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Scientific Research

Case Study: Hydraulic Model Study for Abandoned Channel Restoration

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ABSTRACT

Recently, a paradigm of river restoration is recognized as the importance of flood plan involving abandoned channel. Hence, effort which abandoned channel area by improvement project will become the territory of river area is trying. This study is a part of river restoration project. In this study, hydraulic model experiment and numerical simulation were performed to understand the flow characteristic and bed change for abandoned channel restoration. The target area of the hydraulic model was the midstream of the Hampyeong Stream (stream length: 1.3 km). Horizontal scale was 1/50 and vertical scale was 1/40. For numerical simulation, the FESWMS model was used. Cases of hydraulic and numerical models were frequency flood discharge (50 and 100 years) and channel formation discharge (100 m^3/s and 120 m^3/s). Flow characteristics were analyzed in fixed condition using hydraulic and numerical models. Bed change on abandoned channel restoration was analyzed on deposition trend using sediment supply from upstream in hydraulic model, and was compared with results of bed shear stress in numerical model. Results velocity profile and bed shear stress of numerical model were similar with trends of measured velocity and deposition of hydraulic model. The results of this study will be applied to restoration design of abandoned channels.

Keywords: Abandoned Channel; Hydraulic Model; RMA2; FESWMS; Deposition

1. Introduction

Abandoned channel restoration is to conduct topographic restoration of abandoned channels by comparing current river channels, which have been unified due to land consolidation and flood control project, with past river channels. In other words, it is to restore the original components of rivers (abandoned channels), such as wetland, water impingement area, ecological stronghold, and alluvial island. Abandoned channel restoration is the beginning of river restoration, and is essential for improving river environments by waterway restoration.

In terms of flood control, the artificial channel straightening and bank-related measures, which have been performed to date, are problematic as they could increase potential flood damage intensity considering the current abnormal climate. Also, in terms of ecosystem, they could cause the damage of organism inhabitation stronghold (wetland, bush, biotope, etc.) and the destruction of eco-tone due to concrete revetments and unified cross section type (single section and double section). In terms of culture, the space for river culture and the space for the coexistence of residents and ecosystem could also disappear.

Most of the existing domestic river restoration projects have used passive restoration, by which ecological space is constructed within river channels only for the existing river channels that have already been narrowed by banks. However, the purposes of the river restoration in this study are to improve relative flood safety by expanding river zones, to improve the ecological stronghold of ecotone and waterside, to conserve the nature of local community by providing various habitats of living organisms, to maintain culture and tradition, and to provide waterfront areas. Nevertheless, the river restoration in this study also restores abandoned channels while maintaining current river channels, and it is not that the waterways before river improvement are completely restored. Thus, for the design of abandoned channel cross section, the difficulty lies in suggesting a new river channel while maintaining the current river channel. Also, for abandoned channel restoration, the difficulty lies in considering comprehensive components of river channel design and river hydraulics because abandoned channels which are maintained or used in various forms and rivers can be abruptly changed by external factors.

In this study, hydraulic model experiment and numerical simulation were performed to examine flood control stability and restored river channel sediment deposition effect for the river channel design suggested as a part of the river restoration project. The purposes of this study are to propose an alternative for the optimal river channel restoration design and to provide basic data for various numerical simulation by analyzing the problem of the suggested river channel design through the comparison of hydraulic model experiment and numerical simulation.

2. Research Area

The Hampyeong Stream is the first tributary of the Yeongsan River, and is a national river with a drainage area of 196.4 km^2, a flow channel length of 28.8 km, an average basin width of 6.82 km, a downstream bed slope of about 1/1800, and an upstream bed slope of about 1/800. The upstream river bed mostly consists of sand, and the downstream part consists of sandy silt. Among the ecological park that is constructed in the midstream area of the Hampyeong Stream as part of "Hampyeong Stream Theme Ecological River Construction Project", the target area of this study is the abandoned channel section 1.34 km downstream of the Daekyung weir in Gigak-ri, Hakgyo-myeon. The purposes of the project are to maintain flood control safety during flood season, to secure instream flow during dry and normal seasons, and to provide various habitats of living organisms, as well as to restore the abandoned channel of the main stream and to provide waterfront areas by constructing weir, close-to-nature fish way, ecological habitats, insect theme forest, and butterfly ecological pond. **Figure 1(a)** shows the current status of the target area, and **Figure 1(b)** shows the bird's-eye view after the restoration.

