STUDY ON TSUNAMI PROPAGATION INTO RIVERS

Min Roh[1], Xuan Tinh Nguyen[2], Hitoshi Tanaka[3]

ABSTRACT

When tsunami wave propagation from the narrow river mouth, water surface is raised and fluctuated by long wave propagation to river upstream area. Observed water level measurement data within rivers in Ishinomaki area from the 2010 Chilean Tsunami event was used to estimate the impacts of tsunami propagation to river upstream. At that time, almost measurement station detected the change of water height due to tsunami wave. In this process, measured data shown that water surface have a different variations and wave height due to river mouth morphology. In this study, a series of numerical tests of tsunami behaviors when it passes through various river entrance morphologies was conducted. Constructed river entrance tests are similar to the characteristic of existing rivers in this area. The numerical results show a significant river mouth types that affect the wave height and water level due to tsunami wave.

1. INTRODUCTION

February 27, 2010, magnitude 8.8, earthquake occurred in Chilean coast. Due to this earthquake, tsunami was caused and propagated along the Pacific Ocean. As the tsunami was occurred, 53 countries issued the tsunami warning system. Also 2010 Chilean Earthquake is regarded as the latest powerful earthquake. The tsunami arrived the eastern part in Japan through the Pacific Ocean after 22 hours. Tsunami wave was detected on the east coast of Japan. The recorded data shown over 1 m maximum tsunami height and tsunami propagation distance was estimated a several tens kilometers.

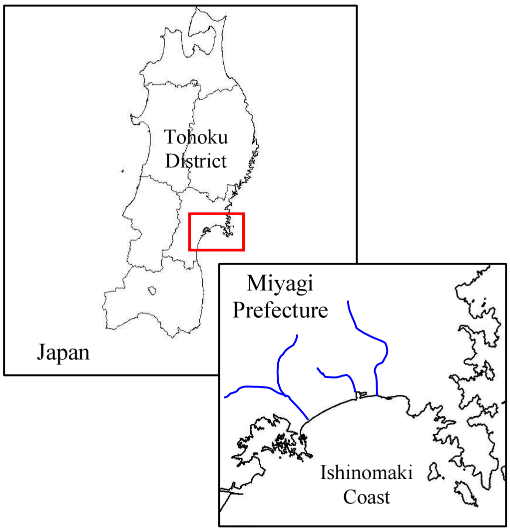

Figure 1 : *Location of study area*

Generally, approaching tsunami wave into the coastal regions are companied many phenomenon such as inundation near coastal regions, wave propagation into rivers, erosion and overwash in sand spit, etc. However, this study has concentrated on the tsunami propagation into rivers. In that tsunami event, tsunami wave is propagated along the tidal wave, and tsunami wave height is dominated by river mouth morphology. Also, tsunami wave penetrate in rivers, especially the bottom friction, river bed slope, width, water depth, upstream river discharge, etc. are affected to propagate tsunami wave.

In this regard, Abe (1986) analyzed tsunami height data in rivers about Nihonkai Chubu Earthquake of 1983. Tanaka et al. (2011) proposed the classification of river group according to river mouth morphology through relationship between river mouth structure and tsunami propagation also studied influence of sand spit type of river mouth due to tsunami overtopping. Wijetunge (2009) researched influence of coastal geomorphology and topography due to 2004 Sri Lanka tsunami using the field measurements and numerical simulation. Recently, Yasuda (2010) conducted numerical analysis of various wave models about tsunami ascending into rivers.

In this study, when the tsunami propagation into rivers, the river mouth is one of the important factors from the previous research. Therefore, main purpose is to evaluate the effect of river mouth morphology by using the numerical model. The collected water level variation data have been shown that tsunami impacts were affected by the tsunami and numerical results can be expected the change of wave height due to river mouth.

