CHAPTER 225

Response Characteristics of River Mouth Topography in Wide Time Scale Range

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Abstract

Based on the observations, response characteristics of sand barrier and flood terrace for the Abukuma River mouth are analyzed in wide time scale range spanned from several hours to half century. We propose some measures representing magnitude of the deformation and the external forces to find quantitative relationship between them. The analyses deal with breaching in the flood process, development of the sand barrier, alternation of the barrier side, and the formation and decay of flood terrace, together with their time scales. There will be also shown interaction between the barrier and the terrace.

1 Introduction

The final goal in the study of river mouth topography is to predict it in the near and far future, and to make control, if necessary, for the flood passage, voyage, or coastal sedimentation. Stable prediction generally requires both qualitative analyses and quantitative evaluation of long-term history.

The complexity of the topographical deformation in the river mouth area would be produced by complication of the external forces, i.e. duality of river flow and waves, and their fluctuating characteristics, and by influences from the topography itself and man-made structures, which are also changing.

The key to resolve these entangling situation is time scale of each process. Sawamoto and Shuto(1988) have found various time scales on the topographical change around the Abukuma River mouth based on the observations. The time scales range from several hours of flood process to half century of the alternation of the sand barrier side. This paper develops their findings by collecting further observation data on both the deformation and the external forces, and

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by connecting them. To perform the analyses, we introduce some new measures representing their magnitude, that enables some quantitative evaluations.

Further new findings is the existence of the interaction between the sand barrier and the terrace, especially in the stage when the deformation of the terrace is proceeded. This is added to patterns of the deformation.

At the end of this paper, will be presented a diagram summarizing each deformation stage and time scale.

2 Outline of the river and data collection

The Abukuma River is the first class river, with the catchment area of 5,400 km^2 and the main channel length of 239 km, managed by the Ministry of Construction in Japan. The river has a mouth opened eastwards to flow into the Pacific Ocean (Fig. 1). At the mouth, the annual mean discharge of the river is about 120-180 m^3/s, which is comparable with the mean tidal discharge in the half cycle of 50 - 130 m^3/s. Therefore, the channel at the mouth is usually maintained by both the river and tidal flow. The incident waves, there, having dominant direction, ESE, produce littoral drift from the south to the north macroscopically.

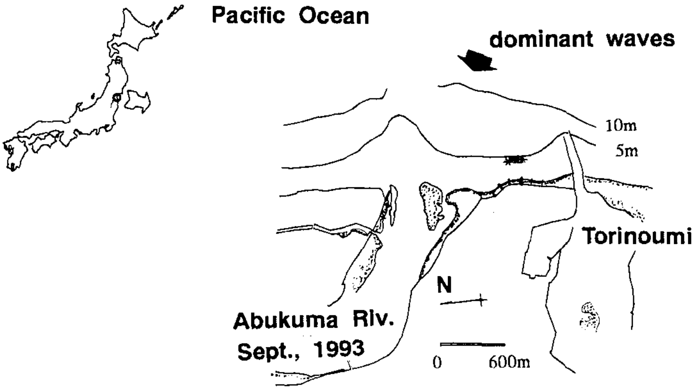


Fig. 1: Geography around the Abukuma River mouth.

There are some man-made structures near the mouth. The large saline barrier called Abukuma Ohzeki, which locates 10 km up the river mouth and was constructed in 1982, prevents the sediment transport for usual flow, that is, except floods. Training jetties have been established, not at the Abukuma river mouth, but at the entrance of Torinoumi lagoon which is an old mouth of the river. They were in construction in 1954 - 1980 to be lengthened to about 400 m. They influence the littoral drift. In order to prevent erosion between the entrance and the mouth, a detached break-water and groins were set up in 1986 - 1992 and 1974 - 1976 respectively. The effect of these coastal structures on the river

Table 1: Observation circumstance

contents	organization	start	period
topographical survey	Geograph. Survey Inst.	1907	
depth sounding	Min. Construction	1940	1 year
river discharge	Min. Construction	1941	1 hour
aerial photograph	Geograph. Survey Inst. U.S. military etc.	1947	1 month - 3 years.
waves(Sendai Harb.)	Min. Transport	1979	2 hours
barrier shoreline	Tohoku University	1984	1 - 2 weeks(usual) continuous(1985 flood)
barrier elevation	Tohoku University	1989	1 - 2 weeks

mouth topography is not so clear, because the river has function as a sediment source also.

