SIMULATION OF LONG-TERM SHORELINE CHANGE DRIVEN BY LONGSHORE AND CROSS-SHORE SEDIMENT TRANSPORT

Yan Ding, USACE-ERDC CHL, Vicksburg, MS 39180, USA. Yan.Ding@usace.army.mil
Sung-Chan Kim, USACE-ERDC CHL, Sung-Chan.Kim@usace.army.mil
Richard B. Styles, USACE-ERDC CHL, Richard.Styles@usace.army.mil.
Rusty L. Permenter, USACE-ERDC CHL, Rusty.L.Permenter@usace.army.mil

INTRODUCTION

Driven by wave and current, sediment transport alongshore and cross-shore induces shoreline changes in coasts. Estimated by breaking wave energy flux, longshore sediment transport in littoral zone has been studied for decades. Cross-shore sediment transport can be significant in a gentle-slope beach and a barred coast due to bar migration. Short-term beach profile evolution (typically for a few days or weeks) has been successfully simulated by reconstructing nonlinear wave shape in nearshore zone (e.g. Hsu et al 2006, Fernández-Mora et al. 2015). However, it is still lack of knowledge on the relationship between cross-shore sediment transport and long-term shoreline evolution. Based on the methodology of beach profile evolution modeling, a semi-empirical closure model is developed for estimating phase-average net cross-shore sediment transport rate induced by waves, currents, and gravity. This model has been implemented into GenCade, the USACE shoreline evolution model (Frey et al 2012).

METHOD

This semi-empirical model for calculating phase-average cross-shore sediment transport rate (ϕ) at a cross-shore section is formulated as follows:

$$\phi = \frac{\alpha_D}{1-p}\left(Q_w + Q_c + Q_D\right) \tag{1}$$

where p = sand porosity, Q_w and Q_c = net sediment transport due to waves and currents, respectively, Q_D = diffusive transport resulting from the downslope effect of gravity, and α_D = a scaling parameter calibrated by observation data. Net sediment transport rates for the wave and current (Q_w and Q_c) are calculated by the formulation proposed by Fernández-Mora et al. (2015), which requires a nonlinear wave shape model to give near-bed wave orbital velocity. The free-stream near-bed horizontal orbital velocity formula proposed by Abreu et al. (2010) and Ruessink et al. (2012) is used, which reconstructs asymmetrical nonlinear waves in nearshore zone. The undertow current is also included in the equation. The net cross-shore rate is added into the shoreline evolution equation of GenCade to simulate shoreline changes driven by both longshore and cross-shore transport.

RESULTS

Model validation was performed by simulating long-term shoreline changes from 1999 to 2005 in a 5-km-long coastline in Duck, North Carolina (NC), USA (Fig. 1a). Simulation results prove that inclusion of cross-shore transport improves significantly the accuracy of the simulated long-term shoreline changes (Fig. 1b and Fig. 2a). Net cross-shore transport estimated by Eq. (1) shows that low-energy waves cause onshore transport for shoreline accretion, and high-energy waves during storms respond to offshore transport which induce erosion (Fig. 2b). The observation data of shoreline positions were extracted from the beach profiles at the mean water level, measured by the USACE Field Research Facility (FRF).

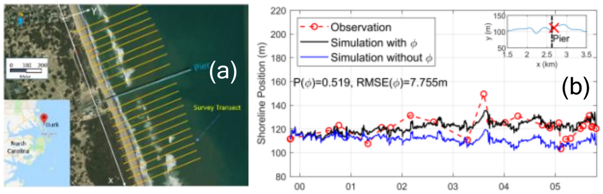

Figure 1. (a) Study site and survey transects in Duck, NC. (b) Comparisons of time histories of shoreline positions at the south shore near the pier (indicated by a red symbol "*X*" in a box in the upright corner). The solid black line denotes the simulated shoreline variations in time by taking into account cross-shore transport. The blue lines is the positions computed without cross-shore transport. $\boldsymbol{P(\phi)}$ is the Pearson correlation coefficient calculated for the case including $\boldsymbol{\phi}$. $\mathbf{RMSE}(\boldsymbol{\phi})$ is the root-mean-square error of the shoreline positions.

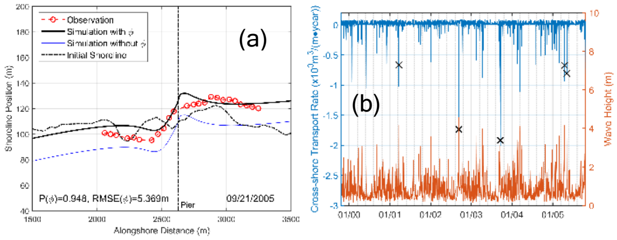

Figure 2. (a) Comparison of shoreline profiles on 09/21/2005. (b) Time series of cross-shore transport rate (blue color) at 300 m north of the pier and offshore wave heights (orange color). "x" indicates a peak offshore transport induced by a high wave.

CONCLUSIONS

Successful simulated long-term shoreline evolution in Duck coast reveal that the inclusion of this semi-empirical cross-shore sediment transport model significantly improve the model's predictability of long-term shoreline evolution. Estimated net cross-shore transport needs to consider the effect of wave nonlinearity, undertow current, and gravity in nearshore zone.

REFERENCES

Abreu, T., et al. (2010). Coastal Eng., 57(7), 656-667.
Fernández-Mora, A., et al. (2015). Geophys. Res. Lett., 42, 2869-2877, doi:10.1002/2014GL063004.
Frey, A.E et al. (2012) GenCade version 1 Model theory and user's guide. USACE, ERDC/CHL TR-12-25, 169 pp.
Hsu, T.J., et al. (2006), Coastal Eng., 53, 817-824.
Ruessink, B. G., et al. (2012). Coastal Eng., 65(7), 56-63.