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出國地區：比利時

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赴比利時出席二００二年國際河川水力學會

主辦機關:

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出國類別: 其他

出國地區: 比利時

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分類號/目: G5／水利工程 G5／水利工程

關鍵詞: 帶工間距，溪流整治

內容摘要: 本次出席「2002年國際河川水力學會議」之目的有二：其一為發表研究論文一篇，題目為「Determination of Groundsills Interval for Stream Training（溪流整治之帶工間距研究）」，其二為學習河川水力的相關新知及經驗交換。就論文發表而言，個人以三年的研究成果，提出現行野溪整治中慣用的帶工間距設計公式，獲得與會專家的注意。本次國際會議的專題演講以「河川型態演變預測的數值模擬發展」、「泥砂輸送理論與實務間的互動」、「河川水力學之生態水力研究挑戰」、「河川工程之新趨勢」、「防洪與生態環境平衡之河川管理」等五大主題，勾畫出河川水力學未來研究的努力方向；其中的重點幾乎著重於河川治理與自然生態及環境之調和。雖然國內近一年開始推行「近自然生態工法」於坡地保育及溪流整治，但就工作的實際推動而言，仍無試驗研究可供設計依據。因此，國內確實有必要在河川水力、溪流整治及生態調查等基礎與應用研究上多下功夫，當然政府相關部門對基礎與應用研究的大力支助，仍是研究工作的最大動力。

摘要

本次出席「2002 年國際河川水力學會議」之目的有二：其一為發表研究論文一篇，題目為「Determination of Groundsills Interval for Stream Training （溪流整治之帶工間距研究）」，其二為學習河川水力的相關新知及經驗交換。就論文發表而言，個人以三年的研究成果，提出現行野溪整治中慣用的帶工間距設計公式，獲得與會專家的注意；尤其是義大利、日本及奧地利的專家學者。發表論文之後，甚至引發會後近一小時的討論，可謂為本次參加國際會議最大的收穫。

本次國際會議的專題演講以「河川型態演變預測的數值模擬發展」、「泥砂輸送理論與實務間的互動」、「河川水力學之生態水力研究挑戰」、「河川工程之新趨勢」、「防洪與生態環境平衡之河川管理」等五大主題，勾畫出河川水力學未來研究的努力方向；其中的重點幾乎著重於河川治理與自然生態及環境之調和，與目前國內新興的「近自然生態工法之溪流整治」恰好不謀而合。

雖然國內近一年開始推行「近自然生態工法」於坡地保育及溪流整治，但就工作的實際推動而言，仍無試驗研究可供設計依據。因此，國內確實有必要在河川水力、溪流整治及生態調查等基礎與應用研究上多下功夫，當然政府相關部門對基礎與應用研究的大力支助，仍是研究工作的最大動力。國內雖有較為優渥的研究資源，但資源的分配往往出現目標或任務導向，缺乏長時間人力與經費投資的遠見。在台灣特殊地形、地質與水文條件下所觀測或研究的成果，應持續給予經費支援，好讓國內的研究成果得以共享甚至貢獻予全世界。

目次

一、目的

本次出席「2002 年國際河川水力學會議」之目的有二：其一為發表研究論文一篇，題目為「Determination of Groundsills Interval for Stream Training （溪流整治之帶工間距研究）」，其二為學習河川水力的相關新知及經驗交換。此次出國參加國際學術研討會，承蒙教育部給予補助，甚感榮幸，核定補助文號：台(九一)文(二)九一〇九六七二一號。

二、過程

- 91.9.2. – 啟程前往比利時。
- 91.9.3. – 抵達比利時魯汶大學會議地點、辦理報到。
- 91.9.4. –「2002 年國際河川水力學會議」於上午 9:00 開幕，本次國際會議與會人數達 214 人，分別來自世界三十五個國家。會議中分三天安排五位專家進行專題演講（keynote speech），其演講的重點針對河川型態演變預測的數值模擬發展（Model-based morphological prediction: From art to science）、泥砂輸送理論與實務間的互動（Sediment transport, from theory to practice, or the other way round?）、河川水力學之生態水力研究挑戰（Ecohydraulics, last frontier for fluvial hydraulics: Research challenges and multidisciplinary perspectives）、河川工程之新趨勢（Novel approaches in river engineering）、防洪與生態環境平衡之河川管理（River management for hydraulic harmony between flood control and environmental considerations）等五大主題，提出未來在河川水力學上仍需要努力的方向。

  本次國際會議由國際水力研究學會(International Association of Hydraulic Research ; IAHR）主辦。會議的進行方式，乃是採分組討論分不同場地同步進行。與會人士可依其興趣與所需，自由穿梭於會場間。分組討論的主要議題包括：河川水力動力學（Hydrodynamics of river flow）、河川之泥砂輸送（Sediment transport in rivers）、河川模型之相關技術與工具(Tools for river flow modeling）。

本日各主議題下的子議題如下：

I. 河川水力動力學：

(1).紊流之混合與擴散機制（Turbulent flow, mixing and diffusion processes）

(2).河道糙度與植生互動影響之訂定（Resistance determination, interactions with vegetation）

(3).河道整治構造物與河流之互動（Interactions between rivers and river control structures, effects of obstacles and river training structures）

