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APPLICATION OF SOBEK MODEL IN THE YELLOW RIVER ESTUARY

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Abstract: At present, the dredging is possible and has some profits in the estuary harnessing of the Yellow River. Nevertheless, some problems have to be solved before employment of dredging for river training, including the redeposition in the dredged channel and efficiency of dredging. In order to study these problems, a prototype experiment of dredging has been executed in the Lower Yellow River in 1998. The simulated reach is downstream from the LJ station in the Yellow River Estuary, about 38 km long. In this paper, a 1-D numerical model of SOBEK in the reach mentioned above is applied and validated separately against the prototype dataset. The analyzed results indicate that the SOBEK model has a strong adaptability and can be applied to the estuary.

Key words: Yellow River Estuary, SOBEK model, Dredging

1. INTRODUCTION

The Yellow River Carries 1.6 billion tons of sediment load, ranked the first in the world. In recent years, the Yellow River transported about 1 billion tons of sediment annually to its estuary and to the coast. Since 1967, the Yellow River was flowing through the Qingshuigou channel running to the Huanghai's Sea. The dikes along the channel had been reinforced, and a few engineering projects were completed to control the flow direction. Now, the river mouth had been seriously silted and the delta was flooded again in summer when a 2750 m^3/s flood occurred. The river mouth training was urgently needed. The traditional solution was to artificially shift the channel again but at great loss because the Gudong oil field would be flooded. If the sediment load and water continue to reduce, dredging will possibly become a main measure to maintain the Yellow River Estuary. Through dredging the river channel shrinkage at individual places can be alleviated and water-conveying channel can be preserved. But, some problems, such as the dredging efforts and opportunity, have to be solved before becoming the main strategy for river training. In order to study these problems, 1-D SOBEK model can be verified and applied to the Yellow River Estuary.

2. SOBEK MODEL

SOBEK is the name of a highly sophisticated software package, which in concise technical terms is a one-dimensional open-channel dynamic numerical modelling system, equipped with the user shell and which is capable of solving the equations that describe unsteady water flow, salt intrusion, sediment transport, morphology and water quality. It can be simulated and solved these problems in river management, flood protection, design of canals, irrigation systems, water quality, navigation and dredging. A very user-friendly interface helps the user schematise the problem and organise the required data into such a form that they can be handled by SOBEK computational core. The interface also helps you in effective analysing and reporting of simulation results.

2.1 BASIC THEORY

The flow in one dimension is described by two equations: the momentum equation and the continuity equation. The sediment includes the continuity equation of sediment and the formula of sediment load, and so on.

(1) Continuity equation

$$\frac{\partial A_t}{\partial t}+\frac{\partial Q}{\partial x}=q_{\text{lat}}$$

In which A_t is the total cross-section area; Q_{lat} is the lateral discharge per unit length; Q is the discharge

(2) Momentum equation

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\alpha_B\frac{Q^2}{A_f}\right)+gA_f\frac{\partial h}{\partial x}+\frac{gQ|Q|}{C^2RA_f}-W_f\frac{\tau_{wi}}{\rho_w}+$$

$$gA_f(\eta+\xi Q|Q|)+\frac{g}{\rho_w}\frac{\partial\rho}{\partial x}A_{1\text{m}}=0$$

Where B is the boussinesq constant; A_f is the cross-section flow area; h is the water level; C is the Chézy coefficient; R is the hydraulic radius; W_f is the flow width, W_i is the wind shear stress; w is the water density; $A_{1\text{m}}$ is the first order moment cross-section.

(3) Continuity equation for bed material

$$\frac{\partial A_s}{\partial t}-\frac{\partial S}{\partial x}=-S_{\text{lat}}$$

where A_S is the sediment-transporting cross-sectional area (m²); S is the sediment transport through the cross-section including pore volume (m³/s); S_{lat} is the lateral sediment supply including pore volume (m²/s)

(4) Formula of sediment transport

In SOBEK model, many formula can be described the sediment load, such as these formulas of Engelund & Hansen, Meyer-Peter & Muller, Ackers & White, Van Rijn and Parker & Klingeman. These formulas have been developed to compute bed load, suspended load or total load. However, because the sediment problem is very complex, and the sediment load is very high and the diameter of sediment is very fine in the Yellow River. These formulas cannot be used directly. In this case, the user-defined formula was elected as follows:

$$\phi=\frac{1}{1-\varepsilon}\beta_u(\mu\theta_s)^{\gamma_u}(\mu\theta_s-\theta_c)^{\alpha_u}$$

$$\theta_s=\bar{u}^2/C^2\Delta_d D_r$$

$$C=R^{1/6}/n_m$$

in which Φ is the transport parameter; μ is the ripple factor; θ_s is the Shields parameter; $\bar{u}$ is the average flow velocity; C is the Chézy coefficient; Δ_d is the relative density of sediment; Dr is the representative grain size; n_m is the manning coefficient

In this formula, the value of the coefficients α_u, β_u, γ_u, θ_c are supplied by the user. In this case, the values of these coefficients are 0, 900, 2.63 and 0 respectively. The ripple factor μ can be computed by the program in the same way as for the Meyer-Peter & Muller formula, but can also be supplied by the user as a constant value.

