CHAPTER 353

Complete Closure of The Nanakita River Mouth in 1994

Hitoshi Tanaka[1], Fumihiko Takahashi[2] and Atsushi Takahashi[3]

ABSTRACT

Very severe draught occurred in Japan during the dry season in 1994. Due to considerably reduced river discharge, complete closure was induced five times at the Nanakita River mouth in Japan during this period. Detailed field observations were carried out immediately before and after the closures. By analyzing hydraulic characteristics measured at the mouth, date of the closure occurrence can be estimated. An analytical solution is derived for predicting time-variation of river mouth width under the combined influence of incoming waves and effluent river discharge.

1. INTRODUCTION

There have been a lot of field measurements of topography change at a river mouth in connection with practical problems such as flood control and maintenance of a navigation channel. Most of them are, however, made at relatively large rivers due to their practical importance, and, consequently, very few attention has been paid to small ones.

The authors have been conducting field measurement of topography change at the mouth of the Nanakita River, one of typical small rivers in Japan, since 1988 (Tanaka and Shuto, 1989, 1991, 1992: Tanaka, Kabutoyama and Shuto, 1995: Tanaka and Ito, 1996). The Nanakita River originates at the northern part of Sendai and pours into the Pacific Ocean as shown in Fig.1. The catchment area and the length of the river are 229km^2 and 45km, respectively.

From 1988 to 1993, the complete closure at the Nanakita River mouth has been observed only twice (Tanaka and Shuto, 1991), whereas in 1994, the closure

[1] Professor, Department of Civil Engineering, Tohoku University, Aoba, Sendai 980-77, JAPAN. e-mail: tanaka@tsunami2.civil.tohoku.ac.jp
[2] Civil Engineer, Penta-Ocean Construction Co. Ltd., Koraku, Bunkyoku, Tokyo 125, JAPAN.
[3] Civil Engineer, Niigata Prefecture, 4-1, Sinkocho, Niigata 950, JAPAN.

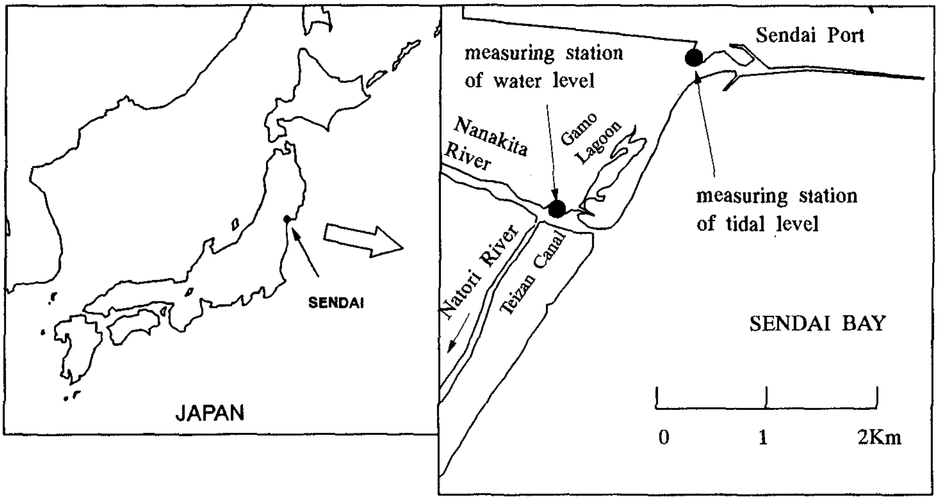


Fig. 1 Location map of the Nanakita River mouth

occurred five times in contrast, probably due to remarkable reduction of the fresh water discharge during the dry season. In this paper, results of detailed field surveying of the topography change will be firstly shown along with corresponding external forces acting at the river mouth. Furthermore, a mathematical model, considering littoral drift by waves and sediment flushing due to river discharge, will be applied to the Nanakita River in order to reproduce the change in the river mouth width.

