NARLabs
國家實驗研究院

從花蓮地震淺談橋梁跨越斷層對耐震性能的影響

Hung Hsiao Hui (洪曉慧)

國家地震工程研究中心 橋梁組

2018/05/29

www.narlabs.org.tw

簡報大綱

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- 花蓮地震橋梁震損調查
- 過去地震經驗
- 跨越斷層橋梁受震行為分析
- 比較與討論

0206 花蓮地震

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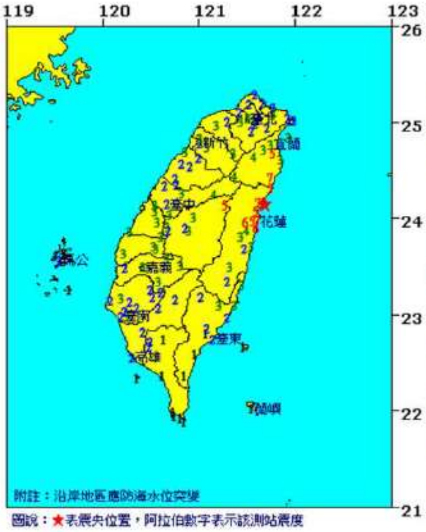
Depth = 6.31Km
Magnitude ML= 6.26

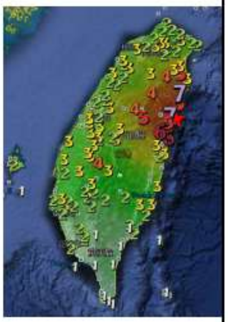


中 央 氣 象 局 地 震 報 告

編號： 第107022號
日期： 107 年 2 月 6 日
時間： 23 時 50 分 42.6 秒
位置： 北緯 24.14 度，東經 121.69 度
即在 花蓮縣政府北偏東方 18.3 公里
位於 花蓮縣近海
地震深度： 10.0 公里
芮氏規模： 6.0
各地最大震度

花蓮縣花蓮市	7級	彰化縣彰化市	3級
宜蘭縣南澳	7級	雲林縣斗六市	3級
南投縣合歡山	5級	嘉義市	3級
臺中市德基	4級	新北市	3級
雲林縣草嶺	4級	苗栗縣竹南	3級
桃園市三光	3級	臺南市佳里	3級
宜蘭縣宜蘭市	3級	新竹市	2級
新竹縣竹東	3級	苗栗縣苗栗市	2級
臺東縣長濱	3級	臺中市	2級
臺北市信義區	3級	基隆市	2級
臺北市	3級	新北市萬里	2級
新竹縣竹北市	3級	新北市石門	2級
新北市五分山	3級	高雄市桃源	2級
南投縣南投市	3級	臺東縣臺東市	2級
嘉義縣阿里山	3級	臺南市	2級
彰化縣員林	3級	屏東縣九如	2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。



from Central Weather Bureau

Investigation route - Day I (Feb 8)

Investigation route - Day II along Meilun Creek

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Nearby Strong-Motion Stations

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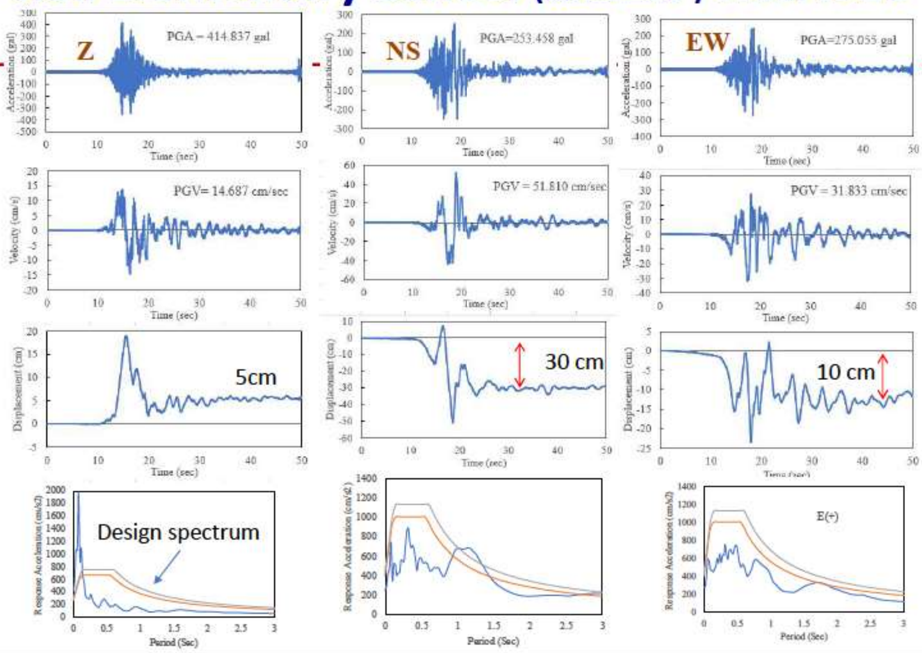
PGA (gal)

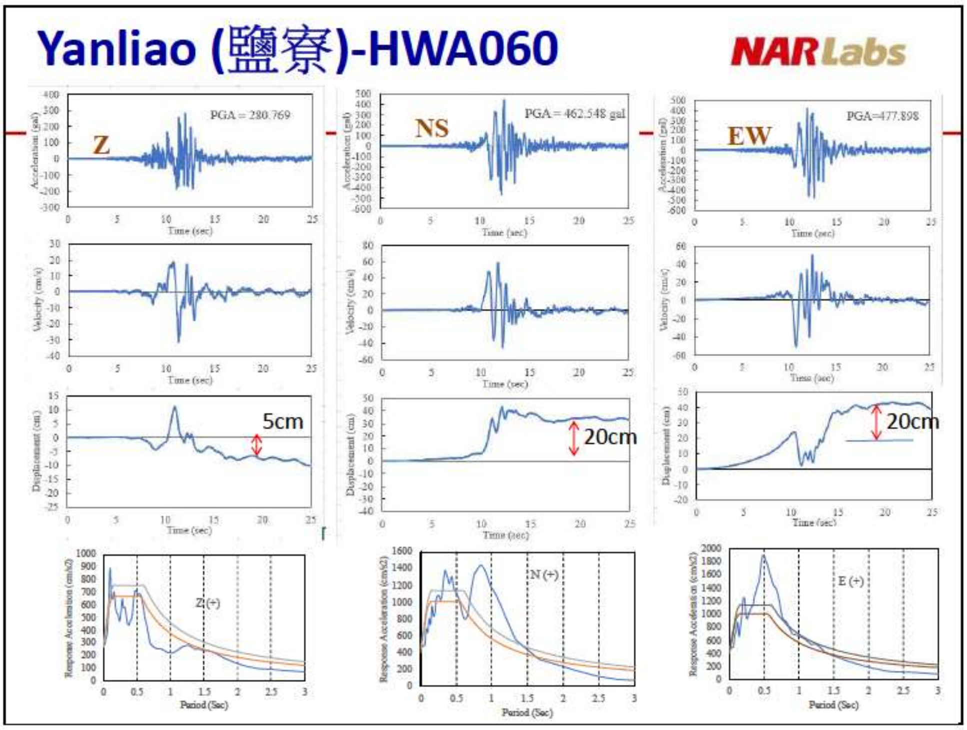
	Z	NS	EW
HWA028	414.84	253.46	275.05
HWA014	397.08	218.82	316.99
HWA012	338.37	280.62	279.70
HWA019	211.01	368.55	402.99
HWA060	280.76	462.55	477.90

