Prediction of Maximum General Scour Depth during a Flood for Intermittent Rivers

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OUTLINE

- Introduction
- Site description & Method
- Results
- Conclusions

INTRODUCTION

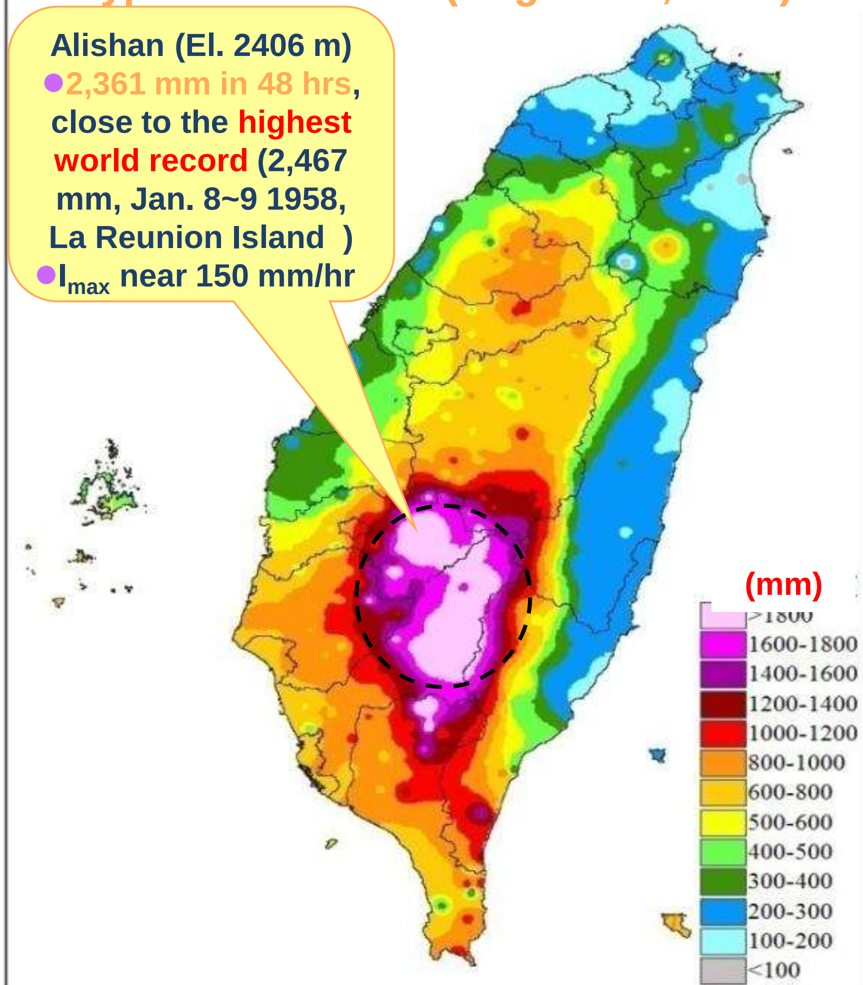
Characteristics of Rainfall in Taiwan

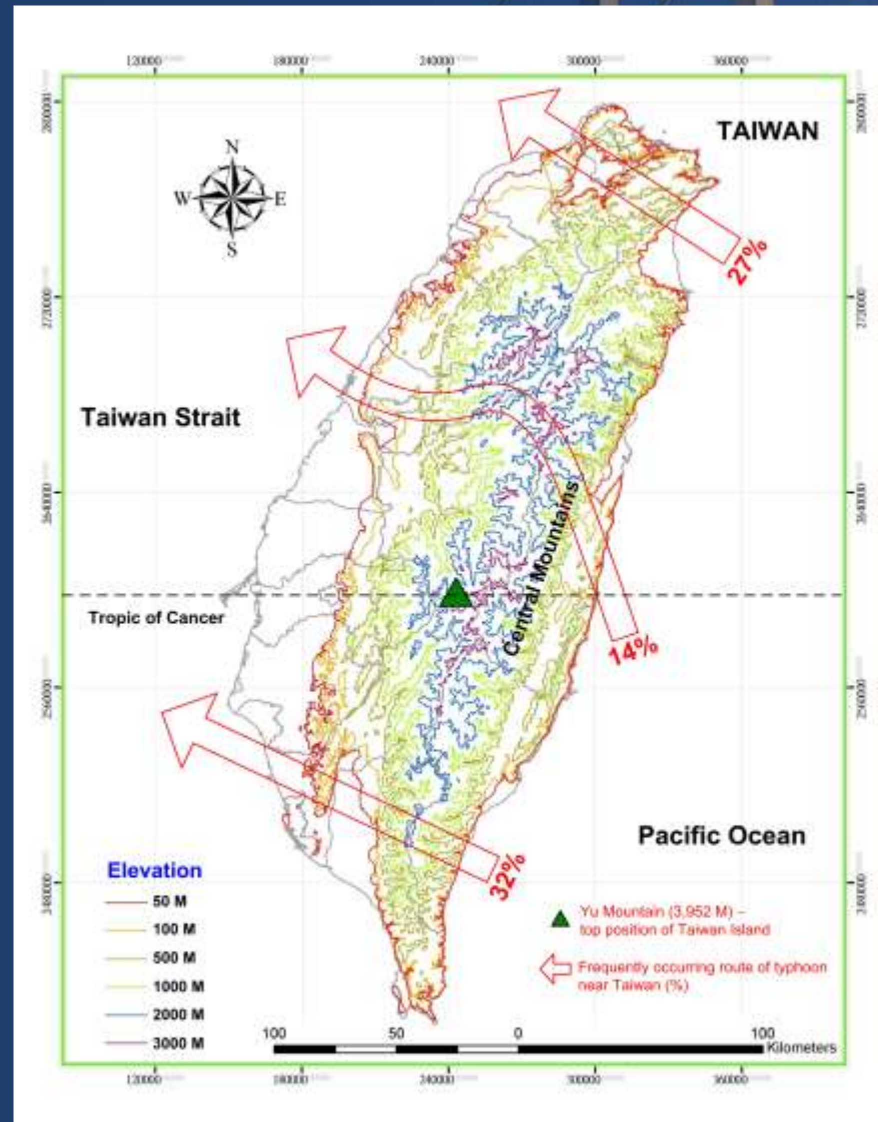
3~5 typhoons/yr

(typhoon seasons: May~ November)