2. RESULTS OF FIELD OBSERVATION

Figure 2 shows the significant wave height H, the wave period T, the wave incident direction θ measured clockwise from the north, and the river discharge Q_r. The wave characteristics are measured 4 km offshore from the river mouth at the mean depth of 20m, while the fresh water discharge is measured at a gauge station 9km upstream. In Fig.2, the dates when the river mouth closure was firstly observed are also drawn by thick arrows. It should be noted that these are not the dates when each closure occurred, but the dates when the authors firstly noticed the closure. It is seen that the river discharge is considerably small due to draught as compared with other years (Tanaka and Shuto, 1989, 1991) and that very high waves immediately before each closure are common to all events.

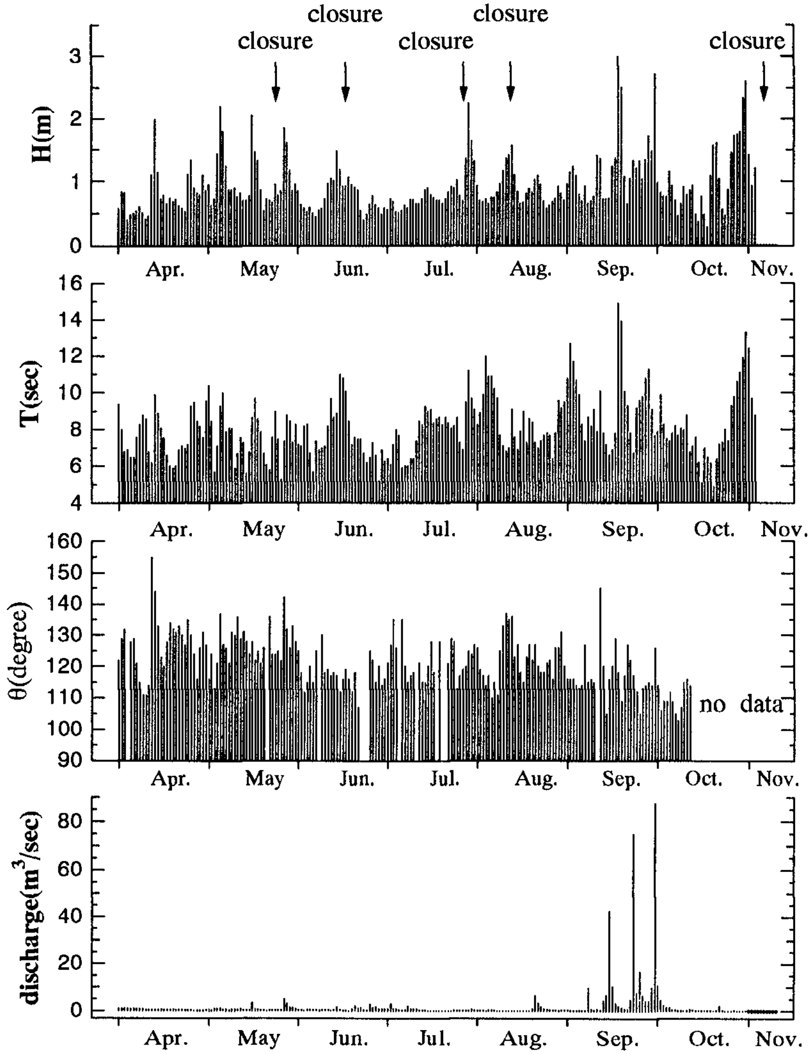


Fig. 2 Time-variation of waves and river discharge

According to Tanaka and Shuto's (1991) study on river mouth closure at the Nanakita River, the incoming waves with incident angle of about 100° are the most unfavorable for keeping the mouth open, suggesting that onshore sediment transport is more effective for the river mouth closure than the longshore sediment movement. In 1994 data set shown in Fig.2, though, such a relationship between the occurrence of closure and the wave incident angle can not be observed.

Water level variation in the mouth is shown in Figs.3 and 4 for June and November respectively, along with the tidal variation measured in the Sendai Port. The location of the measuring stations can be found in Fig.1.

