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中文题名	不同床面形态泥沙输移的大涡模拟研究
英文题名	Large eddy simulation of sediment transport on different river bed morphologies
中文关键词	大涡模拟,床面结构,泥沙输移,卵石床面,三维沙波
英文关键词	Large eddy simulation, Bed form,Sediment transport, Wall-mounted boulder, Three dimensional sediment dune
中文文摘	天然河流的河床往往由各种各样的床面形态组成。如山区河流中，河床底质主要为卵砾石，床面形态表现为由大卵石组成的满天星式床面结构和阶梯-深滩床面结构。而在平原河流中，河床底质主要为沙质，床面形态的表现形式主要为凹凸不平的粗糙床面和具有沙波形态的沙波床面。床面形态对于近床的水流流速、流速脉动以及涡结构均有较大的影响，进而会影响由水流条件控制的床面泥沙运动。全面、精确掌握各种床面形态上泥沙的输移过程，对于河流稳定性、生物多样性、航运安全性以及水工建筑物安全性至关重要。本文基于已有的大涡模拟计算框架，开发了推移质输移模型、悬移质输移模型和河床变形模型，对山区河流段卵石床面水流结构、推移质输移进行了模拟，对平原河流段沙质床面悬移质输移、床面形态演变过程进行了模拟，揭示了回流区等空间因素以及床面紊动事件、涡结构等时间变量对于泥沙输移和沙波形成的影响机理。在卵砾石床面泥沙输移方面。首先通过大涡模拟水动力计算模型，展现了山区河流卵石床面复杂流动的三维性。研究表明卵石阻碍近床流速，形成回流区，造成床面切应力的不均匀分布；产生频率不相同的顶部发卡涡和底部间隙涡两种涡结构，影响近床水流脉动；增加透水床面与主槽中的水流交换，进而增强下游横向二次流，影响下游的平均流场、涡结构输移。其次通过大涡模拟推移质计算模型，研究了卵石引起的局部推移质输移现象。结果表明，卵石四周推移质输移率变化较大。以近床流速作为推移质输移的控制因素，卵石四周推移质输移可分为回流减弱区及侧面增强区；以床面切应力作为推移质输移的控制因素，卵石四周推移质输移可分为回流减弱区、上游增强区、侧面增强区以及间隙涡增强区；以喷射周期作为推移质输移的控制因素，卵石下游的推移质输移则会被大大抑制。在沙质床面泥沙输移方面。首先通过大涡模拟悬移质计算模型，研究了悬移质泥沙的净冲刷和长距离输移过程。发现在泥沙起悬的过程中，局部粗糙高度、垂向流速和沿流向涡结构起到较为重要的作用。此后研究了宽深比对于泥沙起悬的影响，发现宽深比不同，平均流速分布、二次流分布以及切应力分布均会受到影响，泥沙的起悬量随宽深比降低而增加。其次通过大涡模拟河床变形模型，重演了三维沙波的发展过程。提出了微沙纹形成的三个时间过程，揭示了近床水流在其中起到的关键作用，重演了局部沙波形成过程中的展向延伸和纵向衍生现象。
外文文摘	Natural river beds are usually consisted of variaties of bedforms. In the mountainous streams, boulders and gravels with diameter scaling from centemeters to meters cover river beds. Big boulders of different arrange types could form several boulder bedforms, such as boulder arrays and step-pools. While in the alluvial rivers, bed materials are non-uniform sand with diameter ranging between centemeters and millimetres. The river beds are presented either in rough-flat shape or in three dimensional sediment dunes. The presence of bedforms could greatly influence mean flow fields, turubulent intensities and vortex structures near beds, thus affecting sediment transport process on these bedforms. It is found that sediment transport process on bedforms plays an important role in river stability, river biodiversity, shipping security and security of hydraulic structures. However several important issues of sediment transport process on river bedforms still remains unknown, such as the relationship between sediment transport and flow conditions, spacital variety of sediment transport on bedforms and the mechanics in forming three dimensional sediment dunes. In this paper, we conducted several large eddy simulations to study the issues aforementioned.We develope a large eddy simulation model to calculate bedload transport, suspended sediment transport and bed morphology change on bedforms. A well-development in-house LES code, Hydro3D, is used to simulate turbulent flow over bedforms. Bedload transport model, suspended sediment transport model and bed morphology change model are embedded by the current author. We then apply this code on turbulent flows over boulder-array bedforms, rough-flat river beds and three dimensional sediment

	dune bedforms and further study sediment transport process on these bedforms. The results show that sediment transport process is affected both by spacial variables, such as wake-zone, boulder spacing and ratio of width to depth, and time variables, such as instantaneous velocities, turbulent events and vortex structures. Our results show that flow over boulder-array bedforms is strongly turbulent. Boulders cause flow decelaration around boulders, form wakes downstream and redistribute bed stresses. Two kinds of vortices with different frequence, hairpin vortices and gap vortices, are generated by the boulder edge and gaps between boulders and gravels respectively. The fluid exchange between porous bed and the main channel enhanced secondary flow in the spanwise direction. We further calculate bedload transport rate among boulder array beds. The results show great spacial variety near boulders. Based on near bed velocities, a wake-zone low bedload transport region and a boulder-side high bedload transport region are predicted. Based on bed shear stresses, a wake-zone low bedload transport region, a boulder-side high bedload transport region, a boulder-upstream high bedload transport region and a gap vortex high transport region are predicted. Based on near bed turbulent events, the bedload transport rate is stongly suppressed downstream of the boulder. In terms of flow and suspended sediment transport over flat rough beds, our results show that suspended sediment transport is mainly controlled by local roughness height, vertical velocities and elongated vortices. Ratios of width to depth also influence suspended sediment transport via affecting mean flow velocity, secondary flow and Reynolds shear stresses. We successfully simulated the forming process of three dimensional sediment dunes from flat beds. We found that minor sand waves are formed by three steps, local defects formed by high instantaneous velocity, local defects merged together within the region of low instantaneous velocity and formation of wake flow. After minro sand wave forms, these sand waves merge in the streamwise direction and extend in the spanwise direction. And three dimensional sediment dunes are results of this merging and extending processes.
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