(4).潰壩水力學（Rapid transients and dam-break hydraulics）

II. 河川之泥砂輸送

(1).泥砂輸送與河岸破壞力學（Sediment transport and bank failure mechanisms）

(2).河川型態學與型態動力學（River morphology and morphodynamics）

(3).結構物所引發之局部淘刷現象（Interactions with structures, local scour phenomena）

III. 河川模型之相關技術與工具

(1).河川監測與調查之遙測技術（Field instrumentation and remote sensing methods for river monitoring and survey）

- 91.9.5. – 本日各主議題下的子議題如下：

I. 河川水力動力學：

(1).洪水傳遞（Overbank flows, flood propagation）

(2).河道糙度與植生互動影響之訂定（Resistance determination, interactions with vegetation）

(3).河道整治構造物與河流之互動（Interactions between rivers and river control structures, effects of obstacles and river training structures）

II. 河川之泥砂輸送

(1).泥砂輸送與河岸破壞力學（Sediment transport and bank failure mechanisms）

(2).河川型態學與型態動力學（River morphology and morphodynamics）

(3).結構物所引發之局部淘刷現象（Interactions with structures, local scour phenomena）

III. 河川模型之相關技術與工具

(1).河川監測與調查之遙測技術（Field instrumentation and remote sensing methods for river monitoring and survey）

- 91.9.6. –下午發表研究論文「Determination of Groundsills Interval for Stream Training （溪流整治之帶工間距研究)」。本日各主議題下的子議題如下：

I. 河川水力動力學：

(1).洪水傳遞（Overbank flows, flood propagation）

(2).河川水力學與生態之互動（Interactions between river hydraulics and ecology）

II. 河川之泥砂輸送

(1).泥砂輸送與河岸破壞力學（Sediment transport and bank failure mechanisms）

(2).河川型態學與型態動力學（River morphology and morphodynamics）

(3).洪流引發之大型土體移動與土石流（Soil movements and debris flows associated with river floods）

(4).結構物所引發之局部淘刷現象（Interactions with structures, local scour phenomena）

(5).污染源交換機制（Exchange processes between river bed and water column, dispersion of pollutants through sediment transport）

- 91.9.7.－會後參觀。參觀目前列入 UNESCO 世界文物遺產的 Canal du Centre 及 Strepy-Thieu boatlifts。

- 91.9.8.－會議結束，準備返台。

三、心得

本次出席「2002 年國際河川水力學會議」之目的，除發表研究論文外，其二為學習河川水力的相關新知及經驗交換。就論文發表而言，個人以三年的研究成果，提出現行野溪整治中慣用的帶工間距設計公式，獲得與會專家的注意；尤其是義大利、日本及奧地利的專家學者。主要因為這些國家的地形地勢大略與我國相似，山區野溪的問題幾乎可謂同出一轍，以至於所要解決的問題共通性高。本次發表論文之後，甚至引發會後近一小時的討論，可謂為本次參加國際會議最大的收穫。

本次國際會議的專題演講以「河川型態演變預測的數值模擬發展」、「泥砂輸送理論與實務間的互動」、「河川水力學之生態水力研究挑戰」、「河川工程之新趨勢」、「防洪與生態環境平衡之河川管理」等五大主題，勾畫出河川水力學未來研究的努力方向；其中的重點幾乎著重於河川治理與自然生態及環境之調和。

過去以人為本的治水觀念，在自然生態與資源保育意識的抬頭趨勢下，河川的治理開始有了轉變，在不危及河川下游保全對象生命財產安全的前提下，應儘量維繫河川週遭自然生態的繁衍與河道的自然發展。因此，本次會議的宗旨與目前國內新興的「近自然生態工法之溪流整治」恰好不謀而合。

國內過去的河川及溪流整治一直都是採用傳統的防洪觀念，以護岸及河工構造物來預防洪水的氾濫及河道的縱、橫向淘刷，雖可以達到預期的效果，但卻因為河川下游保全對象的增加，而迫使設計之洪水重現期距向極端事件修正。結果導致堤防或護岸的加高，使得原有瀕臨河岸而居的生態物種被阻絕於水域之外，而最終導致瀕水區域生態圈的改變或滅絕。

雖然國內近一年開始推行「近自然生態工法」於坡地保育及溪流整治，但就工作的實際推動而言，仍無試驗研究可供設計依據。由於河川及生態的多樣性與奇異性，使得若要完全抄襲國外的既有研究成果，在實做上仍有「畫虎不成反類犬」的安全疑慮。因此，國內確實有必要在河川水力、溪流整治及生態調查等基礎與應用研究上多下功夫，當然政府相關部門對基礎與應用研究的大力支助，仍是研究工作的最大動力。

另一個值得國內從事相關研究的研究群深思的議題，在於跨專業的合作。「近自然生態工法應用於河川或溪流整治」，必須結合水力工

程、泥砂輸送、生態保育及河相學等相關領域的研究人員，各就其專長提出不同的看法，以營造出接近自然的瀕水環境。如此營造出來的環境才能達到「工法自然化」及「環境生態化」的最高境界。

