CHAPTER 105

RESPONSES OF COASTAL TOPOGRAPHY TO SEA-LEVEL RISE

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ABSTRACT

The impacts of sea-level rise induced by global warming on sandy beaches and sediment deposition around the river mouth are assessed. The exacerbated erosion by sea-level rise is evaluated in a national scale for Japan, on the basis of the Bruun Rule assuming the existence of the equilibrium beach profile. The eroded area reaches 56.6, 81.7, and 90.3% of the total area of the existing beaches for the sea-level rises of 30, 65, and 100cm, respectively. The effects on sandy beaches is extremely large, since such erosion superposes on the already existing erosion. The effect of sea-level rise on the river mouth is also examined by a numerical model. The place of sand deposition changes from the river mouth to the upper reaches along the river as the mean sea level rises higher. Higher risk of flooding is anticipated because of the rise of river floor and the backwater effect of sea-level rise.

INTRODUCTION

It is anticipated that global warming will bring about accelerated sea-level rise through thermal expansion of ocean water and melting of land-based glaciers, and climate change such as changes in precipitation and tropical cyclones. IPCC(1990) projected that the mean sea level would rise 65cm by the year 2100, with an uncertain range of 30 to 110cm in its first report. The best estimate for the sea-level rise has been revised to 50cm by 2100 in the second assessment report(IPCC, 1996), as shown in Fig.1. If climate change and sea-level rise occur in future as estimated, they can impose a variety of impacts on the natural environment and human society in the coastal zones. Since most coasts in the world consist of natural geographic features, such as sandy beach, dune,

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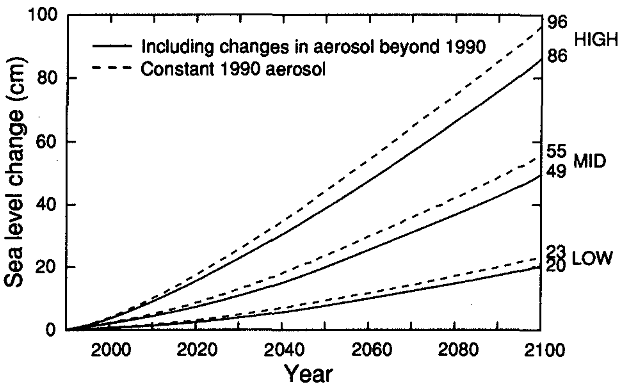


Fig.1 Projections of global sea level(IPCC, 1996)

delta and river mouth, wetlands and coral reef, a concern has arisen about what and how serious the impacts of sea-level rise and climate change on them will be. As the natural geographic features show particular adaptive responses to the changes in external conditions, it is necessary to estimate such responses of the coastal topography in order to evaluate the impacts of sea-level rise and climate change. This paper is an attempt toward this direction focusing on sandy beaches and river mouth.

IMPACTS ON SANDY BEACHES

Outline of the predictive model

Topographic changes of sandy beaches are caused by cross-shore and longshore sediment transport. Sea-level rise due to global warming acts uniformly on the world coasts, though the amount of the rise relative to the land differs place to place because of the uneven distributions of sea temperature rise, plate movement, and local land subsidence, etc. Therefore, it is assumed, as the first step of assessment, that local factors for the beach topographic change, such as sources of sediment supply and the longshore transport, can be neglected. Under such assumption, the response of sandy beaches to the sea-level rise is considered to take place only in the cross-shore direction, i.e. as beach profile change.

A sandy beach is eroded by sea-level rise more than simple inundation. If there is an equilibrium form of the beach profile, the sandy beach changes toward forming a new equilibrium profile for the increased sea level, as shown in Fig.2. This concept is known as the Bruun Rule (Bruun, 1962), and a number of predictive models have been developed on its basis. The Bruun Rule-based models has been calibrated by Mimura et al.(1995) by correlating the land subsidence due to pumping up ground water, i.e. relative sea-level rise, and the resultant retreats of the shoreline in Niigata, Japan. Equation (1) is often

