5th IASPEI / IAEE International Symposium: Effects of Surface Geology on Seismic Motion

Soil Liquefaction Issues in Meinong Earthquake

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August 15-17, 2016

OUTLINE

- INTRODUCTION
- LIQUEFACTION-INDUCED DAMAGE TO BUILDINGS
- LIQUEFACTION-INDUCED DAMAGE TO RIVER REVETMENTS
- CONCLUSIONS

INTRODUCTION

- Meinong earthquake
- Hot news
  - Collapse of 16-story Wei Guan complex building ➡ 115 people died
  - Soil liquefaction ➡ Announcement of liquefaction potential map
- Geotechnical reconnaissance
- Major liquefaction sites

Meinong Earthquake

Local time: 03:57:27.2 am

February 6, 2016

Epicenter: 22.92° N, 120.54° E

Magnitude: M_L6.6 (Mw 6.3)

Focal depth=14.6km

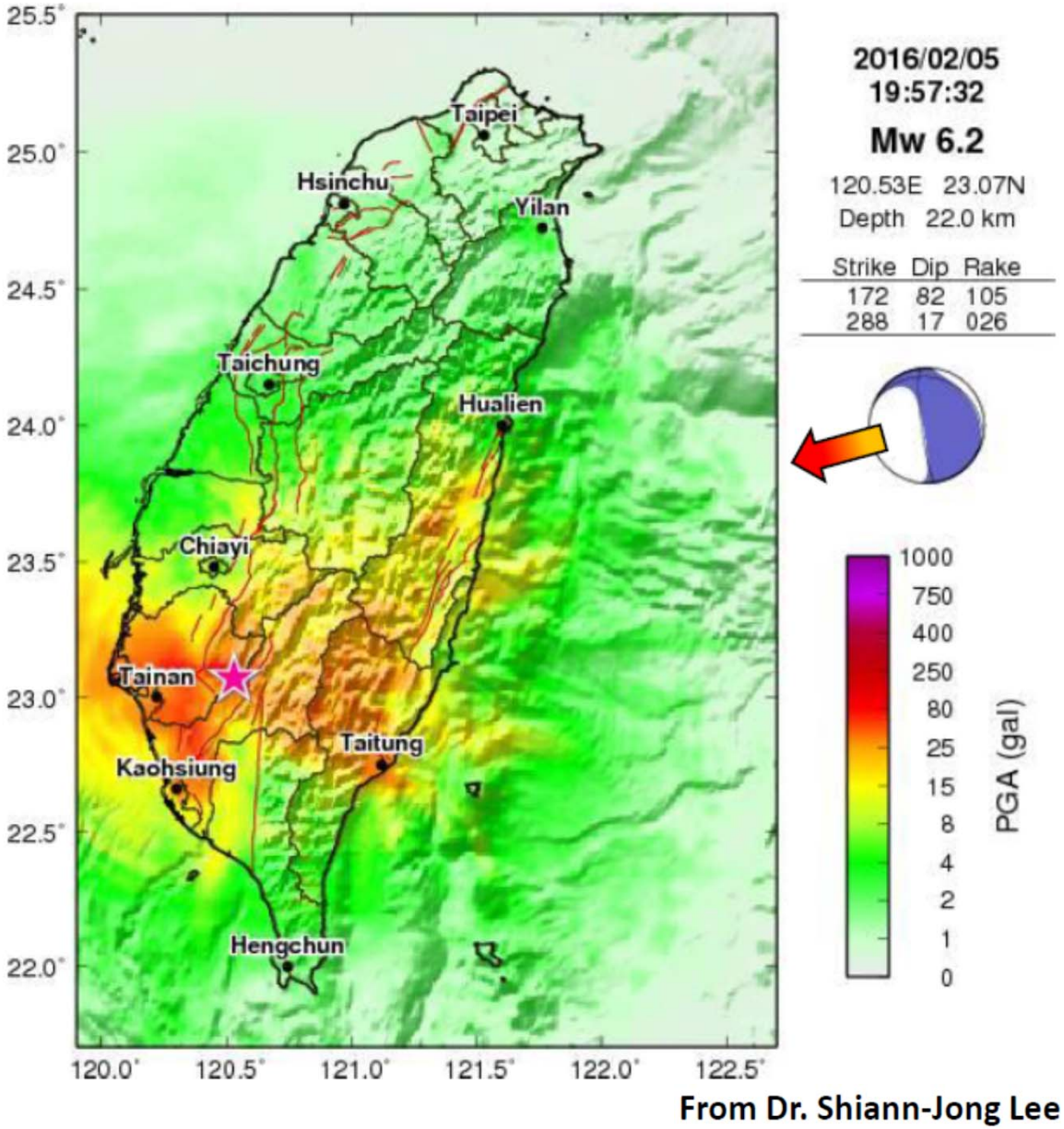
Max. Intensity scale=6

Damaged area: Tainan city

Rupture directivity

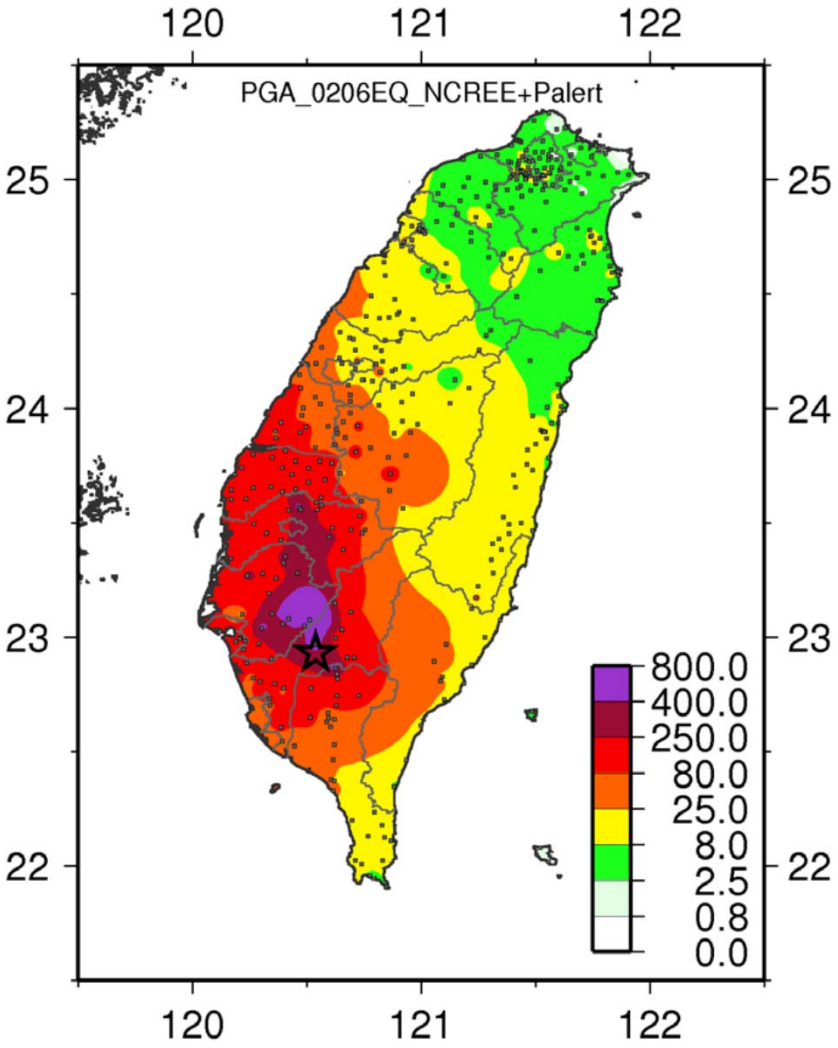
Amplification

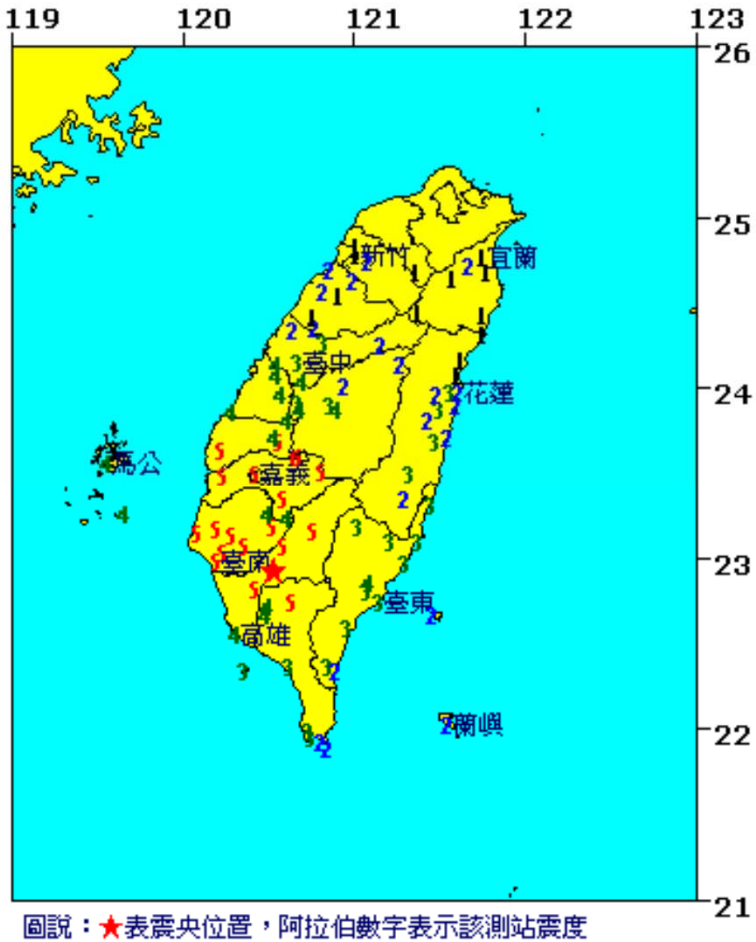
(From CWB report)



From Dr. Shiann-Jong Lee

Meinong Earthquake-Seismic Intensity





圖說：★表震央位置，阿拉伯數字表示該測站震度

中 央 氣 象 局 地 震 報 告

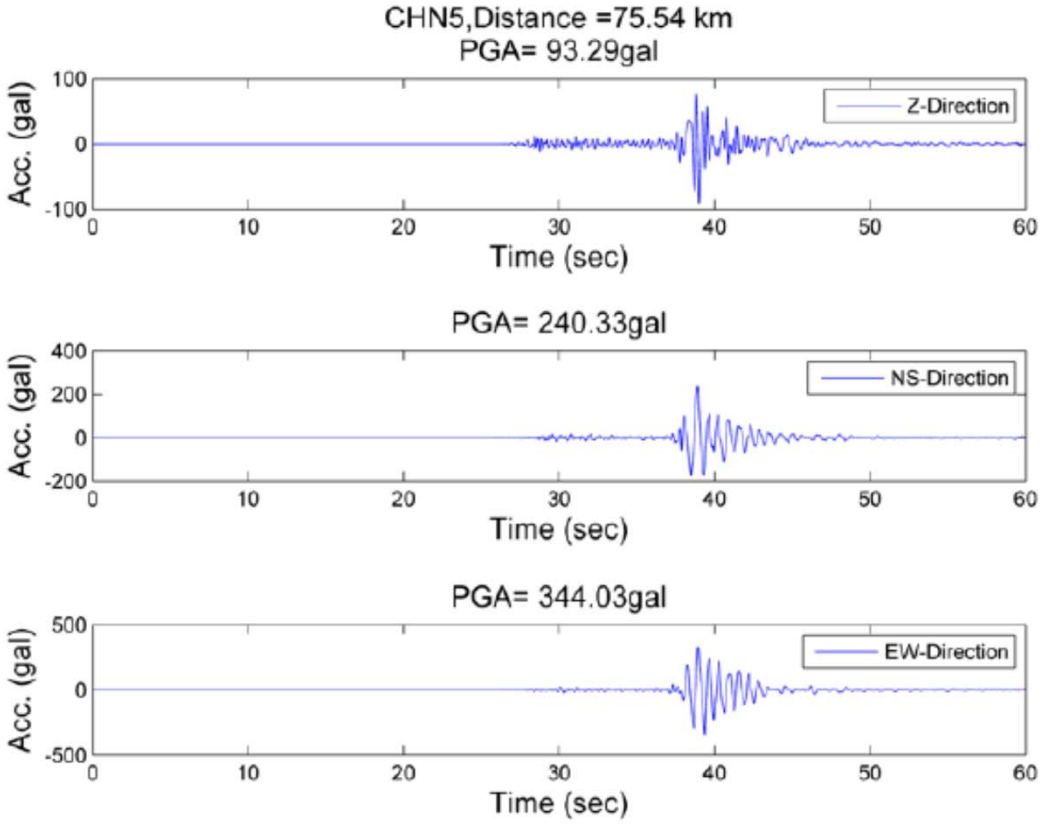
編號： 第105006號
日期： 105 年 2 月 6 日
時間： 3 時 57 分 27.2 秒
位置： 北緯 22.93 度，東經 120.54 度
即在 屏東縣政府北偏東方 27.4 公里
位於 高雄市美濃區
地震深度： 16.7 公里
芮氏規模： 6.4
各地最大震度

