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STUDY ON INTEGRATION OF SEDIMENT DIGITAL SIMULATION AND MATERIAL MODEL AND ITS APPLICATION

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ABSTRACT

Sediment digital simulation and material model test are commonly used in the study of riverbed evolution and river regulation. Due to the differences of boundary conditions, initial conditions and study methods between the two, whichever of the two methods is used, the change and evolution trend of downstream riverbed cannot be reflected completely, especially the impact of a large-scale water resources project on the downstream riverbed evolution. Therefore, on the basis of the study on similarities and differences between the two, this paper puts forward the method to carry out research with the integration of the two methods and its development trend.

1. INTRODUCTION

At present, sediment digital simulation and material model test have become two important methods to predict riverbed evolution and flow and sediment movement pattern, the former is mainly used to tackle one-dimensional problems while the later for three-dimensional problems, for two-dimensional problems, however, both the two methods can be adopted. In practical application, the use of the two methods relate to the importance and study period of engineering. For the impact of a large-scale water resources project on the downstream riverbed evolution, whichever of the two methods is used, the change and evolution trend of downstream riverbed cannot be reflected completely.

Sediment digital simulation study is in the process of continuous development, the study involves two aspects currently: one is sediment discharge formula and resistance formula in basic equations, they are not strictly theoretical formulas but with many empirical factors. This kind of formula is generally suitable for simple situations (namely 1D, steady uniform flow, uniform sediment and equilibrium sediment discharge). Second is, for the conditions of 2D non-uniform flow, unsteady flow, non-uniform sediment and non-equilibrium sediment discharge, what changes will happen for these formulas is not clarified thoroughly yet, it is necessary to carry out many studies so as to make the sediment model accord with actual conditions.

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At present, river sediment model is an important means to study and predict riverbed evolution and flow and sediment movement. Since Louis JeromeFarpe, a French scholar carried out the first river model test in the world in1875, river sediment modeling techniques had developed remarkably. Nowadays, the similarity theory and test technique of river sediment modeling have been perfected gradually. The river sediment model test is based on similarity laws, so appropriate model similarity law shall be selected first when testing according to sediment movement characteristics of prototype river channel in testing. Only thus, the simulation of flow and sediment movement and riverbed evolution can be carried out correctly. But the existing model similarity law does not involve bank simulating similarity conditions, therefore, the change of bank erosion and river pattern can not be reflected, and only scouring and silting of the bed with fixed bank can be simulated. In recent 20 years, for mobile-bed river model test, rich experiences have been accumulated in model design and operation, and the reliability of test results and the technique of measurement and control for test have been improved obviously. The test method of mobile-bed model shall be perfected further. At present, the emphases of research involve: the influence of every kind of distortion on test results, such as geometric distortion, gradient distortion and time distortion; the selection and preparation of light sediment with good quality and its mechanical property.

The common ground of river sediment model test and sediment digital simulation is both of them have a preliminary assumption period, namely, to determine the relationships among each physical factor to be simulated in model. Both of the two methods shall be simplified and approximate, the simplified and approximated model shall conform to the actual conditions of prototype. Suitable empirical coefficients and calibration factors shall be selected for a mathematical model, while the roughness of model shall be calibrated for a physical model. The main difference between the two methods is, the equation describing nodal point or local flow and sediment movement must be established for a numerical model, while for a river sediment model, it is necessary to determine the similarity law of different physical factors by flow and sediment movement equations.

2. INTEGRATION OF SEDIMENT DIGITAL SIMULATION AND MATERIAL MODEL TEST

In previous study on prediction of riverbed evolution and corresponding flow and sediment movement, sediment digital simulation and material model test were used independently. In fact, in study of the impact of a large-scale water resources project on the downstream riverbed evolution, whichever of the two methods is used, the change and evolution trend of downstream riverbed cannot be reflected completely, so it is necessary to carry out research with the integration of the two methods to supplement each other. At present, a 1D mathematic model of long river reach provides boundary conditions for a 2D physical model or a mathematic model of short river reach in this long river reach, this kind of integration can avoid great investment in making physical model or mathematical model of long river reach. At the same time, the immovable bed model of complicated boundary conditions can provide complicated flow field data, which will be used for the calculation of river scour and silting, this kind of integration can avoid great investment in making a movable-bed physical model. In general, the two methods infiltrate each other as research methods. The hybrid model integrating the two models can solve the problems that are difficult to be solved or cannot be solved by a single model.