3. Experimental and Numerical Model Setup

The section for the hydraulic model experiment and numerical simulation of abandoned channel restoration is the river channel that is planned to be 1.34 km downstream of the Daekyung weir, as shown in **Figure 2**.

The scale of a hydraulic model is determined by comprehensively examining the reproducibility of an original form, the discharge supply capability of a laboratory, the space for experiment model production, and the ease of measurement. As a river model generally has very short river length compared to water depth, distorted scale is used. Even when the river length is short, a large river has a wide river channel compared to water depth, and therefore, distorted scale should be used for the hy-

Figure 1. Current status of the research area (a, left); and bird's-eye view of restoration channel (b, right).

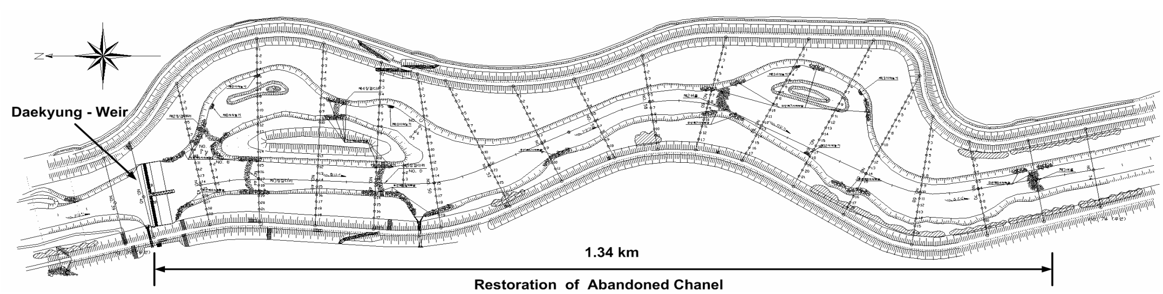

Figure 2. Plan view of the channel restoration project.

draulic model experiment of a large river. In this study, the scale of the hydraulic model experiment was determined to be a model with a distortion ratio of 2 (horizontal scale: 1/50 and vertical scale: 1/25), based on the Froude's similarity law. Also, topography was produced so that it fits the model scale, based on the survey results of the entire section for the project (**Figure 3**).

In this study, the hydraulic model experiment was performed to analyze the water level, flow velocity characteristics, and sediment deposition trend induced by the abandoned channel restoration. **Table 1** summarizes the experiment condition. For the upstream and downstream boundary conditions of the hydraulic model experiment, the 50-year and 100-year frequency flood discharge at each recurrence interval from the MOCT [1] and the bankfull discharge (100 m^3/s and 120 m^3/s) determined by one-dimensional numerical simulation were used. For the roughness coefficient, to use the value that was applied in the MOCT [2], roughness correction was performed by comparing the flood water level from the report (1999) at each cross section with the measured water level of the hydraulic model experiment, and then the obtained value was utilized. The water level and flow velocity were measured by dividing the water level and flow velocity measurement section into 18 cross sections at 1.6 m intervals starting from just upstream of the Daekyung weir, and by adding two survey lines to the inlet and the outlet, respectively, for the detailed measurement of the abandoned channel restoration section. The survey points of each survey line were generally spaced at 0.10 m intervals, and additional survey points were arranged considering the topographic characteristics. For the water level and flow velocity measurement, a water level gauge (PH-355, KENEK) and a one-dimensional current meter (VO-1000, KENEK) were used, respectively. To examine the sediment deposition trend, sediment particle size was selected considering the model scale, and a certain amount of sediment was supplied.

