International Conference on Estuaries and Coasts
November 9-11, 2003, Hangzhou, China

CALCULATION OF LONGSHORE SEDIMENT TRANSPORT IN SHIJIU BAY

Jinhai ZHENG & Jinchun HU
Research Institute of Coastal and Ocean Engineering, Hohai University
1 Xikang Road, Nanjing 210098, China
Tel: 86 25 3786637, Fax: 86 25 3701905, E-mail: zhengjinhai@hotmail.com

Abstract: In order to study the influence of deposition on the dredging works in the Port of Rizhao, the longshore sediment transport in the Shijiu Bay is calculated by using the formula in the Code of Hydrology for Sea Harbor of China (CHSH) and the CERC formula in the Shore Protection Manual. A numerical model based on the wave ray method is used to compute the breaking wave parameters. The net volume of longshore sediment transport is 110000 m^3/a to the north in the southern bay and 10000 m^3/a to the south in the middle bay. This would result in deposition in the Shijiu Bay. The comparisons between the above methods show that the calculations with the CHSH formula are smaller than those with CERC formula in general, and the ratio ranges from 1 to 0.5 and decreases with the increase of wave height and wave period. The reasons lie in that the CHSH formula takes both the wave steepness and the median grain size into account.

Key words: Longshore sediment transport, CERC formula, CHSH formula, Shujiu Bay

1. INTRODUCTION

The Port of Rizhao is situated in the Shijiu Bay, a natural coastline of up to 7km in its ear-shaped harbor with wide gulf and deep water. It borders on the Yellow Sea in the east, facing Japan and Korea across the Sea, and is adjacent to the south of Port of Qingdao and to the north of Port of Lianyungang (Fig.1). The natural depth of the sea 1000m from the shore is as deep as -13m. The coastline is of sand and it is an ideal site for building large-sized berths for vessels of 150 000 to 200 000 DWT. The Port of Rizhao was started to build in 1980 and officially put into operation in 1986. By now, the Port of Rizhao has altogether 18 productive berths with a designed annual throughput capacity of 22.1 million tons. The Port of Rizhao is one of the large-sized coal exporting ports of China and is ranking the 15th place among the main coal ports in the world. The land area is 103 km^2, and the water area is 300 km^2. The total length of wharves available for operation is over 4000m. In order to be seasoned with the rapid development of throughput of coal, it was decided to rebuild the berth of 100 000 DWT into that of 150 000 DWT by dredging. Therefore, the water depth in front of the berth will be changed from –17m to –19m, and those in the basin and the navigation channel will be dredged from –15m to –17m.

For estimating the influence of deposition on the rebuilding works, the formulas in the Code of Hydrology for Sea Harbor of China and the CERC formula in the Shore Protection Manual are used to calculate the longshore sediment transport. Although numerous formulas and models for computing the longshore sediment transport by waves and currents have been proposed during the last decades, ranging from quasi-steady formulas based on the traction approach of Bijker, and the energetics approach of Bagnold, to complex numerical models involving higher-order turbulence closure schemes that attempt to resolve the flow field at small scale (Bayram et al., 2000; Goda, 2001.).

Fig. 1 Locations of Shijiu Bay and Rizhao Port

2. CALCULATIONS

2.1 CALCULATING FORMULAS

Scientific studies of sediment transport began in 1940s. In the early days, the amount of total longshore sediment transport was estimated from the volumetric change of beach and berm on the coast where longshore sediment transport was impounded by some barrier such as a jetty or others. The longshore sediment transport rate was then correlated with the longshore component of wave energy flux during the period in which the amount of the longshore sediment transport was estimated. Through accumulation of many data at various coasts, the so-called CERC formula (USACE, 1984) was evolved, which is the best known and the most widely used method. Its volumetric expression is as follows.

$$q_l = \frac{KH_b^2 (c_g)_b}{8s(1-\lambda)} \sin\alpha_b \cos\alpha_b \tag{1}$$

where K denotes the constant of the CERC formula being 0.385 on the average, H the significant wave height $H_{1/3}$, c_g the group velocity, α the wave angle, the subscript b the value at the breaking point, s the density ratio of sediment to water, and λ the void ratio of sediment in situ being about 0.4. When the root-mean-square wave height H_{rms} is used, then the constant K takes the value of 0.77.

By substituting the relevant parameters, we have

$$q_l = 0.05059 (H_{rms})_b^2 (c_g)_b \sin 2\alpha_b \tag{2}$$

The formula of longshore sediment transport in the Code of Hydrology for Sea Harbor of China can be written as follows.

$$q_l = 0.0064 K' \delta_0 (H_{rms})_b^2 (c_g)_b \sin 2\alpha_b \tag{3}$$

where δ_0 is the wave steepness in the deep water, and the coefficient $K' = (3500 \frac{D}{D^4 + 2})^{(11 - 100\delta_0)/10}$ with the median grain size D.