加速研究成果的國際化，是此次與會的另一個心得。國內相關政府部會及學術單位不斷地投入人力、物力與財力於河川及溪流的治理工作上，而更積極爭取旅外學人歸國貢獻其於河川治理的經驗。目前政府相關部門更積極推動「四大流域整體治理規劃」，無論未來的成績如何，應可提供做為國際相關案例的參考，更應積極吸取國外相關案例治理的經驗，以做為未來整體治理規劃修正的參考。

國內雖有較為優渥的研究資源，但資源的分配往往著重於目標或任務導向，缺乏長時間投資的遠見，使得原先辛苦建立的試驗或長時間觀測的重要資料等，流於中斷或被迫停擺的命運。在台灣特殊地形、地質與水文條件下所觀測或研究的河川水力成果，應持續給予經費支援，好讓國內過去及未來的研究成果，得以共享甚至貢獻予全世界。

四、建議

本次應邀參加「2002 年國際河川水力學會議」的會後建議條列如下，如有需要進一步瞭解之處，請參考本報告的「三、與會心得」部份。

1. 目前國內開始推行「近自然生態工法」於坡地保育及溪流整治，但就工作的實際推動而言，仍無試驗研究可供設計依據。因此，國內確實有必要在河川水力、溪流整治及生態調查等基礎與應用研究上多下功夫，當然政府相關部門對基礎與應用研究的大力支助，仍是研究工作的最大動力。「近自然生態工法」無論用於坡地保育或河川整治，已為國際趨勢，以剛起步的台灣而言，實應多向外吸取經驗。因此建議　鈞部繼續維持對國內專家學者出席國際會議的補助：尤其是參加自然科學相關的國際會議，除增加我國在國際學術舞台的曝光率與知名度外，更可讓國內專家學者增廣見聞，跟隨甚至領導國際學術研究的腳步。

2. 國內雖有較為優渥的研究資源，但資源的分配往往著重目標或任務導向，缺乏長時間投資的遠見，使得原先辛苦建立或長時間觀測的重要資料，流於被迫中斷甚至停擺的命運，最後導致對研究課題的片面瞭解。建議 貴部及相關部會應持續給予經費支援，好讓國內的研究成果，得以共享甚至貢獻予全世界。

3. 建議 鈞部鼓勵受補助出席國際會議的學者專家，於與會期間主動參與、爭取或協助國際學術研討會的舉辦，並於適當時機給於行政或經費上的協助。

附　　　　錄

（發表論文之全文影本）

PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON FLUVIAL HYDRAULICS / LOUVAIN-LA-NEUVE / BELGIUM / 4–6 SEPTEMBER 2002

River Flow 2002

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Determination of groundsills interval for stream training

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ABSTRACT: Check dams or known as sabo dams as well as groundsills have been considered as the standard practices in stream training and management in Taiwan. The installation of groundsills often follows the same design criterion of check dams; regardless their different characteristics geometrically and hydraulically. Hence, the objective of this study is to identify the suitable installation interval between groundsills through indoor hydraulic experiments for various stream widths, flow rates, channel slopes, and sediment sizes. An empirical equation was obtained and assessed results were used to compare with outdoor-regulated channel reach.

1 INTRODUCTION

Steep terrain has made the slopes of most streams in Taiwan run steep, therefore, check dams that also known as sabo dams and groundsills have become the standard practices in stream training and management. They both serve the purposes of preventing longitudinal and lateral scour at streambed. Check dams also assist to control the course of flow and suppress sediment from entering downstream to minimize the possible damage.

Geometrically, the face of a check dam consists of wing walls and spillway with the effective height exceeding 5 m above ground elevation; whereas, the groundsill is no more than a concrete beam installed flush with the channel bed. Groundsills are often constructed in series at relatively mild channel reach; while sequential check dams are only constructed whenever needed.

For sequential check dams and groundsills, same design criterion in determining structure interval was used (Council of Agriculture, 1995). The criterion states that:

$$L = \frac{100}{n - m} h \tag{1}$$

where L = structure interval (m); n = channel bed slope (%); m = intended silt slope (%); h = elevation difference in the channel reach to be protected or effective dam height (m).

Even though both structures share the same standard, the determination of parameter values in Equation 1 for sequential groundsills often requires past experiences. Trial-and-error and limited sediment trapping capacity of groundsills often result the elimination of parameter m in Equation 1 and taking subjective value of h between 0.7 and 1.0 depending upon the size distribution of streambed material.

Hydraulically, greater fall height of the check dam provides the natural setting for hydraulic jump to occur; whereas, groundsills behave as submerged weirs. Hence, different magnitude of energy dissipation as well as scale of channel scour instinctively disintegrates both structures from sharing the same design guideline. Accordingly, the objective of this study is to identify the suitable installation interval for sequential groundsills through indoor hydraulic experiments.

2 DIMENSIONAL ANALYSIS

Different groundsill intervals will apparently affect the channel scour, and the characteristics of the scour will in turns affect the eroding sediment leaving the scour holes and the flow field within as well as above.

For a trained stream or a stream under training, revetments on both banks often confine the flow field. If the stream channel is further confined by series of groundsills, the characteristics of the scour in a straight but restrained channel reach can be simplified as the ratio of (d_{sc}/L_{sc}) where d_{sc} = the maximum scour depth occurs within a groundsill interval; and L_{sc} = horizontal length measured from the lower rim of the upstream groundsill to the point where maximum scour depth occurs within the same interval.