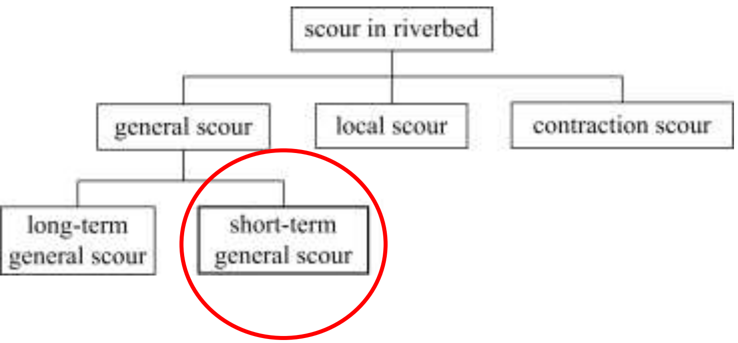
Extreme Concentrated Rainfall

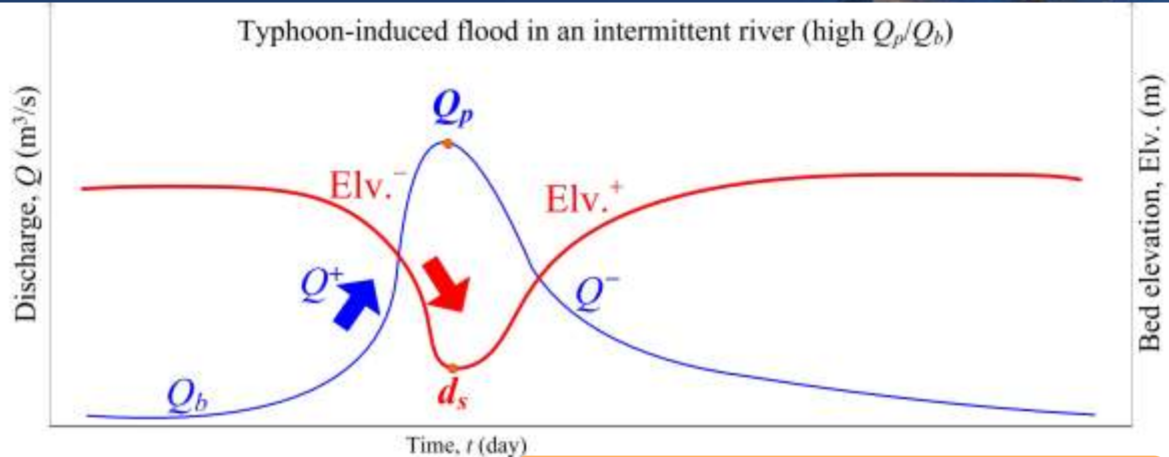
Typhoon Morakot (Aug. 8~10, 2009)