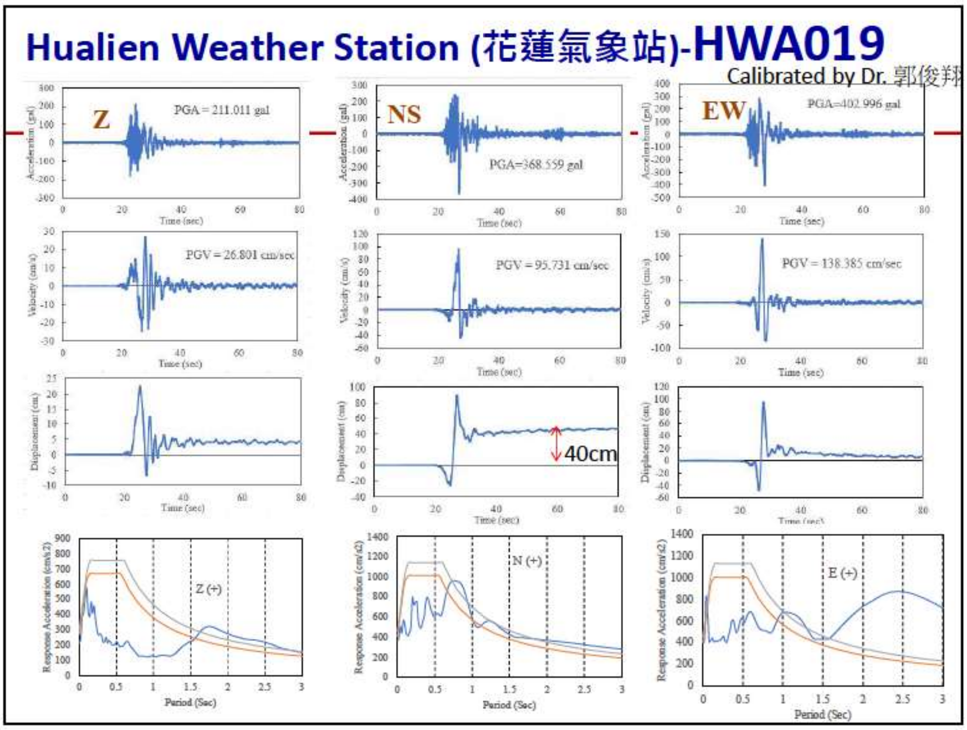
PGV (cm/s)

	Z	NS	EW
HWA028	14.68	51.81	31.83
HWA014	25.85	55.19	146.46
HWA012	27.01	63.88	84.85
HWA019	26.80	95.73	138.38
HWA060	31.17	58.42	50.40

Jiali Elementary School (嘉里國小)-HWA028

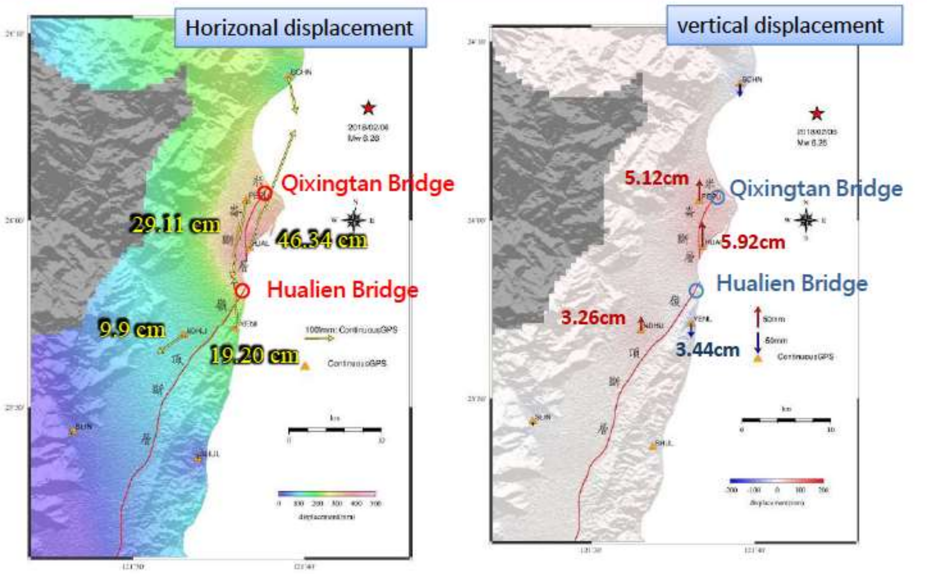



Yanliao (鹽寮)-HWA060
NARLabs
Z
PGA = 280.769
NS
PGA = 462.548 gal
EW
PGA=477.898
5cm
20cm
20cm
Z (+)
N (+)
E (+)
Period (Sec)


Hualien Weather Station (花蓮氣象站)-HWA019
Calibrated by Dr. 郭俊翔
Z
PGA = 211.011 gal
NS
PGA=368.559 gal
EW
PGA=402.996 gal
PGV = 26.801 cm/sec
PGV = 95.731 cm/sec
PGV = 138.385 cm/sec
40cm
Z (+)
N (+)
E (+)
Period (Sec)

Co-seismic Displacement Estimated by GPS

excerpted from 20180206花蓮地震地質調查報告 by CENTRAL GEOLOGICAL SURVEY



Possible Moving Direction of Ground Surface nearby the bridge sites

Qixingtan Bridge

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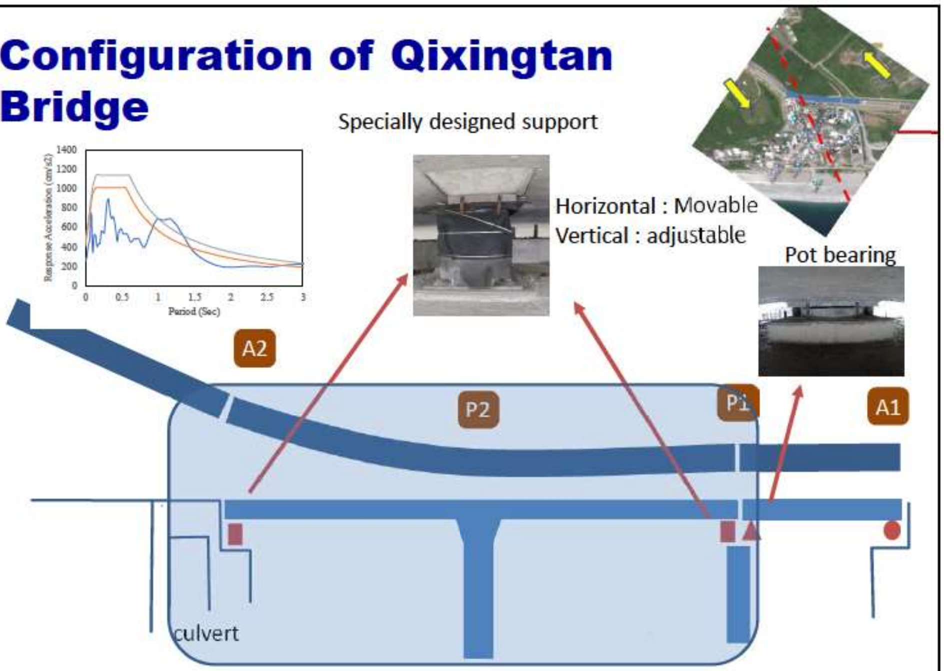
Completed in 2013

七星潭聯外高架橋今上午通車

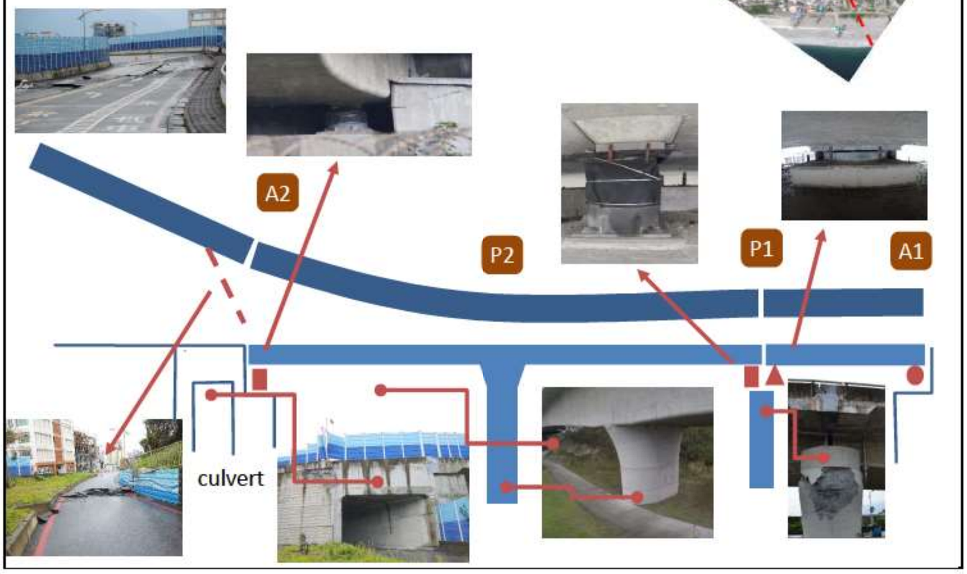
高架橋工程沿著既有道路向空軍基地側拓寬，橋面主線全長710公尺，採高架15公尺雙向雙車道斷面設計，於100年7月22日開工，102年10月25日完工通車，費時2年3個月。

