EFFECT ON WATER MASS STRUCTURE IN WEST JAPAN BY THE 2011 TOHOKU EARTHQUAKE TSUNAMI

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ABSTRACT: The 2011 Tohoku earthquake tsunami devastated the coastal zone in east Japan. It was also reached to the Pacific coast in west Japan area. The most reports have been limited reaching time and height of tsunami. However, it is important to consider the effect on water mass structure by tsunami waves from the viewpoint of sustainable fisheries industry or conservation of marine ecosystem. In this study, from the analysis for monitoring data in Shikoku and Seto Inland Sea, temporal breaking the stratification and the appearance of high-frequency component were confirmed.

Keywords: The 2011 Tohoku earthquake tsunami, the Shimanto River, Brunt-Vaisala frequency, spectral analysis

INTORODUCTION

The 2011 Tohoku earthquake tsunami caused great damage to a wide range of coastal areas in east Japan. It was also reported that tsunami reached at a large distance from seismic origin, such as Hokkaido, Kanto region and Shikoku Island. In most of these reports, the arrival time and height of tsunami were just described. However, as for impact on water mass structure of distant area by tsunami almost has not been examined. From the view point of sustainable fish culture industry, it is important to evaluate quantitatively the effects on the water environment such as water temperature and salinity by Tsunami.

From the social backgrounds described above, in this study, to clarify the impact on water mass structure of west Japan by the 2011 Tohoku earthquake tsunami, the isopleths of water temperature, salinity and the density were drawn and the statistical analysis was conducted.

STUDY SITE AND OUTLINE OF USING DATA

Fig. 1 and Fig. 2 show investigation areas and observation points at each area. In addition, Table 1 shows observation items and information on the monitoring conditions at each observation point.

In this study, 3 palaces which have different geographical features were selected to compare with each other.

Shimanto River mouth is about 1,200 km away from the epicenter of the 2011 Tohoku earthquake. However, it faces to the Pacific Ocean; tsunami waves can reach there directly. In fact, after the 2011 Tohoku earthquake, the propagation of tsunami wave with 76 cm height was confirmed. In this investigation area, 4 observation points for monitoring of water level, current speed and

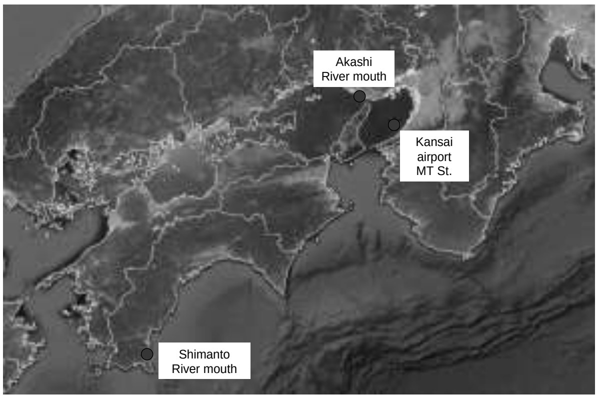

Fig. 1 Investigation areas

its direction and water environment such as water temperature and salinity have been measured. St.1 and St.3 are located in the river mouth and offshore, respectively. The time series of water level also has been collected at Hatsuzaki gauging station. However, St.2 located in the tributary Takashima River was missing by tsunami propagation.

Kansai airport MT station is located in Osaka Bay and it is about 500m offshore from the Kansai International airport island. This meteorological and sea states observation tower is operated 24 hours a day. Osaka bay is well known as one of the typical semi-closed water area in Japan. The decreasing of tsunami propagation might be occurred with the passing of Kitan strait which is the border between Osaka Bay and Kii channel.

