Numerical Analysis on Johgan Tsunami by Using Fault Model in Consideration of the Origin of Miyagi-Ken-Oki Earthquake

S. Takada, Student Member, The University of Tohokugakuin
Y. Kono, Regular Member, The University of Tohokugakuin
F. Imamura, Regular Member, The University of Tohoku
K. Minoura, Regular Member, The University of Tohoku

1 Johgan tsunami and earthquake

A strong earthquake struck Tagajo castle in Northern Japan and destroyed them in 869. At the same time tsunami occurred and came surging upon the coastline of Sendai plain in Miyagi Prefecture. Most of the coastline of Sendai plain became like sea. This is called Johgan tsunami because it occurred in the year of Johgan. This is one of the oldest historical tsunami in Japan and also it must be one of the oldest historical tsunami in the world. This tsunami is written in Sandai Jitsuroku which is the official written history of Heian government, 794-1192.

Johgan tsunami has been considered as this type tsunami that occurred at the Japan Trench of Sanriku area. However, the different result showed that Johgan tsunami must had been occurred much closer than Japan Trench and much closer to Sendai bay from our underwater research.

Miyagi-Ken-Oki earthquake occurred in 1978 and struck a big damage to Sendai area. The magnitude of this earthquake was 7.4 and the origin was 80 km from coastline of Sendai plain. The height of this tsunami wave was not so big because the origin of this earthquake was comparatively small. However, the result of tsunami simulation was similar to the real wave of Miyagi-Ken-Oki earthquake tsunami. It was discussed in the previous conference [1]. This location must be one of possibility of origin of Johgan tsunami. In this study the normal fault models with different magnitude at the continental shelf are considered and used for analysis even though the large scale tsunami never been occurred recently at the continental shelf.

2 Governing Analysis

The continuity equation and the momentum equation are given as below. The long wave theory is used to derive the next equations.

Where,

x, y : axes

$$\frac{\partial \eta}{\partial t} + \frac{\partial}{\partial x}\left[u(h+\eta)\right] + \frac{\partial}{\partial y}\left[v(h+\eta)\right] = 0 \qquad (1)$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + g\frac{\partial \eta}{\partial x} + \frac{\tau_x}{\rho} = 0 \qquad (2)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + g\frac{\partial \eta}{\partial y} + \frac{\tau_y}{\rho} = 0 \qquad (3)$$

h : depth

u : velocity in x direction

v : velocity in y direction

τ_x : shear stress of sea bottom in x direction

τ_y : shear stress of sea bottom in y direction

t : time

η : the risen water level from original water depth

g : gravitational acceleration

D is given by $(h+\eta)$, then M is shown by uD and N is shown by vD. The shear stress is ignored because the depth of sea is very deep.

$$\frac{\tau_x}{\rho} = \frac{\tau_y}{\rho} = 0 \qquad (4)$$

$$M = u(h+\eta) = uD \qquad (5)$$

$$N = v(h+\eta) = vD \qquad (6)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial M}{\partial x} + \frac{\partial N}{\partial y} = 0 \qquad (7)$$

The acceleration term becomes zero when it is assumed as long wave and the governing equations becomes as below.

$$\frac{\partial M}{\partial t} + \frac{\partial}{\partial x}\left(\frac{M^2}{D}\right) + \frac{\partial}{\partial y}\left(\frac{MN}{D}\right) + gD\frac{\partial \eta}{\partial x} = 0 \qquad (8)$$

$$\frac{\partial N}{\partial t} + \frac{\partial}{\partial x}\left(\frac{MN}{D}\right) + \frac{\partial}{\partial y}\left(\frac{N^2}{D}\right) + gD\frac{\partial \eta}{\partial y} = 0 \qquad (9)$$

These equations are non-linear partial differential equations. They are arranged as linear equations as equation (10) and (11) for long distance calculation. They are solved numerically by the leap frog method.

$$\frac{\partial M}{\partial t} + gD\frac{\partial \eta}{\partial x} = 0 \qquad (10)$$

$$\frac{\partial N}{\partial t} + gD\frac{\partial \eta}{\partial y} = 0 \qquad (11)$$

3 Fault parameter of tsunami

Table -1 shows that that parameters of different models. We use the Miyagi-Ken-Oki model for Johgan tsunami basically, extending the area of origin, using the dislocation 10 and 15 m, and changing magnitude from 8.0 to 8.5 for tsunami calculation. Two different dislocations, 10m and 15m are used because the submerged island was found at this depth by our underwater diving research. Normal fault model is used throughout because this area is not the Japan Trench but the continental shelf.

