國家地震工程研究中心
National Center for Research on Earthquake Engineering

An Evaluation on Flood Resistant Capacity of Scoured Bridges

- A Case Study of the Shuang-Yuan Bridge in Taiwan

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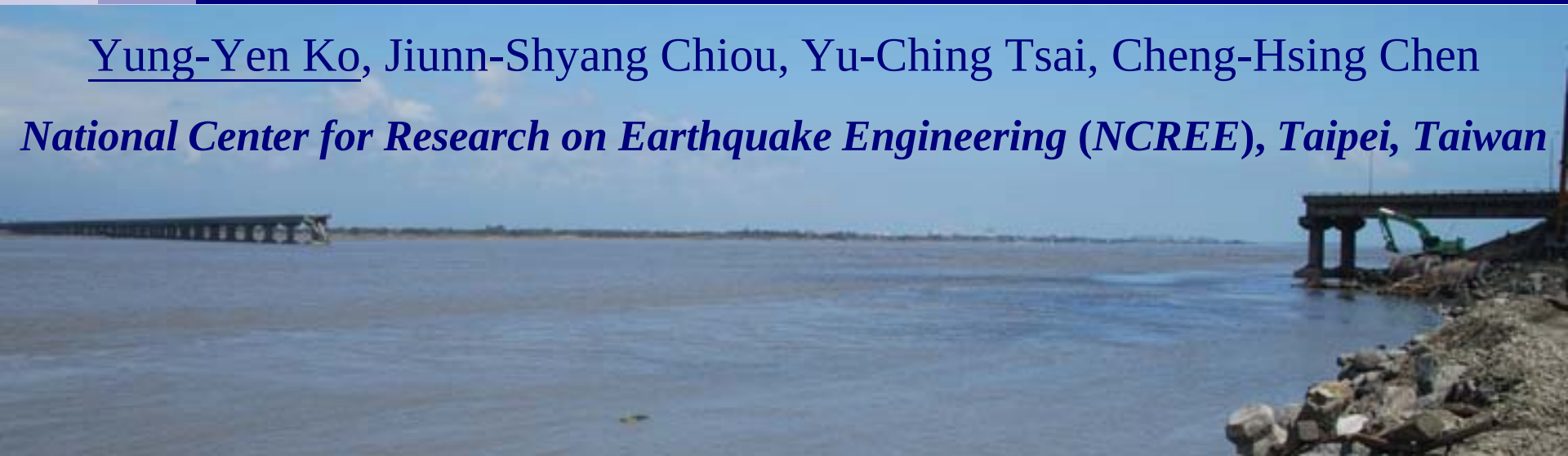
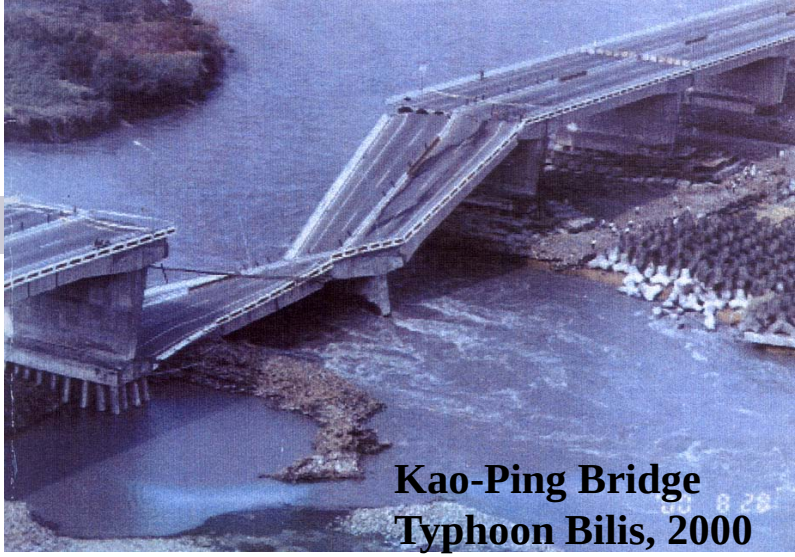


Major Highway Bridge Failures in Taiwan

- Several major highway bridge failures occurred in Taiwan in recent years.
- Most of them were due to **the exposure of the pier foundation** because of **scour**.