In June, the closure was firstly observed on 17th, and artificial excavation was carried out on 20th. The water level in the mouth shows less variation before and after 17th and is always higher than the tidal level. Even after the closure, slight time-variation can be seen in the Nanakita River mouth. This is due to the tide propagated through the Teizan Canal shown in Fig.1, which connects the Nanakita and Natori River mouths.

The closure in November was firstly observed on 6th. However, judging from Fig.4, it seems that the closure of the mouth progressed gradually from the end of October. Figure 5 shows a temporal variation of the shoreline in the process of river mouth closure in November. Since it can be confirmed that the topography change affected much the water level inside the mouth (Tanaka and Shuto, 1991), the ratio

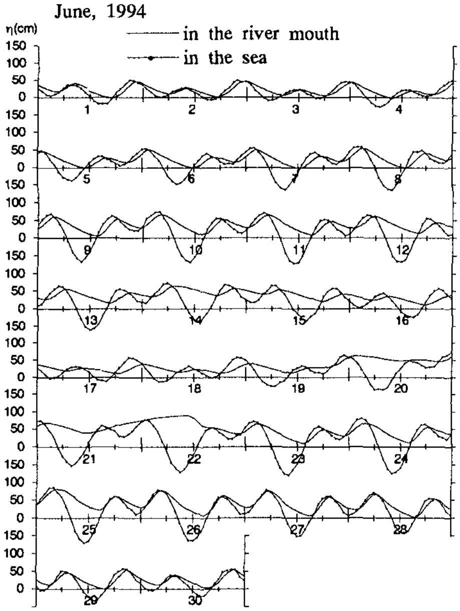
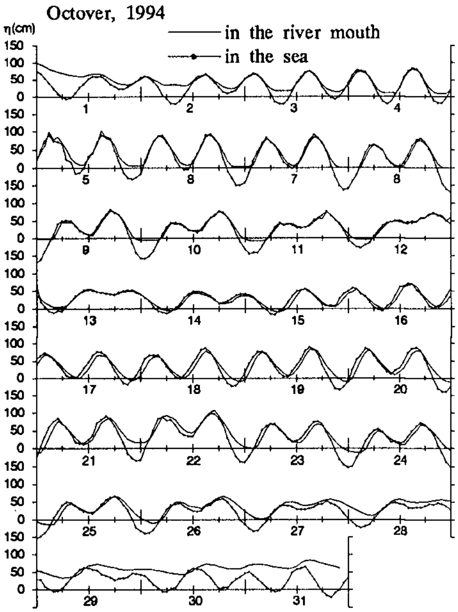