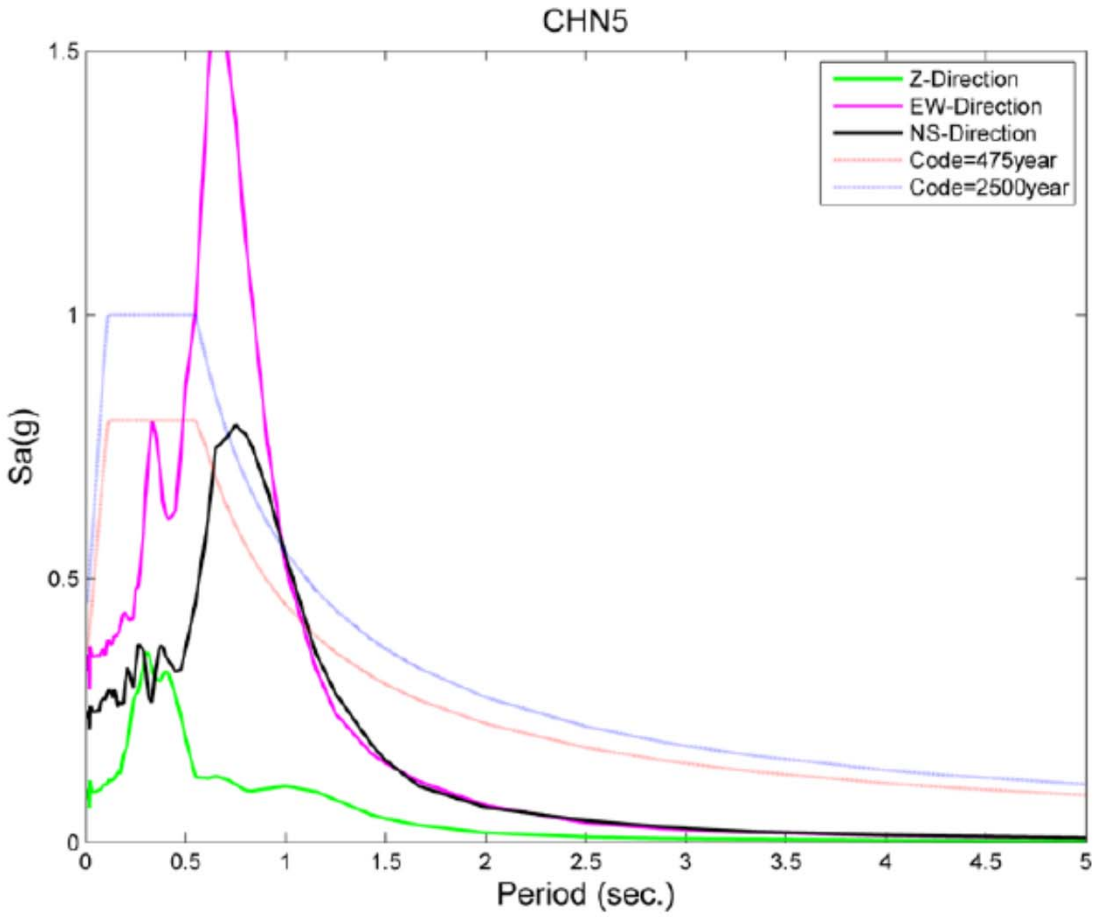
雲林縣草嶺	6級	彰化縣彰化市	4級
高雄市旗山	5級	臺東縣臺東市	3級
屏東縣三地門	5級	花蓮縣紅葉	3級
臺南市楠西	5級	屏東縣南灣	3級
臺南市	5級	南投縣南投市	3級
嘉義縣草山	5級	臺中市	3級
嘉義市	5級	花蓮縣花蓮市	2級
屏東縣屏東市	4級	苗栗縣鯉魚潭	2級
高雄市	4級	苗栗縣苗栗市	2級
臺東縣初鹿	4級	新竹縣竹東	2級
雲林縣斗六市	4級	宜蘭縣內城	2級
澎湖縣東吉島	4級	桃園市三光	1級
彰化縣二水	4級	新竹市	1級
南投縣名間	4級	新竹縣竹北市	1級
澎湖縣馬公市	4級	宜蘭縣宜蘭市	1級
臺中市霧峰	4級		

本報告係中央氣象局地震觀測網即時地震資料地震速報之結果。

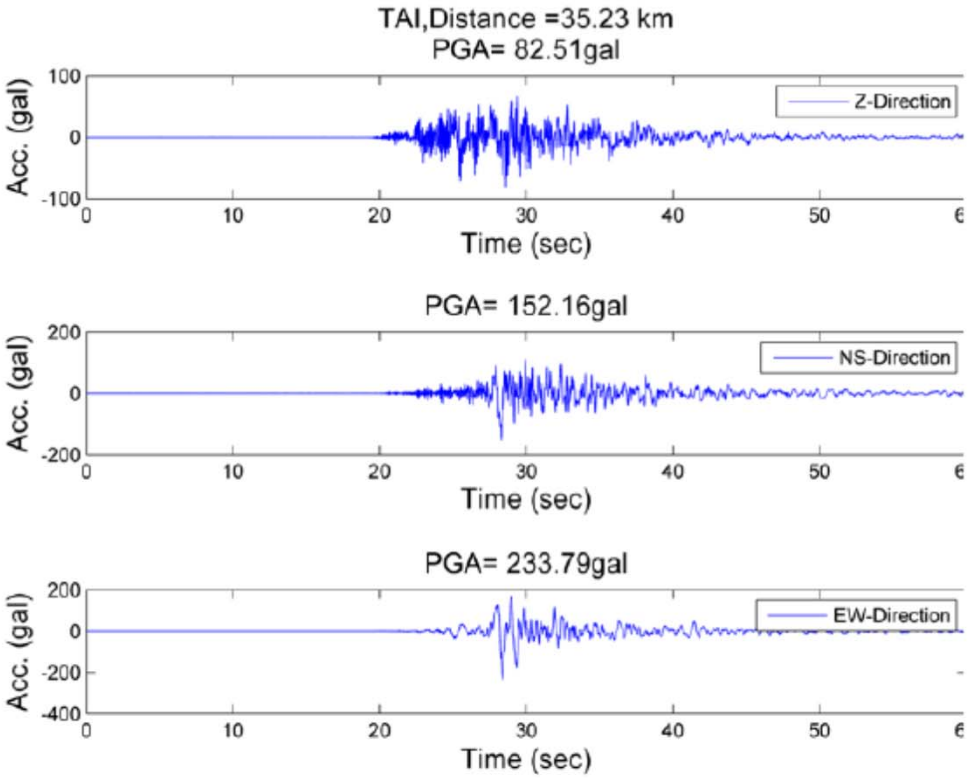
Caoling Station(CHN5)

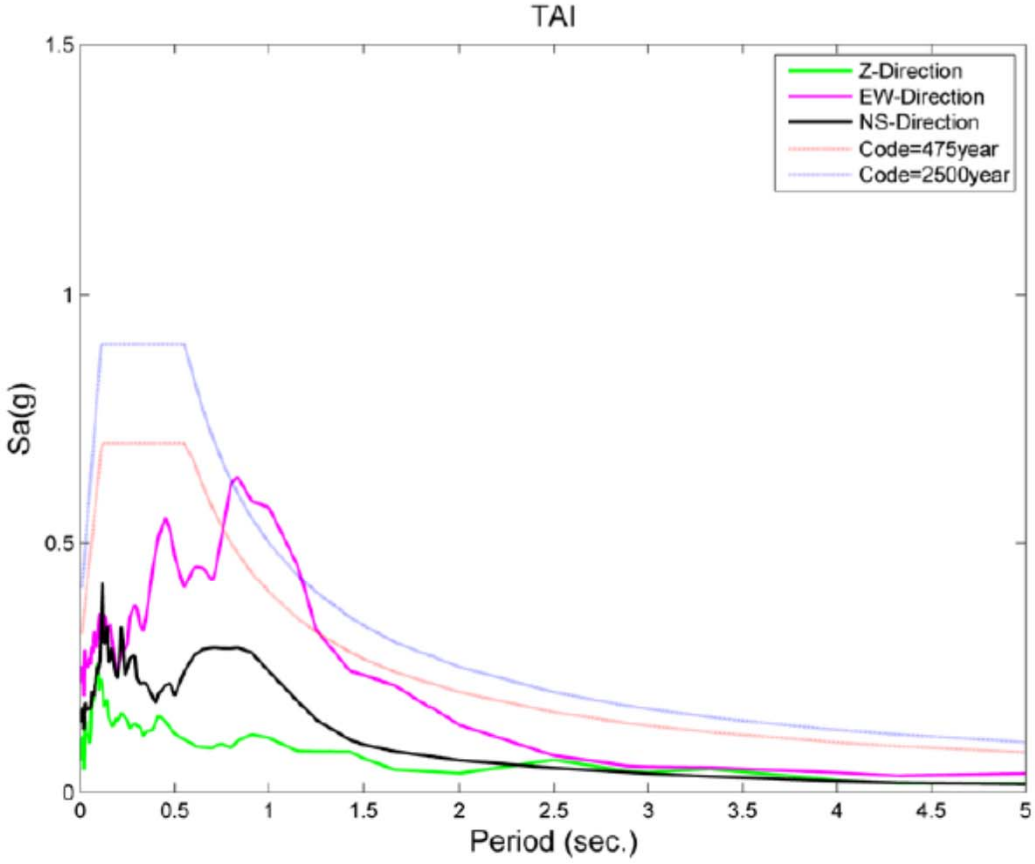
SI=6, td<5 sec





Tainan Station (TAI)
SI=5, td>10 sec



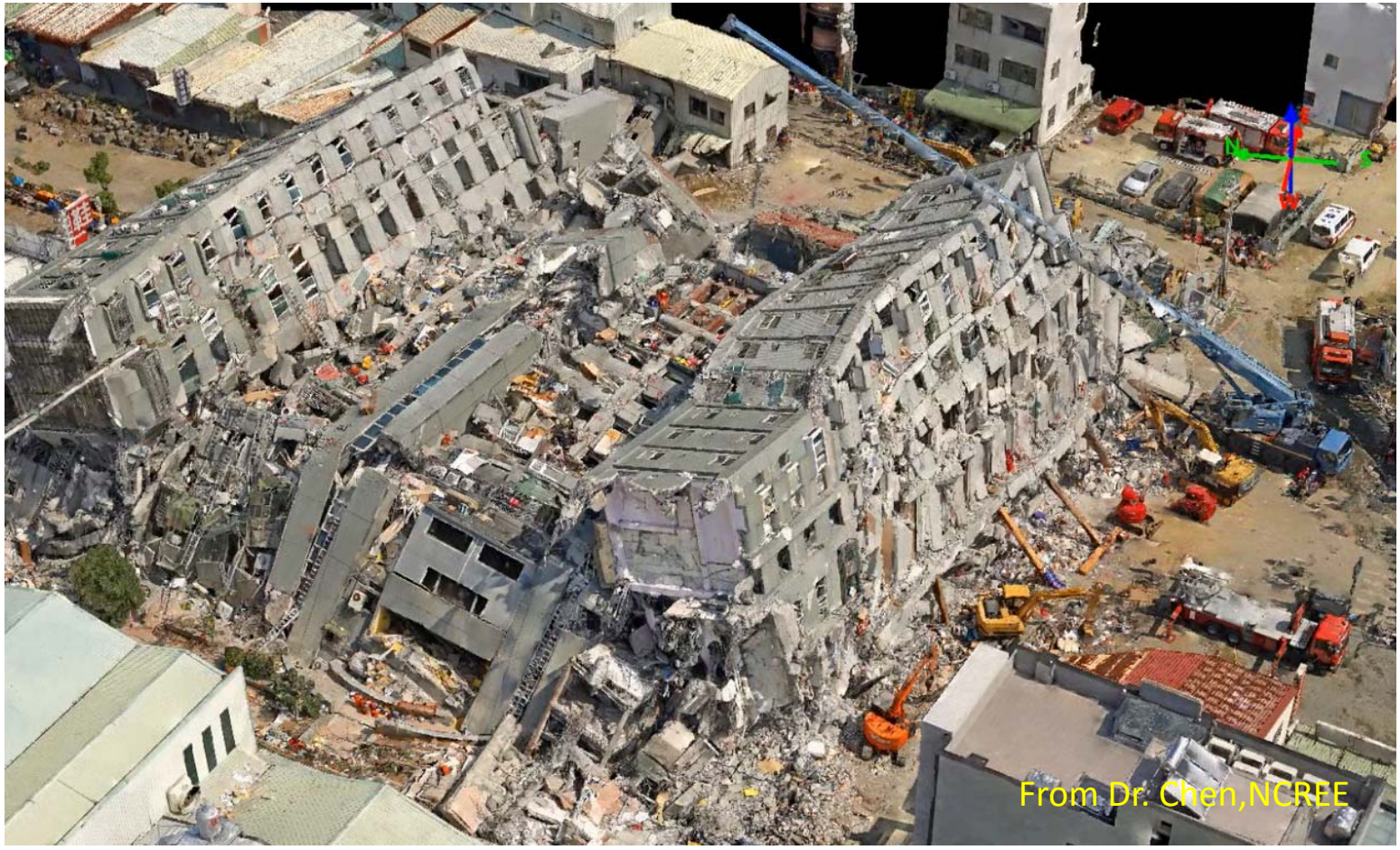


Hot News

- Collapse of 16-story Wei Guan building ➡ 115 people died
- Soil liquefaction ➡ Announcement of liquefaction potential map