Configuration of Qixingtan Bridge

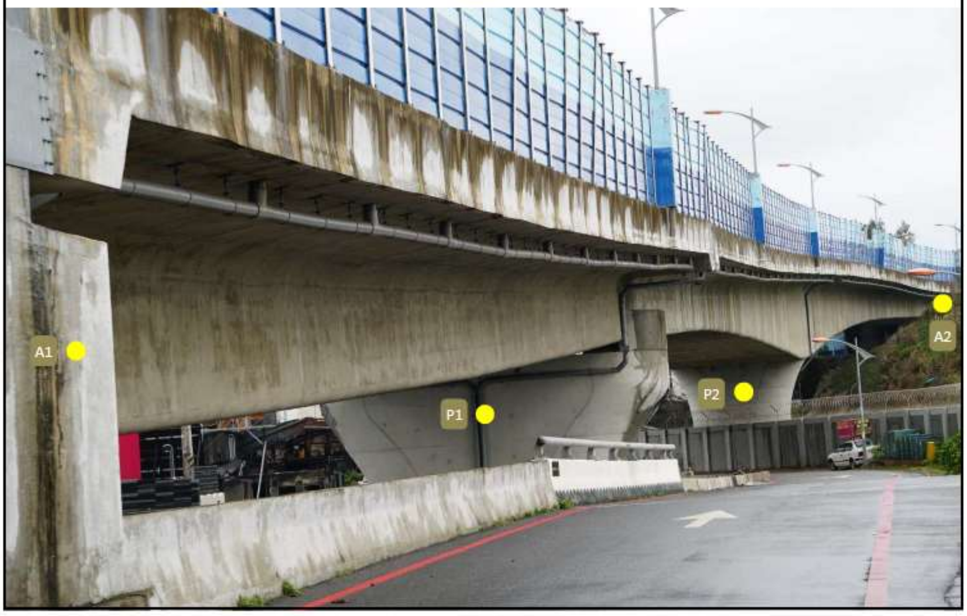


Will not be affected by the differential displacements between substructure

Major damage of Qixingtan Bridge



Qixingtan Bridge



Qixingtan Bridge

NARLabs

Qixingtan Bridge

NARLabs

Qixingtan Bridge

Qixingtan Bridge

Qixingtan Bridge

Qixingtan Bridge

Qixingtan Bridge

NARLabs

Qixingtan Bridge

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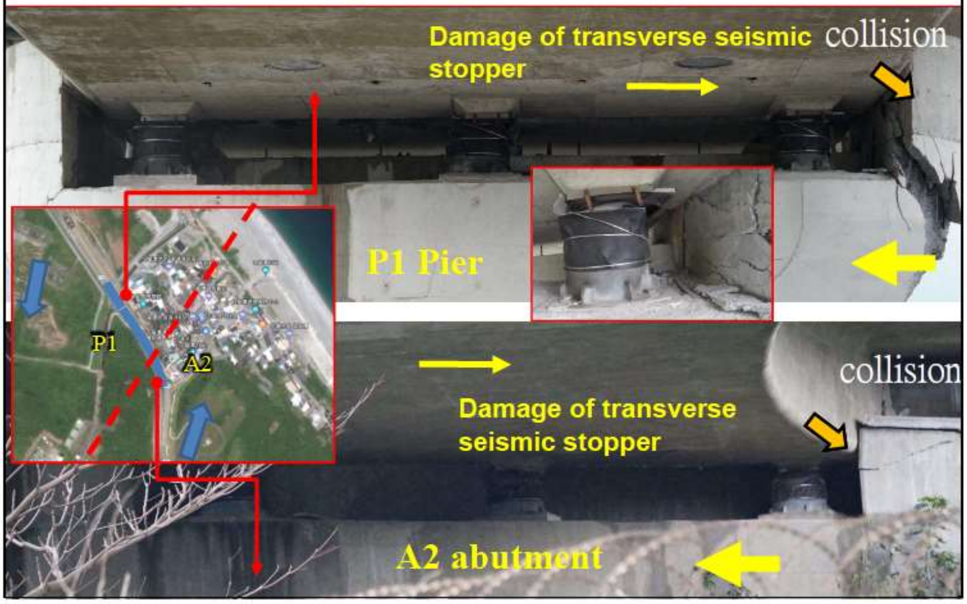
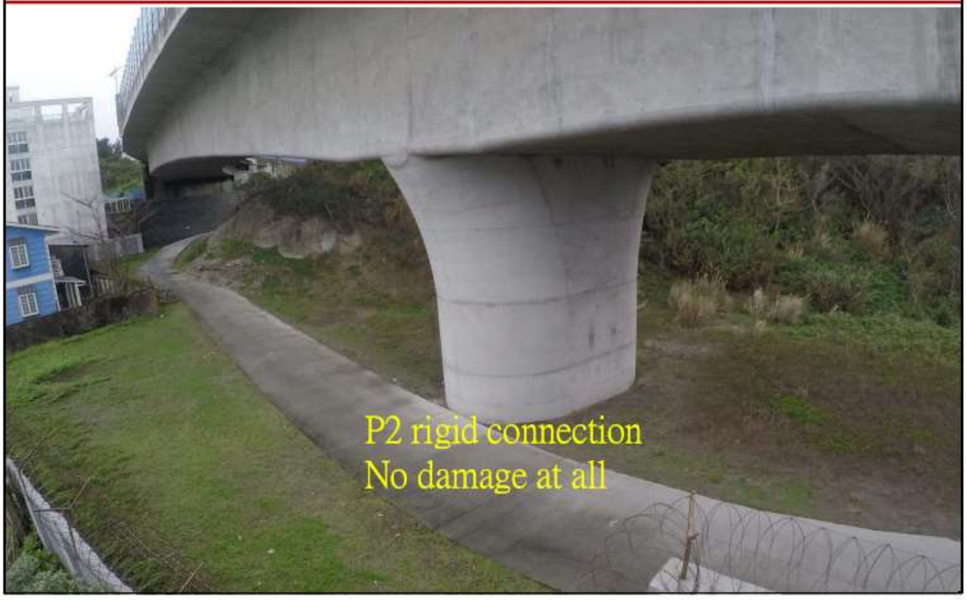
Qixingtan Bridge



Qixingtan Bridge (P1)

Qixingtan Bridge (P2)