The development of the scour viewing from the ratio of (d_{sc}/L_{sc}) is not only affected by the flow regime but also by the attributes of the sediment. Hence the functional equation governing the development of scour within a pair of groundsills can be written as:

$$\frac{d_{sc}}{L_{sc}} = f(Q, B, L_l, S, h, D_{50}, \rho_s, \rho, g, \mu) \quad (2)$$

where Q = flow rate; B = channel width; L_l = groundsill interval; S = hydraulic gradient; h = average flow depth; D_{50} = median diameter of the sediment; ρ_s = density of the sediment; ρ = density of the flow; g = acceleration of the gravity; and μ = flow viscosity.

Equation 2 can be further reduced under the concept of unit width and the assumption of symmetric scour with respect to the centerline as:

$$\frac{d_{sc}}{L_{sc}} = f(q, L_l, S, h, D_{50}, \rho_s, \rho, g, \mu) = f(V, L_l, S, h, D_{50}, \rho_s, \rho, g, \mu) \quad (3)$$

where q = unit-width flow rate and V = mean flow velocity.

By taking mean flow velocity (V), average flow depth (h), and flow viscosity (μ) as repeated variables, total of six dimensionless Π terms can be derived as:

$$Y = f(\Pi_1, \Pi_2, \Pi_3, \Pi_4, \Pi_5, \Pi_6)$$
$$Y = \frac{d_{sc}}{L_{sc}}$$
$$\Pi_1 = S$$
$$\Pi_2 = \frac{\rho_s - \rho}{\rho}$$
$$\Pi_3 = \frac{D_{50}}{h} \quad (4)$$
$$\Pi_4 = \frac{\rho V h}{\mu} = Re$$
$$\Pi_5 = \frac{V}{\sqrt{gh}} = Fr$$
$$\Pi_6 = \frac{h}{L_l}$$

where Y = relative scour shape factor; Π_1 = hydraulic gradient; Π_2 = submerged specific gravity of the sediment; Π_3 = relative roughness; Π_4 = Reynolds number; Π_5 = Froude number; and Π_6 = relative flow depth with respect to the groundsill interval.

Since the gravitational force dominated in the open-channel flow, therefore the Reynolds number seldom plays significant role. In addition, the relative roughness defined as the ratio of sediment median diameter and average flow depth may not be one of the key components in the scour development between groundsills. It is simply because the non-erodible nature and the spacing (or interval) of the groundsills controls the characteristics of the scour or the relative scour shape factor.

Since the plunging force of the flow and the submerged weight of the sediment control the relative scour shape factor, the relative scour shape factor can then be simply viewed as the tractive force per unit channel bed exerted on sediment unit area. It can also be expressed as:

$$\frac{d_{sc}}{L_{sc}} = Y = f(\Pi) = f\left(\frac{ma/A}{m_s g S/A_s}\right) \quad (5)$$

where m = mass of the flow; a = the average acceleration of the flow; A = area of the channel bed between two groundsills; m_s = the mass of the sediment; g = acceleration of the gravity; S = hydraulic gradient or channel slope; and A_s = sediment unit area.

The Π term thus defined can be further arranged as follows:

$$\Pi = \frac{ma/A}{m_s g S/A_s} = \frac{m\dot{V}/A}{m_s g S/A_s} = \frac{\dot{m}V/A}{m_s g S/A_s} = \frac{\rho Q V/BL_l}{\rho(S_g - 1)g S D_{50}^3/D_{50}^2} = \frac{qV}{(S_g - 1)g S D_{50} L_l} \quad (6)$$

Furthermore, considering groundsills as submerged weirs that critical depths gradually develop in the course of scour development, Equation 6 can be re-arranged as:

$$\Pi = \frac{q\left(\frac{q}{y_c}\right)}{(S_g - 1)g S D_{50} L_l} = \frac{q^{4/3}}{(S_g - 1)g^{3/2} S D_{50} L_l} = \frac{1}{(S_g - 1)S D_{50} L_l}\sqrt[3]{\frac{q^4}{g^2}} \quad (7)$$

3 EXPERIMENTAL APPARATUS, MATERIAL, AND PROCEDURES

3.1 *Hydraulic flume and model groundsills*

This study was conducted using a semi-circulated hydraulic flume in Steepslope Hydraulics Laboratory at National Pingtung University of Science and Technology. The flow supply network that connecting head- and tail tank of the flume and a underground storage reservoir completed a circulation; whereas, sediment that left the hydraulic flume was kept in a stilling basin located at the tail end of the flume.

The flume measured 4 m in length, 0.91 m in width, and 0.30 m in depth with the adjustable slope up to 11%. Channel slopes used in this study consisted of 2, 4, 6, and 8%. A pair of revetments with the slope of 1 : 0.3 (V : H) that running the full length of the flume was furnished to simulate the commonly-adopted revetments. The top width of the experimental channel that constrained by revetments could be freely adjusted as desired. Total of four channel widths; 0.1, 0.2, and 0.4 m representing 5, 10, and 20 m of the prototype; were used in this study. Once the channel width was set, a series of model groundsills was installed in the channel to form sequential groundsills.