2.2 PREPARED DATA AND BOUNDARY CONDITIONS

2.2.1 Verified data

The verified data in this case come from a prototype experiment of dredging that was carried out at the delta area of the Yellow River Estuary. The duration of the experiment lasted about five months, from June to October in 1998. The measured data included mainly the altitude of cross-sections, discharge, sediment concentrations, water levels, and bed material distributions and suspend loads. The length of the concerned reach is about 80 km with sixteen measured cross-sections, including three hydraulic stations at LJ, ZJ and QS cross-sections respectively and three water level stations at YH, YW and XH cross-sections respectively. The reach of dredging channel is between ZJ section and SI section with a distance of 11 km, shown in Fig. 1.

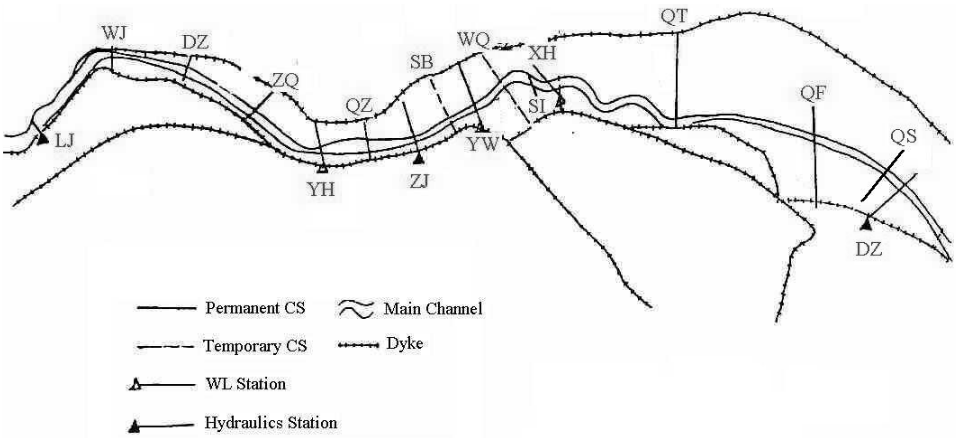

Fig. 1 Sketch of the simulated reach in the Lower Yellow River

2.2.2 Initial conditions

(1) Friction

The friction is very important for numerical calculation. In the Yellow River, the cross section can be divided in a main channel and a flood plain. The same division was made for the friction. But, because the maximum discharge in this simulation wasn't over flood plain, the friction can only be considered in the main channel. The Manning coefficient was used for the compensative friction. In the main channel the Manning coefficient is low and varies between 0.007 and 0.025, and decreases with the increment of flow discharge. In general, when the discharge is larger than 1000 m^3/s, the Minning coefficient would be taken a small value, 0.007.

(2) Diameter of bed material

The grain size is the characteristic dimension of bed material and suspend load. The bed material is the granular material forming river bed. It is characterized by a relative density of sediment and a characteristic grain size. The sediment density has one value for the entire model. The characteristic grain size may be a function of place in a SOBEK model. In SOBEK the following characteristic grain sizes should be entered, such as D_{35}, D_{50}, D_{90} and D_m. In this case, their average diameters are 0.041mm, 0.054mm, 0.086mm and 0.053mm. The grain size of suspend load can not be considered in SOBEK model.

2.2.3 Boundary conditions

(1) Cross section

A cross-section is defined as an input element of SOBEK in which the shape and size of the river profiles perpendicular to the flow is described. The field data of cross section are the relations between the vertical, Z and the lateral, Y. In SOBEK model, these cross sections must be given as the relations between the vertical, Z and the width of cross-section, W. In a cross-section the sediment transport rate is computed and morphological changes are distributed over the sediment transporting width Ws. This width is always smaller or equal to the width of the main channel, and is prescribed by the user. In this case, I assumed these two widths are equal.