Kao-Ping Bridge
Typhoon Bilis, 2000

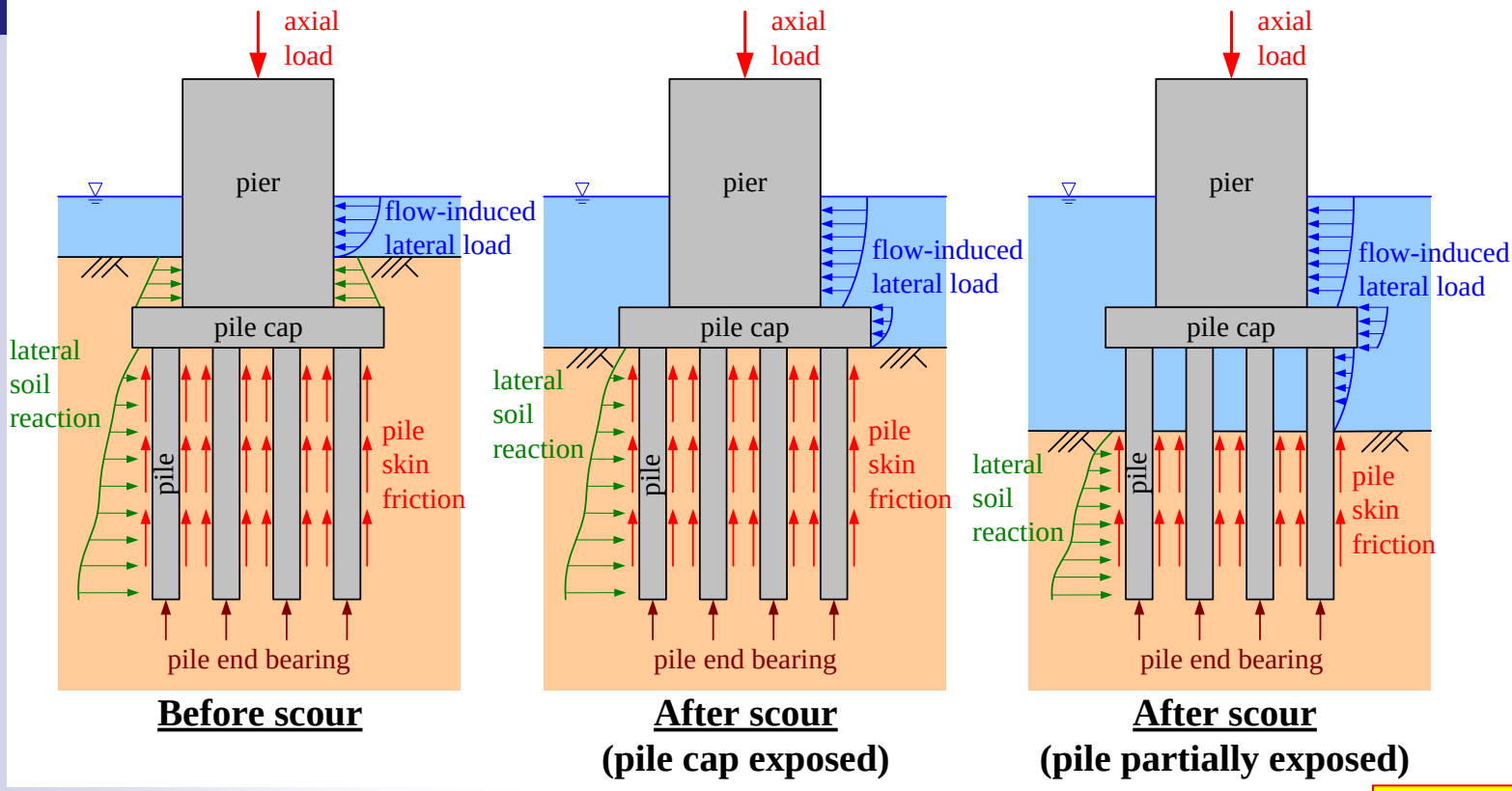

July 30, 2009


Hou-Fong Bridge
Typhoon Sinlaku, 2008


Aug. 13, 2009
Da-Jin Bridge
Typhoon Morakot, 2009


Shuang-Yuan Bridge
Typhoon Morakot, 2009

Influence of Scour on the Pier Foundation



- Lateral resistance of the pier-soil system will be decreased.
- Larger flow-induced loads will be applied on the pier

} **reducing the stability of foundation**

- To prevent bridge failures, it is important to estimate the performance of scoured bridges during flood.