Collapse of 16-Story Wei Guan Building

115 death



Soil Liquefaction

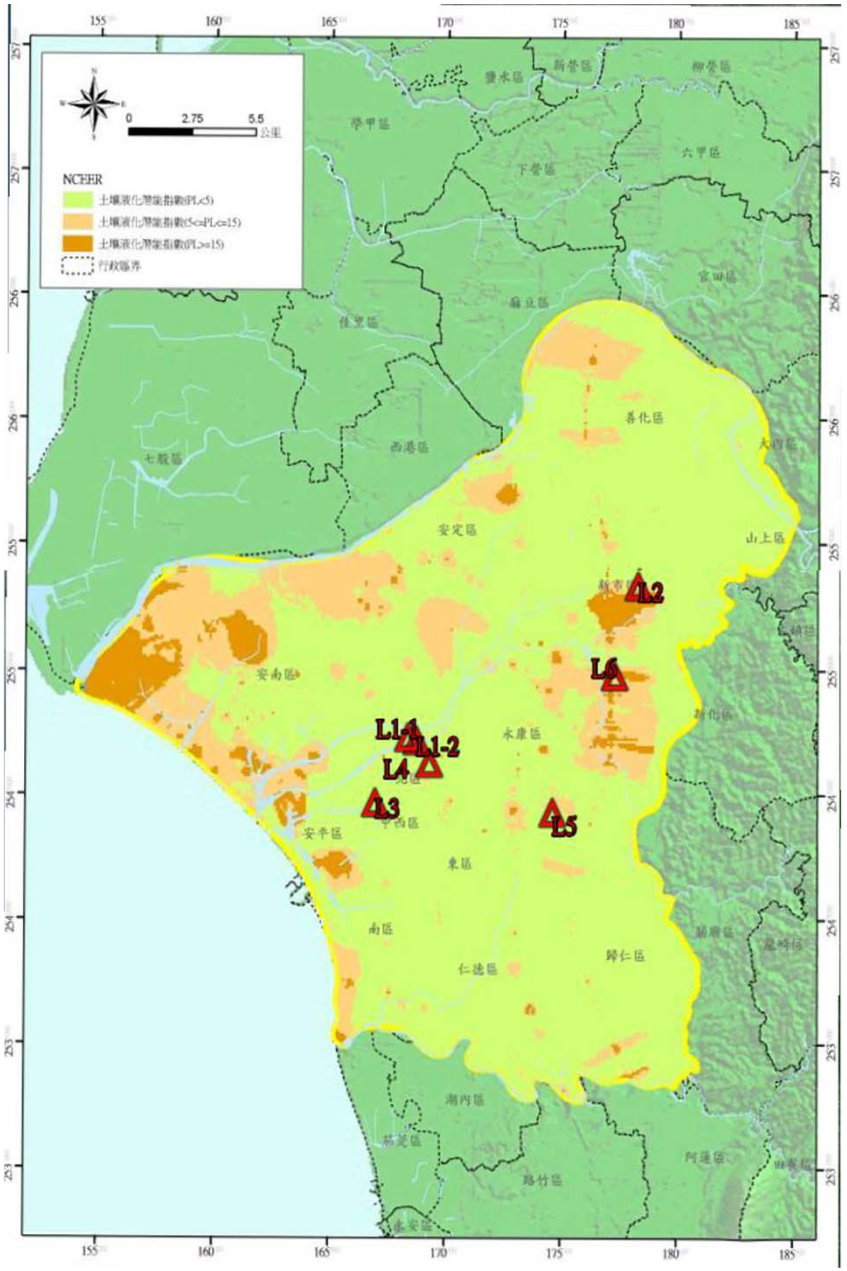
severe damage to buildings

Soil Liquefaction

Announcement
of
Liquefaction Potential Map

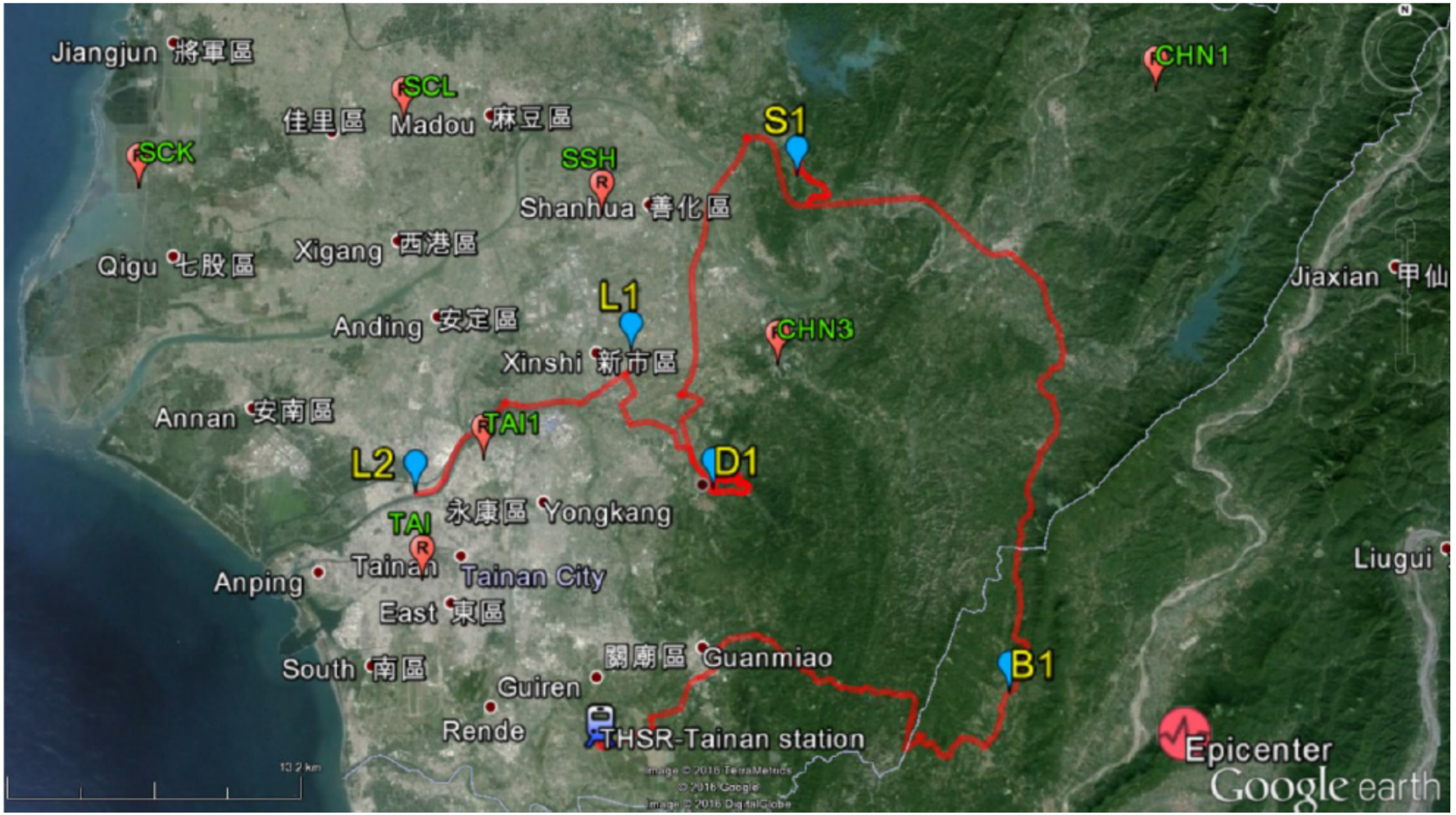
Comments:

- low accuracy
- data base is not reliable and enough



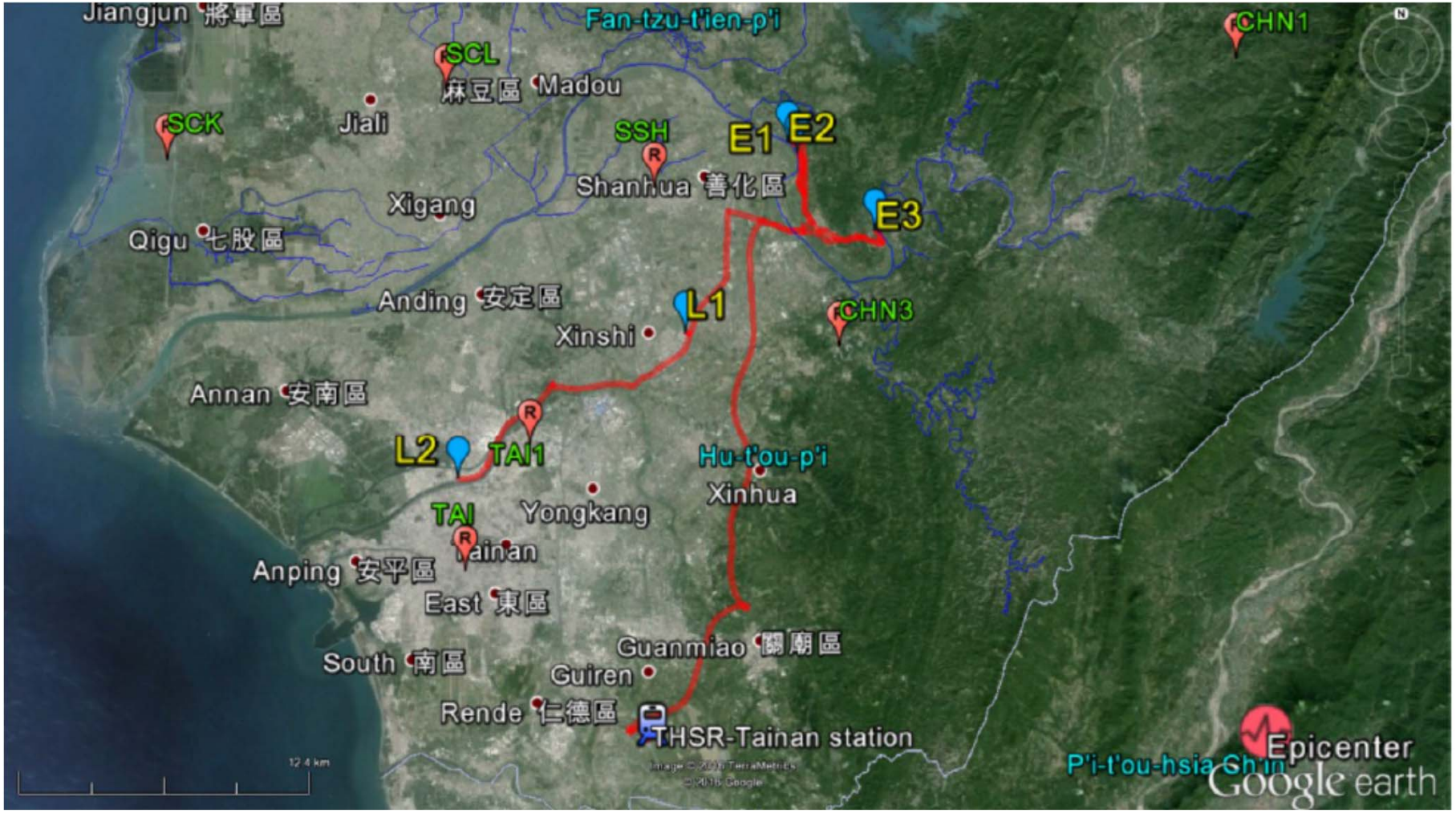
Geotechnical Reconnaissance

2/11 Field Survey

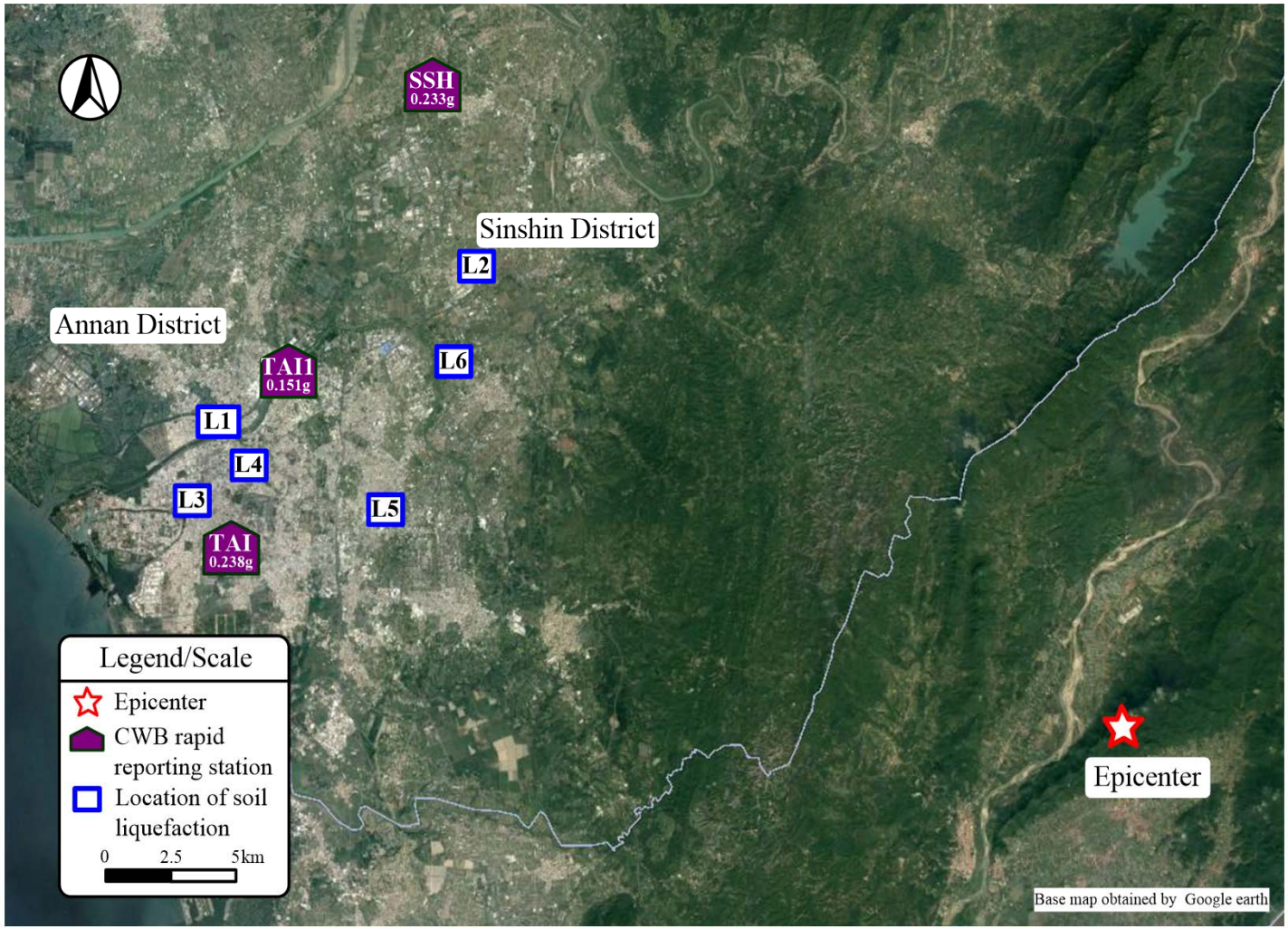


Geotechnical Reconnaissance

2/13 Field Survey



Major Liquefaction Sites



LIQUEFACTION-INDUCED DAMAGE TO BUILDINGS
Damage Degree Based on Field Investigation

Table 1 Ground Failure Index (after Bray and Stewart, 2000)

Index	Description	Interpretation
GF0	No Observable Ground Failure	No settlement, tilt, lateral movement, or sediment ejecta
GF1	Minor Ground Failure	Settlement, D < 10 cm; tilt < 1 degree; no lateral movements
GF2	Moderate Ground Failure	10 cm < D < 25 cm; tilt of 1-3 degrees; small lateral movements (< 10 cm)
GF3	Significant Ground Failure	D > 25 cm; tilt of > 3 degrees; lateral movement > 25 cm

$P_L \leq 5$ $5 < P_L \leq 15$

LIQUEFACTION-INDUCED DAMAGE TO BUILDINGS

Damage Index Based on Liquefaction

Liquefaction Potential Index (LPI) , Iwasaki et al. (1978)

$$P_L = \sum_{i=1}^{NL} (P_L)_i = \sum_{i=1}^{NL} F_i \times w_i \times \Delta H_i$$

$$F_i = \begin{cases} 1 - FS_i & for \quad 0 \leq FS_i < 1 \\ 0 & for \quad FS_i \geq 1 \end{cases}$$

