

Sediment trap with hydraulic and mechanical control on open check dam
開口式防砂壩水理及物理囚砂功能介紹

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簡報大綱

1. Introduction
2. Sediment traps and bed load retention controls
3. Experimental set-up
4. Results and analysis
5. Conclusions

前言

- 在山坡地土砂災害治理上，防砂壩為山區土砂災害治理常用工法之一，主要目的攔阻崩塌、土砂流、高含砂水流等挾帶大量土砂材料之土砂運動行為，以降低沿岸及下游聚落衝擊。
- 防砂壩主要可以分為封閉式(closed-check dam)與開口式(open-check dam)防砂壩兩種。
- 近年來有許多學者在研究切口壩(slit-check dam)其開口比例(opening ratio)與囚砂功能之間關係。
- 開口式防砂壩的優點在於常流水或是較小洪水事件(small, non-hazardous floods)時，其能發揮自我清潔能力(self-cleaning capacity)，而當土砂災害事件發生時，其亦發揮能攔阻及囚砂功能(sediment trap and retention)。

前言

- 由於封閉式防砂壩囚砂功能，其在常流水事件或小洪水事件將上游來砂全部儲砂，導致下游河道高程下降，而在較大事件，則是儲砂空間不足造成囚砂能力喪失，土砂往下游沖刷。
- 本研究提出透過式囚砂功能(permeable sediment traps)，藉由引導式渠道和複合式防砂壩組成，使防砂壩在平時可維持上下游河道土砂材料動態平衡，而在土砂災害事件時，能攔阻土砂。
- 在加入引導渠道時，考量其滿岸流量(bankfull discharge)，當災害事件之流量大於滿岸流量，並不會造成大量土砂往下游輸送 (unwanted sediment flushing)，其受到複合式防砂壩囚砂功能所攔阻，而當上游流量小於滿岸流量，其土砂材料能通過防砂壩，不會造成下游河道高程下降。

防砂壩

山區集水區常以防砂壩攔阻土砂，然而過往在設計上，為減免下游土砂災害，以提高壩體高程方式增加囚砂空間，造成對於河川連續性(river continuity)及河川生態形態(eco-morphological)造成不良影響。

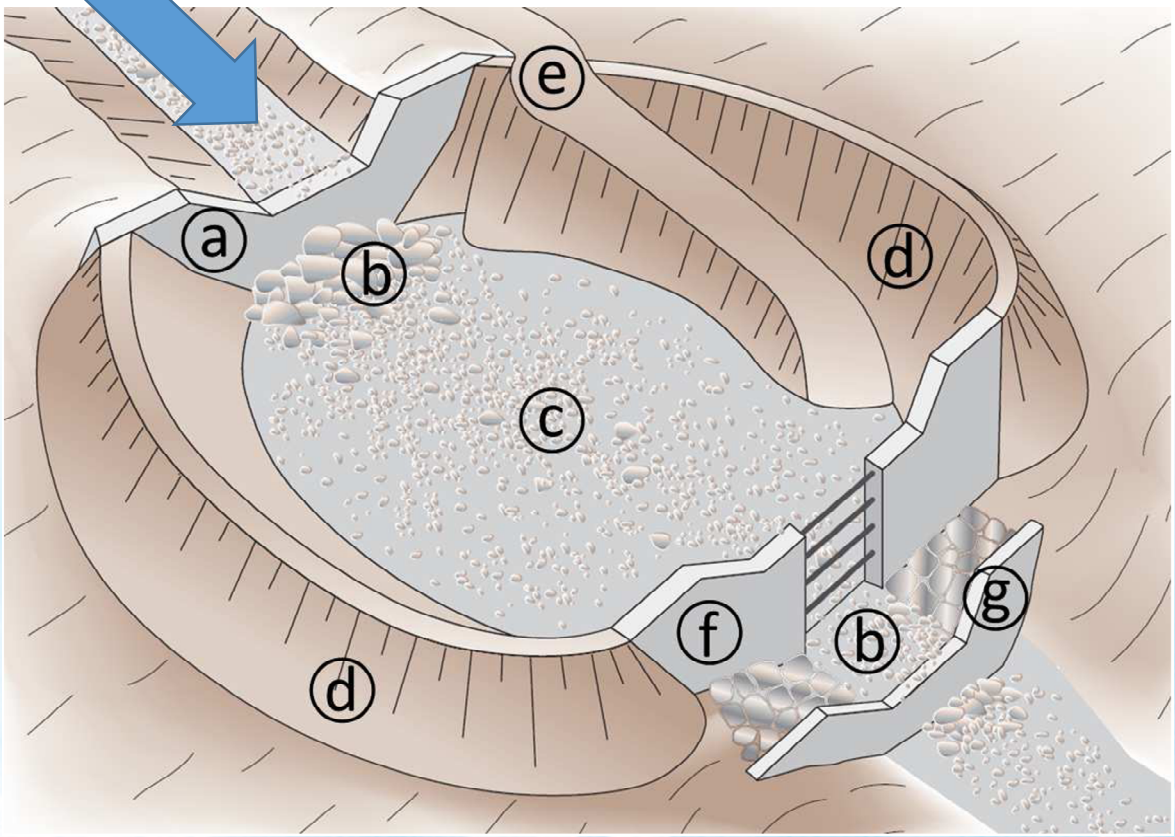
近年生態保育意識抬頭，防砂壩設計上採用開口式防砂壩，為在傳統溢洪口下方增設一開口，為減少對生態形態影響，以減少河床上下游落差，藉以維持河川連續性，改善負面影響。





詹勳全等人，2019

開口式防砂壩
Sediment trap with an open check dam

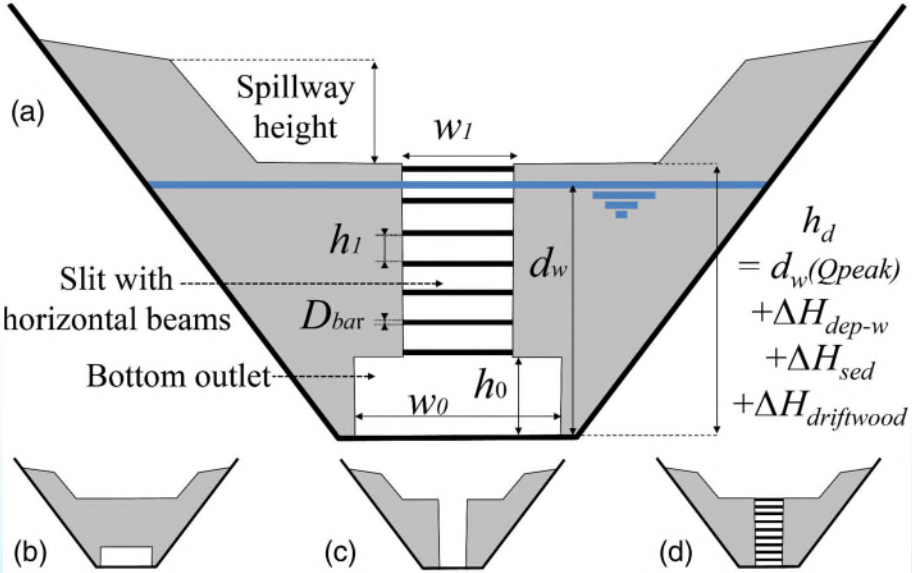


Characteristic components
(a) Inlet structure 入流構造物
(b) Scour protection 抗沖保護
(c) Basin 囚砂區
(d) Lateral dikes 側岸堤
(e) Maintenance access 維護通道
(f) Open check dam 開口式防砂壩
(g) Counter dam 副壩