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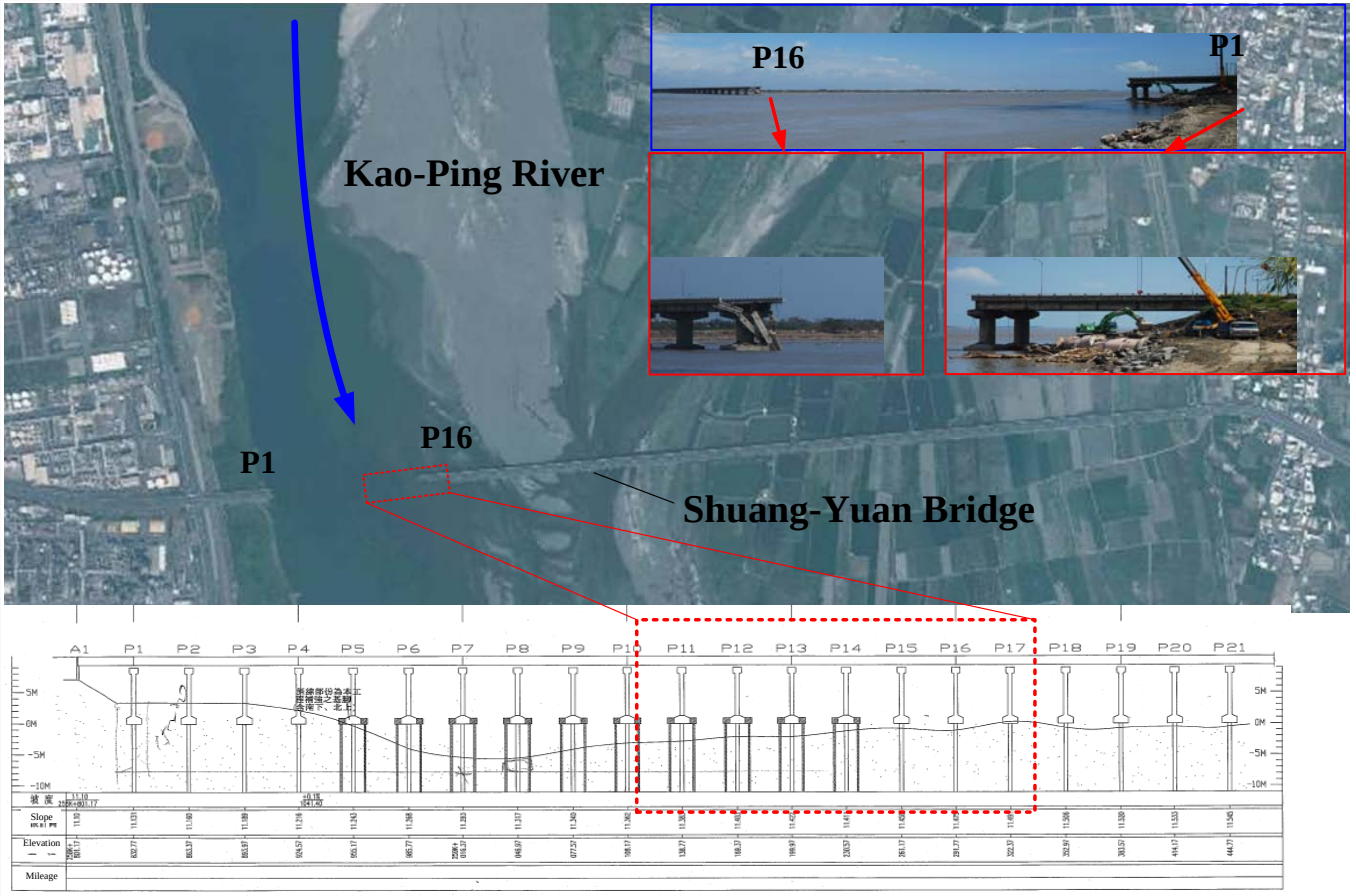
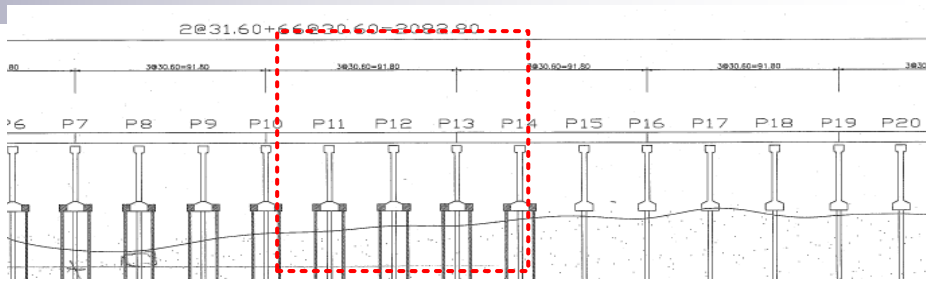
Failure of the Shuang-Yuan Bridge during Typhoon Morakot

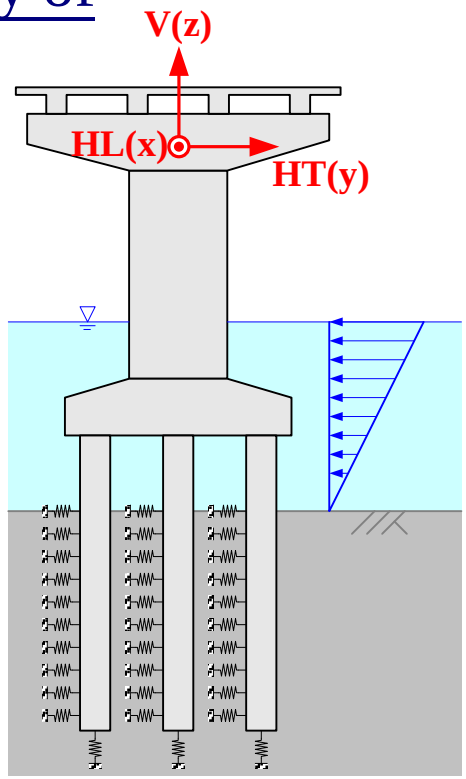
- Main channel of the river shifted toward the right river bank and caused the powerful torrent concentrated on section P10~P16.
- Failure could begin at P10~P16, and resulted in sequential damage that propagated to P2.
- What need to be clarified :
  - Failure mode of the foundation.
  - Scour depth at failure moment.

