CHAPTER 191

FIELD INVESTIGATION AT A MOUTH OF SMALL RIVER

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Abstract

Field measurements have been carried out at the mouth of the Nanakita River in Japan. The maximum velocity at the throat section was kept constant, 1 m/sec, although the river mouth topography changed much rapidly in a week. It therefore seems that the equilibrium condition at the river mouth can be expressed in terms of the maximum velocity. The wave set-up height measured in the river mouth was also analyzed and was found to be responsible for the intrusion of sand into the mouth.

1. Introduction

Up to now, a great number of field observation have been carried out at river mouths to understand a dynamic process of sand movement due to combined effect of wave motion, river flow and tidal current. Many of these field measurements are, however, restricted to relatively large rivers (e.g. Ogawa, Fujita and Shuto (1984), Sawamoto and Shuto (1988)), since they are of considerable importance from a view point of hydraulic engineering. The process of topography change at a mouth is greatly dependent on the dimensions of the river. It is therefore difficult to generalize the observed results at different river mouths with different dimensions.

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We initiated a field study in 1988 at the mouth of the Nanakita River, a typical small river in Japan, to find an appropriate countermeasure against the closure of the mouth. Some interesting features are observed which are distinctly different from those seen at big rivers.

2. Study Area

The Nanakita River mouth is located on the Pacific Ocean coast as shown in Fig.1. The catchment area of the river is 229km^2 and the river length is 45km. During rainy season, the tidal discharge and the fresh water discharge are of the same magnitude except for the very short period of big floods induced by typhoon or low pressure. The river discharge during winter season becomes negligibly small as compared with the tidal discharge. Thus, a complete closure of the mouth takes place rather frequently (Tanaka and Shuto (1991)).

The Teizan Canal 9km long connects the Nanakita River mouth with another river mouth, the Natori River mouth. The lock gates, located at the joint with the Nanakita River, are kept partially open. Accordingly, a part of discharge of one river might flow to the other if there is a difference in water level between the two rivers.

The planform of the river mouth topography and the shape of the narrowest cross-section have been measured every two weeks since 1988. The water level variation has also been measured by means of automatic water level gauges which are installed at Stations A, B and C in Fig.1. The velocities at the mouth and in the Teizan Canal were continuously measured for 25 hours at the consecutive spring and neap tides on August 20 to 21 and 27 to 28, 1990, using propeller-type currentmeters.

3.Results and Discussions

3.1 Change of Cross-Sectional Area and Velocity In A Week

Figure 2 shows the change of the planform of the river mouth topography and the narrowest cross-section in a week. The sand spits on both sides intruded into the mouth due to wave action and, subsequently, the narrowest section shifted upstream. Distinct decrease of the cross-sectional area also took place within one week.

The time-variations of the water levels during the first observation are shown in Fig.3(a). It is noted that the water level in the river mouth was almost always

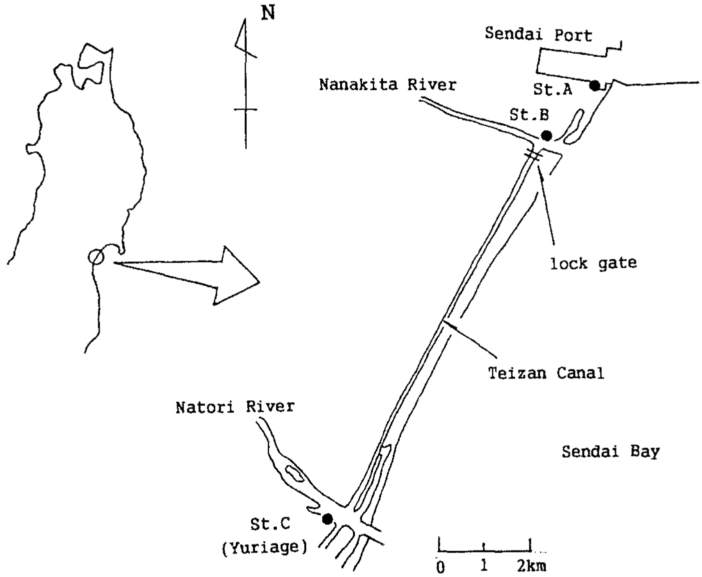


Fig.1 Map of the river mouth.

