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ARRANGEMENT OF THE CONSOLIDATION WORKS FOR STRAIGHT RIVERS

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ABSTRACT

This study is to investigate the difference of river habitat patterns before and after the construction of the consolidation works for the straight rivers based on a series of flume experiments and numerical simulations. The objective of this study was to conduct simulations using SMS model (Surface Water Modeling System) developed by the BOSS Company to search for the optimum arrangements of the consolidation works with consideration of both safety and ecological conditions.

It was found that relative accurate flow phenomena can be simulated using RMA2 (Resource Management Associates) model. The results of the simulations indicated that the saw-tooth consolidation work was a better tool for energy dissipation and flow regulation than the conventional consolidation work. In general, highest flow diversity of habitat was observed for a saw-tooth consolidation work with an interval 2.5 times of the channel width, and when the saw interval of the consolidation work was a three-fourths value of the saw width. The above consolidation work arrangements can provide multiplicity of stream habitat, and form a better river habitat environment for aquatic creatures.
Keywords: SMS model, saw-tooth consolidation work, flow diversity.

1. INTRODUCTION

In the past, safety and precaution against natural disasters were to take the principal conditions of stream works into account, but it is less to take account of that constructions are attacking nature ecology and environment. In the current, environmental protection of river is growing with each passing day as a result of the quality of common people's life is promoting continuously. In addition to safety of stream work, we should add ecological factors which to keep multiplicity for stream habitat and to reach amphibious habitats corridor integrity.

There are many kinds of constructions in stream works. Consolidation works are very common protection construction of river bed in Taiwan; it is horizontal to the river and having many functions which include flow regulation, alleviative slope of bed, reduce flow velocity and scour of river bank. In this study, there are two kinds of consolidation works were compared. Fig 1(a) shows conventional consolidation work which is installed without considering corridor of aquatic and may cause habitat environment change. This study focus on the foregoing question, we propose to use

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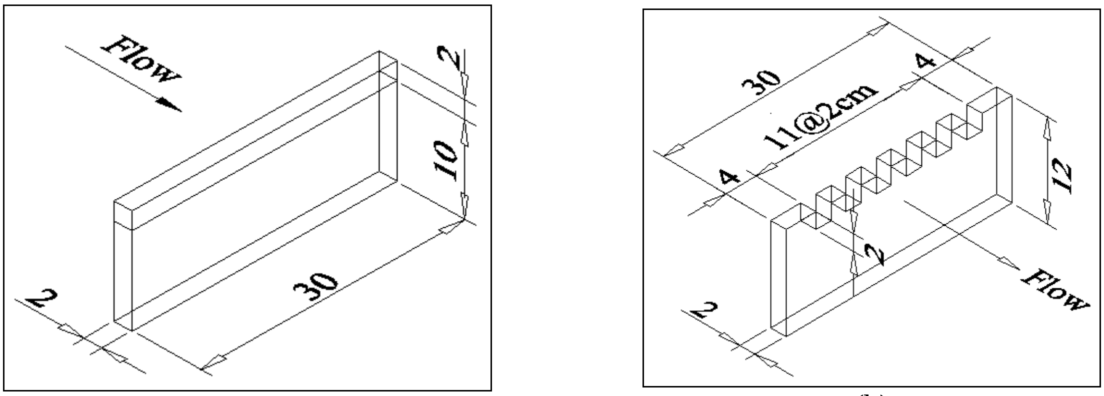
numerical model to simulate saw-tooth consolidation work, such as Fig 1(b). It was researched in river habitats change for various consolidation work forms and was proved by flume experiments. It hopes to find and supply the best deploy for engineers against various hydraulic conditions, consolidation work forms and set-interval.

In view of that the developments of numerical models and computers are promoting substantially and have high precise result, they are often used to simulate fluid mechanics, for example bridge pier to stuff, back water and dam break etc. Owing to SMS model (Surface Water Modeling System) is simple and easy to set up, can control grid easily, and obtain simulate outcome quickly, in this study we choose the suitable model from SMS to simulate consolidation works and to analyze the fluid factors such as flow depth, Froude number and velocity gradient etc to comprehend the relation between consolidation works and habitats.