Table -1 Parameters of fault models

Model	Magnitude M	North N (¡)	East E (¡)	length L (km)	width W (km)	dislocation D (m)
A-1	8.0	38.35	142.58	83.7	41.8	10.00
A-2	8.1	38.35	142.58	99.0	49.5	10.00
A-3	8.2	38.35	142.58	117.5	58.7	10.00
A-4	8.3	38.35	142.58	139.3	69.6	10.00
B-1	8.0	38.35	142.58	68.3	34.2	15.00
B-2	8.1	38.35	142.58	80.8	40.4	15.00
B-3	8.2	38.35	142.58	95.9	48.0	15.00
B-4	8.3	38.35	142.58	113.7	56.9	15.00
C	7.4	38.19	142.27	26.0	65.0	2.00

Key words : tsunami, analysis, Johgan, Miyagi, Earthquake
Faculty of Engineering, The University of Tohokugakuin, 1-13-1 Tyuo, Tagajo, Miyagi 985-8537, Japan (Tel : 022-368-1115)

4 Result of tsunami analysis

4.1 Maximum wave height

Figure-2 shows the initial tsunami wave when the tsunami started to appear. The negative wave occurs at first because the normal fault model is used for analysis. It clearly shows that the origin of tsunami is located 80 km from the coastline (500 m deep) and it is between Sendai bay and the Japan Trench where is located 150 km from the coastline and 7000 m deep. The length of the origin is about 100 km long alongside the coastline of Miyagi-Fukushima prefectures.

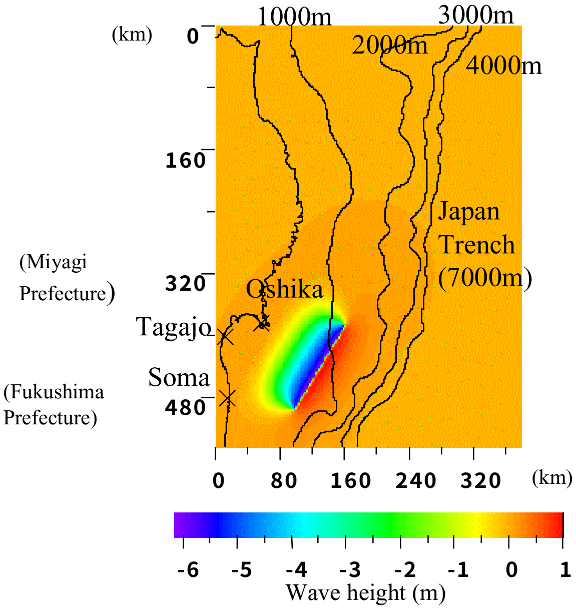
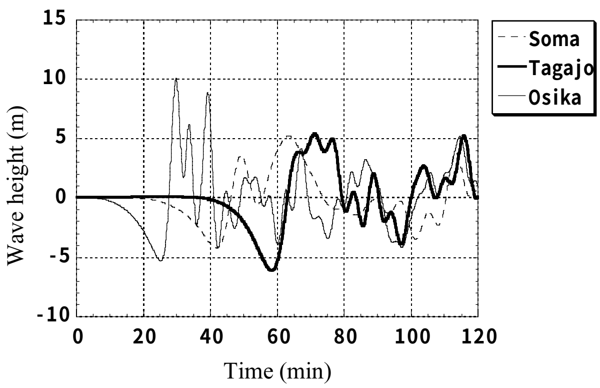