FS_i is the safety factor of the i th layer

NL is the number of soil layers

$w_i = 10 - 0.5 z_i$

$z_i(m)$ is the depth of the i th layer

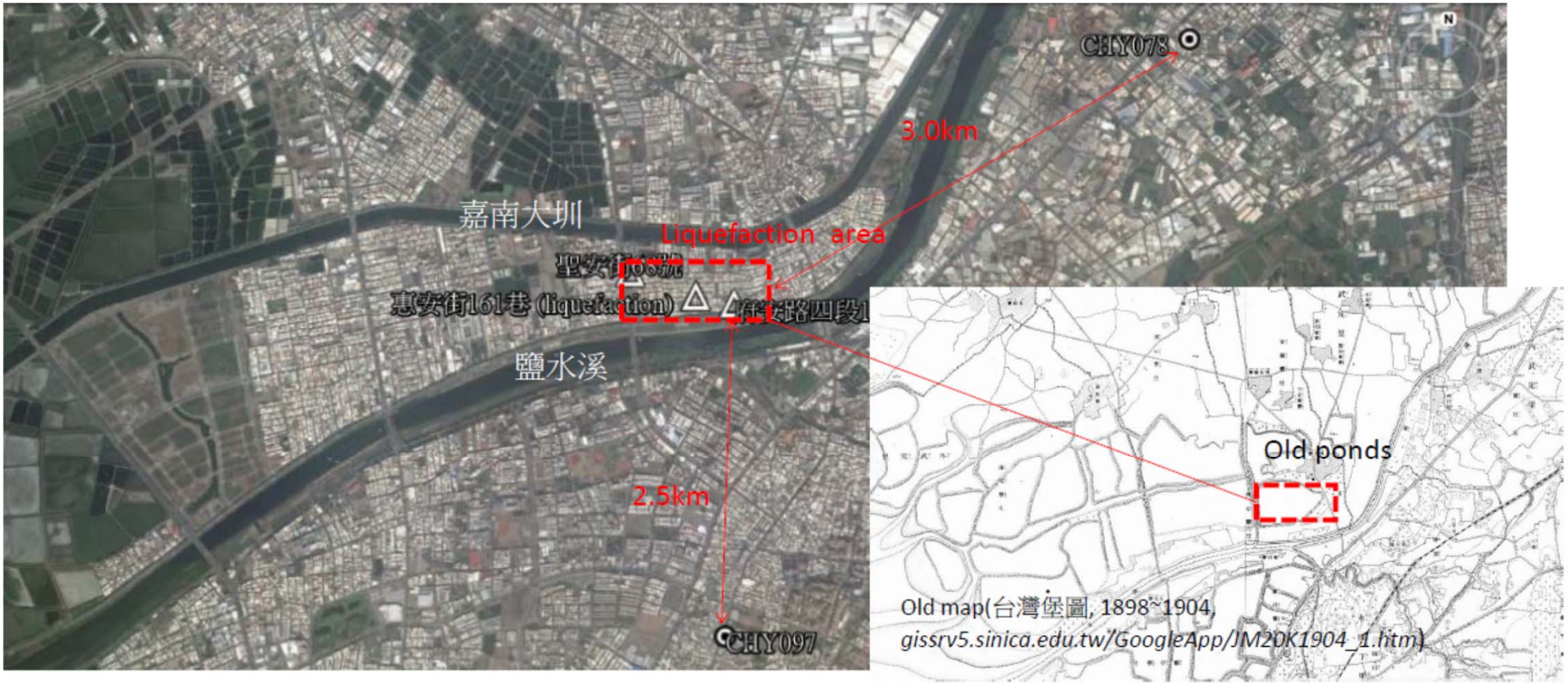
$\Delta H_i(m)$ is the thickness of the i th layer.

LPI	Degree of damage
$P_L \leq 5$	No to light damage
$5 < P_L \leq 15$	Moderate damage
$P_L > 15$	Severe damage

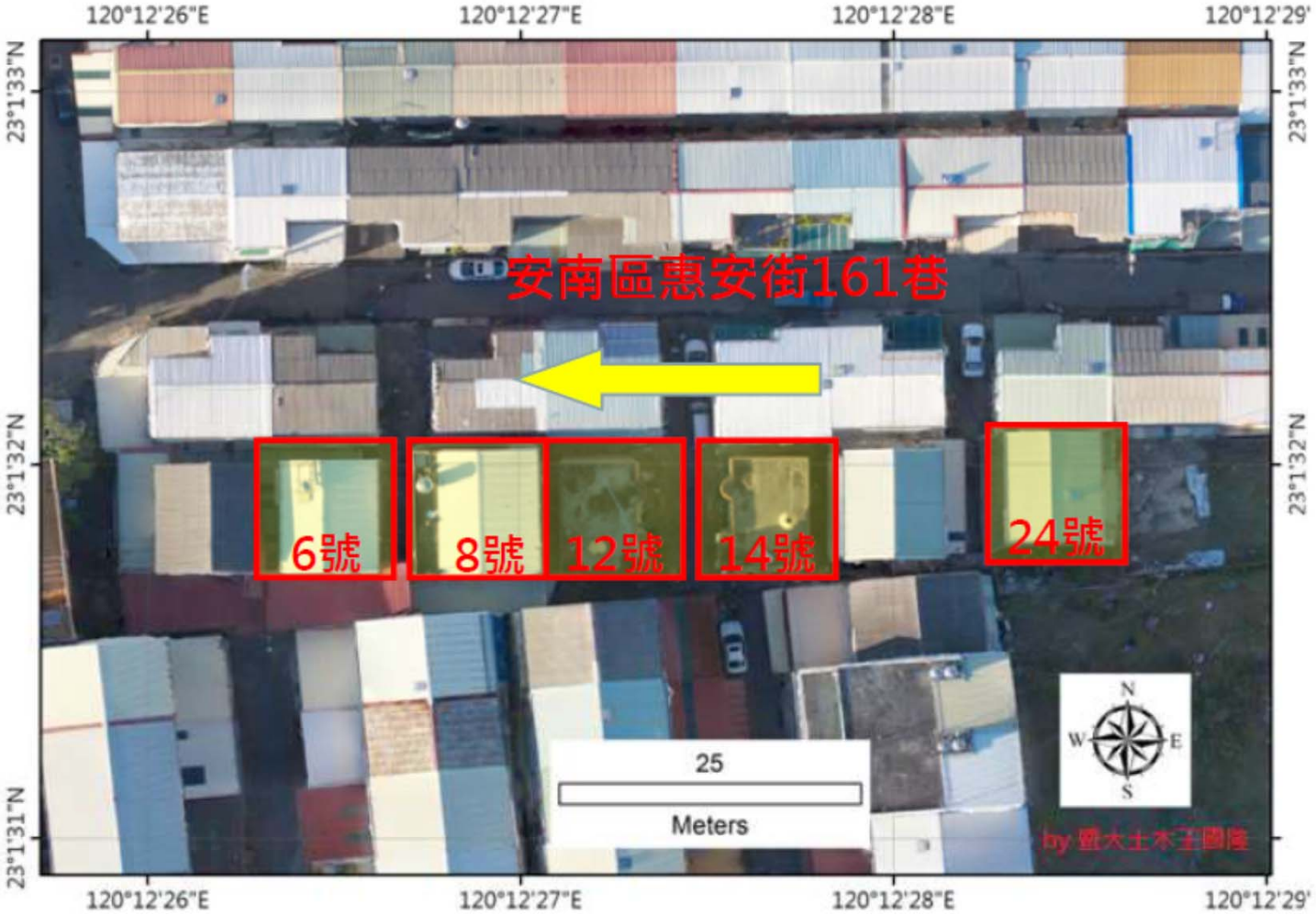
Ground Failure Index of Major Liquefaction Sites

Location	Index	Description
Annan	GF1	The settlement of this area ranged from 10~20cm mainly occurred at and around the building. The differential settlement caused cracks between the building and road, meanwhile, the pipeline at the interface was destroyed.
Annan	GF2	
Annan	GF3	The building in this area seriously settled (40~90cm) and tilted (1~7 degrees). The road heaved much and had extensive sand boiling.
Sinshih	GF1	The settlement of building is minor due to soil liquefaction.
Sinshih	GF2	The maximum settlement of column was about 10cm. the maximum tilt of building is about 1 degree. Boiling sand deposited in the kitchen and ditch behind the building. The first floor slab heaved and cracked. The edge of road cracked and damaged the water pipeline.
Sinshih	GF3	The area was fishpond before. The three-story building here is a two span frame structure in long direction with a garage add-on in front of house. Due to soil liquefaction, the column seriously settled and caused the indoor first floor slab heaving and cracking much. The sand/mud boiling was obvious inside the house. Fire lanes heaved and sand deposited in the ditch. The road in front of building heaved and the pipeline was damaged. The sand boiling could be observed everywhere.
Wenhe St.	GF2	The settlement of building was a few of centimeters. The first floor slab and road pavement had minor cracks. Sand boiling took place nearby.
Wenhe St.	GF3	The maximum tilt and settlement of the building were 4 degrees and 20 cm respectively. It could be found the sand boiling on the surface of roads nearby.
Zhengjue St.	GF1	The degree of soil liquefaction was slight. The differential settlement of building caused brick wall cracked, window railings deformed, as well as road and floor slab cracked.

Damage Conditions of Huian Street (Annan)



GF3 Buildings at Lane 161, Huian Street



No.8 and No.6, Lane 161, Huian Street

3-story RC Building

No.8

No.6

Settlement: 90cm
Tilt angle: 3 deg. Clockwise in EW
4 deg. Clockwise in NS

By Chi-Chin Tsai 2016/2/14

Settlement: 60cm
Tilt angle: 2 deg. Clockwise in EW
2 deg. Clockwise in NS

Close view to No. 8 Building

Close view to No. 6 Building

No.8 and No.6, Lane 161, Huian Street

Ejecta and foundation settlement
(North side of No. 8)

Heave at the center of road and subsidence near the building

By Chi-Chin Tsai 2016/2/14

Fire Lane Between No.8 and No.12

No.12 and No.14, Lane 161, Huian Street

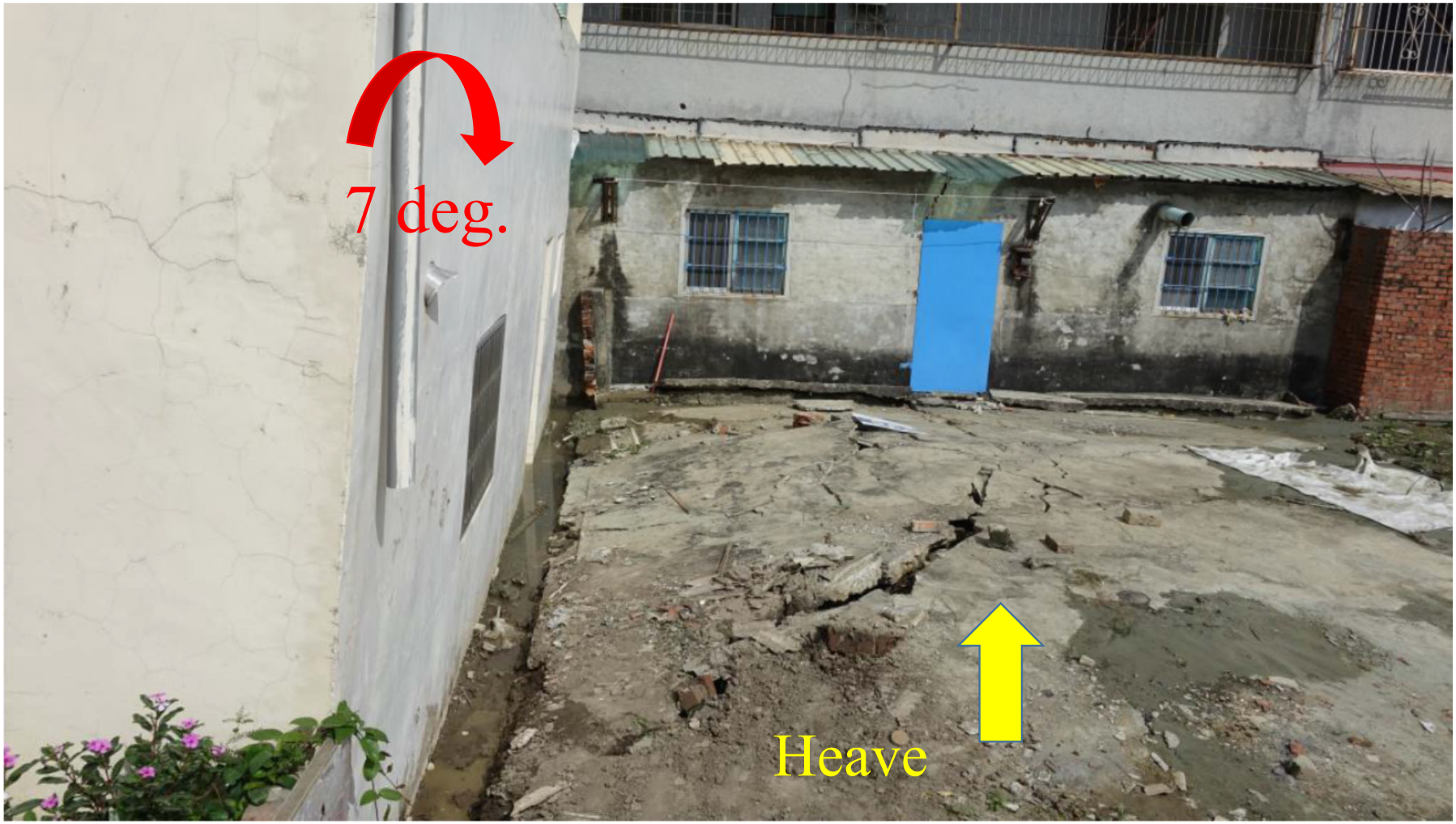
(South-east corner)

- The build settled and tilted
- Ejected sediment filled the first floor

By Chi-Chin Tsai 2016/2/14

Heave of Ground Floor in No.12

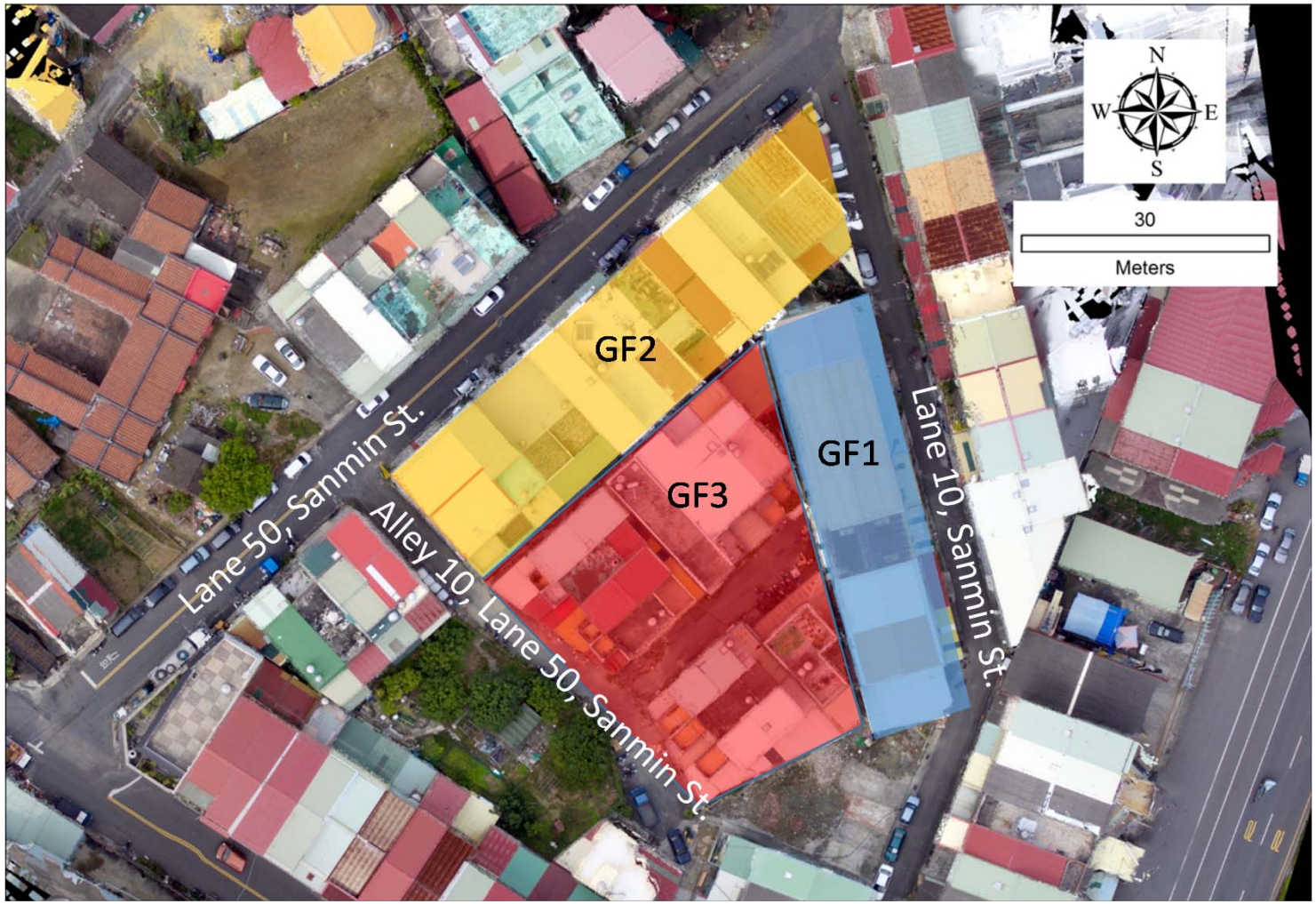
No.24, Lane 161, Huian Street



Post-Earthquake Investigation, Huian St.