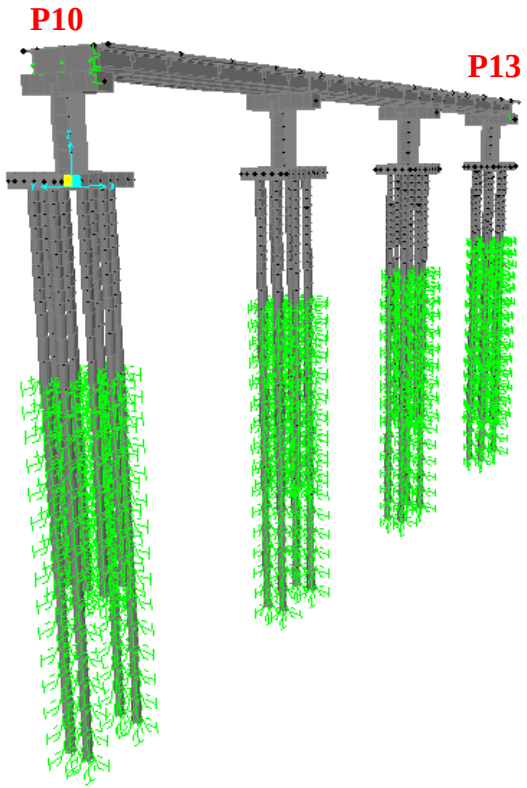


Analysis Model of Shuang-Yuan Bridge

- Unit P10-P13 was chosen as the target of interest.
- SAP2000 was employed to establish the soil-structure model considering the nonlinearity of pile-soil system
- **Pile cap:** rigid plate.
- **Pile-soil system:** Winkler beam model
  - **Pile:** beam elements
  - **Soil reactions:** spring elements
  - **Pile exposure:** removing the soil springs.



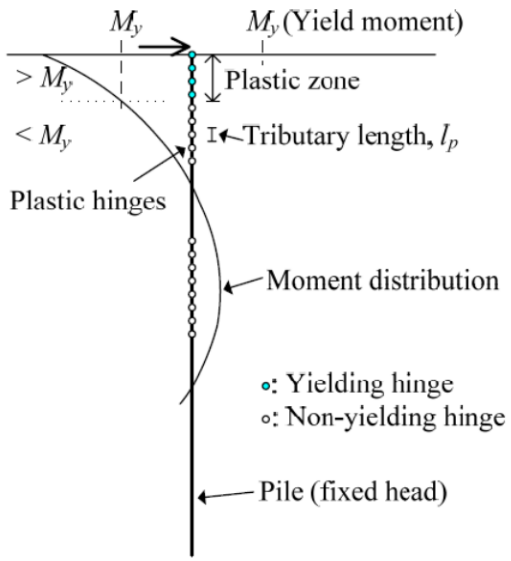




Modeling the nonlinearity of pile-soil system

- **Nonlinearity of the pile:** the distributed hinge model.
- **Nonlinearity of soil:** Nonlinear *p-y* curves.

Distributed hinge model



$$k_h(y_1) = 0.34(\alpha E_0)^{1.1} D^{-0.31} (EI)^{-0.103}$$

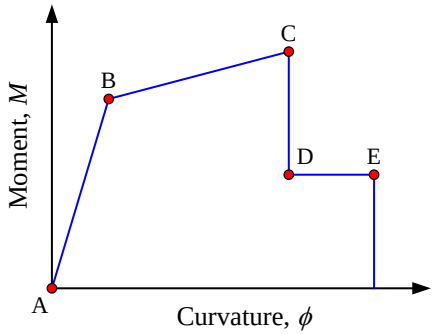
(Japan Road Association, 1996)

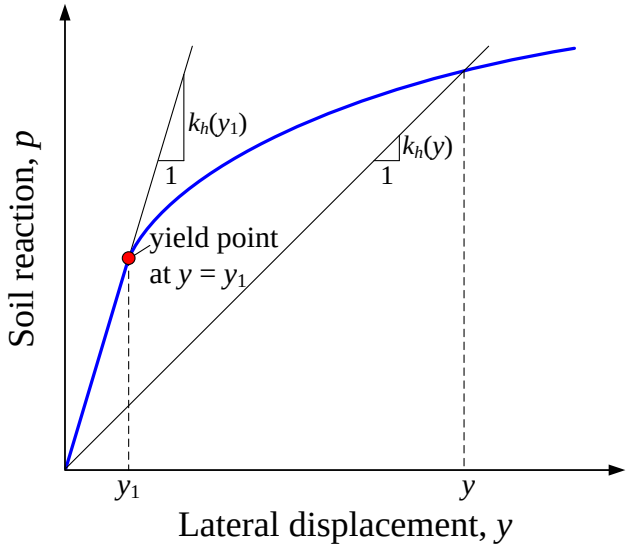
$$k_h(y) = k_h(y_1)\left(\frac{y}{y_1}\right)^{-0.5}$$

(Architectural Institute of Japan, 1988)