Fig. 3 Water level variation in June



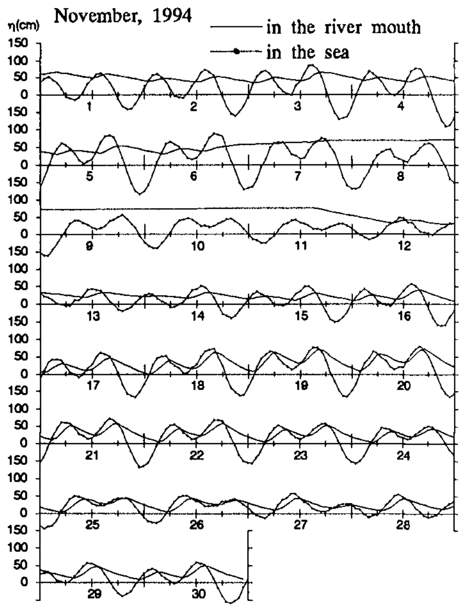


Fig. 4 Water level variation in October and November

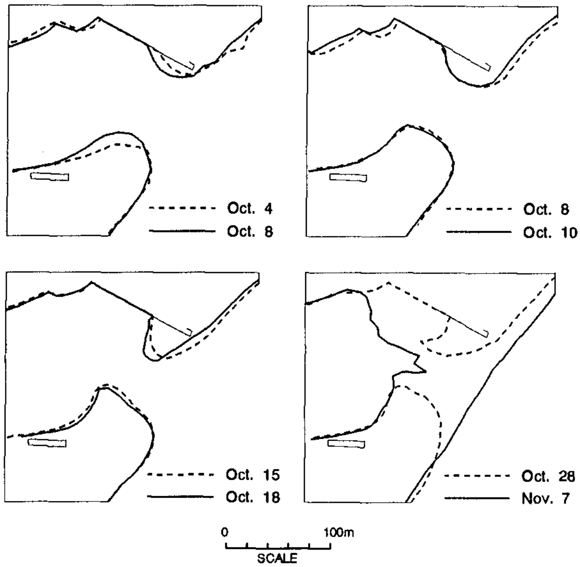


Fig. 5 Shoreline change at the Nanakita River mouth

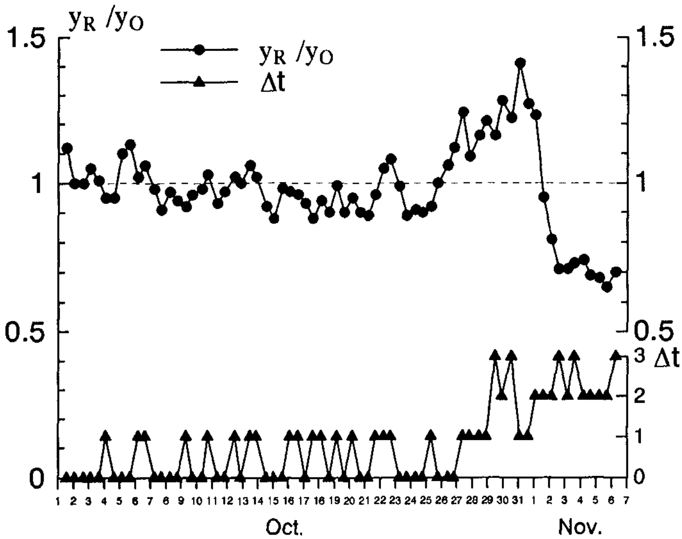


Fig. 6 Water level ratio and lag time

y_R/y_O and the lag time Δt are plotted in Fig.6, where y_R and y_O the daily highest water levels in the river mouth and the sea, respectively, and Δt the time difference between y_R and y_O. At first, the water level ratio shows gradual increase from 1.0 on October 26th to 1.4 on November 1st, and then distinctly decreased to 0.6 on November 3rd, while Δt shows an increase from 0 hour up to 3 hours. Thus, this figure suggests that the river mouth closure was completed on November 3rd. The water level rise in the mouth immediately before the closure in Fig.6 was induced by wave set-up due to wave breaking in front of the river mouth (Tanaka and Shuto, 1992), and the wave set-up height measured in the mouth shows close relationship with the wave height.

3. MATHEMATICAL MODELING

3.1 Governing Equations

A mathematical model proposed by Ogawa et al. (1984) will be employed for predicting closing process at a river mouth owing to predominant wave motion. It is assumed that the wave motion is responsible for the intrusion of sediment into the mouth, while the river discharge is effective for flushing sediment out of the mouth as illustrated in Fig.7. Thus, the corresponding governing equation is expressed as follows (Ogawa et al., 1984).

$$(1-\lambda)Lh\frac{dB}{dt} = e_r q_r B - e_w(1-\lambda)Q_w \tag{1}$$

where λ the porosity of sand, L the width of sand spit, h the water depth at a mouth, B the width of a river mouth, and e_r and e_w the efficiency of sediment inflow by waves and that of sediment outflow by current, respectively. The sediment transport rate due to current, q_r, and that induced by wave motion, Q_w, can be evaluated by means of conventional formulae, Eq.(2) (Brown, 1950) and Eq.(3) (CERC, 1984), respectively.

$$q_r = K\left(\frac{u_*}{sgd}\right)^m u_* d \tag{2}$$

$$Q_W = \alpha(Ec_g)_b \sin\theta_b \cos\theta_b \tag{3}$$

where K is the constant (=10.0), u_* the shear velocity, s the immersed specific weight

