ESTIMATION OF FLOW VELOCITY FOR TSUNAMI PROPAGATION INTO RIVERS

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1. INTRODUCTION

On March 11, 2011, the Great East Japan Earthquake with magnitude of 9.0 occurred in the eastern coast of Japan and generated a huge tsunami. Buildings, houses, and infrastructures in the coastal area were destroyed and washed away due to the tsunami. It also caused a large number of casualties and survivors were evacuated from the affected area. Most of the hydraulic measurement stations were destroyed. Thus, the process of collecting data is limited. On the contrary, videos were recorded by the government, other organizations, and from the survivors.

Generally, tsunami wave is followed by several other phenomenons such as tsunami inundation, over-topping, erosion and so on. Tsunami wave propagation into rivers is one of the most important phenomenons because of its characteristics. Tsunami in river propagates faster and thus, arrives early at the upstream river than tsunami over land.

Researchers have studied about the tsunami propagation into rivers. Fritz et al. (2006) conducted the calculation of tsunami velocity using survivor videos of 2004 Indian Ocean tsunami event. Mutsutomi et al. (2010) surveyed the relationship between tsunami flow velocity and inundation depth. According to the past studies results, tsunami flow velocity is an important parameters in explaining and understanding the characteristics of tsunami wave propagation.

In this study, the collected video was analyzed to estimate the tsunami flow velocity by tracing debris such as car wreck and remains of houses on the water surface.

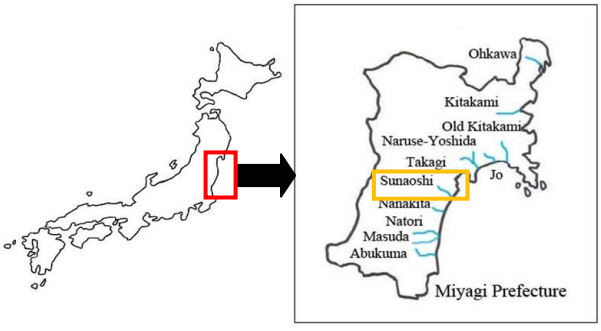

Fig.1 Location of study area

Study area is the Sunaoshi River in Miyagi Prefecture as seen in **Fig.1**. The Sunaoshi river mouth is connected to the Sendai Port. This location was severely damaged in the tsunami event due to The Great East Japan Earthquake. The measurement stations along the river were not damaged. Moreover, video data is available, recorded by survivors. Thus, this place is appropriate for this study.

2. DATA COLLECTION AND ANALYSIS

2.1 Video image analysis

A raw video image contains important information of tsunami wave propagation. However, video data is often distorted due to oblique view and camera motion during the recording process. For that reason, the raw image should be adjusted to minimize the distortion effects before calculating the tsunami flow velocity. Image composition method was proposed in order to reduce the distortion. Several still frames were captured from the video and composited using planar motion as shown in **Fig.2**. Unfortunately, the actual time cannot be confirmed in this video.

Fig.2 Composited video images of Sunaoshi River

The composited image was rectified from the video frame coordinates to real world coordinate according to three different rectification methods that were utilized to evaluate the accuracy of the method. In this process, the root mean square error between rectified point and original point (28 points) was used to quantify the accuracy. The result is summarized in Table 1.

Table 1 Distance error of rectification method

Method	Root mean square error(m)
Affine method	61.9
Polynomial method	16.3
Triangulation method	2.8

Tsunami flow velocity calculation depends on the rectification method. In this study, the triangulation transformation method gives the minimum error. Hence, the method was chosen and used to for video image rectification.

2.2 Conservation equation

Tsunami flow velocity in river can be calculated based on water level measurement by using the conservation equation as written in the following

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equation,

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0 \qquad (1)$$

where, A is river cross section, Q is river discharge. t is time, and x is position at time. Eq.(2) is derived from Eq.(1) taking integration in two arbitrary points.

$$\int_{x_1}^{x_2} B\frac{\partial \eta}{\partial t}dx+Q_2=Q_1 \qquad (2)$$

where, B is river width that is constant, η is water level variation, Q_1, Q_2 are river discharges at x_1 and x_2. In order to solve Eq.(2), the river upstream discharge was ignored during the calculation, wave form between two points was assumed that water level variation is linear motion according to time interval. The measurement data of 10 minutes interval was used as water level variation data (Roh et al., 2012).

3. RESULTS AND DISCUSSIONS

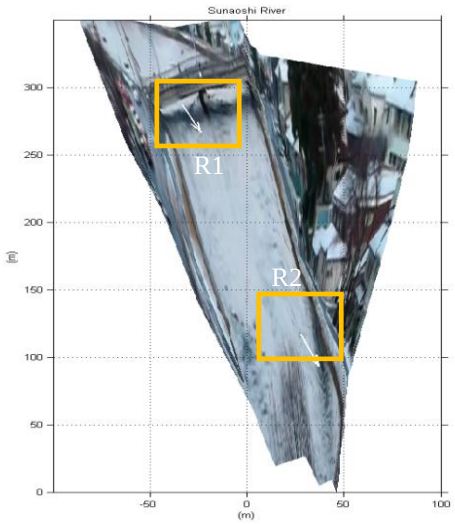

Fig.3 Rectified image and velocity vector

In **Fig.3**, the velocity vector can be calculated by the tracing debris from the rectified video image. Instantaneous tsunami flow velocity was obtained 1.02m/s in river downstream area (R1) and 1.12m/s in river upstream area (R2), respectively. **Fig.4** shows the displacement of debris on the real world coordinate system.

The tsunami velocity also can be calculated by conservation equation. As seen in **Fig.5**, the velocity variation at the two measurement stations show that the max value is 1.8m/s at 2.9km from river mouth and 0.6m/s at 5.5km from river mouth. Here, the positive and negative sign indicate propagation direction, upstream or downstream, respectively.

4. CONCLUSION

Video image analysis and conservation equation have been utilized to estimate the tsunami flow velocity. However, survivor video does not contain the actual time and coordinates. Nevertheless, this study may overcome difficulties and provide valuable information, related to real case tsunami where data can be very limited.

Both methods require further verification. More data are being collected. In addition, other studies related to tsunami modeling may provide ways to verify these methods.

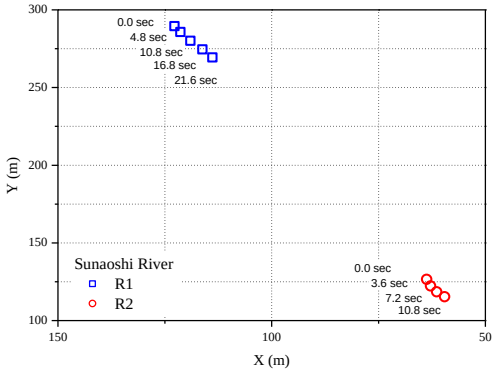

Fig.4 Displacement of tsunami debris

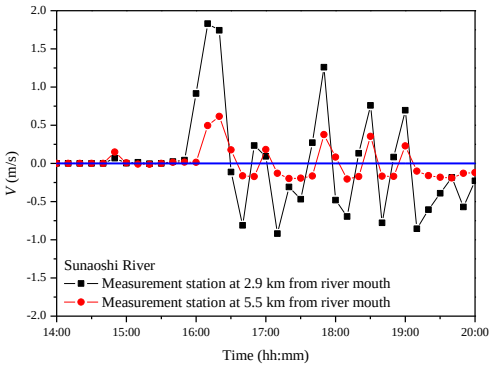

Fig.5 Calculated tsunami flow velocity

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