Postseismic crustal movement of the 2011 Tohoku Earthquake and its impacts on hydrographic surveys and charts

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Contents

1. 2011 Tohoku Earthquake and JHOD’s responses to the disaster

2. Issues related to postseismic crustal movement and JHOD’s actions
2011 Tohoku Earthquake

North American Plate

North American Plate

Tohoku Region

focal region

Shiogama
Sendai

Nuclear Power Plant

Tokyo

M9.0

11 March 2011

@Kamaishi
Coseismic movement

**Horizontal**
- on land (by GSI)
- on seafloor (by JHOD)

**Vertical**
- on land (by GSI)
- on seafloor (by JHOD)

- 5m
- 24m
- 1.2m
- 3m

50cm
JHOD’s Responses

1. Phase 1  (March - April 2011)
Obstruction surveys for re-opening damaged ports

All the ports were re-opened **within 15 days** after the earthquake.

2. Phase 2  (May 2011 - )
Hydrographic surveys for chart revision

1st stage: high-priority areas in a port

2nd stage: other areas in a port
Re-determination of chart datum levels

“CDL-11” = postseismic chart datum level determined in 2011

Before the earthquake

After the earthquake

Ref. point

subsidence

re-determine

chart datum (N.L.L.W)

Hachinohe
Kuji
Miyako
Kamaishi
Ofunato
Kesennuma
Shiogama
Sendai
Soma
Onahama
Hitachi-naka
Oh-ari
Kashima
Tokyo
Choshi

(subsidence)

3 cm
82 cm
71 cm
34 cm
43 cm
45 cm
26 cm
22 cm
18 cm
12 cm
1st-stage survey:
high-priority areas in a port

(May-June 2011)

Shiogama port

HL04 Tenyo

SEABEAM 1180

survey boat

SEABAT 8125
New edition chart (Sep. 2011)

Shiogama port

Zone of Confidence Diagram

Survey after the earthquake

Zone of Confidence (ZOC) Diagram
2nd-stage survey: other areas in a port

Shiogama Port

Airborne Lidar survey (2011-12)
Areas shallower than the water depth of ~3 m:

SHOALS1000

surveyed (2011)
surveyed (2012)
surveyed by other organization (2011)
All data merged  (June 2012)

Shiogama Port
Progress as of Oct. 2013

2nd-stage survey completion

<table>
<thead>
<tr>
<th>Location</th>
<th>2nd-stage survey completion</th>
<th>2nd-round chart revision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hachinohe</td>
<td>FY2012</td>
<td>FY2013</td>
</tr>
<tr>
<td>Kuji</td>
<td>FY2013</td>
<td>completed in the 1st stage</td>
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<tr>
<td>Miyako</td>
<td>FY2014</td>
<td>FY2014 - 2015</td>
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<td>Kamaishi</td>
<td>FY2014</td>
<td>FY2013</td>
</tr>
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<td>FY2014</td>
<td>FY2014 - 2015</td>
</tr>
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<td>FY2013</td>
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<td>Sendai</td>
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<td>FY2013</td>
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<td>Soma</td>
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<td>FY2013</td>
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<td>Ishinomaki</td>
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<td>Oh-arai</td>
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<td>Kashima</td>
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<td>FY2012</td>
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<tr>
<td>Tokyo</td>
<td>FY2012</td>
<td>FY2014</td>
</tr>
</tbody>
</table>
Postseismic movement (GEONET)

total displacement from 12 Mar. 2011 to Aug. 2013

Horizontal

Uplift

Eastward movement

Vertical

Subsidence

Data: GPS network “GEONET” (by GSI)
Time series of displacement

Period: 12 March 2011 to August 2013

Subsidence
- Yamada: ~6 cm
- M-Oshika: ~29 cm
- Yamato: ~24 cm
- Choshi: ~11 cm

Uplift
- 11 Mar. 2011 M9.0

Data: GPS network “GEONET” (by GSI)
Mechanism of postseismic movement

Postseismic movement

- Phenomenon common to major earthquakes
- Due to a slow slip in an adjacent region to a coseismic slip region

Estimated by terrestrial GPS data and seafloor GPS/Acoustic data
Significant uplift will lead to...

Real depth << Chart depth -> Risk to safety navigation

danger
**“Re”-revision of chart datum levels**

(May 2013)

**Period:** 12 Mar. 2011 to Apr. 2013

<table>
<thead>
<tr>
<th>Port</th>
<th>nearest GEONET station (land)</th>
<th>Tide observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hachinohe</td>
<td>+2 cm</td>
<td>re-determined for 4 ports in May 2013</td>
</tr>
<tr>
<td>Miyako</td>
<td>-6 cm</td>
<td>&quot;CDL-13&quot;</td>
</tr>
<tr>
<td>Kamaishi</td>
<td>+6 cm</td>
<td>= postseismic chart datum level determined in 2013</td>
</tr>
<tr>
<td>Ofunato</td>
<td>+10 cm</td>
<td></td>
</tr>
<tr>
<td>Kesen-numa</td>
<td>+13 cm</td>
<td></td>
</tr>
<tr>
<td>Onagawa</td>
<td>+14 cm</td>
<td>+13 cm (from June 2011)</td>
</tr>
<tr>
<td>Ishinomaki</td>
<td>+22 cm</td>
<td>+15 cm (from June 2011)</td>
</tr>
<tr>
<td>Shiogama</td>
<td>+14 cm</td>
<td>+13 cm (from June 2011)</td>
</tr>
<tr>
<td>Sendai</td>
<td>+14 cm</td>
<td>+14 cm (from June 2011)</td>
</tr>
<tr>
<td>Soma</td>
<td>+12 cm</td>
<td></td>
</tr>
<tr>
<td>Choshi</td>
<td>+11 cm</td>
<td></td>
</tr>
</tbody>
</table>

Ofunato +10 cm, Kamaishi +6 cm, re-determined for 4 ports in May 2013.
Impact on survey data/charts

- a huge amount of existing sounding data collected after the earthquake, based on old chart datum levels
- soundings of nautical charts published after the earthquake

How should we deal with?
- to throw them away and do re-survey?
- to leave them as they are?
Approaches we took

To do test surveys for checking if water depth change due to postseismic uplift has occurred over a chart area.

3 ports
- Large uplift has been observed
- New edition chart is to be published soon.
Test survey (Shiogama port, July 2013)

- May-Aug. 2012 (CDL-13)
- Apr.-July 2011 (CDL-11)
- Sep.-Nov. 2011 (CDL-11)
- July 2013 (CDL-13)

CDL: chart datum level
Another example of fully-surveyed port

Ishinomaki

surveyed for 1st edition of chart (Dec. 2011)
Another example of fully-surveyed port

Ishinomaki

- July 2012 - Mar. 2013
- June 2011
- Sep. 2011
- Feb.-Mar. 2012

Test survey lines

- chart datum level - 11
- chart datum level - 13
2nd edition of chart (Sep. 2013)
Concluding remarks

- For the three ports, depth correction was applied to existing older survey data across the board, using values of chart-datum-level change.
- Postseismic movement is anticipated to continue for further several years.
- In near future, similar depth correction may be needed for other ports and/or the above-mentioned three ports.
Thank you for your kind attention!