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中文题名	水流与柔性植被相互作用机理及模拟分析
英文题名	Mechanism and Simulation Analysis of Interaction Between Submerged Flexible Vegetation and Water Flow
中文关键词	沉水柔性植被,大涡模拟,湍流,相干波动,标量传输
英文关键词	Submerged flexible vegetation, Large-eddy simulation, Turbulent structure, Coherent waving motion, Scalar transfer
中文文摘	沉水植被是水生生态系统中重要组成部分，会显著改变水流流速的垂向分布，在植被冠层附近诱导形成复杂的涡结构，加剧植被内部和上覆水流的物质、动量交换，为水生生物提供栖息地、食物等。研究水流与柔性植被相互作用机理是认识水生生态系统物质、能量传输规律重要的基础性工作，对于水生生态系统的修复与管理也具有重要意义。本文利用大涡模拟和浸没边界法，建立了三维全自由度的高度柔性沉水植被-水流相互作用模型，主要解决了数值模拟中水流和大变形、复杂形状植被耦合的困难。通过对不同水流条件、植被分布密度、相对浸没深度等条件下，水流的流速分布、湍流结构、植被运动、标量输移的数值模拟，研究水流-植被相互作用的物理机理、植被的相干波动和标量的输移规律。在湿地和河道的边滩等水深较浅、流速较低的水域，大多存在小规模沉水植被群，即植被斑块。本文研究了沉水植被斑块与水流相互作用的规律和物理机理，并分析了水流-植被相互作用，结果表明：与刚性植被相比，柔性植被的倾斜不会显著改变植被冠层内外的速度差和湍动能量级，但会减弱对水流的扰动，从而减小阻力。植被的摆动则会显著增加冠层内外的流速差。形成 Kelvin－Helmholz-发夹涡结构，加剧湍流强度，从而增强了对水流的扰动和阻力。在单向恒定来流的条件下，沉水植被阵列的冠层高度处的 Kelvin－Helmholz 不稳定性会导致植被冠层做周期性的相干波动运动。本文研究了沉水植被阵列相干波动的周期性规律及影响因素。结果表明，流速的增大会使植被相干波动的波长减小，频率和幅值增大；植被分布密度的增大会使运动的波长和振幅减小，频率增大。当植被处于浅淹没范围内时，改变相对浸没深度对相干波动周期性影响不大。由于植被的存在和运动会显著改变水流的湍流强度，因此水流中的标量传输对植被的运动十分敏感。本文以溶解氧为例，研究植被的存在和摆动对标量传输和扩散的影响。结果表明：刚性植被尾流和冠层附近的小尺度 K－H 涡是湍流强度增强、标量湍流扩散强度增加的主要原因。柔性植被的摆动在冠层附近诱发了大规模的 K－H 涡，导致湍流强度显著增加。植被的摆动增加了各深度处的标量浓度，同时增加了标量的湍流扩散强度。
外文文摘	Submerged vegetation is an important part of the aquatic ecosystem. The presence of submerged vegetation can significantly change the vertical distribution of flow velocity, induce complex vortex structures near the vegetation canopy, intensify the mass and momentum exchange between inside and outside the vegetation canopy, and provide habitat and food for aquatic organisms. Studying the interaction mechanism between water flow and flexible vegetation is an important basic work to understand the law of mass and energy transport in the aquatic ecosystem, and is also of great significance for the restoration and management of the aquatic ecosystem.In this paper, large eddy simulation and immersed boundary method were used to establish a three-dimensional full-freedom highly flexible submerged vegetation-flow interaction model, which mainly solves the difficulty of coupling water flow with vegetation that has large deformation and complex shape in numerical simulation. Through numerical simulation of flow velocity distribution, turbulent structure, vegetation movement, and scalar transport under different flow conditions, vegetation distribution density and relative submergence depth, the physical mechanism of flow-vegetation interaction, the coherent waving motion of vegetation and the characteristics of scalar transport in the vegetated flow are studied.In water bodies with shallow water depth and lo

	w flow velocities such as wetlands and shoals, there are always small-scale submerged vegetation groups, namely vegetation patches. The characteristics and physical mechanism of interaction between small submerged vegetation patches and water flow were studied. As compared to the vertical rigid vegetation, the flexible vegetation tilt does not significantly change the velocity difference and the turbulent kinetic energy magnitude between inside and outside the vegetation canopy, but is to weaken the disturbance to flow, thus reducing the resistance to flow. However, the vegetation swaying is to significantly increase the velocity difference between inside and outside the canopy. It forms the Kelvin-Helmholtz-hairpin vortices intensifying the turbulence production, and enhancing the disturbance and resistance to flow.Under the inflow condition of unidirectional constant flow, the Kelvin-Helmholtz instability at the canopy height of the submerged vegetation array will cause the vegetation canopy to make a periodic coherent waving motion. The periodicity of coherent waving motion of vegetation array and its influencing factors are studied. It is revealed that as the flow velocity increases, the wavelength of the coherent waving motion decreases, while the frequency and amplitude increase. Besides, as the vegetation distribution density increases, the wavelength, and amplitude of the coherent waving motion decrease, but the frequency increases. When the vegetation is in the shallow submergence range, the relative submergence depth has little effect on the periodicity of coherent fluctuation. Since the presence and movement of vegetation significantly change the turbulence intensity of water flow, the scalar transport in water flow is very sensitive to the motion of vegetation. The influence of vegetation presence and swaying on scalar transport and diffusion is studied, taking dissolved oxygen as an example. The results show that the wake flow downstream of rigid vegetation and the small-scale Kelvin-Helmholtz vortices near the top of the canopy are the main reasons to enhance the turbulence intensity in the flow and significantly increase the turbulence diffusion of scalars. However, the flexible vegetation movement induces large-scale KH vortices near the top of the canopy. It also causes to increase the turbulence intensity in the flow, the scalar concentration across the flow depth, and the scalar turbulence diffusion intensity.
答辩日期	2023.05.