Two complementary approches
1) Hydraulic control
2) Mechanical control

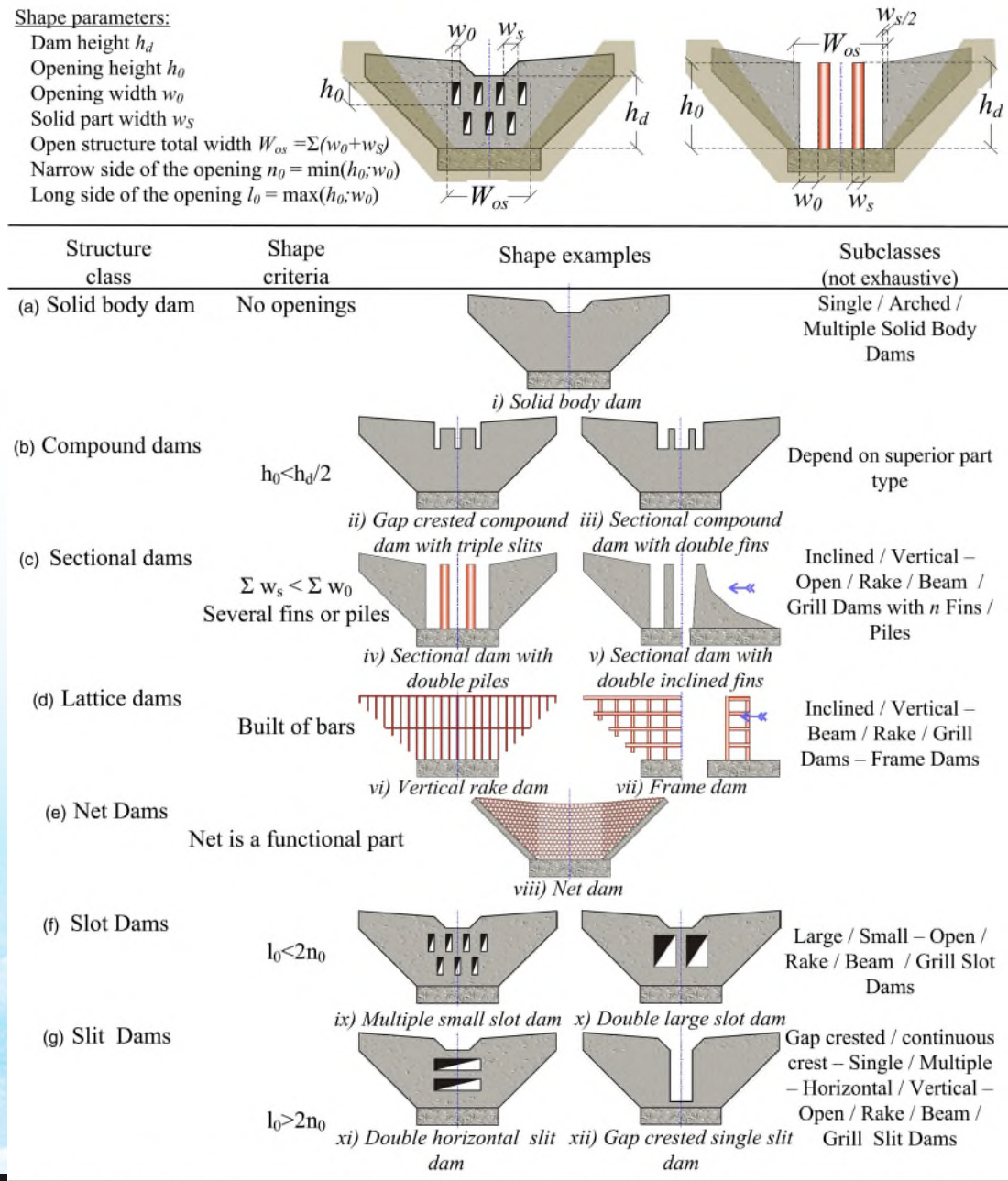
Piton G. & Recking A., (2015) "Design of sediment traps with open check dams. I: hydraulic and deposition processes." Journal of Hydraulic Engineering.

開口式防砂壩



Definition of shape parameters (Piton et al., 2015)

Wehrmann et al. (2006); Piton et al., 2015



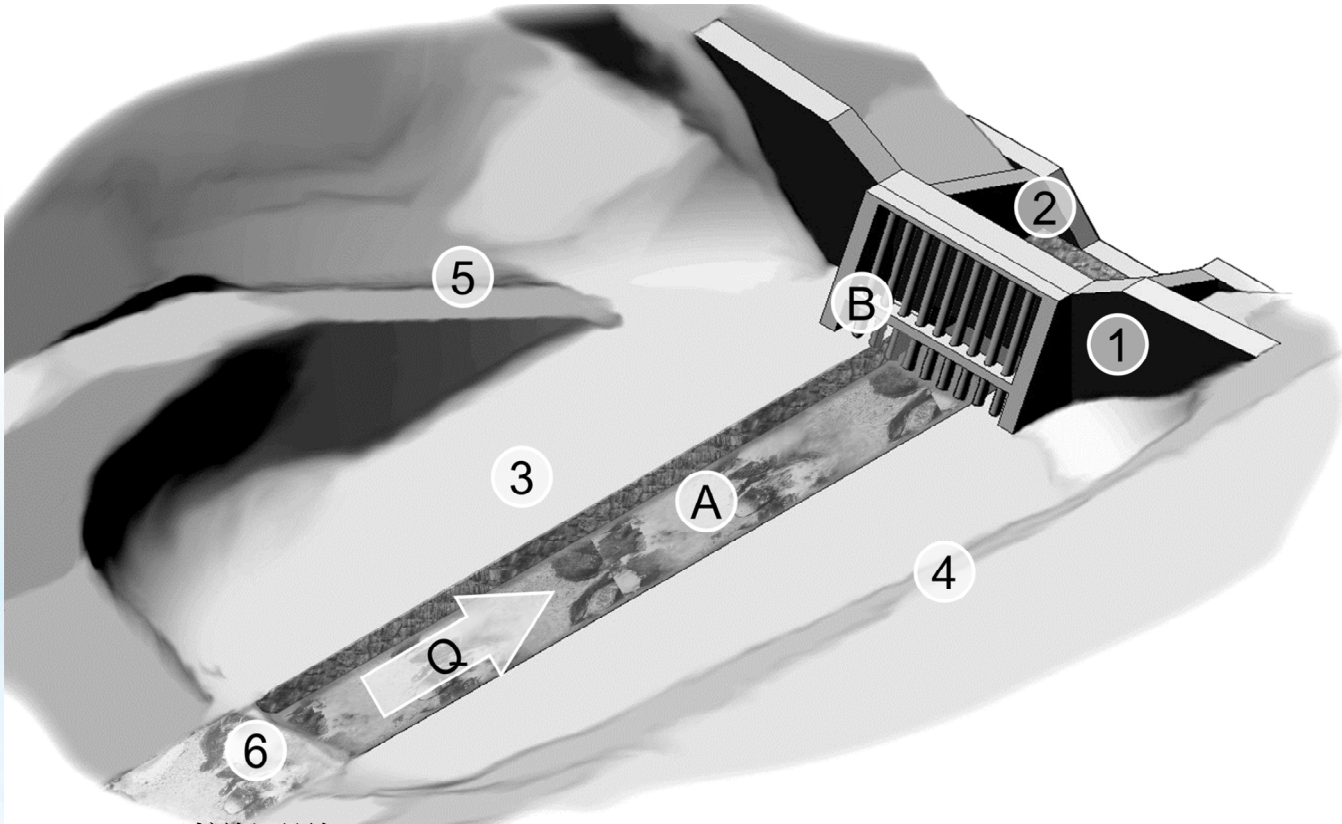
Note: If there are several openings in the dam body, the opening with the maximum height (h_0), width (w_0) or long side (l_0) is relevant for selecting the suitable dam classification. Further detail can be found in Wehrmann et al. 2006

設計功能及目標

(a) Stabilization (穩定): fixation of the longitudinal profile of a torrent bed at a distinct elevation to stop incision and/or lateral erosion
(b) Consolidation (固結): elevation of the longitudinal profile for the same purpose and to stabilize upstream hill slopes
(c) Upstream slope reduction (減緩上游坡度): in order to reduce the flow erosive power and ability to transport boulders
(d) Retention (沉砂滯洪): storage of water and/or deposition of sediment during an event aiming to reduce total transferred volume
(e) Sorting or sizing (粒徑篩選): filtration and storage of undesirable components during an event (bed-load sizing and/or wood grading)
(f) Dosing (調整): peak flow modulation by temporarily retaining water/sediment, an effect obtained with a lower slope in the trap basin and/or the open check dam shape
(g) Debris flow breaking (消能): reducing the high-energy level of a debris flow to a lower level

Piton G. & Recking A., (2015) "Design of sediment traps with open check dams. I: hydraulic and deposition processes." Journal of Hydraulic Engineering.

開口式防砂壩
Sediment trap with an open check dam



此透過式防砂壩主要的組成元素為:
儲砂區及開口式防砂壩
攔阻功能分為二種：
1 對底床載進行沉砂滯洪；
2 對致災粒徑(hazardous diameter)進行攔阻。

1 開口式防砂壩 (open sediment check dam)
2 梳子式構造物 (counter dam)
3 儲砂區 (deposition area)
4 側岸堤 (lateral dykes)
5 維護通道 (maintenance access)
6 上游入流處 (inlet structure with scour protection)

(A) 引導渠道 (guiding channel)
(B) 攔阻構造物 (**bar screen for mechanical control** and **flow constriction for hydraulic control**)

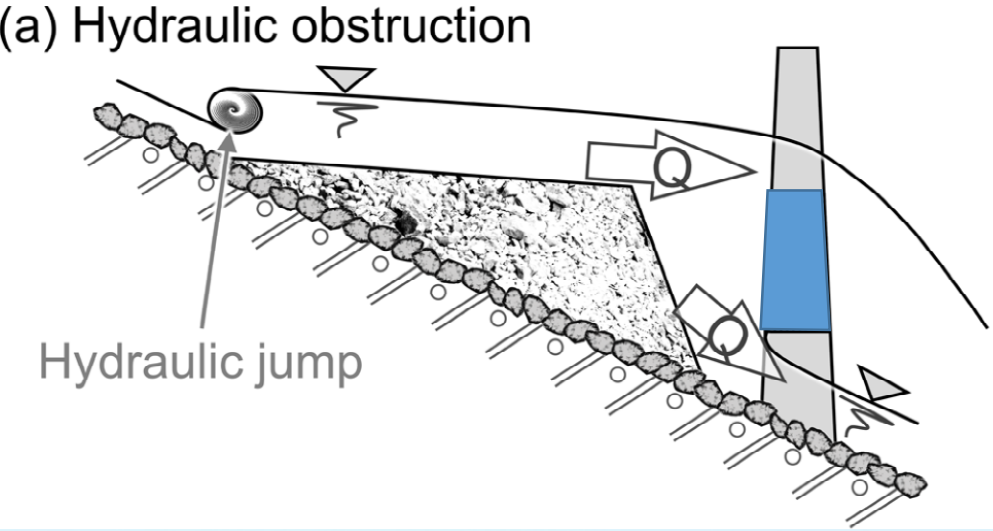
Schwindt et al., (2018)"Sediment traps with guiding channel and hybrid check dams improve controlled sediment retention." Nat. Hazards Earth Syst. Sci.