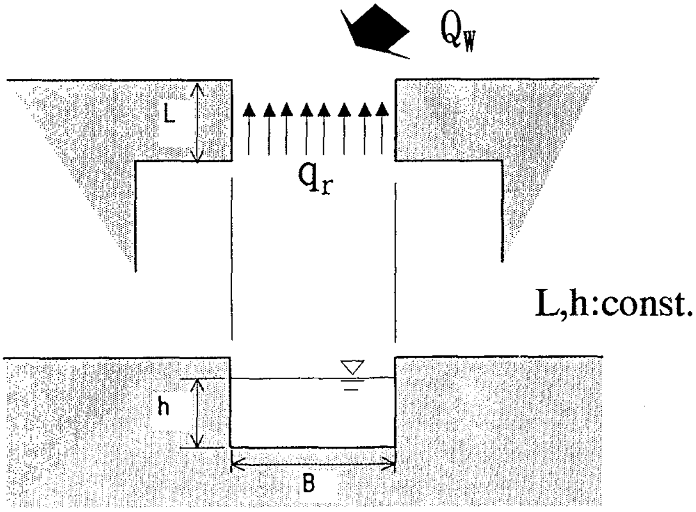


Fig. 7 Schematic explanation for the model

of sediment, g the gravitational acceleration, d the grain diameter, m the power (=2.0), α the empirical coefficient, $(Ec_g)_b$ the incident wave energy flux evaluated at the breaker line, and θ_b the breaking wave angle to the shoreline. The coefficient α in Eq.(3) has already been evaluated to be 0.05 by Tanaka and Shuto (1991) by applying the one-line model to shoreline change adjacent to the Nanakita River mouth.

3.2 Analytical Solution

The following exact solution can be derived from Eq.(1), assuming the wave condition and the river discharge are constant.

$$(B^* - 1) + \frac{A_1^*}{4}\log\left|\frac{(B^* - A_1^*)(1 + A_1^*)}{(B^* + A_1^*)(1 - A_1^*)}\right| - \frac{A_1^*}{2}\left\{\tan^{-1}\left(\frac{B^*}{A_1^*}\right) - \tan^{-1}\left(\frac{1}{A_1^*}\right)\right\} = -t^* \quad (4)$$

where the dimensionless quantities in Eq.(4) are defined as

$$B^* = \frac{B}{B_0}, \quad A_1^* = \sqrt[4]{\frac{A_1/A_2}{B_0}}, \quad t^* = \frac{A_2 t}{B_0} \quad (5)$$

$$A_1 = \frac{e_r K d(\sqrt{g} n Q)^{2m+1}}{(1-\lambda) L h (sgd)^m h^{7(2m+1)/6}} \tag{6}$$

$$A_2 = \frac{e_w Q_w}{Lh} \tag{7}$$

in which B_0 denotes the initial river width, n the Manning's friction coefficient and Q the effluent discharge consists of fresh water and tidal prism.

Some interesting asymptotic behaviors of a river width can be derived from Eq.(4). First of all, if the river discharge is zero, substitution of $A_1^*=0$ into Eq.(4) yields the following simplification.

$$B^* = 1 - t_* \tag{8}$$

Namely, the dimensionless river width shows linear reduction with the passage of time until it closes completely at $t_*=1$. Secondly, the width of equilibrium stage can be easily obtained by substituting $dB/dt=0$ in Eq.(1). The dimensionless form normalized by B_0 is

$$B_\infty^* = \frac{B_\infty}{B_0} = A_1^* \tag{9}$$

According to Eq.(4), it takes infinite duration to reach equilibrium width, though, t_∞ will be herewith defined as the duration when B becomes $0.99 B_\infty$. A dimensionless form for t_∞ can be derived from Eq.(4).