(a) (b)

Figure 1 (a)Conventional consolidation work (b)Saw-tooth consolidation work

2. Background

2.1 Surface Water Modeling System (SMS)

SMS (Surface Water Modeling System) V6.0 includes TABS-MD(RMA2, RMA4, SED2D-WES), HIVEL2D, FESWMS, ADCIRC, CGWAVE, STWAVE and WSPRO etc.. It is provided with pre- and post-processor for surface water modeling and design. The study will be only conferred fluid mechanics calculation. The TABS-2 (Open-Channel Flow and Sedimentation) model was developed by USA Department of the Army, Waterways Experiment Stations, Crops of Engineers in 1972~1984, which including three base formula: RMA-2, SED2D-WES and RMA4. We introduce and explain RMA-2 and HIVEL2D as follows.

SMS includes a model specific interface for the hydrodynamic analysis model RMA2. RMA2 computes flow velocities and water-surface elevations at each mesh node with a mesh constructed using SMS; it also computes the dynamic boundary between wet and dry regions in the model. Flow separations and eddy currents are modeled accurately. Both steady state and transient solutions can be computed. RMA2 is part of the TABS modeling system. It has been used extensively by the Army Corps of Engineers and their consultants. It supports multiple methods of handling wetting and drying situations and its output can be used by RMA4 and SED2D to model contaminant migration and sediment transport problems.

HIVEL2D is a free-surface, depth-averaged, two-dimensional finite element model designed specifically to simulate flow in typical high-velocity channels. HIVEL2D is applicable for flow fields that contain supercritical and subcritical regimes as well as the transitions between the regimes. HIVEL2D provides numerically-stable solutions of advection-dominated flow fields containing shocks such as oblique standing waves and hydraulic jumps.

The system of nonlinear equations is solved using the Newton-Raphson iterative method. The Newton-Raphson method was selected for this model because the nonlinear terms in high-velocity channel flow fields are quite significant. Stresses are modeled using the Manning's formula for boundary drag and the Boussinesq relation for Reynolds stresses. Eddy viscosities are approximated using an empirical relation based on Manning's coefficient and local flow variables.

2.2 Step-Pool Channel-Bed

Consolidation works are lateral constructions and sequence of building to expand protected area, particularly for high-gradient stream stabilization. The sequence of consolidation works is based on step-pool channel-bed (Mario Aristide Lenzi, 2002). The purpose is stabilizing the river bed and soil delivery by energy dissipation of consolidation works. Such as Figure 2.

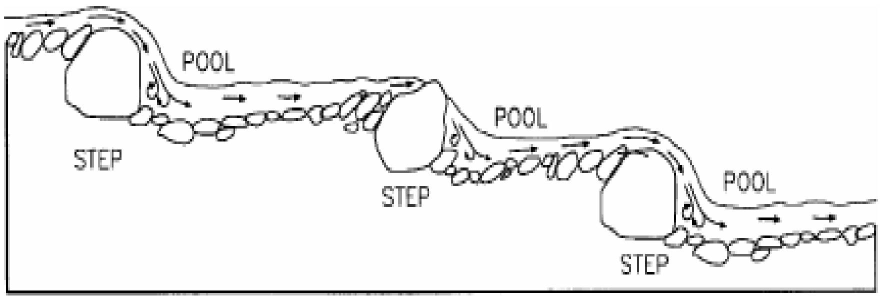


Figure 2 Step-pool channel-bed (Mario Aristide Lenzi, 2002)

2.3 Flow Diversity Index

There is diverse or non-similar individual existing in biological system. It was called diversity of individual and its degree of diversity was called "Diversity". The types of nature rivers flow are pool, slow water, riffles and rapids. The pools have the character of hide and slowing flow so it can provide fish with rest. The slow water is a transit strip or buffer strip between pools with riffles; aquatics agree with breed because of the slow flow of slow water; there also have high density microorganism gathering because of the speedy velocity of riffles and the high rate of the dissolve oxygen, it provides fish with foods.

