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WAVE ENERGY EVOLUTION OF YELLOW RIVER DELTA INDUCED BY CLIMATE CHANGES

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ABSTRACT: Nowadays, climate changes are reported by many researches including IPCC, which might bring many problems in coastal engineering. In the present work, the evolution of extreme wave and wave energy around Yellow River Delta (YRD) induced by climate changes was analyzed since coastal erosion situation is becoming more and more seriously as result of reducing of upstream sediment. The Yellow River is very famous in the world because of her carrying out huge sediment before. However, from 1990 to now, sediment into seas carried by the Yellow River decreases due to the construction of several dams in the upstream. So many coastal structures are being threatened by wave and wave induced erosion. Based on the results given in former researches, the possible SLR around YRD in the past several decades are assumed as 0.2m, 0.5m and 1.0m. Thirdly, evolution of wave energy and wave-induced bottom shear stress (WIBSS) are studied by numerical simulation under the above three possible SLRs. Wave model SWAN is adopted to simulate wave. The wave parameters including wave height, wave energy and WIBSS with effects of possible changes are predicted numerically, which help government or constructers to design coastal protection engineering. Results by now show that the obvious enhancements of wave energy and WIBSS appear in zones shallower than 5 water depth contours. More attention should be paid to the security of coastal structures and sediment transport under climate change in this area.

Keywords: Yellow river delta, climate change, wave, sea level rise.

INTRODUCTION

There is a significant increase of global temperature since 1980s. A increase of 0.74 degree are found comparing the global temperature of 1981-1990 with that of late 19th century(Core Writing Team). As a result of the increasing temperature, sea level rise (SLR) are also found. Based on the tide data from 1870~2004, the global mean sea level are increasing at a speed of 1.7±0.3mm/a(John A. Church and Neil J. White), while based on satellite data from 1993~2009, the global mean sea level rise at 3mm/a. The IPCC 2007 concluded that the global sea level rise will be 18~59cm by the end of 21th century(Core Writing Team).

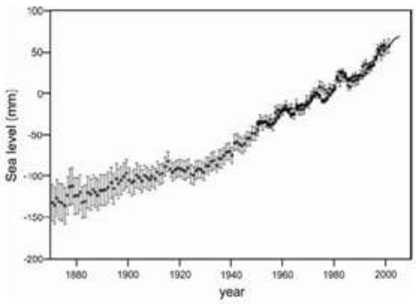

Fig. 1 Average Global Sea levels

As China concerned, a significant sea level rise is also found in the last 30 years. The mean sea level of 2010 is 67mm higher than common years and at the peak point of history, at a similar level with 2009. Figure 2 is a comparison of SLR of 2009 and 2010 for Bohai, Yellow Sea, East China Sea and South China Sea(State Oceanic Administration People's Republic of China).

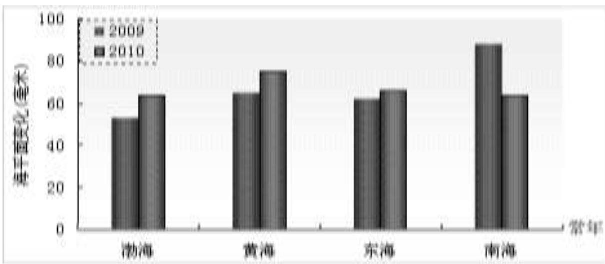

Fig. 2 The impact of sea level rise on coasts (mm)(State Oceanic Administration People's Republic of China)

In this paper, Yellow River Delta in Bohai is selected to study the impacts of SLR on extreme wave energy evolution in the coastal zones.

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Some researchers have paid much attention to coastal environment problems induced by climate changes(Nobuhito Mori, Tomohiro Yasuda, HajimeMase). They attend to predict wave climate in the future or SLR.

BATHYMETRY AND WIND CONDITIONS

The bathymetry of Yellow River Delta is digitalized from the Chart of Yellow River Delta published in 2000.

The wind data from 1959~1980 at Gudao Station is corrected with the short term wind data recorded at Huanghe Port. Then the extreme wind parameters are calculated using corrected wind time series by Poison III curve. The extreme wind velocities are listed in Table 1.