Model groundsills in the scale of 1:40 were cut from 14-mm thick waterproof plywood with various lengths to suit the selected channel width. The width of the model groundsill perpendicular to the flow direction was set at 0.15 m so that the top and bottom rim of the groundsill became flush with the sand-filled channel bed and the flume bed respectively. In order to maintain the stability of groundsills in the channel throughout the experiment, silicone seal was applied around the perimeter of the groundsills. Silicone seal was also applied at the bottom of the revetments to prevent water from seeping out of the test channel. After the seal was set, experiment sand was filled and carefully leveled. The end product of the entire experiment setup is shown in Figure 1.

Figure 1. Flume and experiment setup.

3.2 *Flow regulation*

The inflow rate was regulated by a set of gate valves, which consisted of one inlet and one return valve. When the water supplied by the constant-speed pump exceeds the required inflow rate, the excess inflow was routed through the return valve back to underground reservoir.

Flow rates that selected for this study were 0.0006, 0.0014, 0.0020, and 0.0028 cms; which represented the flow rate of 10.61, 24.75, 35.36, and 49.50 cms of the prototype respectively. With the combination of selected channel widths, these flow rates produced a total of 12 unit-width flow rates to run experiments on.

3.3 *Velocity measurement*

Velocity measurements in this study consisted of surface velocity and velocity profile measurements. Surface velocity measurements were taken for each experiment run; whereas, velocity profile measurements were taken only for pre-selected experiment conditions.

Due to the shallow depth and turbidity of the flow, limited options of velocity measurement techniques were available. Hence, either float method or dye method was used for surface velocity measurement. Floats with average area of 4 mm^2 and thickness of 0.5 mm were cut from high-density Styrofoam. Total of 20 surface velocity measurements were taken within the reach of 1.8 m centered at the experiment channel to eliminate the effect of inlet and outlet control sections. As flow became rough due to the occurrence of scour at the channel bed that often made floats less suitable for velocity measurement, dye method was used instead.

As for velocity profile, a 1.6-mm OD Pitot tube connecting to a differential pressure transducer, A/D converter, and personal computer was used for measurements and data acquisition. Velocity profile measurements in the depth direction were set at 1-mm increment and they were carefully executed towards the free surface to the extent so that basic rules for velocity measurement using Pitot tube were followed.

Signals were captured at 1-second interval but monitored continuously. They were recorded as long as needed for each measurement point so that at least 60 acceptable data were stored for later analysis. Once the velocity profile was completed, Pitot tube was moved to the next section within the same groundsill reach and velocity profile measurements continued.

3.4 *Flow- and channel-surface profile measurement*

A digital point gauge with the accuracy of 0.1 mm was used for flow- and channel-surface profile measurement. A series of waterproof rules with the accuracy of 1 mm was glued to the sidewall of the revetment for quick reference during flow-surface profile measurement. Measurements were taken for all groundsill reaches within the 1.8-m experiment reach, and total of five repetitions was gauged during the course of a run.

Channel-surface profile was measured at the end of each run. Outlet of the experiment channel was first blocked, water supply was cut off, and the flow that trapped in the channel was slowly drained to prevent possible downfall of less cohesive profile.

3.5 *Experiment sand*

Sand originated from river sediment was purchased from local factory. They came with three distinguishable median sizes (d_{50}): 0.595, 0.912, and 1.770 mm. These median sizes; if converted back to that of the prototype using the scale of 1:50, represented 29.75, 45.6, 88.50 mm respectively.

3.6 *Procedure*

The independent variables considered in this study included flow rate, channel widths and slopes, sediment sizes, and groundsill intervals. For the ease of experiment setup, channel width and slope was first selected randomly and set. Model groundsills were then fixed in place with each groundsill face set perpendicular to the horizon. As all the structures in place, Silicon seal was applied and set aside for settlement.

Cavities between groundsills were then filled with pre-selected experiment sand to the rims of groundsills. Sediment thus filled was carefully wetted manually without causing erosion or apparent sediment size changes on the surface. Additional experiment sand were then refilled to compensate the possible consolidation so that the end product of the mobile bed remained flushed with groundsills.

Flow rate that previously determined was calibrated for 30 minutes prior to the start of an experiment run. To achieve the tranquil condition, inflow had to go through a perforated chamber in the head tank. A Styrofoam pad with an adjustable counter-weight mechanism was installed at the entrance of the flume to eliminate the cross-waves that caused by surface tension at the entrance.

Flow-surface profile and surface velocity measurement started around ten minutes after the introduction of inflow to the channel. A single experiment run often took an hour to complete all measurements except channel-surface profiling. For those pre-selected experiment conditions that velocity profile measurement were required, a single run might last more than four hours depending upon the groundsill interval.

At the end of an experiment run, sediment in the cavities between groundsills was removed and sediment with different median size was refilled in the same manner. Experiments continued. With the combinations of four channel slopes, three channel widths, four inflow rates, four groundsill intervals, and three sediment sizes, a total of 576 runs were conducted in this study.

4 RESULTS AND DISCUSSIONS

4.1 *Effect of sediment size to scour*

Sediment size has a dominating effect on the submerged weight, which also affects the angle of repose, incipient motion, and sediment transport. All these contribute to different scour in a channel.