The circumstance of observations is given in the Table 1. Depth sounding, river discharge, and aerial photograph have half century's history, while our observations for the sand barrier are relatively new, but the period of the observations covers short to middle term change. Especially, the flood process in 1985 was recorded on the video tape. The aerial photographs have been taken by the U.S. military, and the Geographical Survey Institute and Tohoku Regional Construction Bureau, the Ministry of Construction.

The discharge is observed at Iwanuma, located 7.8 km up the mouth. Since the floods are most influential on the response among the river flow, we have collected hydrographs of major floods, as well as daily mean discharge in the long period. They are utilized in the examination of the new measure. The maximum flood in the peak discharge occurred in 1986. Its flush and the recovery process have been observed by ourself as well.

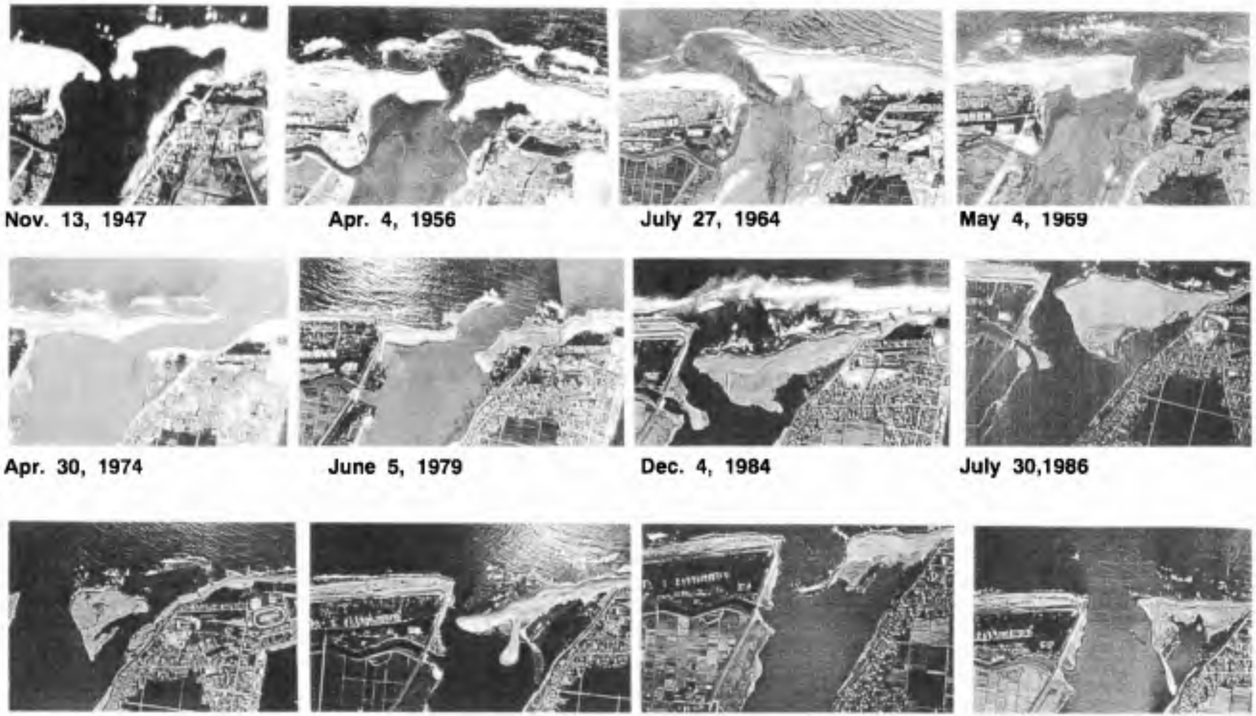
The wave observation is performed off the Sendai Harbour locating about 26 km NNE of the mouth and has relatively short history corresponding to the construction of the harbour.

3 Response of sand barrier

3.1 long-term change

The history of sand barrier in the long time span is shown in Fig. 2 which is edited from the aerial photographs. The oldest plate of 1947 indicates the barrier in the right side, which is dominant due to the macroscopically prevailing direction of the littoral drift. The shoreline position of the barrier is more seaward than resent one is.