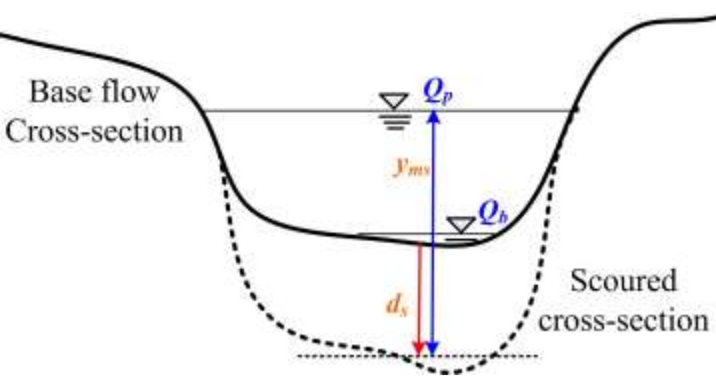


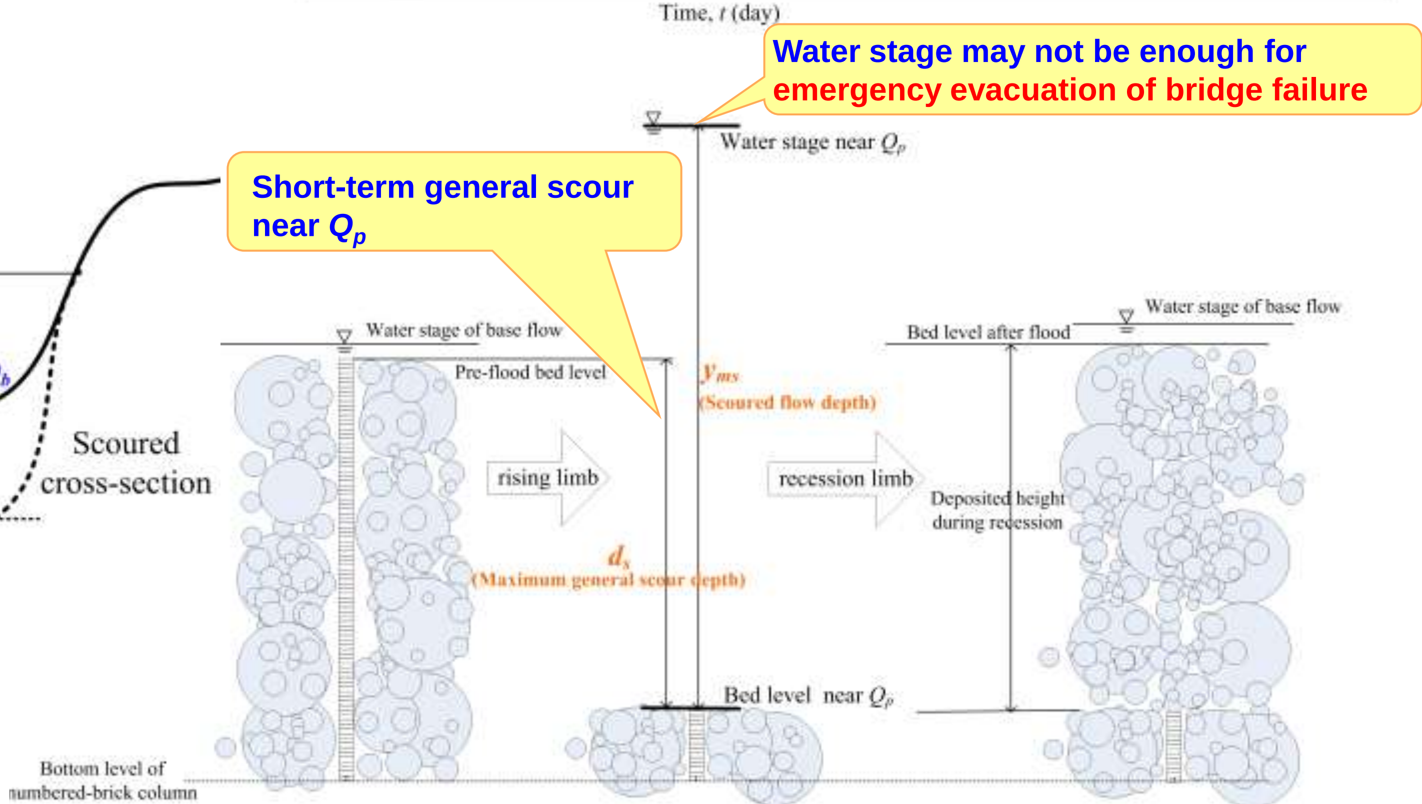


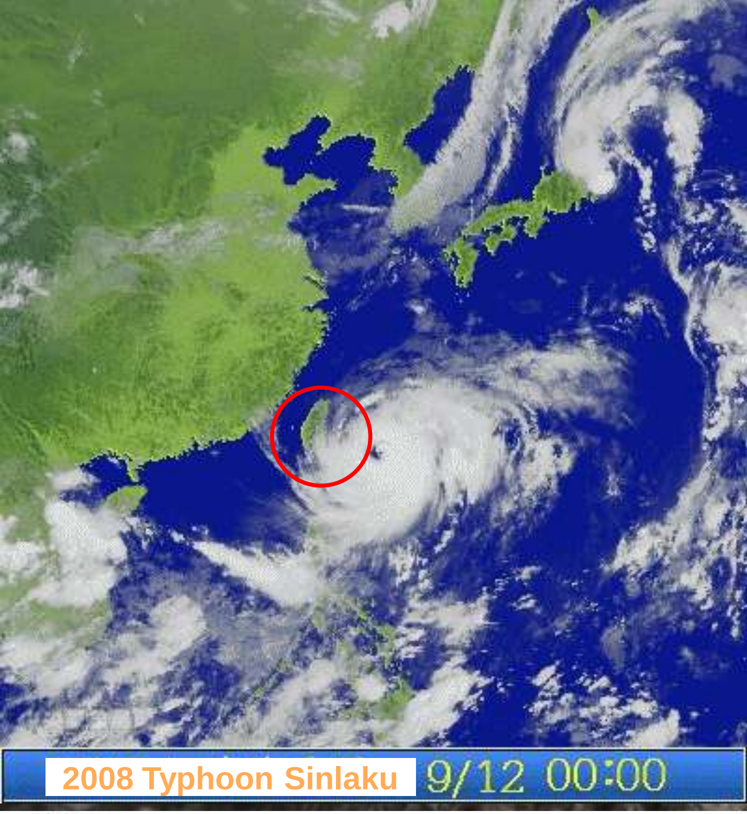
Short-term general scour during a typhoon-induced flood for a steep intermittent river in Taiwan

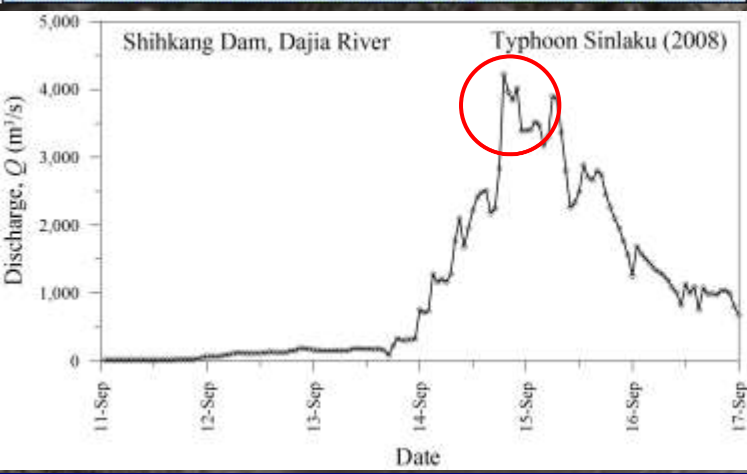












Houfeng Bridge failure at flood peak of Typhoon Sinlaku (7:00 pm, Sept. 14, 2008) in Dajia River (Hong et al., 2012)

Q_p= 4,225 m^3/s

≅ Q_5= 3,800 m^3/s

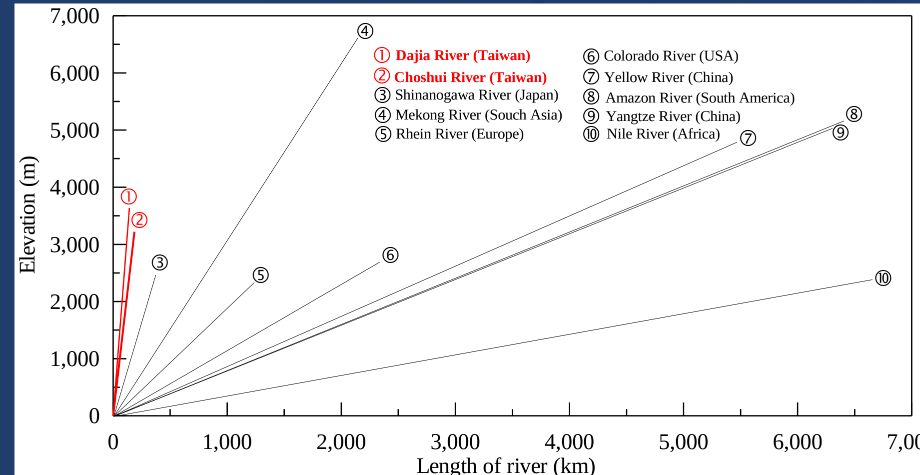
Disasters at Highway Bridge during Typhoon Sinlaku (Sept. 14, 2008) flood in Dajia River