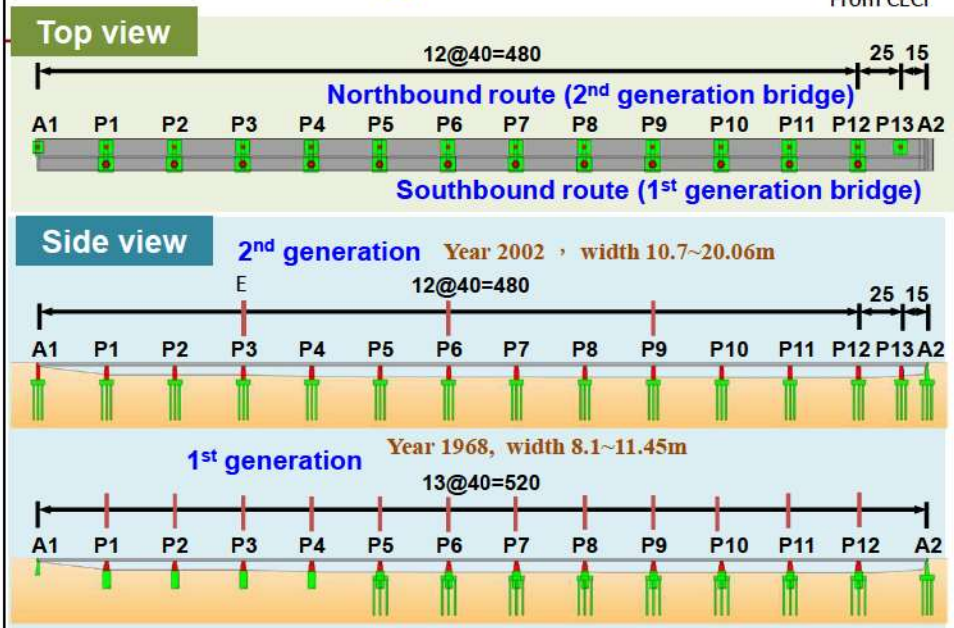


Hualien Bridge

Hualien Bridge

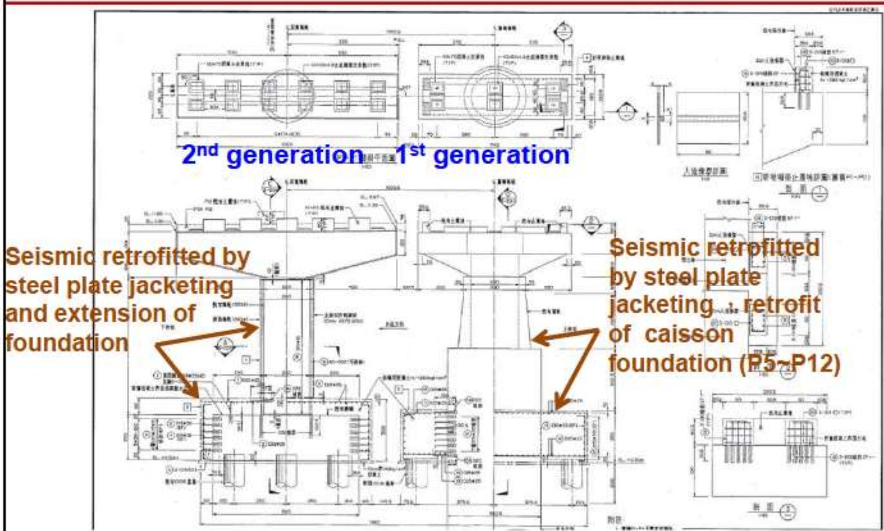
NARLabs

From CECI



Hualien Bridge

NARLabs



2012

Hualien Bridge

Hualien Bridge

Hualien Bridge

Hualien Bridge

Hualien Bridge

Hualien Bridge

Hualien Bridge (P9)

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Hualien Bridge (P12)

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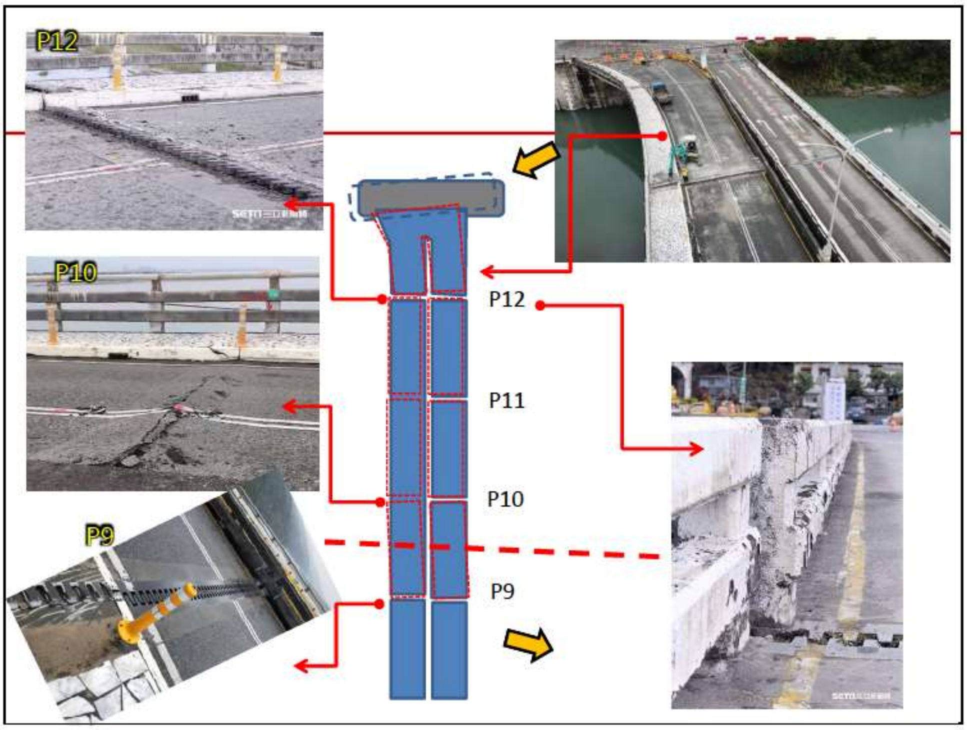
40

Hualien Bridge (P12)



Hualien Bridge (P10)

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Hualien Bridge (P11)

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Hualien Bridge (P12)

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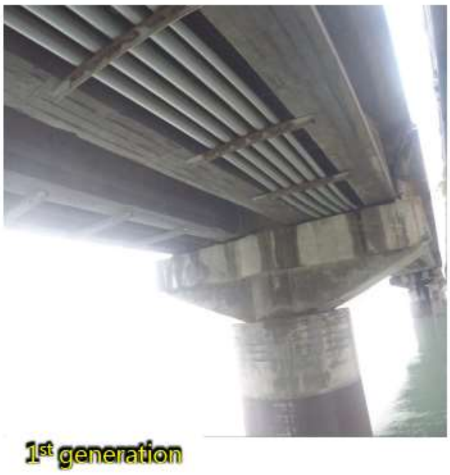

2nd generation

Hualien Bridge (P13)

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Investigation route - Day II along Meilun River

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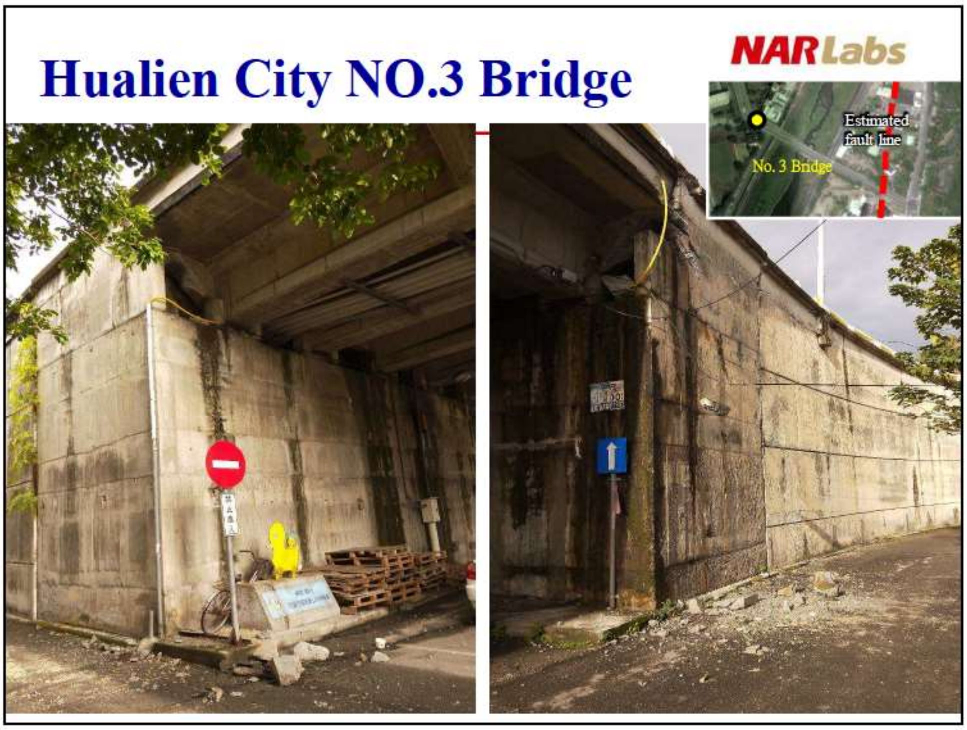
Hualien City NO.3 Bridge
NARLabs
PCI bridge
Completed in 1993/Simply supported bridges
No. 3 Bridge
3@35.1M+20.2M+20.1M=145.6M
guardrail damage
Surface rupture
Abutment damage