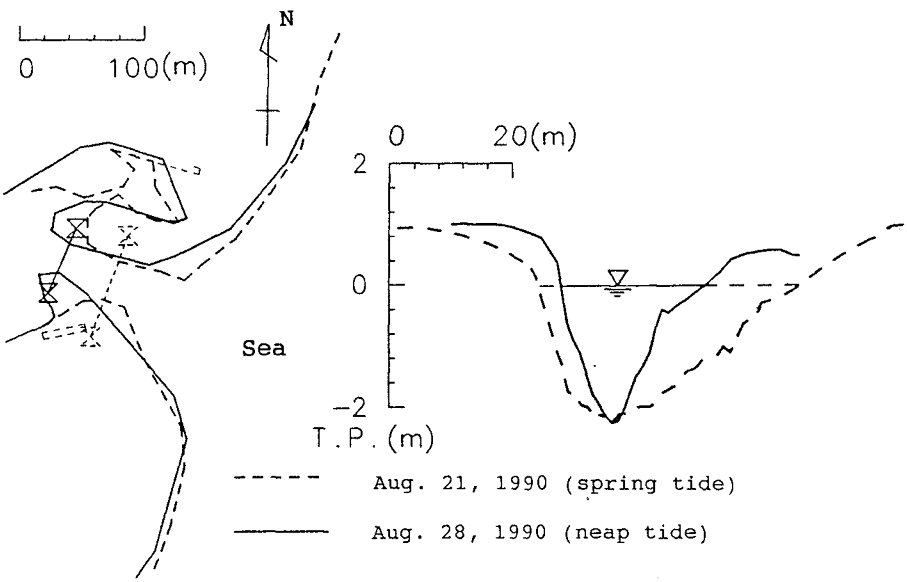


Fig.2 Change of plan topography and cross section in a week.

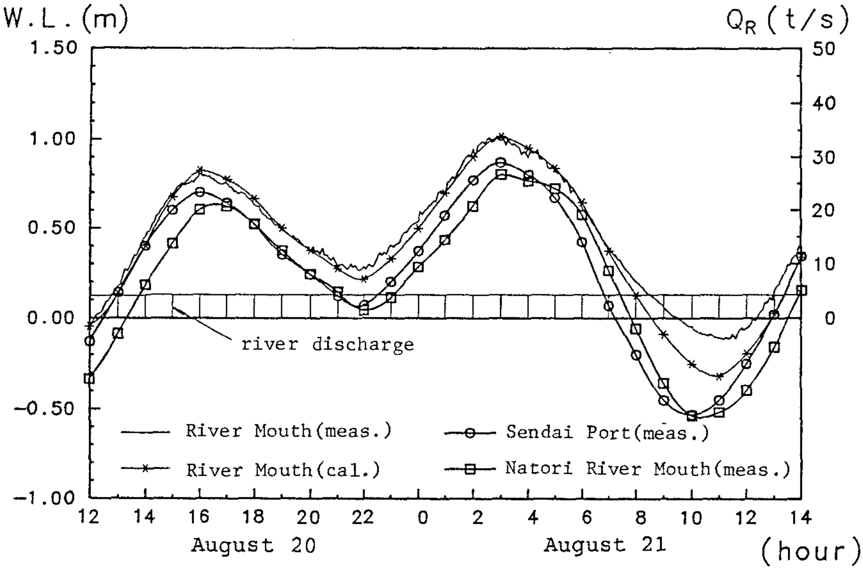


Fig.3(a)Time-variation of water levels.
(August 20-21, 1990)

