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How does Land respond to Sea-level Changes ?

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Beaches and low-lying coastal areas have been seriously eroding at many places along the global coastlines during the past century. The coastal erosion problem during the next century is said to be potentially worse due to the sea-level rise by global warming.

Coastal erosion, whatever the time scale is, is the result as a response of land to oceanic, atmospheric, and human impacts. Constructing coastal structures such as groins or breakwaters, or dredging bottom sands to manage a harbor may cause to change or to block the natural path of the sediment transport. These human activities for protecting beaches or a harbor often result in erosion, especially unless considering all the design factors in a proper manner (Gerritsen and Jeon, 1991). Waves and wave-induced currents may cause beach accretion/erosion depending on the net flux as the sum of longshore and crossshore sediment movements. For a beach with no longshore transport from/to the neighboring beaches, wave asymmetry (nonlinearity) and return flow may affect crossshore sediment transport. In general, offshore sediment transport occurs for high waves because the effect of the return flow is larger than that of wave asymmetry and hence the resultant flux is offshorewards. And vice versa for low waves. Although the time scale of wave actions is typically in the order of seconds to minutes, the effect of waves on beach erosion is still significant in a long-term scale. As an extreme, storm waves may severely erode low-lying coastal region and the large part of the eroded material can never be recovered even after much longer duration with mild wave condition (for onshore transport).

Ever since Bruun (1954) suggested a simple model of offshore sediment transport by sea-level rise (trend), this geometric rule has been examined by many authors including himself. But there is a fundamental lack of physical reasoning in the Bruun Rule, which is the fact that sea levels never continuously rise or fall. They continuously fluctuate with several time scales. The rising trend of long-term sea levels may be the result of ice melting or sea-surface expansion (due to global warming) or of the land subsidence (due to tectonic movement or sediment loading). But the average effect of global sea-level trend on beach erosion seems not to be significant up to the present. The fluctuation itself, not the trend, of sea levels is a more effective factor to beach erosion.

The fluctuation of sea levels is similar to wave actions. In addition, since the time scales of sea-level changes are much longer, the result may be even worse for relatively small 'wave energy'.

Based on the data analysis of long-term shoreline recession, a hypothesis is suggested such that the beach erosion rate (χ) exponentially decreases as a function of the period of sea-level fluctuation. That is,

$$\chi(t) \;=\; A * \exp\left(-\frac{t}{T_c} \right)$$

where A = beach-erosion coefficient (= 1 for sands) as a function of underlying geology, sediment characteristics

t = period of sea-level fluctuation in months

T_c = characteristic time scale of the chronic beach erosion

During the rising period of sea-level fluctuation, the longer the duration of drawned sediments is, the more the sediments are lost to the deep region because of return flow and gravity (pushing the drawned sediments toward the deep region). The eroded sediments cannot be fully recovered during the falling period of sea levels and the permanent loss increases as the time scale of sea-level fluctuation.

Including the annual and interannual components of sea-level fluctuation, the shoreline retreat (R) can be formulated as follows:

$$\begin{aligned} R(t) &= R_1(t) + R_2(t) + R_3(t) \\ &= \frac{L}{H}\, t*\left[\; S + S_1\left(1 - A_1 \exp\left(-\frac{t_1}{T_c}\right)\right) + S_2\left(1 - A_2 \exp\left(-\frac{t_2}{T_c}\right)\right)\right] \end{aligned}$$

where

R_1 = retreat by long-term sea-level rise

R_2 = retreat due to interannual sea-level fluctuation

R_3 = retreat due to annual sea-level oscillation

S = vertical sea-level rise

S_1 = mean height of interannual fluctuation

S_2 = mean height of annual oscillation

A_1 = coefficient for annual oscillation with time t_1 ($\doteqdot$ 12)

A_2 = coefficient for interannual fluctuation with quasi-period t_2

This hypothesis critically depends on the time scale of chronic beach erosion (T_c), which will be reasonably proposed with more quantitative study of long-term crossshore sediment transport as well as with aerial photographs for shoreline changes.

References

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