IMPACT OF SEA LEVEL RISE ON PHYSICAL ENVIRONMENT IN BRACKISH LAKES AND TIDAL RIVERS

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ABSTRACT

The climatic change on global scale--global warming would lead to a sea level rise in the near future, and we have to study its impacts on environments in coastal regions. After general review of various impacts, some special effects on physical environments in brackish lakes and tidal rivers have been investigated quantitatively using simple models.

A sea level rise would cause a decrease in movement of lower saline water in brackish lakes, and it would promote a salt wedge intrusion along tidal rivers of weak mixing type, while it would promote a retreat of saline water in rivers of strong mixing type. Field surveys are needed for more advanced study.

KEYWORDS:Sea Level Rise, Brackish Lake, Tidal River, Physical Environment, Model

1. INTRODUCTION

The climatic change on global scale -- the global warming would lead to a sea level rise in the near future, and the rise in mean sea level will have various effects on society,for example in the fields of economics, public health, ecology and sociology in every country in the world.

Therefore, we have to assess these impacts and plan effective countermeasures, if necessary. Of course, the impact of sea level rise depends on the natural and artificial conditions of coastal regions, for example tides and waves in sea and land use state in land, and an individual study is necessary for each water region to assess the characteristic impacts on the region. But there are some common features of impacts through the same type of water regions where the fresh water from land and saline water from sea contact and mix through the common physical processes.

In this report, first we will describe general features of impacts of sea level rise on coastal regions which bring about various natural hazards and environmental changes, and next explain some common changes in physical environments of brackish lakes and tidal rivers which are often found in many coutries having similar coastal conditions.

2. PHYSICAL IMPACTS OF SEA LEVEL RISE ON COASTAL REGION

General features of direct physical impacts of sea level rise on coastal regions are as follows.

1) everlasting submergence of land
2) increase in area and frequency of damage caused with high tide and tsunami
3) increase in flood caused with bad drainage
4) change in contacting and mixing of fresh and saline waters in brackish lake
5) change in going upstream of sea water along tidal river
6) change in salt intrusion through groundwater permeable layer in coastal land

In these features, people will regard 1)-3) as natural hazards and 4)-6) as environmental changes through water quality change.

As an example of 1), all islands of The Republic of Maldives are built entirely of coral materials with elevation less than a few meters above sea level and the peoples are afraid of submergence of most islands caused with a sea level rise.[3)]

As an example of 2), Netherlands have protected the coast line with high dykes against storm surges with a frequency of once every ten thousand years by the Delta Plan, but a one meter rise of sea level will reduce the frequency to once every thousand years--the order of 10% of the present factor.[4)]

As an example of 3), Bangladesh has wide and low delta areas which have often been attacked with floods or high tides even in the present state, and a slight rise of sea level will cause a serious increase in flood damages resulting many displaced persons.[5)]

The environmental changes through quality change in surface and underground waters described in 4)-6) would not bring about direct and acute damages in a short period, but would cause a gradual and unceasing change in ecosystem through a long period affecting human life in various styles. In the next sections, some physical processes causing the environmental changes in coastal regions are explained using fluid dynamical models.

3. IMPACT OF SEA LEVEL RISE ON PHYSICAL ENVIRONMENT IN BRACKISH LAKE

There are many brackish lakes in Japan along a long coastal line, and they are playing important roles for human life and activity, for example, brackish lakes produce special fishes and shellfishes and give good ports for transport between inland and sea, and many people live around the brackish lakes. Then we have to keep good environments understanding the characteristic of the brackish lakes.

The most distinctive feature of brackish lakes is a stable density stratification with lighter fresh water and heavier saline water through all seasons, while a thermal stratification in ordinary lakes exists only in warming season.

The height of boundary surface between lower saline water and upper fresh water is controlled by the inflow rate of fresh and saline waters and vertical mixing effect with wind waves and shear turbulence in two layers and it is very difficult to estimate the height of boundary surface or the thickness of two layers numerically. But it is natural to consider that the boudary surface will rise up when the sea level rises and a larger amount of sea water flows in the lake and settles on the bottom surface making a thicker layer. The observed fact in Naka-umi where the seasonal change in level of Japan Sea with a range of a few tens of centimeters affects the height of the boundary surface shows the rising tendency of the boundary during summer with sea level rise.

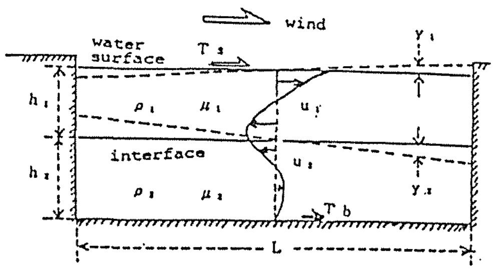
Then we used the simplest model of two layers in two dimensional space as shown in Fig.1 to calculate the effect of increase in thickness of lower layer on the wind-induced circulating current in the vertical plane.