The flow behavior of a river is generally analyzed using a plane two-dimensional model. In this study, the RMA2 model was used. The RMA2 model was developed by the U.S. Army Corps of Engineers in 1973, and has been widely used for the hydraulic analysis of river waterways, reservoirs, and estuaries, which include alluvial islands and piers (Barbara [3]). For the governing equation, the model uses the two-dimensional shallow water equation, which is integrated in water depth direction. In this study, the RMA2 model simulation was limited to the simulation of steady flow condition; and for the boundary condition, the 100-year frequency flood discharge and flood water level of the target section from the MOCT [2] were used. For the topography input data, the survey results of the target section were used. The finite element mesh used in the model was triangular finite element mesh, where the number of elements was 9268 and the number of nodes was 18986. The major parameters of the RMA2 model are Manning's n coefficient and eddy viscosity coefficient. For the roughness coefficient used in the numerical simulation, a roughness coefficient of 0.025 suggested in the Hampyeong Stream Improvement Basic Plan (supplemented) (1999) was uniformly applied. The eddy viscosity coefficient was

Table 1. Experimental conditions.

Case	Upstream Boundary Condition (Discharge, m^3/s)	Downstream Boundary Condition (Water surface EL., m)
50-year Frequency Flood	740	6.99
100-year Frequency Flood	840	7.36
50-year Bankfull Discharge	100	4.12
100-year Bankfull Discharge	120	4.25

Figure 3. Channel reproduction for hydraulic model experiment.

determined to be 2000 N·sec/m^2 by correcting the coefficient so that the eddies and flow velocity distribution of the restoration section, which were observed in the hydraulic model experiment, could be appropriately simulated.

4. Analysis

The analysis items for the restored abandoned channel using the hydraulic model experiment and numerical simulation can be broadly divided into flood control stability evaluation, discharge allocation, and restored river channel deposition effect evaluation.

4.1. Comparison of the Hydraulic Characteristics of the Current and after the Restoration River Channel

The hydraulic model experiment was performed in stationary condition. The comparison of the flood water level was conducted for the river channels before and after the abandoned channel restoration using the recurrence interval 100-year frequency design flood discharge. For the flood water level of the river channel before the abandoned channel restoration, the design flood water level obtained by one-dimensional numerical simulation was applied. For the flood water level of the river channel after the abandoned channel restoration, it was divided into the existing river channel and the restored river channel, and the flood water levels of the hydraulic model experiment and the two-dimensional numerical simulation were applied.

Figure 4 shows the comparison of the flood water levels before and after the abandoned channel restoration. For the flood water level distribution of the river channel before the abandoned channel restoration, it linearly decreased, showing a maximum water level difference of 0.69 m between upstream and downstream areas. For the flood water level distribution of the river channel after the abandoned channel restoration, in the upstream restoration section, the maximum flood water level difference of the hydraulic model experiment and numerical simulation was 0.21 m for the existing river channel and 0.14 m for the restored river channel, and the maximum flood water level difference occurred at the same spot. During the numerical simulation, unlike the hydraulic model experiment, river structures such as the Daekyung weir and protection work were not taken into account. Thus, the above flood water level difference is thought to be the difference from the actual water level that occurred at the spot where the river structure was located. The flood water level change was similar after the restoration section.

For the flood water level change of the river channel before and after the restoration, a flood water level difference of 0.38 - 0.14 m was observed in the restoration section and it is thought that the cross section expansion from the Hampyeong Stream abandoned channel restoration could secure the flood control safety through the flood water level reduction effect. Thus, the flood water level reduction effect could be identified. On the other hand, the flood water level at the downstream end of the river channel after the restoration was slightly higher than that before the restoration. This is thought to be because only the local target section was considered during the hydraulic model experiment and the numerical simulation.