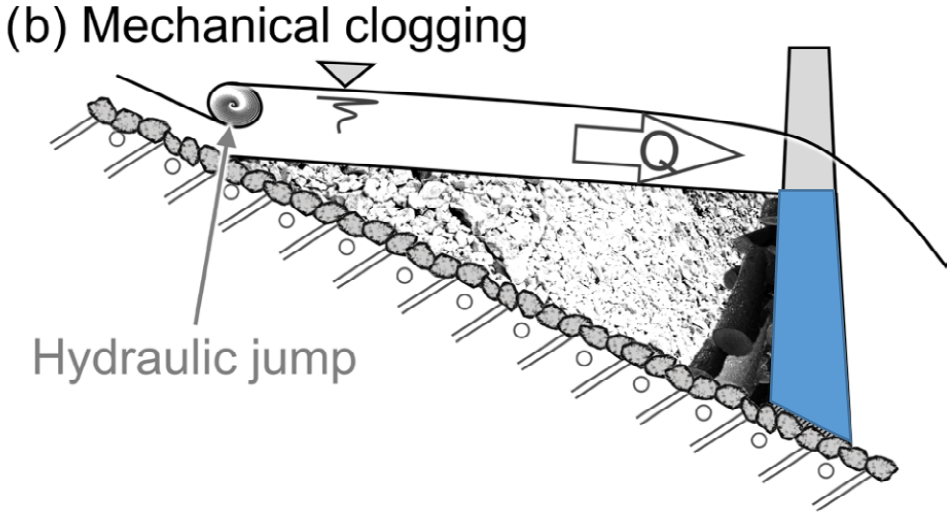
囚砂及底床載沉砂控制
Sediment traps and bed load retention controls

Design approach for permeable sediment traps

- 主要目的為考慮在囚砂時僅留住底床載，避免造成下游聚落或都市區域河道阻塞，並降低維護成本。
- 藉由設計引導渠道、儲砂區及開口式防砂壩等組成。
- 上游流量超過設定流量時(case-variable threshold)，啟動底床載滯砂功能；輸送材料超過設定粒徑時，則由梳子構造物啟動物理攔阻功能。
- 此開口式防砂壩對底床載的沉砂功能，設定上為山區陡坡河道，流況為超臨界流況(supercritical)且需發生水躍(hydraulic jump)才能啟動。
- 另由於過小開口高度或是寬度，將造成下游河道不連續且對於生態形態(eco-morpholocial)造負面效應。

泥砂囚砂機制
Control Mechanisms of sediment retention





(a) Hydraulic deposition:
the opening creates backwater, decrease in shear stresses, the flow velocity and shear stress fall under the threshold transport value, sediment trend to deposit.

(b) Mechanical deposition caused by large objects

1 當流量超過臨界值時，由水利控制(hydraulic control) 發揮囚砂滯洪功能 (for bed-load) ；
2 當上游運移土砂材料超過一定粒徑時，則是由物理性控制(mechanical control)發揮功能，將大於格柵尺寸或是梳子開口尺寸的材料攔阻。

Schwindt et al., (2018) and Piton et al. , (2015)

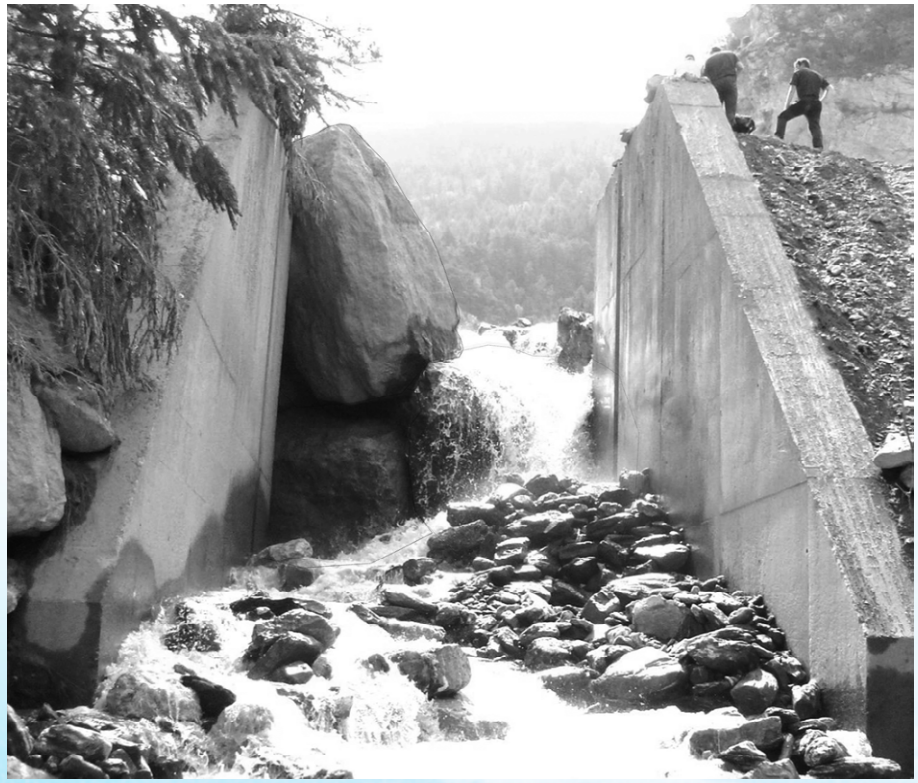
泥砂囚砂機制 Control Mechanisms of sediment retention

(b) Mechanical control:
direct clogging of small openings when compared to coarse transported materials (Fig.b).

This trapping process mainly concerns debris flow boulders and driftwood.

Sectional, lattices, frame, net open check dams use mechanical control design criteria.

During extreme events, debris flows are able to clog several-meter-wide slits with a few large boulders or to create dense wood jams (如右圖).



1 當流量超過臨界值時，由水利控制(hydraulic control) 發揮囚砂滯洪功能主要是底床載；
2 當上游運移土砂材料超過一定粒徑時，則是由物理性控制(mechanical control)發揮功能，將大於格柵尺寸或是梳子開口尺寸的材料攔阻。

Schwindt et al., (2018) and Piton et al. , (2015)

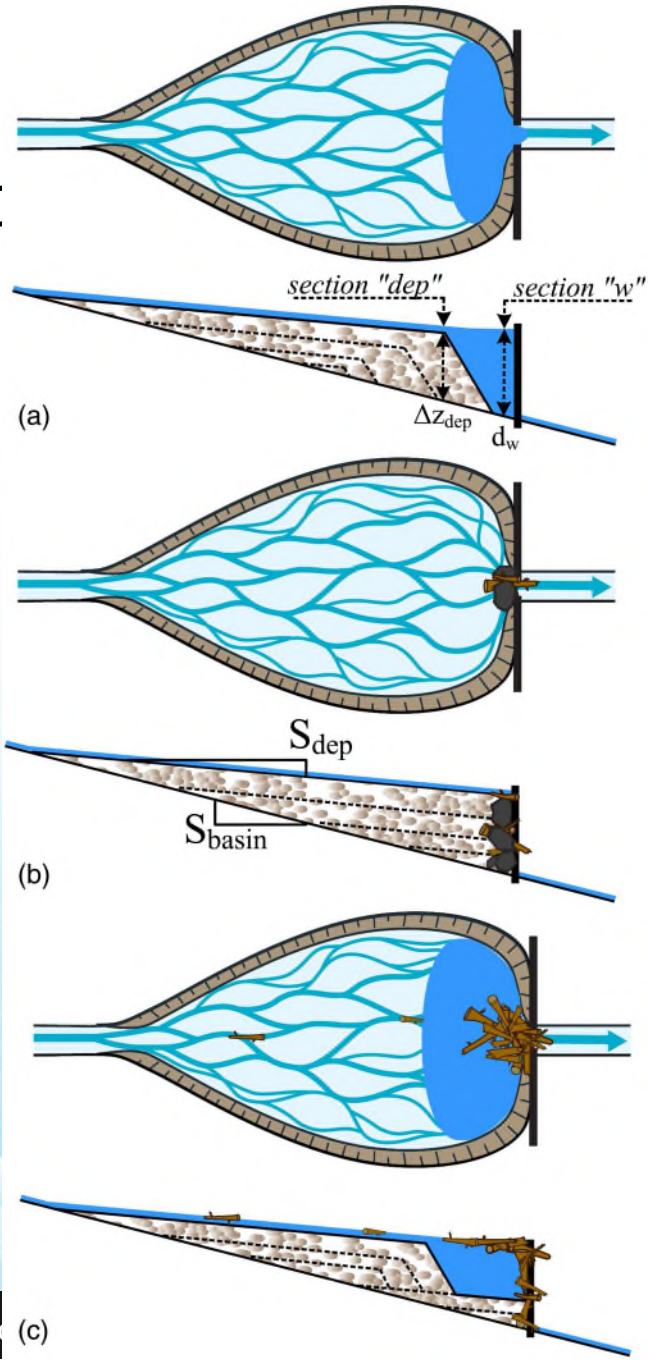
囚砂及底床載遲滯控制
Sediment traps and bed load retent

Sediment deposition processes and pattern

Mixed control/ Hybrid control: Fig.(c)
In bed-load and drift-wood-laden flows, mechanically controlled driftwood jams at the open check dam can generate upstream hydraulically controlled sediment deposition.

