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学位の種類	博士（工学）
学位記番号	博第1253号
学位授与の日付	2022年3月31日
学位授与の条件	学位規則第４条第１項該当　課程博士
学位論文題目	EFFECTS OF PILE-GROUP LAYOUTS ON THE FLOW AND BED CHARACTERISTICS IN AN OPEN CHANNEL （開水路における杭群の配置が流れと河床変動に及ぼす影響）
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論文内容の要旨

Flow velocity and attributes can cause riverbank erosion and failure, which can lead to property damage or loss, sedimentation of in-stream structures, water quality deterioration, aquatic habitat damage, channel widening, and more. Pile-groups are one of the hydraulic structures which can control the flow velocity in the downstream and increase sediment deposition along the bank for enhancing the riverbank stability. Numerous examples of different permeable pile-groups exist along the banks of the Kiso, Yahagi, and Toyo Rivers in Japan for many decades as river training structures to control the bank erosion and enhance navigability of the channel. Nevertheless, there is no appropriate design and sufficient explanation of the effective pile arrangement with better performance of these structures.

The main purpose of this study is the improvement of riverbank stability with the objectives of smoothly decelerating the velocity in the downstream, creating a sandbar along the bank, and reducing the local scour around the structure. Herein, an experimental study was conducted to study the flow characteristics and bed deformations around pile-groups. Different pile-group layouts with two types of pile arrangement, namely in-line and staggered arrays, were studied and compared. Additionally, an impermeable structure was considered for comparison of the flow field with the permeable structures. Effects of pile-group layout parameters including the number, spacing and arrangement of piles on the flow characteristics, turbulence, and bed deformation around the structure and in long downstream distance of the structure were investigated experimentally. Furthermore, a two-dimensional depth-averaged numerical calculation with a low Reynolds-number turbulence model was conducted to simulate the effects of pile-groups on the flow characteristics on a fixed bed around the structure, in long downstream, and inside the structure. Based on the results and discussion of the experimental and numerical studies, the main outcomes of this study are drawn as follows.

In all the pile-groups, the flow penetrated to the pile-group and the penetrated flow was discharged from the structure with reduced velocity. In contrast with the impermeable structure, the momentum transfer by the water flowing through the permeable structures prevented the formation of a recirculating flow and resulted in a unidirectional flow toward the downstream.

Although the in-line pile arrangement is the most common type in practice, however, the results of this study suggested that the staggered arrangement creates a desirable flow change for bank protection behind the pile group. The smooth gradual flow-deceleration from the mainstream to the sidewall, the substantial decrease in turbulence around the structure, and preservation of the retarded flow to a far downstream distance were the main favorable features of the staggered type. In contrast, the in-line cases indicated a non-smooth flow deceleration with a high velocity near the bank and a minimum value behind the tip of the structure. With the sudden jump of velocity from a minimum to the maximum value along the shear layer in the in-line type, a high turbulence was observed in the region.

Mechanism of the flow change by different arrangements of piles in a group was demonstrated with the existence of different flow paths within the group. From the type of flow paths within a pile-group, it was inferred that the width and direction of the paths were responsible for determining the magnitude, pattern and direction of the downstream flow. A milder angle of the flow path provided better flow guidance from upstream to the downstream of the staggered type and enhanced supplying the flow to the downstream tip of the structure through the flow paths. Therefore, the minimum velocity region behind the downstream tip of the structure disappeared in the staggered cases.

Average velocities behind the pile-groups were predicted using a multiple regression model among the pile-group layout parameters. The number and spacing of piles in longitudinal and transverse directions were expected to be the effective parameters for expressing the velocity reduction behind the pile-group. The regression statistics having a multiple R value of 0.99 for both the in-line and staggered cases indicated strong predictability of the obtained models and resulted in a high fitting feature of the predicted and the experimental velocities.

Flow resistance was expressed in terms of the pile-group drag force using the momentum equation. The drag force exerted by the pile-group controlled the velocity reduction behind the structure. The velocity in the pile-group region decreased almost linearly with an increase of the drag force. From the velocity reduction trend in the in-line and staggered pile-arrangements, it was revealed that the velocity reduction caused by a pile-group is determined by the drag force of the pile-group in spite of the different pile arrangements.

Turbulence characteristics around the structure were surprisingly affected by the pile-arrangement type. A region of intense turbulence in the downstream region behind the tip of the in-line cases were observed, whereas it was suppressed to the minimum in the staggered type. The frequency spectra analyses confirmed the existence of organized vortices generated by the Kelvin-Helmholtz instability in the in-line cases, while it was suppressed in the staggered type. Although the mechanism of suppressing the generation of the organized vortices in the staggered type is still not clearly described, but it was presumed that the momentum transport from the downstream region of the pile-group to the mainstream suppressed the generation of the organized vortices.

Channel bed deformation was also affected by the pile-group layout parameters. The flow penetrated into the pile-group due to permeability of the structure, which caused scour inside the structure and provided sediment supply to the downstream through the structure. The decelerated flow downstream of the structure enhanced the deposition of the supplied sand along the bank, which can be a good feature for improvement of riverbank stability. The velocity magnitude, maximum scour depth and the amount of sediment deposition al bank were controlled by changing the number and arrangement of piles. The horse-shoe vortex is expected to drive the local scour around the structure. The maximum scour depth was well expressed by the modified blockage ratio λ_b in both the in-line and staggered arrangements. The total scoured volume was almost proportional to the maximum scour depth in all the cases.

A two-dimensional depth-averaged numerical calculation with a low Reynolds-number turbulence model was conducted to simulate the effects of the pile-groups on the flow characteristics around the structure, in long downstream, and inside the structure. Different flow structures and turbulence characteristics generated by both the in-line and staggered arrangements of piles were well simulated with the numerical model and represented strong agreement with the experimental results. Furthermore, the calculated flow results revealed the flow patterns inside the pile-groups for both the in-line and staggered pile-arrangements, while measuring the flow inside the structure was not possible with the PIV experiments due to the limitation of laser projection in every point inside the pile-group.

Comparing the maximum scour depth, sediment deposition and velocity deceleration values of the two types of pile arrangements, in-line and staggered, from a point of view of riverbank protection and structural stability, it was revealed that a lower number of piles in the staggered type can perform similarly or better than a higher number of piles in the in-line arrangement. It was found that, this feature of the staggered arrays can reduce the number of piles to almost half in most cases. Therefore, the material, construction, and maintenance cost could be considerably decreased by using the staggered type.

This study uncovered some unknown perspectives of the flow induced by different pile-groups with various layout parameters and pile arrangements. However, the detailed mechanism of the turbulence generation, the effects of pile-group submergence, pile diameter, and pile-group length require further investigations to be conducted in the future.

論文審査結果の要旨

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