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目 次

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CONTENTS

《水利学报》第九届编辑委员会组成名单

EDITORIAL BOARD

Theoretical framework of floodwater resources utilization in a basin I: Quantitative interpretation

WANG Zongzhi[1], WANG Yintang[1], HU Siyi[1,2], LIU Kelin[1], CHENG Liang[1]

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Abstracts: Since the early 21st century, the serious situation of water shortage in northern China has spawned to the concept of flood resources utilization, aiming at taping the flood utilization potential, relieving the contradictions of water resources shortage, and quickly become a hot research topic in the field of flood control and high efficient utilization of water resources. Floodwater resources utilization research and practice started with optimizing design and dynamic control flood limited water level of reservoirs. After more than 10 years of research, the research scales has been extended to the whole basin flood control system from a reservoir, the technology is improved gradually. However, the floodwater resources utilization concept has not yet unified so far, and its theoretical system has not yet been established, which hinders its concrete application in practice. In this paper, the authors established the definition of flood resources utilization in a basin and its conceptual model based on the evolving concept of flood resources utilization formation and river basin water balance equation, and pointed out that the nature of flood resources utilization in a basin is the balance between the risks and benefits, and then reasoned and discriminated some concepts related flood resources utilization potential evaluation and their quantitative relationship . The basic principles and key technology of serval common development patterns of flood resources utilization in a basin are discussed. As a result, the theoretical framework and development patterns of flood water resources utilization is built including potential evaluation, pattern selection, and risk assessment and so on.

Keywords: floodwater resource utilization; theoretical framework; conceptual model; development patterns; limit analysis theory

Multi-objective optimization model of watershed emission rights trading based on pollution control

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Abstract: The emission rights trading has become an important measure to balance the regional economic development and the environment protection under the situation of the increasingly serious water environment pollution problems in China in recent years. In this paper, a multi-objective emission rights trading optimization model based on the pollution control from the view point of the better economic benefits and water quality was put forward. And the emission rights trading scheme set was generated by the application of Non-dominated Sorting Genetic Algorithms (NSGA-Ⅱ). Then the Young Conflict Resolution Theory (YCRT) was applied to select a better scheme. At last, all theoretical methods above were applied to the Shayinghe River to get the recommended emission rights trading scheme and the trading scheme showed that nine calculation units involved in the emission rights trading, and the tradable emission rights were about 1888t which could bring additional economic benefits of 383.27 million, and the water quality compliance rate was improved from 81 % to 85 %.

Keywords: pollution control; emission rights trading; multi-objective optimization; Shayinghe River

Satellite remote sensing of lake area in Wuhan from 1973 to 2015

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Abstract: In recent years, the Wuhan city has suffered flood disasters frequently, and the decrease of lake area is thought to be an important factor. Up to now, there is no consistent data of Wuhan lakes area. In order to analyze spatial and temporal variation of the Wuhan lakes in recent decades, this study used multi-source satellite data, to retrieve the lake images with a combined algorithm of normalized difference water index (NDWI) and object-oriented segmentation from 1973 to 2015. The influence factors of this change were also analyzed in combination with meteorological data and Wuhan Statistical Yearbooks. The results are as follows: (1) in 1973, the area of lakes in Wuhan was 1170.84 km^2, and was 856.27 km^2 in 2015. The decrease was 314.57 km^2 during the period, and the severe decrease period occurred in 1973-2005, after 2005, it basically stabilized. (2) In 1973, the area of lakes in central districts of Wuhan was 148.90 km^2, and the area was basically stable from 1973 to 1996. After 1996, the area of lakes in central districts of Wuhan began to decrease drastically, and tends to be stable after 2010. In 2015, the area of lakes in Wuhan central districts was 99.94 km^2, a decrease of 48.96 km^2 compared to 1973. (3) From 1973 to 2015, the annual precipitation in Wuhan showed a slight increase trend, while the average annual air temperature showed a significant increase trend. After 1990, the population growth, urban development and real estate development in Wuhan led to a large number of lakes were encroached. Climate change combined with human activities led to the changes of lake area in Wuhan, in which human activity may be the main factor.