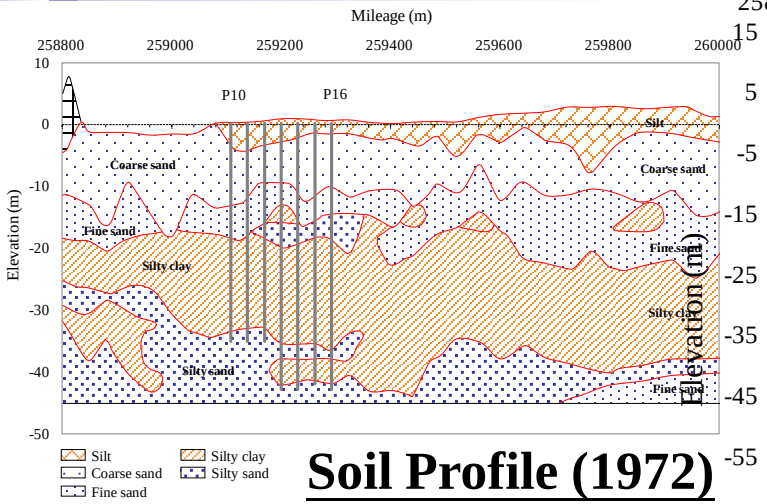
M-ϕ curve of hinge

B: yield point
D: failure point

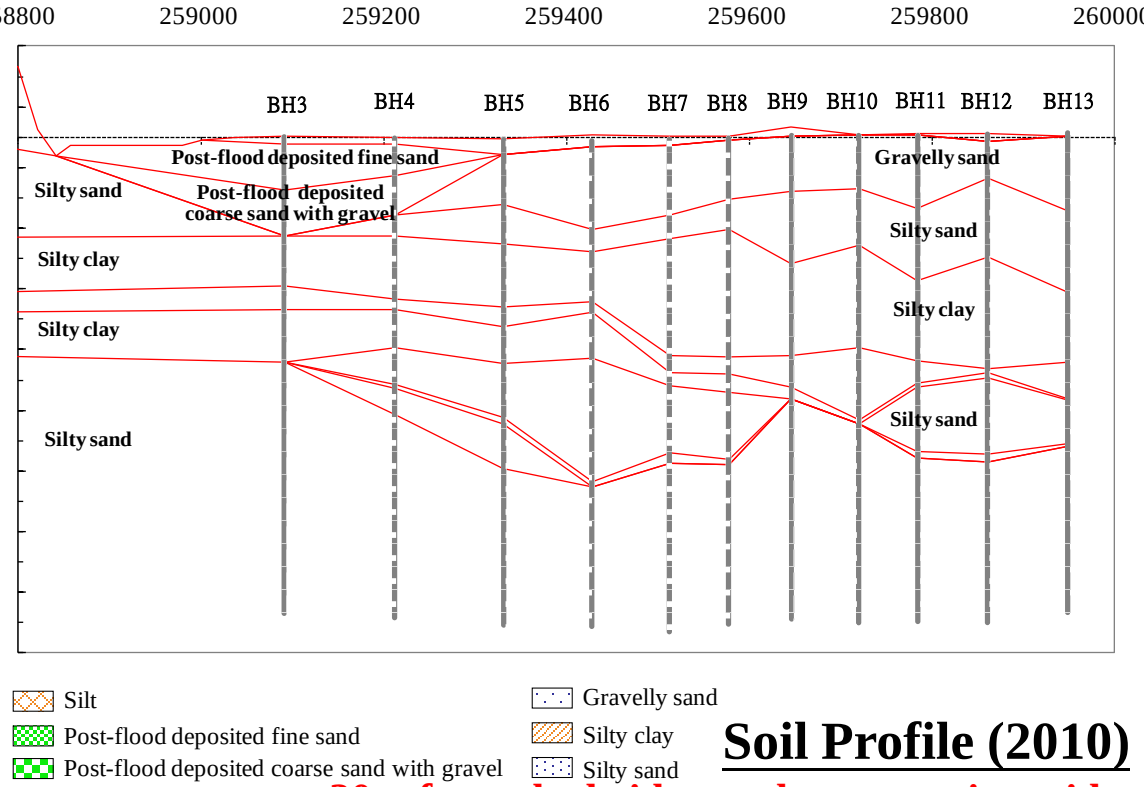




Soil Profile



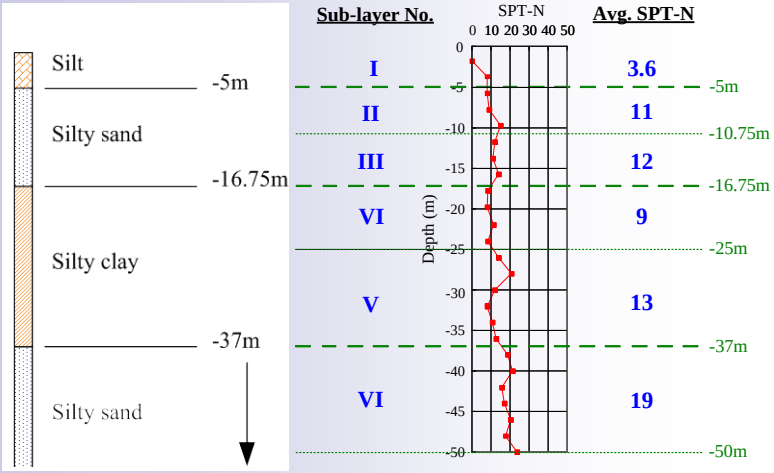
Soil Profile (1972)