Hualien City NO.3 Bridge
NARLabs
Estimated fault line
No. 3 Bridge

Hualien City NO.3 Bridge

Hualien City NO.3 Bridge

Hualien City NO.3 Bridge

Hualien City NO.3 Bridge

Hualien City NO.3 Bridge

Hualien City NO.3 Bridge


Shangzhi Bridge
Completed in 2001
Simply supported bridges
PCI bridge
Fault line
Shangzhi Bridge
2@40M+39.9M+35M+40.1M=195M
Crush in the expansion joint
Sidewalk stair damage
crack in the RC stopper


Shangzhi Bridge
NARLabs
Fault line
Shangzhi Bridge

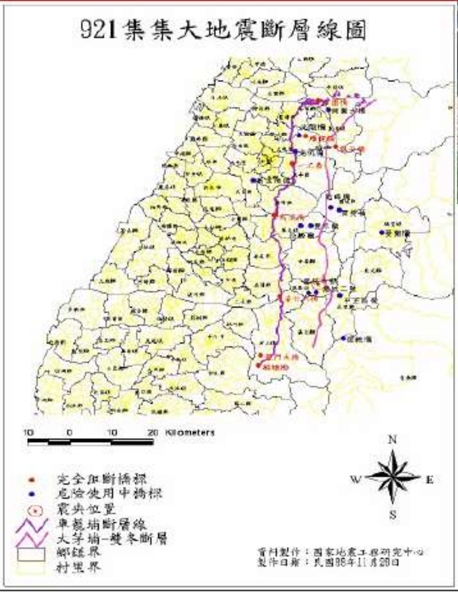
Shangzhi Bridge

Shangzhi Bridge

Shangzhi Bridge

Shangzhi Bridge

921 地震經驗



石圍橋

烏溪橋

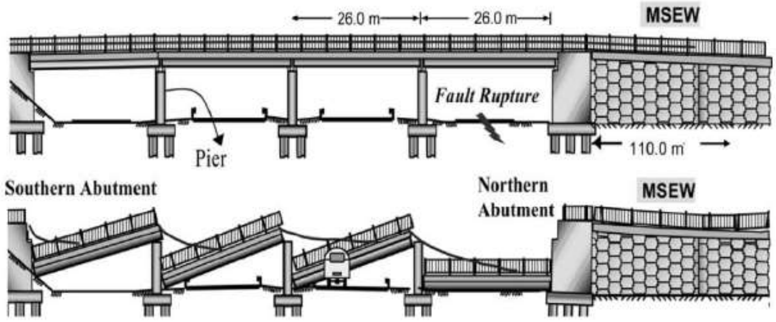
名竹大橋

1999 年土耳其地震經驗

8月17日 Kocaeli 地震 /規模M=7.4

地震前

地震後



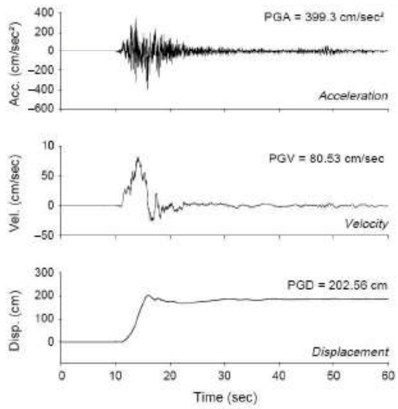
Arifiye高架橋

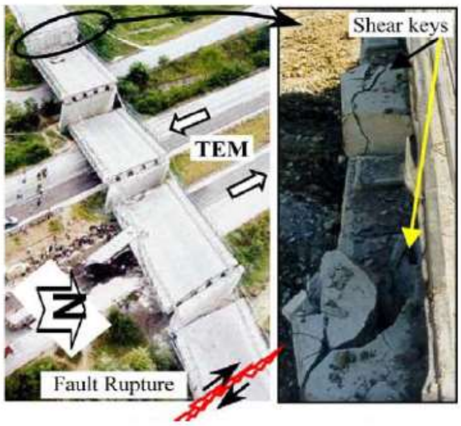
- ✓ 四跨預鑄簡支梁
- ✓ 60度斜橋
- ✓ 支承為橡膠支承墊

1999 年土耳其地震經驗

NARLabs

8月17日 Kocaeli 地震 /規模M=7.4





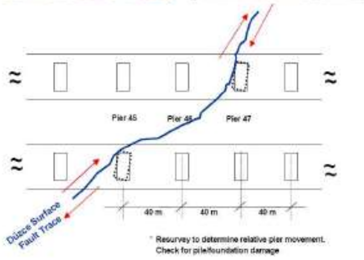
摘自 Ulusay, R., Aydan, O., Hamada, M. (2002)
Pamuk, A., Kalkanb, E., Linga, H.I. (2005)

1999 年土耳其地震經驗

NARLabs

11月12日 Duzce地震 /規模M=7.2

土耳其博盧高架橋（Bolu Viaduct）



摘自 Ghasemi, H. (2004). Bolu Viaduct: Damage Assessment and Retrofit Strategy

- ✓ 59跨之連續簡支梁橋
- ✓ 跨徑約40 m
- ✓ 盤式支承，搭配能量消散裝置（Energy Dissipation Unit，EDU）

Observations and Discussions

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- Bridges crossing active faults may be subjected to large differential displacements between adjacent piers and/or abutments due to surface faulting. Therefore, it is important to provide the **sufficient displacement capacity**.
- For the simply supported bridge with support of neoprene pad, simple spans can tolerate large relative movements, so most of the damage occurs at the expansion joint or hinge connection at the deck, dislocation of the neoprene pad, and the crack of the seismic stopper. However, it is difficult to ensure that the spans do not become unseated, especially for the longitudinal direction.
- For a continuous bridge with superstructures integrated with substructures will reduce the probability of total collapse. However, the substructure has to accommodate the amount of relative displacement across a fault.

Observations and Discussions

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Simply supported bridges

- can tolerate large relative movements, easy for retrofit and replacement
- difficult to ensure that the spans do not become unseated

continuous superstructures

- can reduce the risk of collapse
- Superstructure may have a large displacement demand

continuous superstructures that are integral with their substructures

- can reduce the probability of total collapse
- the substructure has to suffer large displacement demand due relative displacement across a fault.

Observations and Discussions

NARLabs

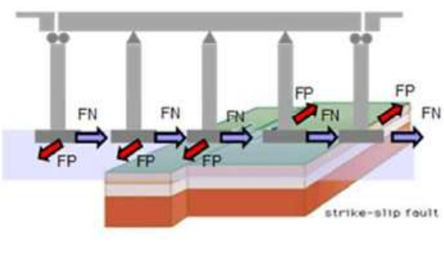
- ☐ Key points: **sufficient displacement capacity**
- ☐ Which component to accommodate the displacement demand?

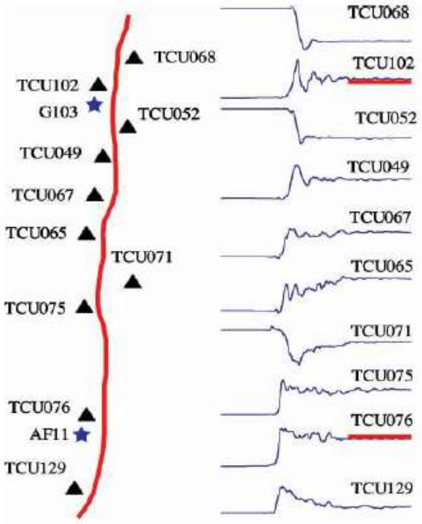
Continuous bridge with bearings that can accommodate relatively large displacements

- ☐ (FPS, elastomeric bearings, equipped with energy dissipation devices…)
- ☐ sufficient support length
- ☐ Unseating Prevention Devices
- ☐ adding extra confinement in the plastic hinge zones of the substructure to provide the maximum displacement capacity.