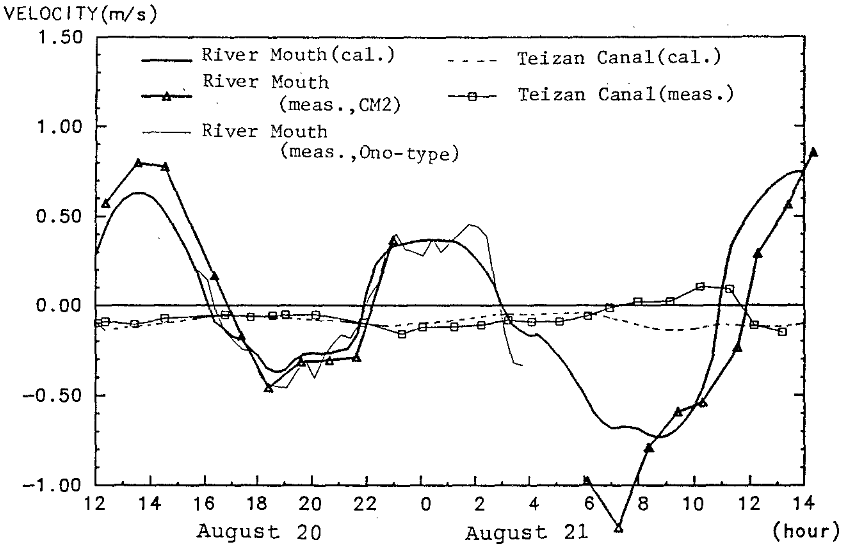


Fig.3(b)Time-variation of velocities.
(August 20-21, 1990)

higher than that in the sea, while the water elevation measured in the Natori river mouth was almost identical with the sea water level. Such a difference is due to the fact that, at the Natori River mouth, where two jetties have been already constructed, the water depth at the mouth was deep enough to prevent wave motion from breaking, while at the Nanakita River, waves broke in front of the mouth, resulted in the water level rise, that is, the wave set-up.

The corresponding variation of the velocities measured at the Nanakita River mouth and in the Teizan Canal are shown in Fig.3(b). The positive velocities denote the flow into the river from the sea through the mouth or through the Teizan canal. The velocity along the Teizan Canal was always negative, which shows the flow direction in the canal was from the Nanakita to the Natori river due to the difference of water level explained above.

The observed results during the second measurement are shown in Fig.4. The water level rise is smaller than the 1st observation due to the difference of the significant wave height; during the 1st observation, the significant wave height, $H_{1/3}$, was 1.4m, while during the second observation, $H_{1/3}$=0.9m.

According to Figs.3(b) and 4(b), the maximum current velocity at the mouth was kept 1m/s by tidal and river flows, although the cross-sectional area was rapidly narrowed by waves within one week. This result suggests that the dynamic equilibrium condition of the cross-section at the Nanakita River mouth can be expressed in terms of the maximum velocity. Similar result has already been reported by Bruun (1978).

The solid lines in Figs.3 and 4 show the calculated water levels and velocities obtained using a one-dimensional model which is commonly applied in the analysis of sea-inlet-bay system (e.g. see Bruun (1978)). The governing equations are as follows.

Equation of motion:

$$\eta_o-\eta_R = \frac{L_c}{g}\frac{du}{dt} + (K_{en}+K_{ex}+K_{cu}+\frac{2gn^2L_c}{R^{4/3}})\frac{|u|u}{2g} \quad \cdots\cdots\cdots(1)$$

Equation of continuity:

$$u = \frac{1}{A_c}(A_R\frac{d\eta_R}{dt} - Q_R) \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots(2)$$

where η_o the ocean elevation, η_R the water level in the river mouth, L_c the length of the channel, u the velocity at the river mouth, K_{en}, K_{ex}, K_{cu} the coefficients of entry loss, exit loss and bend loss, respectively, n the Manning's friction coefficient, R the hydraulic radius, A_c the area of the cross-section at the river mouth, A_R

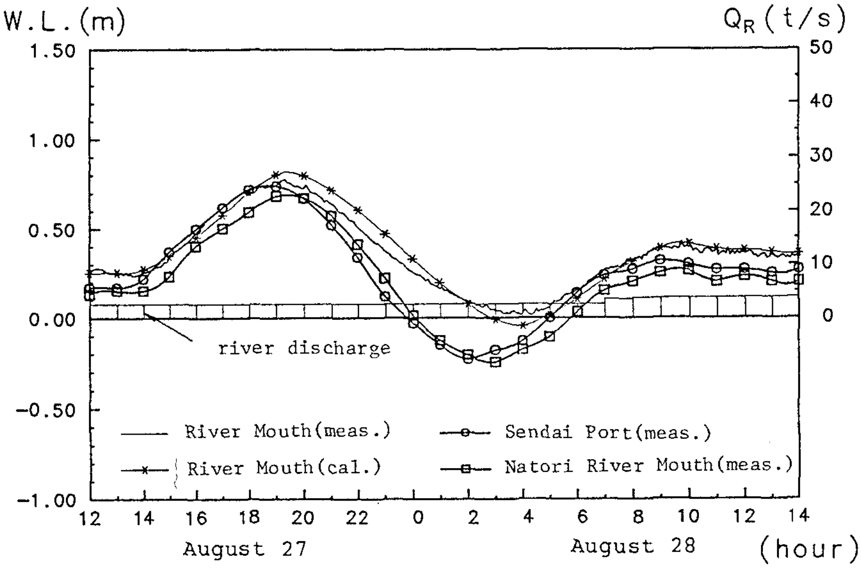


Fig.4(a)Time-variation of water levels.
(August 27-28, 1990)

