Tidal Records in Sendai, Miyagi, JAPAN, & observations of the Fukushima-oki tsunami signal

Volker Roeber

Tohoku University, International Research Institute of Disaster Science (IRIDeS)

468-1 E304 AzaAoba, Aramaki, Aoba-ku

Sendai 980-0845, JAPAN

roeber@irides.tohoku.ac.jp

Contents

1 Tide Records in Japan

Tidal records in Japan are available for many ports and harbors. The Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) is responsible for data archiving. Several websites provide the enduser with data in table and chart format.
In Japan, all tidal data is referenced with respect to the Nihon Suijun Genten, often abbreviated T.P. (Tokyo Peil). The reference gauge was constructed in 1891 and refers to the MSL (Mean Sea Level) at the particular location in Tokyo Bay.
Each harbor in Japan has its site-specific MSL. This depends on the geoid and local interactions of the tidal waves with the bathymetry.
Usually, the zero level refers to the Mean Lower Low Water (MLLW) stage, which is the long-term average of all spring tide low water values. The reason of using MLLW as zero reference is the maritime navigation. Only in very rare cases, mariners will encounter water levels that are lower than MLLW. It is therefore a safe reference for nautical charts as the water level is higher than MLLW during most of the time. In Japan, the MLLW level is the Yedogawa peil (Y.P.), i.e. the zero point in a nautical chart at the Edogawa River, which is $-0.84\ m$ below T.P. However, each gauge has it s own MLLW datum based on the local tide statistics.
In the following we show that the historic tide gauge records have a **different zero reference** than the recent tide gauge data. The plots are showing the tidal elevation above the Y.P. MLLW chart datum, which is below the local sea level.

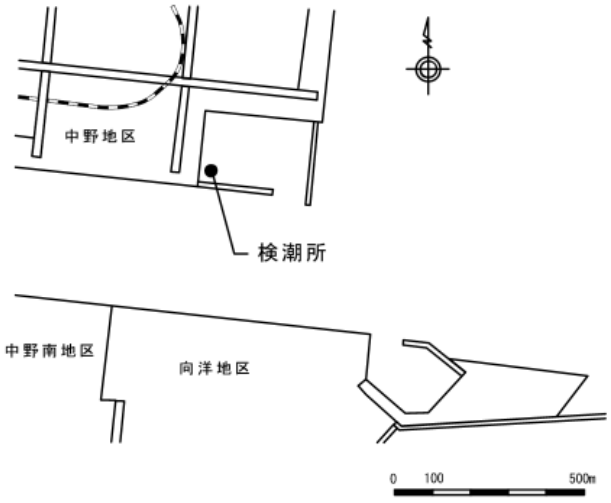
2 Sendai Tide Gauge

The MSL in Sendai Port, Miyagi, is $0.9\ m$ above Y.P. and $0.06\ m$ above T.P. (see Fig. 1). The location of the gauge in Fig. 1 is not correct. According to the GSI website (*http://cais.gsi.go.jp/cmdc/center/kentyoujo/sendai/sendai.html*), it should be approximately located at 38.272896°N 141.00393°E. Fig. 3 shows the tide gauge array. The location can also be found on Google Earth.

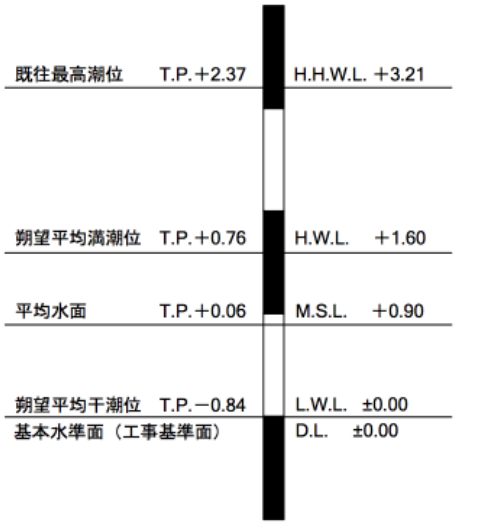
②潮位

仙台塩釜港の潮位は、次のとおりである。

［仙台港区］



図Ⅷ－２－２３ 潮位観測位置図



図Ⅷ－２－２４ 潮 位 図

Figure 1: Reference level of Sendai tide gauge. In Sendai, T.P. is 0.06 m under the local MSL. This means that MSL in Tokyo is slightly lower than MSL in Sendai.
Note that the location is from prior to 2011. Figs. 2 and 3 show the correct location.

Figure 2: Location of the tide station in Sendai Port. After the 2011 earthquake and tsunami, the gauge was moved further into the harbor basin. Fig. 3 below shows the correct location.

仙台港
（ＳＥＮＤＡＩＫＯ）

験潮場名	仙台港（ＳＥＮＤＡＩＫＯ）	登録番号	４６１２
所在地	宮城県仙台市宮城野区港3丁目地先	管理者	東北地方整備局塩釜港湾空港工事事務所
観測開始	昭和４５年１０月（１９７０年）	1/2.5万地形図名	塩竈
取付水準点	一等水準点０４５－０１３	験潮儀型式	ＤＦＴ－３
位置	緯度＝３８°１６′２２″　経度＝１４１°００′１４″（地図表示）		
年平均潮位のグラフ(白丸点は１ヶ月以上の欠測があった年)			

Figure 3: Location and design of Sendai tide gauge. The pier-type structure is sitting on the Northern side at the Western end of the main harbor basin.