跨斷層橋梁差異位移

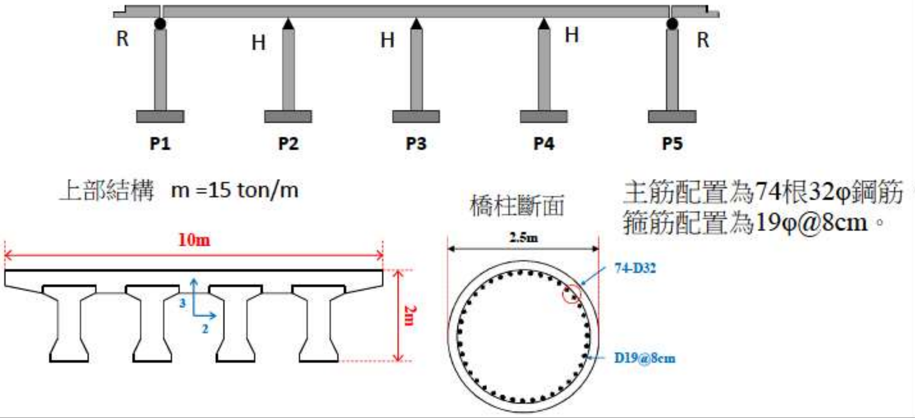
NARLabs



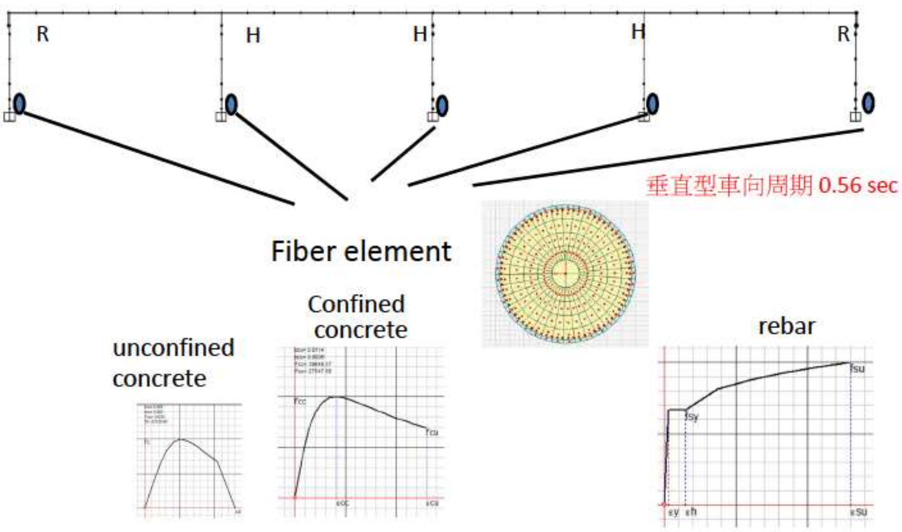


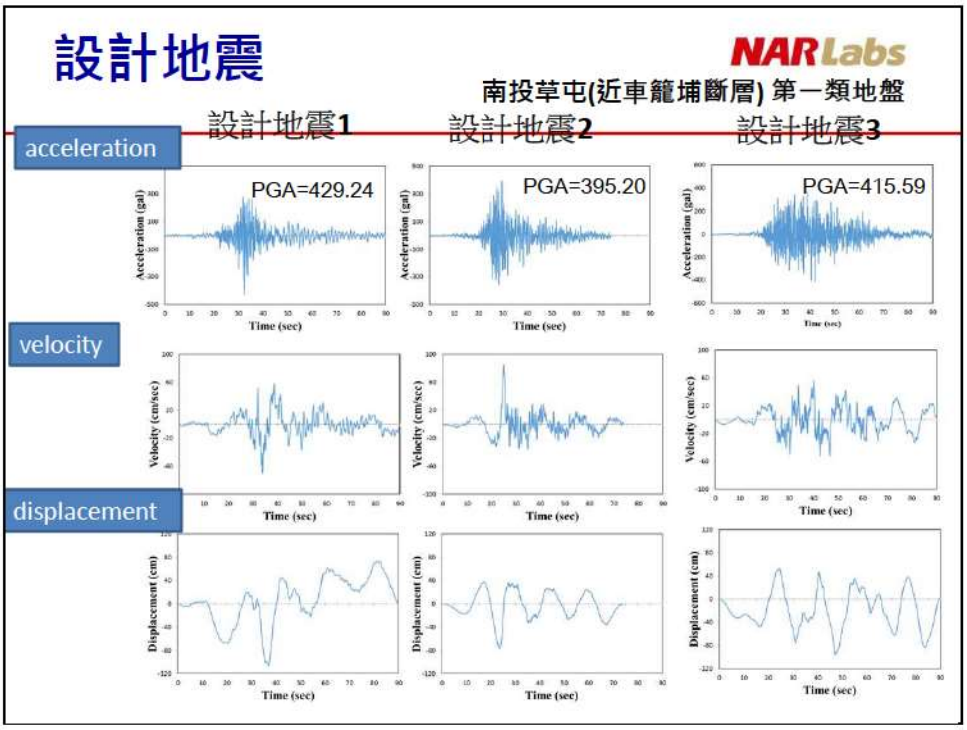
橋梁模型

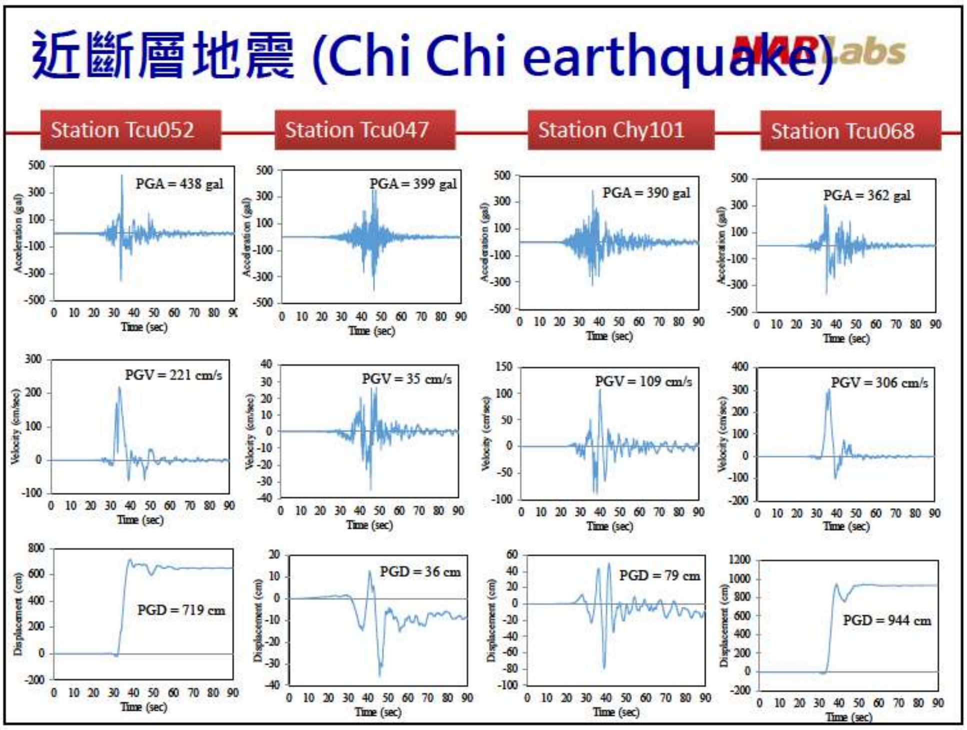
- 四跨連續橋： 4@40m =160m
- 橋柱：10m之單柱式圓形RC橋柱
- 位置：南投草屯(近車籠埔斷層) 第一類地盤