Table 1 Habitats classification

Type	Fr	Others
Riffles	$0.255<Fr<1$	$b/h>15$
Slow run	$0.095<Fr<0.255$	$15<b/h<30$
Pools	$Fr<0.095$	Surface slope≒0 $b/h<15$
Rapids	$Fr>1$	No limiting

note: *b/h* is aspect ratio

Froude number represents the above-mentioned four types of flow. It is also the ratio of velocity (V) with flow depth (h). Lin (2002) gave a definition of the flow to class as Table 1. Habitat of natural rivers is full of variety. In order to understand the various habitats made by different consolidation works, we use Simpson's Diversity Index to represent the flow diversity index of this study. The Simpson's index was first proposed by the British statistician Edward Hugh Simpson in the paper in Nature in 1949.

$$D_S = 1 - \lambda \tag{1}$$

$$\lambda = \sum_{i=1}^{S'} Pi^2 = \sum_{i=1}^{S'} \left(n_i / N\right)^2 \tag{2}$$

Where D_S is Simpson's Diversity Index; P_i is proportion of the ith habitat type; n_i is amount of the ith flow type; N is total types of flow; S' is amount of some type and λ is Simpson's Index. The λ is regarded as dominance index or species evenness. It was taken a value between 0 and 1. If λ was taken to 1, the habitat is complete evenness. When D_S tend to 1, the habitat is diversification. There provides aquatic with many natural resources and flood asylum. (Gorman and Karr, 1978)

3. Result and Discussion

3.1 Numerical Model Selection

Wang and Po (2003) used SMS to simulate consolidation works experiment of Chang (2003). They had chosen RMA2 to simulate consolidation works. We had taken one step ahead to simulate consolidation works by different hydraulic conditions. We would find the best arrangement by energy dissipation analysis, result of flow regulation, and flow diversity index. Figure 3 is the study flowchart.

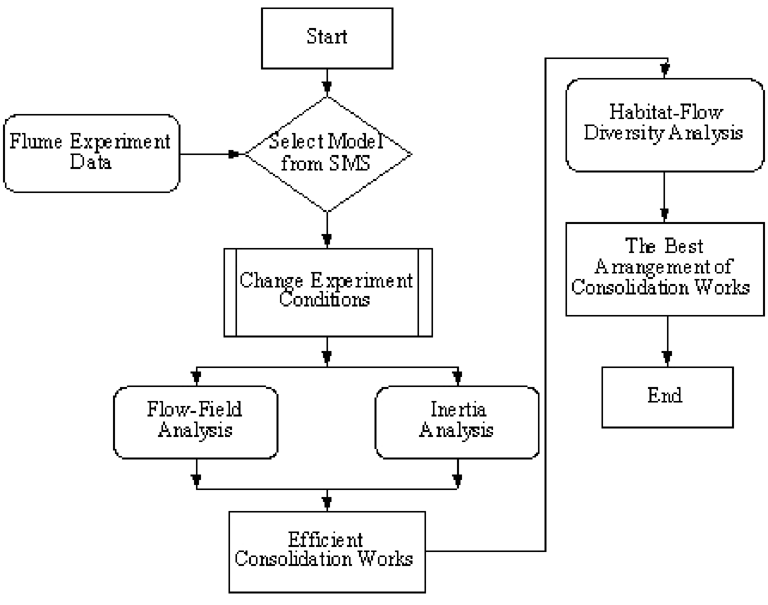


Figure 3 Study flowchart

Flume experiment arrangement of Chang (2003) is as Figure 4. Two sides of channel are smooth and aspect ratio is about 1:10. The effect of secondary flow can be neglected. Figure 5 is the interval of consolidation works arrangement. The length (L) of channel is 410cm, width (B) is 30cm, depth is 30cm and slope (S) is 0.1745%. The conditions of flume were simulated according to table 2. We compared the variation in three sections of channel, section A located downstream side 5cm from first consolidation work, section C located upstream side 5cm from second consolidation work and section B located between the two.