(2) Discharge

The discharge is the amount of water passing a grid point per unit of time. It is by default given in [m^3/s]. In this case, the simulated period is from June 3, 1998 to Sept. 25, 1998, and includes three flood peaks. The maximum discharge is about 3060 m^3/s as in Fig. 2. This kind of discharge runs generally in the main channel, not over flood plain.

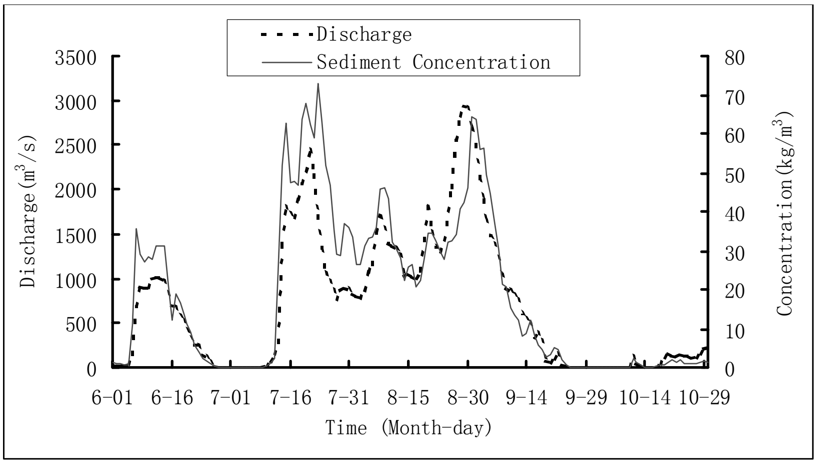

Fig. 2 Relations of discharge and sediment concentration with time at LJ station

(3)Sediment transport

The collected data about sediment transport are some sediment concentrations (see in Fig. 2). In SOBEK model, sediment transport must be offered as the sediment load including pore volume [m^3/s]. The sediment load can be divided into wash load, suspend load and bed load. The wash load can't be included in the user-defined formula. This part of sediment must be deleted. According to our experiences to handle the Yellow River, the sediment to be smaller than five percent in grain size of bed material will be known as wash load. By this ruler, the percent of wash load in suspend load is about forty-five, and the critical diameter is about 0.015mm. The difference of the total sediment load and the bed load (no wash load) can be seen in Fig. 3.

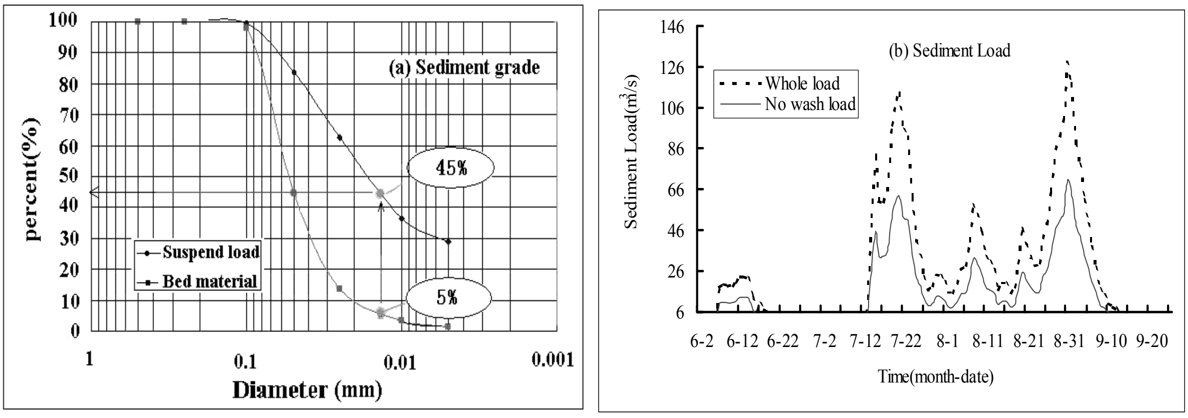

Fig. 3 Criterion to divide out wash load and two kinds of sediment load

(4) Water level

The relation of water level with time has been given at the outlet of simulated reach. Its location is at the QS cross-section.

2.2.4 Time step and space scale

The time step used in this case is five minutes. The flow and the morphological calculation are same step. The grid size was varying from 200 to 500 meters.

3. VERIFIED RESULTS OF SOBEK MODEL

The verification of the model was carried out in two steps. First the flow part was verification, and next, the morphological part was verification. The verified time is over two months, from July 13, 1998 to September 25, 1998. In the simulated period, four peaks of flood can be executed, including two bigger peaks and two smaller peaks. The peak discharges are 2450 m^3/s, 1710 m^3/s, 1810 m^3/s and 2930 m^3/s on July 21, August 8, August 20 and August 30, 1998 respectively. The sediment concentration was relatively low during this flood and the maximum only arrived at 72.9 kg/m^3.