To examine the flow velocity distribution of the existing river channel and the restored river channel depending on the abandoned channel restoration, the recurrence interval 100-year frequency design flood discharge was applied to the hydraulic model experiment and the two-dimensional numerical simulation.

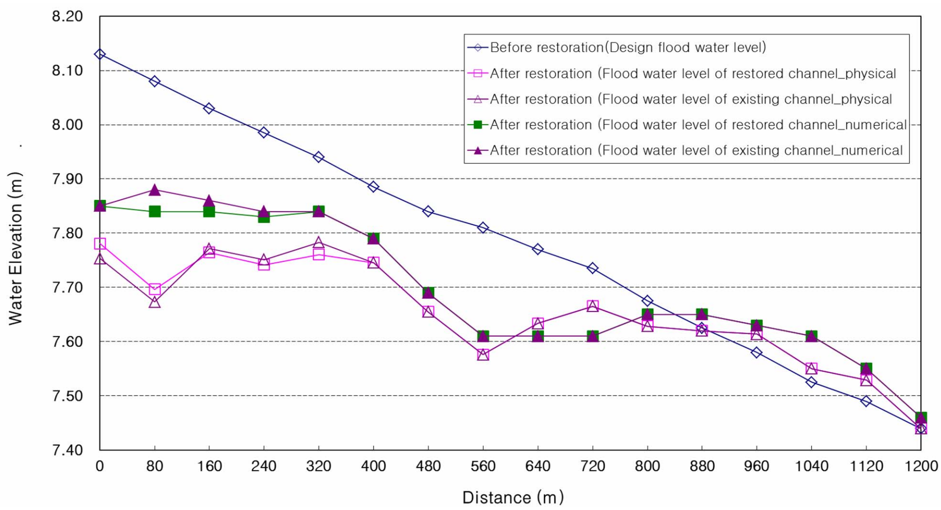

Figure 4. Comparison of the flood water levels before and after the abandoned channel restoration using the design.

Figure 5 shows the results of the flow velocity distribution after the abandoned channel restoration. In the restoration section, the flow velocity of the restored river channel was slightly lower than that of the existing river channel. For the inlet of the restored river channel, a large flow velocity value (1.8 m/s) was observed because the river width narrowed as the river channel was separated by the alluvial island. On the other hand, for the outlet of the restored river channel, a small flow velocity value was observed because the flow became stagnant due to the flow of the existing river channel. The flow velocity change was similar after the restoration section. The maximum flow velocity (2.25 m/s) was observed at the spot that had a cross section shape in which the river width narrowed and was curved toward the right bank after the restoration section.

Figure 6 shows the flow velocity distribution map obtained by the numerical simulation. For the flow velocity of the restored river channel, eddies occurred in the diverged flow at the restoration section due to the curved shape of the bank, and then the flow became stagnant at the wide waterside area. For the flow velocity at the inlet and outlet of the restoration section, relatively large flow velocity difference was observed because of the correlation between the shape of the restored river channel cross section and the flow of the existing river channel. It is expected that due to this flow velocity distribution, river bed change would occur in the abandoned channel restoration section during floods by sediment transport.

Bankfull discharge is a major factor for the design of stable river channels. The bankfull discharge of the Hampyeong Stream abandoned channel restoration section was selected to be 100 m^3/s and 120 m^3/s using one-dimensional numerical simulation. For these two cases, hydraulic model experiment was performed, and the flow characteristic changes of the existing river channel and the restored river channel after the abandoned channel restoration were analyzed.

The changes of the water surface shape at the bankfull discharge were similar in the entire section. The water level distribution for each case was EL. 4.12 - 4.80 m at 100 m^3/s, and EL. 4.25 - 4.95 m at 120 m^3/s (**Figure 7**). The flood water level difference between the two cases was 0.1 - 0.2 m, and the water level of the restored river channel was about 0.1 m lower than that of the existing river channel.