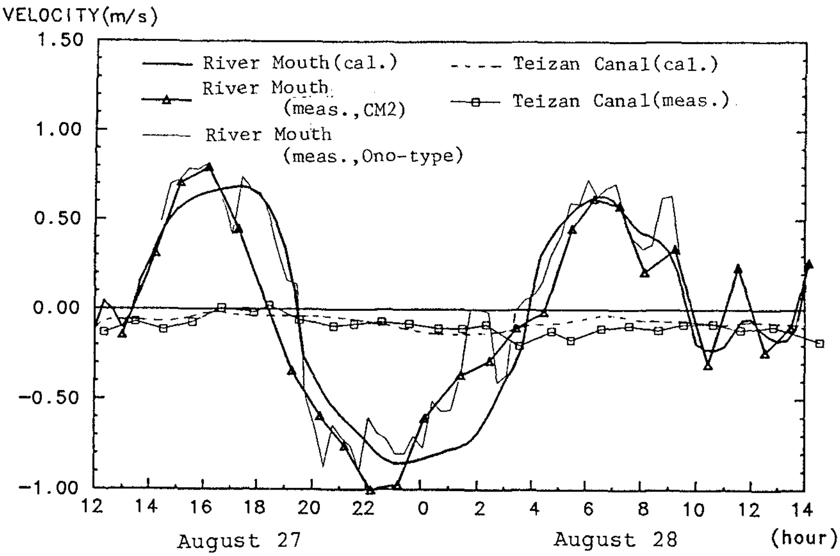


Fig.4(b)Time-variation of velocities.
(August 27-28, 1990)

the surface area of the river under the influence of tidal variation, and Q_R the fresh water discharge. The equations for the Nanakita River mouth and those for the Teizan Canal are solved simultaneously using the Runge-Kutter method. In the calculation of the latter, the energy loss due to the lock gates are considered, referring to a diagram proposed by Chow (1959). The effect of the wave set-up height at the Nanakita River mouth is also included in the numerical analysis, assuming that the sea level rise was 10% of the deep water wave height (see Fig.6). The unidirectional current in the Teizan Canal as well as the oscillatory current at the river mouth is predicted very well through the numerical model.

3.2 Wave Set-Up in the River Mouth

As seen in the previous section, the wave set-up is remarkable in the Nanakita river mouth. Although the same phenomenon might be observed at a mouth of rivers with similar or smaller dimensions, field studies on the wave set-up at a river mouth have been very few. This is partly due to the fact that most of the field measurement up to the present have been made at big rivers which are of practical importance. At these rivers, the water depth is so large that no wave breaking takes place, consequently, no wave set-up at the river mouth.

At the Nanakita river mouth, wave set-up has great influence on the flow field near the river mouth and must be responsible for the topography change at the mouth. Thus, analysis of wave set-up height is carried out in this section. The set-up height, $\bar{\eta}$, can be calculated by taking difference of the water levels at the Nanakita river mouth and the Sendai port, since the water level measured at the latter station was free from the effect of wave breaking as seen in Fig.5. Furthermore, the water level rise induced by other forces such as wind and low pressure must be included equally in both records, because the distance between these stations is only 2km.

Figure 5 shows the water level variations at St.A in the Sendai port, St.B in the Nanakita river mouth and St.C in the Natori river mouth, measured on the day when the maximum set-up height of 66cm was observed at the Nanakita River mouth. As mentioned above, the Natori River mouth is protected by two jetties to keep the cross-section large, while the Sendai port is protected by a breakwater of 2 km long as shown in Fig.1. That is the reason why the water level at St.C was almost identical with the sea level at St.A and was lower than the water elevation measured in the Nanakita River mouth.