Keywords: Wuhan; lake; multi-source remote sensing data; temporal and spatial variation; human activity

Multi-objective cascade reservoir optimal operation rules based on decision factor selection

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Abstract: A cascade-reservoir input-variables selection (CIS) method considering the relations between input variables and decision-making in optimal reservoir operation was proposed using the Extra-Tree model. According to the selection results, the multi-objective reservoir operation rules for the maximization of water supply and power generation were extracted by Gaussian Radial Basis Functions and optimized by Pareto-Archived Dynamically Dimensioned Search (PA-DDS) algorithm. With a case study of Hanjiang cascade reservoirs, it is shown that the CIS method can select stable input variables with less redundant information for the reservoir decision-making, and the input variables selected by CIS not only help to obtain better distributed non-dominated solutions in multi-objective optimization, but also can control the use of available water in different seasons effectively. The annual mean power generation and water supply increase 0.33% and 7.84% in the operation mainly for power generation.

Keywords: cascade reservoir operation; multi-objective optimization; data mining; input-variables selection; radial basis functions

Infiltration-runoff model affected by air resistance for layered soil during unsteady rainfall

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Abstract: During the period of rainfall or irrigation, the air in soils fails to fully escape, which is trapped in soils and causes air resistance that hinders soil water infiltration. Considering the impact of air resistance on the soil water infiltration process, the Green-Ampt model is modified. A modified Green-Ampt model (MGAM) is proposed for simulating infiltration into layered soil profile with consideration of air resistance under unsteady rainfall. In order to account for the effect of air resistance, the saturation coefficient (S_a), actual water content (θ_a), air bubbling pressure (h_{ab}) and water bubbling pressure (h_{wb}) are introduced in the model. All parameters could be approximately determined by soil physical properties. To evaluate the performance of MGAM developed by the authors, one-dimensional infiltration-runoff experiments are performed in multi-layered soil columns during unsteady rainfall with air confined. Then soil cumulative infiltration, runoff rate and soil water content calculated by MGAM are compared with the observed data from the experiments, and the calculated results of the traditional Green-Ampt model (TGAM) without consideration of air resistance. The results indicate that soil cumulative infiltration, runoff rate and soil water content calculated by MGAM are all in better agreement with the observed than the existed models. The calculated soil water content and soil cumulative infiltration by TGAM are larger than the observed, and runoff rate is less than the observed.

Keywords: multi-layered soil; Green-Ampt model; infiltration-runoff; air resistance

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The correlation analysis between hydraulic characteristics of vertical slot fishway and fish movement characteristics

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Abstract: The vertical slot fishway (VSF), which can be viewed as an ecological compensation measure, plays a major role in enabling anadromous fish migration, which has received extensive attention. The fishway passage efficiency is closely related to the VSF hydraulic characteristics and fish's swimming capability. Therefore, an excellent VSF design should be suitable between the hydraulic characteristics of VSF and the fish's swimming capability. Taking two anadromous fishes, Ctenopharyngodon idellus and Aristichthys nobilis, as an example, this paper quantitatively analyzed the fishes' movement characteristics, the preferred hydraulic ranges and the relevance of hydraulic factors and fish trajectories by combined the spatial distribution of hydraulic factors with fish trajectories in VSF. The results show that the preferred ranges of turbulent kinetic energy, velocity, turbulent dissipation rate and strain rate are 0.02-0.035 m^2/s^2, 0.16-0.4 m/s, 0.02-0.04 m^2/s^3 and 2-3.5 s^{-1}, respectively with the flow of 0.135 m^3/s in VSF. The times swimming upstream of the two fishes in different water areas are greatly associated with turbulent kinetic energy and velocity. In our study, the flow velocity, as a vector reflecting the rheotaxis of fish, determines the movement of fish, but their swimming behavior in local water area is mainly determined by turbulent kinetic energy.

Keywords: VSF; major Chinese carps; hydraulic factors; fish movement trajectories; correlation analysis

Three-dimensional grouting simulation in fractured rock mass of the dam bedrock

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Abstract: It is important to have a good understanding of the accuracy of 3D fracture network model and the spread process of the grouting. Current 3D geological model are not efficient and cost-effective in visualizing complex fracture distribution for grouting simulation. Researches on grouting simulation simplified the stochastic fracture as one planar fracture or regular fracture network. To solve the above problems, the Carlo Monte method is adopted and a 3D stochastic fracture network model is established. Considering Bingham fluid characteristic, a three-dimensional grouting model is proposed. The bedrock curtain grouting of a hydropower station is taken as a case. The results show that the grout almost flows in the fractures that pass through the borehole, and grouting pressure decreases the fastest near the borehole and affects the diffusion markedly. Compared with the traditional results, this method can not only reveal the actual fractures features, but also obtain more reliable simulation results,which provides a reliable theoretical basis for engineering safety and economic efficiency.