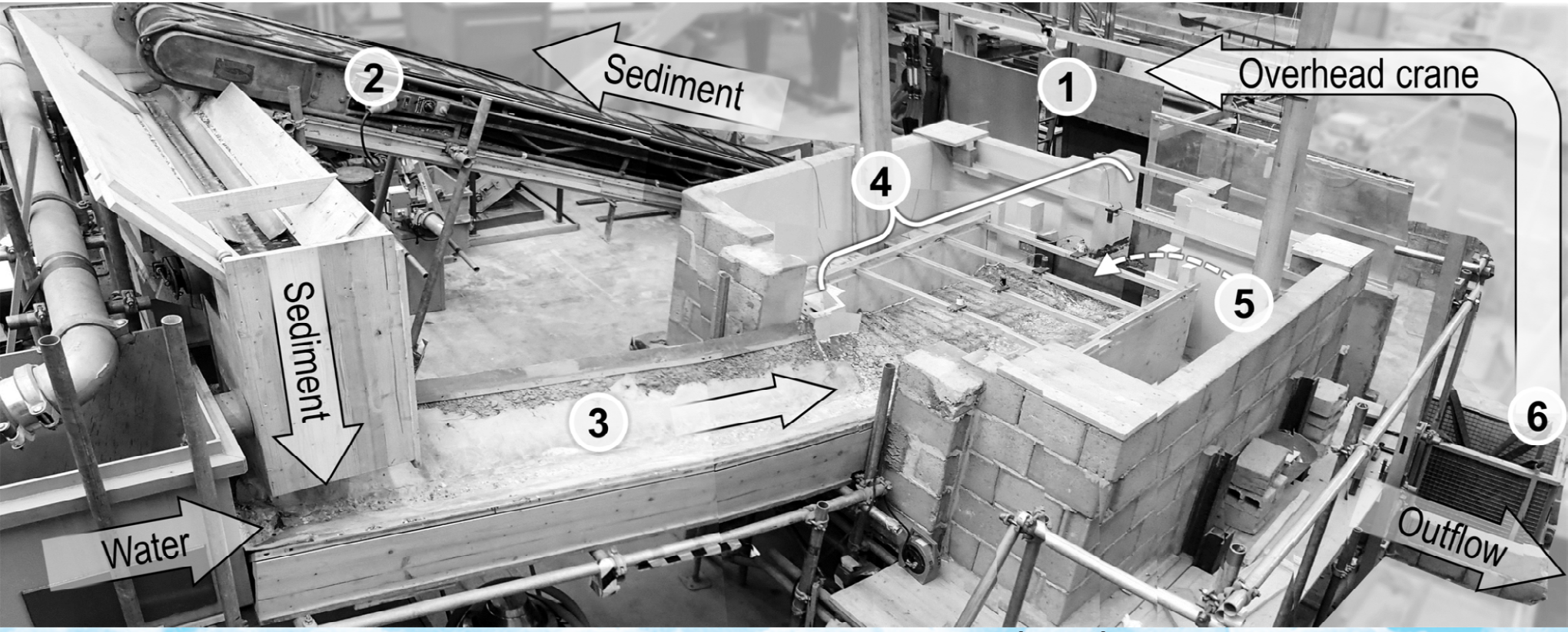
Plan and longitudinal schemes of (a) hydraulic control of the deposits: shear stresses collapse in tranquil water; (b) mechanically controlled deposits: boulders and driftwood jamming leading to open check dam clogging; (c) mixed controlled deposits: mechanically blocked driftwood generates a calm water area and thus a hydraulically controlled deposit of sediments

Piton G. & Recking A., (2015)



Experimental set-up

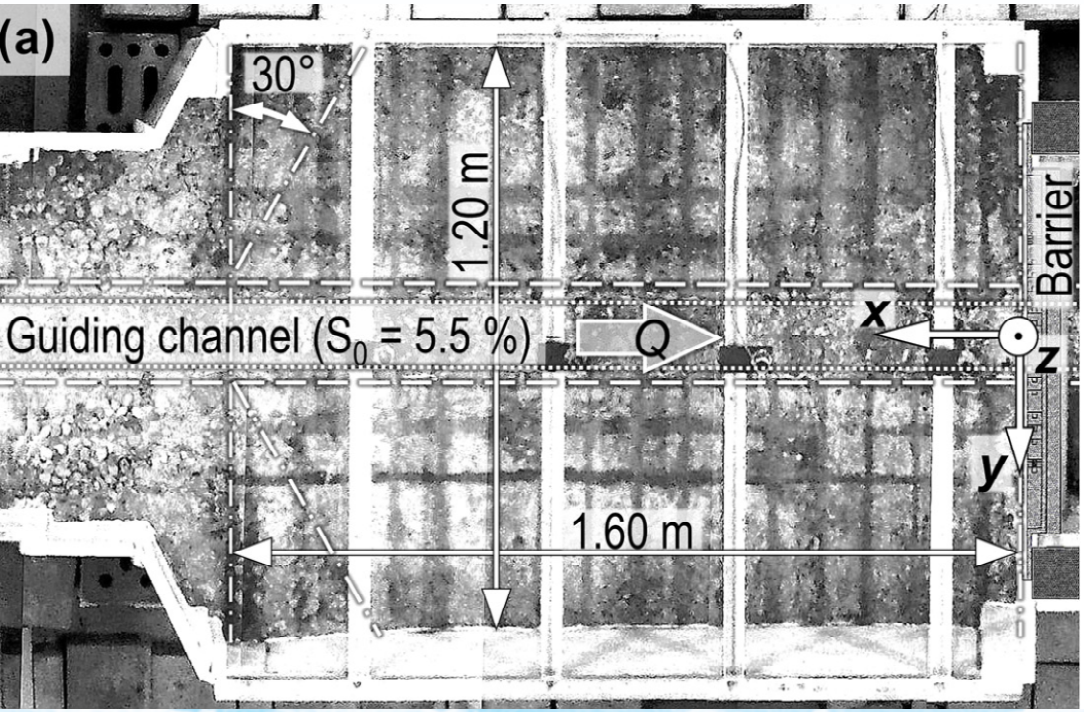
1儲砂箱; 2輸送帶; 3水、砂混合調整渠道; 4觀測道; 5濾砂裝置; 6接砂箱

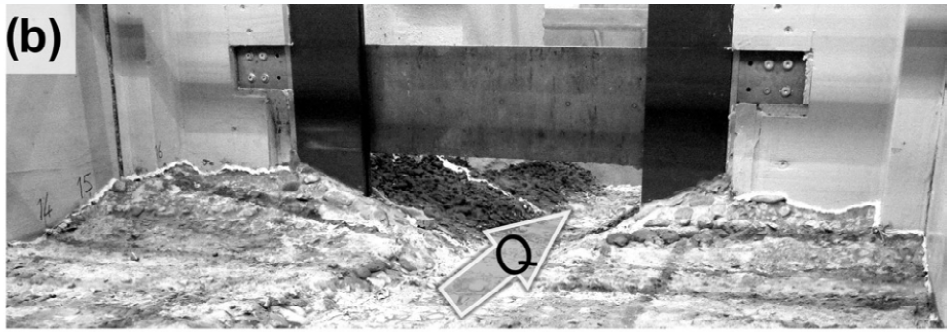


S. Schwindt et al., (2018): sustainable sediment traps

Experimental set-up

Details of the observation reach consisting of the deposition area (reservoir) with guiding channel
(a) 觀測區長度 = 1.6m，寬度 1.2m，渠道坡度 5.5%，開口角度 30度;
(b) 防砂壩位置; (c) 堆積區及引導渠道

