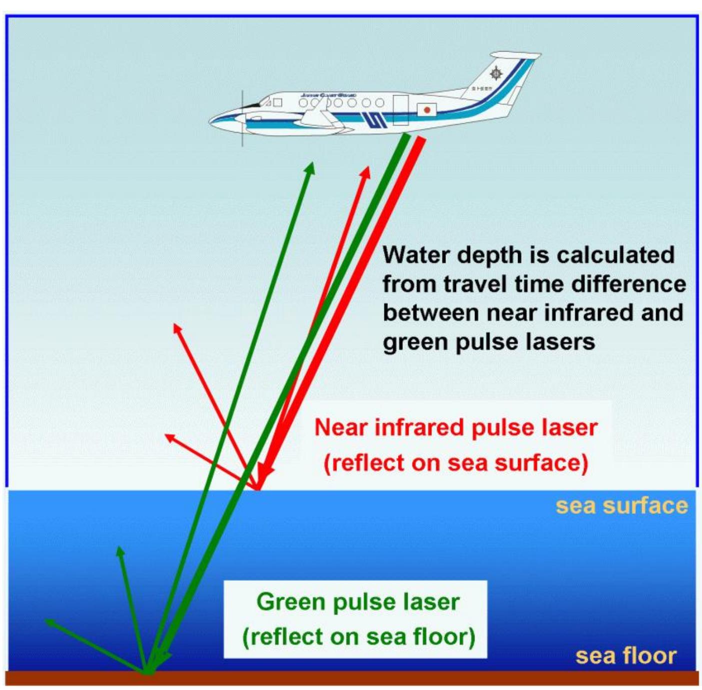

Figure 11 *The principle of airborne LIDAR bathymetry.*

We had fine weather during the surveys. The transparency of seawater, which decreased just after the earthquake, had improved. We successfully obtained the data up to about 10m deep in the neighboring coast of Sendai, and about 15m deep in Miyako Bay, which helped us to have clear bathymetric detail (*Figure 12*).