Then, switch of the side to the left is recognized in the plate of 1969 and this side continues until the plate of 1979, with the thickness getting very thin. Again, the barrier in the right side appears in the plate of 1984 to last up to now. The recent two plates of 1992 and 1993 show quite different shape of the barrier from



Nov. 13, 1947 | Apr. 4, 1956 | July 27, 1964 | May 4, 1969

Apr. 30, 1974 | June 5, 1979 | Dec. 4, 1984 | July 30,1986

Aug. 13, 1986 | Aug. 13, 1987 | Dec. 13, 1992 | Nov. 2, 1993

Fig. 2: History of the sand barrier. The photographs of 1947 and 1956 were taken by the U.S. military; 1964, 1969, 1974, 1979, and 1984 by the Geographical Survey Institute; 1986, 1987, 1992, and 1993 by Tohoku Regional Construction Bureau.

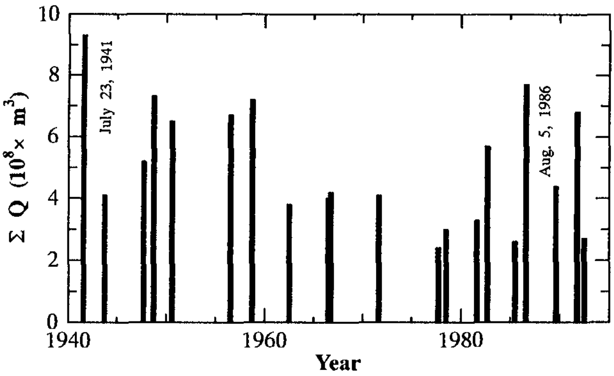


Fig. 3: History of the floods.

any other one. This will be analyzed in Section 5.

Here, let us focus on the long term change, that is the alternation of the side. This is corresponding to the activity of the floods. Figure 3 shows the whole history of the major floods observed. The ordinate indicates the total discharge, integrated in one flood, which is a new measure and will be discussed in the next subsection.

Long-term fluctuation exists, that is, in 1940s and 1950s there occurred many floods in huge magnitude, which caused serious disasters. The flood in 1941 is the biggest in the total discharge. In the following two decades; 1960s and 1970s, the flood activity calmed down and then in 1980s and 1990s floods are again active. The flood in 1986 is another representative having the biggest peak discharge in the history. The time scale of the long-term fluctuation is about half century.

The alternation of the side to the left would be triggered by the overhang of the right side barrier in 1964, because this is unstable for the flood passage. Backwater induced by the resistance of the overhang would cause the overflow somewhere around the lower part of the barrier to make a new channel there. The channel at the mouth is usually maintained strait by the flush due to floods in appropriate period. The calmness of the flood activity in 1960s promotes the overhang. Once the side is changed to the left, the supply of the littoral drift to the barrier is prevented by the flow in the channel. Hence the barrier becomes thin, that is corresponding the barrier shape in 1960s and 1970s. Although thin barrier is unstable for the flood passage, the left side barrier continued until 1979, that is more than 10 years. This continuation is also assisted by the calmness of the flood in this period.

Therefore the long-term deformation of the side alternation synchronizes with the fluctuation of the flood activity, through the mechanism provoked by the calmness in the flood intensity.

3.2 short-term change

The opposite extreme in the time scale range would be flood process. The breaching of sand barrier during the flood of 1985 was recorded by the video tape and analyzed by Sawamoto et al.(1988). Here we will examine about the measure of the flood relating with the breach. Figure 4, showing the change of the minimum channel width at the mouth ,B, during the flood, indicates that significant change occurs even after the peak of the discharge has passed. Therefore the terminal channel width B_T after one flood passage should be related to the quantity representing the whole flood.

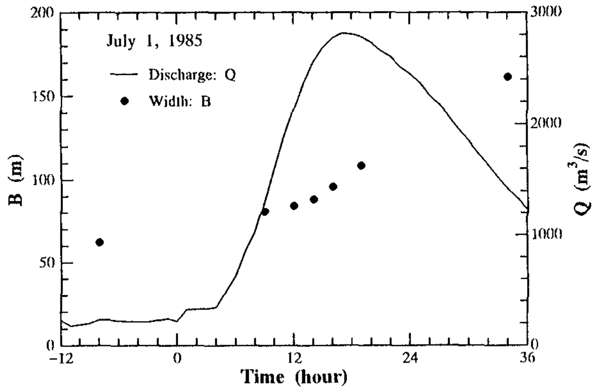


Fig. 4: Breaching process.