[1]Doctoral student, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan
[2]Post-doctor Fellow, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan
[3]Professor, Department of Civil Engineering, Tohoku University, 6-6-06 Aoba, Sendai 980-8579, Japan

2. FIELD MEASUREMENT DATA COLLECTION AND ANALYSIS

2.1 Study Area

Ishinomaki Coast is located in the eastern part of the Miyagi Prefecture as shown in Figure 1. This area consists of four different rivers namely, Old Kitakami River, Jo River, Naruse and Yoshida Rivers in which Naruse and Yoshoda Rivers area sharing the same river entrance. The maximum tsunami height by the Chilean tsunami event was obtained about 1.2 m in the Jo River. The rivers have a specific river mouth structures and classified into different river scale. In this way, study area provides variety of research environments and interesting facts. Therefore, Ishinomaki Coast is most proper place to study about the influence of tsunami propagation by river mouth morphology. (Figures 2, 3, 4)

Old Kitakami River and Naruse-Yoshida Rivers belong in First Grade River and Jo River is Second Grade River like this each river has different river mouth morphology and the river scale. Thus, this study area can be expected to the various comparison and analysis research about river mouth due to the tsunami.

2.2 Classification of river mouth

The measurement data and the aerial photo are used to classify river mouth type for each river. Type 1 is inside the port or bay and part of jetties is non-constriction in river mouth. Type 2 is composed sand spit and the constriction structure. (Tanaka et al., 2011) The classification is applied three rivers systems in the study area. Based on these criteria, Old Kitakami River and Jo River are Type 1 (Figure 2, Figure 3) and Naruse-Yoshida Rivers are Type 2 (Figure 4). Old Kitakami River and Naruse-Yoshida Rivers are contained jetties structure in river mouth but there are distinct difference in width between inside of river and river mouth. Old Kitakami River has non-constriction river mouth and jetties type is straight, Figure 4 is shown for the constriction structure of river mouth. Both of two types indicate one of greatly difference feature. Jo River mouth is connected to Ishinomaki Industrial Port and river mouth width became narrow to upstream river.

Figure 2 : *River mouth morphology of Old Kitakami River (Type 1)*

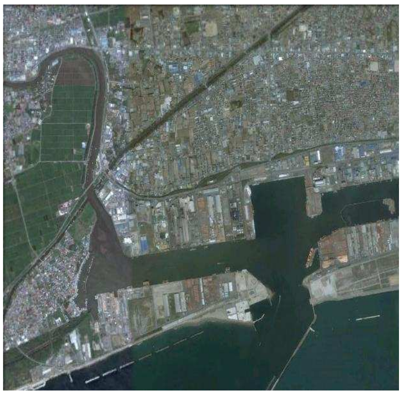

Figure 3 : *River mouth morphology of Jo River (Type 1)*

Figure 4 : *River mouth morphology of Naruse-Yoshida Rivers (Type 2)*

2.3 Measurement station data

Each rivers system has about 1~3 measurement stations to collect water level variation data of 10 minutes intervals. First measurement station is used to calculate the tsunami height in river mouth, Ayukawa tidal level data was used to compare with measured water level inside of river for all stations.

In order to know influence of the tsunami wave, draw the water level data in station of each river mouth. Figure 5 shown that water surface was fluctuated in all station by tsunami. These station data follow the Ayukawa tide but when tsunami wave arrived at the small river, Jo River, observed rising the water level and wave phase is delayed clearly during tsunami propagation. These phenomena can be explained that wave propagation is affected by the river scale. First Grade River such as Old Kitakami River and Naruse-Yoshida Rivers, water level moved along the Ayukawa tidal level but Jo River has the difference water level and wave phase compare with the tidal level. Furthermore, the relationship between river scale and river characteristics can be considered in this field. First of all, the different factors are bottom friction and river bed condition according to the river scale when the long wave through a river. So, to analyze tsunami propagation into rivers, it should be firstly considered river mouth morphology, tidal wave and river scale. Totally, Figure 5 contains this facts and information when the tsunami propagation in rivers.