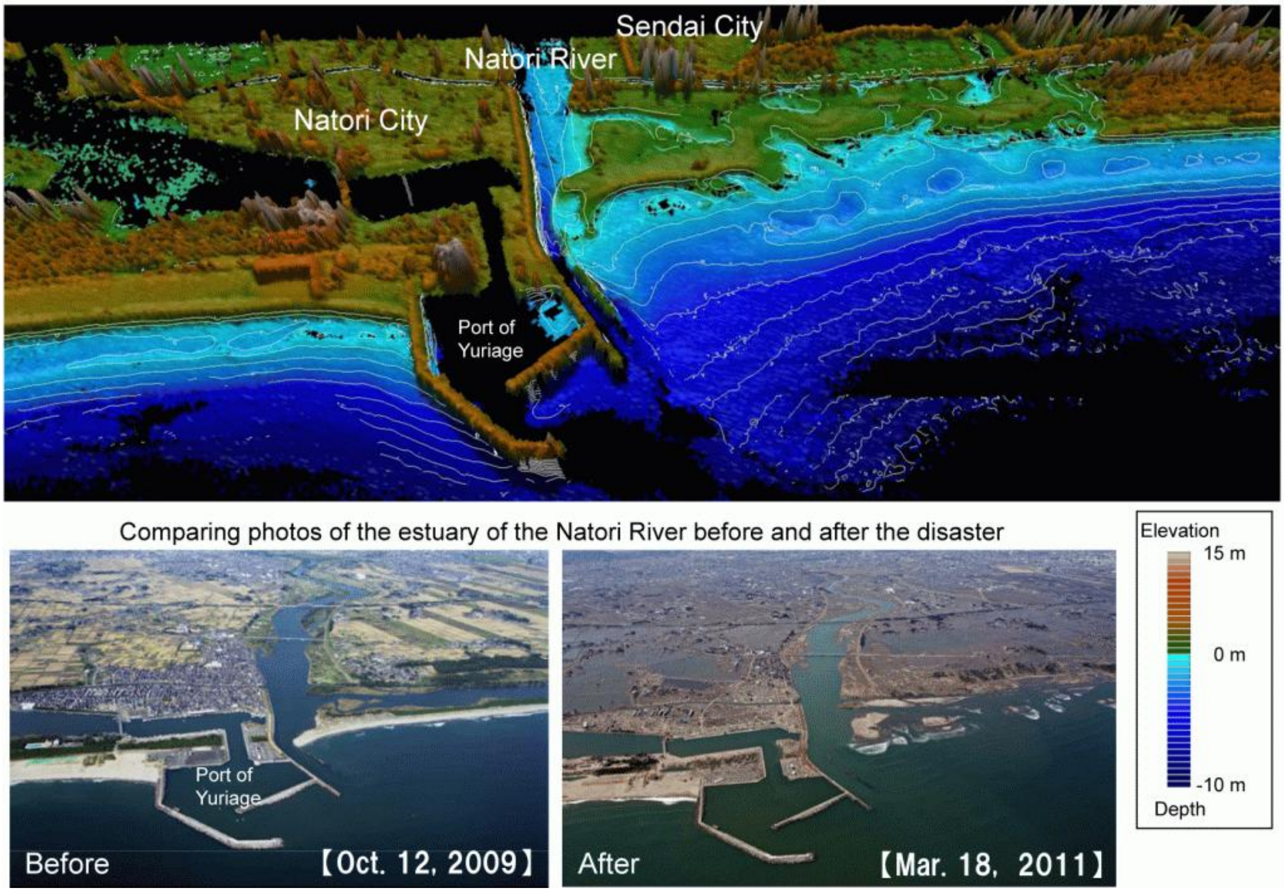

Figure 12 *The seafloor topography near the estuary of the Natori River, south of Sendai. The result of airborne LIDAR bathymetry (upper panel) and aerial photographs taken before (lower left panel) and after (lower right panel) the Great East Japan Earthquake.*

With airborne LIDAR bathymetry, we were able to observe the disturbed seafloor topography in shallow waters due to the earthquake and tsunami. Characteristic depression features considered to be caused by the tsunami flow were recognized on the seafloor running parallel to the disturbed beaches and windbreaks. These results were already identified in the nautical charts and will be used for future restoration projects and disaster control in the relevant areas.

4. Effort to Publish New Editions of the Affected Charts

4.1 Policy of Hydrographic Surveys and Chart Updating for the Affected Ports

After the earthquake and tsunami, the JHOD provided chartlets and preliminary notices to mariners for the 27 affected harbor-charts containing the following warnings:

> *"CAUTION: As a consequence of earthquake and tsunami which occurred on 11 March 2011, depths, coastlines etc. may have changed, wrecks and obstructions may have been displaced, and new obstructions may exist. Mariners should expect considerable change."*

Since late April, the JHOD had started hydrographic surveys to provide new editions of the affected charts (***Figure 13***). By that time, main shipping routes of the affected ports had been cleared of hazardous obstructions enabling cargo vessels loaded with relief supplies on board to enter those ports. These vessels were however using out-of-date charts using pre-quake information. Such vessels requested us to update charts of the ports urgently.