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Table 1 Observation items

observation point		sea area	layers	observation item		
				water level	current direction current speed	water temprature salinity
Shimanto River mouth	St1	The Pacific Ocean	6	–	○	○
	St3		2	–	○	–
	Hatsuzaki		1	○	–	–
Aakashi River mouth		Harima-nada	1	○	–	○
Kansai airport MT St		Osaka bay	3	○	○	surface layer only

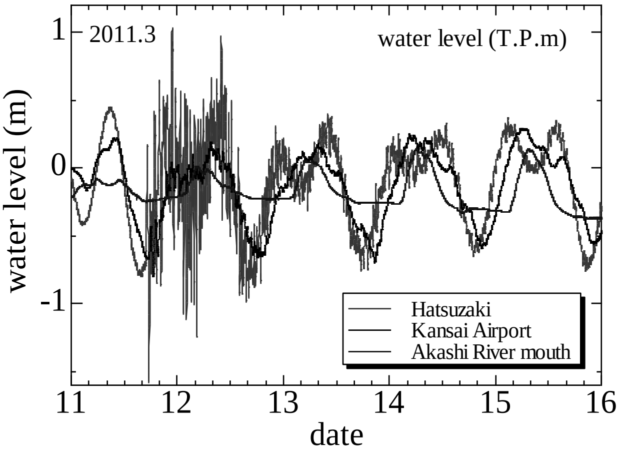

Fig. 3 Time series of water level

Akashi River mouth is connected to Harima-nada sea area in Seto Inland Sea. In this river, periodical topographic change has been confirmed. Namely, the river mouth closure formed by wave in winter tends to be flushed in summer rainy season. In this river mouth, at the right bank 400m upstream, the water level, water temperature and salinity have been measured by auto recording measurement equipment (HOBO U-20 for water level and COMPACT-CT for water temperature and salinity).

RESULTS AND DISCUSSIONS

Water level

Fig. 3 shows time series of water level at Shimanto River mouth, Kansai airport MT station and Akashi River mouth, respectively.

At the Shimanto River mouth (observation station name: Hatsuzaki), large amplitude vibration was confirmed in the evening March 11, 2011 and it was continued to the next afternoon. Moreover, until March 15, around both high and low tide - the timing of tidal current was very weak -, noise-like variation caused by tsunami propagation was still detected. Therefore, it is judged the effect of tsunami had been continued for at least 4 days or more in Shikoku Island.

On the other hand, at Kansai airport MT station, the vibration caused by tsunami propagation was also detected. However, the amplitude of turbulence was smaller than at Shimanto river mouth. Moreover, the variation caused by tsunami propagation was shown