2.2 CALCULATING PROCEDURES

According to the statistical analysis of the wave data (1980−1994, Shijiu Ocean Station), the mean wave height is 0.6m and the mean wave period is 3.2s in this area. The wave rose diagram at Shijiu Bay is illustrated in Fig.2. The predominant wave direction in this region comes from the east. The mean water level is 2.7m above the chart datum. The bed material consists mainly of fine sand.

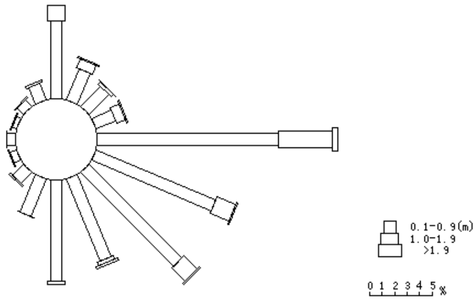

Fig. 2 Wave Rose at Shijiu Bay

A simple but rather accurate computational model based on the wave ray method, is used for calculating breaking wave parameters such as d_b, H_b, L_b and α_b from the deep water values. The governing equation can be written as

$$\frac{d\theta}{ds} = -\frac{1}{c}\left(-\sin\theta\frac{\partial c}{\partial x} + \cos\theta\frac{\partial c}{\partial y}\right) \tag{4}$$

where θ is the wave angle, s is in the wave direction, c is the wave celerity, x direction is in the onshore direction, and y direction is in the longshore direction .

The above equation can be solved by using the Runge-Kutta method

$$\theta_{i+1} = \theta_i + \frac{ds}{6}\left(K_1 + 2K_2 + 2K_3 + K_4\right) \tag{5}$$

where $K_1 = f(\theta_i)$; $K_2 = f\left(\theta_i + \frac{ds}{2}K_1\right)$; $K_3 = f\left(\theta_i + \frac{ds}{2}K_2\right)$; $K_4 = f(\theta_i + dsK_3)$; $f(\theta_i) = -\frac{1}{c}\left(-\sin\theta_i\frac{\partial c}{\partial x} + \cos\theta_i\frac{\partial c}{\partial y}\right)$。

For conservation of energy, equation is developed readily relating the wave heights at two points of interest.

$$H = H_0 K_s K_r \tag{6}$$

where K_s is the shoaling coefficient and K_r is the refraction coefficient.

The breaker criterion used is that of McCowan, which determines that waves break when their height becomes equal to a fraction of the local water depth.

$$H_b = \kappa h_b \tag{7}$$

where $\kappa = 0.78$.

The net longshore movement of sediment is the sum of the transport under all the individual wave trains arriving at the shore from many wave directions. According to the wave characteristics of Shijiu Bay, five calculating wave directions from NE to SE are considered. The longshore sediment transport for each wave train is evaluated with equations (2) and (3) respectively, and then the net sediment transport is obtained by balancing the individual values according to wave direction.

2.3 CALCULATING RESULTS

There are two calculating cross-sections in this case, as shown in Fig.3. The calculations of longshore sediment transport are given in Table 1, where Q_l denotes the longshore sediment transport of individual wave direction, Q_n the net longshore sediment transport and Q_t the total longshore sediment transport.

Table 1 Longshore Sediment Transport in Shijiu Bay（$\times 10^4$ m^3/a）

		Q_l					Q_n	Q_t
		NE	ENE	E	ESE	SE		
CHSH formula	Cross section a	—	—	+2.758	-0.157	-1.732	+0.869	4.647
	Cross section b	+0.308	+0.355	-2.879	-5.250	-3.846	-11.312	12.639
CERC formula	Cross section a	—	—	+4.258	-0.165	-2.328	+1.765	6.751
	Cross section b	+0.529	+0.500	-4.595	-6.884	-4.457	-14.908	16.966

Note: "+" stands for the sand movement from north to south;
"-"stands for the sand movement from south to north.

As shown in Tab. 1, since the north and south sediment transports through the cross section a are almost equivalent, the net transport is much smaller than the total transport up and down the shore, and the net transport is about 10000 m^3 to the south. On the shore of the southern Shijiu Bay the transport is predominately to the north, being 110000 m^3. Thus there results in the deposition in the Shijiu Bay. The as shown in Fig.3. This accords with the morphological analysis of the Shijiu Bay (Li, 2001).

