THE INFLUENCE OF CHILEAN TSUNAMI WAVE IN 2010 ON RIVERS IN THE TOHOKU DISTRICT, JAPAN

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Water level rise inside of river, which is mainly caused by extreme events such as floods, storm or tsunami waves, is very important in terms of inundation area protection, river embankment risk, saline intrusion into river and water environment especially for a river which has a lagoon or lake at the entrance. A serious Chilean Earthquake, rating magnitude of 8.8, occurred on February 27, 2010 causing a large tsunami wave in the Pacific Ocean after that. The tsunami height was about 1m as it reached the Tohoku District of Japan and further propagated into the upstream of rivers in this area. The main objective of this study is to investigate the tsunami wave propagation at different river morphologies. The analyzed results have been shown that the tsunami wave can be affected up to 22km upstream of river and the measured tsunami travel time inside the river is almost similar to the tsunami travel time calculated by using the long wave theory.

Key Words : *Tsunami wave, Chilean Earthquake, rivers, river mouth, tsunami propagation, Tohoku District*

1. INTRODUCTION

Tsunami is usually caused by an earthquake. As the tsunami wave approaches near to the shoreline it can cause an extreme damages to the coastline due to a huge wave energy dissipation at shallower water depth. The tsunami wave can also further propagate into the upstream of rivers and because of the confliction between the river morphologies and river discharge with coming tsunami wave, the wave level rise due to that can be very significant high. Inundation area and overtopping the river embankments could be observed in small rivers.

There have been a number of studies on the influences of tsunami wave to the rivers such as Abe (1986), Tsuji et al. (1991), Sato et al. (1995), Tanaka et al. (2008) and Yasuda (2010). Among them Abe (1986) has found that the tsunami wave can propagates upstream of river up to around 15km from the river mouth. Resonance occurred in river in about 80 minutes and causing a standing wave.

There was a serious Chilean Earthquake, rating magnitude of 8.8, took place on February 27, 2010 causing a large tsunami wave propagation in the Pacific Ocean. The tsunami height was recorded about 1m as it reached the Tohoku District of Japan and further propagated into the upstream of rivers in this area. Based on the details water level measurements (10 minutes time interval) inside of rivers in the Miyagi and Fukushima Prefectures, a comprehensive study is carried out to analyze the effects of tsunami in this group of river.

As a result when tsunami invades into river, it may not only a threat of damages to the banks but also cause the environmental problem such as inundation. Therefore, tsunami studies become more important. The main objective of this study is to investigate the tsunami wave propagation at different river morphologies. The analyzed results have been shown that the tsunami wave can be affected up to 22km upstream of a large river and the measured tsunami travel time inside the river is almost similar to the tsunami travel time calculated by using the long wave theory.

2. DATA COMPILATION AND ANALYSIS

(1) Study area

Fig. 1 shows the location of studied rivers in the Tohoku District area in Japan varying from small to large river morphology. In order to detect the effect of tsunami wave inside of river, the required data sets are the measurement of water level variations inside and outside of a river, the river morphology such as river slope and river entrance width are also necessary. An attempt is made to collect as many full data sets as possible from the Ministry of Land, Infrastructure and Transport, as well as Fukushima Prefectural Government and Miyagi Prefectural Government. At present, field data of water level measurement from 14 rivers were compiled and analyzed. However, because of each river entrance has their own morphology so the influence of tsunami needs to be analyzed individually and compared among them.

(2) Water level measurement data

In Japan, water level was often measured at 1 hour of time interval in normal condition, however, due to some short-term extreme events such as typhoons or tsunami the measurement method can be switched to smaller time interval in order to catch the peaks of event. **Table 1** illustrates the information of all studied rivers. The name of water level stations and its location from the river entrance together with the catchment area as well as the river mouth characteristic are shown.

Japanese Rivers were classified into two different categories Class-A and Class-B according their dimensions and its importance. The Class-A rivers have relatively larger in terms of catchment and river morphology as compared to the Class-B rivers. The former are governed by the national government, while the latter by prefectural government.