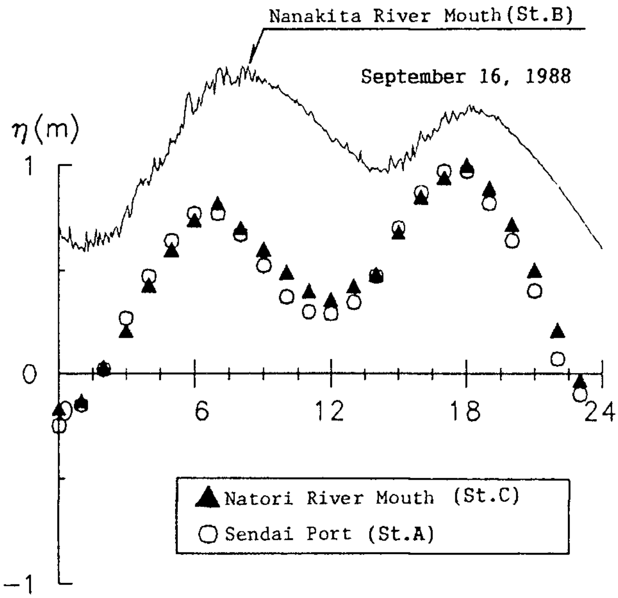


Fig.5 Water level variation (September 16, 1988).

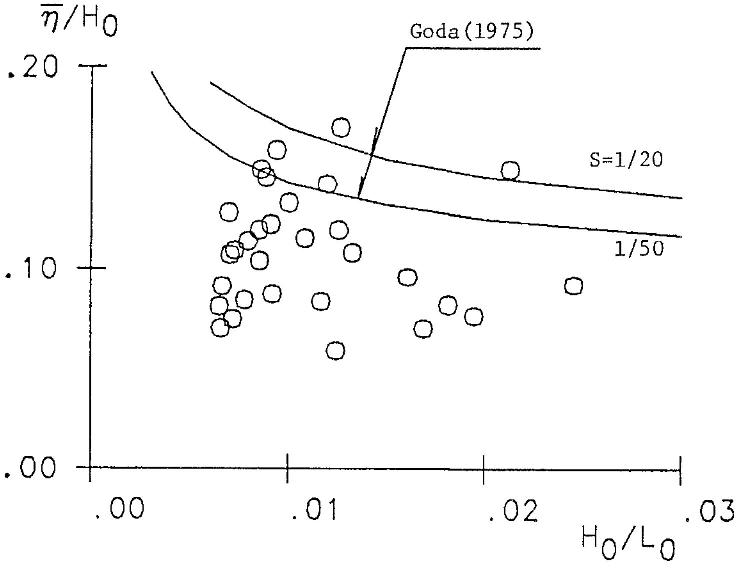


Fig.6 Relationship between wave set-up height and steepness of deep water wave.

Figure 6 shows a correlation between the dimensionless set-up height, $\bar{\eta}/H_o$, and the steepness of deep water wave, H_o/L_o, where H_o and L_o are the wave height and the length of deep water waves, respectively. Theoretical curves according to the Goda's theory (1985) are also shown in the figure. Yanagishima and Kato (1990) measured the wave set-up height on the Kajima Coast in Japan and reported that the Goda's theory showed good agreement with their measurement. According to the present measurement, however, the observed data are consistently less than the predicted values by the theory. Possible reasons for this discrepancy are: (i) the wave set-up in front of the river mouth was not two-dimensional phenomenon due to the distorted bottom topography near the river mouth, and (ii) the sea water could intrude into the river mouth when the water elevation in the river mouth was lower than the sea level in the surf zone.

3.3 Influence of The Teizan Canal on The River Mouth Topography

At the Nanakita River mouth, the tidal discharge is very important factor to keep the mouth open (Tanaka and Shuto (1989)). Generally speaking, the magnitude of the flow induced by flood and ebb tides at a river mouth is of the same order, as the tidal discharge changes sinusoidally. At the Nanakita River mouth, however, the ebb tide flow is of smaller magnitude, because of the southward flow into the Teizan Canal as seen in Figs.3 and 4. This means that the tidal flow is effective to transport sand into the mouth rather than flushing sand out of the mouth.

Photo 1 was taken on February 1st, 1991, when the daily averaged fresh water discharge was $3.7m^3/sec$, while the tidal discharge was $7.5m^3/sec$. Sand deposition which is commonly designated "bay shoal" (Bruun (1978)) is observed in the river mouth. Dotted lines in the photograph show an upstream edge of the shoals. Such a topography is seemed to be induced by predominant current into the river mouth during the flood tide.