Keywords: grouting simulation; fractured rock mass of bedrock; 3D stochastic fracture network model; 3D mathematical model of fracture grouting; Bingham fluid; Monte Carlo method

Essential difference and design application of boundary effect model and size effect model

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Abstract: A comparative study of the essential difference, design, and application of boundary effect model (BEM) and size effect model (SEM) was conducted. SEM applies the four different multi-parameter empirical equations to the different ratio of initial crack length and specimen depth α. SEM is limited to a data-fitting function. BEM model involves the use of a unique analytical solution. On one hand, BEM can determine the material parameters-fracture toughness K_{IC} and tensile strength f_t through the fitting of experimental data. On the other hand, it can establish a complete designed curve that describes the overall fracture of structure based on the identified K_{IC} and f_t. The effect on three fracture controlled model (f_t-controlled, K_{IC}-controlled and quasi-brittle fracture) were systematically calculated and analyzed from specimen to structure (size W=25-25000mm). The results show that linear elastic fracture mechanics (LEFM) applies for very long crack and very large structures, and there is no further need for size effect study. The size effect model is only relevant when the crack tip is close to either the front or back boundaries. The so-called "size effect" is only a special case of boundary effect. Based on the results of fracture tests (the specimen size W is 40, 93, 215 and 500 mm, and the ratio of initial crack length and specimen depth α is 0, 0.02, 0.075, 0.15 and 0.3), the different combination conditions of tested data that BEM systematically studied are adopted to determine the influence law of K_{IC} and f_t. The results are shown that, values are basically consistent to K_{IC} and f_t, which have been determined by BEM, when the test data reaches a certain amount and one or two groups of data are removed from the overall data, either the specimens have the different W with same $\alpha=a_0/W$, or the same W but different $\alpha=a_0/W$. The studied results of this paper gave a new ideal to solve the problem that the material parameters cannot be accurately obtained using small size specimen, as well as the problem on predicting the actual structure fracture by using the material parameters.

Keywords: boundary effect; size effect; three-point-bend; maximum aggregate size; fracture toughness; tensile strength

Review of the crescent-rib steel bifurcation of hydropower station

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Abstract: Crescent-rib steel bifurcation is one of the most widely applied bifurcation type in hydropower station all over the world, with the following advantages of convenient manufacture and installation, adequate structure size, and reasonable flow pattern. A lot of research works on crescent-rib steel bifurcation have been well documented as well as the engineering practice experience. However, full acknowledgement has not been achieved on some issues of crescent-rib steel bifurcation. In this study, the latest researches of the crescent-rib steel bifurcation are presented in five aspects, including shape optimum design, stress control criterion, combined bearing mechanism of embedded steel branch pipe, computer aided design system, and bearing capability in Z-direction of the steel rib. The values of related design parameters are proposed based on a wide range of engineering practice while the guideline for the research and design of the crescent-rib steel bifurcation are yielded, which can be a well reference through the related design and research work of the crescent-rib steel bifurcation of hydropower station.

Keywords: crescent-rib steel bifurcation; shape optimum design; stress control criterion; combined bearing capability; computer aided design system; bearing capability in Z-direction of rib

Responses of subsurface flow characteristics to natural rainfall in red soil slopes of different surface covers