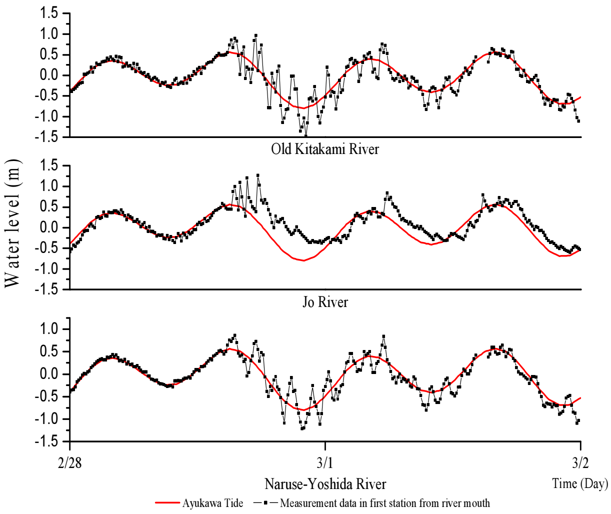

Figure 5 : *Water level variation in river mouth measurement station*

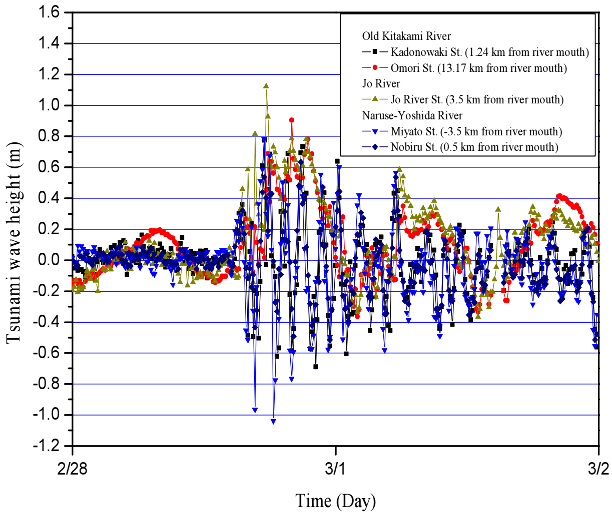

Figure 6 : *Tsunami wave height in river mouth station*

In this study, Ayukawa tidal level is eliminated to consider the influence of tsunami wave from measurement data of the stations and then tsunami wave height can be drawn like that Figure 6. This figure provides maximum tsunami height in each river mouth. The measurement data is summarized in Table 1.

Table 1 : *Summary of river mouth type and maximum tsunami height in Ishinomaki Coast*

	Old Kitakami River	Jo River	Naruse-Yoshida River
River mouth type	Type 1	Type 1	Type 2
Maximum tsunami height (m)	0.775	1.12	0.666
Propagation distance (km)	21.78 (Wabuchi St.)	3.5 (Jo River St.)	4.18 / 8.99 (Ono-Naruse St./ Kashimadai-Yoshida St.)

Table 1 provides that Type 1 have a higher maximum tsunami height than Type 2. It means Type 1 river mouth is possible to easily propagate into river and wave energy is maintained far away until river upstream area, measurement data is clearly shown the difference of tsunami effect due to river mouth morphology, river scale. Thus, the classification of river mouth can be applied to simply in study area.

3. Numerical Experiments

This section is to investigate the effects of different type of construction at mouth to tsunami energy dissipation. In general, Type 1 is known a non-constriction mouth and having higher maximum tsunami height compare with Type 2 from field data. So it needs numerical experiments to evaluate influence of river mouth structure. Numerical results will provide useful information about hypothesis of river mouth morphology. A numerical experiment was conducted simple and representative river mouth structure, also Initial condition and boundary condition limited through an assumption because only to consider the impact of tsunami propagation due to the change of various river mouth structures.

3.1 Governing Equation

In this study, the wave motion is simulated by the horizontal two-dimensional shallow water equation model, this model use depth averaged velocity, including bottom friction. In river area, river bed condition and bottom friction are important factors to calculate wave height in shallow water depth. So, this model was employed Manning coefficient approaching method. Wave simulation model was based on Vu et al. (2002) in this study and that paper shown the theory about numerical model.

3.2 Initial Condition and Boundary Condition

This wave model is restricted initial condition and boundary condition. Basically, Initial condition is assumed the regular sinusoidal wave from estimated the tsunami wave height at Miyato coastal station in Figure 7. Computational domain was composed of sea, river, and land boundaries. In the sea area, a wave-absorbing zone is approached at the lateral boundaries to minimize wave reflection. The bottom friction is assumed constant within first five meshes, and a free slip boundary condition is applied at surfaces of the coastal structures.

To calculate bottom friction, Manning coefficient is adapted 0.035 and the grid size is the square of 50 m vertically and horizontally.