2.1 Sendai historic tide records

Tide records in Sendai (and possibly also at other locations) can show different reference levels. We can download historic tidal gauge records for Japan tide stations from *http://jdoss1.jodc.go.jp/cgi-bin/1997/tide_data* . For Sendai, the data comes with the information in Fig. 4 below.

Station Code 0112

Station Name SENDAIKO

Date	Career
2001	Station Position: 38-16 N 141-01 E (WGS-84)
	Type of Tide Gauge: Float
2007	[Addition] Zero of Tide Height: -415.5cm Below the Standard Mark, -84.0cm Below the T.P.
Sep. , 2012	[Updating] Zero of Tide Height: -448.0cm Below the Standard Mark
	Zero of Tide Height: -84.0cm Below the T.P.
2013	[Updating] Zero of Tide Height: -553.0cm Below the Standard Mark, -189.0cm Below the T.P.

*T.P. : Tokyo Peil

Figure 4: Reference information for historic tide gauge data from Sendai. MSL is given as 1.89 m above T.P. datum. Prior to 2013, the difference was 0.84 m.

The latest full year of tidal records with hourly data for Sendai is 2014. Fig. 5 shows the Sendai record in blue, the MSL of the record in magenta, the 28-day average in green, and the predicted tidal fluctuations from the OTPS (Oregon Tide Prediction Software) in red. The OTPS data is referenced to the local MSL. From averaging the Sendai record, we can see that MSL in Sendai is 1.89 m above the zero reference. According to Fig. 4, the zero level is the T.P. value. This is different from the chart in 1 but consistent with the data description at *http://jdoss1.jodc.go.jp/cgi-bin/1997/tide_data*.
It is also evident that there is a small tidal anomaly in Sendai with slightly higher water levels in late summer and lower water levels in late winter. The difference is about 0.2 m and can be seen in the 28-day average .

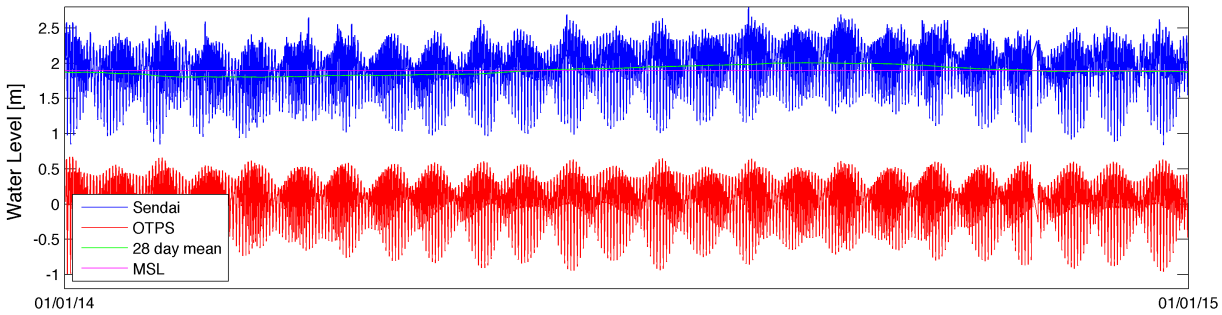


Figure 5: 2014 record at Sendai tide gauge. From Fig. 4, MSL is given as 1.89 m above T.P., which is 1.0 m higher than what the current tide charts are showing.

2.2 Sendai tide records of the Fukushima-oki tsunami waveform

Now, it is also possible to find the latest tidal records for Sendai on the web. In this case, NOWPHAS is providing the data at *http://nowphas.mlit.go.jp/index_ eng.html*. The data are constantly updated and listed in 1-minute increments for the past week. Unfortunately, the data is provided in inconvenient image format and it is not possible to obtain the data in textfile format. To obtain the 1-minute tide gauge record for Sendai, 72 screenshots over a 3-days period were taken and the images were analyzed in Matlab to extract the tidal information from.

Fig. 6 shows the Sendai gauge record in 1-minute intervals between November 21 and 23, 2016. The gauge recorded the Fukushima-oki Tsunami from 2016/11/22. The Fukushima-oki Tsunami occurred during a flood tide phase around 7 AM on 2016/11/22.

According to Fig. 1, the Sendai record in Fig. 6 is the result of the ***original data + 0.06 m***. The NOWPHAS data was recorded at the T.P. level of 0.84 m above Y.P. (MLLW). Since the MSL in Sendai is 0.90 m higher than the MLLW zero level, we had to add 0.06 m to the original data record. The OTPS prediction matches the Sendai record quite well. The NOWPHAS prediction shows a significant positive offset that might be due to an error in the tidal constituents used.