In order to make a quantitative estimation of the effect of the Teizan Canal, the one-dimensional analysis is carried out using Eqs.(1) and (2) under the following three conditions (see Fig.7): (i) assuming that the lock gates at the joint with the Nanakita River are completely open, (ii) the lock gates are kept partially open as the present state, and (iii) the gates are closed completely to prevent the southward flow into the canal. Calculation is carried out for the days in August, 1990,

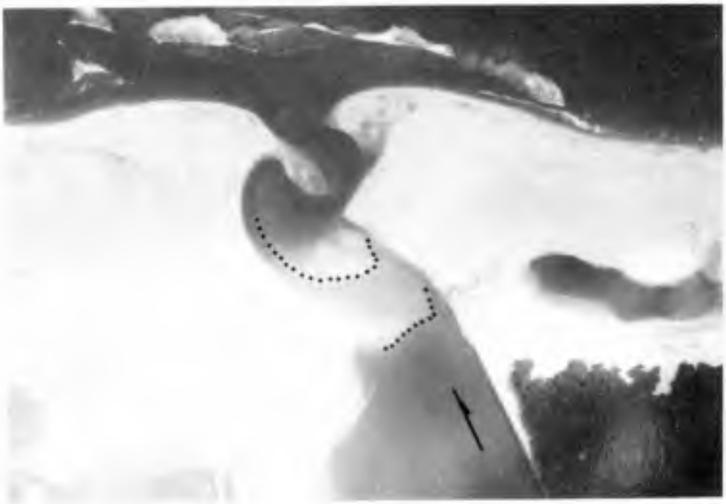


Photo 1 Aerial photograph on January 1, 1991.

when the field observations were continuously made for 25 hours.

The gross volume of water entering or exiting through the mouth and the Teizan Canal is calculated for each flood and ebb tides and is summarized in Table 1, in which the ratio of each volume to the corresponding value in Case 2 is also shown in brackets. The unit of the tabulated value is $10^3 m^3$ and the positive value shows volume of water entering into the Nanakita river through the mouth or the canal. It is seen that the flow in the Teizan Canal is always negative in Cases 1 and 2 due to the wave set-up effect. In Case 1, the discharge into the Teizan Canal will consistently increase during both flood and ebb tides as compared with Case 2, due to the enlarged cross-sectional area of the Teizan Canal. At the river mouth, the volume during the ebb tide will decrease, while that during the flood tide will increase. Thus, the entering flow into the mouth will become more predominant in Case 1. On the other hand, in Case 3, the reduction rate of the flood tide discharge will attain to 20%, while the ebb tide flow will increase by 16% at its maximum. Therefore, it can be concluded that, by closing the gates, the intrusion of sand into the Nanakita River Mouth during the flood tide will be reduced, resulting in the improvement of the river mouth closure.