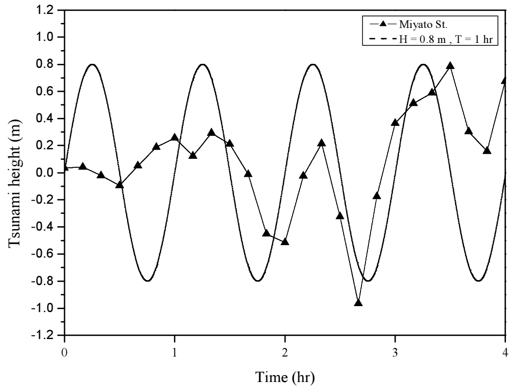

Figure 7 : *Initial condition of numerical model*

3.3 Numerical Case Test Results

In the numerical test, the model is applied for the six kind of different river mouth structures. In facts, these cases are based on the representative river mouth type to see easily in the coastal area, and Figure.8 shows top view of total calculation domain and the bathymetry data of the sea and river. In addition, the test cases are illustrated with the size of river mouth.

Figure 9 shows the horizontal distribution of the wave height for Case 6 near the river mouth. It can be seen that the wave reflected by the structure interact with the tsunami wave, propagate a part of wave energy to the river upstream.

Figure 10 provides the change of maximum wave height of the first peak wave due to river mouth morphology. Most importantly, the numerical results have the definite relationship between maximum wave height and river mouth morphology. From the results, Case 4 such as Jo River is most greatly

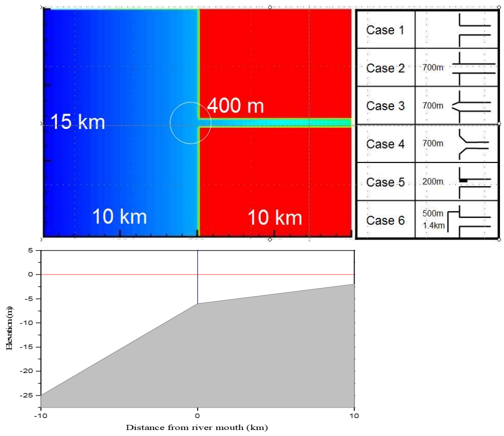

Figure 8 : *Numerical domain and test cases*

affected by the tsunami wave. Wave energy is possible to penetrate and concentrate readily into rivers through the river mouth type and wave energy is retained for a long time to the river upstream area. And computed Case 6 give the interesting result because the maximum wave height is second higher than another cases although the connected breakwater or inside a port. So, it can be seen the coastal structure can not prevent long wave propagation such as tsunami wave and tidal wave. Case 2 is similar to the river mouth of Old Kitakami River, this case also indicate the high maximum wave height like that Case 4 and Case 6.

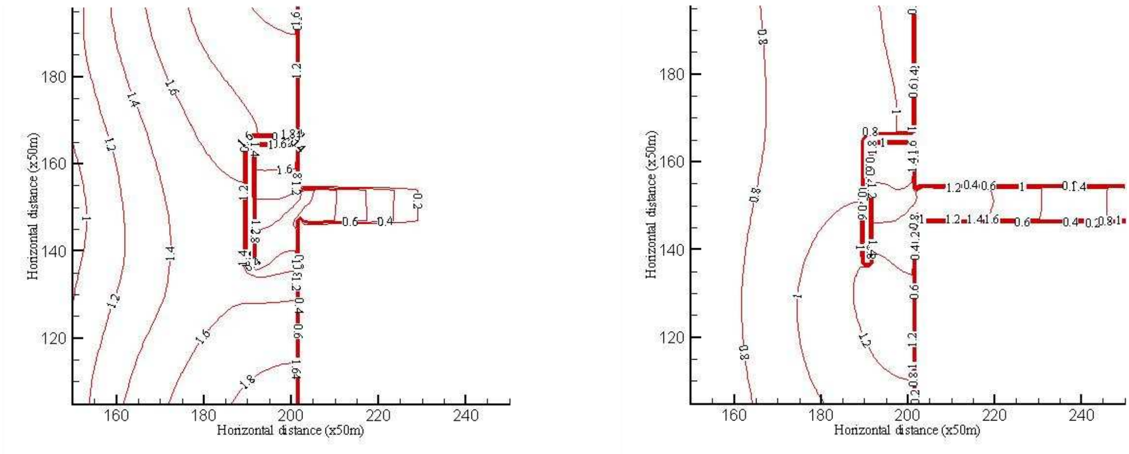

Figure 9 : *Computed wave height of Case 6 (t=400 sec, t=500 sec)*

Case 3 and Case 5 show the different results compare with another cases, the opening rate of river mouth is the important factor to travel the long wave into a river. Case 5 was represented the entrance of Naruse-Yoshida Rivers and Type 2 of river mouth classification. It can be seen the constriction structure is difficult to propagate into rivers. As a result, numerical results follow the long wave theory and it can say that river mouth morphology dominate the change of wave height due to tsunami wave.