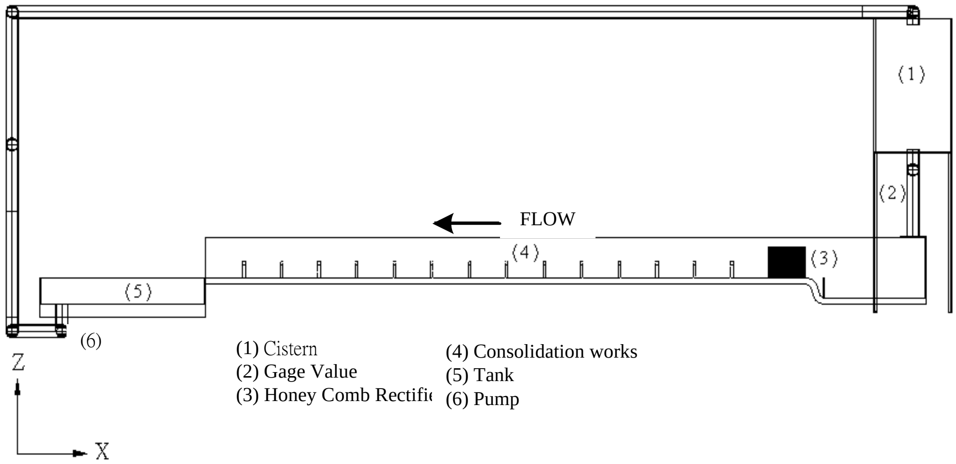


Figure 4 Arrangements of flume experiment

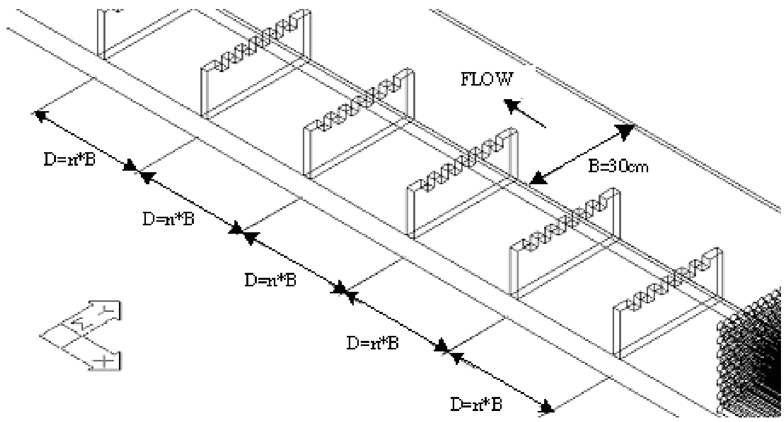


Figure 5 Arrangements of consolidation works

Table 2 Flume experiment parameters

Fluid experiment parameters				
Consolidation work	Q (cms)	S (%)	Z (simulate sections)	D (multiple of wide)
	0.0036	0.1745	A、B、C	4

The parameters of RMA2 and HIVEL2D were 25 times of those in flume experiments by similar law. The length of channel is 102.5m, width is 7.5m, and interval of the consolidation works is 30m. Numerical parameters are $\triangle x = 1.25$m and $\triangle y = 2.5$m respectively.

RMA2 and HIVEL2D were used to simulate flow depth, velocity and Froude number of channel (Table 3) that we compared with data of flume experiments. The result of RMA2 is better than HIVEL2D in this study. So we used RMA2 to simulate consolidation works.

Table 3 Error percentage of models simulation

Error percentage	Depth (%)	Flow velocity (%)	Froude number (%)
RMA2	-2.18～1.67	2.81～2.86	1.41～3.62
HIVEL2D	2.66～4.23	51.57～54.32	52.38～54.92

3.2 Result of RMA2 Simulation

The three sections A, B and C were analyzed in order to understand the variation of upstream and downstream consolidation works. In numerical model, Section A locates downstream side 1.25m from first consolidation work. Section C locates upstream side 1.25m from second consolidation work. Section B locates between the two; here we use Z-A, Z-B and Z-C to represent the foregoing sections respectively. The main research zone is a range of 13.75m to 71.25m from honey comb rectifier of upstream which are including seven consolidation works when the interval is equal to the channel width, or three consolidation works when it is 2 times of the channel width, or two consolidation works when it is 3 times of the channel width or one when it is 4 times.

We adopt three kinds of flow discharge: the small (Q1=3.75cms), middle (Q2=7.5cms) and large (11.25cms) in this study, and two kinds of slope (S1=0.1745% and S2=3.49%) to simulate conventional or saw-tooth consolidation works in order to find the best arrangement of consolidation works from the energy dissipation, and compare the result of flow regulation with the one of flow diversity index. The conditions of this study were coded such as Table 4.