The changes of the flow velocity were also similar in the entire section. However, due to the effect of the eddies that occurred in the flow at the end of the alluvial island for the restored river channel, a flow velocity difference of about 2.0 m/s was observed compared to the existing river channel (**Figure 8**). A flow velocity reduc

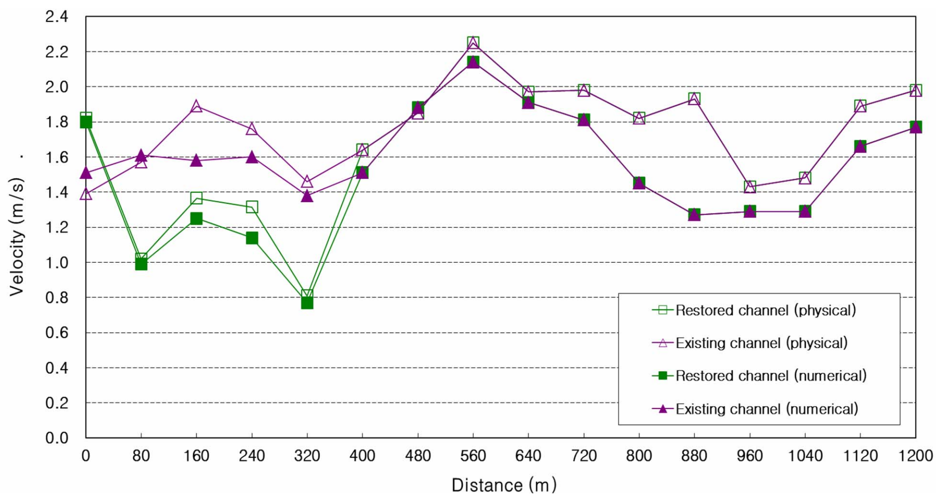

Figure 5. Flow velocity change after the abandoned channel restoration using the design flood discharge.

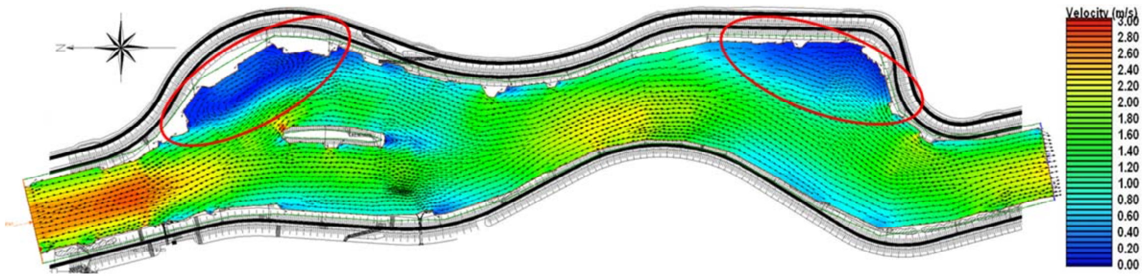

Figure 6. Flow velocity distribution map by the numerical simulation.

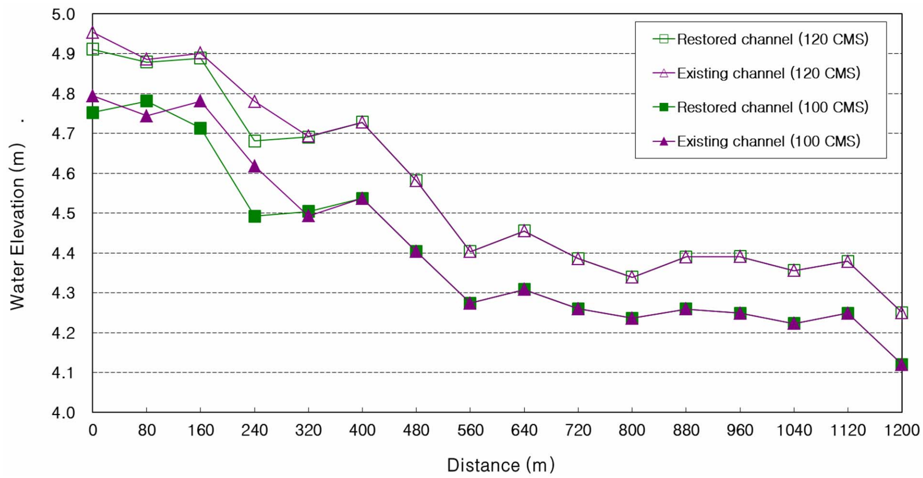

Figure 7. Change of the water surface shape at each bankfull discharge.