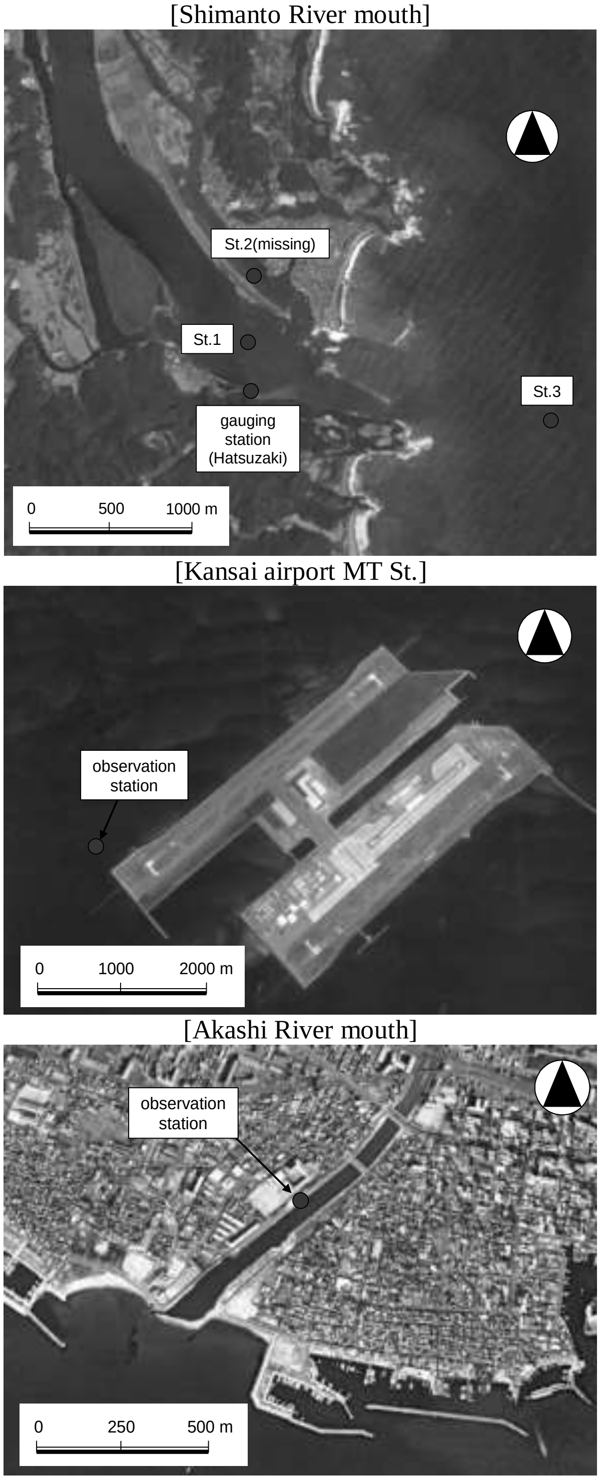

Fig. 2 Observation point

little on March 15. From these observation results, we can see the effect of tsunami propagation in Osaka Bay is weaker than Pacific coast in Shikoku Island due to Kitan strait which contributes the decreasing of tsunami propagation.

At the Akashi River mouth, it was almost closed due to the sediment transport by ocean waves. The turbulence caused by tsunami propagation couldn't be detected. We can confirm it from the shape of water level change in Fig.3. However, in fact, at some places in Seto Inland Sea, reaching tsunami was reported.