Suffix 1 and 2 are used for the geometrical or physical quantities in upper and lower layers respectively. Following symbols are used for various quantities.

h:thickness of layer, u:current velocity, ρ:density, μ:eddy viscosity

Ts:water surface stress, Tb:bottom surface stress, y:vertical displacement

Fig.1 Wind-induced current in two layer model for a brackish lake



The calculated current pattern is shown in the figure and two circulating currents appear in two layers.

Main results from this model analysis are as follows.

Under the assumption of large eddy viscosity in the upper layer and small increase in the lower layer thickness

1) only a slight change in inclination of water surface and boundary surface
2) decrease in bottom stress with thickness of lower layer
3) decrease in periods of external and internal seiches
4) decrease in current speed of lower layer of wind-induced current and internal seiche

In conclusion, a rise of sea level would bring about an increase in thickness of lower saline layer, but not so large change in water movement except a decrease in the current of lower layer and bottom stress which may promote settlement of fine particles on the bottom bed.

4. IMPACT OF SEA LEVEL RISE ON PHYSICAL ENVIRONMENT IN TIDAL RIVER

There are many tidal rivers where the water level and current change periodically owing to the tide and saline water rises upstream, and they are affected directly by the rise of sea level. As known well, there are three types of tidal river with different mixing states,--weak mixing (salt wedge), partial mixing and strong mixing which are demonstrated in Fig.2 schematically.

In this report, we treat two extreme types--weak and strong mixing which are easily discussed using simple models.

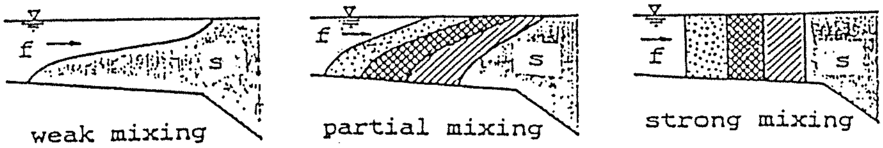
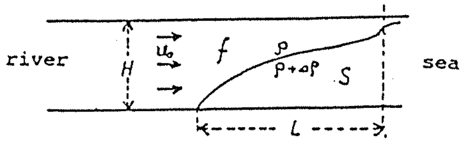


Fig.2 Three types of tidal rivers, f:freshwater, s:saline water

4.1 Salt intrusion in the case of weak mixing --rising up of salt wedge

The simplest model of weak mixing is the case of standing salt wedge along a horizontal river bed as shown in Fig.3 and it gives the possible longest length of the wedge expressing the extreme example necessary for practical planning.

Fig.3 Standing salt wedge on a horizontal river bed f:fresh water, s:saline water



In this case, the length of salt wedge L is given as a funtion of mean water depth H in the following equation taking dimensionless form:[2)]

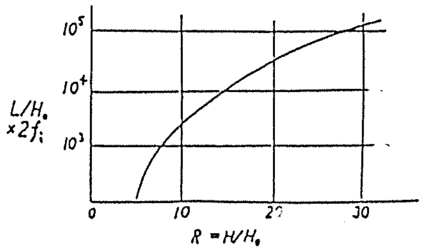
$$(L/H_o)*(2f_i) = 0.2R^4 - 2R + 3 - 1.2R^{-1}, \qquad R = H/H_o$$

here f_i: friction coefficient at the interface between fresh and saline waters

H_o: critical depth of river which makes the salt intrusion possible and equal to $u^2/(\Delta\rho g/\rho)$ $\Delta\rho$:density difference between fresh and saline waters, ρ:mean density, g:gravity acceleration, u:mean velocity

The relationship between the dimensionless salt wedge length (L/H_o) and dimensionless depth (H/H_o) is shown as the curve in Fig.4 and in the practical range of most tidal rivers, L is proportional to about 4th power of H .

Fig.4 Relationship between water depth H and salt wedge length L (dimensionless expression)



Then a slight increase in river depth brings about a large increase in rising up length of salt wedge as well known empirically through a dredging work.

In coclusion, a sea level rise would promote the rising up of sea water and cause a large increase in salt wedge length assuming that other parameters -- *river discharge, friction coefficient and density difference are kept unchanged.*

4.2 Salinity ditribution in the case of strong mixing

A strong vertical mixing makes a uniform salinity distribution along the vertical direction and we can discuss the horizontal distribution of salinity using one dimensional diffusion equation in stationary state as the following approximately.

$$uS + K_x(dS/dx) = 0$$

S:salinity, x: distance from river mouth, u:mean velocity of river flow,
Kx:turbulent diffusion coefficient in x-direction

Boundary condition at river mouth: $S=S_o$ at $x=0$

Accoding to mixing length theory, we assume that Kx is proportional to the product of amplitude of tidal current and distance of tidal excursion, and get

$$K_x = CU_o \exp(-2\alpha x)/w = C \exp(-2\alpha x) A_o^2 g^{\frac{1}{2}}/wH$$

C : proportional coef.,
Ao: amplitude of vertical oscillation of water surface at river mouth,
g : gravity acceleration, w : angular velocity of tidal oscillation
H : mean depth of river, α: damping coef. of tidal oscillation

This expression of Kx can be applied with a good approximation to the tidal rivers where amplitudes of tidal oscillation of water surface level and tidal current diminish exponentially with upstream distance x from river mouth i.e. $\exp(-\alpha x)$ as shown in Fig.5 schematically.