3.1 WATER LEVEL

There are one hydraulic station at LJ cross-section and five stations of water level at YH, ZJ, YW, XH and DZ cross-sections. Because only was one process of discharge at inlet. The process of discharge cannot be verified at simulated reach. But the water level can be verified at difference locations. It can be seen from Fig. 4 that the measured and the calculated water levels can be calibrated well by adjusting the manning coefficient. The difference of the calculated water level at LJ station is worst than others. The maximum error will be near to 0.7 meter at some place, but is still acceptable. The errors of flood peak are smaller.

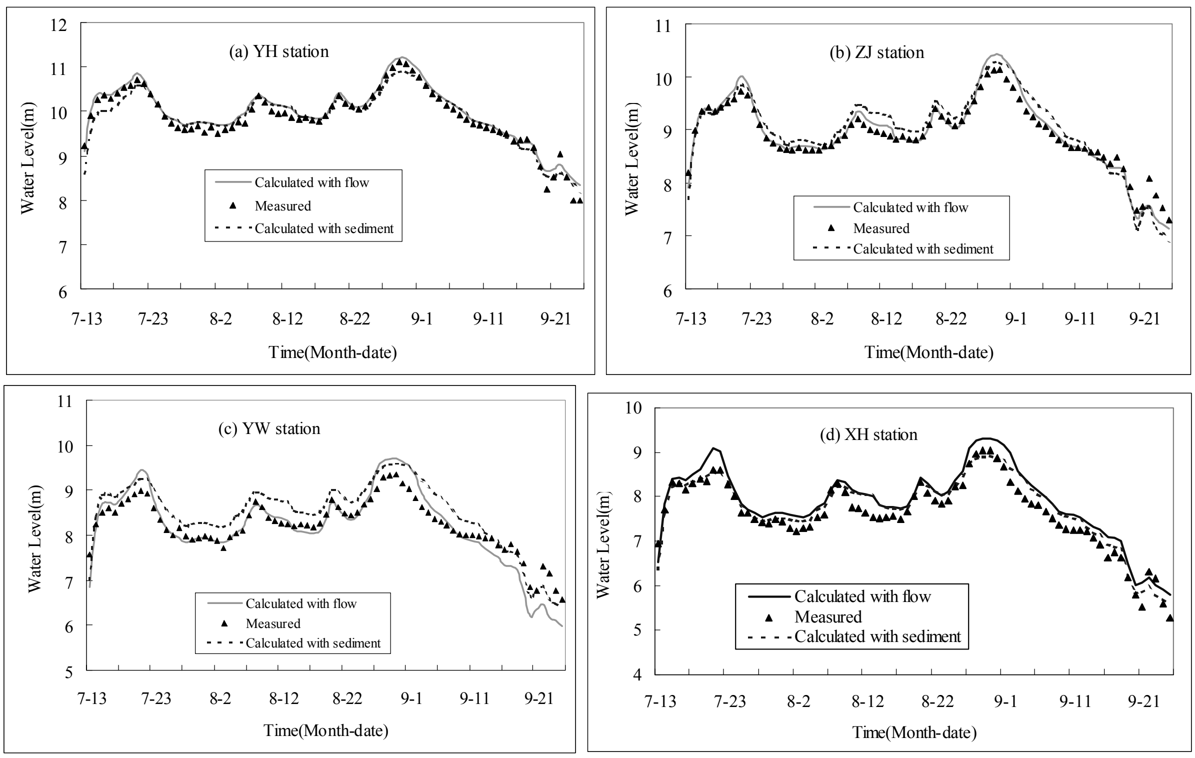

Fig. 4 Verification of water level at different stations

3.2 VOLUME OF SEDIMENTATION

The verification of the morphology included two parts. The one is a distribution of sedimentation along the simulated reach. The other is amount of sedimentation at difference reaches.(1) Distribution of sedimentation.

The bed level change creates a decrease in cross sectional area. With the use of the available data the cross sectional change between June and September 1998 was calculated. The Fig. 5(a) is the verified distribution of sediment deposition. The X – axis indicates the distance along the simulated reach. The Y- axis indicates the decrease area at difference cross-section. It can be seen from the figure that their distributional tendencies of the calculated and the calculated areas of cross-section are near. In order to decrease these calculated errors, we have done our best to adjust these coefficients in the user-defined formula. But these efforts cannot acquire some better outcomes. We think the structure of the formula must be modified. Because their mechanisms of sediment transport for the bed load and the suspend load are difference, and most of sediment transport in the Yellow River are the suspend load. We think the difference formula should be applied for the bed load and the suspend load in SOBEK model.