Objectives

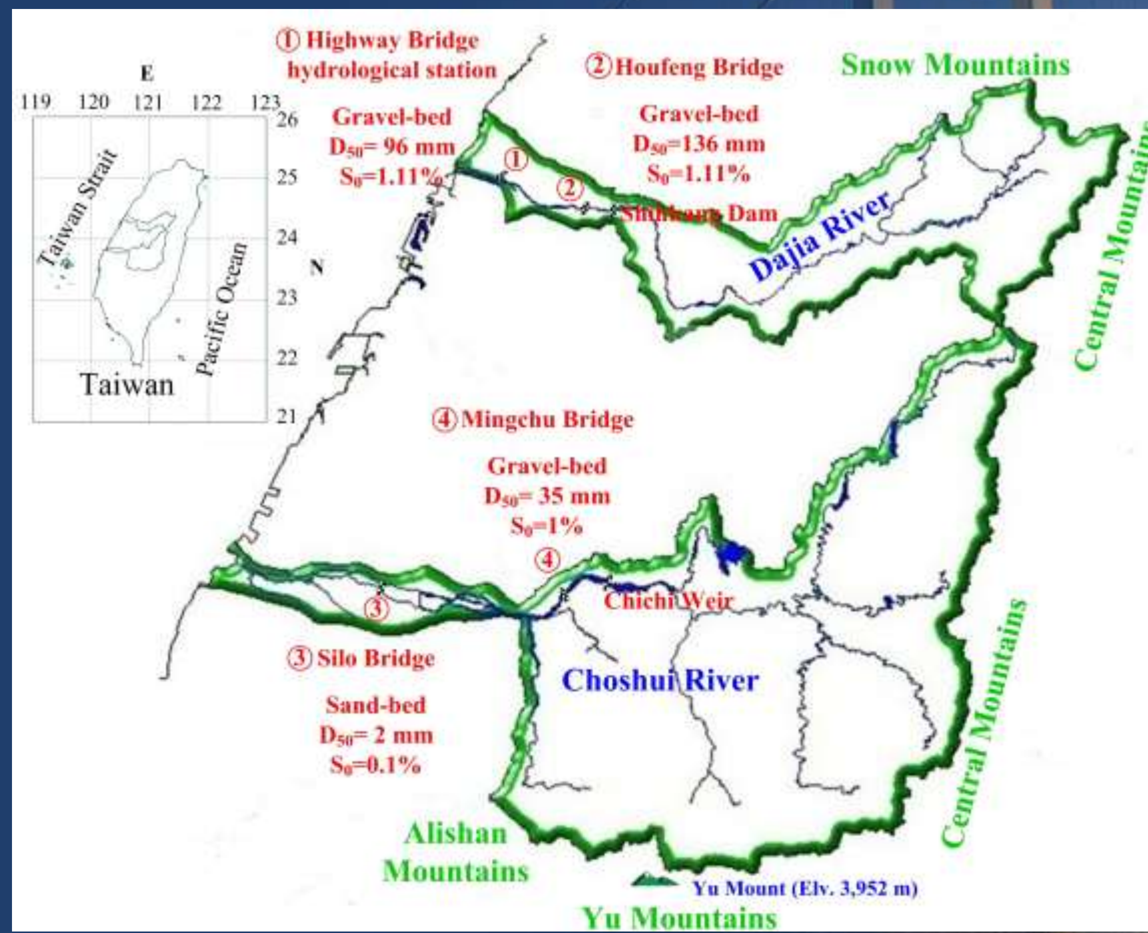
- Measure the maximum short-term general scour depths and the scoured flow depths during a typhoon-induced flood for both sand-bed and gravel-bed reaches in intermittent rivers
- Derive an empirical formula to predict the short-term general scour for the high gradient intermittent rivers

SITE DESCRIPTION & METHOD

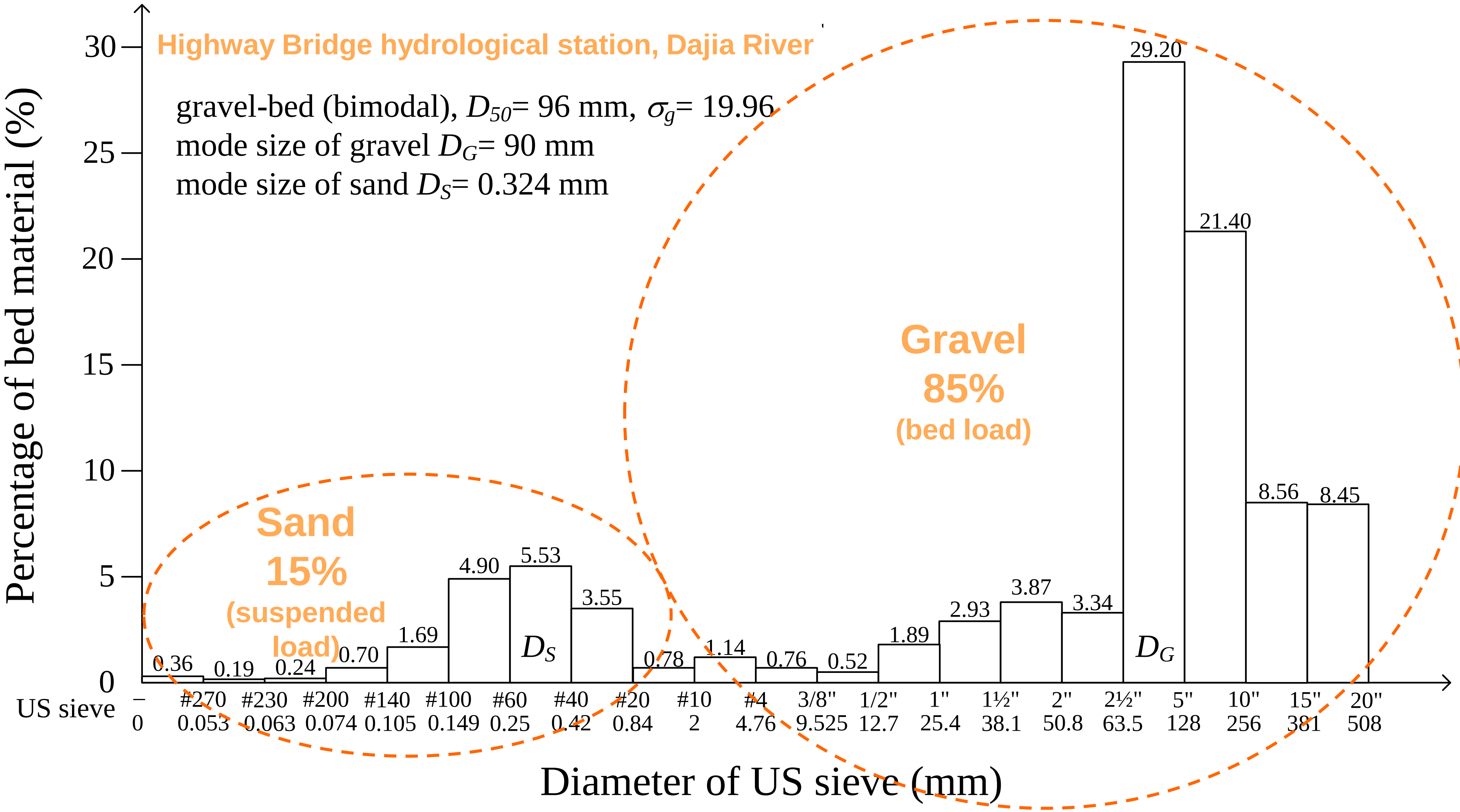
Test sites



- **4** bridges in **Dajia** & **Choshui Rivers**
- **Steep** bed slope S_0= **0.1~1.11%**
- Degrading riverbed for the lower river reaches
- 921 Chichi Earthquake (Richter magnitude 7.3)
- Small drainage area< 3,157 Km^2
- Short river length< 186 Km