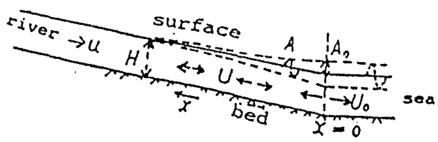


Fig.5 Profile of tidal river with oscillation of water level and current

Dimensionless expression of amplitude diminishing is shown in Fig.6 using a characteristic length L $(=1/\alpha)$, it means that the amplitude diminishes 1/e = 0.318 of Ao at x = L .

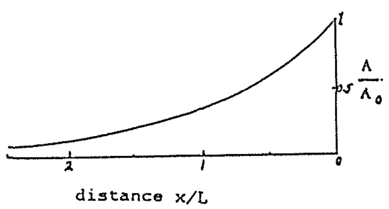


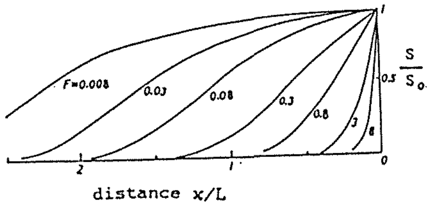
Fig.6 Relationship between distance from river mouth and amplitude of water level oscillation (dimensionless)

Along such a tidal river, the distribution of salinity is given by the following equation, the solution of above differential equation.

$S/S_o = \exp[F*\{1-\exp(2x/L)\}]$, Flushing number $F=CqH^{\frac{1}{2}}/A_o^2 g^{\frac{1}{2}}$
$q=uH$ (river discharge per unit width)

Dimensionless relationship between salinity (S/S_o) and distance (x/L) is shown by curves with different values of F in Fig.7,; a larger value of Flushing number F shifts the curve toward the sea side, and it means that the higher F value is, the more saline water is pushed out to sea side.

Fig.7 Relationship between distance from river mouth and salinity (dimensionless) in a tidal river of strong mixing type
F: Flushing number



As for the effect of sea level rise, it should be noticed that square root of H is included in F and if the sea level rises increasing the mean depth H of river, increase of F promotes the pushing out of saline water as mentioned above.

In conclusion, a sea level rise would cause a retreat of saline water to sea side in a strong mixing state, and this is a completely inverse tendency to the case of weak mixing.

The other analysis on salinity distribution in a lower tidal region of strong mixing state with a limited length L had been carried out by A.B.Arons and H. Stommel[1], and their result is shown in Fig.8 which is similar to our result in Fig.7 except that two boundary conditions are used at x=0 and L and that Flushing number $F = CqH/A_o^2 wL$. In their case also, F includes H and a sea level rise would cause the pushing out of saline water.

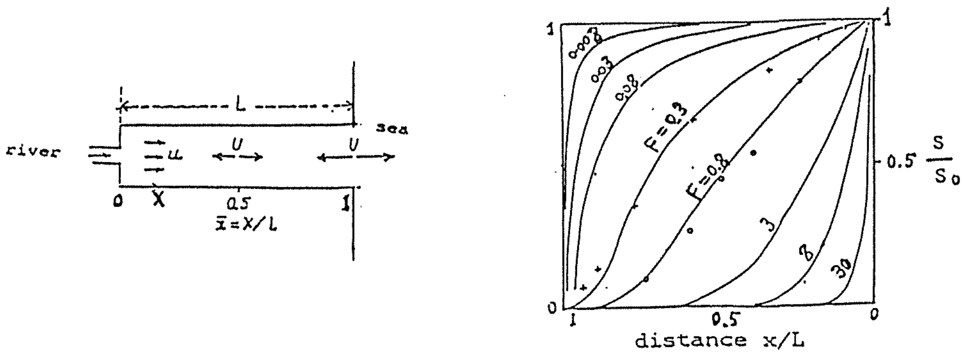


Fig.8 Relationship between distance from river mouth and salinity (dimensionless) at a lower region in a tidal river of strong mixing type with a finite length L
F: Flushing number

5. IMPORTANCE OF FIELD SURVEYS

In the avobe sections, we investigated the impact of sea level rise on physical environment in brackish lakes and tidal rivers by theoretical analysis using simple models, and we have to examine the results through the field surveys. But it is difficult to observe the effect of sea level rise directly because it proceeds too slowly to measure the changing state exactly. However, in some places where seasonal change in sea level of a few tens of centimeters order appears (western part of Japan sea) or rapid ground subsidence is proceeding with a rate of order of cm/year (around Nagoya or Tokyo), we can measure some effects of sea level rise relative to the land directly by careful observation.

We need to promote such field observations in near future to understand the real impacts of sea level rise on various coastal regions and to plan effective countermeasures before we get serious and wide areal damages.

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