Soil Profile (2010)

30m from the bridge to the upper river side

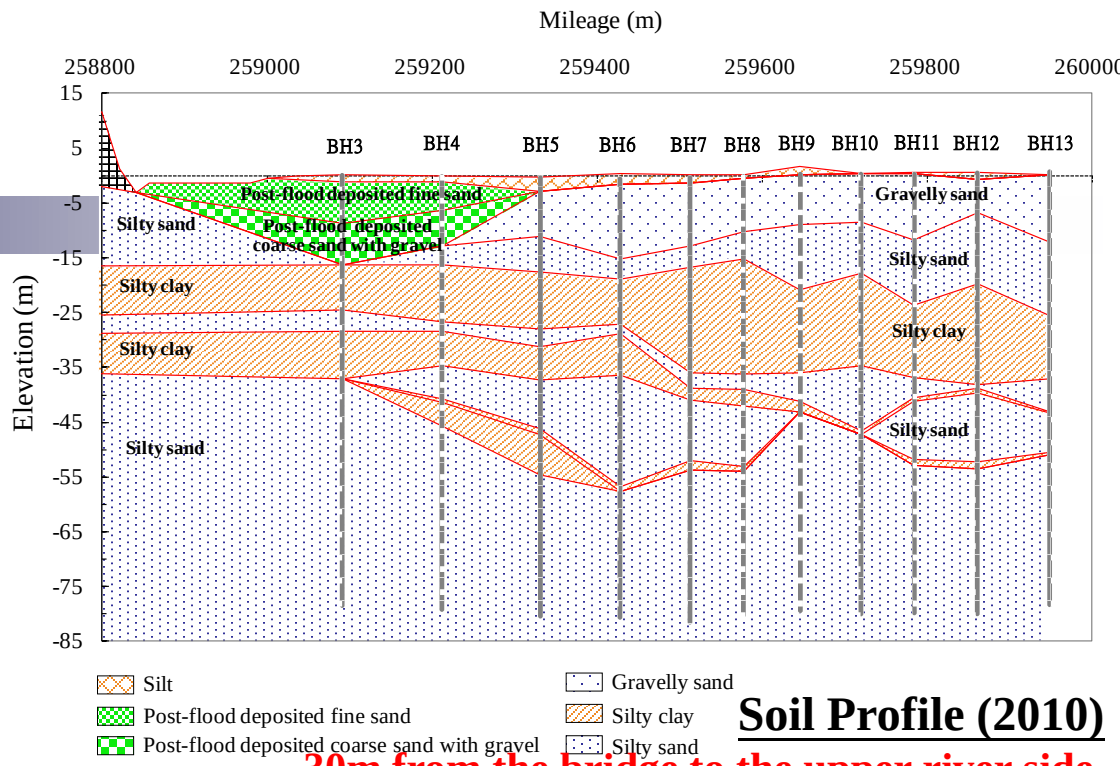
Simplified Soil Profile



- Soil properties wer estimated mainly according to the soil profile (2010)
- Nonlinear p-y curves were obtained based on the SPT-N values

Scour Depth

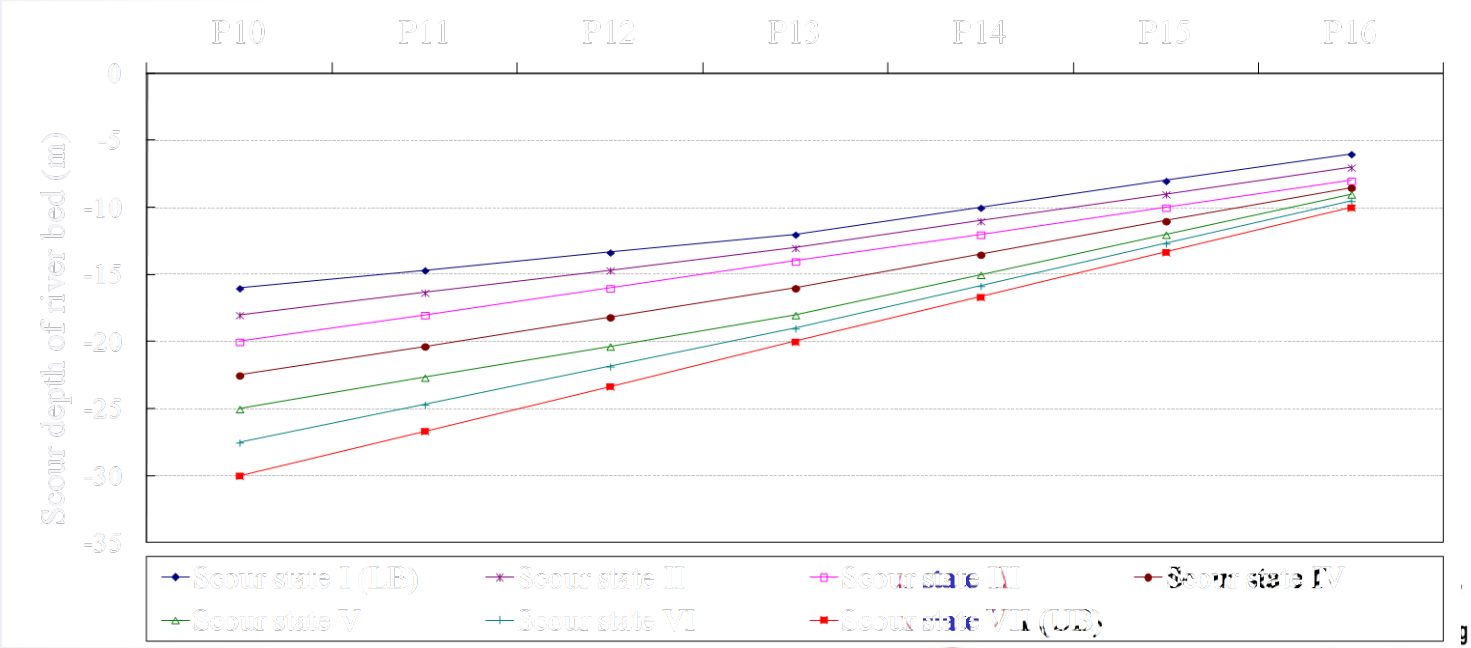
- Scour depth @ 30m from the bridge to the upper river side as the lower bound (LB)
- Scour depth up to 30m around P4~P12 and 15~20m @ P13 (by ERT)