Damage Conditions of Sanmin Street (Sinshih)

Damage Conditions of Sanmin Street (Sinshih)



GF3 Buildings at Sanmin St., Sinshih District

Private Alley, Lane 50, Sanmin St.

No.7,5,3,1 , Alley 10, Lane 50, Sanmin St.

No.19, 21, 23, Alley 10, Lane 50, Sanmin St.

No.7, Alley 10, Lane 50, Sanmin St.

Settlement of Column
No.7, Alley 10, Lane 50, Sanmin St.

Heave of Garage Floor of No.5 Building

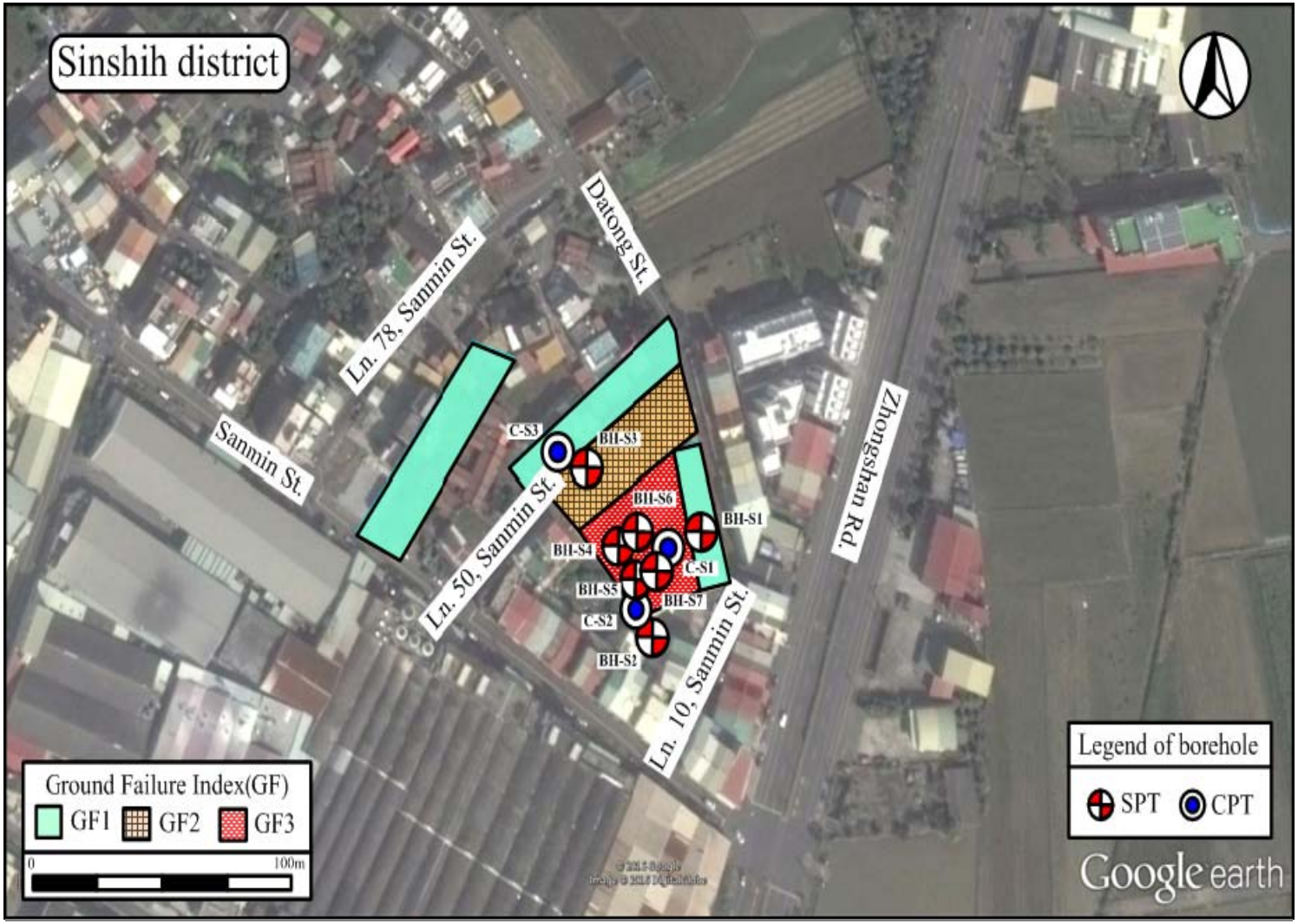
Heave of 1st Floor of No.5 Building

Deposited Sand in the Bath Room of No.5, Alley 10, Lane 50, Sanmin St.

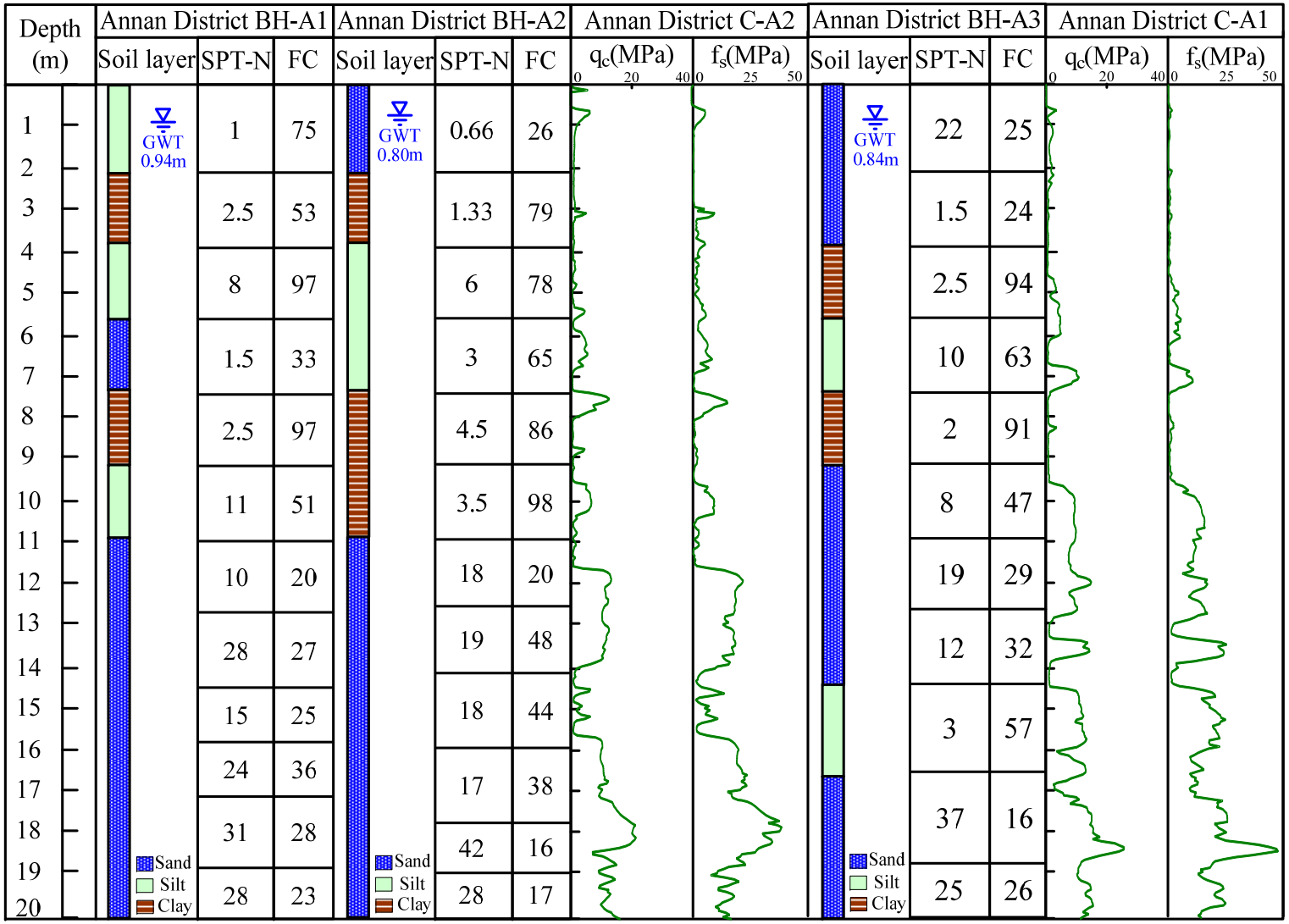
Crack of Beam due to Differential Settlement

Sand Boils at the Fire Lane

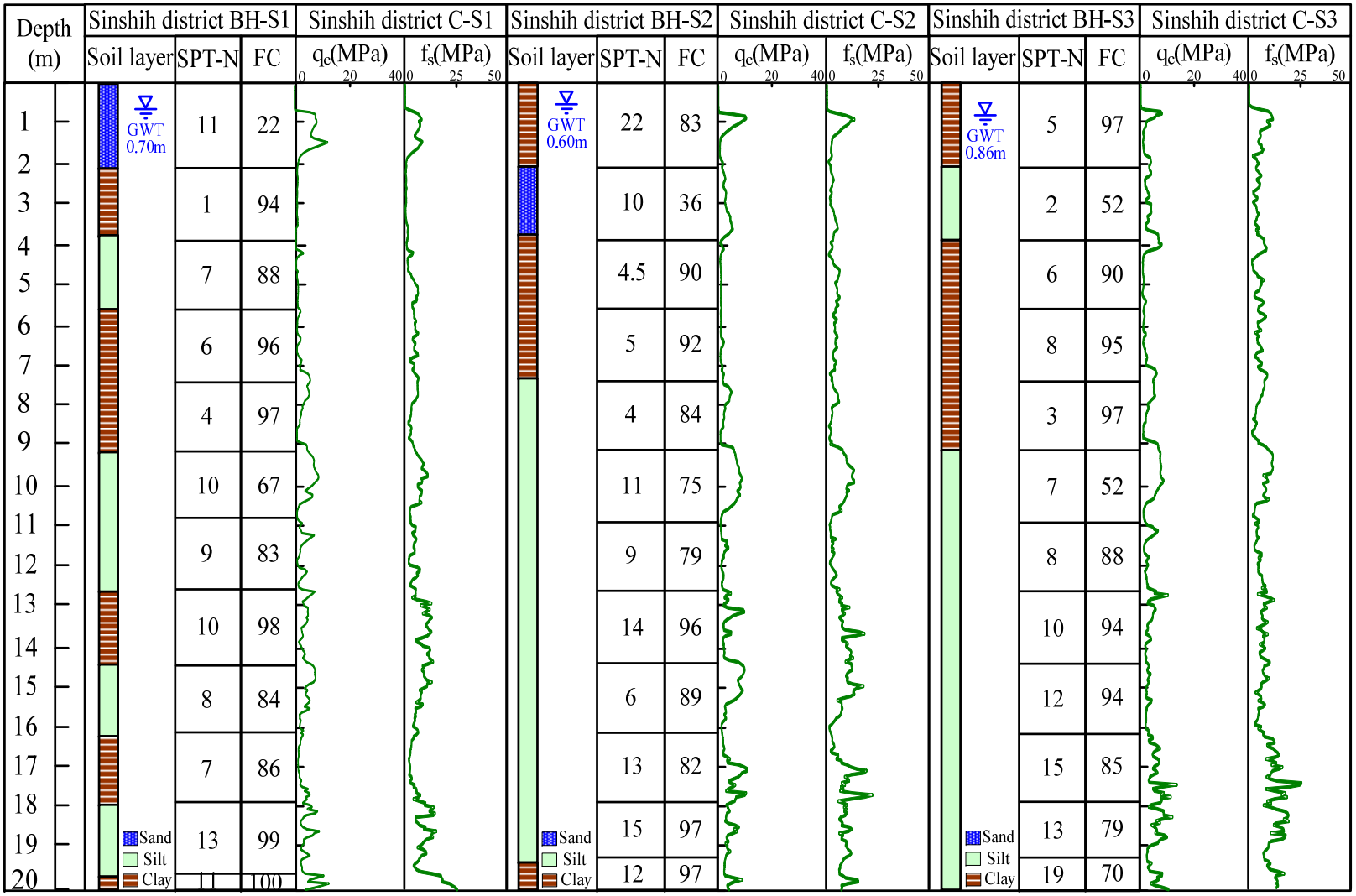
Post-Earthquake Investigation, Sanmin St.