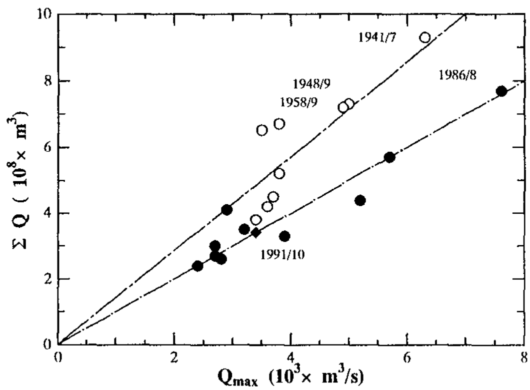


Fig. 5: Runoff characteristics.

Another examination is about the relationship between the peak discharge, Q_{max}, and the total discharge(Fig. 5). In a short period, these two quantities are on one linear relationship, but in the long time span the gradient apparently changes. The border of the change is in 1960s and 1970s, which are not clear because of the absence of the huge floods in the period. The change would be resulted from the channel improvement of the Abukuma River after the serious disasters in 1940s and 1950s. Decrease of the gradient corresponds to decrease of the resistance in the channel. The flood in October, 1991 has special hydrograph with two peaks which are produced by the twin typhoons. Filled diamond in Fig.5 is the plot of half of the total discharge for this flood. This is still on the recent relationship.

Since the total discharge is a simple and invariant quantity including the information of the whole flood, we adopt it as a measure of magnitude of the flood relating with the breach. The dependence of the terminal width on the total discharge is given by the linear relationship(see Fig.6). The flood in 1991 is also included in this figure and on the relationship. The flood in 1992 is the exception, that is, the channel was widened for relatively small amount of total discharge. Although the thin barrier at the tip(see Fig.2)is the direct cause, it will be shown later that the influence of the deformation of the flood terrace with different time scale is more original cause.

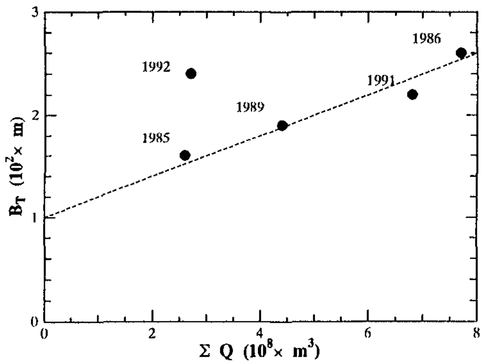


Fig. 6: Terminal channel width after the flood passage.

3.3 middle-term change

The breaching follows the recovery process of the sand barrier. The change of the channel width and the area of the sand barrier are plotted in Fig. 7, where the region accounting the area is defined in the left plate. After the flood, the littoral drift is spent to fill up the channel deepened by the flood. Therefore the change of the width is not evident. Then, the channel width starts to decrease rapidly to reach the stationary value of 50 - 60 m. The time scale of the decrease is 4 to 12 months depending on the scale of breaching. The stationary state is maintained by the dynamic equilibrium between the traction by the flow and deposition by waves, that is shown by Aota and Shuto (1980).