Soil Profile (2010)

30m from the bridge to the upper river side

- 7 scour states are specified
- **LB:** scour depth is 16 m at P10
- **UB:** scour depth is 30 m at P10



Flow Induced Load and Analysis Processes

$$P_{avg} = 52.5K(V_{avg})^2$$

"Standards Specification for Highway Bridges" (AASHTO, 2002):

where

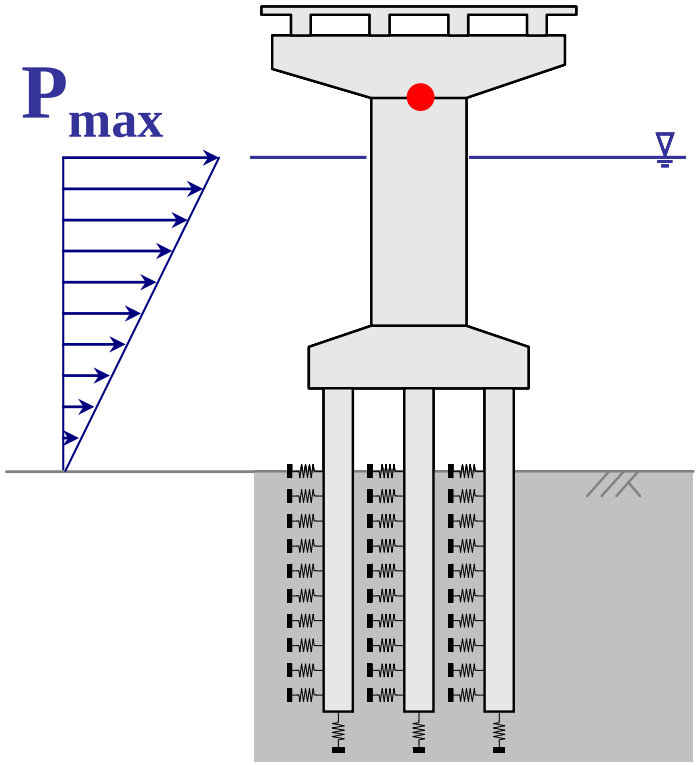
P_{avg} (kgf/m^2) is the average stream pressure;

V_{avg} (m/s) is the average velocity of water ;

K is a constant based on the shape of the pier:

for a circular piers, K=0.7;