Fig. 7 shows the OTPS prediction for November 2016. The Fukushima-oki Tsunami occurred during a flood stage but, luckily, during a neap tide cycle. The high water level at neap tide is about about 0.5 m lower than the high water during a spring tidal cycle.

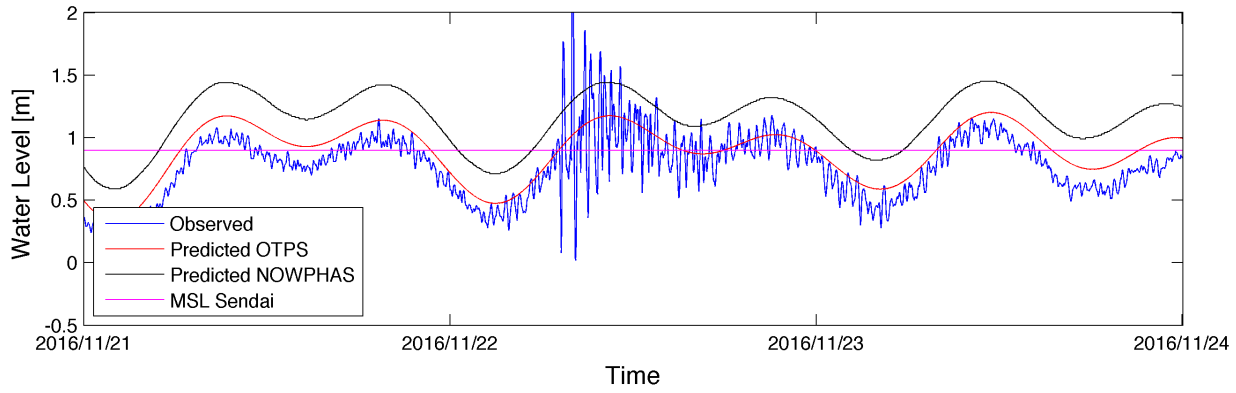


Figure 6: 21-23 November 2016 record at Sendai tide gauge. MSL is 0.90 m above MLLW (Y.P. datum). MSL is 0.06 m above T.P..

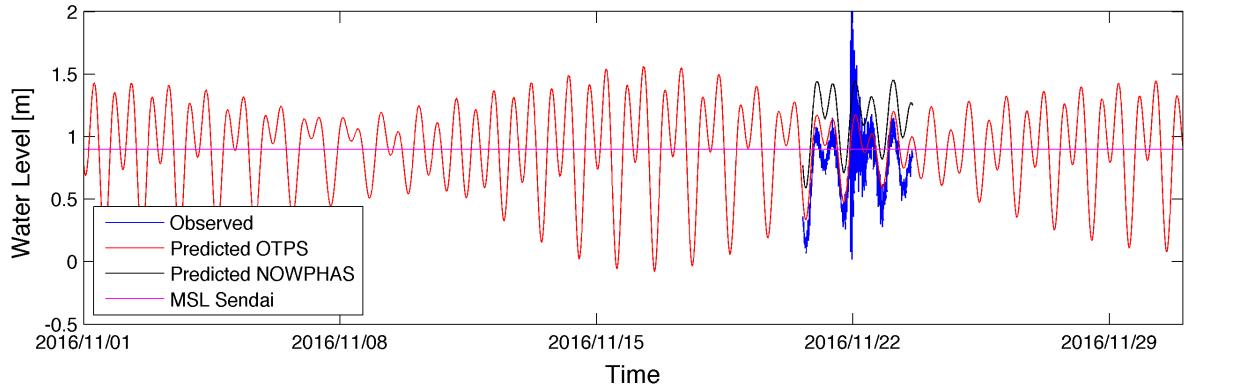


Figure 7: OTPS prediction for November 2016 at Sendai tide gauge. The Fukushima-oki Tsunami occurred during a neap tide cycle.

3 Recommendations

When dealing with tide gauge data in numerical models, it is important to project them to the same reference level as the bathymetry/topography model input. Usually, topography data are referenced to MHW (Mean High Water) and the zero level for bathymetry data is usually the nautical chart datum (MLLW). As there would be a gap between the two standards, the most conventional level for combined bathy/topo data is the local MSL, which automatically is the zero contour (shoreline).

Since the water level in the numerical models usually fluctuates around zero, the tidal input

should also have zero as its mean elevation. Here, it does not matter what absolute reference is being used. The zero level is only of importance when the data is compared to other water level records. For such comparisons, the T.P. reference is recommended.
To set the mean tide gauge elevation to zero, apply one of the following:

- **Recent NOWPHAS data**: The current tide gauge data for the past week is referenced to T.P., which is 0.84 m above MLLW. We subtract the T.P. offset of 0.84 m to obtain the tidal fluctuation around zero.
- **Historic tide gauge data**: The *http://jdoss1.jodc.go.jp/cgi-bin/1997/tide_ data* data mean value of 1.89 m. We subtract the 1.89 m offset from the record to obtain the tidal fluctuation around zero.

4 Acknowledgements

We would like to thank Dr. Yuta Mitobe from the Department of Civil Engineering, Tohoku University, for having generously provided the Matlab code for the extraction of tide gauge data from images and for many fruitful discussions.