Geological Profile of Huian Street



Geological Profile of Sanmin Street



Summary of Geological Profile

- The ground water tables are very shallow. The water tables are 0.80-0.95m and 0.60-086m below the ground surface at Huian Street (Annan District) and Sanmin Street (Sinshih District), respectively.
- The shallow foundation soils consist of silty sand (SM), silt (ML) and clay (CL). The SM soils have fines content of 22%-36% with very low N values (<1.5) in Annan District and with N =10-11 in Sinshih District. The ML soils have N values of 2-8 in general. The CL soils have N values of 1-2.5 in general. However, the soils near the ground surface often have an unusually high N value of 22. This is may be caused by the compaction of the base material due to construction of road pavement.

Uncertainty in soil liquefaction evaluations

- Different methods to estimate PGA
- Different simplified methods for analysis
- Different penetration tests (SPT or CPT)
- Different locations of Borehole and sounding point

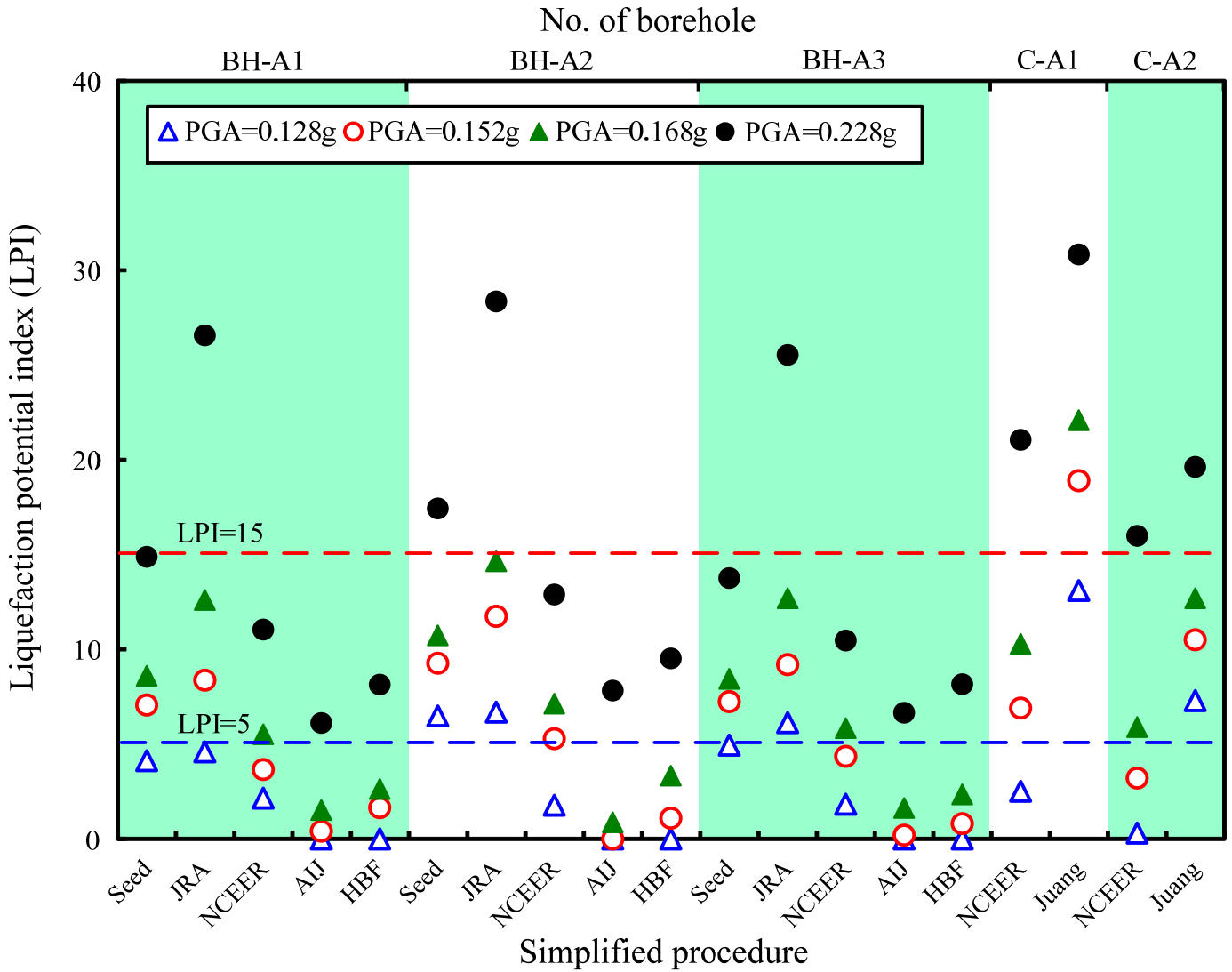
Different Methods to Estimate PGA

PGA estimation method	Annan District	Sinshih District
Referring to the nearest seismograph	0.168g (TAI)	0.233g (SSH)
PGA contour map (NCREE, 2016)	0.152g	0.196g
Empirical attenuation model (Jean et al., 2006)	0.128g	0.140g
1.5 times the PGA of contour map (roughly consider site effect)	0.228g	0.294g

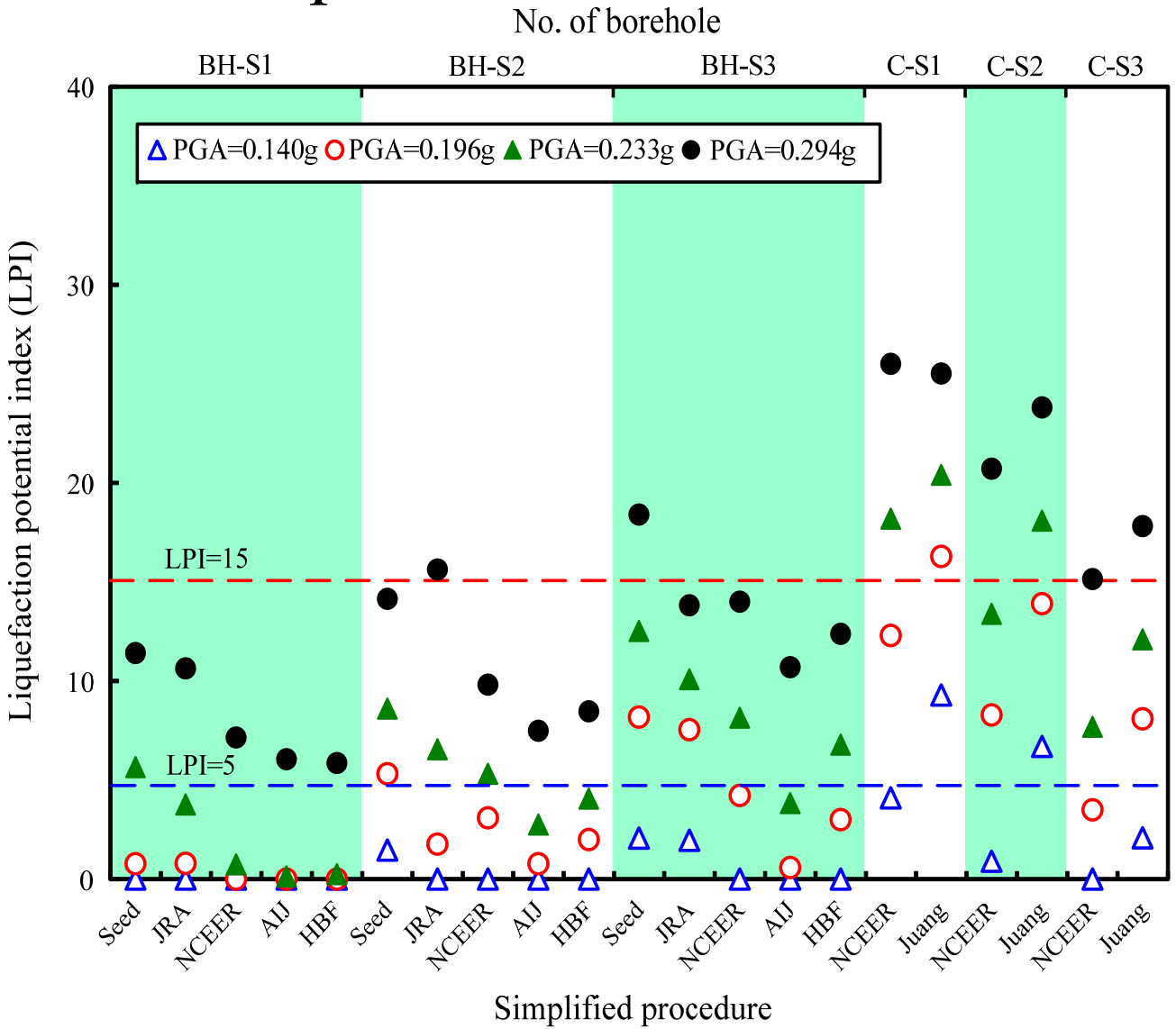
Different Simplified Methods for Liquefaction Evaluation

- SPT-N Methods
  - Seed's method (Seed et al., 1985)
  - JRA method (Japanese Road Association, 1996)
  - NCEER method (Youd and Idriss, 1997)
  - AIJ (Architecture Institute of Japanese, 2009)
  - HBF method (Hwang et al, 2012)
- SCPT Methods
  - NCEER method (Youd and Idriss, 1997)
  - Juang's method (Juang et al., 2008)

Results of Liquefaction Evaluation-Huian St.



Results of Liquefaction Evaluation-Sanmin St.



Summary of Results

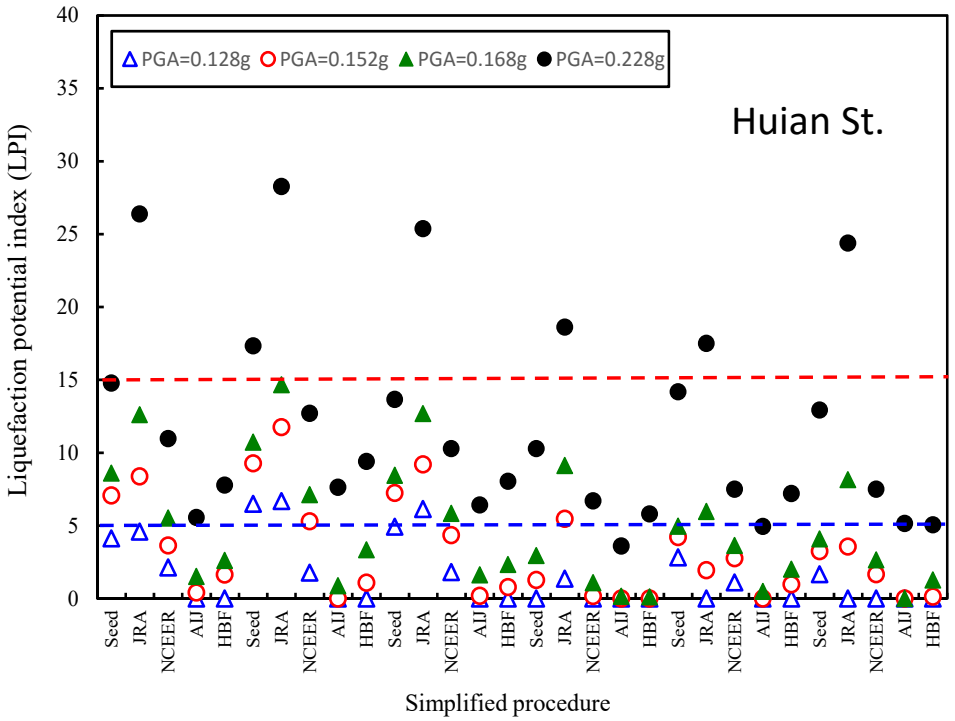
- The estimated PGA has the largest influence on the LPI. The larger the PGA, the larger the LPI. The evaluated LPI results using the estimated PGA considering amplification effect are more close to the damage conditions in the field. The use of PGA by the empirical attenuation law predicts no damage.
- The CPT methods generally predict larger LPI than the SPT methods.
- Among the SPT-N Methods, JRA and Seed methods are more conservative ones and AIJ method is the most non-conservative one. The NCEER and HBF methods are in between. The predicted LPIs by JRA and Seed methods are more consistent to the damage conditions in the field.
- Among the CPT Methods, Juang's method is more conservative than NCEER method.

Summary of Results

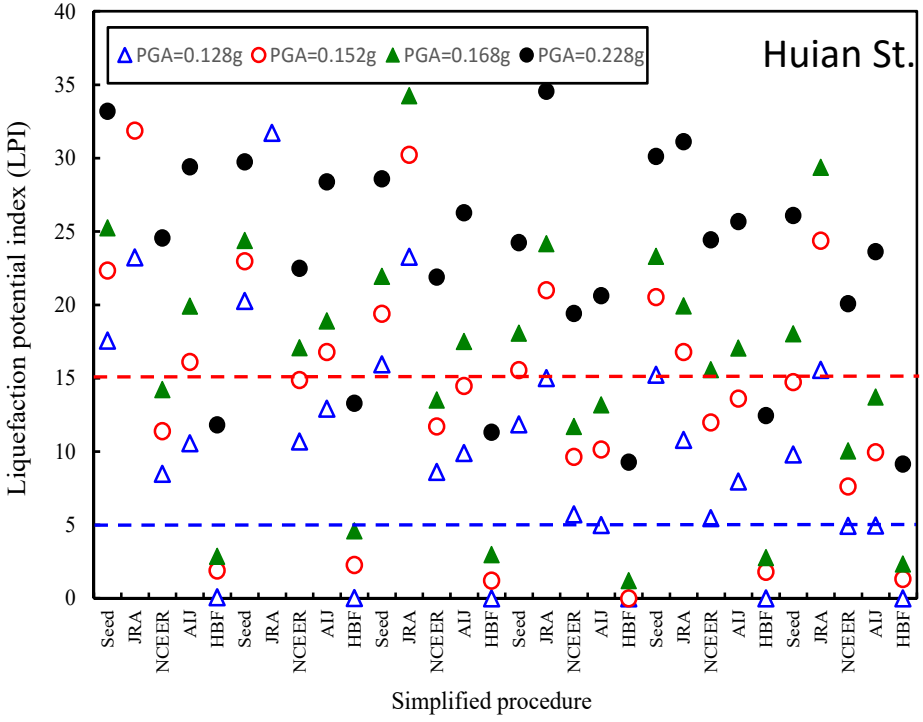
- Basically, the evaluated LPIs predict only light to moderate liquefaction-induced damages which are not consistent to the severe GF3 damage condition observed in the field.
- Possible Reasons
  - There may exist a very soft clay layer below the liquefied sandy soils. The foundation load will be transferred to the soft clay beneath the liquefied sandy soils and induce more settlement of building
  - Over-estimate the contribution of non-plastic fines to the cyclic strength in simplified methods
  - Over-estimate the Magnitude Scaling Factor (MSF) to the cyclic strength

Comparison of the evaluated results with and without considering the effect of fines