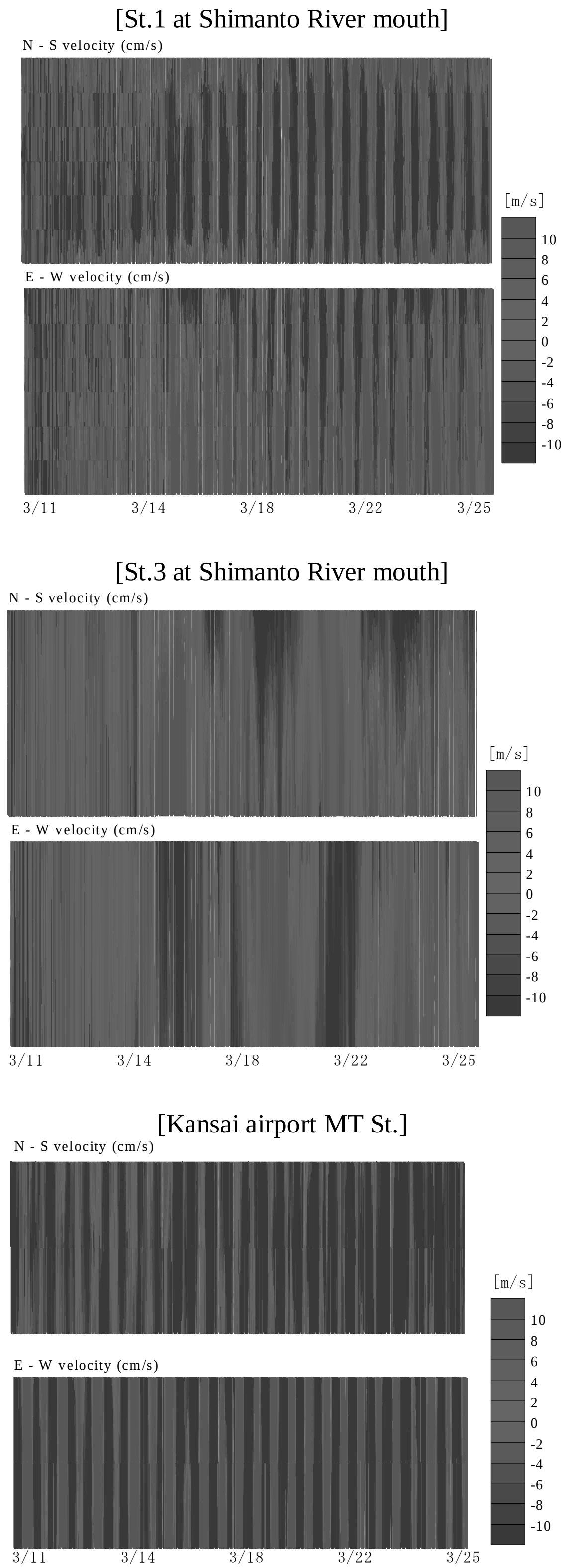

Fig. 4 Isopleths of current velocity by direction

Temporal and spatial variation of current

Fig. 4 shows isopleths of current velocity by direction at Shimanto River mouth (St.1 and St.3) and Kansai airport MT station, respectively.

In these figures, we define the positive value means the current speed of northward in N-S direction or eastward in E-W direction.

At St.1 of Shimanto River month where has been strongly affected by river discharge, we can confirm the appearance of northwest – southeast direction which is the same direction to river channel. However, from March 11 to 14, 2011, such clear pattern couldn't be detected. This phenomenon shows the appearance of effect of tsunami propagation.

On the other hand, at St.3 of Shimanto River mouth, the effect of river discharge was weak; the current velocity at St.3 tended to be smaller than at St.3 and the periodical change couldn't be seen in Fig. 4.

In this station, there were the currents which had different directions between upper and lower layer according to time of the day.

At Kansai airport MT station, the strong current was detected in all layers in the evening of March 11. This phenomenon presents the reaching the 2011 Tohoku earthquake tsunami to Osaka bay. However, after March 14 when the effect of tsunami propagation was gradually weak, the southward-current tends to be exceeded on the surface layer. This specified direction current might be the part of the permanent current of eastern shore or the *Okinose* ring current in Osaka bay.

Temporal and spatial variation of water temperature, salinity and density

Fig. 5 shows isopleths of water temperature, salinity and density at Shimanto River mouth (St.1 and St.3). As for density, it was calculated by Knudsen empirical formula with water temperature and salinity.

At St.1 of Shimanto River month, due to river discharge on surface layer and the run-up of sea water from bottom layer, we can see the water mass structure has formed the stratification. Namely, it was low water temperature and salinity on the surface layer and high water temperature and salinity in the bottom layer. However, in the evening on March 11, both water temperature and salinity was mixed from surface layer to bottom layer and the stratification was broken by tsunami propagation. From the Isopleths of density, we can clearly see the recovery process after breaking the stratification.

On the other hand, at St.3 of Shimanto River month, there almost no effects on river discharge. Therefore, the clear stratification could not be seen in Fig.4. Especially, as for salinity, the high concentration over 30 ‰ has