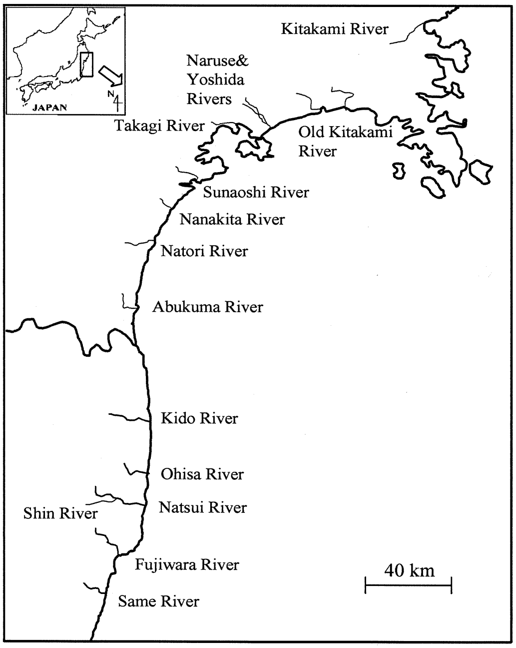

Fig. 1 Locations of studied rivers in the Tohoku District

(3) Moving average method

In order to eliminate the tidal oscillation effects to the water level measurement, the moving average method is used with time series data to smooth out short-term fluctuations. **Fig.2** shows the result of comparison between measured water and the moving average for the Kitamaki River as an example. Hence, the tsunami wave can be detected by taking the actual water measurement minus to the moving average results. Based on the tsunami variation graph the tsunami occurrence time and the tsunami height are able to analyze (**Fig.3**).

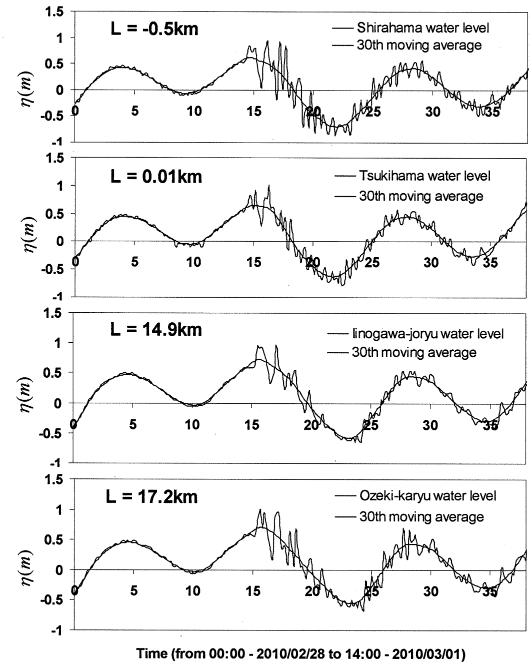

Fig. 2 Comparison the measured water level with the moving average result in the Kitakami River (where L is the distance from the river entrance)

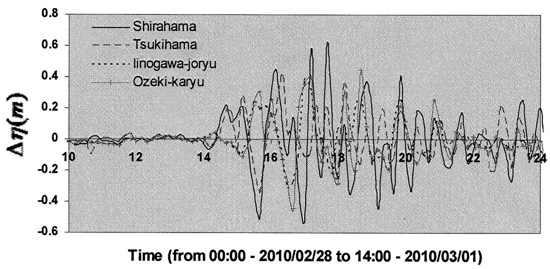

Fig. 3 Water level fluctuations due to the tsunami only in further upstream of the Kitakami River

Table 1: Location of water level station and river characteristics

River name	Class	Water level st.	Location from the river entrance (km)	River mouth width (m)*	Catchment area (km2)	River mouth morphology
Kitakami	A	Shirahama	-0.5	185	10150	Sand spit
		Tsukihama	0.01			
		Iinogawa-joryu	14.94			
		Ozeki-karyu	17.2			
Old Kitakami	A	Kadonowaki	1.24	299		Jetties structure
		Omori	13.17			
		Wabuchi	21.78			
		Wakuya	25.73			
Naruse	A	Miyato	-0.3	208	1130	Jetties structure
		Nobiru	0.5			
		Ono-Naruse	4.18			
		Kashimadai-Naruse	8.99			
Yoshida	A	Miyato	-0.3			
		Ono-Yoshida	4.04			
		Kashimadai-Yoshida	8.99			
		Hataya-Yoshida	13.6			
Takagi	B	Takagi	0.98	116	142.3	Inside the Port
Sunaoshi	B	Hachiman Br.	3.01	71	54.8	Inside the Port
		Konoike	5.47			
Nanakita	B	Nanakita	0.59	80	229	Sand spit
		Fukuda	5.15			
Natori	A	Yuriage	1.77	92	984	Jetties structure
Abukuma	A	Arahama	0.78	330	5390	Sand spit
		Iwanuma	8.07			
Kido	B	Kido	1.2	24	263.1	Sand spit
Ohisa	B	Ohisa	0.75	21	51.3	Sand spit
Natsui	B	Suga	1.2	36	119.3	Sand spit
		Shimokamiya	2			
		Nakakamiya	5.2			
		Kamata	7.6			
Shin (Natsui Branch)		Umemoto	10.4			
Niida (Natsui Branch)		Toda	0.38			
Fujiwara	B	Minamitomioka	3.7	160	115.1	Inside the Port
Same	B	Matsubara	3.2	40	601	Sand spit