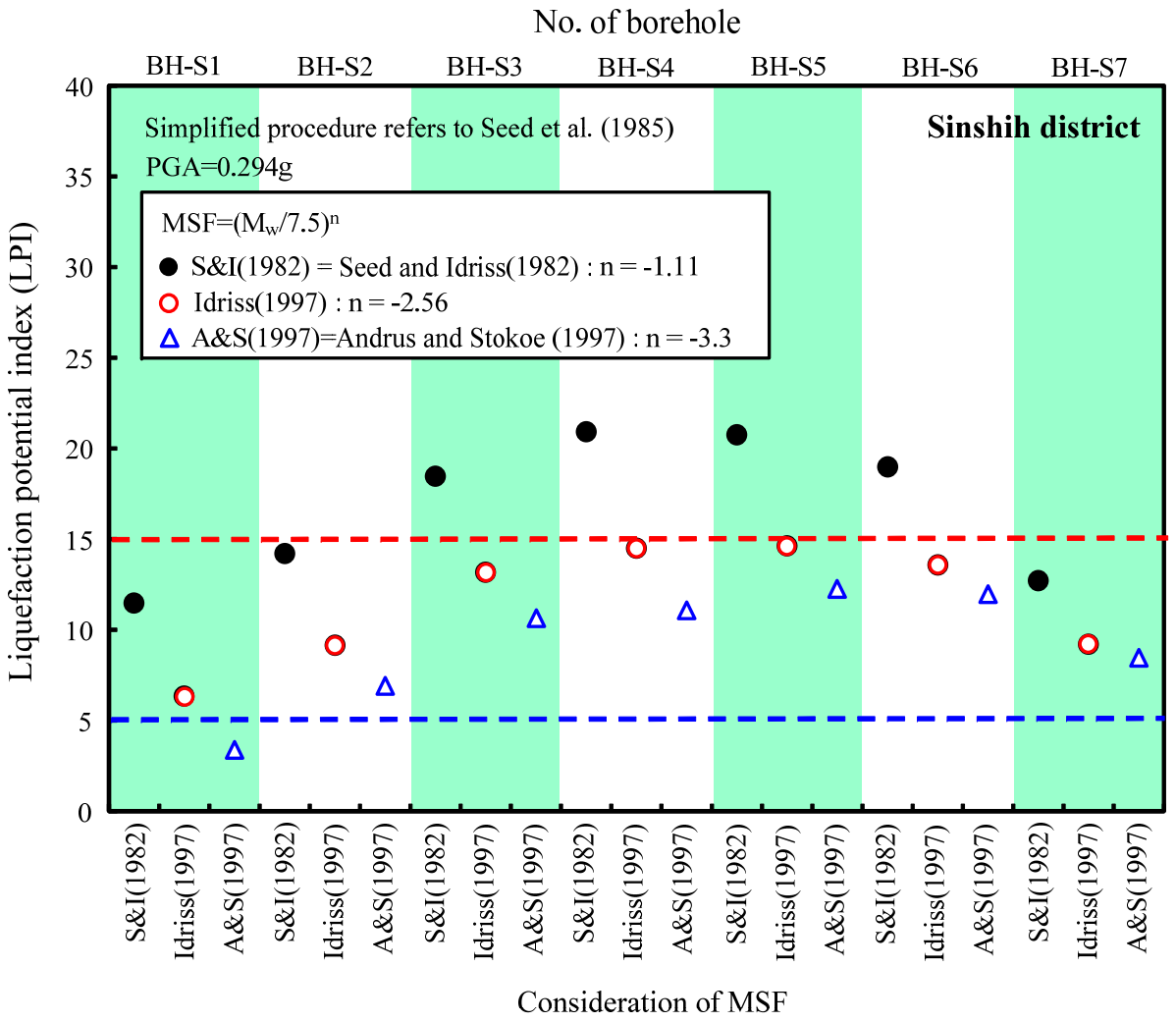
Considering the effect of fines



Without considering the effect of fines



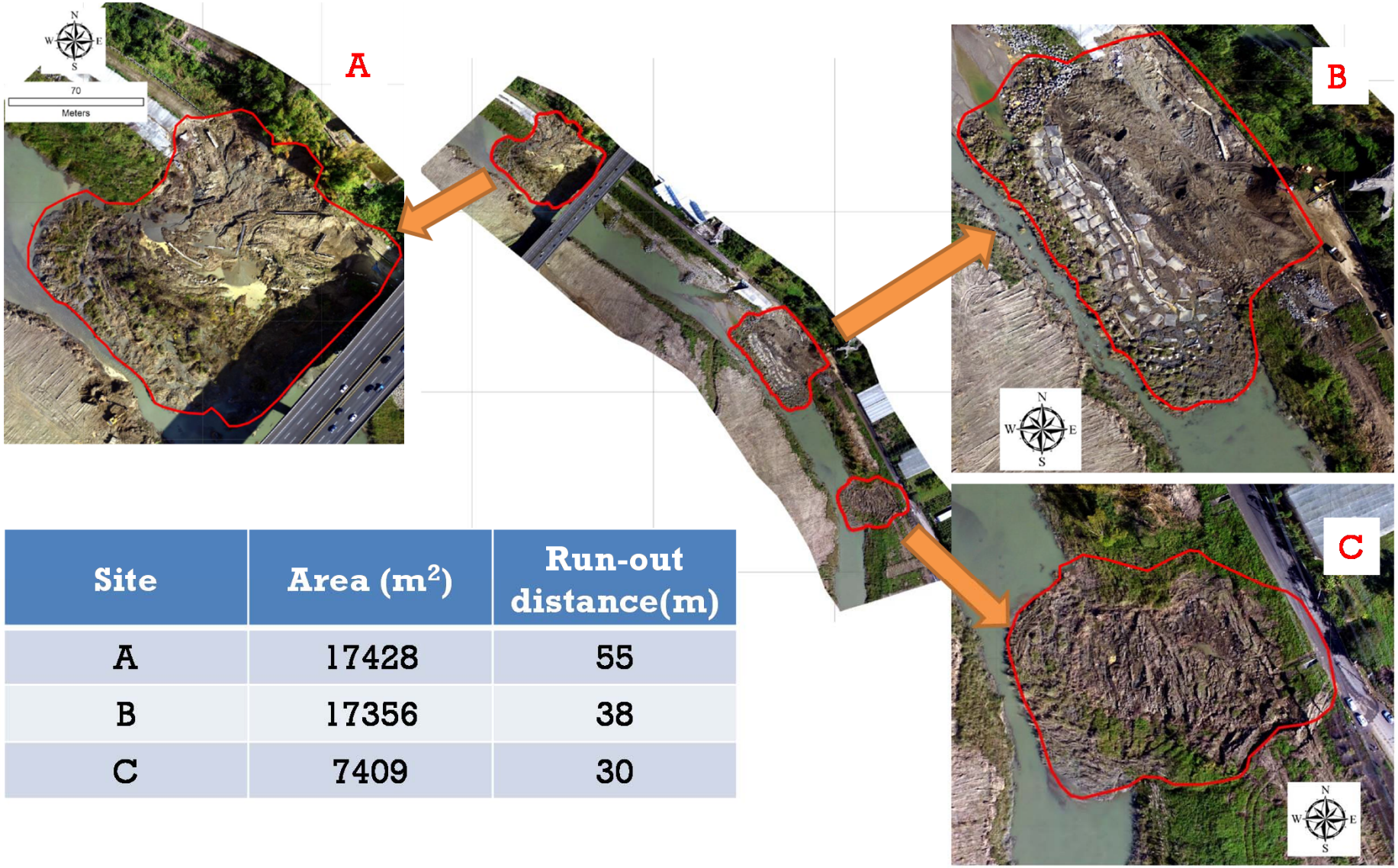
The influence of MSF on the evaluated results



Liquefaction-Induced Damages to River Revetments

- Three slides are at the upper stream of Tsengwen river
- One slide at Yufeng weir

Slides at Tsengwen River

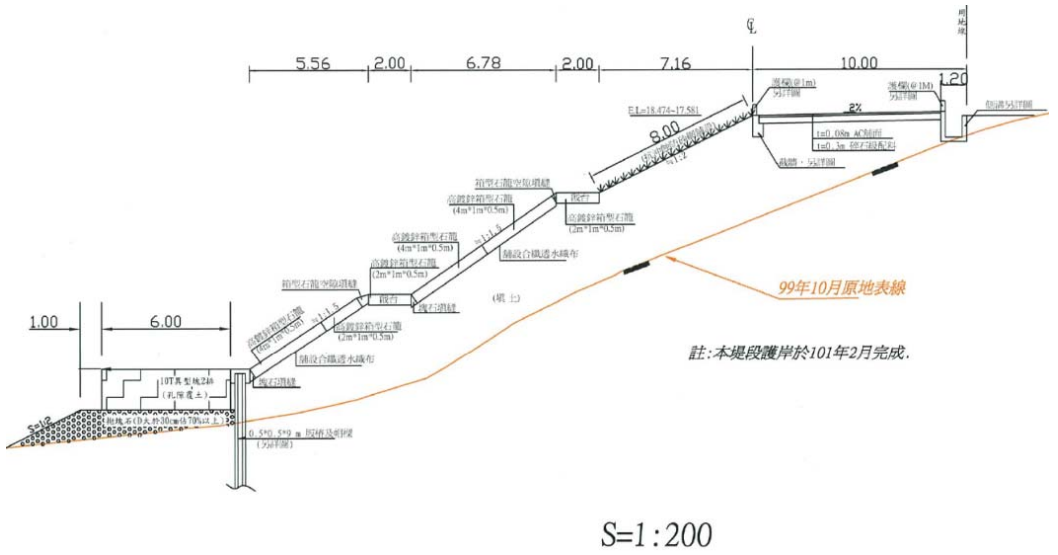


Site	Area (m^2)	Run-out distance(m)
A	17428	55
B	17356	38
C	7409	30

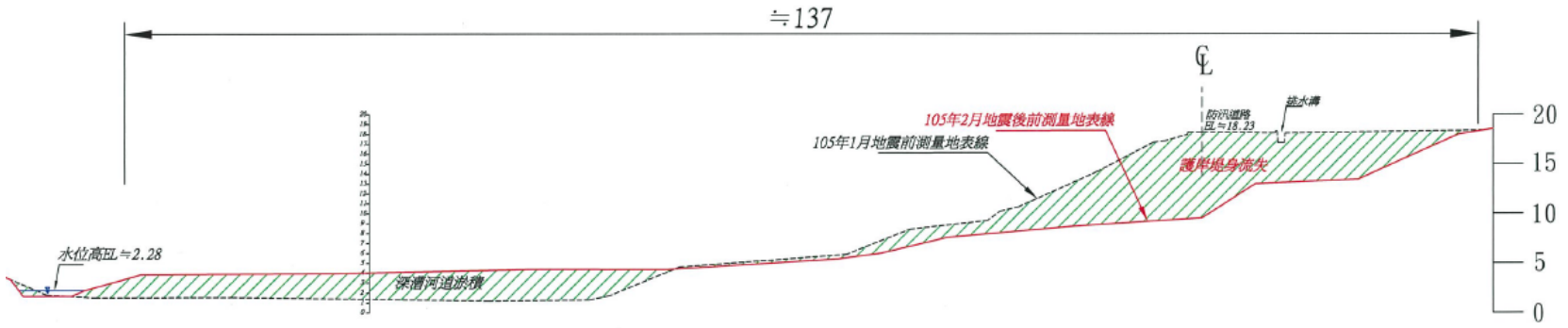
Slides at Tsengwen River

- Height: 15m (Slope: 1:2)
- 30cm unreinforced concrete slab
- Completed in 2011
- PGA about 287.5 gal

Slide at A Site



S=1:200



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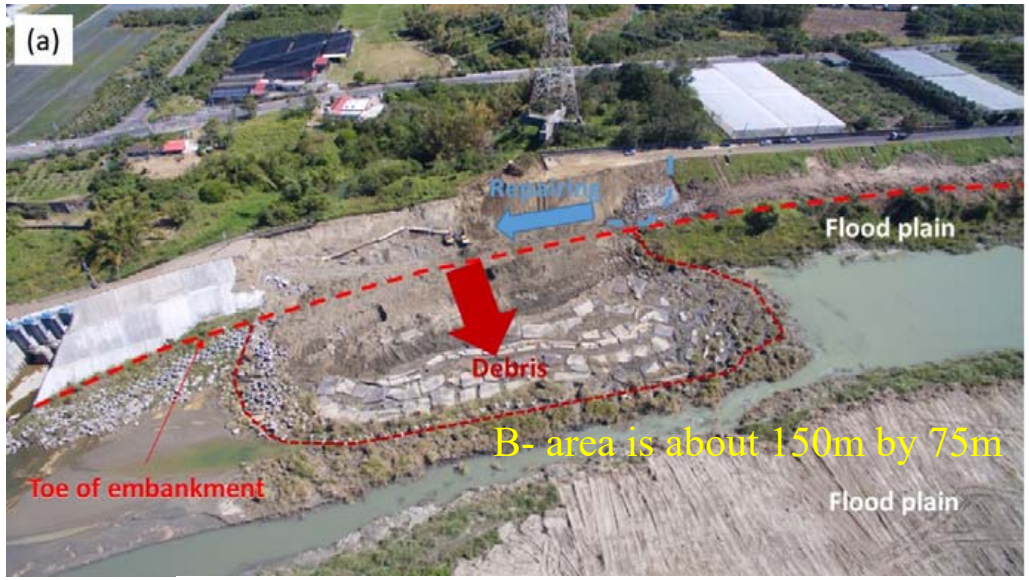
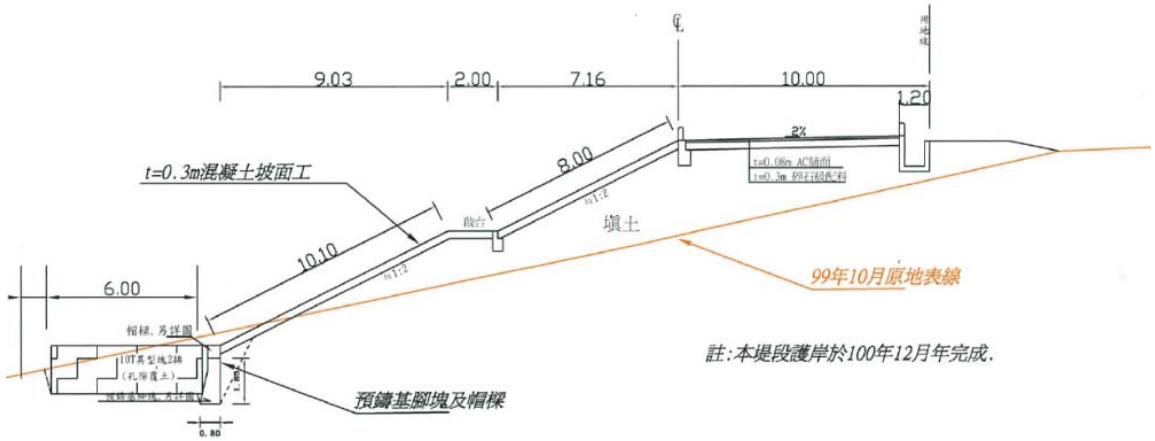
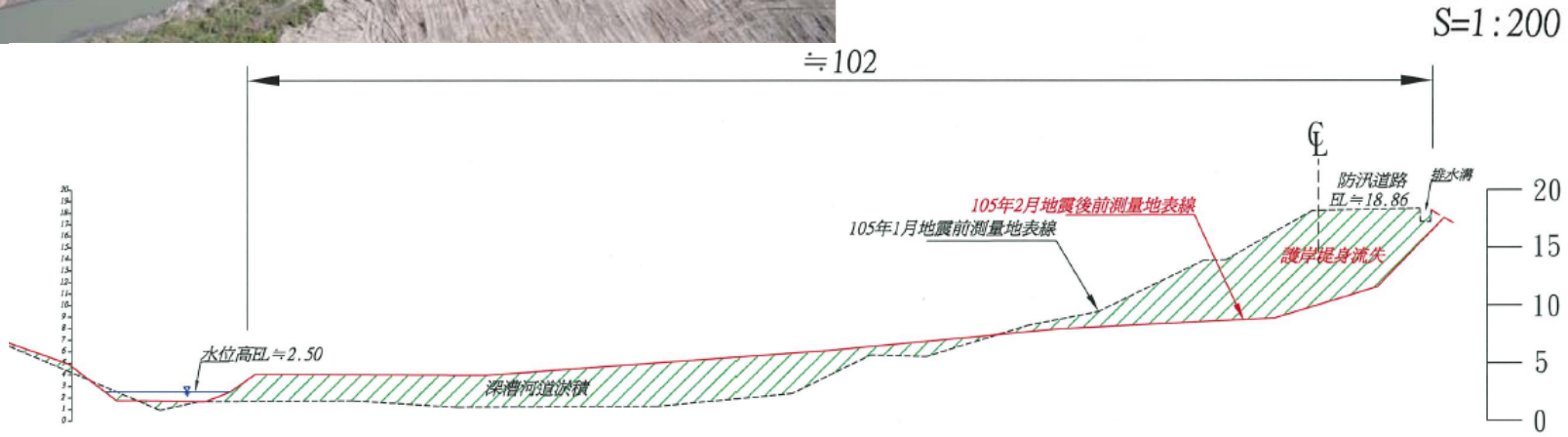
Panoramic View of the Slide at Site A