非線性分析模型



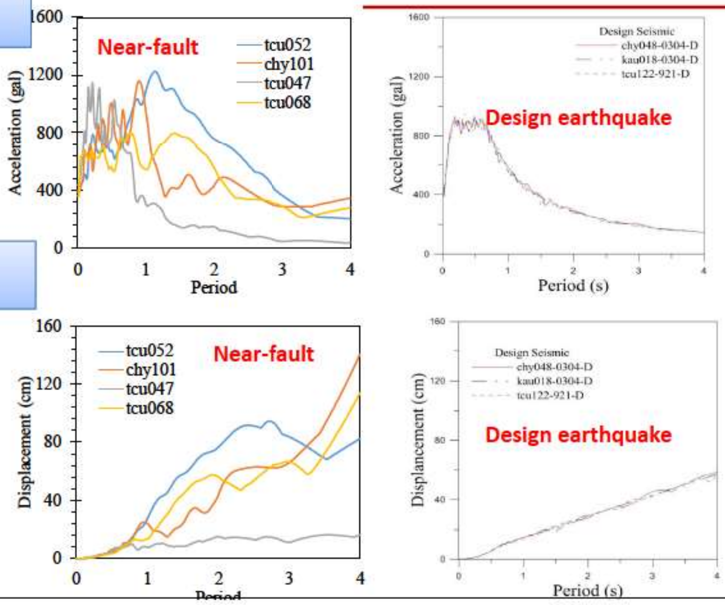

設計地震
NARLabs
南投草屯(近車籠埔斷層) 第一類地盤
設計地震1
設計地震2
設計地震3
acceleration
velocity
displacement
PGA=429.24
PGA=395.20
PGA=415.59
Time (sec)


近斷層地震 (Chi Chi earthquake)
NARLabs
Station Tcu052
Station Tcu047
Station Chy101
Station Tcu068
PGA = 438 gal
PGA = 399 gal
PGA = 390 gal
PGA = 362 gal
PGV = 221 cm/s
PGV = 35 cm/s
PGV = 109 cm/s
PGV = 306 cm/s
PGD = 719 cm
PGD = 36 cm
PGD = 79 cm
PGD = 944 cm
Time (sec)

反應譜

Acceleration response spectrum

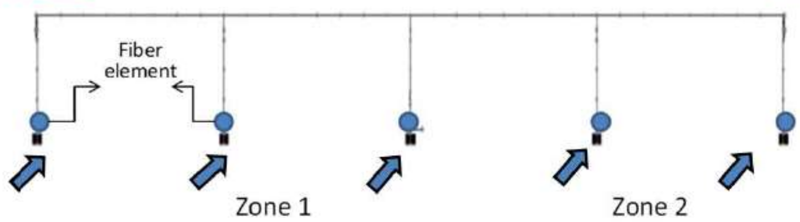
Displacement response spectrum



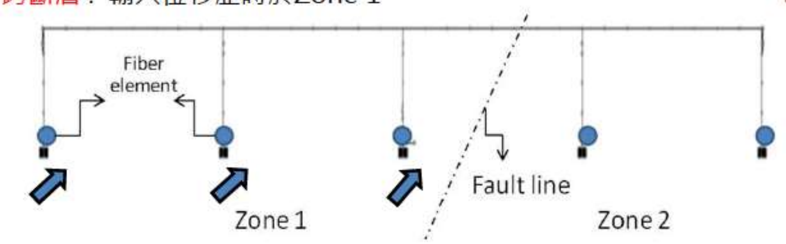
非線性動力歷時分析

Input displacement time history records

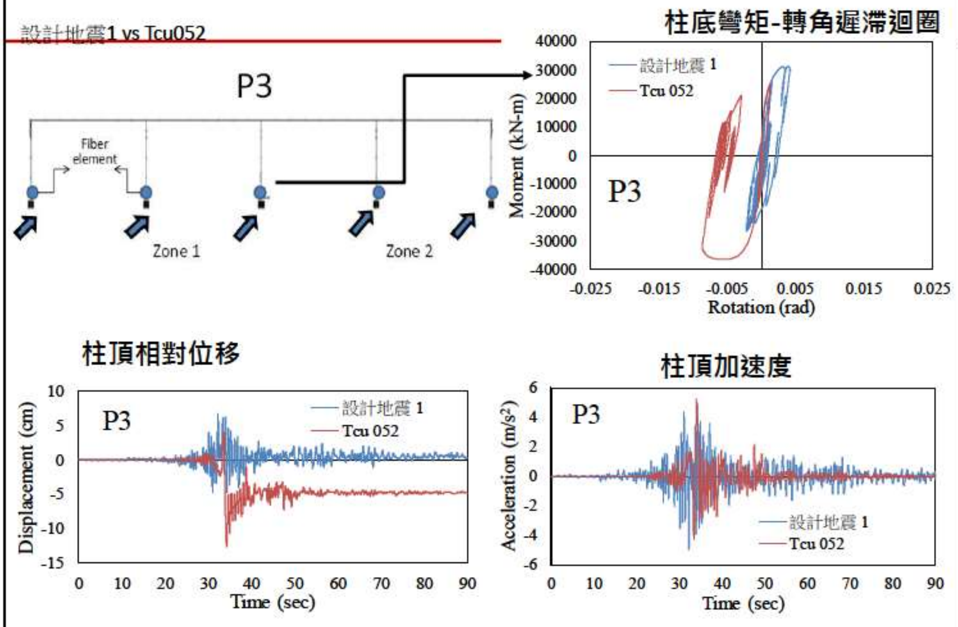
非跨斷層：同時輸入位移歷時於Zone 1& zone 2　　7組地震力



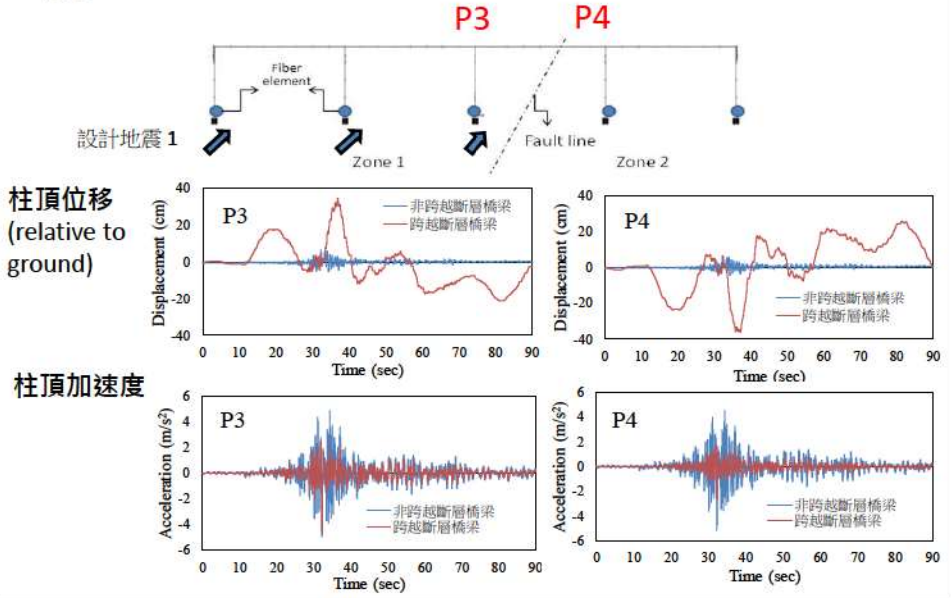
跨斷層：輸入位移歷時於Zone 1　　7組地震力



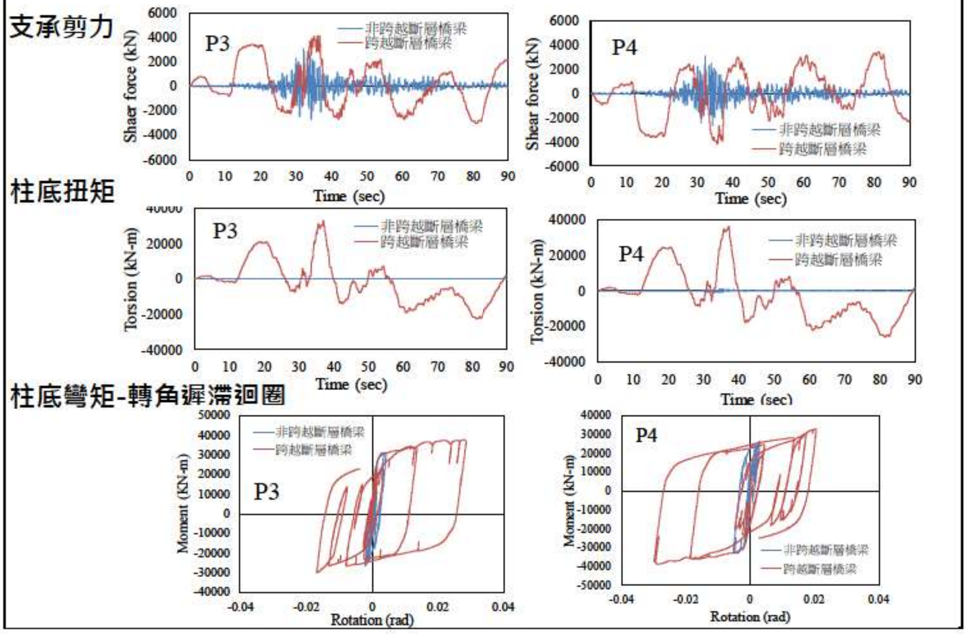
近斷層地震反應和設計地震反應比較



跨/非跨斷層反應比較(設計地震)