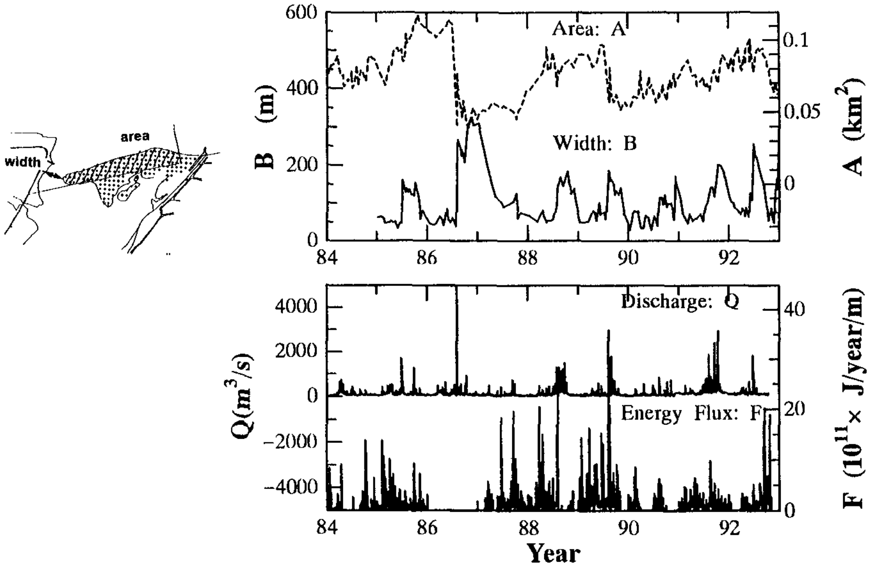


Fig. 7: Middle-term deformation of sand barrier.

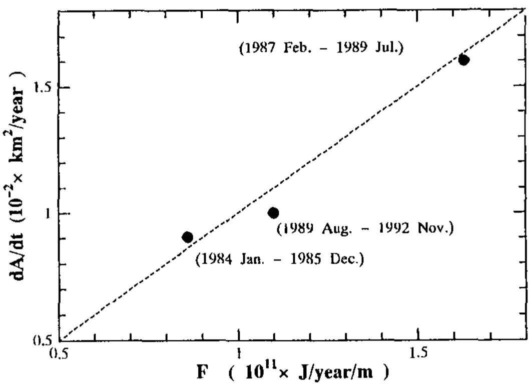


Fig. 8: Barrier development rate.

Even though the equilibrium at the channel is reached, the shape of the sand barrier is still thin. The thickening process of the barrier continues, which is indicated by the increase of the area. In this figure the daily mean discharge of the river and the wave energy flux are also shown. The flux is calculated by the equation;

$$F = \frac{1}{32\pi}\rho g^2 H^2 T \cos\theta$$

where, H and T are the wave height and period, respectively, θ is the wave direction measured clockwise with the origin at the direction normal to the macroscopic coastline. These three quantities are all measured off Sendai Harbour. This figure shows the response characteristic that the channel width decreases sensitively for even minor flood, but the change of the area is more gradual. Hence, we evaluate the mean increase rate of the area in the three regions bounded by the major floods in 1986 and 1989 to correlate with the energy flux(Fig. 8).

It is shown that the increase rate of the area, dA/dt, is directly proportional to the wave energy flux, F. This relation gives the time scale of the recovery of the sand barrier. Since the flood in 1986 flushed the area 0.01 km^2 out of 0.11 km^2, the recovery would require 7 years for the energy flux of the ordinal sea condition, 1.0×10^{11} J/year/m, that is 3.2 kW/m.

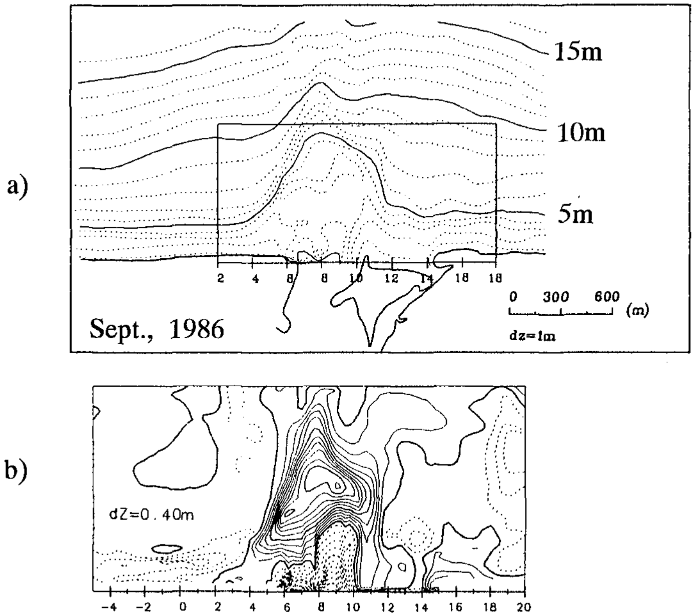


Fig. 9: Formation of flood terrace in 1986.