* River mouth width was measured from the Google Earth software in May 25, 2010

Table 2 Tsunami propagation in the upstream of rivers

River name	Class	Max. tsunami height (m)	Distance of tsunami propagation (km)	Corresponding tsunami travel time (hrs)	Wave celerity (km/h)
Kitakami	A	0.57	17.2	1	17.20
Old Kitakami	A	0.66	21.78	1.17	18.62
Naruse	A	0.626	4.18	0.5	8.36
Yoshida	A	0.54	8.99	0.83	10.83
Natori	A	0.185	1.77	0.5	3.54
Abukuma	A	0.215	8.07	0.84	9.61
Takagi**	B	0.55	0.98	2	0.49
Sunaoshi**	B	0.53	5.47	2	2.74
Nanakita	B	0.18	5.15	1.17	4.40
Kido	B	No tsunami	--	--	--
Ohisa	B	No tsunami	--	--	--
Natsui	B	0.305	2	1	2.00
Shin (Natsui Branch)	B	No tsunami	--	--	--
Niida	B	No tsunami	--	--	--
Fujiwara	B	0.31	3.7	1	3.70
Same	B	0.11	3.2	1.16	2.76

** Results of these both rivers might not accurate because of the analysis based on one hour time interval data set

3. RESULTS AND DISCUSSION

As mentioned above, rivers in Japan were divided into two group A and B. A details analysis of tsunami impact will discuss further in this section depend on this classification.

(1) In the Class-A rivers

Table 2 is shown the summarise of influences of tsunami wave height and uppermost point where tsunami can propagate for all studied rivers.

When tsunami propagates near to the river entrance the energy will be dissipated due to the combination of river morphology and river bed friction. The larger rivers width and depth may make easier for tsunami wave to transport faster and longer distance to upstream. As seen in **Table 2**, tsunami can approach to the distance of 21.78km upstream with approximately speed of 18.62 km/h in the Old Kitakami Rivers.

Fig.4 is an example result to show the tsunami travel time along the river for three point occurrence, first peak, and second peak points in the Kitakami River. The tsunami took about 1 hour to reach up to 17.2km upstream of the Kitakami River, where the sluice gate is located. Thus, the tsunami wave celerity is estimated equal to 17.2 km/h. If we assumed the average water depth at the Kitakami River is about 4m, then the estimated celerity is very well agreement with the result from the shallow water equation which is equal to 19.62 km/h.

Fig.5 is shown that the tsunami peak is reduced about 5% as entered to the Kitakami River and increased a bit at the end due to the reflected waves from the sluice gate wall causing a standing wave in front of the gate. Other rivers, water level rise reduces gradually.

Naruse and Yoshida Rivers have the same river mouth (**Fig.1**). As discussed previously, the tsunami energy dissipation and tsunami celerity are mostly dependent on the friction of river bed morphology and elevation. The tsunami is moving faster in a deeper region. This phenomenon is clearly seen in the Naruse and Yoshida Rivers in **Fig.6**. Because of the river bed elevation in the Yoshida River is flatter than compared to the Natuse River so the tsunami travel distance in the Yoshida River is longer than the Naruse River.

(2) In the Class-B rivers

The Class-B rivers are relative small, the water depth and width at the entrance are narrow and shallow, respectively. Therefore, most of the tsunami wave energy was dissipated in the coastline and in front of river mouth areas. Tsunami cannot further propagate into the upstream of river as observed in the Kido, Ohisa, Shin and Niida Rivers (see **Table 2**).

At the entrance of some Class-B rivers, there are some rivers in which the water depth and river width remain as high enough for tsunami can invade into the upstream such as in the Nanakita, Natsui and Same. However, the tsunami height is quite low and it can only affect to a short distance upstream (maximum is about 5km upstream was obtained in the Nanakita River, see **Table 2**). In addition, the tsunami takes longer time to travel along the river as well as smaller wave celerity due to the confliction of narrow river geometry and water depth.