Figure-1 Initial tsunami wave

4.2 Tsunami wave variation with time

At the model A-3 the maximum wave height of 10 m reaches to Oshika 25 minutes after the tsunami occurrence. The maximum wave height of 5.5 m reaches Tagajo and Sendai area in 70 minutes after the tsunami occurrence. As the characteristics at Tagajo the high wave height last 10 to 15 minutes long after positive tsunami wave reached. The negative tsunami wave starts at 40 minutes after the tsunami occurrence and reaches to the lowest wave height —6 m at 55 minutes. The wave height changes to the positive wave immediately and suddenly reaches to the high peak of 4 m. The wave height rises 10 m in total in 6 or 7 minutes according to the result of analysis. The maximum wave height of 5.5 m reaches Soma, where is located southern end of Sendai bay at 65 minutes and the wave height reaches - 4 m at 45 minutes.



Model A-3 Magnitude 8.2

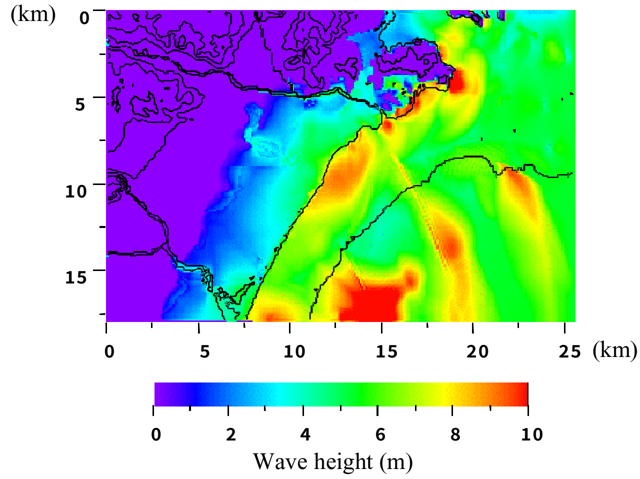
Figure-2 Result of analysis (Tsunami wave height with time interval)

5 Tsunami inundation area

The result of Miyagi-ken-oki model is satisfactory in quality. Finally the magnitude from 8.0 to 8.5 which is assumed for Johgan tsunami is used for calculation with two different dislocation. The deformation, angle and other parameters of fault were changed according to the magnitude and used for calculation. The results of tsunami wave height are used for tsunami inundation analysis. The tsunami run-up problem with wave dumping by shear stress is not considered and transmission process is used for tsunami inundation area.

It is shown on figure-6 that the result of this analysis was used for tsunami inundation area of Sendai plain. It became clear that this analytical result is very resemble as the description in Sandai Jitsuroku which was written in AD 869.

The magnitude of the earthquake caused Johgan tsunami is considered 8.2 or 8.3 according to the result of analysis.



Model A-3 Magnitude 8.2

Figure-3 Tsunami inundation area in Sendai plain (18 km x 26 km)

6 Conclusion

1. The result of Johgan tsunami model by using Miyagi-Ken-Oki earthquake is satisfactory.
2. The origin of Johgan tsunami must be very special and considered to be occurred in the continental shelf by the normal fault, not at the Japan Trench by the reverse fault.
3. The magnitude of the earthquake caused Johgan tsunami is considered 8.2 or 8.3 according to the result of analysis. The inundation area of tsunami shows similarity to the description of Sandai Jitsuroku which was written on May 26, AD869.
4. The lost island was found by our underwater diving research and the depth of the artificial structures was successfully applied to analysis as dislocation of the normal fault.
5. The duration time of high tsunami wave is long as about 15 minutes according to the result of analysis. It might be the cause of having made new lakes and dark blue sea on Sendai plain.

References

[1] Kono, Y., Murakami, H. , and Imamura, F.: Historical tsunami that occurred 1,100 years ago and underwater diving research., The Fourth International Conference on Hydro-science and Engineering, IAHR, CD-ROM, pp. 11, September 2000