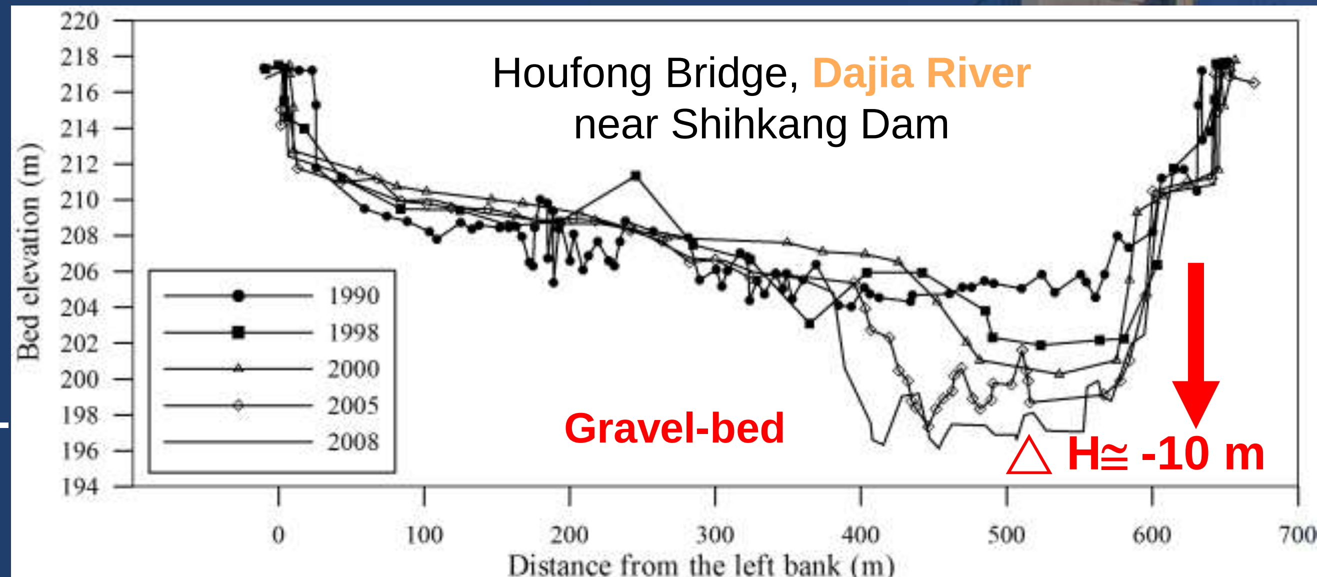


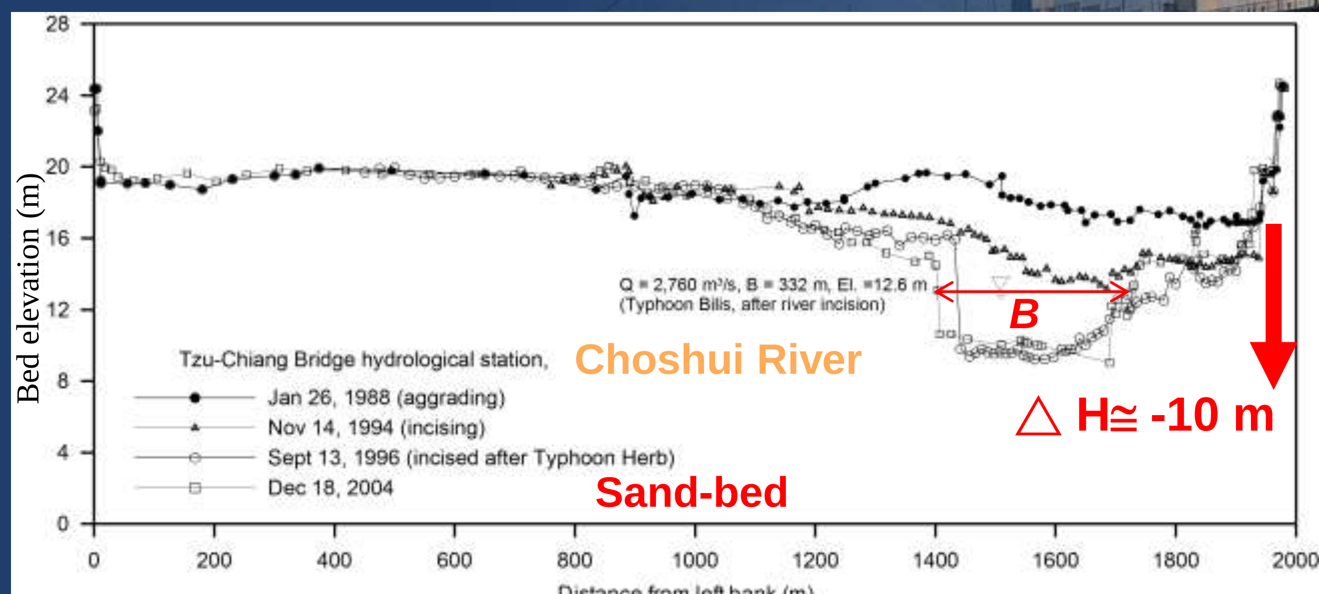
Special Features of Gravel-bed River Reach in Taiwan– Bimodal



River incision

- **Cause**
  - **Human activies**
    - **Sand mining**
    - **Dam / Weir**
    - **GCS**
  - **Natural events**
    - **Extreme typhoon-induced floods**
    - **921 Chichi Earthquake**
- **Effect**
  - **Long-term general scour**
    - **Main channel △H/△t ≅ 10 m/20 yrs = 0.5 m/yr**
  - **Short-term general scour**
    - $B^{-} \Rightarrow q^{+} \Rightarrow (d_s)^{+}$