The result shows that saw-tooth consolidation work is more complex and than conventional one in structure shape and it is more turbulence than conventional type when flow passes through saw-tooth consolidation work. Figure 6 and Figure 7 are the result of model simulation.

Table 4 Conditions of numerical models

	Q	S	D/B	R/H
Code	Q1 (3.75cms)	S1 (0.175%)	D1.5	0.5H
	Q2 (7.5cms)	S2 (3.50%)	D2.5	0.75H
	Q3 (11.25cms)		D3.5	1H
note: Q is the discharge. S is the slope of bed. D is the interval of two consolidation works. R is the interval of saw-tooth. B is the width of channel. H is the height of saw-tooth.				

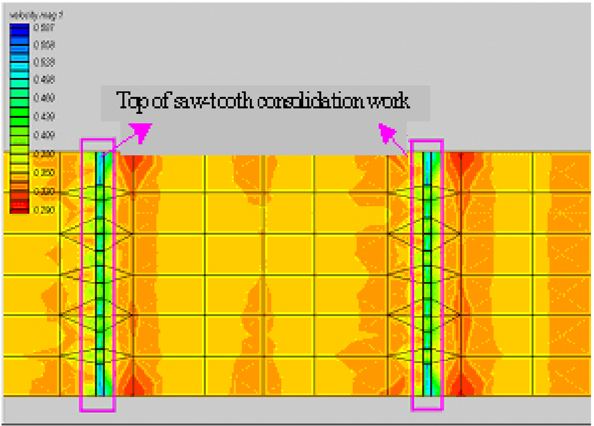


Figure 6 Simulation of saw-tooth consolidation work in RMA2

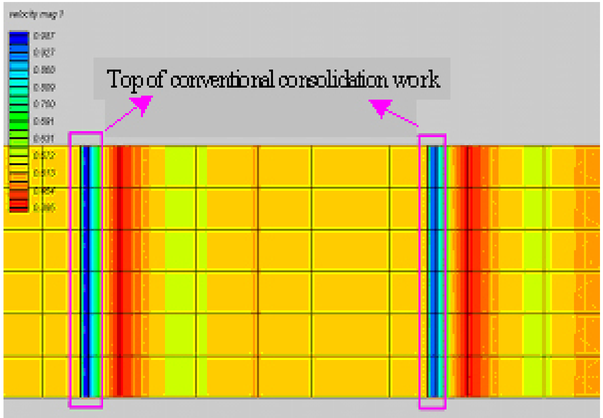


Figure 7 Simulation of conventional consolidation work in RMA2

(1) Energy Dissipation

Flow velocity is the main factor of riverbed scour; it has low transportable capability when the velocity is low, so the variation of bed is small. Consolidation works reduce energy to stable bed rely on stair arrangement. Figure 8 ～ Figure 11 are the comparisons of conventional or saw-tooth consolidation works in Section A and Section B respectively. In these charts, CCW represents conventional consolidation work and STCW represents saw-tooth type. We could find that the saw-tooth consolidation works are smaller than the conventional ones according to these charts. So we decided that the saw-tooth consolidation work has better energy dissipation than the conventional one. A viewpoint of safety, the saw-tooth consolidation work is better than conventional one. Touching upon the best ratio of interval, the best channel width for energy dissipation is 1.5 times secondly best is 2.5 times.

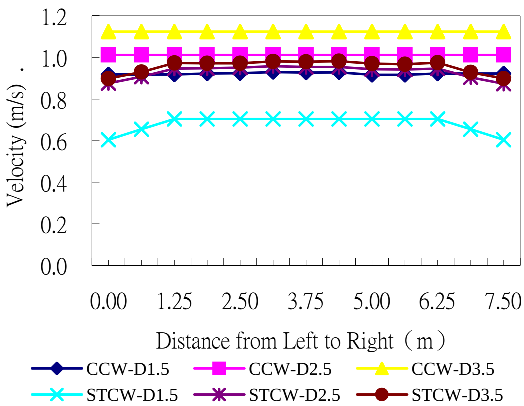


Figure 8 Relationship between flow velocity and arrangement of consolidation works (Q3S1Z-A)