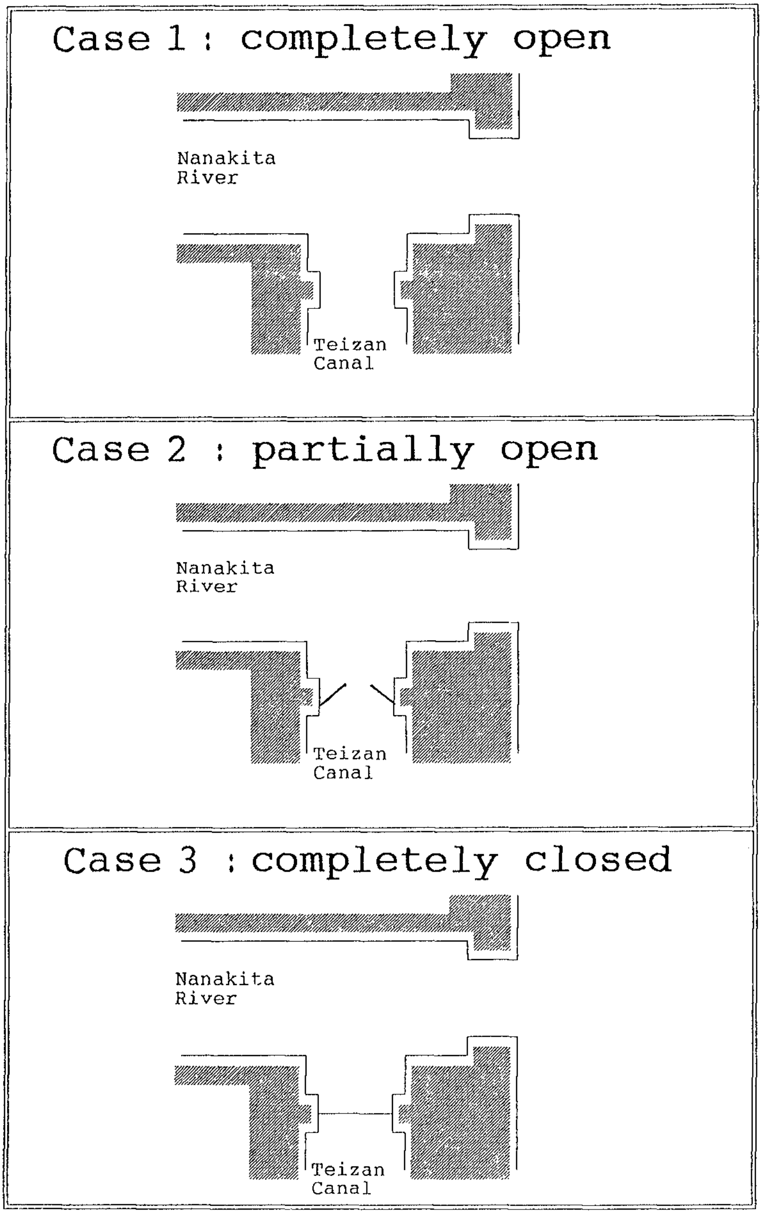


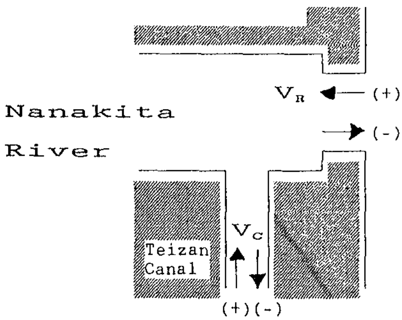
Fig.7 Condition of calculation.

Table 1 Calculated water discharge.

UNIT: $10^3 m^3$

Date		Case 1 (completely open)		Case 2 (partially open)		Case 3 (completely closed)	
		V_C	V_R	V_C	V_R	V_C	V_R
Aug. 20 ~ 21	1st ebb tide	-92 (1.80)	-337 (0.85)	-51 (1.00)	-395 (1.00)	0 (0.00)	-436 (1.10)
	1st flood tide	-116 (1.97)	473 (1.13)	-59 (1.00)	419 (1.00)	0 (0.00)	359 (0.86)
	2nd ebb tide	-102 (1.59)	-799 (0.94)	-64 (1.00)	-848 (1.00)	0 (0.00)	-912 (1.08)
Aug. 27 ~ 28	1st flood tide	-77 (1.75)	323 (1.08)	-44 (1.00)	300 (1.00)	0 (0.00)	262 (0.87)
	1st ebb tide	-135 (1.44)	-441 (0.91)	-94 (1.00)	-482 (1.00)	0 (0.00)	-560 (1.16)
	2nd flood tide	-57 (1.33)	247 (1.05)	-43 (1.00)	236 (1.00)	0 (0.00)	186 (0.79)

V_C: discharge through the Teizan Canal
V_R: discharge through the Nanakita River mouth



4. Conclusions

The principal results of the present study are as follows:

(1) The water level at the Nanakita River mouth was higher than that in the Natori River mouth due to the wave set-up, resulting in a unidirectional flow along the Teizan Canal to the Natori River. This indicates that the tidal flow during the flood tide is effective to transport sand into the river mouth rather than flashing sand out of the mouth. Shoals in the mouth are seemed to be formed due to such a predominant flow into the mouth.

(2) The cross-sectional area of the narrowest section at the Nanakita river mouth decreased remarkably in a week, while the maximum of the velocity at the throat section was kept constant, 1m/sec. This result suggests that the equilibrium condition at the river mouth can be expressed in terms of the maximum velocity at the narrowest section. The time-variations of water level and the velocity are successfully reproduced by a one-dimensional analysis.

(3) Wave set-up height measured in the river mouth attained to 10-20% of the deep water wave height, slightly lower than Goga's theory.

(4) Numerical simulation indicates that, by closing the lock gates at the joint with the Teizan Canal, sand intrusion due to tidal current into the mouth will be reduced. However, further investigation should be made to evaluate the role of the Teizan Canal not only from engineering view point but also from a environmental and ecological view points.

5. Acknowledgements

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