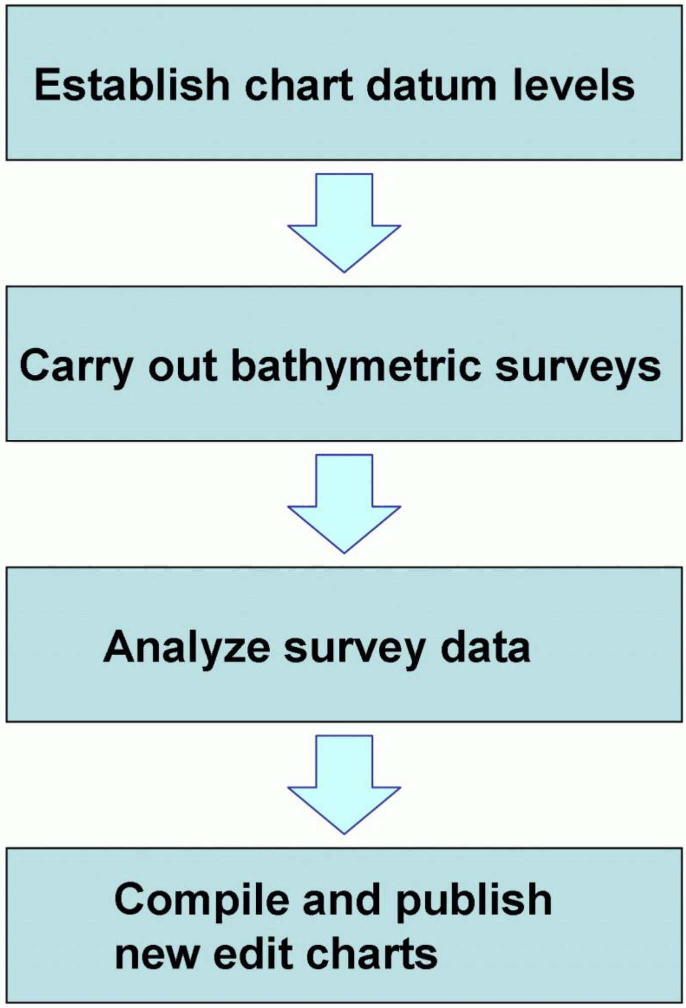

Figure 13 *The flowchart of work for new edition nautical charts.*

We expected that it would take an enormous amount of time to accomplish updating the whole chart of every affected port and that the hydrographic information of the ports would change in the future according to the progress of restoration and reconstruction of the ports. Therefore, we planned to take a step-by-step approach to surveying and updating the charts in the order of priority. The Regional Development Bureau, which is a local branch of the MLIT, is expected to carry out hydrographic surveys each time restoration or reconstruction work is done. We apply those survey results to the charts as soon as we receive the survey data.

To update the affected charts quickly and efficiently, we set priority to ports and areas within those ports in which we would carry out hydrographic surveys and updating charts. We determined the order of priority of ports, considering economical importance, restoration status, and progress situation of obstruction removal in shipping routes of the ports. In that consideration, we collaborated with port authorities on the latest information of situation of the ports. As a first step, we planned to survey and update charts in front of available major quays, and within main shipping routes and anchorage areas. Then, we expand the coverage of surveyed and updated areas of charts step-by-step in the order of priority.

To provide users with the latest information as soon as possible, we offer fair sheets of the surveys as information diagrams before we start to compile nautical charts using the fair sheets.
We published the sailing directions (Japanese version) covering the affected areas just on the day of the earthquake, and an additional correction (special post-earthquake edition) summarizing the situation after the earthquake on 30 September 2011.

4.2 Setting the Work Schedule

To publish a new edition of the affected charts, we needed to systematically carry out:

1) a determination of the chart datum,
2) hydrographic surveys,
3) processing of survey data, and
4) compiling charts.

In order to publish new edition charts quickly, the JHOD drew up a schedule of these works, considering our available capacity for hydrographic survey and chart compilation.
The top priority was the port of Sendai-Shiogama. We determined the chart datum and completed hydrographic surveys in the main shipping routes in the port by early June. Then we completed the processing of the survey data by the end of July, provided the seafloor information maps, compiled the charts of the port of Sendai-Shiogama and published new editions of the charts on 9 September 2011.
We are undertaking the same sequences of work for major affected ports in parallel, and we will have provided new edition charts or chartlets for the 11 major affected ports by March 2012.
We are undertaking these works as swiftly as possible to help restore and reconstruct the affected ports. However, the coverage reflecting new information obtained from the surveys after the earthquake is expected to be only 15% of the whole areas of the affected charts as of March 2012. The JHOD will continue updating charts for several years, considering the progress of restoration and reconstruction works in affected ports.

4.3 Determination of Datum Level

After the earthquake, large subsidence of ground level was observed along the coast of Pacific Ocean in Tohoku region. The Geospatial Information Authority of Japan reported the subsidence in some areas amounted to more than 1m from GPS observation. A number of quays and tidal stations were destroyed in ports, and most of the benchmarks necessary to define a datum level have significantly subsided or been lost. Re-determination of datum level at these ports was urgently required because datum level is used for not only depth sounding for nautical charts but also construction work in ports.

The JHOD, collaborating with port authorities and local municipalities, has been working to determine a datum level since mid-March 2011 by carrying out tidal observations at these affected ports. We determined datum levels at the Ports of Onahama and Hachinohe on 18 May 2011 (*Figure 14*), and 16 other ports by early July 2011.