3. APPLICATION OF INTEGRATION OF SEDIMENT DIGITAL SIMULATION AND MATERIAL MODEL TEST

In the study on the change of navigation conditions in the key channel reach between Zhicheng and Qixingtai (downstream of the Three Gorges Dam) after the completion of TGP, the integrated method of sediment digital simulation and material model test is used. In the hybrid model, the collection and analysis of prototype observation data are the basis; the 1D long river channel mathematical model provides the boundary conditions of entrance and exit for other models; the 2D mathematical model reveals the problem of blocking in navigation by critical shoals to select the optimal river regulation scheme; the material model test mainly reveals the evolution of shoals for the arrangement of regulation works. The research results have provided scientific basis for navigation channel regulation of this channel. In the hybrid model, the calculation range of 1D long river channel mathematical model is from Yichang to Datong with division sections of 820 and the length of 1120km, and the calculation time is 100 years after the operation of TGP; for the 2D sediment mathematical model test, the calculation range is from Jing 3 # section 67km from Yichang to Jing 21# section 119km away, with the division nodal points of nearly 20000, the length of 52km and the calculation time of 20 years; for material model test, the research range is from Jing 3# section 67km from Yichang to Jing 13# section 84km away, with the length of 17km, the horizontal scale of 400, vertical scale of 100, and the test time of 10 years(see Fig. 1)

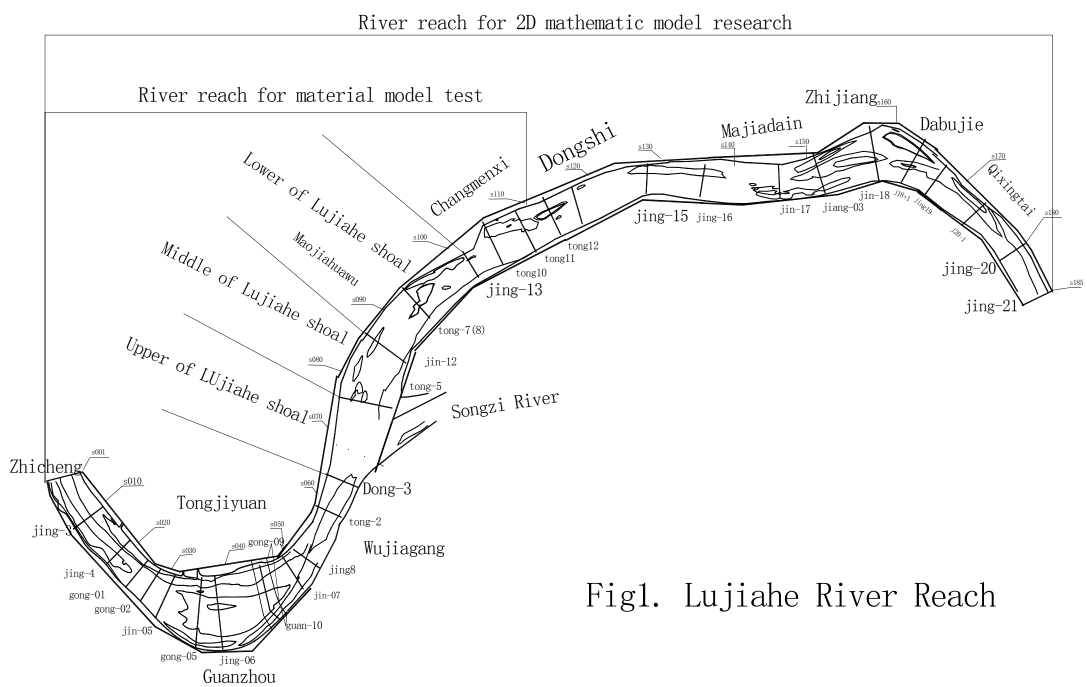

Fig1. Lujiahe River Reach

The reach from Zhicheng to Qixingtai in the Middle Changjiang River is 52km long, located in upland and borderland of upland and plain. A distributary flows into Dongting Lake from Songzikou. The reach upstream of Songzikou belongs to hill section, the reach downstream of Songzikou is flat-land section. The channel is a slightly curved and braided channel and is the same in width, where there are 3 braided reaches such as Guanzhou, Zhijiang and Jiangkou. Lujiahe shoal is located 12km downstream from Zhijiang, where the bank erosion-resistance capacity is strong, there is no obvious lateral deformation happens for many years, vertical scour and silting is the expression of riverbed evolution, and in natural conditions, the rule of “silting when the water lever rising and scour when falling” represents in a year. Due to the differences of bed configuration and boundary conditions, the deep channel undulates greatly.

Due to the complicated boundary from Zhicheng to Qixingtai, it is necessary to use several research methods so as to reflect the riverbed variation processes and law, especially the change of navigation conditions after the completion of TGP. With the two research methods, the channel variation process and trend is identical through the analysis of scouring and silting capacity and variation process. For example, the results of river sediment model test show that, 9,841,900m^3 sediment is scoured in Lujiahe Shoal section in 3 years after operation of TGP reservoir, and 19,088,400m^3 in 7 years; from the distribution of progressive scour, the maximum is in the middle and upper part of the shoal, the second in the tail, and the minimum in the entrance and exit with uniform distribution. After execution of regulation works, the scouring capacity is reduced in shoal section, 8,680,800m^3 sediment is scoured in Lujiahe Shoal section in 3 years after operation of TGP reservoir, and 18,365,700m^3 in 7 years. While the calculation results of 2D mathematical model show that, 12,910,000m^3 sediment is scoured in Lujiahe Shoal section in 3 years after operation of TGP reservoir, and 32,100,000m^3 in 7 years. After execution of regulation works, the scouring capacity is reduced in shoal section, 12,230,000m^3 sediment is scoured in Lujiahe Shoal section in 3 years after operation of TGP reservoir, and 26,850,000m^3 in 7 years.