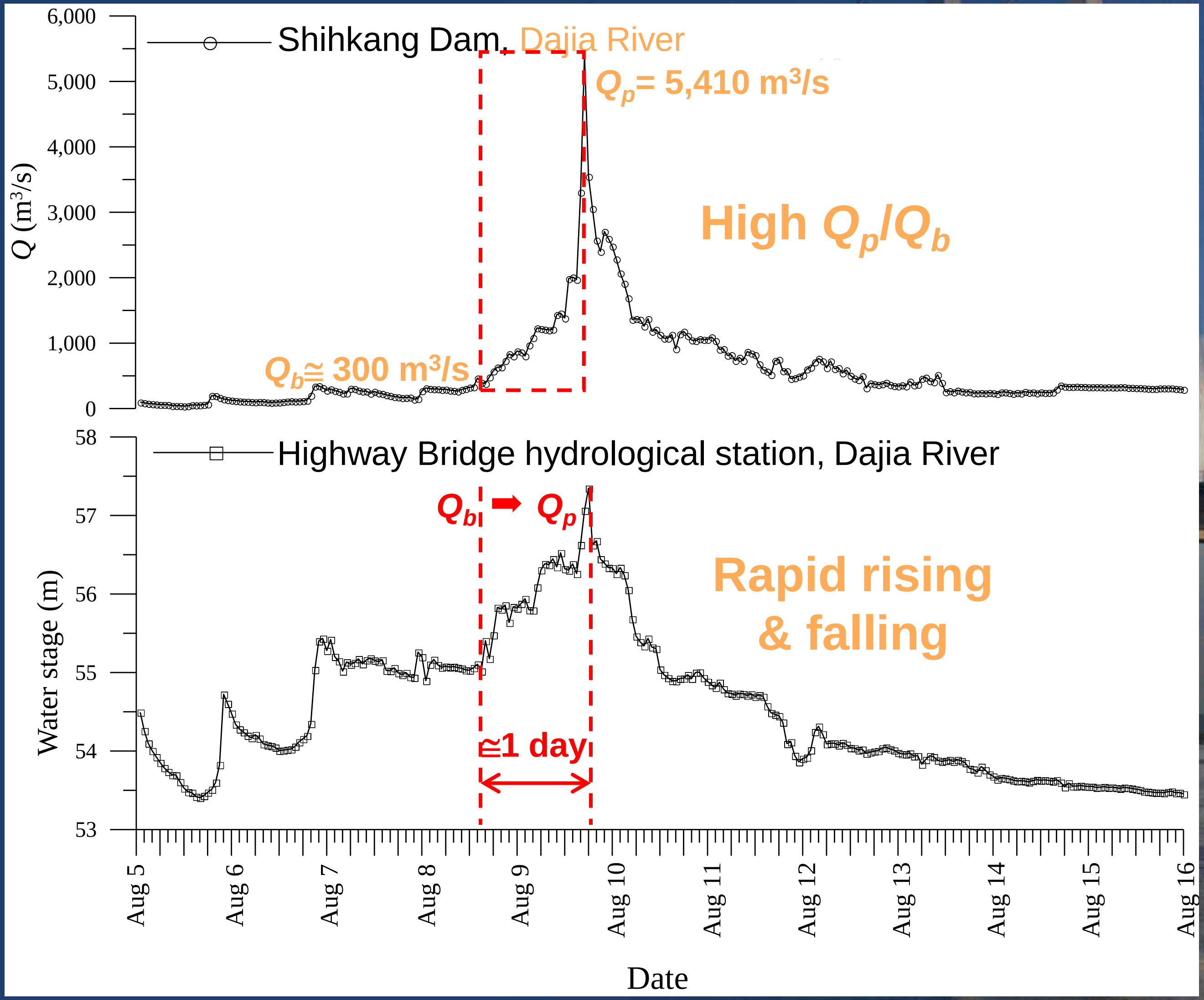
High efficiency numbered-brick column laying Method- reliability

- **Local scour monitoring**
  - Sliding magnetic collar(SMC), sonar, scour chains, fiber Bragg grating sensors, float-out device, falling steel rod, piezo film senor, temperature senor (heat pulse method), electrode senor rod, wireless sensor network, Tell-Tail, wireless vibration monitoring etc.
  - Severe environmental restriction, e.g. temperature, pressure, debris impact etc.
- **General scour monitoring– numbered-brick column**
  - Problem
    - No supporting structures available [far away (≅155 m) from bridge, in main channel]
    - Severe scouring & deposition during the flood
  - Method
    - 5 m long supplementary hollow steel rod + excavator (90 pieces of brick)
    - Flood stage gauge– peak flood level

RESULTS

Typical flow and stage hydrographs during a typhoon for intermittent river in Taiwan

- Typhoon Morakot (Aug. 8-10, 2009)
  - Discharge
  - Water stage



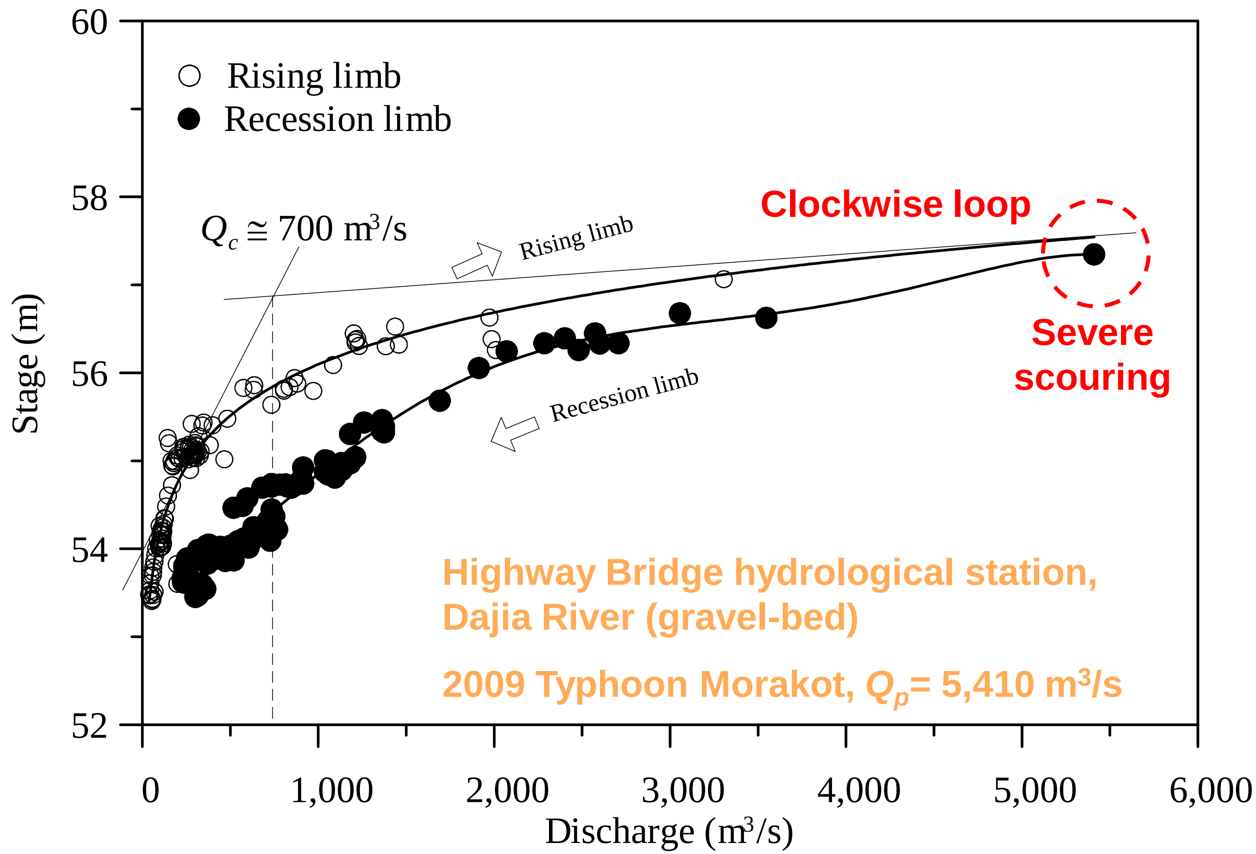
Extreme short-term general scour near peak flow of Typhoon Sinlaku