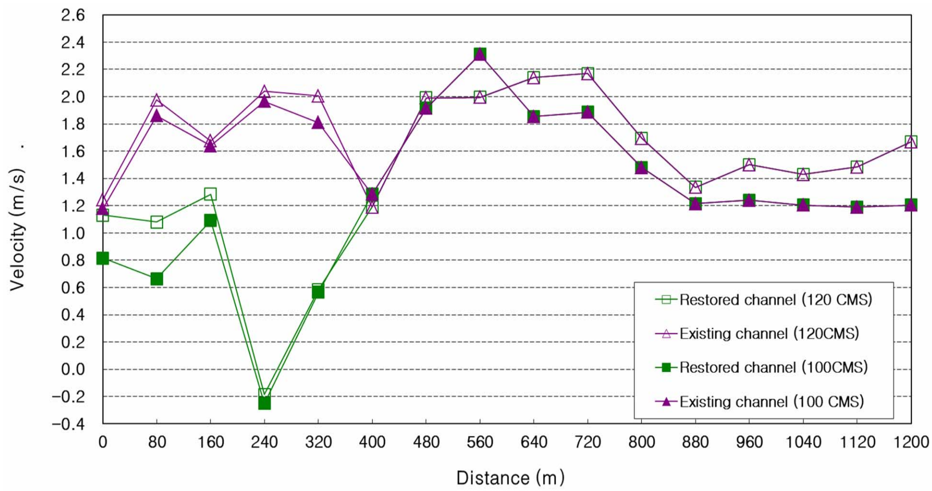

Figure 8. Comparison of the flow velocity at each bankfull discharge.

tion phenomenon occurred in the restored river channel section due to the flow velocity difference between the restored river channel and the existing river channel and the occurrence of eddies. It is expected that this phenomenon could induce a stagnant flow in the restored river channel section and cause problems by sediment deposition.

Figure 9 shows the flow velocity distribution map at the bankfull discharge of 100 m^3/s. It is expected that deposition could occur at both banks of the cross section expansion region formed by the abandoned channel restoration, and it is thought that flow needs to be controlled using river structures such as spur dike and protection work.

4.2. Flow Distribution for the Flood Discharge

Table 2 summarizes the discharge allocation ratios of the existing river channel and the restored river channel, based on the abandoned channel restoration design. The discharge allocation ratios for the design flood discharge at each case were 34.9% - 38.3% for the restored river channel, and 61.7% - 65.1% for the existing river channel. Considering that the river channels are currently stabilized, these discharge allocation ratios could affect the river bed change of the existing river channel. Therefore, for the discharge allocation in the design condition that maintains the existing river channel, it is important to supply minimum discharge considering the ecological discharge of the restored river channel.

4.3. Sedimentation Test of Restored Channel

To examine the sediment deposition trend due to the sediment transport by the flood discharge at each recurrence interval, hydraulic model experiment and numerical simulation were performed. For the hydraulic model experiment, the sediment deposition trend was examined after supplying a certain amount of sediment; and to investigate the bed shear stress distribution trend, the

FESWMS model was used (David [4]). The FESWMS model simulates two-dimensional shallow water flow in steady flow and unsteady flow conditions, and it basically considers the effects of bed shear stress and turbulent flow drag. Also, in the option, the water surface shear stress drag by winds and the deflection force can be considered.