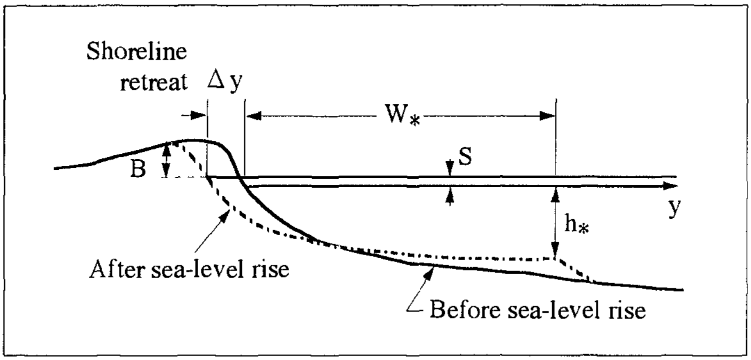


Fig.2 Response of the beach profile to sea-level rise

used to represent the equilibrium beach profile.

$$h=Ay^{2/3} \tag{1}$$

where, h is water depth at an offshore distance y from the shoreline, and A is a shape coefficient determined for the individual beach. The amount of shoreline retreat, Δy, can be calculated by balancing the sediment volumes eroded in the foreshore and transported offshore(Dean, 1991; Mimura et al., 1993). The formula derived by Dean is as follows.

$$\Delta y+\frac{3}{5}\frac{h_*W_*}{B}\left(1+\frac{\Delta y}{W_*}\right)^{5/3}=\frac{3}{5}\frac{h_*W_*}{B}-\left(\frac{S}{B}W_*\right) \tag{2}$$

Mimura et al.(1993) took into account the foreshore slope in the calculation, whereas Dean(1991) assumed that the foreshore above the mean sea level was vertical. However, as there were no significant difference in the shoreline retreat calculated by the two formulas, Eq.(2) was used in this study.

Data and Calculation

In order to apply the Bruun Rule-based model, it is necessary to know the height of berm, B, critical depth of sediment movement in the offshore region, h_*, and the median diameter of sand to determine A. The first two parameters, i.e. B and h_*, can be estimated by the existing studies such as Takeda and Sunamura(1983) and Hallermeir(1981) if the wave conditions and the average slope of the beach are given. Therefore, the necessary data for the calculation are at least the dimensions of incident waves, the sediment diameter and the average beach slope.

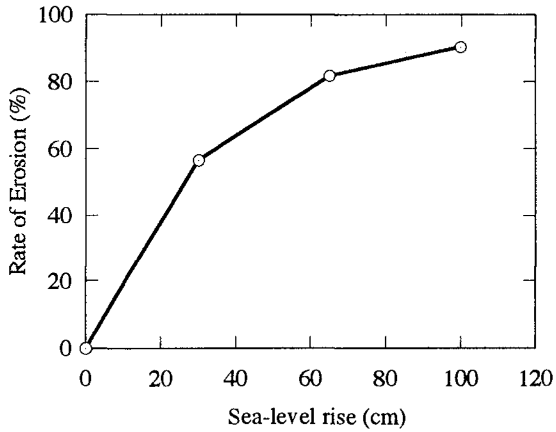
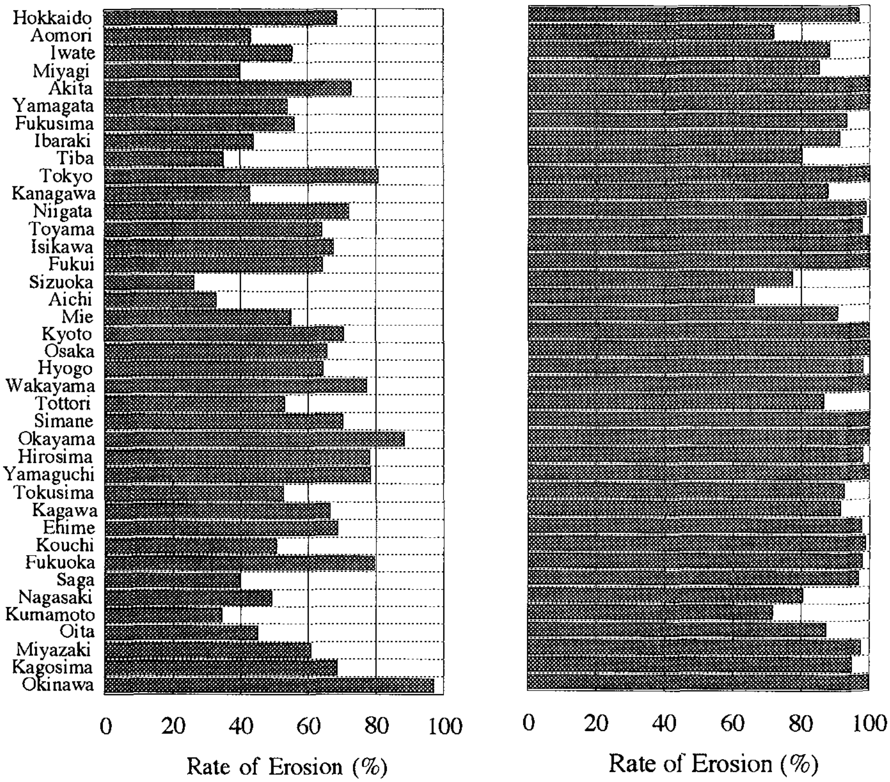