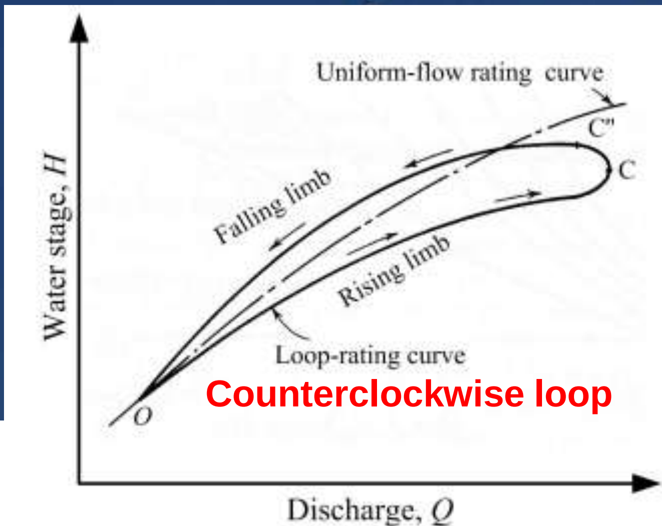
- Typhoon Sinlaku (Sept. 12~16, 2008)
  - Flood peak discharge Q_p = 4,225 m^3/s ≅ Q_5
  - Maximum short-term general scour depth d_s (4.5 m) > ½ scoured flow depth y_{ms} (7.73 m)
  - Short-term general scour rate (4.5 m/day) >> long-term general scour rate (≅ 0.5 m/yr)

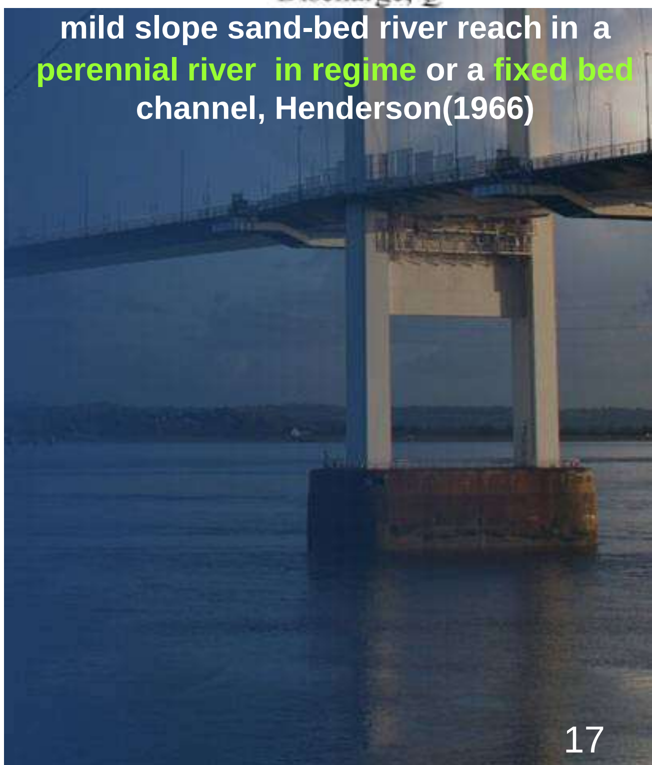
Distance from Highway Birdge	(1)	(2)	(3)=(2)-(1)	(4)	(5)=(1)-(4)	(6)=(2)-(5)	(7)	(8)=(7)-(5)
	Preflood bed level (Top level of numbered brick column)	Bed level after flood	Difference of bed level before and after flood	Maximum general scour depth d_s	Bed level during peak flow	Deposited height during recession	Water stage of peak flow	Scoured flow depth y_{ms}
155 m down-stream	52.09 m (No. 90)	53.75 m	1.66 m	4.5 m (75×0.06 m)	47.59 m (No. 15)	6.16 m	55.32 m	7.73 m

Unusual rating curve of gravel-bed intermittent river

- **Extreme short-term general scour** occurred near typhoon-induced flood peak
- For disaster prevention (bridge/ embankment failure) of typhoon-induced flood, in addition to the water stage measurement, proper prediction of maximum short-term general scour depth is very important







Field data of short-term general scour and scoured flow depth during typhoons

River basin	Field site, flood event	Q_p (m^3/s)	B (m)	$q(=Q_p/B)$ ($m^3/s/m$)	S_0 (%)	Bed material D_{50} (mm)	Bed material σ_g	Bed material Riverbed	d_s (m)	y_{ms} (m)	y_{ms}(m) by Blench (1969)
Choshui River	Silo Bridge, 2003 Typhoon Dujuan	2,268	506	4.46	0.1	2	9.86	sand-bed (unimodal)	1.2	3.29	3.04
	Silo Bridge, 2004 Typhoon Mindulle	8,050	758	10.62	0.1	2	9.86		1.65	5.68	5.61
	Mingchu Bridge, 2003 Typhoon Dujuan	2,146	247	8.69	1	35	10.49	gravel-bed (bimodal)	2.1	4.86	3.87
	Mingchu Bridge, 2004 Typhoon Mindulle	7,250	275	21.54	1	35	10.49		6	10.5	7.08
Dajia River	Highway Bridge, 2008 Typhoon Sinlaku	4,225	400	10.56	1.11	96	19.96	gravel-bed (bimodal)	4.5	7.73	4.05
	Houfeng Bridge, 2009 Typhoon Morakot	5,410	230	23.52	1.11	136	5.35	gravel-bed (bimodal)	1.56	5.12	6.71