4 Formation and decay of flood terrace

Figure 9 a) shows the flood terrace produced by the flood in 1986 and b) the distribution of deposition (solid line) and erosion (dashed line) obtained by taking difference of the two bathymetry charts sounded before and after the flood in the interval of six month. The terrace is about 4 m in depth and very flat. The maximum deposition is 4 m in height and locates the distance 800 m offshore of the shoreline. The channel at the mouth, the sand barrier, and its front area were eroded by the flood. The volume of the erosion estimated to be about 60 % of that of the deposition by Mano et al.(1993). Hence, the rest would be due to the transport in the river. For any kind of sediment, the formation of flood terrace requires work transporting a large quantity of sediment by the long distance from the mouth.

Here we adopt the total kinetic energy in one flood at the mouth, $T.K.E.$ as a measure of the flood magnitude relating to the terrace formation. The assumptions introduced to compute the quantity are; 1) the flood flow is critical at the mouth, 2) the channel width changes, linearly in terms of time, from the initial width to the terminal width. Where for the floods before 1982, we used 50 m and the terminal value shown in Fig. 6. as these width respectively. The energy is written as follows;

$$T.K.E. = \int \rho g^{2/3} \frac{Q^{5/3}}{2B^{2/3}} dt$$

where, ρ is density of water, g gravitational acceleration, Q the discharge, B the channel width. The integration is taken over one flood. While the measure on the terrace formation is also necessary. Since we can not extract precise information from the old bathymetry chart, we define L_5 as the longest distance from the macroscopic shoreline near the mouth to the contour line of 5 meter depth. The changes of these two measures in half century time span are well corresponding (Fig.10). The threshold of the external force for the big terrace formation would be given by the value, 1.3×10^{13}J. The figure shows that major floods are of 1941, 1948, 1858, and 1986. In the case of 1986 flood, sediment near the mouth also contributed to the terrace formation.

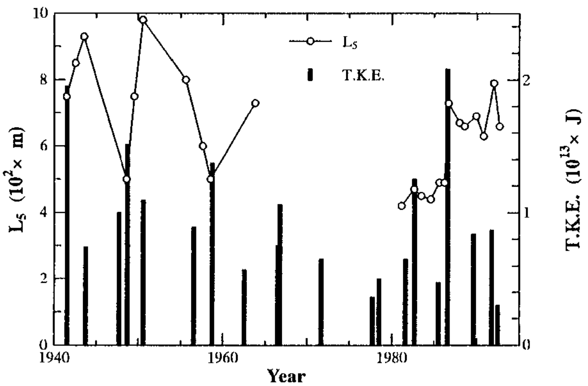


Fig. 10: Terrace formation and T.K.E.

The bathymetry chart sounded just before the 1986 flood still shows small terrace. From the interval of major floods, the time scale of disappearance of the big terrace would be given by more than 27 years.

5 Interaction

The last two plates in Fig. 2 show the recent sand barrier. The formation of big arc at the barrier tip in the plate of December, 1992 shows the wave direction approximately normal to the shoreline, which is different from the offshore wave direction. The effect of wave refraction becomes important. Although there exist some small arcs at the tip before, they would not be influential. The wave direction at the arc in 1992 prevents the development of the barrier toward the tip to result in the thin tip and to change the response characteristics of terminal width in Fig. 6. The plate of November, 1993 shows more advanced stage. Two strait shoreline facing the sea and river would be formed by waves refracted near the mouth. In this stage, the channel width is kept open.

The characteristics of the wave refraction is shown in Fig. 11. Wave rays, given by the numerical integration of the ray equation, see, for example, Mei(1983),pp. 66, are plotted for the bathymetry of 1993. The wave condition is for the dominant wave; direction of ESE and period of 8 s.

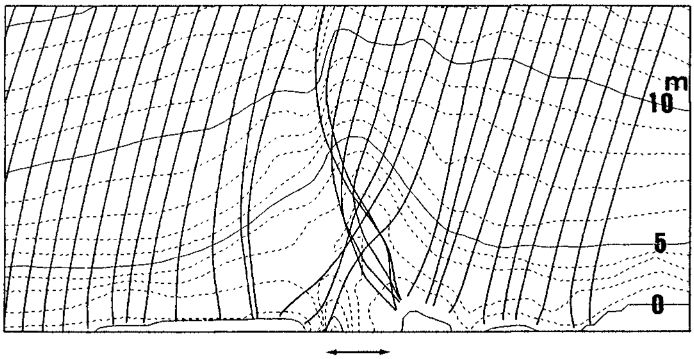


Fig. 11: Refraction characteristics.