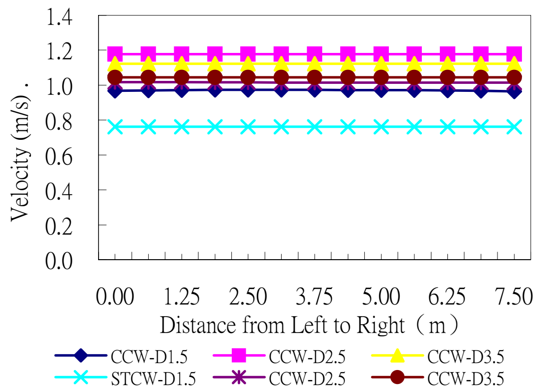


Figure 9 Relationship between flow velocity and arrangement of consolidation works (Q3S1Z-B)

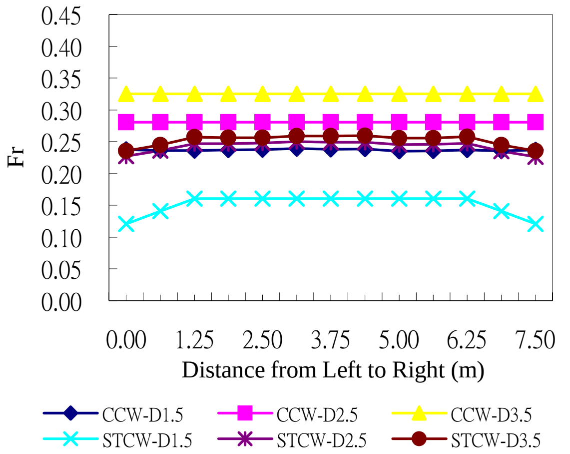


Figure 10 Relationship between Froude number and arrangement of consolidation works (Q3S1Z-A)

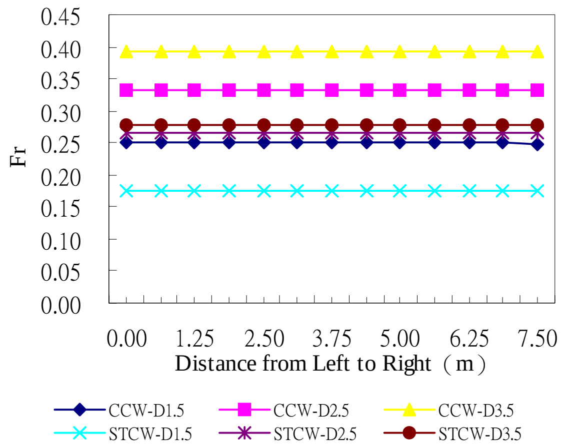


Figure 11 Relationship between Froude number and arrangement of consolidation works (Q3S1Z-B)

The velocity and Froude number have diversity when the arrangement of saw-tooth interval (R) and the height of saw-tooth are different. Therefore, this study went a step further to confer the energy dissipation when the saw-tooth interval is 0.5 times, 0.75 times and 1 times respectively as Figure 12. Figure 13 and Figure 14 are the comparison of velocity and Froude number with interval of saw at section A when slope is 0.1475%. Velocity and Froude number are least when saw-tooth interval is 0.75 heights of saw-tooth height, so the energy dissipation is superior when it is 0.75 times of saw-tooth height and this type of consolidation work is more safety.