$$t_\infty^* = A_1^* \left\{ a^* - \frac{1}{4} \log \left| \frac{1 + A_1^*}{1 - A_1^*} \right| - \frac{1}{2} \tan^{-1} \left(\frac{1}{A_1^*} \right) \right\} + 1 \tag{10}$$

where $a^*=0.722$ for $A_1^*>1$ and $a^*=0.711$ for $0<A_1^*<1$. As A_1^* approaches infinity, Eq.(10) can be approximated by the simple expression,

$$t_\infty^* = 0.723 A_1^* \tag{11}$$

Time-variation of dimensionless width, B^*, computed from Eq.(4) is depicted in Fig.8. The parameter A_1^* denotes the ratio of sediment transport rate out of a river mouth due to river discharge to sediment intrusion into a river mouth caused by wave

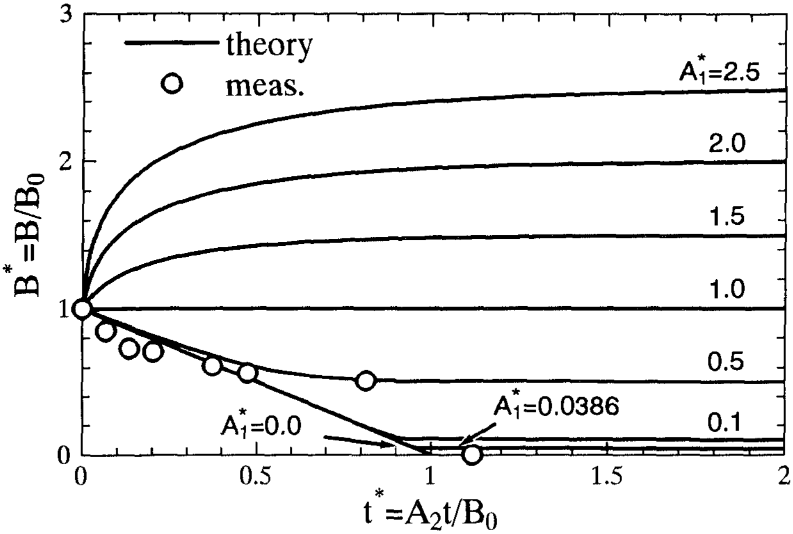


Fig. 8 Time-variation of river mouth width

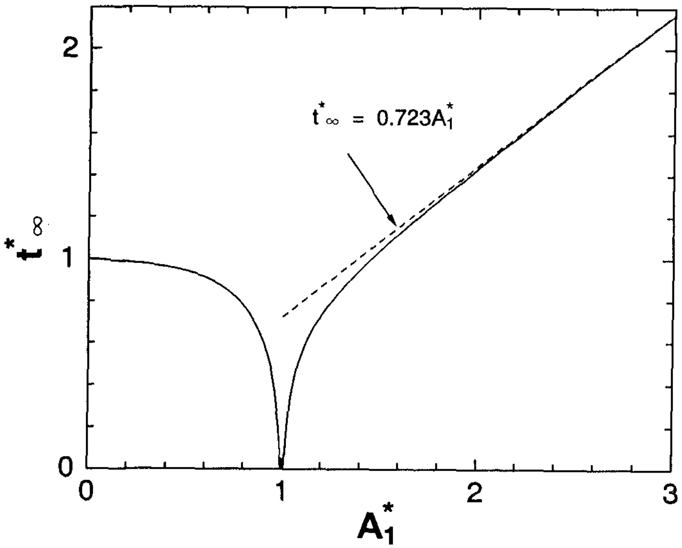


Fig. 9 Relationship between t^*_∞ and $A_1{}^*$

motion, as defined by Eq.(5). Thus, the horizontal line for A_l^*=1.0 in Fig.8 corresponds to dynamic equilibrium state, in which sediment transport rates out of and into a river mouth are balanced, whereas the family of curves for A_l^*>1.0 and A_l^*<1.0 represents widening and reduction processes of river mouth. In case of A_l^*=0.0, the river mouth closes completely at t^*=1.0 as mentioned earlier because of no sediment flushing out of a river mouth. According to the existing theory for river mouth closure without sediment outflow from a river mouth, the solution is given in terms of exponential function, denoting that infinite duration is needed for completion of closure (Tsujimoto et al, 1989). It seems that the present solution, in which closure can be completed within finite duration, is more realistic.