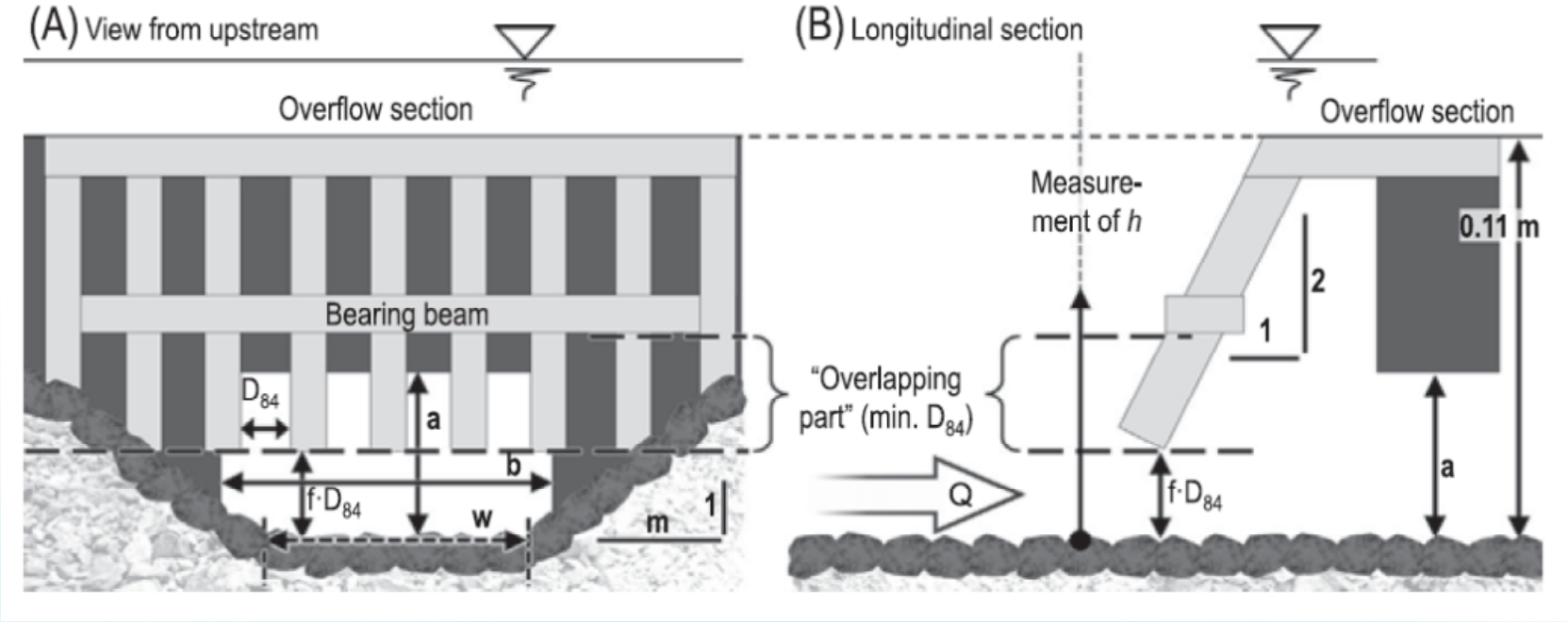






S. Schwindt et al., (2018): sustainable sediment traps

Experimental set-up



the combination of sediment deposition control:

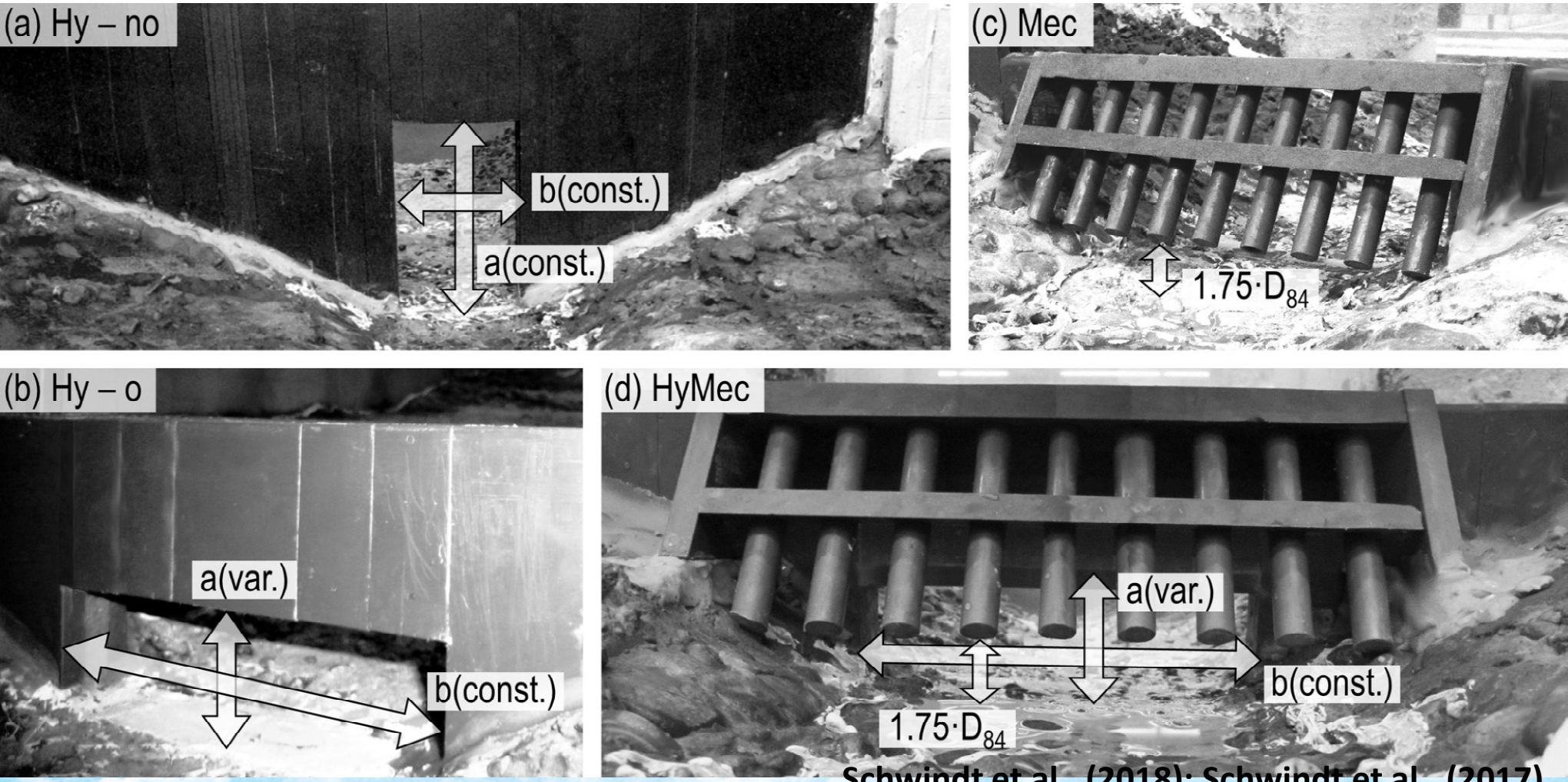
(a) hydraulic control by flow constrictions, with height a and width b

(b) mechanical control by a bar screen

The elements constituting the hydraulic control are represented in dark gray, whereas the elements in light gray correspond to mechanical control.

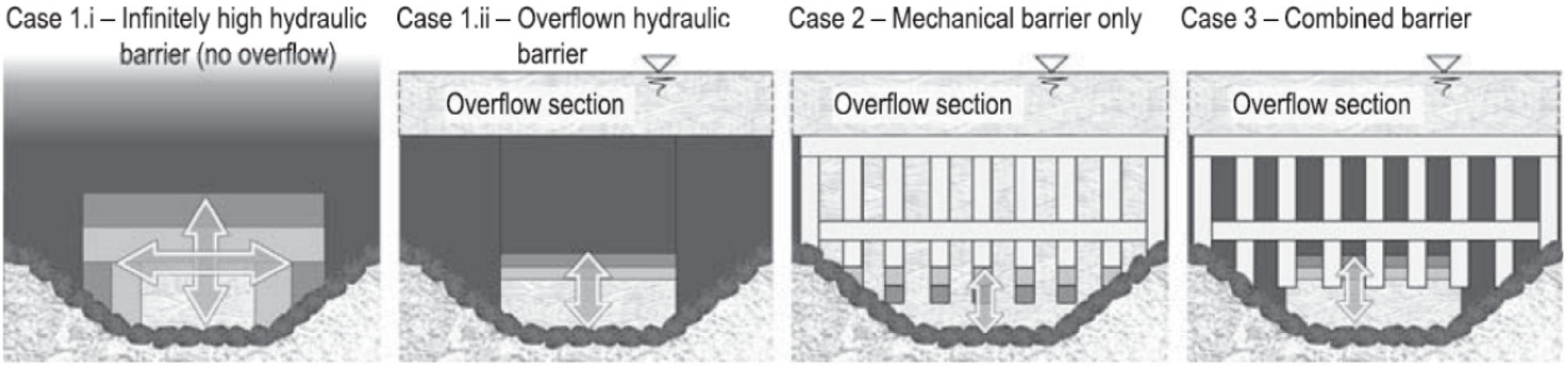
S. Schwindt et al., (2017)

Experimental set-up



Schwindt et al., (2018); Schwindt et al., (2017)

Experimental set-up



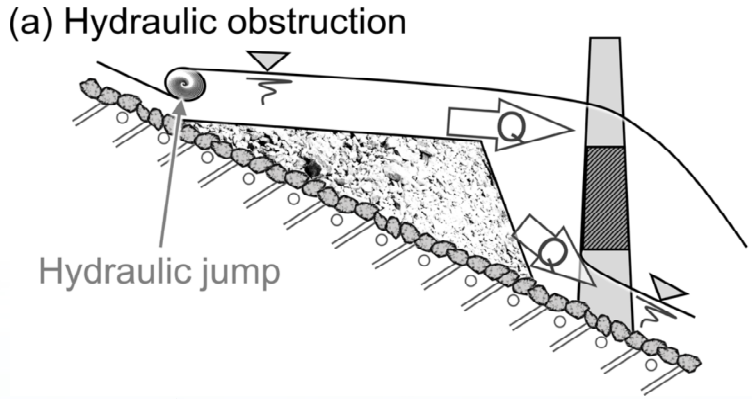
Case	Type	Rel. barrier height [−] $0.11/D_{84}$	Relative height [−] a/D_{84}	Constriction width [−] b/D_{84}	Bar screen placed	Hydrograph tests No.	Flushing
Hy-no	Hydraulic	Inf.	11.1	5.6	No	2	Yes
Hy-o	Hydraulic	8.0	$a_1 = 2.89$	11.0	No	1	No
Mec	Mechanical	8.0	–	–	Yes	2	No
Hymec.a_1	Combined	8.0	$a_1 = 2.89$	11.0	Yes	2	No
Hymec.a_2	Combined	8.0	$a_2 = 3.14$	11.0	Yes	2	Yes
Hymec.a_3	Combined	8.0	$a_3 = 3.44$	11.0	Yes	2	No