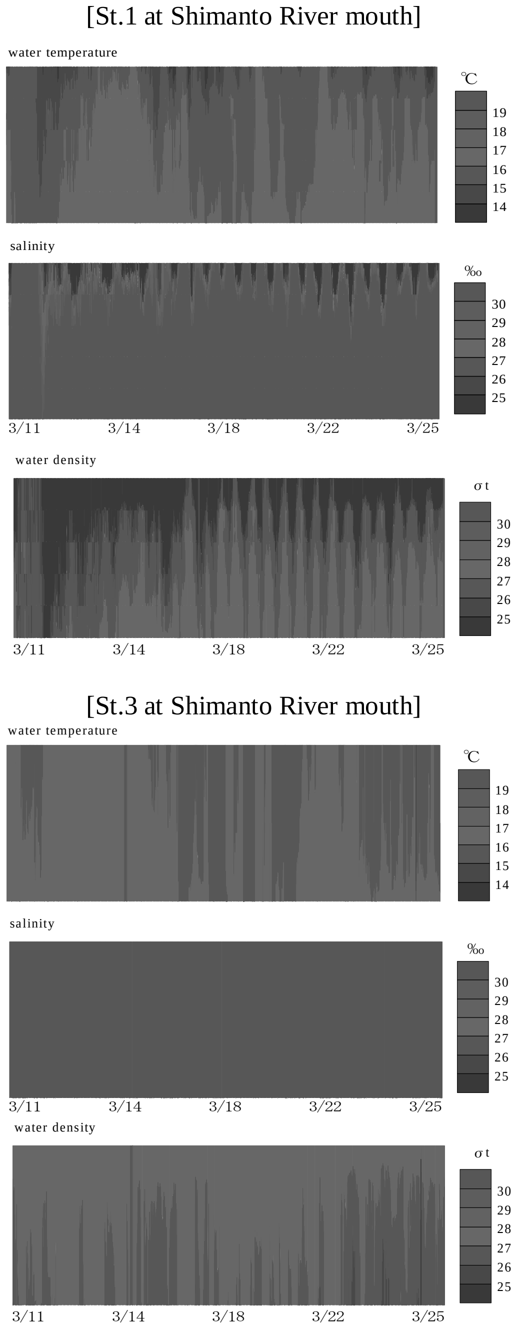

Fig. 5 Isopleths of water temperature, salinity and water density

been distributed in all layers. From the Isopleths of density in Fig. 5, forming the stratification could not be seen clearly. This situation means that the vicinity of St.3 is vertical mixture-prone area.

Time series of water level, water temperature and salinity at Kansai airport MT St. and Akashi River mouth

The measurement of water temperature at Kansai airport and Akashi river mouth has been conducted just in one layer; their isopleths couldn't be drawn. Therefore, the time series of water level, water temperature and

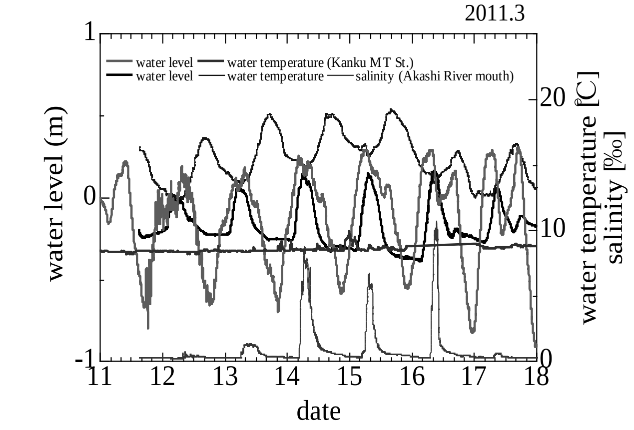

Fig. 6 Time series of water level, water temperature and salinity

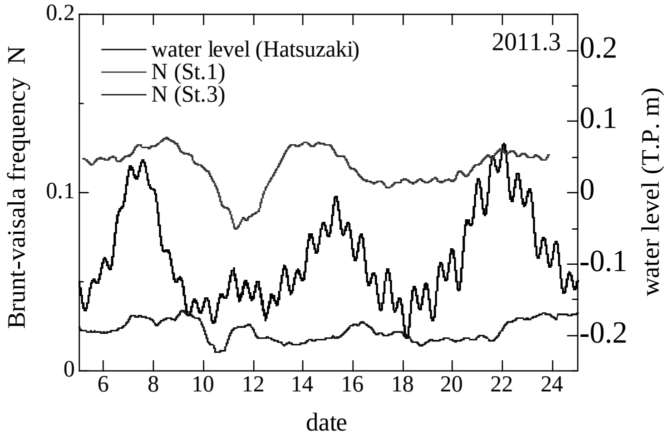

Fig. 7 Time series of Brunt-vaisala frequency

salinity at Kansai airport and Akashi River mouth show in Fig. 6.

From the Time series of water level at Kansai airport, tsunami propagation was detected in the evening March 11 as same as shown in Fig.3. However, reaching tsunami hasn't affect on water temperature on the surface layer.

At the Akashi river mouth, it was almost closed due to sediment transport by ocean waves in winter. The water level change caused by tsunami propagation couldn't be detected. As for salinity, the reaching of high salinity water body was confirmed at the timing of high water level in spring tide; however, the direct impact of tsunami propagation could be little detected.