As for the effect of sediment size to the maximum scour depth d_{sc} is concerned, smaller the sediment size, deeper the maximum scour depth. The sediment size also affects the location of maximum scour depth. Smaller the sediment size, further the maximum scour depth migrates downstream.

Pseudo-plunged flow (Vischer & Hager 1998) was observed during the experiment. It occurred immediately downstream of the groundsill as scour developed, which initiated the sediment movement. As scour deepened, pseudo-plunged flow became more and more apparent and flow became circulating inside the scour.

For sediment already set in motion by plunged flow, the sediment size appeared to have no effect at all escaping from circular motion of the flow. The chances for sediment leaving the scour hole became dependent upon the flow rate, channel slope, groundsill spacing, as well as the slope and velocity gradient along the adverse slope of the scour.

4.2 *Effect of groundsill interval to scour*

The major effect of groundsill interval to the channel bed is the constraint of scour development. As groundsill interval shortens, sediment entrained by the pseudo-plunged flow becomes less easily to escape from the scour hole. The flow depth on top of the groundsill rim becomes deepened that greatly retards the velocities of the pseudo-plunged flow just leaving the scour. A submerged hydraulic jump thus occurs.

On the other hand, pseudo-plunged flow can freely attack the sediment in the scour hole as groundsill spacing widens. Velocities of the pseudo-plunged flow become less affected by the backwater effect brought by downstream groundsill. Therefore, entrained sediment has better hydraulic environment to escape from the scour hole. If submerged hydraulic jump does occur in long groundsill spacing, the submergence of submerged hydraulic jump also decreases by the same reason.

Figures 2–4 are velocity profile measurements conducted under the same experiment condition except

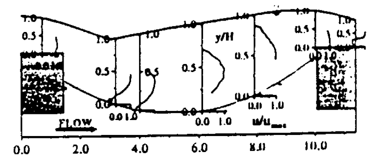

Figure 2. Velocity profile between groundsills (L_I = 0.1 m).

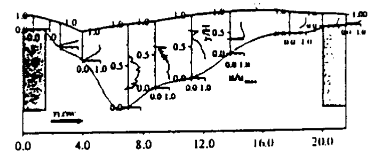

Figure 3. Velocity profile between groundsills (L_I = 0.2 m).

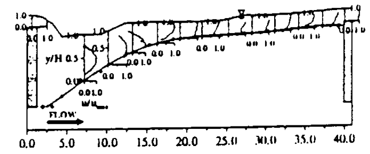

Figure 4. Velocity profile between groundsills (L_I = 0.4 m).

the groundsill interval. The horizontal and vertical axis of the velocity profile is defined as u/u_{max} and y/H respectively; where H = the flow depth at the velocity measurement station; y = location of the measurement in the flow-depth direction; u_{max} = the maximum measured velocity at the station; and u = the measured point velocity at location y. These figures may help illustrate the viewpoint that previously described.

Since the groundsill spacing restricts the development of the scour, the scour as well as the channel profile at the end of each experiment run can be simply cataloguized into Bedforms S, M, and L respectively as shown in Figure 5.

Bedform S represents the strongest constraint the short groundsill interval places on scour development. During the development of Bedform S, submerged hydraulic jump dominates the flow regime. The flow encounters a direct hit to the downstream groundsill structure.

Bedform M represents the hydraulic environment that favors the scour development. Pseudo-plunged flow becomes more apparent as compared to the Bedform S situation. The interaction of plunging flow and mobility of the sediment becomes distinct.

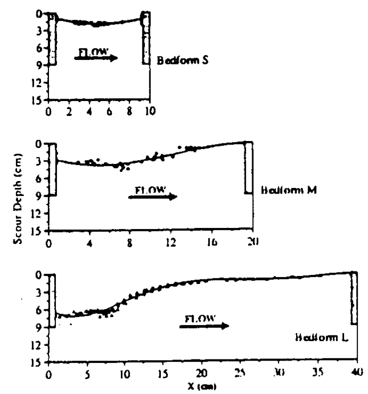

Figure 5. Different bedforms due to groundsill constraint.

As for Bedform L, pseudo-plunged flow dominates the flow regime in the scour hole and long groundsill spacing provides favorable adverse ramp for sediment to escape. Once leaving the scour hole, the mobility of the sediment dominates its transport behavior and flow gradually recovers its velocity and ready to provide the next impact downstream.

4.3 *Effect of channel slope to scour*

Slope of the channel plays its role in scour formation in three folds: (1) It affects the stability of the sediment in the scour hole, (2) It influences the duration required for flow to change from pseudo-plunged to submerged hydraulic jump, and (3) It alters the submergence of submerged hydraulic jump.

As channel slope steepens, the inflow that entering the groundsill interval takes relatively shorter duration to change from pseudo-plunged into submerged hydraulic jump. At the meantime, the degree of submergence deepens which produce deep scour. Figure 6 illustrates the effect of channel slope to scour profile at groundsill interval of 0.2 m which is equivalent to the interval of 10 m for prototype.