$P_{max} = 2P_{avg}$ → a triangular distribution



Analysis Processes

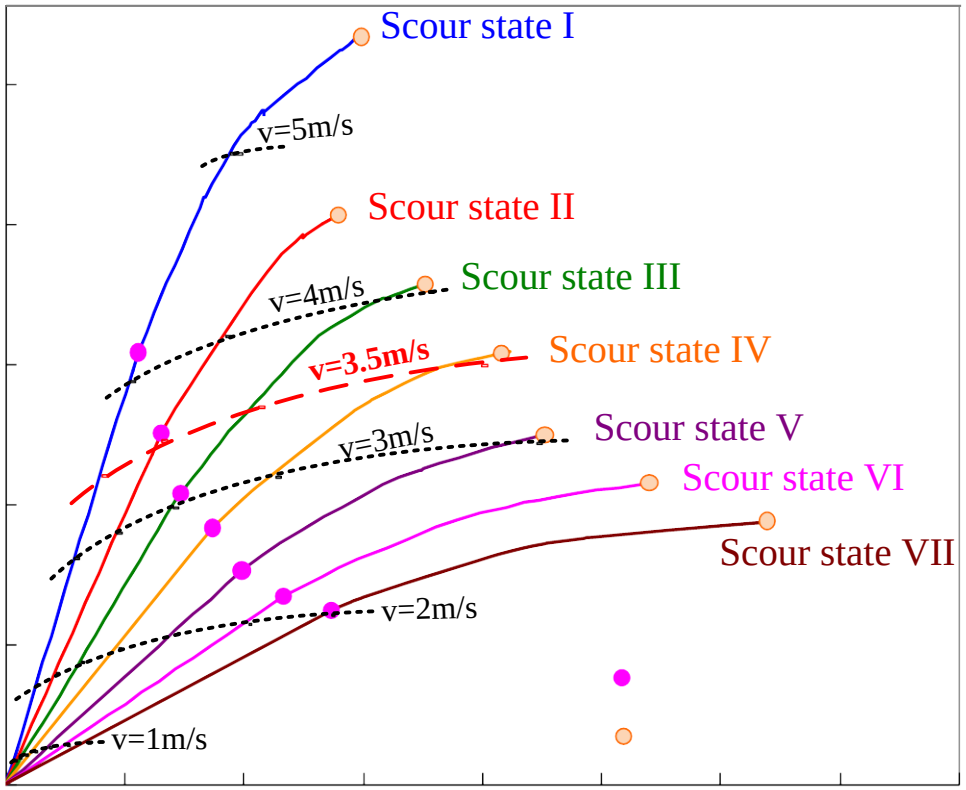
- Self weight equilibrium analysis
- Displacement-control nonlinear quasi-static analysis under flow-induced load
  - Performed at each specified scour depth
  - Total lateral load v.s. lateral displacement → **flood resistant capacity curve**

Flood Resistant Capacity Curves at Various Scour State

- Each point on capacity curve represents a specific V_{avg} .
- Foundation scour reduces the stiffness and strength of bridges.

- V_{avg} = 3.5 m/s during flood by hydraulic analysis.
- At scour state II (scour depth=18m @P10) , the structure is close to the yield state
- At scour state IV (scour depth=22.5m @P10) , the structure is close to the complete failure state

→ scour depth could had been beyond **22.5m @ P10**



Development of Plastic during Analysis

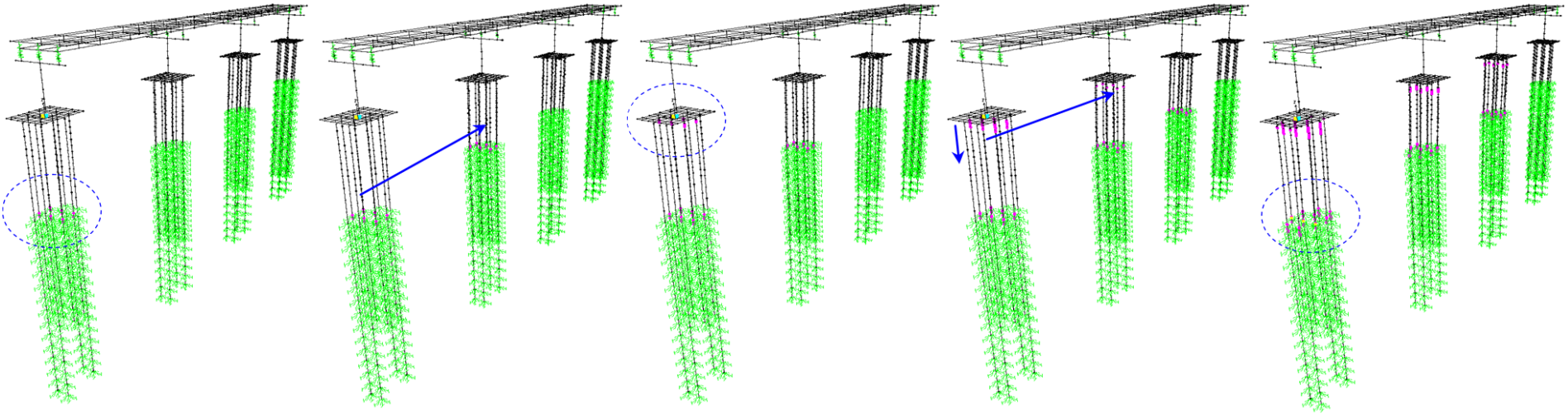
a) Original piles of P10 yield at segments near the river bed.

b) The yield zone of P10 spread upward and downward. Meanwhile, original piles of P11 also yield at segments near the river bed.

c) Piles of P10 yield at segments below the pile cap.

d) Yield zone below the pile cap of P10 spread downward, and the pile segments below the pile cap of P11 yield well.

e) The pile segments near the river bed of P10 completely fail.



Summaries

- Procedure for the evaluation on the flood resistant capacity of scoured bridges with pile foundations were proposed.
- The failure of the Shuang-Yuan Bridge in Taiwan in 2009 was chosen as a case study.
- An FE model was generated for a nonlinear quasi-static analysis under the action of flow-induced loads.
- The exposed foundations of unit P10-P13 would reach an initial damage state if local scour depth was more than 18m.
- If the local scour depth was above 22.5m, the unit P10-P13 would attain a complete failure state.

Thanks for Your Attention

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