Table 1 Extreme Wind Velocities of multiyear return periods (m/s)

Return period / Direction	50	25
NE	27.8	25.5
NNE	25.6	24.9
ENE	23.9	23.1

THEORY DESCRIPTIONS

The wave governing equation of swan is the spectral action balance equation, described as (Booij N, RIS RC, Holthuijsen LH., 1999):

$$\frac{\partial}{\partial t}N+\frac{\partial}{\partial x}c_xN+\frac{\partial}{\partial y}c_yN+\frac{\partial}{\partial \sigma}c_\sigma N+\frac{\partial}{\partial \theta}c_\theta N=\frac{S}{\sigma} \qquad (1)$$

Where, N is the action density, which is obtained by dividing the energy density by the relative frequency σ ; parameters $c_x, c_y, c_\sigma, c_\theta$ are the wave propagation velocities in the x-, y-, σ -, θ -space, respectively. The first term on the left-hand side of this equation represents the local rate of change of the wave action density in time, and the second and third terms represent the propagation of action in geographical space. The fourth term represents shifting of the relative frequency due to the variations in depths and currents. The fifth term represents the depth-induced and current-induced refraction.

Based on linear wave theory, wave energy density can be obtained by,

$$\overline{E}=\frac{1}{8}\rho g H^2 \qquad (2)$$

$$\Delta E=\frac{E'-E_0}{E_0}=\frac{H'^2-H^2_0}{H^2_0}\times 100\% \qquad (3)$$

The simulation area covers 37°15′N~38°31′N and 118°50′E to 119°51′E. The grid number is 80 by 99 with the space resolution of about 1400m. At the boundary, 50a return period significant wave height is 6.0m and the corresponding wave period is 8s, which is from the NE direction. Constant wind field of 20m/s from the NE direction is adopted.

Three SLRs are taken into account, which are 0.2m, 0.5m and 1.0m respectively.

VERIFICATION OF THE WAVE MODEL

Figure3 and Figure4 show the comparison of significant wave height and spectrum peak period between buoy and hindcasted respectively. The wind velocity for the verification period is obtained by WRF. Both significant wave height and spectrum peak period of models matched with buoy waves. However, there is a little difference, which may be attributed to the precision of water depth and the wind data. Thus the SWAN model can be used to study the wave transformation in this area.

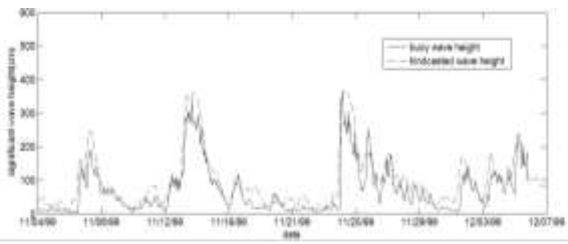

Fig. 3 The comparison of hindcasted wave height and measured wave height

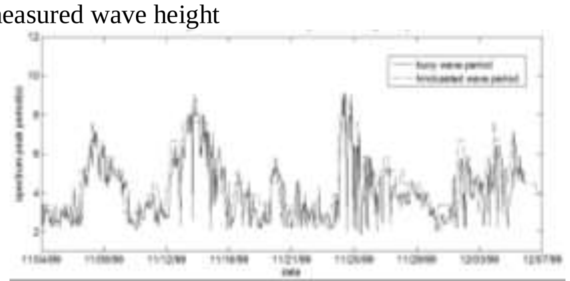

Fig. 4 The comparison of hindcasted wave period and measured wave period

DISCUSSION OF WAVE SIMULATION RESULTS

Figure 5 shows the simulation results of extreme wave transformation in Yellow River Delta for the 0m, 0.2m, 0.5m and 1.0m SLR conditions. Figure 6 shows the increase of wave height under different SLR. The wave height shows little difference in deeper water zones, and the maximum enhancement can be up to 0.4m in the smelted shallow area.

Wave energy density can be estimated with equation (2) and (3), and the results are shown in figure 7. As 5 meter bathymetry contour as concerned, wave energy rises 14.5% for SLR of 0.2m, 37% for 0.5m, and 56% for SLR of 1.0m respectively. In zones deeper than 15 meters, there is no obvious enhancement, and the nearshore areas are more impacted by the SLR. The increasing wave height and wave energy cannot be ignored since it can lead to more serious erosion.