Schwindt et al., (2018); Schwindt et al., (2017)

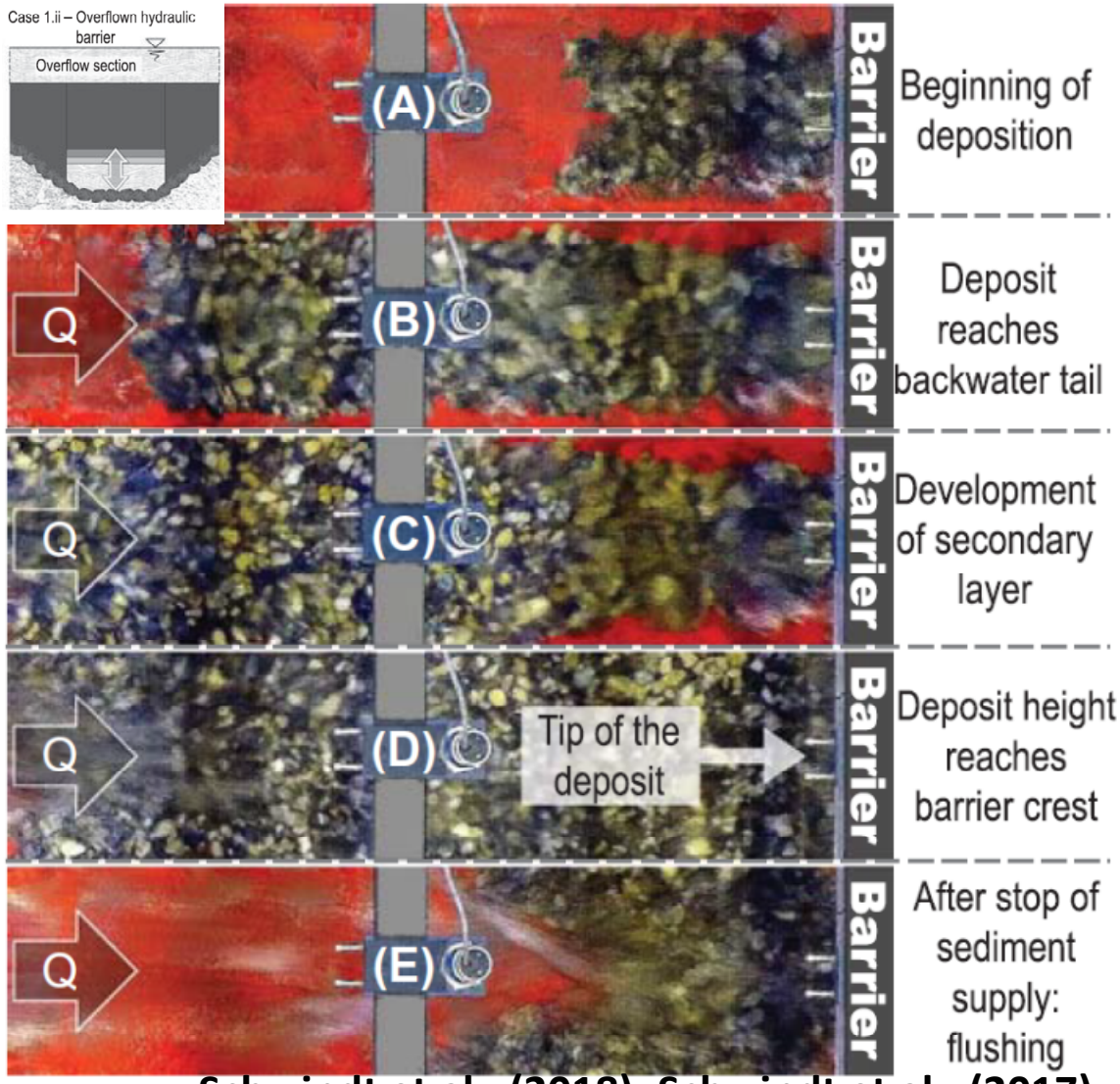
Results and analysis

- Evolution of bed load transfer through the barrier
- Volume of sediment deposits in the deposition area
- Deposition patterns
- Sediment flushing

The temporal evolution of sediment deposits



(case 1.ii):
(A) first deposit (淤積開始);
(B) beginning of the secondary deposit layer (第二層淤積);
(C) evolution of the secondary layer from upstream toward the barrier (淤積前緣抵達防砂壩);
(D) maximum deposit size, immediately before flushing occurs (最大淤積尺寸); and
(E) Flushing (沖刷)



Schwindt et al., (2018); Schwindt et al., (2017)

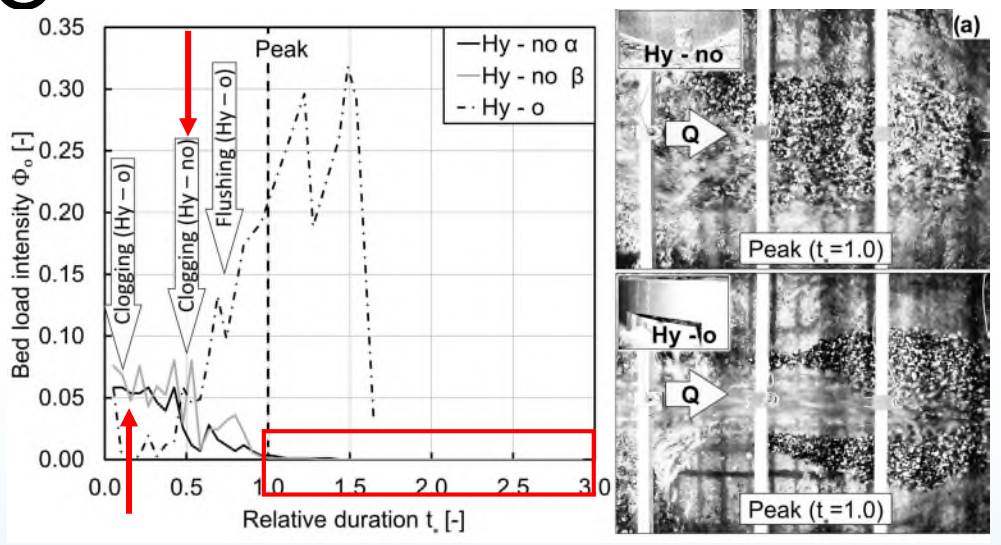
Result-Case Hy-no

Case Hy-no: 淤積範圍較廣且深

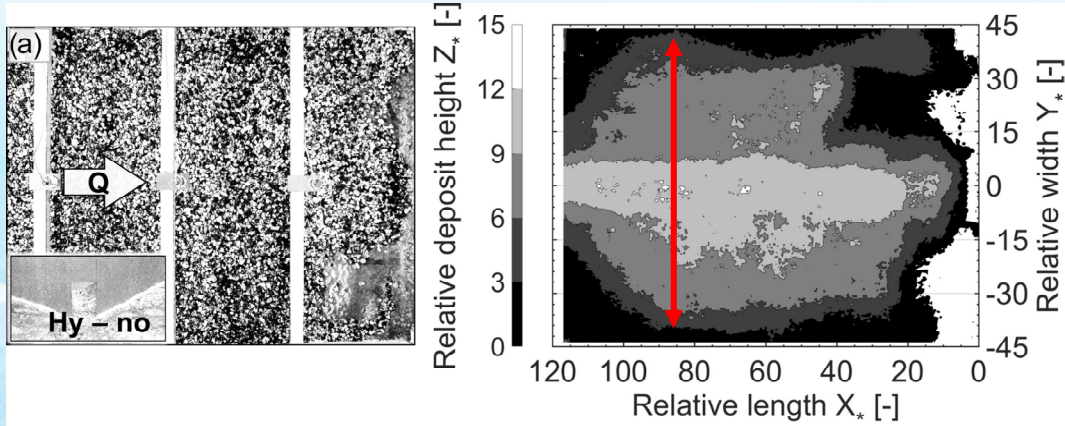
Case Hy-no, the outflow bed load intensity drop after a duration of t*= 0.5, which corresponds to the hydraulic clogging of the barrier.

The backwater increased with increasing discharge (t* < 1) and resulted in a regressive of sediment deposition in the upstream direction.

As a consequence, the sediment flux through the barrier ceased with the flood peak and the deposit laterally spread toward the banks of the deposition area at the end of the hydrograph.