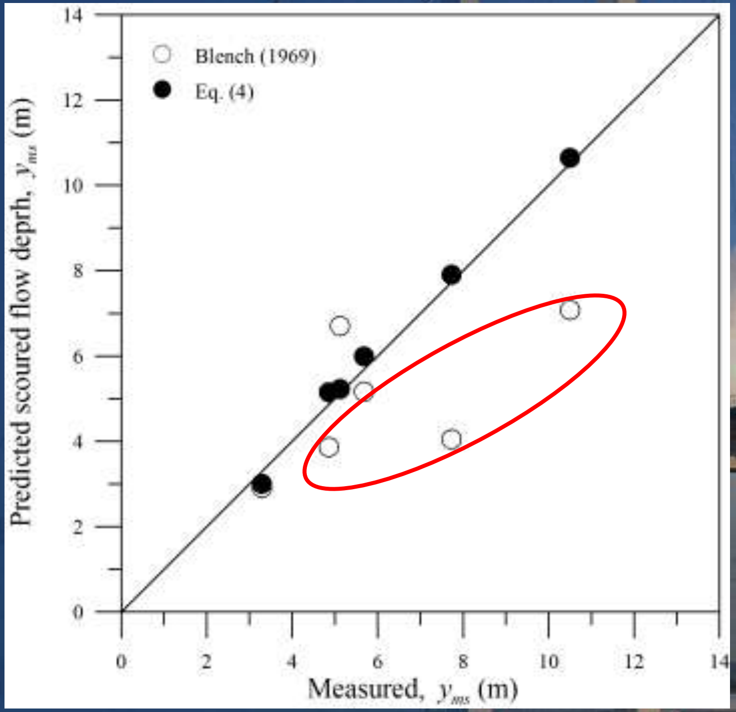
sediment load dominated by near-saturated suspended load, lower potential for d_s

bed load with non-equilibrium sediment transport, higher potential for d_s

Note: Q_p= peak discharge of a flood event; B= flow width; q= unit peak discharge for the main channel; S_0= bed slope; D_{50}= median size of bed material; σ_g= geometric standard deviation of the sediment; **d_s= maximum short-term general scour**; and y_{ms}= scoured flow depth

Scoured flow depth prediction formula

- **Current data in intermittent river**
  - **Extreme typhoon-induced unsteady floods**
  - **Maximum scoured flow depth near typhoon-induced flood-peak**
  - $y_{ms} = fn(q, S_0, D_{50}, \sigma_g)$
  - $$y_{ms} = 1.26\left[\frac{q^{0.80} \times S_0^{0.27} \times \sigma_g^{0.74}}{D_{50}^{0.23}}\right]$$ **Eq. (4)**



- **Blench (1969)**
  - **Sand-bed (D_{50}<2 mm)–** $$y_{ms} = 1.20\left[\frac{q^{2/3}}{D_{50}^{1/6}}\right]$$
    - **Indian canals in regime**
  - **Gravel-bed (D_{50}>2 mm)–** $$y_{ms} = 1.23\left[\frac{q^{2/3}}{D_{50}^{1/12}}\right]$$
    - **Gilbert's (1914) equilibrium and steady flow flume data**
  - **Blench's (1969) Eq. generally under-predicted y_{ms} for our gravel-bed data (intermittent rivers)**

CONCLUSIONS

CONCLUSIONS

1. The scour potential is rather high in the steep gravel-bed intermittent river reach for a typhoon-induced flood with high flows because the gradation of bed material is wide, and a significant amount of sediment moves irregularly as bed load under non-equilibrium condition.

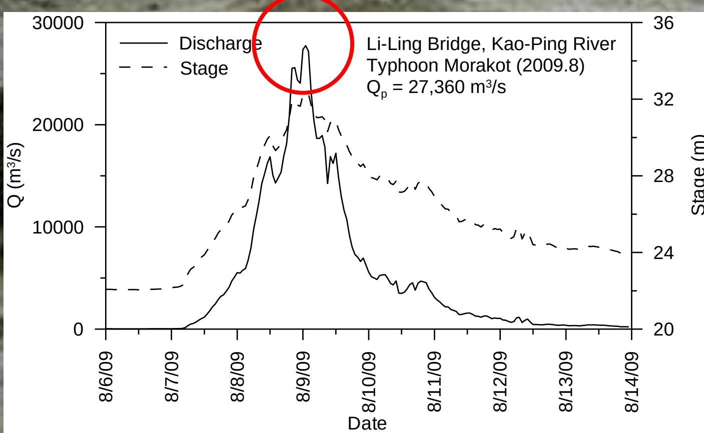
2. For the sand-bed river reach with a milder slope, the scour potential is lower because the sediment load is dominated by the near-saturated suspended load due to the abundant sediment supply from the riverbed.

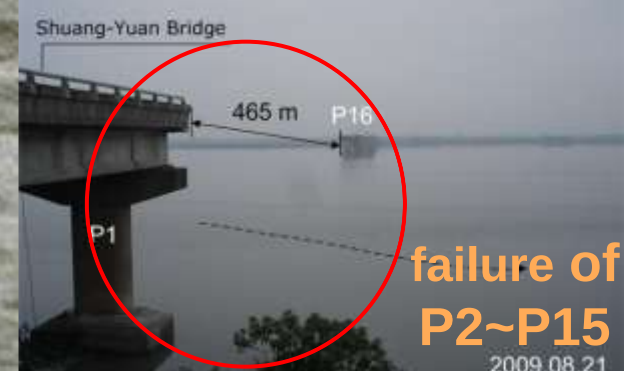
CONCLUSIONS

3. For steep gravel-bed and sand-bed intermittent rivers in Taiwan, the **scoured flow depth formula** developed in the current study gave **reasonable predictions**.

4. With **slight modification** when more data are available, the proposed equation can be used as a powerful tool for the **design** of the cross-river hydraulic structures and the **emergency evacuations** of the bridge failures.

Thank you for your attention





Shuang-Yuan Bridge failure at flood peak of Typhoon Morakot (0:40 am, Aug. 9, 2009) in Gao-Ping River

Maximum short-term general scour depth prediction formula

- **Current data in intermittent river**
  - **Extreme typhoon-induced unsteady floods**
  - **Maximum short-term general scour depth near typhoon-induced flood-peak**
  - $d_s = fn\left(q, S_0, D_{50}, \sigma_g\right)$
  - $$d_s = 1.15\left[\frac{q^{1.07} \times S_0^{0.70} \times \sigma_g^{1.34}}{D_{50}^{0.45}}\right]$$