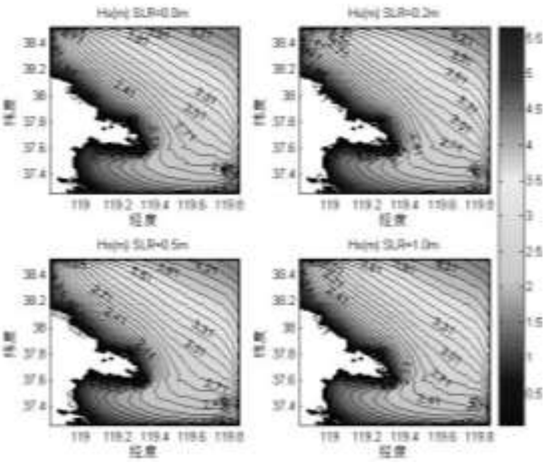

Fig. 5 Wave Field under Different Sea Level Rising (SLR)

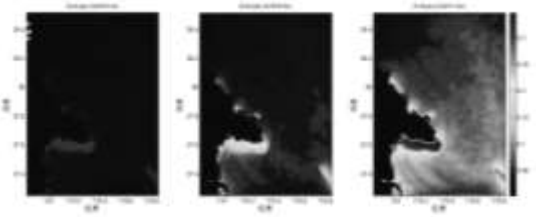

Fig. 6 Enhancement of Wave Height under Different Sea Level Rising (SLR)

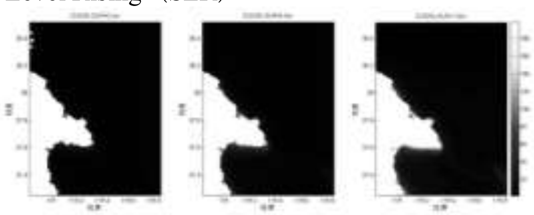

Fig .7 Enhancement of Wave Energy under Different Sea Level Rising (SLR)

DISCUSSION OF ENHANCEMENT BOTTOM SHEAR STRESS INDUCED BY SLR

Based on linear wave theory, the maximum bottom shear stress induced by waves can be calculated by

$$\tau_b = \frac{1}{2}\rho f_w u_b |u_b| \quad (3)$$

Where, u_b is bottom velocity, u_m is the maximum bottom velocity. f_w is wave friction coefficient. d_s is roughness. A_m is the maximum motion amplitude. σ is frequency.

$$u_b = u_m \cos\sigma t,\ u_m = \frac{\pi H}{T}\frac{1}{\sinh(kh)} \quad (4)$$

$$\frac{1}{4\sqrt{f_w}} + \lg\frac{1}{4\sqrt{f_w}} = -0.28 + \lg\frac{A_m}{d_s},\ \frac{A_m}{d_s} \succ 1.57 \quad (5)$$

$$f_w = 0.30,\ \frac{A_m}{d_s} \prec 1.57 \quad (6)$$

Figure 8 shows the changes of bottom shear stress due to SLR. It can be seen that nearshore high bottom shear stress (>300%) area can extend to a few kilometers offshore. With the SLR rising, the width and area enhanced bottom shear stress increases too. The increasing bottom shear stress means more sediment suspension and transport by the waves. The trend of sediment transport and the delta development must be considered.

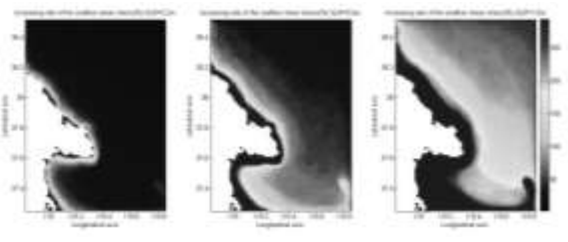

Fig. 8 Increasing ratio of the bottom shear stress(%)

CONCLUSIONS

In the present work, extreme wave height and wave energy evaluates due to sea level rise in Yellow River Delta are investigated using the third generation wave model SWAN. The simulation results show that the nearshore waves can be enhanced by the increasing sea level. The enhancement of wave height induced by SLR is a nonlinear process due to the complex bathymetry. The future extreme wave height can be 0.5m higher than the present scenario around the mouth of Yellow River when SLR amounts to 1.0m. The wave energy density at the 5 meter bathymetry contour can increase 56% if the sea level rises 1.0m. In the nearshore zones, the bottom shear stress rises obviously. The effects of SLR on wave energy, sediment transport and long-term morphology change cannot be ignored in the coastal regions.

In the future, the critical bottom shear stress for sediment re-suspension of YRD will be recovered and the sedimentation environment will be given too.

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