Evolution of bed load transfer through the barrier



Volume of sediment deposits in the deposition area

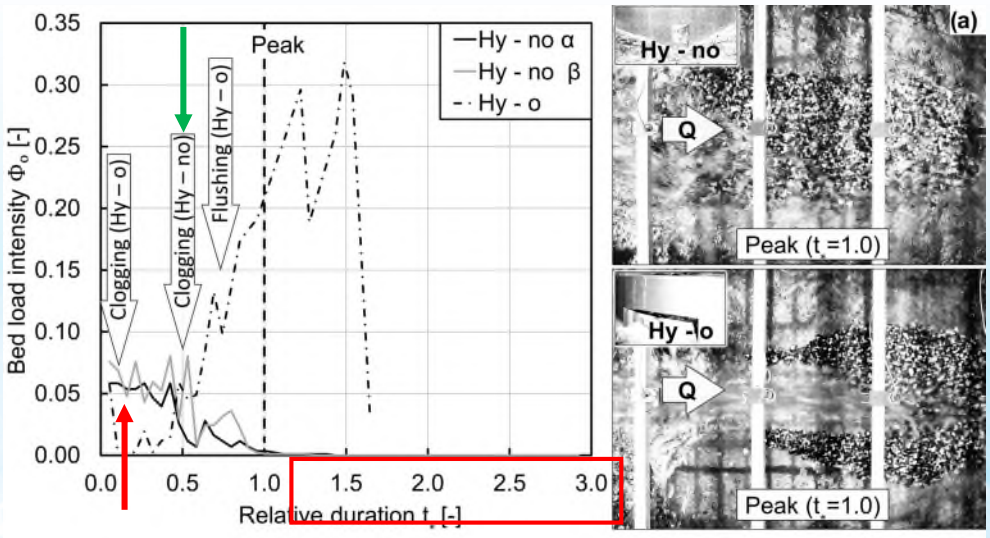
S. Schwindt et al., (2018): sustainable sediment traps

Result-case Hy-o

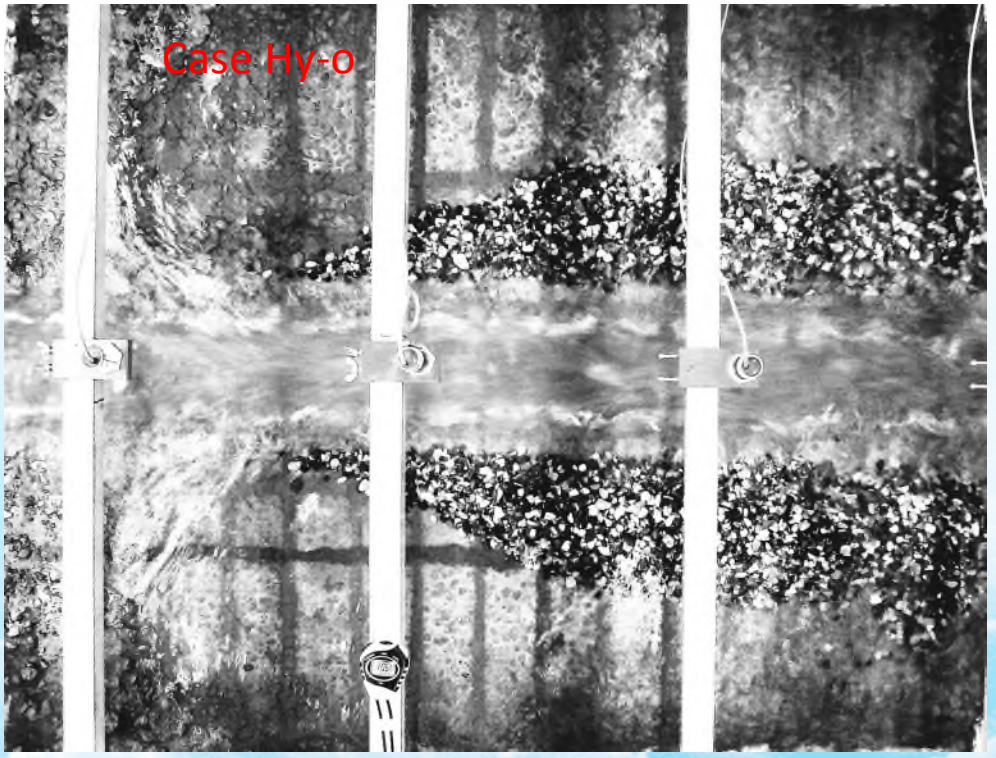
Case Hy-o, smaller constriction height resulted in the all of the supplied sediment was retained (t*<0.5).

The outflow intensity restarted to increase with the rise in the discharge(t*=0.37), the sediment flushing started before the flood peak (t*<1).

After flood peak (t* >=1), the flushing of nearly all the previously deposited sediment occurred.



Evolution of bed load transfer through the barrier



Volume of sediment deposits in the deposition area

S. Schwindt et al., (2018): sustainable sediment traps

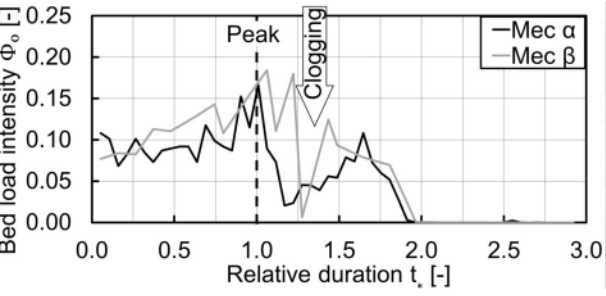
Result-Case Mec

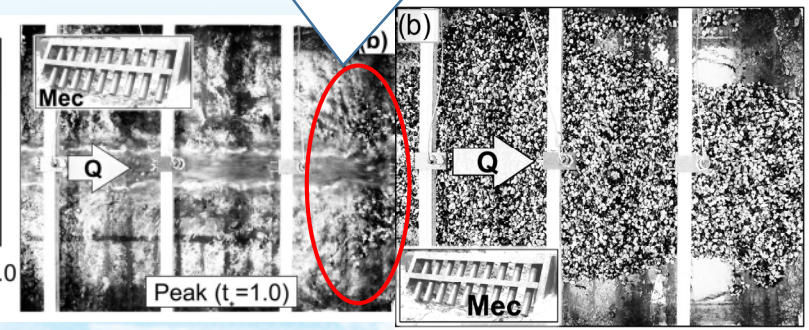
The outflow intensity was similar to the supply intensity (t*=1), only marginal sediment deposits close to the barrier.

t* < 1.25, the bar screen mechanically clogged, the outflow intensity decreased to zero in stages.

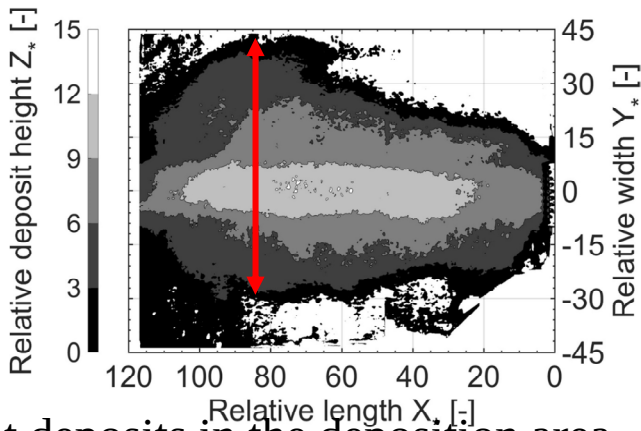
An elongated deposit in the deposition area was observed at the end of of hydrograph. (Fig. b)

Sediment deposit





Evolution of bed load transfer through the barrier



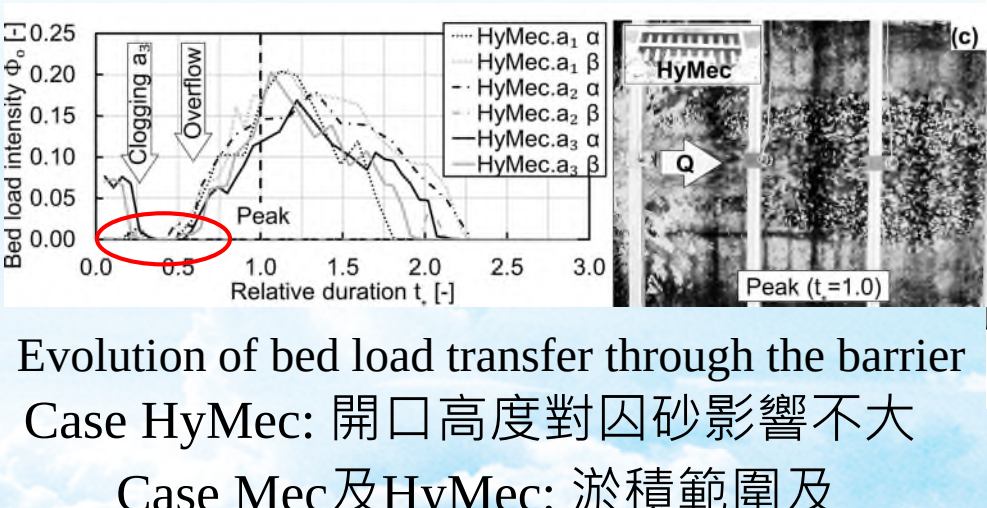
Volume of sediment deposits in the deposition area

S. Schwindt et al., (2018): sustainable sediment traps

Result-Case HyMec

In case HyMec, the outflowing intensity decreased rapidly to zero for the smaller opening heights.