Takagi, Sunaoshi and Fujiwara Rivers are located inside of the Port contruction. Thus, the river width is always fixed by structures and river water depth are kept high for the navigation transportation purposes, so tsunami can easily propagate in this kind of rivers. Table 2 is shown that the tsunami height in these Takagi, Sunaoshi and Fujiwara is higher compared to others Class-B rivers.

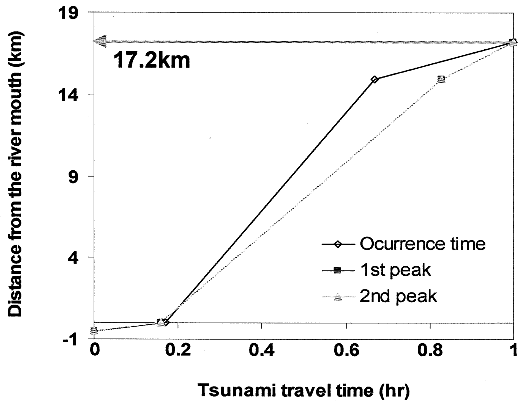

Fig.4 Tsunami travel time in the Kitakami River

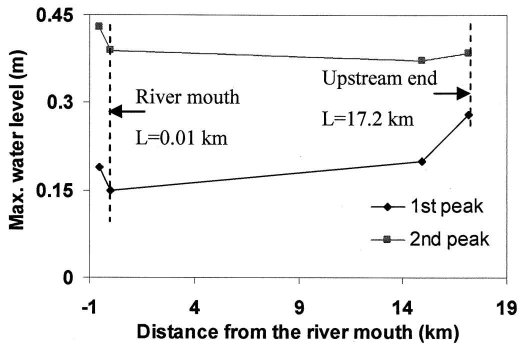

Fig.5 Water level peak variations along to the Kitakami River

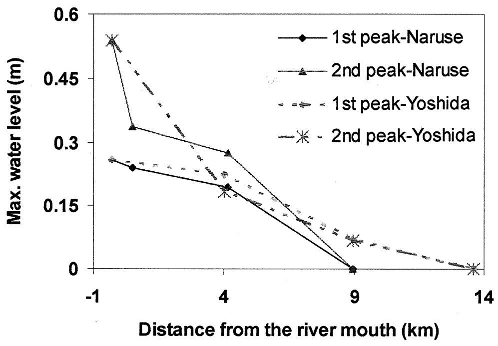

Fig.6 Water level peak variations along to the Naruse and Yoshida Rivers

4. CONCLUSIONS

A comprehensive study on the influences of the Chilean Tsunami wave in 2010 on rivers, which have various river geometries, in the Tohoku District of Japan was carried out. The tsunami can propagate much further upstream distance in deeper river and less in shallower river. The results of this study indicate that tsunami has more impacts to a large river in terms of wave hight and upstream most distance. Even though this Chilean Tsunami when it arrived to Japan was rather small, there was not observed any inundation areas during this time but in case of bigger tsunami wave coming in the future that might cause wave overtopping the sand spit then the phenomenon is slightly different, tsunami can affect even to small rivers.

This empirical study is helpful for river authority, river management and engineers to find out the best solution in controlling the river environment and structure design in the river.

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REFERENCES

Abe Kuniaki (1986): Tsunami propagation in rivers of the Japanese Islands, *Continential Shelf Research*, Vol. 5, No.6, pp. 655-677.

Sato H., T. Shimamoto, A. Tsutsumi and E. Kawamoto (1995): Onshore tsunami deposits caused by the 1993 Southwest Hokkaido and 1983 Japan Sea earthquakes, *Pure and Applied Geophysics*, Vol.144, No.3-4, pp. 693-717.

Tanaka H., K. Ishino, B. Nawarathna, H. Nakagawa, S. Yano, H. Yasuda, Y. Watanabe and K. Hasegawa (2008): Field investigation of disasters in Sri Lankan Rivers caused by the 2004 Indian Ocean Tsunami. *Journal of Hydroscience and Hydraulic Engineering*,Vol.26,No.1, pp. 91-112.

Tsuji Y., T. Yanuma, I. Murata, and C. Fujiwara (1991): Tsunami ascending in rivers as an undular bore, *Natural Hazards*, Vol.4, pp.257-266.

Yasuda H. (2010): A one-dimensional study on propagation of tsunami wave in river channels, *Journal of Hydraulic Engineering*, ASCE, Vol.136, No.2, pp.93-105.

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