As for water temperature, it has circadian phases in Akashi River mouth due to shallow water depth; such regularity could not be seen at Kansai airport MT station where water depth is enough.

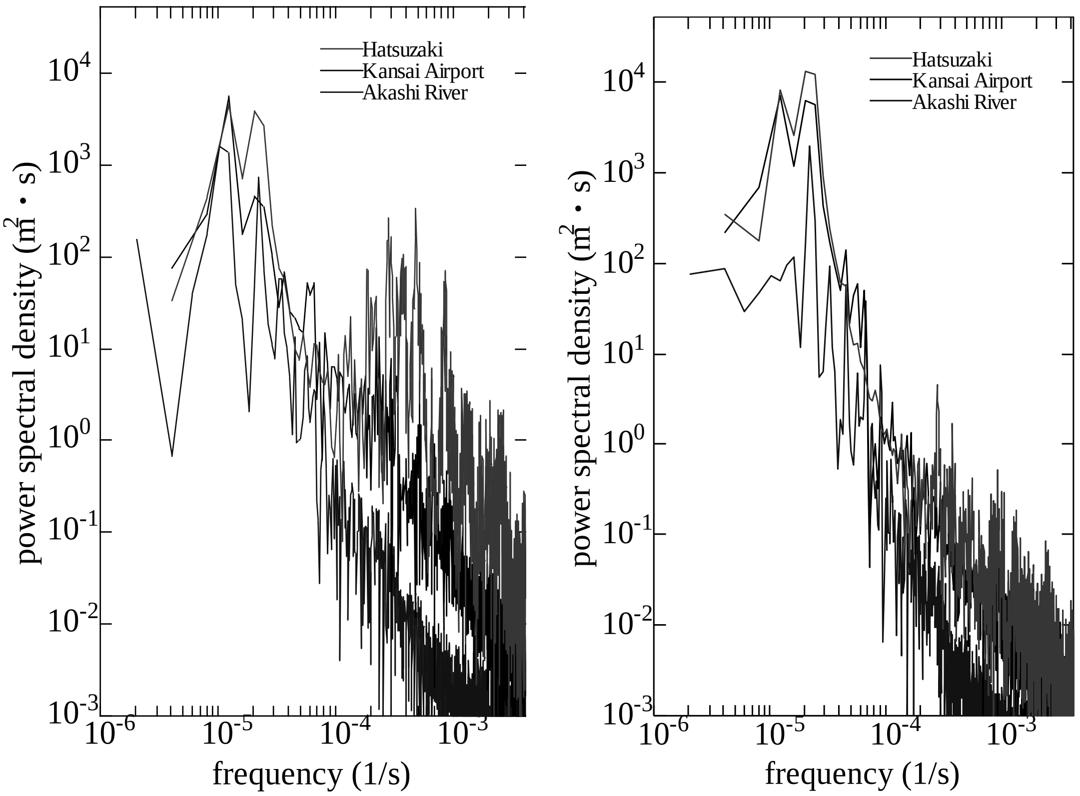

Fig. 8 Results of spectral analysis

Examination of stability of stratification

Brunt-vaisala frequency N is one of the indexes on atmospheric dynamics, oceanography, aster seismology and geophysics. Its square value N^2 is defined by the following equation.

$$N^2 = \frac{g}{\rho} \cdot \frac{dp}{dz} \qquad (1)$$

Where g : gravitational acceleration, ρ : correction density, dp : deference of density between upper and lower layer, dz : distance between upper and lower layer.

If stratification is strong, the number becomes large. On the other hand, in the case of $N^2 < 0$, stratification becomes imbalanced.

Fig. 7 shows the time series of Brunt-vaisala frequency at Shimanto River mouth (St.1 and St.3). In this figure, the time series of water level which corrected 25 hours moving average at Hatsuzaki station. From this time series of water level, the variation caused tsunami propagation was confirmed and it continued to 10 days later from reaching tsunami.

At St.1 where the stratification was formed clearly before reaching tsunami, the behavior of Brunt-vaisala frequency N coincides with the variation of water level. Especially, at the timing of ebb current Brunt-vaisala frequency N tends to decrease due to outflow of fresh water with low temperature. In the evening on March 11, it also clearly decreases its value due to tsunami propagation.