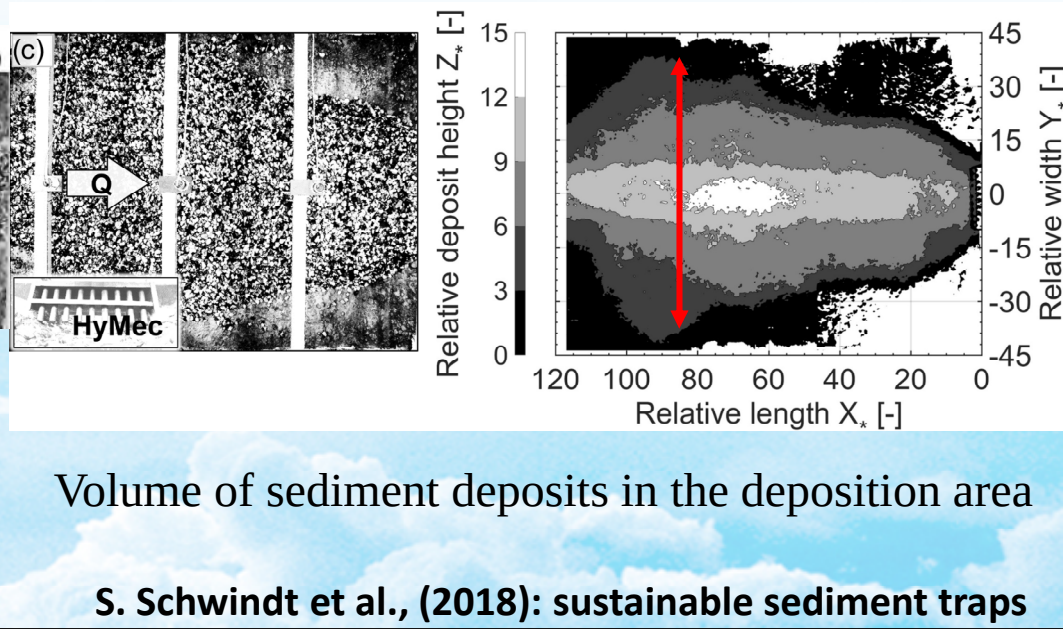
After the barrier clogging, an elongated deposit developed in layers until it reached the barrier height at t* ~ 0.6. In consequence, the supplied sediment was transported over the barrier, the outflow intensity is slightly smaller than supply intensity, as the deposit enlarged after t* =0.6.



Evolution of bed load transfer through the barrier

Case HyMec: 開口高度對囚砂影響不大

Case Mec及HyMec: 淤積範圍及深度較相似，僅邊界處不同



Volume of sediment deposits in the deposition area

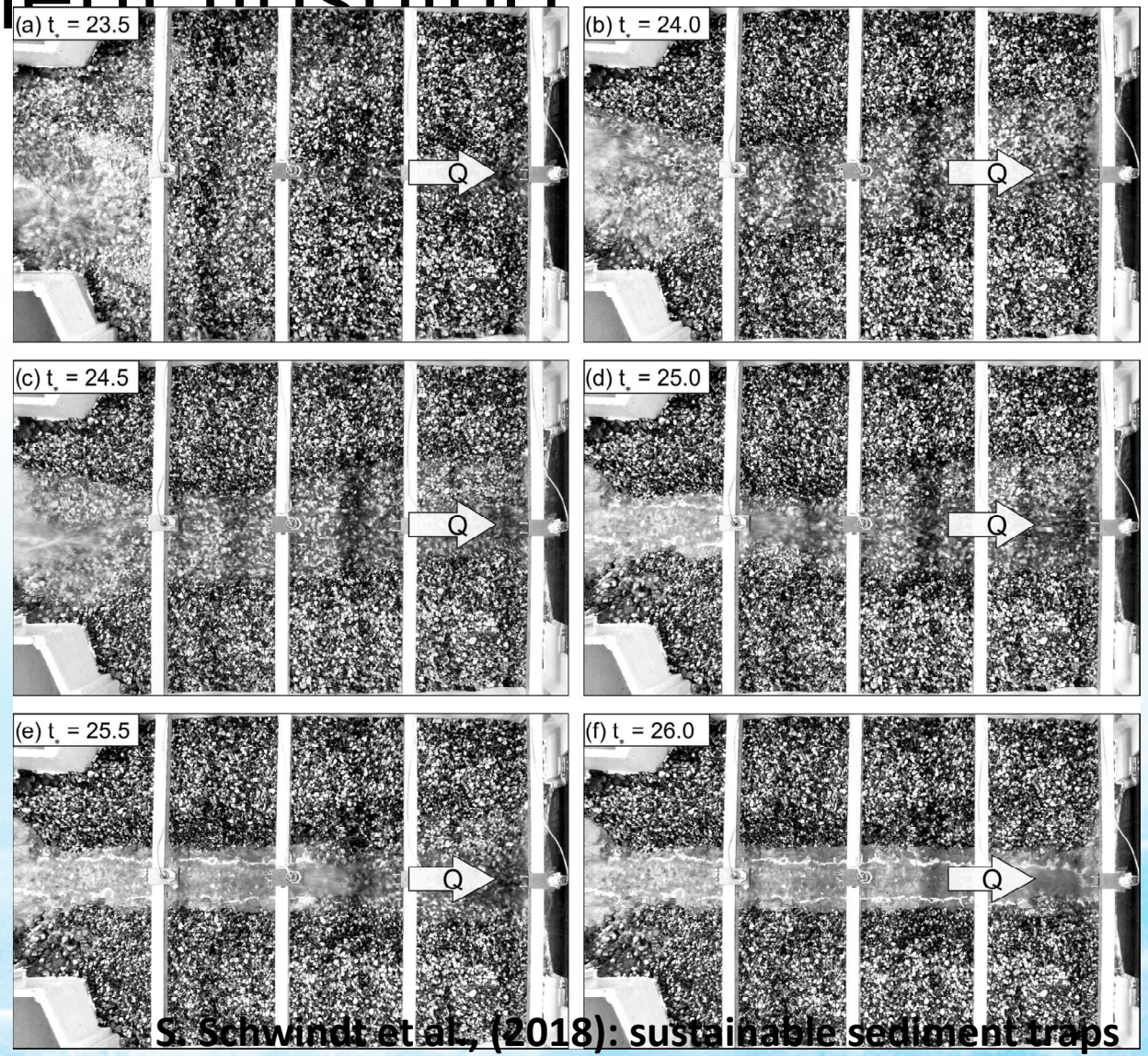
S. Schwindt et al., (2018): sustainable sediment traps

Result-sediment flushing

Case Hy-no:
The flushing of the non-overflowed barrier was not possible without artificial intervention.
Apparent grain imbrication caused the armoring of the surface layer of the deposit.
Only a trial of artificial breaking of the armouring layer along the longitudinal axis of the guiding channel enabled sediment flushing.

因砂之沖刷過程是由流動驅動重新形塑子河道的連續過程。這一持續過程將沿著初始河道逐漸下切堆積區。

為減少堆積土體，在可控制土砂沖刷量條件下，其在洪水事件後需透過物理性手段移除部份土砂，使引導河道能發揮自我清潔能力將土砂運移至下游河道。



S. Schwindt et al., (2018): sustainable sediment traps

Conclusions

The guiding channel ensures sediment transport through and deposition area, without any deposition, up to its bank-full discharge.
The guiding channel serves as the flow control in the deposition area, which is important to ensure the triggering of sediment retention when floods become hazardous.
Sediment retention is triggered by an open barrier at the downstream end of the guiding channel once the discharge becomes hazards. (At this point, the bankfull discharge of the guiding channel is exceeded.)

1 The guiding channel fulfils its purpose of promoting the river continuity until its bankfull discharge is exceeded

2 Overflowed barriers with only hydraulic control are susceptible to unwanted sediment flushing (self- cleaning) during floods.

3 Unwanted sediment flushing (self-cleaning) is prevented by combining the hydraulic and mechanical controls of triggering sediment retention.

4 Partial, desired sediment flushing through hydraulic control barriers after a flood can be artificially enabled.

The maintenance of sediment traps after important floods still remains indispensable but the frequency and the extent of dredging reduce when a guiding channel conveys the sediment up to small, non-hazardous and frequent floods

Reference

- **Piton G. & Recking A., (2015) “Design of sediment traps with open check dams. I: hydraulic and deposition processes." Journal of Hydraulic Engineering.**
- **Piton, et al., (2016) “Bedload trapping in open check dam basins – measurements of flow velocities and depositions patters.” 13th Interpraevent 2016, Lucerne, Switzerland.**
- **Schwindt et al., (2018)“Sediment traps with guiding channel and hybrid check dams improve controlled sediment retention." Nat. Hazards Earth Syst. Sci.**
- **Schwindt et al., (2017)“ Effects of lateral and vertical constrictions on flow in rough steep channels with bedload." Journal of Hydraulic Engineering.**
- **Schwindt et al., (2017)“Analysis of mechanical-hydraulic bedload deposition control measures." Geomorphology.**
- **Chan, et al., (2019), Theoretical and experimental analyses of discharge estimation for open check dam, Journal of Chinese Soil and Water Conservation, 50(1): 11-21.**



Thank you for your attention

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