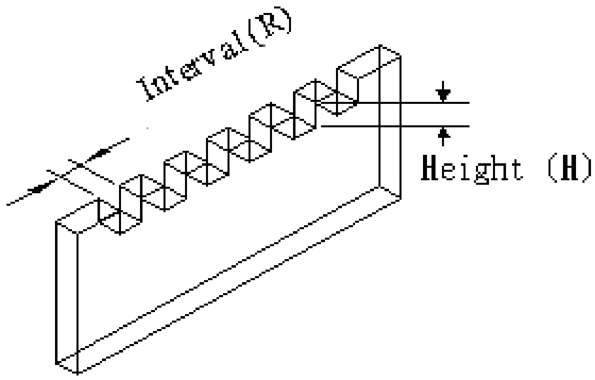


Figure 12 Interval of saw-tooth consolidation works

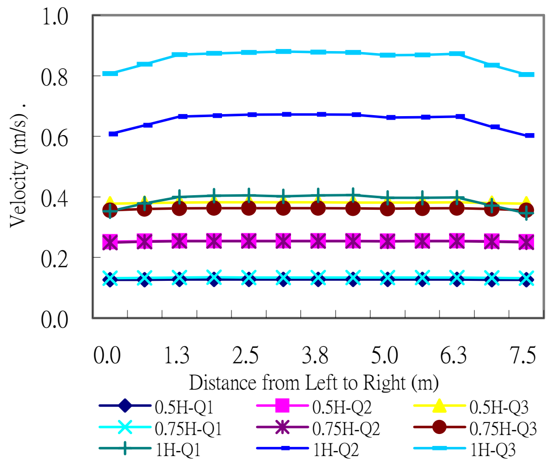


Figure 13 Comparison of flow velocity with intervals of saw-tooth in section A

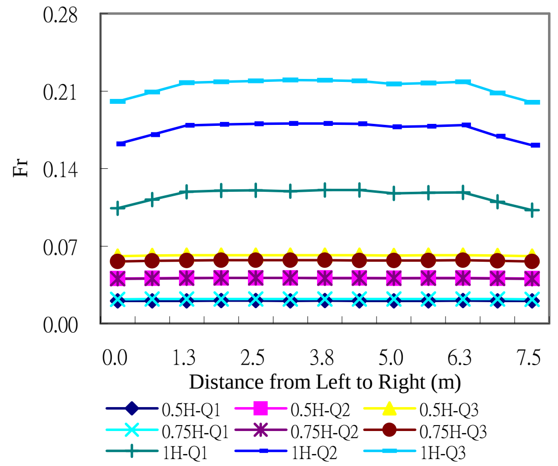


Figure 14 Comparison of Froude number with intervals of saw-tooth in section A

(2) **Flow Regulation**

The Froude number variation is difference of each point value (Fr_i) with average value ($\overline{Fr}$) in the same hydraulic conditions. The ratio of difference value to average value is:

$$\Delta Fr = \frac{Fr_i - \overline{Fr}}{\overline{Fr}} \tag{3}$$

The growth or decline of inertia and gravity can be expressed by variation rate of Froude number; two sides of the channel are minus when the center of the channel is growing up and therefore flow affects the inertia of bank of the channel less. Flow is controlled in center of the channel so it is safety and can reduce scour of river bank. According to these, we can find that variation of Froude number for the conventional consolidation work is smaller than saw-tooth type, such as Figure 15～Figure18; That shows inertia decline at the bank and therefore the saw-tooth consolidation work is better than the conventional one on flow regulation and has better protection of the bank. In different interval of saw-tooth consolidation works, the Froude number variation has close trend is similar to the value in addition.

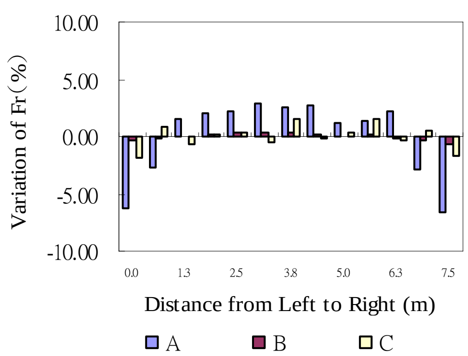


Figure 15 Froude number variation of saw-tooth consolidation work (Q3S1D1.5)

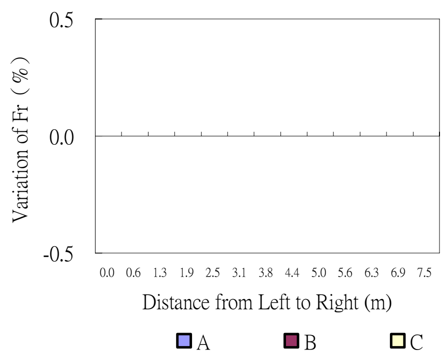


Figure 16 Froude number variation of conventional consolidation work (Q3S1D1.5)