Fig.3 Nation-wide average of erosion rate with sea-level rise

Table 1 Present situation of Japanese coasts and impacts of sea-level rise

Total coastline	34,386 km
Sandy beaches	
Length	5,508 km
Area	191 km^2
Ave. Width	35 m
Sandy beaches eroded (past 70 yrs)	125 km^2
Impact of SLR	
0.3 m	108 km^2
0.65 m	156 km^2
1 m	173 km^2

The Japanese coastline of about 34,000 km in length is divided into 9,688 segments for the purpose of management by four governmental ministries and agency. About one sixth of the total length is occupied by sandy beaches as indicated in Table 1. It was fortunate for us to be able to use the results of a national coastal survey carried out by the related ministries in 1993. The coastal survey covered the length, width and average slope of the beach. The data of incident waves were collected from this survey, Sugahara et al.(1986), and field measurements where available. These data were used to determine the height of berm, B, the critical depth of sediment movement, h_*, and the shape-factor, A. Then the amounts of shoreline retreat, Δy, was calculated for each sandy beach using Eq.(2).



(a) 30cm sea-level rise (b) 100cm sea-level rise

Fig.4 Distribution of erosion rate with prefectures

Regarding the sea-level rise, three scenarios of 30, 65, and 110cm rise were used according to IPCC(1990). The best estimate of sea-level rise by the year 2100 has been revised from 65 cm in IPCC(1990) to 50cm in IPCC(1996) as mentioned above. However, the scenarios used in this study are still useful to examine the possible range of the impacts.

Sea level rise-induced erosion estimated for the Japanese beaches

The results of the estimation for the area of erosion are shown in Fig. 3 and 4. Figure 3 shows the national summary of the percentage of eroded area, which is called the erosion rate here. A 30 cm sea-level rise would erode 11,775 ha or 56.6% of the present sandy beaches in Japan. The total area eroded for the past about seventy years was 12,880 ha, which was estimated by the comparison between old and the present topographic maps by Tanaka et al. (1993). Therefore, the area to be eroded by a 30 cm sea-level rise is comparable to that occurred for the past several tens years. It is surprising that even a 30cm rise of mean sea level would cause such sever erosion. If the sea-level rise becomes 65cm and 100cm, 81.7% and 90.3% of the present sandy beaches will disappear by erosion, respectively. Table 1 shows a summary of the present situation of the Japanese coasts and the estimated impacts.

In Fig. 4, the distributions of the estimated erosion rate are shown with coastal prefectures which are thirty-nine out of forty-seven prefectures in total. The areas eroded by 30cm sea-level rise range from 24 to 95% of the existing beaches. If the sea-level rise reaches 1 m, most prefectures would lose more than 90% of their beaches. Large differences in the erosion rate can be seen among prefectures in Fig. 4. Figures 5 and 6 show the relationships between the erosion rate, and the significant wave height of the incident waves and beach width of the coastal segments. There is no apparent correlation between the erosion rate and the significant wave height, while it decreases clearly with the beach width. Such tendencies indicate that there are no large differences in the amount of the shoreline retreat among beaches for the same sea-level rise, and that narrow beaches tend to disappear early as the sea-level rise proceeds.