With the two research methods, the gradient variation process and trend is identical through the analysis of gradient variation process of representative flow in this reach. For example, the test results of river sediment model show that, during operation of TGP according to 156m scheme and without regulation works, when the low-water discharge Q=4854 m3/s, the surface gradient of the upper of Lujiahe shoal (3827m) is about $0.88^{0}/_{000}$ ~$3.30^{0}/_{000}$, and the surface gradient of the middle of Lujiahe shoal (2714m) reaches to $3.30^{0}/_{000}$. After implementation of regulation works, when the low-water discharge Q=4856 m3/s, the surface gradient of the upper of Lujiahe shoal (3827m) is about $0.81^{0}/_{000}$ ~$2.37^{0}/_{000}$, and the surface gradient of the middle of Lujiahe shoal (2714m) reaches to $2.37^{0}/_{000}$. In flood seasons, the surface gradient does not change greatly with or without regulation works, when discharge Q=35000m^3/s, the variation range of surface gradient is about $0.37^{0}/_{000}$ ~$1.89^{0}/_{000}$ without regulation works, and $0.33^{0}/_{000}$ ~$1.34^{0}/_{000}$ with regulation works.

The calculation results of 2D mathematical model show that, during operation of TGP according to 156m scheme and without regulation works, when the low-water discharge Q=5000 m^3/s, the surface gradient of the upper of Lujiahe shoal (3827m) is about $0.75^{0}/_{000}$—$1.663^{0}/_{000}$ and the surface gradient of the middle of Lujiahe shoal (2714m) reaches $4.737^{0}/_{000}$. After implementation of regulation works, when the low-water discharge Q=5000 m^3/s, the surface gradient of the upper of Lujiahe shoal (3827m) is about $0.75^{0}/_{000}$ ~$1.098^{0}/_{000}$, and the surface gradient of the middle of Lujiahe shoal (2714m) reaches $4.075^{0}/_{000}$. In flood seasons, the surface gradient does not change greatly with or without regulation works, when discharge Q=35000m^3/s, the variation range of surface gradient is about $0.29^{0}/_{000}$—$0.61^{0}/_{000}$ without regulation works, and $0.28^{0}/_{000}$—$0.32^{0}/_{000}$ with regulation works.

Through analysis of the change of navigation conditions in the key channel reach from Zhicheng to Qixingtai (downstream of the Three Gorges Dam) after completion of TGP and the effects of engineering measures with the hybrid model, it is found that the same cognition can be gained with two different research methods. Therefore, the integrated model can solve the problems that are difficult to be solved or cannot be solved by a single model, and play the role of compensation and verification each other.

4. TREND OF INTEGRATION OF SEDIMENT DIGITAL SIMULATION AND MATERIAL MODEL TEST

The sediment digital simulation and material model test used in different reaches or the same reach will supplement each other. But the present integration only involves providing information each other on boundary conditions of entrance and exit, the coupling of the two has not been studied. In order to well simulate and reflect the riverbed evolution and flow and sediment movement, further study shall be carried out in the way of coupling of the two methods, which can begin with technical methods and corresponding parameters of the coupling, and then combine the study on measurement and control techniques of material model test, such as the coupling method of bed variation data, the integration and system analysis of sediment content, flow velocity, flow pattern and stage fluctuation, to make the integration of sediment digital simulation and material model more reliable in theory and systematic.

In addition, corresponding research on coupling of sediment digital simulation results and material model test results shall be carried out to improve the ability of predicting and analyzing riverbed evolution.

5. CONCLUSIONS

Sediment digital simulation and material model test are commonly used in the study of riverbed evolution and river regulation. Due to the differences of boundary conditions, initial conditions and study methods between the two, whichever of the two methods is used, the change and evolution trend of riverbed cannot be reflected completely, especially the impact of a large-scale water resources project on the downstream riverbed evolution. Therefore, the integration of the two models can solve the problems that are difficult to be solved or cannot be solved by a single model.

In order to well simulate and reflect the riverbed evolution and flow and sediment movement, further study shall be carried out in the way of coupling of the two methods, which can begin with technical methods and corresponding parameters of the coupling, and then combine the study on measurement and control techniques of material model test, to make the integration of sediment digital simulation and material model more reliable in theory and systematic.

The research of techniques and corresponding parameters of coupling the two models will be the important orientation of riverbed evolution research.

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