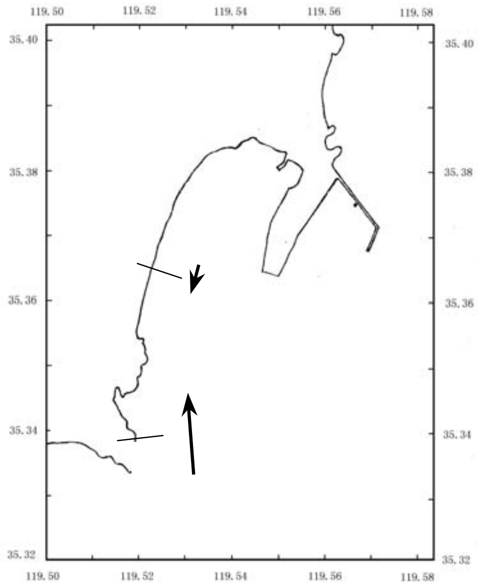

Fig. 3 Longshore Sediment Transport in Shijiu Bay

3. DISCUSSIONS

The reliability of the CERC formula for making prediction of the longshore sediment transport has been discussed over many years. One of focuses is the value of the constant *K*. While *K* is thought to be affected by the grain size, Komar (1988) could not find a clear relationship because of large scatter of field data. Del Valle (1993) supported the grain-size dependency of *K* with the field data of coarse sand coast with the grain size up to 1.5mm. Schooness and Theron (1994) calculated the value of *K* for many field data by grouping then with grain size. For the group grain size smaller than 1mm, the mean value of *K* is 0.41, while for the group grain size larger than 1mm the mean value is 0.01, although the effect of grain size could not be revealed within the two groups. A recent paper by van Wellen et al. (2000) also used the value of *K* of 0.07 to fit the data on shingle beaches in their assessment of various longshore transport formulas.

Fig.4 shows the comparisons of the calculations with the CHSH formula and those with CERC formula. It is clear that the calculations with the CHSH formula are smaller in general. The reason lies in that the CHSC formula takes both the wave steepness and the median grain size into account. With the increase of wave heights and wave periods, the wave steepness decreases, which results in the decrease of the parameter $(3500\frac{D}{D^4+2})^{(11-100\delta_0)/10}\delta_0$. The results of the longshore sediment transport obtained from the CHSH formula are therefore smaller. It should be pointed out that the median grain size in the Shijiu Bay is about 0.12mm, which is smaller than the general value of the median grain size on sand beaches. This is the other reason why the calculations of the longshore sediment transport with the CERC formula are generally greater in this case.

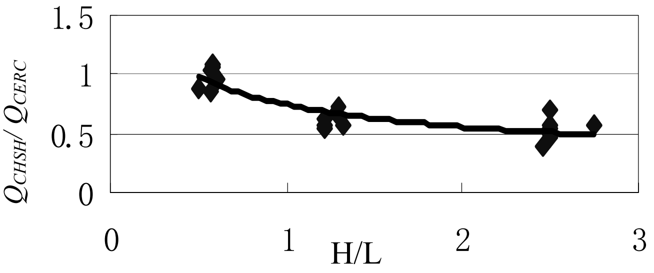

Fig. 4 Comparison of Longshore Sediment Transport with CHSH and CERC Formulas

4. CONCLUDING REMARKS

The longshore sediment transport in the Shijiu Bay is calculated by using the CHSC formula and the CERC formula respectively for estimating the influence of deposition on the dredging works in the Port of Rizhao. The net volumetric longshore sediment transport is 110,000 m^3/a to the north in the southern bay and 10,000 m^3/a to the south in the middle bay, which would result in deposition in the Shijiu Bay. The calculations with the CHSH formula are generally smaller than those with CERC formula. The reasons lie in that the CHSH formula takes both the wave steepness and the median grain size into account.

REFERENCES

Bayram A., Larson M., Miller H. C. and Kraus N. C., 2000. Performance of longshore sediment transport formulas evaluated with field data. *Proc. 27th Int. Conf. on Coastal Engrg.*, ASCE, pp. 3114-3127.

Del Valle R., Medina R. and Losada M. A., 1993. Dependency of coefficient K on grain size. *J Wtrwy, Port, Coast., and Ocn. Engrg.*, ASCE, Vol.119, No.5, pp. 568-574.

Goda Y., 2001. A new approach to beach morphology with the focus on suspended sediment transport. *Proc. 1st Asia and Pacific Coastal Engineering*, pp. 1-24.

Li Ruijie, 2001. Numerical Study on Deposition in Rizhao Port. Technical Report. Research Institute of Coastal and Ocean Engineering, Hohai University, pp. 30-36. (in Chinese)

Ministry of Communication, P. R. C., 1998. Code of Hydrology for Sea Harbor of China. People's Communication Press. pp. 1~219. (in Chinese)

Schoonees J. S. and Theron A. K., 1994. Accuracy and applicability of the SPM longshore transport formula. *Proc. 24th Int. Conf. on Coastal Engrg.*, ASCE, pp. 2595-2609.

U. S. Army Corps of Engrgs., Coastal Engrg., Res., Center, 1984. Shore Protection Manual (3rd Ed.), U. S. Gov. Print. Office.

Van Wellen E., Chadwick A. J. and Mason T., 2000. A review and assessment of longshore sediement transport equations for coarse-grained beaches. *Coastal Engineering*, Vol.40, pp. 243-275.