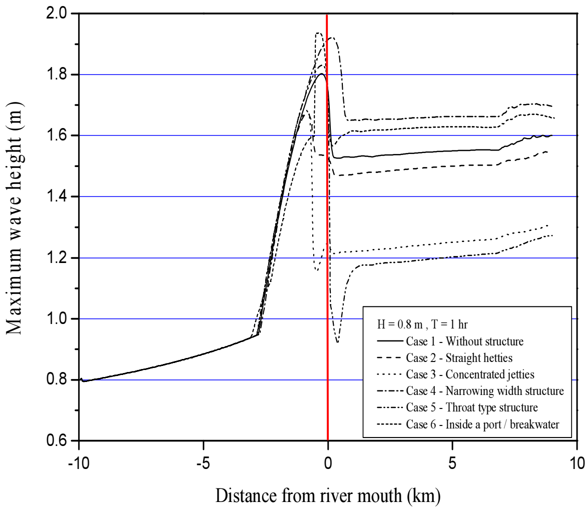

Figure 10 : *Maximum wave height along the center line*

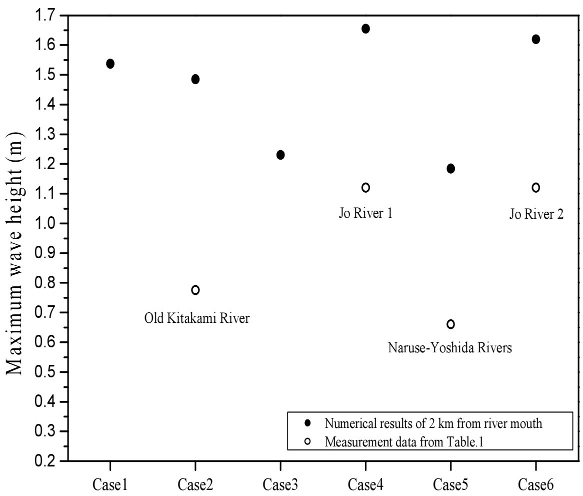

Figure 11 : *Comparison with measurement data*

Finally, Figure 11 shows the comparison between the observed data and the computational results. The tendency of maximum wave height is similar to the comparison according to the river mouth type although the numerical analysis has many limited condition that initial, boundary condition and numerical geometry, etc. Therefore, this model can be used for the evaluation of the influence of tsunami propagation and expectation of the significant wave height in this field.

4. Discussion

In this study, the importance of river mouth morphology can be known by the numerical results and measurement data as well as the tidal wave and river scale also should be considered to express the real phenomenon. Jo River shown the wave phase delayed and risen in measurement data compare with large rivers data of Old Kitakami River and Naruse-Yoshida Rivers because the tidal wave is closely related to the size of river and a small river is generally affected by bottom friction. Actually, the process is difficult to prove compounding the operation of these factors. Therefore, first step, the numerical model was simulated about influence of river mouth morphology using the simple assumption and geometry. As a result, threatening river mouth type is found by the Numerical experiment results and measurement data. In addition, this model can be able to simulate natural phenomenon physically when the tsunami propagation into rivers. For the future, modified numerical model can help to expect influence of tsunami wave into rivers and provide the tsunami protection method on the inundation of river upstream area.

5. Conclusions

- The river mouth type of adjacent the port and narrowing the width have the maximum tsunami height as the most significant cases. In this area, maximum tsunami height is recorded 1.12 m in Jo River, and Type 1 river mouth group have a higher wave height than Type 2 and river mouth morphology can be classified the effect of tsunami from water level variation according to the river scale.
- The numerical results and measurement data have a similar tendency of maximum wave height due to each river mouth type. The model is useful for many researchers to simulate and analyze the tsunami wave.

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