The comparison of the hydraulic model experiment and the numerical simulation indicated that the sediment deposition trends were similar, and the deposition mostly occurred at the waterside area of the restored river channel (**Figures 10(A)** and **(B)**). It is thought that the deposition phenomenon occurring at the restored river channel could cause problems such as the transport and depo-

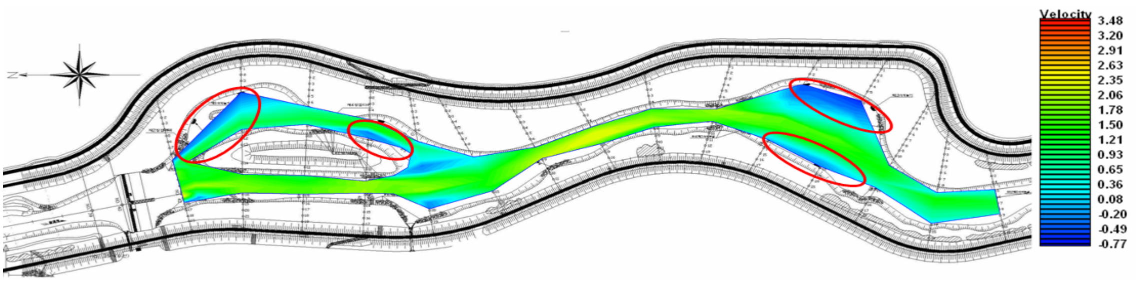

Figure 9. Velocity distribution map at the bankfull discharge (100 m^3/s).