Figure 9 shows the relationship between t^*_∞ and A_l^* obtained from Eqs.(10) and (11). At A_l^*=0, sediment movement at the mouth is in dynamic equilibrium state as described before. Therefore, t^*_∞ is exactly zero at A_l^*=0. The accuracy of Eq.(10) is sufficient as long as A_l^* is higher than 2.0.

3.3 Comparison with Field Observation

The measured shoreline change at the river mouth shown in Fig.5 can be now compared with the present theory. The open circles in Fig.8 denote measured data at the Nanakita River mouth in 1994. Since the wave characteristics and the fresh water discharge are assumed to be constant in the theory, the quantities shown in Fig.2 except wave direction are averaged from October 4th through November 7th, whereas the averaging of wave direction is done from October 4th through November 12th due to lack of the data after November 13th as depicted in Fig.2. As for the coefficients, e_r and e_w in Eq.(1), the values determined by one of the authors (Tanaka, Kabutoyama and Shuto, 1995) are used for the present computation. It is observed that the measured change in the river mouth width shows reasonable agreement with the present theory.

4. CONCLUSIONS

River mouth closure was observed five times at the Nanakita River mouth in Japan in 1994. Conclusions drawn from this study can be summarized as follows:

(1) One of the authors has already reported that the closures of the Nanakita River mouth in 1988 and 1989 were induced by high waves having a incident angle 100° . In 1994, however, the incident angle of high waves which caused the closure did not show this tendency.

(2) By analyzing the ratio and lag time between the water level measured in the mouth and that in the ocean, the date when the closure had completed can be determined. Distinct rise of water level in the mouth caused by wave set-up can be observed immediately before the completion of the closure.

(3) A mathematical model proposed by Ogawa et al. (1984) is used for predicting

time-variation of width at a river mouth under the combined influence of incoming waves and effluent river discharge. Analytical solution can be obtained, assuming constant wave characteristics and fresh water discharge. The measurements and the theory showed reasonable agreement.

5. ACKNOWLEDGMENT

The authors would like to express their grateful thanks to the members of River Engineering Laboratory and Tsunami Engineering Laboratory, Tohoku University, for their cooperation during the course of the field measurements. Their appreciation should be extended to the Shiogama Construction Office, Ministry of Transport, and the Higashi Sendai Construction Office, Miyagi Prefectural Government, for their offer of the field data. A part of this study was supported by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture of Japan.

6. REFERENCES

Brown, C.B., Sediment Transportation, In H. Rouse (ed.), *Engineering Hydraulics*, pp.769-857, John Wiley & Sons, Inc., New York, 1950.

Coastal Engineering Research Center, *Shore Protection Manual*, U.S. Army Corps of Engineers, 1984.

Ogawa, Y., Fujita, Y. and Shuto, N.: Change in the cross-sectional area and topography at river mouth, *Coastal Eng. in Japan*, Vol.27, pp.233-247, 1984.

Tanaka, H. and Ito, T.: An estimation method of gorge section at a river mouth, *Coast. Eng. in Japan*, Vol.39, No.1, pp.27-38, 1996.

Tanaka, H., Kabutoyama, H. and Shuto, N.: Numerical model for predicting seasonal migration of a river mouth, *Computer Modelling of Seas and Coastal Regions II*, pp.345-352, 1995.

Tanaka, H. and Shuto, N.: Field measurement of topography change at a river mouth, *Proc. Int. Symp. Sediment Transport Modeling*, pp.480-485, 1989.

Tanaka, H. and Shuto, N.: Field measurement of the complete closure at the Nanakita River mouth in Japan, *Proc. Int. Symp. Natural Disaster Reduction and Civil Eng.*, pp.67-76, 1991.

Tanaka, H. and Shuto, N.: Field investigation at a mouth of small river, *Proc. 23rd Int. Conf. Coastal Eng.*, pp.2486-2499, 1992.

Tsujimoto, T., Mori, A., Okabe, T. and Ohmoto, T.: Non-equilibrium sediment transport, *Proc. 33rd Japanese Conf. on Hydr.*, pp.445-461, 1989. (in Japanese)