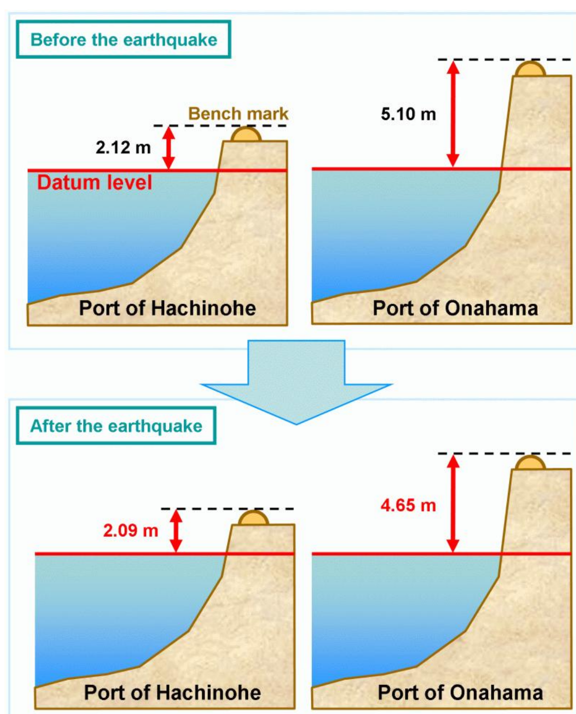

Figure 14 *Land subsidence found in determination of a datum level at Ports of Onahama (right panel) and Hachinohe (left panel).*

4.4 Hydrographic Surveys

We carried out sea-bottom obstruction surveys to enable vessels to enter ports immediately after the earthquake. These survey results could not be used for updating nautical charts because the datum level was unclear and tidal corrections could not been made.

Therefore, we need to carry out additional hydrographic surveys at each port after the datum level determination. Since the extent of damage varied port by port and the port reconstruction works such as dredging and the construction of breakwaters were scheduled differently at each port, we had to carefully determine the necessary survey areas, collecting all the information available to avoid rescheduling. Although drifting debris decreased as compared with the time just after the earthquake, there is still a large amount of debris left off the main passages. In case clearing operations of sunken debris is underway, we need to postpone the surveys in these areas.

4.5 Providing the Seafloor Information Maps

It usually takes a couple of months after hydrographic surveys to process the measured data and to compile the nautical charts. However, considering the urgent needs of seafarers, we decided to provide users with the smooth fairsheets that we make upon completion of the measured data analysis as "seafloor information map" for users' reference. We provided two maps for Sendai Section and Shiogama Section of Port of Sendai-Shiogama. These were the first of these maps and were issued in early August 2011 (***Figure 15***).