4.4 *Combined effects of hydraulic condition to scour*

As indicated in the previous section, profiles of the scour can be grouped into three distinct forms that fully demonstrate the restriction of groundsills exert on scour development. Bedform S only occurs in short groundsill interval; namely L_I = 0.05 m in this study. The occurrence of Bedform M covers the moderate

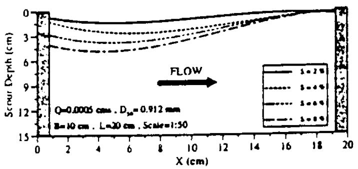

Figure 6. Scour profiles caused by different channel slopes.

Table 1. Experiment results for groundsill interval of 0.2 m.

Y*	Π*	Y	Π	Y	Π
0.36	727.06	0.37	789.48	0.18	385.37
0.28	426.15	0.29	372.89	0.24	406.78
0.26	1157.48	0.39	1041.73	0.30	1228.71
0.31	1041.73	0.27	39.29	0.29	1089.09
0.26	777.70	0.36	818.42	0.35	789.48
0.28	781.59	0.39	789.48	0.33	785.51
0.31	551.99	0.07	560.53	0.16	590.99
0.18	560.53	0.06	610.91	0.32	870.55
0.30	155.09	0.30	156.26	0.37	156.26
0.39	152.79	0.34	156.26	0.33	81.33
0.30	82.59	0.16	80.72	0.41	238.31
0.38	241.33	0.53	160.93	0.51	160.53
0.49	162.58	0.72	165.54	0.57	109.53
0.45	110.09	0.54	109.53	0.52	110.65
0.48	173.55	0.50	173.11	0.64	169.63
0.36	174.90	0.37	103.54	0.36	105.12
0.52	60.52	0.59	60.82	0.59	31.23
0.81	31.60	0.63	61.15	0.72	61.46
0.73	60.85	0.79	60.95	0.53	42.17
0.54	41.96	0.63	42.24	0.65	42.24
0.68	65.75	0.70	65.31	0.65	66.87
0.62	65.31	0.54	40.20	0.53	40.68
0.25	40.00	0.50	40.13	0.71	31.08
0.65	12.75	0.84	30.93	0.61	12.64
1.04	31.01	0.81	31.04	0.76	12.74
0.65	12.55	0.79	31.04	0.58	30.97
0.67	12.67	0.61	12.70	0.93	33.87
1.15	33.79	0.71	20.55	0.87	33.62
0.69	20.70	0.82	20.62		

* Y and Π are arranged according to Equation 8.

to short groundsill intervals; namely $L_I = 0.1$ m. On the other hand, Bedform L occurs in moderate to long groundsill interval; namely $L_I = 0.2$ and 0.4 m in this study.

Because of the strong restriction of short groundsill interval imposed on scour development, experiment results obtained from Bedforms S and M are excluded from the dimensional analysis. The rest of the data

Table 2. Experiment results for groundsill interval of 0.4 m.

Y*	Π*	Y	Π	Y	Π
0.14	1015.19	0.36	1004.83	0.28	502.37
0.25	545.58	0.26	545.58	0.25	539.78
0.33	1437.50	0.31	1472.57	0.34	1494.43
0.17	520.40	0.34	1004.83	0.32	1064.58
0.47	516.15	0.47	518.81	0.36	525.56
0.38	510.93	0.40	350.40	0.41	350.40
0.26	350.40	0.39	341.66	0.46	193.94
0.66	186.98	0.49	195.89	0.38	101.70
0.13	102.47	0.35	101.44	0.57	305.61
0.66	205.36	0.75	202.76	1.03	200.73
0.55	139.06	0.46	138.35	0.58	140.49
0.62	138.70	0.79	212.65	0.69	210.55
0.33	205.46	0.62	210.03	0.56	130.13
0.26	135.54	0.83	75.99	2.18	74.50
0.67	39.48	0.64	38.14	1.21	77.94
1.07	77.94	1.05	78.08	1.42	78.35
1.01	32.49	1.08	32.49	0.90	32.55
0.90	31.24	0.49	60.54	3.64	59.41
1.03	60.54	1.26	60.01	0.92	38.08
0.72	38.23	0.83	38.62	0.67	37.61
4.74	39.31	5.71	16.07	0.75	39.16
1.30	3.55	1.83	39.21	1.75	16.05
0.97	38.97	1.25	39.26	1.02	16.29
1.13	16.09	0.95	16.05	1.38	42.89
1.55	42.51	2.56	43.17	2.77	26.15
1.59	26.05				

* Y and Π are arranged according to Equation 8.

are arranged in dimensionless terms of Y and Π of Equation 8 and summarized as Tables 1 and 2.

$$Y = \frac{d_{sc}}{L_{sc}} = f(\Pi) = f\left(\frac{1}{(S_g - 1)D_{50}SL_I}\sqrt[3]{\frac{q^4}{g^2}}\right) \quad (8)$$

Data thus arranged were further plotted and analyzed using regression analysis. A simply power function was selected to better describe the relation between dimensional terms of Y and Π as illustrated in Figure 7 and Equation 9.

$$\left(\frac{d_{sc}}{L_{sc}}\right) = 2.7046\left(\frac{1}{(S_g - 1)D_{50}SL_I}\sqrt[3]{\frac{q^4}{g^2}}\right)^{-0.3384} \quad (9)$$

To achieve the objective of the study and to enhance the practicability of the research results, Equation 9 was further rearranged so that the dependent variable became the groundsill interval L_I; whereas, the rest of the parameters became independent variable except the relative scour shape factor; namely d_{sc}/L_{sc}.