The caustic is stably formed at the hollow on the flood terrace for the various offshore directions and the periods. The wave rays refracted at the hollow approach the barrier from ENE, that is, two dominant wave directions exist at the sand barrier. As stated above, these waves change significantly the barrier shape and various response characteristics.

This hollow would be formed by the river flow, mainly by the passage of floods after 1986. The time scale on the hollow formation is about 6 years.

6 Concluding remarks

We have shown various deformation of the river mouth topography and its time scales, and their interactions. Figure 12 shows the summarizing diagram mainly for the right side barrier. The lines with arrow indicate the direction of the change with the cause, which is distinguished by the type of lines. The right direction

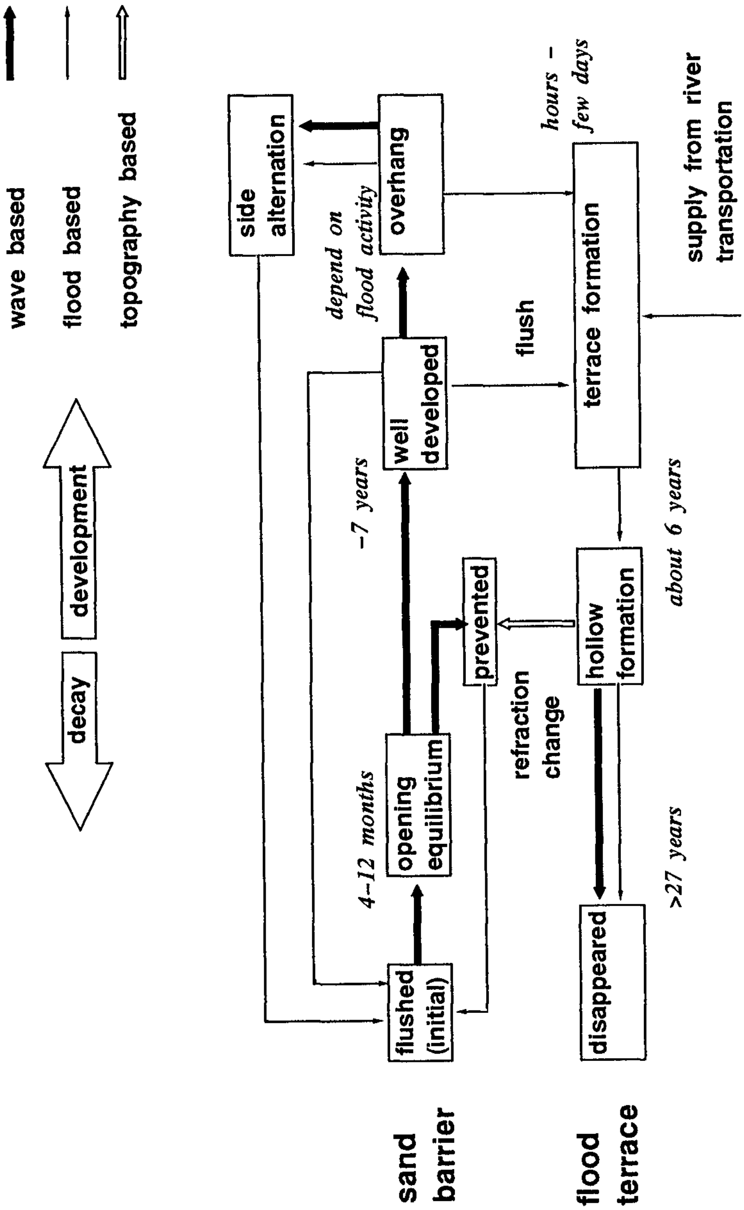


Fig. 12: Deformation stage and time scale.

corresponds to development and vice versa. Each box shows the stage of the deformation. The italic numbers are time scales based on the recent observations. The initial condition of the sand barrier is flushed state by the flood. Then it changes into equilibrium at the opening channel, well developed state, and overhang, depending on the flood activity. Although the main cause for the terrace formation is flood, sediment at the barrier contributes as well. Once the hollow is formed, it changes the refraction characteristics to prevent the development of the barrier. Depending on the timing, the barrier may not reach the equilibrium.

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