作者	程伟
中文题名	生物膜泥沙床面阻力和紊动特性的实验研究
英文题名	Experiment of Bed Resistance and Turbulent Characteristics above biofilm-coated Bed
中文关键词	生物膜,床面形态,阻力,紊动特性
英文关键词	biofilms,bedform, bed resistance, turbulent characteristics
中文文摘	近年来我国由于水体富营养化引起的环境问题日益突出。水体富营养化为水体中各类微生物的生长和繁殖提供了丰富的物质基础。自然界中大部分微生物附着于海洋、河流和湖泊等各类湿地环境的固体物质表面，以生物膜聚集体的形式存在。泥沙作为河流湖泊的边界组成物质，为微生物的附着和生长提供了良好的基底条件。生物膜在泥沙床面上的生长将改变泥沙颗粒和群体的几何特征以及生物化学等内在性质，如床面泥沙干湿容重、颗粒的表面形貌和吸附特性等。也会改变水流作用下的泥沙侵蚀、起动和沉降等运动特征，从而改变泥沙的输移规律和环境效应。因此研究新环境条件下泥沙的输移特征，不仅拓展了传统的泥沙理论研究范围，还促进了泥沙与环境学科的交叉。本文中采用水槽实验研究的方法，对生物膜泥沙床面形态与阻力和生物膜泥沙床面上水流的紊动特征两个问题开展了研究，并讨论了水体紊动特征变化对生物泥沙输移的影响。研究首先通过水槽试验，得到了不同工况条件下长膜泥沙床面形态和尺度以及与之对应的水流泥沙条件，然后借鉴非黏性沙的研究方法对生物膜泥沙床面的形态进行分类，建立了生物膜泥沙床面尺度与水流泥沙条件之间的关系。同时还建立生物膜泥沙床面水力粗糙度与床面沙波尺度的关系，进而提出了计算生物膜泥沙床面阻力的方法。结果表明生物膜在泥沙床面上生长后，相同水流条件下的床面沙波尺度和阻力均减小。针对生物膜泥沙床面水流紊动特性的变化，通过实验对比了相同水流条件下，生物膜泥沙与干净沙床面垂线上纵向时均流速分布、雷诺应力分布、紊动强度分布、紊动能通量分布、紊动能平衡关系以及紊动猝发事件的变化等。结果表明，床面生物膜生长后垂向上纵向时均流速增大，紊动特征向着不利于泥沙起动和悬浮的方向变化。另外通过对比分析，研究了生物膜生长后垂向上相对和绝对悬沙浓度分布的变化规律，床面上上扬通量的变化以及垂向紊动扩散的变化对悬沙的影响。结果表明生物膜生长后，受生物膜影响的泥沙浓度分布向底部集中，相同水流条件下，底部浓度相对和绝对值均有较大增加，上扬通量在水流强度较小时比干净沙小，但超过一定的水流强度后将比干净沙上扬通量增大 1 倍；生物膜的生长使得相同水流条件下，床面上垂向紊动扩散系数的变化进一步加剧了浓度向底部集中的趋势。
外文文摘	Water eutrophication in China has caused severe environmental problems and has been given more and more attention in recent years, which provides adequate nutrients for the reproduction and growth of the microorganisms in the water column. In natural environment, vast majority of microorganisms are living as aggregates, called biofilms, forming on the solid-water surfaces in marine, rivers, lakes and wetlands. Sediments consisted of the boundary of rivers and lakes provide excellent substrata for the attachment and growth of microorganisms. Biofilms growing on the sediment bed will change the geometrical, physical and bio-chemical properties of the sediment mixture and single particles, such as the wet and dry bulk density, the microtopography of the particle surface and the adsorption characteristics. Furthermore, the characteritics of the sediment erosion modes, erosion threshod and settling will be changed under a given flow condition. Thus the characteristics of sediment transport and its environment effect will be quite different from that of sediment bed without biofilm. Therefore the study on the bio-sediment under the current environment situation will not only expand the research of traditional sediment theory, but enhance the interdisciplinary study of hydraulic engineering and environmental science. In this study, flume experiments were conducted in the laboratory to study (1) the bedform characteristics and bed resistance of the bio-sediment bed and (2) turbulent characteristics of the flow on the bio-sediment bed and the effect of the changing turbulent structure, comparing with the identical flow condtition on the sediment bed without biofilm, on the sediment concentration near the bed and suspended sediment distribution along water depth. Aiming the first problem, experiments were done to obtain the bedforms, its dimenions and the corresponding flow conditions. Then the method from

	the tradition sediment study for noncohesive sediment was adopted and classified the bedforms of bio-sediment bed as dunes. The relationship between the dimension of the bedform and flow condition has been established empirically according to the experiment data. Moreover, the relationship between the hydraulic roughness and dimensions of the bedform has been proposed, and the further proposed was the method to predict the bed resistance. Results show that dimensions of the bedform and bed resistance are reduced by the biofilm, comparing with that of nocohesive sediment bed without biofilm under an identical flow condition.Aiming the second problem, experiments were conducted to compare flow properties on bio-sediment bed with that of clean sediment bed, which including the distribution of time average velocity, Reynolds shear stress, turbulent intensity and turbulent kinetic energy flux, the balance of the turbulent energy and the change of turbulent bursting events. Results show that the time average velocity increases as the biofilms grow on the bed and the change of turbulent chacteristics inhibit the sediment entrainment and suspension of the sediment particles or flocs. Futher anlysis on the distribution of suspended sediment concentration, entrainment of the sediment flux and vertical diffusion coefficient indicates that, after biofilms growing on the bed bio-sediment particles or flocs assemble towards the bottom and thus increasing the sediment concentration near the bed, entrainment flux for bio-sediment is less than clean sediment when the flow power is low, however up a certain level the entrainment flux for bio-sediment increases to be towfold that of clean sediment. Finally, the change of vertical diffusion coefficient enhances assemble of bio-sediment towards the bottom.
答辩日期	2016.12.16