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Abstract: The subsurface flow constitutes an important portion of total runoff in the sloping field of red soil. However, the occurrence mechanism and quantification of subsurface flow are the difficult issues in red soil region. To determine the subsurface flow associated with different surface cover types on sloping red soil under natural rainfall events, observational data on surface and subsurface flows from 5 m × 15 m plots were collected from 2010 to 2012 in an experiment with three treatments (grass cover, litter cover and bare land) in the Jiangxi Provincial Soil and Water Conservation Ecological Park. The results show that land cover involving grass or residue can convert more of the surface flow into subsurface flow, and relieve the impact of seasonal rainfall on the surface flow generation in red region. Under individual rainfall event, the surface flow coefficients of grass cover and litter cover are 10.80% and 12.55% of that of bare land, while the subsurface flows are 2.47 times and 3.22 times of bare land. The generation characteristics of subsurface flow are significantly influenced by surface covers. The average annual subsurface flow coefficient at a depth of 30 cm is 79.25 percent of that at a depth of 60 cm for bare land. In contrast, subsurface flow generated in plots with grass or litter cover at a depth of 30 cm is greater in spring, taking 34.90% and 39.63% of the total annual output, respectively, without significant effect on subsurface flow at a depth of 60 cm. The process of subsurface flow is mainly affected by rainfall depth and duration except for the rainfall intensity. Therefore, surface cover could effectively regulate the rainfall–runoff relationship and control rainfall erosion in red soil sloping erosion control. The findings will be of significant interest to understand the mechanism of soil erosion and its conservation of red soil slope.

Keywords: subsurface flow; surface covers; natural rainfall events; red soil slope

Numerical study on suspended sediment transport in a vortex settling basin

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Abstract: The vortex settling basin is a hydraulic structure which used a vertical vortex to exclude sediment particles from diverted water. In order to ascertain the suspended sediment transport characteristics and the sediment removal mechanism in a vortex settling basin, an Euler-Lagrange method is used to simulate the air-water-sediment multiphase flow in the device. In this method, the turbulent flow of gas and liquid is modelled using the Reynolds stress model (RSM) and the Volume of fluid (VOF) interface tracking technique. A discrete particle model is adopted to calculate suspended sediment motion. The calculation results of the mean suspended sediment concentration distribution are in good agreement with measured results. The calculation results show that the sediment concentration distribution in the outer region of the basin is more uniform, and that there is a significantly high concentration zone near the bottom in the inner region of the basin. The authors hold that the sediment concentration distribution is mainly caused by the secondary flow within the vortex settling basin.

Keywords: vortex settling basin; suspended sediment; numerical simulation; discrete particle model

Numerical investigation of flow around blunt trailing edge hydrofoil using transition SST model

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Abstract: Boundary layer transition is one of the primary factors that affect the hydrodynamic characteristics of flow over hydrofoils. This paper presents numerical calculations of flow around the NACA0009 blunt trailing edge hydrofoil at angle of attack 0° by coupling the $\gamma - Re_{\theta t}$ transition model and the SST $k-\omega$ model, aims to explore the applicability of the $\gamma - Re_{\theta t}$ transition model in predicting of boundary layer transition and wake vortex shedding with low free-stream turbulence intensity. The sensitivity of the calculation model to the grid resolution is examined. The boundary layer, features of the wake, and the vortex shedding characteristics of flows at different free-stream velocities are predicted. The calculation results are compared with experimental data and the prediction by the SST $k-\omega$ model. It is shown that the transition location of the hydrofoil boundary layer moves upstream with increasing y^+ of the first grid near the wall. The predicted transition location converges to a fixed point when the maximum y^+ less than 1. Compared with the SST $k-\omega$ model, the transition SST model shows better prediction of eddy viscosity in the boundary layer and the wake region. The boundary layer thickness and wake flow parameters obtained by the transition SST model agree well with the experimental data. The results shown that the transition SST model can give promising prediction of the frequency of the vortex shedding, with a maximum relative error of 6.2 % for flows at different Reynolds number.

Keywords: hydrofoil; boundary layer transition; $\gamma - Re_{\theta t}$ transition model; vortex shedding

Roof rainwater source controlling technology based on design of sponge city

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Abstract: Based on the sponge city advocating accumulation on the spot and natural penetration of rainwater, some technologies of roof rainwater harvesting, recharging groundwater and green roof were presented to increase the source reduction of rainwater runoff, decrease the pressure of urban drainage system, and enhance the capacity to prevent waterlogging. According to the characteristics of high head and easy collection on roof runoff, this study analyzed the design scheme of rainwater harvesting and split-flow for roof initial rainwater using belt-pulley systems, recharging groundwater after rainwater collection using multiple sensors and microcontrollers, and normalized the construction procedure of them on the base of analysis of existing green roof systems. The implementation of roof runoff source reduction and process control technologies and methods can provide great support for constructing sponge city, preventing urban waterlogging, flood control and disaster prevention, etc.

Keywords: sponge city; roofing rainwater; rainwater harvesting; urban waterlogging; regulation and storage