On the other hand, there is no difference of density between surface layer and bottom one at St.3; therefore the Brunt-vaisala frequency is smaller than at St.1. It was also confirmed temporal decrease at the timing of reaching tsunami in the evening on March 11, 2011.

Spectral analysis

To extract the dominant period, spectral analysis on water level variation was examined. Analysis period are just after reaching tsunami and 10 days later, respectively.

Fig.8 shows the results of spectral analysis. The left side figure is the result for data just after reaching the tsunami and the right side one is the result for data 10 days later, respectively.

At Shimanto River mouth and Osaka bay, the dominant daily and semi-daily period was detected. In addition, the result for data just after reaching tsunami shows the appearance of high frequency components which might be caused by tsunami propagation. These high frequency components drastically decrease 10 days later.

At Akashi River mouth, the power spectral density is lower than at Shimanto River mouth due to the effect of river mouth closure.

CONCLUSIONS

After The Great East Japan Earthquake in that occurred at 14:46 JST on 11 March 2011, the tsunami waves were propagated around east coast of JAPAN.

In this study, the time series of the monitoring record of water level at Shimanto River poured into the southwestern part of Kochi prefecture, Shikoku Island, Kansai airport MT station in the Osaka Bay and the Akashi River mouth in the Seto Inland Sea were displayed and analyzed by the statistical method.

In Shimanto river, where it is 800km or more away from the seismic center, the height of the propagated tsunami was confirmed at the river mouth was 0.84 m and it arrived about 140 minutes later after the earthquake. Moreover, in this river, the river run-up of tsunami waves was also confirmed.

On the other hand, at MT station of KANSAI International Airport and the Akashi River mouth also confirm the tsunami propagation, but the wave height was smaller than at Shimanto River. These observation points are located in inner bay, the damping of amplitude of tsunami wave height is more remarkable. The results of statistical analysis show the detection of the component of tsunami propagation.

These findings might be useful for the conducting of the countermeasures against the big earthquake occurred in Tokai, Nankai and Tohnankai areas for in the near future.

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REFERENCES

The Japan Weather Association (2011). The brief overview on the tsunami generated by the 2011 earthquake off the Pacific coast of Tohoku (flash report), http://www.jwa.or.jp/static/topics/20110329/touhokujishin110329.pdf.

Abe, T., Yoshikawa Y., Yasuda H. and Hirai Y. (2011). Tsunami propagation up rivers in Hokkaido caused by 2011 Tohoku Pacific Coast Earthquake, Journal of Japan society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol.68, No.4 : pp.I_1525-I_1530.

Akoh, R. and Ishikawa T. (2012). The numerical simulation of runup tsunami in Tone river caused by the 2011 off the Pacific coast of Tohoku earthquake, Journal of Japan society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol.68, No.4 : pp.I_1543-I_1548.

Fukumoto, Y., Sukegawa H., Iwamae N., and Ikeya T. (2012). The 2011 off the Pacific coast of Tohoku earthquake Tsunami hydraulic data observed at Choshi offshore, Journal of Japan society of Civil Engineers, Ser. B2 (Coastal Engineering), Vol.68, No.1 : pp.1-5.

Matsukawa, Y., Ara, S., Kato, M., Aburakawa, Y., Watanabe, K., Nagaoka, H. and Yamaguchi, H. (2012). Observation of the tsunami runup in the Hokkaido Tokachi-river due to the 2011 off the Pacific coast of Tohoku earthquake, Journal of Japan society of Civil Engineers, Ser. B1 (Hydraulic Engineering), Vol.68, No.4 : pp.I_1513-I_1518.

Ministry of Land, Infrastructure, Transport and Tourism Shikoku Regional Development Bureau. (2011). Extent of the impact of the 2011 off the Pacific coast of Tohoku earthquake Tsunami for Shikoku rivers. http://www.skr.mlit.go.jp/pres/h23backnum/kasen/110422/110422-1.pdf.