It is quite natural that beach erosion due to sea-level rise will superpose on those by other mechanisms such as lack of sediment supply and imbalance of the longshore transport. Therefore, the role of sea-level rise is to exacerbate the present trend of beach erosion.

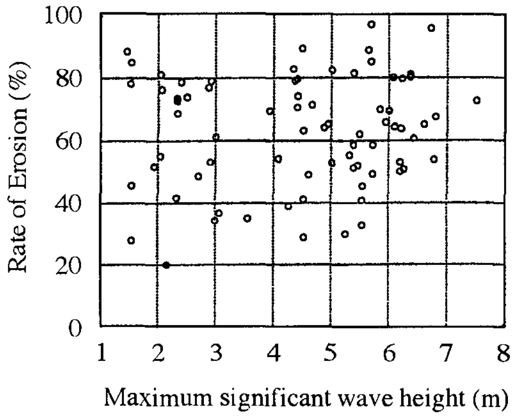


Fig.5 Relationship of erosion rate and incident wave height

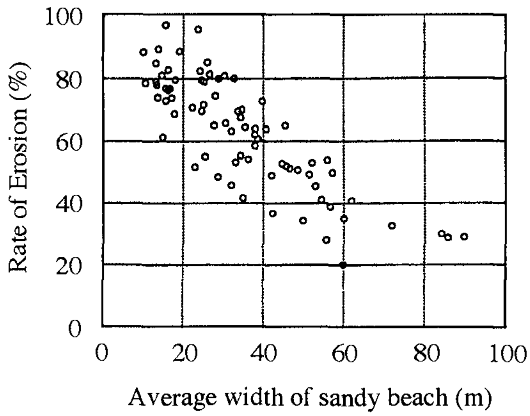


Fig.6 Relationship of erosion rate and beach width

IMPACTS ON RIVER MOUTH

Applied model

The topographic change of river mouth consists of complicated interactions of river and marine forces, and topography, so the response to sea-level rise must vary widely from place to place. Therefore, it seems more appropriate to take a simple case to study the basic phenomena related to the sea-level rise. In this study, a small-scaled and simplified model of the river mouth was studied on a basis of the numerical simulation.

The numerical model developed by Sawai et al.(1993) was used, since it has been verified to simulate the results of laboratory experiments well. The model consists of two sub-models; one is to calculate the flow field based on the equations of continuity and momentum, and the other the sediment transport and topographic changes. The equations are as follows.

1) Flow field

$$\frac{\partial \zeta}{\partial t}+\frac{\partial}{\partial x}[(\zeta+h)u]+\frac{\partial}{\partial y}[(\zeta+h)v]=0 \quad (3)$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv+g\frac{\partial \zeta}{\partial x}-A_h\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+\frac{gu\sqrt{u^2+v^2}}{(\zeta+h)C^2}=0 \quad (4)$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu+g\frac{\partial \zeta}{\partial y}-A_h\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)+\frac{gv\sqrt{u^2+v^2}}{(\zeta+h)C^2}=0 \quad (5)$$

where, ζ is elevation of water surface, u and v components of velocity, h local water depth, f the Coriolis factor, A_h vertical eddy viscosity, C Cezy's coefficient of friction, and g the gravitational acceleration.

2) Topographic change

$$\frac{\partial z}{\partial t}+\frac{1}{1-\lambda}\left(\frac{\partial q_x}{\partial x}+\frac{\partial q_y}{\partial y}\right)=0 \quad (6)$$

where, q_x and q_y are sediment transport rates, and λ is the void ratio of the sand layer.

Regarding the sediment transport rate, the longitudinal and transverse components are given separately for bed and suspended loads. In the calculation of topographic change by bed load, the effect of gravity was taken into account to prevent the slope of the local topography from becoming too steep.

The model of river mouth consists of a straight river and rectangular sea as shown in Fig. 7. The conditions of flow rate and sediment discharge were given at the uppermost boundary of the river, and were kept constant for all the calculations. Three scenarios of sea-level rise were assumed as shown in Fig. 8, i.e. no sea-level rise, slow and fast rise scenarios.