As for relative scour shape factor, it demonstrates the stability of the scour "wall" under the attack of pseudo-plunged or submerged hydraulic jump. As the flow circulates inside the scour hole, the circulating

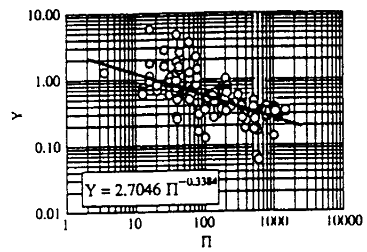

Figure 7. Relation between dimensionless Y and Π.

flow may provide additional uplift to support sediment setting on the sidewalls of the scour against gravitational force. No matter how strong the circulation is inside the scour hole, the maximum stable slope angle that sediment can achieve is often limited by the angle of repose in submerged condition. Therefore, for the practical point of view, the relative scour shape factor is replace by the angle of repose tan ϕ. The end results of the equation for the determination of groundsill interval can be written as:

$$L_I = \frac{0.156q^{1.333}}{(S_g - 1)D_{50}S}(\tan\phi)^{0.3384} \quad (10)$$

where L_I = groundsill interval (m); q = unit-width flow rate (cms/m); S_g = specific gravity of the sediment; D_{50} = median diameter of the sediment (mm); S = hydraulic gradient or channel slope; $\tan\phi$ = angle of the repose for submerged sediment.

The behavior of the Equation 10 makes sense in most cases as compared to the experiment observations. For instance, as channel slope steepens while other parameters in Equation 10 remain unchanged, the increase in denominator gives shorter groundsill interval. As unit-width flow rates increases while other parameters remain unchanged, the plunging effect of the inflow is greatly reduced or even transform into skimming flow (Chanson 1994) which was also observed during the experiments of this study.

The least satisfactory terms that may require further investigation are those related to the sediment properties; such as sediment sizes, specific gravity of the sediment, and the angle of repose for submerged sediment. The angle of repose for coarse and fine sediment may not change in the same magnitude as sediment diameter changes. As median sediment diameter increases, Equation 10 suggests shortening the groundsill interval so that channel bed thus trained can sustain the occurrence of scour between groundsills.

5 CONCLUSIONS

The results from this study provide inside view of the effect of groundsill interval onto the development of scour, pseudo-plunged flow, and submerged hydraulic jump. The combined effects of all either promote or degrade the development of scour between groundsills, of which groundsill interval plays an important role by providing most-, less, and least constraint to the scour.

The end product of this study; Equation 10; outranks the current design criterion of groundsills for stream training in Taiwan. It provides more practical aspects and accessible parameters for field hydraulic engineers to choose from.

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Determination of groundsills interval for stream training

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ABSTRACT: Check dams or known as sabo dams as well as groundsills have been considered as the standard practices in stream training and management in Taiwan. The installation of groundsills often follows the same design criterion of check dams; regardless their different characteristics geometrically and hydraulically. Hence, the objective of this study is to identify the suitable installation interval between groundsills through indoor hydraulic experiments for various stream widths, flow rates, channel slopes, and sediment sizes. An empirical equation was obtained and assessed results were used to compare with outdoor-regulated channel reach.

1 INTRODUCTION

Steep terrain has made the slopes of most streams in Taiwan run steep, therefore, check dams that also known as sabo dams and groundsills have become the standard practices in stream training and management. They both serve the purposes of preventing longitudinal and lateral scour at streambed. Check dams also assist to control the course of flow and suppress sediment from entering downstream to minimize the possible damage.

Geometrically, the face of a check dam consists of wing walls and spillway with the effective height exceeding 5 m above ground elevation; whereas, the groundsill is no more than a concrete beam installed flush with the channel bed. Groundsills are often constructed in series at relatively mild channel reach; while sequential check dams are only constructed whenever needed.

For sequential check dams and groundsills, same design criterion in determining structure interval was used (Council of Agriculture, 1995). The criterion states that:

$$L = \frac{100}{n - m} h \tag{1}$$

where L = structure interval (m); n = channel bed slope (%); m = intended silt slope (%); h = elevation difference in the channel reach to be protected or effective dam height (m).

Even though both structures share the same standard, the determination of parameter values in Equation 1 for sequential groundsills often requires past experiences. Trial-and-error and limited sediment trapping capacity of groundsills often result the elimination of parameter m in Equation 1 and taking subjective value of h between 0.7 and 1.0 depending upon the size distribution of streambed material.

Hydraulically, greater fall height of the check dam provides the natural setting for hydraulic jump to occur; whereas, groundsills behave as submerged weirs. Hence, different magnitude of energy dissipation as well as scale of channel scour instinctively disintegrates both structures from sharing the same design guideline. Accordingly, the objective of this study is to identify the suitable installation interval for sequential groundsills through indoor hydraulic experiments.

2 DIMENSIONAL ANALYSIS

Different groundsill intervals will apparently affect the channel scour, and the characteristics of the scour will in turns affect the eroding sediment leaving the scour holes and the flow field within as well as above.

For a trained stream or a stream under training, revetments on both banks often confine the flow field. If the stream channel is further confined by series of groundsills, the characteristics of the scour