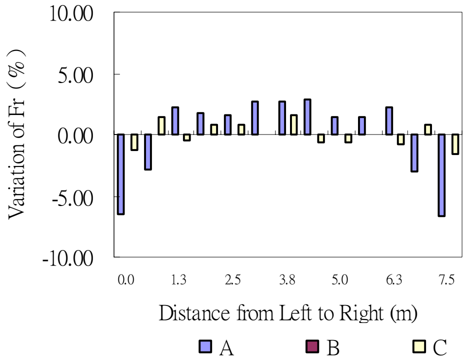


Figure 17 Froude number variation of saw-tooth consolidation work (Q3S1D3.5)

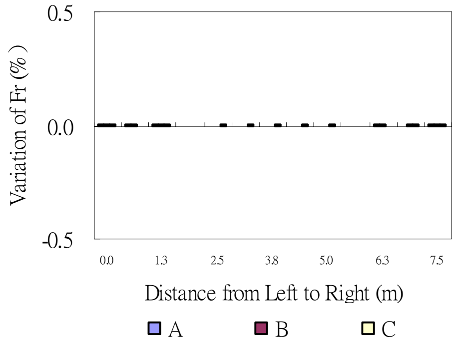


Figure 18 Froude number variation of conventional consolidation work (Q3S1D3.5)

(3) Habitat-Flow Diversity Index

We analyzed the flow diversity (D_S) in different hydraulic conditions and intervals of consolidation works or saw-tooth. If the flow diversity tends to 1, the habitat is diversified and fit for aquatic to exist. On the other hand, habitat is monotone and unfavorable for existing if it tends to 0.

The result shows that the habitat has the highest flow diversity by using a saw-tooth consolidation work with an interval 2.5 times of the channel width when the saw interval of the consolidation work was a three-fourths value of the saw width as Figure 19.

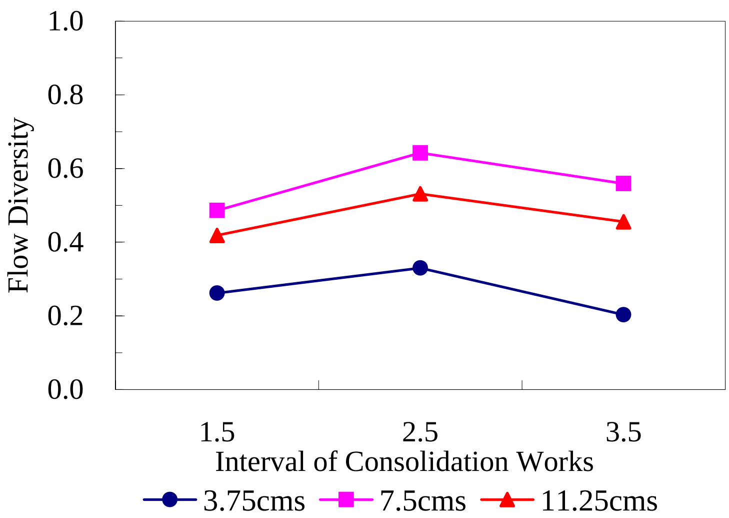


Figure 19 Relationships between flow diversity and arrangements of consolidation works (saw-tooth、S=3.5%、R=0.75H)

4. Conclusion

The following conclusions are drawn from this study.

1. In terms of energy dissipation and flow regulation, saw-tooth consolidation works are better than conventional consolidation works.
2. In the case of saw-tooth consolidation, the best ratio of interval to channel width for energy dissipation is 1.5 secondly best is 2.5.

3. The highest flow diversity index of habitat was observed for a saw-tooth consolidation work with an interval 2.5 times of the channel width.
4. Considering the economy of engineering, the safety requirement and the protection of ecology, the saw-tooth consolidation works with an interval 2.5 times of the channel width is a superior pattern.
5. On the other hand, when the interval of saw-tooth is 0.75 times of saw height, the saw-tooth consolidation works will produce better ratio of energy dissipation and flow diversity.
6. It will be a barrier for simulating a real condition of flow. Therefore, the study of 3-D simulating model is also a key point in research.

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