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中文题名	推移质输移的大涡模拟研究
英文题名	Large Eddy Simulation of Bedload Transport
中文关键词	大涡模拟,推移质输移,形状因子,床面粗糙度,自由水面
英文关键词	Large eddy simulation, Bedload transport, Shape factor, Bed roughness, Free water surface
中文文摘	天然河流中，推移质运动在全沙输移和河床变形中起着重要作用，并对污染物或营养物质的输移、动植物生存分布的栖息地环境有重要影响。因而探究推移质与水流、河床相互作用下的输移规律对提高推移质输沙率的预测精度，掌握河流演变过程具有重要的科学意义和工程价值。随着超算技术的快速发展，各类流体力学计算模型得以广泛运用。大涡模拟技术是求解计算 N-S 方程的一种有效方法，较好地平衡了计算精度和计算效率关系，适用于天然河流紊流条件下推移质颗粒输移的模拟研究。本文基于模拟湍流运动的大涡模拟模型，结合欧拉-拉格朗日点颗粒方法，开发了水沙双向耦合的颗粒平移、旋转及碰撞的推移质输移模式；发展了粗糙度闭合模型、浸没边界模型及水平集模型等边界设置模型，构建了适用于复杂边界条件的推移质输移计算方法。研究了颗粒形状、床面粗糙度、涡结构和自由水面等四类影响因素对推移质输移的影响。研究表明：（1）颗粒形状会改变推移质跃移参数特征，进而影响推移质输沙率。扁椭球体、长椭球体颗粒的跃移长度和高度比球体颗粒大；跃移速度随椭球比的增加单调减少；在 Meyer-Peter-Müller 经典输沙率公式的基础上，拟合得到考虑颗粒形状因子的推移质输沙率修正公式。（2）随着床面粗糙度的增加，推移质颗粒停留时间增大，跃移长度、速度和旋转速度减小，跃移高度无明显变化。光滑床面上跃移高度、长度、旋转速度和停留时间的概率密度分布分别服从线性、伽马、正态和指数分布，随床面粗糙度的增加曲线的峰度和偏度发生变化，跃移速度由对称的正态分布转变为非对称的伽马分布。推移质输沙率与粗糙度雷诺数呈负相关关系。（3）推移质输移塑造床面沙波形态，输沙率受近床湍流涡结构影响，水流涡团运动可分解为旋转项、变形项和平移项三项组成，随水流强度的增加，旋转项、变形项和平移项均值增大，推移质输沙率随之增大。（4）高水流强度下，水流在沙波床面背水面发生流体分离并出现回流区，流体分离层内脉动流速增强、雷诺切应力增大，由此自由水面波动增强，水面形态更加复杂。
外文文摘	In natural rivers, bedload transport plays an important role in the total sediment transport and bed formation. It also has a significant impact on pollutants or nutrients transport and habitat environment for the survival and distribution of animals and plants. Therefore, exploring the bedload transport with the interaction between flow and riverbed is of scientific and engineering significance in improving the prediction accuracy of bedload transport rate and mastering the process of river evolution. With the rapid development of supercomputing technology, models of computational fluid dynamics have been widely used. The large eddy simulation is an effective method for solving N-S equation, which better balances the calculation accuracy and efficiency, and is suitable for the simulation of bedload particle transport in natural turbulent flow.In this paper, a two-way coupling bedload transport model including particle translation, rotation and collision is established based on the large eddy simulation model and the Euler-Lagrangian point particle method. The boundary setting models such as roughness closure method, immersed boundary method and level set method are developed, and the computational method of bedload transport suitable for complex boundary conditions is constructed. Then, the effects of four factors, such as particle shape, bed roughness, vortex structure and free water surface, on bedload transport are studied.It is found in the research that: (1) the shape of bedload particles changes the characteristics of bedload saltation parameters, and then affect the bedload transport rate. The saltation length and height

	of oblate-spheroid and prolate-spheroid particles are larger than that of sphere particles, and the saltation velocity decreases monotonously with the increase of ellipsoid ratio. On the basis classical formula of Meyer-Peter and Müller, the modified formula of bedload transport rate considering particle shape factors is proposed by fitting. (2) With the increase of bed roughness, the resting time of bedload particles increases, and the saltation length, velocity and angular velocity decrease, but the saltation height has no obvious change. The probability density distributions of saltation height, length, angular velocity and resting time for smooth bed case obey linear, gamma, normal and exponential distribution, respectively. With the increase of bed roughness, the kurtosis and skewness of the curve change, and the saltation velocity transforms from symmetrical normal distribution to asymmetric gamma distribution. In addition, there is a negative correlation between bedload transport rate and roughness Reynolds number. (3) Bedload transport shapes the bed morphology, and the transport rate is affected by the vortex structure of the near-bed turbulence. The vortex is composed of terms of rotation, deformation and translation. The mean values of rotation, deformation and translation term increase with the increase of flow intensity. And the bedload transport rate increases with the increase of flow intensity as well. (4) Under the circumstance of high flow intensity, the fluid separation occurs on the leeside of dunes and the recirculation zone forms. The velocity fluctuation and the Reynolds shear stress increase in the fluid separated shear layer. Hence, the fluctuation of the free water surface is enhanced and the shape of it becomes more complex.
答辩日期	2021.12.06