Slide at B Site







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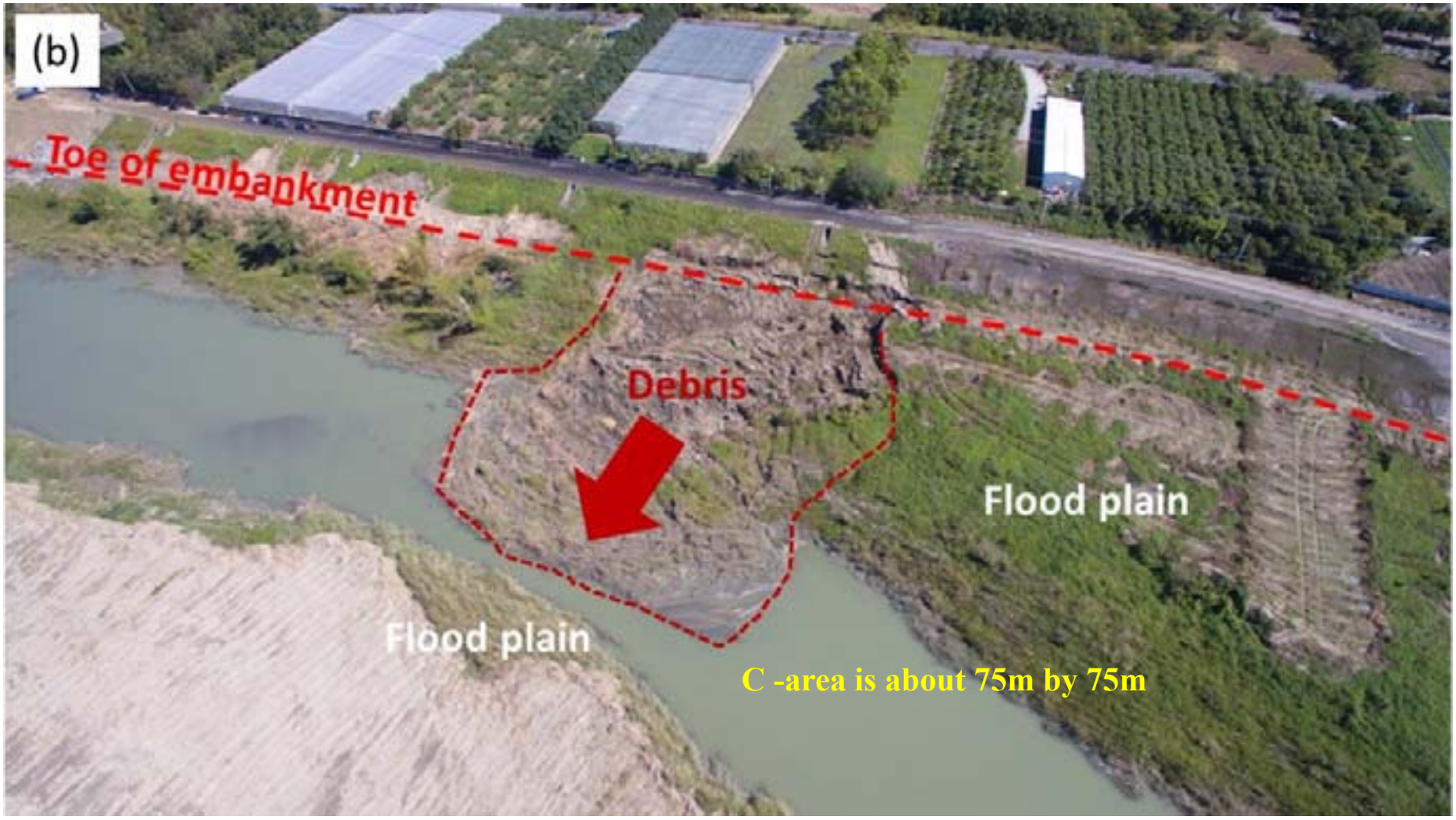
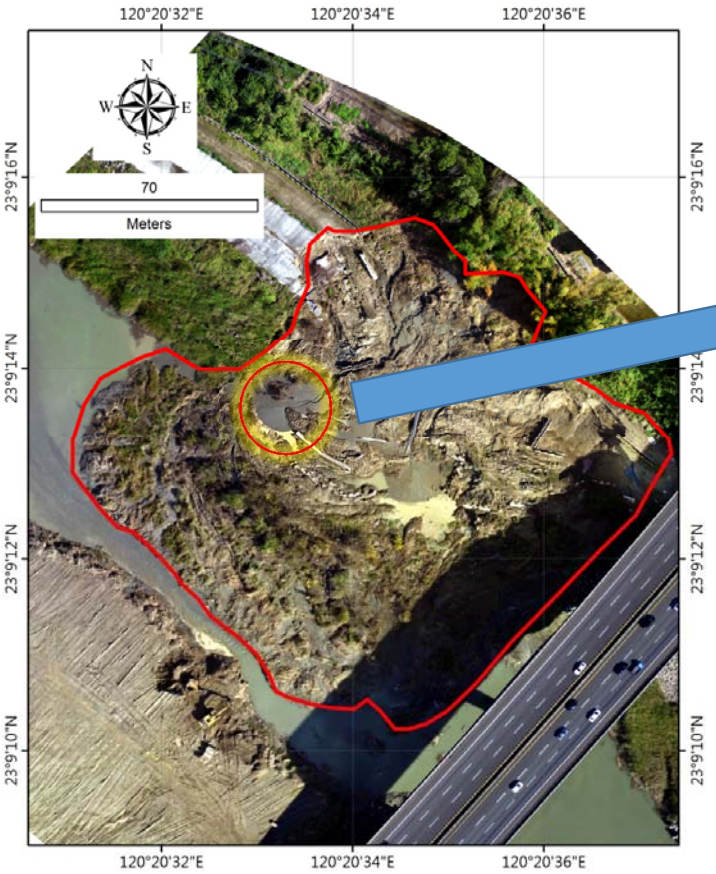
Panoramic View of the Slide at Site B

Slide at C Site



Soil Sampling at Site-A



Repair Works After Earthquake

Observations and Discussions about the Three Slides

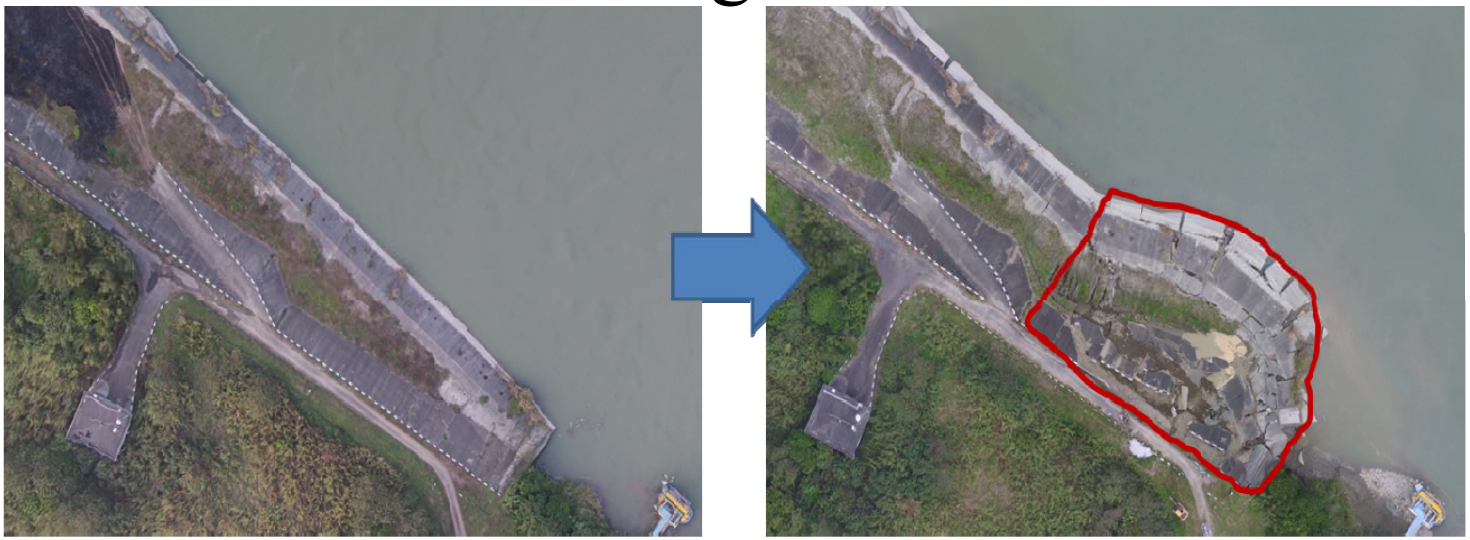
- Flow slides caused by soil liquefaction?
- The soil formations of the three sites are mainly ML and CL soil layers
- whether the cohesive soils have the possibility to cause large-scale flow slides or not?
- The seepage of ground water at the scarps of the slides are clearly observed after earthquake
- The underlying soils below the concrete slab for protecting the slope of revetment may be eroded away
- The concrete slab may be thrown far away due to strong seismic motion

Slide at Yufeng Weir

- Height: 19m (Slope: 1:2 and 1:1.5)
- 30cm unreinforced concrete slab
- Completed in 1996
- PGA about 325 gal

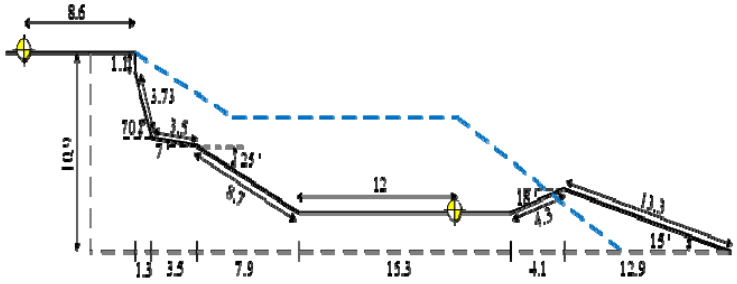
Area (m^2)	Run-out distance(m)
2854	45

UAV images and the cross sections of the damaged revetment

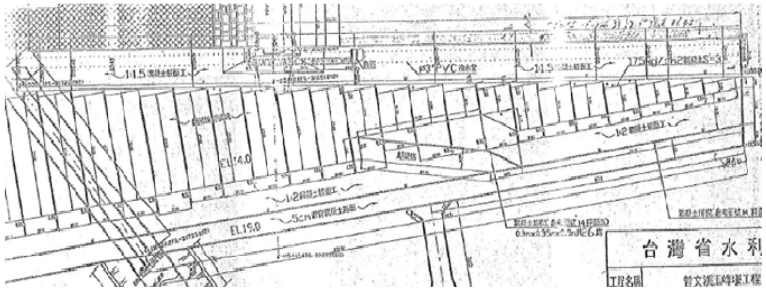


(a) UAV image before EQ

(b) UAV image after EQ



(c) Cross sections before and after EQ



(d) Design plan of revement

Panoramic View of the Revetment Slide at Yufeng Weir

Close View to the Slide

Temporary Repair Works After Earthquake

Observations and Discussions About the Slide at Yufeng Weir

- The seepage of ground water was clearly observed at the scarp.
- It was guessed the underlying sandy soils below the concrete slab was eroded away and deposited at the toe of the revetment.
- The saturated sandy soils at the toe of revetment liquefied during the earthquake and caused the slide of the lower slope and then induced the slide of the upper slope.
- this slide is intuitively considered as the flow slide caused by soil liquefaction. However, future study is necessary to confirm this slide was really triggered by soil liquefaction.

Conclusions

- The results of soil liquefaction evaluation by simplified methods underestimate the field damage degree in this earthquake event
- Some possible reasons for this are proposed and the uncertainties in liquefaction evaluation procedure are discussed
- Liquefaction assessment is not a simple job and this case highlights some issues worth to study in the future
- The run-out distances of these slides are very long. They are intuitively regarded as flow slides caused by soil liquefaction
- However, the soil formations underneath the revetments are mainly cohesive soils of CL and ML. Whether these materials can induce large scale flow slide event is still in doubt--worth to study in the future

Thanks for Your Kind Listening