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中文题名	悬移质泥沙输移的大涡模拟研究
英文题名	Large Eddy Simulation of Flow and Suspended Sediment Transport
中文关键词	大涡模拟,悬移质泥沙,丁坝绕流,净淤积,净冲刷
英文关键词	large eddy simulation,suspended sediment,groin flow,net deposition,net erosion
中文文摘	紊流在实验室试验水槽和自然河道中普遍存在。紊流中存在着涡系，对泥沙起动和输移有重要的影响，而传统的雷诺时均模型只能给出时均条件下流速和泥沙浓度分布，不能反映瞬时流动特性以及瞬时流动对泥沙输移的影响，因此需要研究更加精细的模拟技术。随着计算机计算速度和存储能力的提高，大涡模拟技术得到了迅速发展，大涡模型可以计算得出水流和泥沙输运的瞬时规律。本文建立了悬移质泥沙输移的大涡模型及边界条件。在大涡模拟中，通过过滤将水沙模型中的变量分解成大尺度量和亚格子量，直接求解大尺度量，引入亚格子应力模型模拟小尺度量。在程序中，基于有限体积法对控制方程进行离散，变量布置在非交错曲线网格上，采用中心差分近似扩散通量，分别采用中心差分和 HLPA 格式近似水流和泥沙计算中的对流通量，时间推进利用低存储的三步 Runge-Kutta 法。在 Runge-Kutta 法的第 3 步，采用 SIP 方法求解压强修正方程。针对复杂的几何边界问题，本文构建了基于直接强迫力法的浸没边界法，用于模拟复杂边界下的大涡模拟流动；采用直槽流动、方腔流动和丁坝绕流检验了流速分布、紊动强度分布、涡系分布和切应力分布；分析了丁坝绕流中丁坝长度 L、丁坝长度与丁坝距离的比值 L/D 对流速分布、回流区的流动形式、紊动强度分布、涡量分布及涡系结构分布的影响，并研究了涡体的发展变化过程。针对自然条件的泥沙床面，建立了粗糙边界处理方法和悬沙计算模式；采用经典的净淤积试验对沿程的流速分布和泥沙浓度分布进行验证，获得与实测数据符合较好的结果；引入不同的对比算例，分析了水流的宽深比 B/H 对横断面上二次流动和涡体结构的影响，讨论了宽深比 B/H 和二次流动对主流流速、紊动强度和切应力在横断面上分布的影响，并研究了宽深比 B/H 和二次流动对泥沙浓度在横断面上的分布以及沿程沉积率的影响。针对悬移质泥沙输移的三维特性，建立了悬移质泥沙计算中含有恢复饱和系数的近底部边界条件，用于研究细颗粒悬移质泥沙起动与输移的特性；采用直接模拟结果和 Rouse 公式分别检验了直槽中的流速分布和泥沙浓度分布；采用循环算例和长槽道算例分析了冲刷平衡的条件下和净冲刷条件下的流速、紊动强度、切应力的分布、泥沙浓度以及垂向泥沙紊动通量的分布，讨论了瞬时流动结构对瞬时泥沙浓度分布的影响，以及猝发与扫射对泥沙浓度分布的影响，给出了紊动扩散系数和 Schmidt 数的分布，并探讨了近底部泥沙紊动通量的概率分布。
外文文摘	Turbulence is very common both in laboratory channels and natural rivers. Vortices exist in turbulence and have an important impact on sediment transport. RANS is widely used in numerical simulations of engineering. It can only give time-averaged velocity and sediment concentration, and could not reflect the effects of unsteadiness and turbulence anisotropy on sediment transport. So it needs to introduce some advanced simulation techniques. With the advances in computer capabilities and LES, LES becomes popular in the simulation of water flow and sediment transport, and it can give the instant distributions of water flow and sediment transport. A LES model, calculating water flow and suspended sediment transport under the conditions of complex topography, has been set up in the thesis. As for the simulations under complex boundaries, an immersed boundary module based on the direct forcing method is introduced into the LES model. Firstly the model is calibrated using channel flow, duct flow and groin flow. And accurate results are obtained including distributions of velocities, turbulence intensities, vortices and shear stresses. A series of cases for flow past rounded-head groins are set up to investigate flow characteristics, involving flow patterns, turbulent intensities, vorticity distribution and vortex dynamics. Groin aspect ratio L/D and groin length L are defined to study the impact of groin parameters on the flow properties. As for natural boundary in the channel, a module dealing with rough boundary and a module of suspended sediment calculation are added into the LES model, in order to study the impact of the secondary flow on the deposition and transport of fine sediment in rough channel flow. After validating the model use a classic

	experiment of net deposition, different cases are set up to explore the effect of the width to depth ratio B/H on secondary flow and vortex structures at the cross sections. The influences of the secondary flow on flow properties like the mainstream velocities, turbulence intensities and shear stress distribution at the cross section, are discussed. The results of the distribution of sediment concentration at the cross sections and deposition ratio along the channel are also studied.As for the 3D characteristics of suspended sediment transport, a boundary with a restoring saturation coefficient near the bottom is presented, to study the characteristics of fine sediment entrainment and transport in channel flow. The velocities and sediment concentration are validated by DNS and Rouse equations separately. A case with cyclic boundary and a long case with inlet-outlet boundary are calculated to study the flow and fine sediment transport in the equilibrium and net-erosion conditions. The results are given out such as velocities, turbulence intensities, the distribution of shear stresses, sediment concentration, as well as turbulence flux of sediment. The strong relations between instantaneous flow and sediment concentration, and contribution of bursts and sweeps are analyzed through statistics. According to the study, turbulent Schmidt number is not constant along the vertical direction. The turbulence flux of sediment near the bottom is discussed at the end.
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