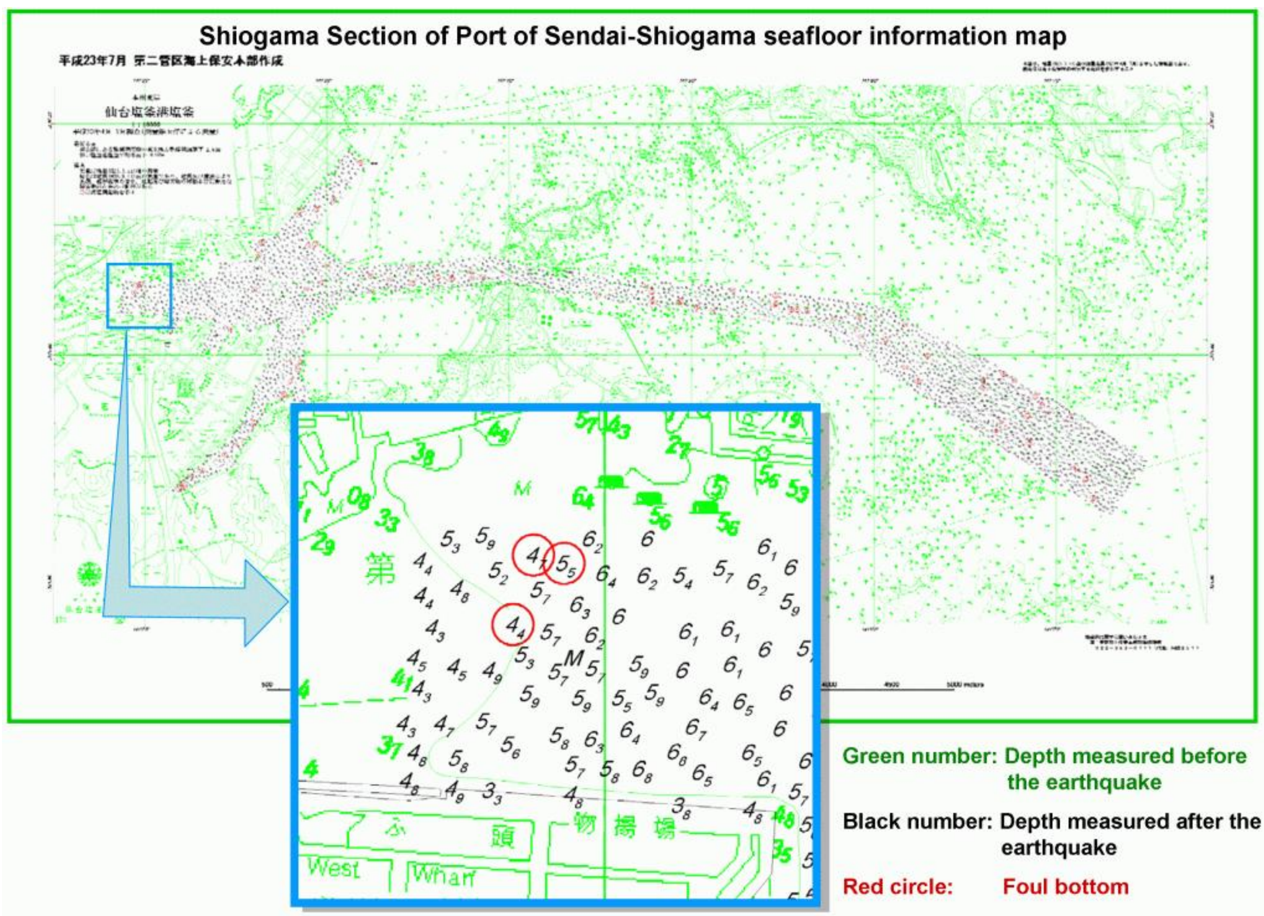

Figure 15 *Land subsidence found in determination of a datum level at Ports of Onahama (right panel) and Hachinohe (left panel).*

From survey data analysis of the Port of Sendai-Shiogama, the following changes to water depth were found:

1. The water depth deepened by 0.5 to 1m throughout the passages, which is probably due to the subsidence caused by the earthquake.
2. We observed small foul bottoms in many parts of the passages. The shallowest water depth with these obstructions were revealed.
3. The narrow part in the middle of the passage in Shiogama section deepened by about 2m, which would be due to erosion caused by the tsunami back-and-forth motion.

4. We found a partly shallow area next to the main passage. This was possibly due to sedimentation of sand and mud caused by the tsunami.

4.6 Compiling of Nautical Charts

When updating the nautical charts, we decided to specify the range of surveys after the earthquake using the following two methods. The first method is a Zone Of Confidence (ZOC) diagram newly introduced to the nautical charts, which indicates the newly surveyed areas (***Figure 16***). The second method is a magenta dotted line shown on the nautical charts to indicate the range of the newly surveyed areas after the earthquake. The latter method is not listed in the IHO Publication INT 1 – Symbols, Abbreviations and Terms Used on Charts. We decided to create it with explanations in charts, after hearing opinions of users, such as pilot organizations and captain organizations, which supported the method.