Results of calculations

The calculated profiles along the river channel are indicated in Fig. 9 (a)~(c), while three-dimensional pictures of the results are shown in Fig. 10. Figure 9 (a) is for the case

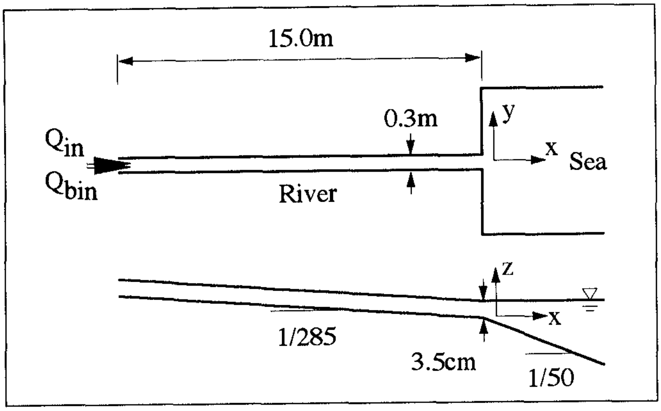


Fig.7 Model of river mouth

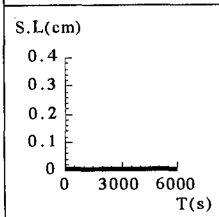
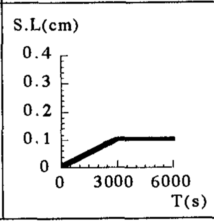
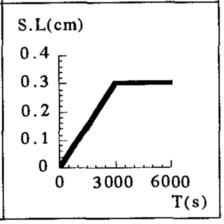
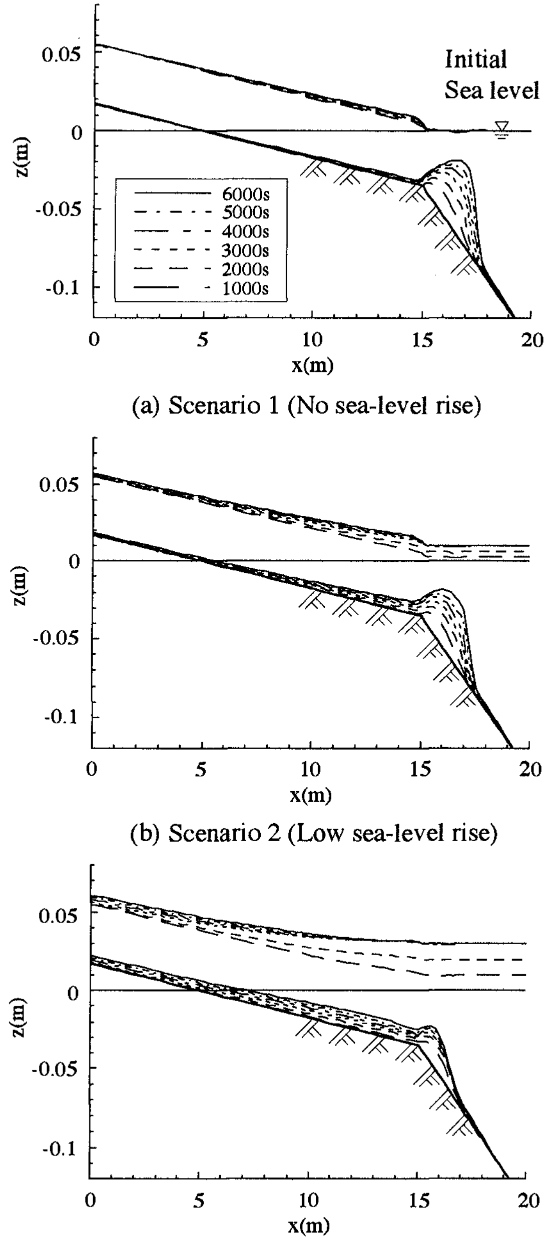
Scenario 1	Scenario 2	Scenario 3
No sea-level rise	Low sea-level rise	High sea-level rise
		

Fig.8 Assumed scenarios of sea-level rise

case of no sea-level rise, showing that a terrace is forming around the river mouth as time proceeds. After the terrace reached some length in the cross-shore direction, it stopped growing in that direction and started to expand in the longshore direction. In the case of no sea-level rise, little deposition of sand takes place on the river floor.