(2) Amounts of sedimentation at difference reaches

Fig. 5(b) is some amounts of sedimentation at LJ to ZJ, ZJ to SI and SI to QS. They are the upper reach, the reach and the lower reach of dredged channel, respectively. The error in amount of sedimentation is smallest at the upper reach than at the other two reaches, and the percent of error is about 15%. The measured amount of sedimentation in the total simulated reach is about 4.88 millions m^3, and the calculated amount is about 4.54 millions m^3. They are very close.

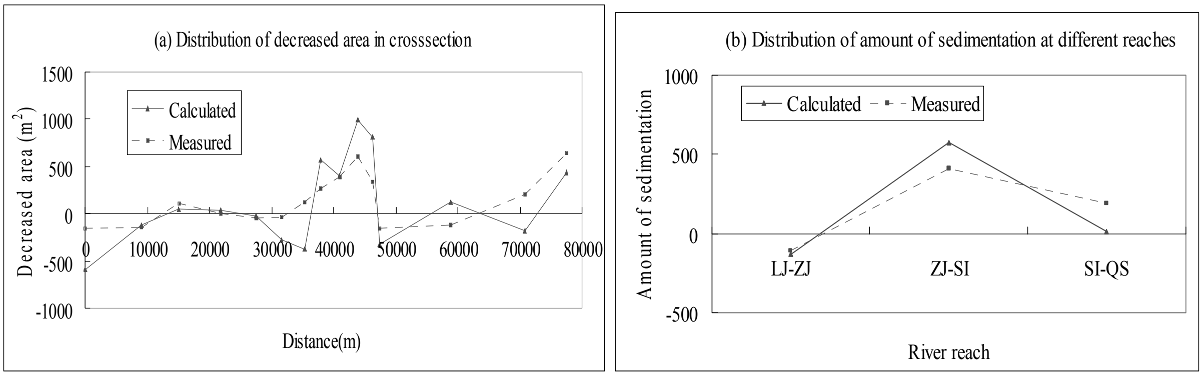

Fig. 5 Verified distribution of decreased area and amount of sedimentation

4. COMPARED WITH OUTCOMES AT DIFFERENT METHODS

Table 1 is some compared outcomes with the upper scouring and deposition rate (SDR), the lower SDR, the fill-in rate and the dredging efficiency at the numerical model, the physical model and the field measure. No dredging influence has been considered when the fill-in, the upper scouring and the depositing volumes are calculated. In the table, the dredging efficiency and the upper SDR of three methods are near. The fill-in rate and the lower SDR of the calculated and the measured methods have some clear differences. The reason is the distribution of sedimentation is not close well at the verification of the SOBEK model. The fill-in rate and the lower SDR of the physical and the measured methods are still near, but these are smaller in the physical model than in the measured method. The reason is too many generalizations at making physical model.

Table 1 Compared with Recovery and Dredging Efficiency at Different Methods

Type	Calculated	Measured	Physical_1	Physical_2

Width of dredged channel (m)	200	200	200	200
Depth of dredged channel (m)	2.5	2.5	2	3
Length of dredged channel (m)	10000	10000	10000	10000
Dredging volume (10^4m^3)	547.00	547.00	335.00	590.00
Fill-in volume (10^4m^3)	870.00	350.82	171.00	255.00
Upper scouring volume (10^4m^3)	174.00	294.38	165.00	201.00
Lower depositing volume (10^4m^3)	-618.00	31.57	9.00	6.00
Upper scouring rate	0.32	0.54	0.49	0.34
Lower depositing rate	-1.13	0.06	0.03	0.01
Fill-in rate	1.59	0.64	0.51	0.43
Dredging efficiency	0.86	0.84	0.96	0.90

5. CONCLUSIONS

1. In this dredging case, the water level and the total amount of sedimentation in the simulated reach have been be verified well, but the distribution of sedimentation at different reaches has been fitted closely, and its precision can not still be applied to the dredging prediction in the Lower Yellow River, but it can improve the precision of sedimentation in some degree to adjust some parameters in the user-defined formula.

2. The numerical mode, the physical scale model and the analysis of field data have been used and compared each other in this case. Compared with the physical model and the field data, the fill-in rate and the dredging efficiency are near, but all of these are smaller in the physical model than in the field data. Compared with the numerical model and the field data, the dredging efficiency is similar, but the fill-in rate exist a large difference.

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