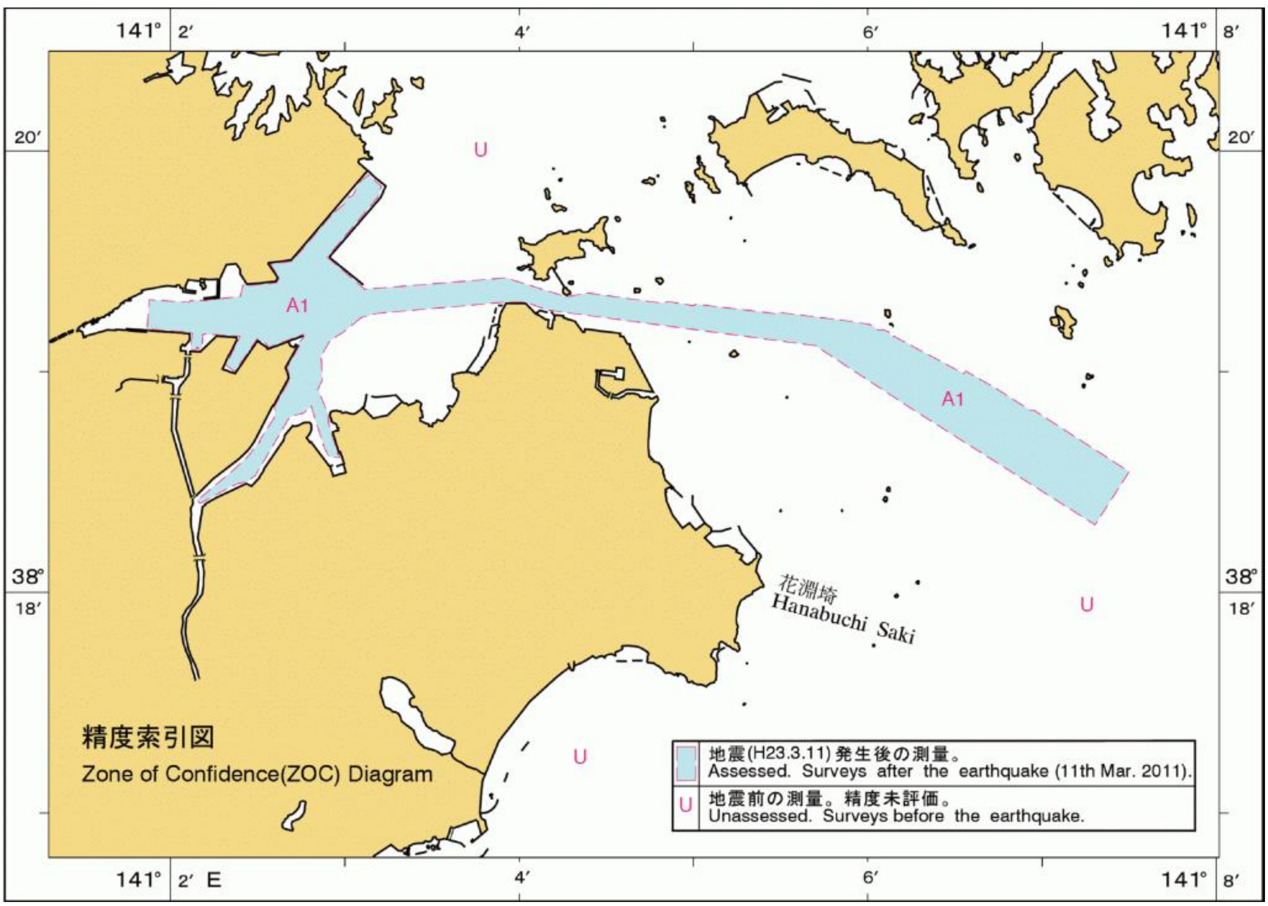

Figure 16 *The Zone of Confidence (ZOC) diagram newly introduced in a new edition nautical chart of Shiogama Section.*

Figure 17 shows the present status of hydrographic surveys and nautical chart updates. As of 6 Feb. 2012, we have published six new edition nautical charts and one chartlet of the damaged ports. Six more new edition charts will be published up to the end of next March. Our estimation shows it will take another three to five years to update all the hydrographic information in the nautical charts of damaged ports. We intend to continue the work in order to support the local community until the reconstruction of damaged ports is finished.