Figures 9(b) and (c) show the results for the cases of slow and fast sea-level rise. The water surface of the river tends to increase due to the backwater effect as the sea level rises. The significant feature of these cases is that the deposition of sediment occur along the river channel with the increase of river water surface, even in the upper reach. As the deposition on the river floor takes place, the terrace to be formed around the river mouth stay small compared with the no sea-level rise case. When the elevation of river floor is increased by sand deposition, this makes the river surface higher in addition to the backwater effect. According to such feedback mechanism, the area of sediment deposition moves further upstream.

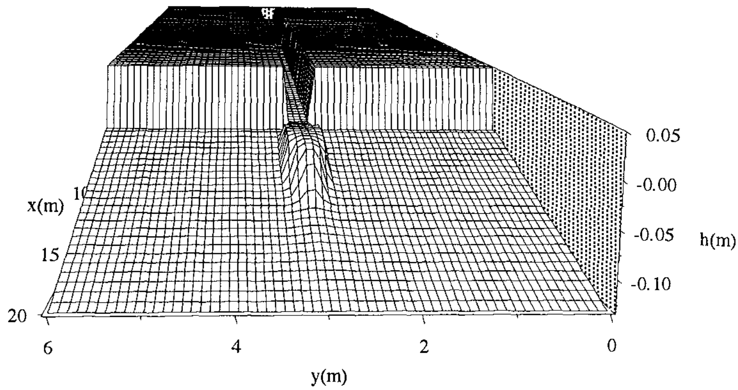


(a) Scenario 1 (No sea-level rise)

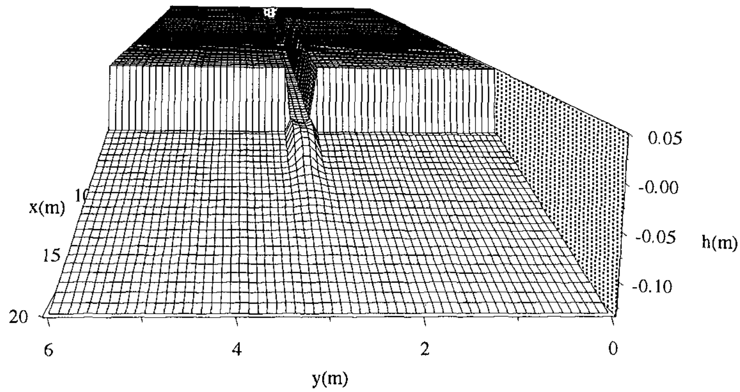
(b) Scenario 2 (Low sea-level rise)

(c) Scenario 3 (High sea-level rise)

Fig.9 Topographic changes of river mouth with different sea-level rise scenarios



(a) No sea-level rise



(b) High sea-level rise

Fig.10 Three-dimensional picture of the topographic changes around river mouth

The combined effects of sea-level rise and sand deposition along the river floor exacerbate the potential danger of river flood. Attention has to be paid to this phenomena, as a possible impact of sea-level rise.

CONCLUSIONS

In the present paper, responses of coastal topography to sea-level rise and related impacts have been examined. Regarding the beach erosion, the nation-wide assessment revealed that the effect of sea-level rise is extremely large; even a 30 cm sea-level rise may cause beach erosion comparable with that took place for the past 70 years. Keeping such fact in mind that the sea level rise-induced erosion superposes on the existing erosion, it is necessary to pay careful attention to the future trend of sea-level rise.

Regarding the impacts on the river mouth, sea-level rise has two effects; one is the backwater effect to increase the water level along the river, the other the changes in the place of sediment deposition. If the scale of sea-level rise is large, the deposition of sand transported by rivers will move upstream. Both effects act to increase the water level along the river, suggesting that the risk of river flooding would increase. Since the analyses performed in this study were rather simple, further studies are needed to evaluate the impacts of sea-level rise on the complicated situation of real river mouths.

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