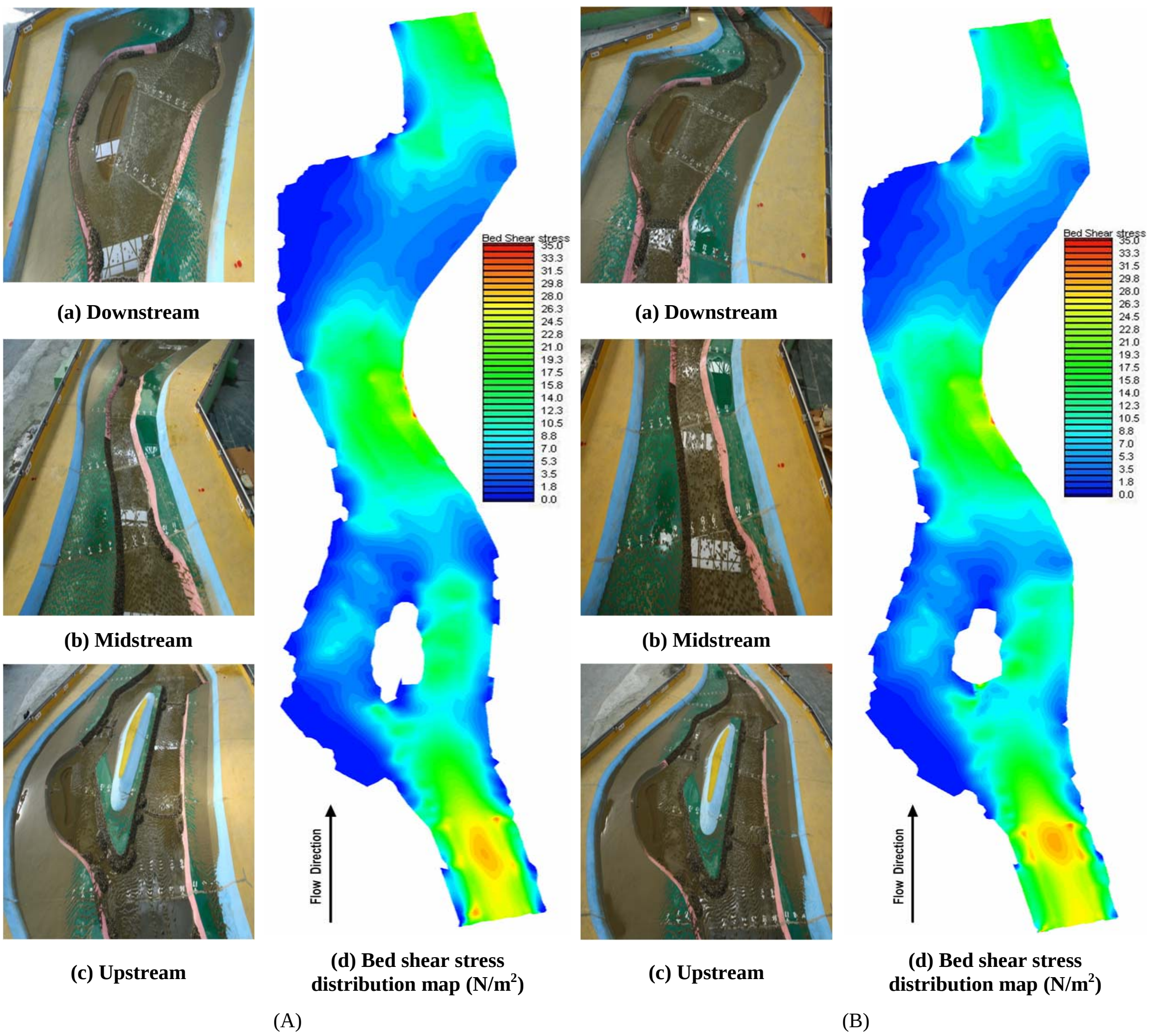

Figure 10. (A) Comparison of the sediment deposition trend and the bed shear stress (50 yr); (B) Comparison of the sediment deposition trend and the bed shear stress (100 yr).

Table 2. Flow distribution rate between the river channels based on the abandoned channel restoration design.

Case	Restored channel (%)	Existing channel (%)	Remark (%)
50-year Frequency Flood	38.3	61.7	100
100-year Frequency Flood	36.0	64.0	100
50-year Bankfull Discharge	34.9	65.1	100
100-year Bankfull Discharge	37.7	62.3	100

sition of debris flow during floods and unnecessary vegetation rooting. Also, it is thought that the problems need to be resolved by the flow control using river structures and by maintenance measures.

5. Conclusions

In this study, for the design river channel of the abandoned channel restoration section is constructed in the midstream area of the Hampyeong Stream as a part of "Hampyeong Stream Theme Ecological River Construction Project", the flood control stability and sediment deposition effect before and after the abandoned channel restoration were examined using hydraulic model experiment and numerical simulation. In the comparison of the flood water levels at design flood discharge before and after the abandoned channel restoration, the average flood water level reduction of 0.2 m was observed in the river channel after the restoration, compared to the river channel before the restoration. This is because the conveyance increased due to the cross section expansion caused by the restored river channel. The flow velocity after the abandoned channel restoration was reduced compared to that before the restoration, because of the increased conveyance. The flow velocity difference between the existing river channel and the restored river channel was rather large, and this is thought to be due to the shape of the restored river channel cross section and the occurrence of eddies. It is thought that for the discharge allocation of the existing river channel and the restored river channel, the discharge of the restored river channel was rather large considering the condition that maintained the existing river channel. It is necessary to supply minimum discharge considering the ecological discharge of the target area. For the flow regime of the restored river channel, stagnant flow and reverse flow occurred in part of the section, and deposition is expected in this part of the section. The sediment deposition trend of the hydraulic model experiment was compared with the bed shear stress of the FESWMS model. The comparison indicated that the results were similar, and the deposition mostly occurred at the wide waterside area of the restored river channel. It is thought that the deposition phenomenon occurring at the restored river channel could cause problems such as the transport and deposition of debris flow during floods and unnecessary vegetation rooting. Also, it is thought that the problems need to be resolved by the flow control using environmental structures and by maintenance measures.

The examination of the design river channel for the Hampyeong Stream abandoned channel restoration indicated that the design proposal is stable in terms of flood control. However, considering the discharge allocation and the local flow of the restored river channel, it is necessary to prepare measures such as nature-friendly structures.

6. Acknowledgements

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