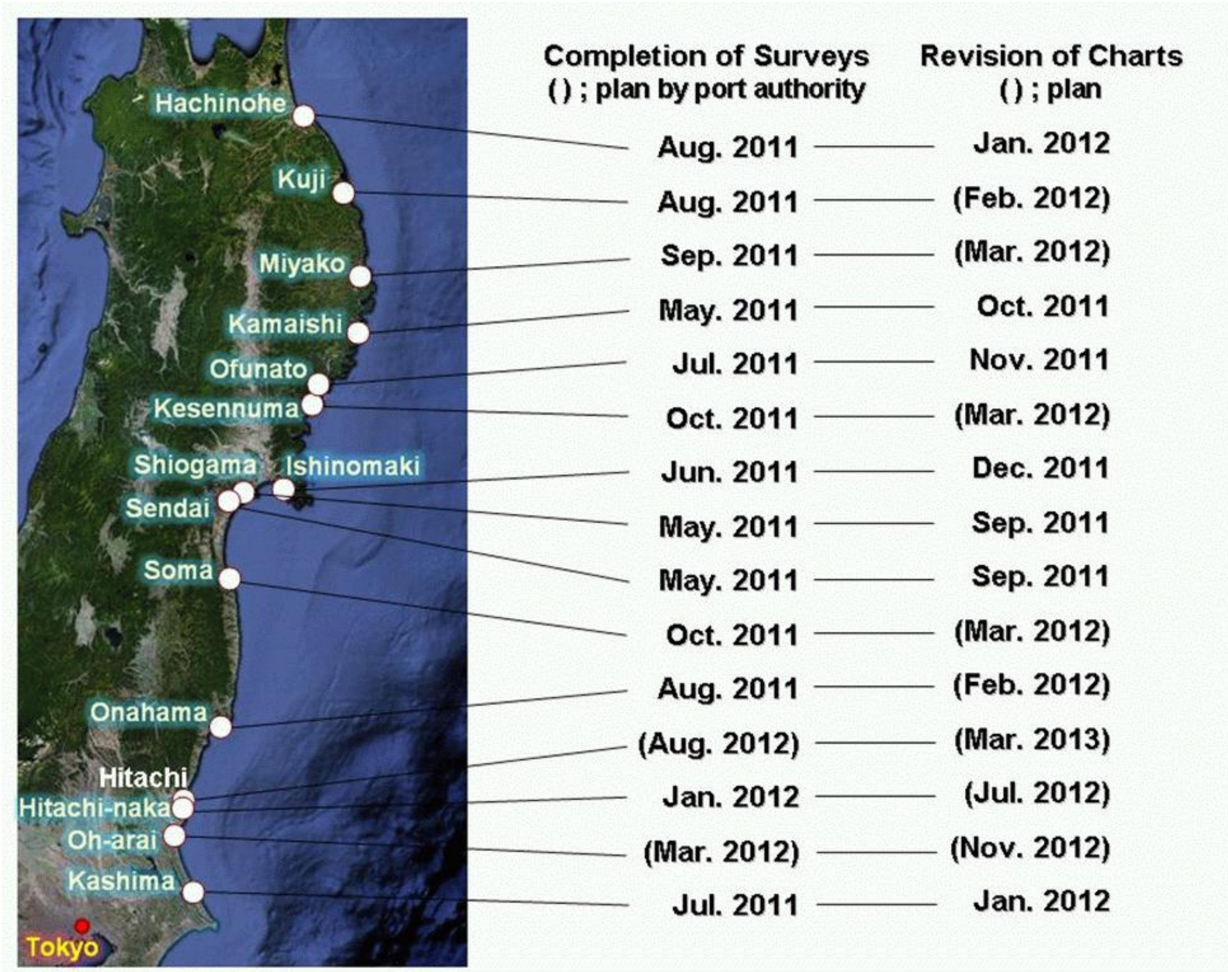

Figure 17 *Progress and plan for publishing new nautical charts (as of Jan. 2012).*

5. Conclusions

One of the most important lessons we have learnt is that hydrographic activities play an indispensable role after natural disasters by providing hydrographic information necessary to ensure safety of navigation. In order to transport relief supplies for refugees, we need to identify obstructions in the passages to open ports as quick as possible. In order to support recovery of the local economy, new editions of nautical charts need to be published quickly. It is the responsibility of national hydrographic offices to quickly respond to the urgent needs of the local community as well as of seafarers.

Immediately after the earthquake, we received letters, emails and phone calls from the President and staff of the IHB, and many hydrographic offices of member states of the IHO including the East Asia Hydrographic Commission. They expressed sympathy for us and kindly offered us support. All the JHOD staff members have been greatly encouraged and have sincerely appreciated these messages.

It has been almost eleven months since the Great East Japan Earthquake occurred, which was the postwar largest natural disaster in Japan. About 3,600 people are still missing, and the struggle with the Fukushima nuclear disaster continues. The JHOD will continue to undertake the necessary actions to provide information for navigational safety at sea through nautical charts, sailing directions and navigational warnings.

We do hope that the newly revised nautical chart information based on the survey data after the earthquake that the JHOD has provided will help improve safety of navigation, be useful for restoring the community and economy of affected areas, and aid in the reconstruction of port facilities, logistic centers, fisheries facilities and coastal factories.

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