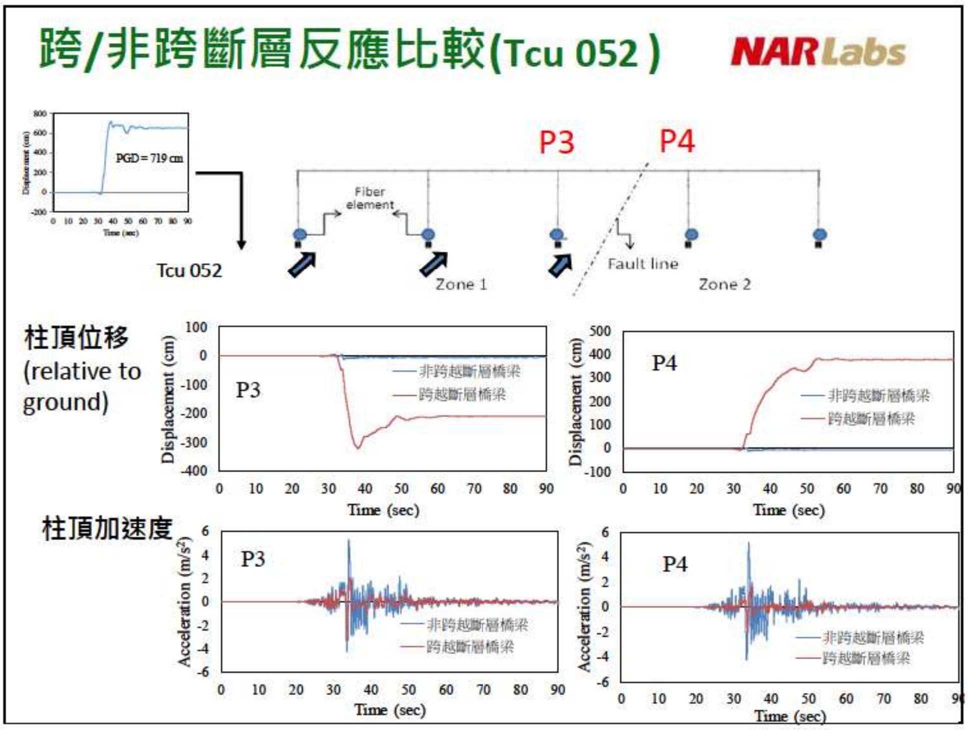
跨/非跨斷層反應比較(設計地震)

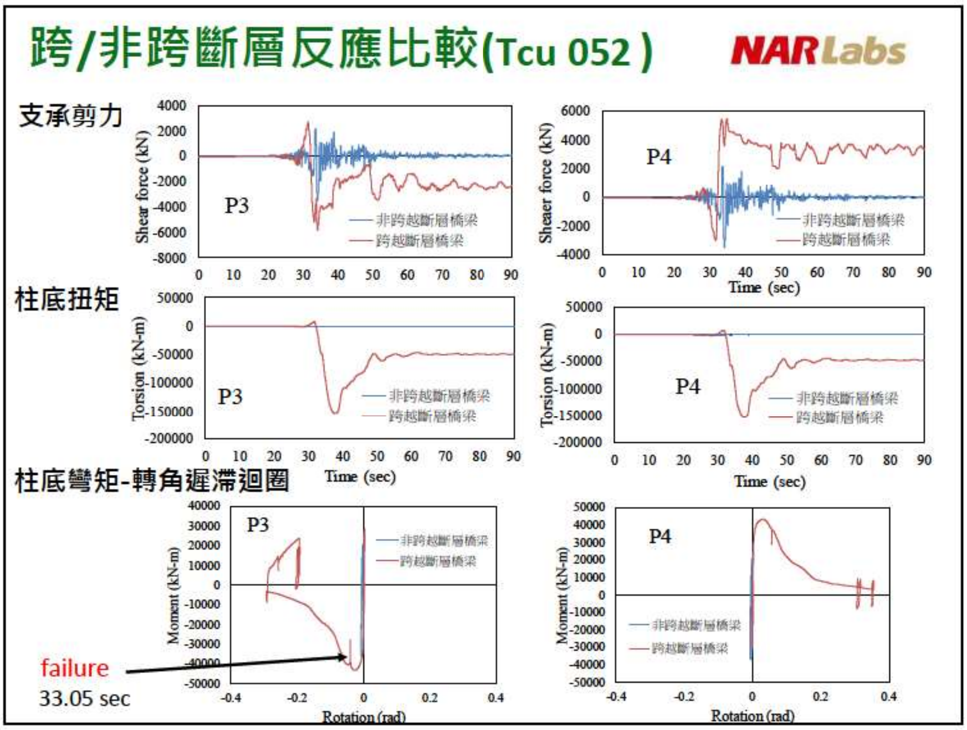


橋梁最大歷時反應之比較 (設計地震)

地震歷時	設計地震1		設計地震2		設計地震3	
歷時最大反應	跨斷層	非跨斷層	跨斷層	非跨斷層	跨斷層	非跨斷層
P3柱頂位移(cm)	34.63 >	6.75	21.34	6.4	27.98	7.42
P4柱頂位移(cm)	36.19	6.71	27.32	6.06	34.57	6.91
P3柱頂加速度(gal)	455 <	497	311	481	307	501
P4柱頂加速度(gal)	267	512	198	487	220	470
P3支承剪力(MN)	4.11 >	3.06	3.67	2.96	3.85	3.03
P4支承剪力(MN)	4.20	3.10	3.82	2.95	4.23	3.02
P3柱底扭矩(MN-m)	32.859 >>	0.003	23.382	0.003	28.648	0.003
P4柱底扭矩(MN-m)	36.288	1.065	27.394	1.107	33.796	1.366
P3柱底塑性變形比	15.87 >>	2.34	9.211	1.71	12.57	2.22
P4柱底塑性變形比	16.68	2.93	12.22	1.54	15.85	1.94

θ/θ_y


跨/非跨斷層反應比較(Tcu 052)
NARLabs
PGD = 719 cm
Tcu 052
P3
P4
Fiber element
Fault line
Zone 1
Zone 2
柱頂位移
(relative to ground)
Displacement (cm)
Time (sec)
非跨越斷層橋梁
跨越斷層橋梁
柱頂加速度
Acceleration (m/s²)


跨/非跨斷層反應比較(Tcu 052)
NARLabs
支承剪力
Shear force (kN)
P3
P4
非跨越斷層橋梁
跨越斷層橋梁
Time (sec)
柱底扭矩
Torsion (kN-m)
柱底彎矩-轉角遲滯迴圈
Moment (kN-m)
Rotation (rad)
failure
33.05 sec

橋梁最大歷時反應之比較 (near-fault)

地震歷時	TCU047		TCU052		CHY101		TCU068	
歷時最大反應	跨斷層	非跨斷層	跨斷層	非跨斷層	跨斷層	非跨斷層	跨斷層	非跨斷層
P3柱頂位移 (cm)	11.91	7.37	318.23	12.64	23.61	6.12	416.69	10.67
P4柱頂位移 (cm)	11.09	7.04	374.73	12.16	29.05	6.13	523.01	10.00
P3柱頂加速度(gal)	345.16	525	349	517	373	481	148	475
P4柱頂加速度(gal)	187.41	534	218	509	220	491	152	.68
P3支承剪力 (MN)	3.75	3.259	5.84	3.46	4.26	2.92	5.66	3.37
P4支承剪力 (MN)	3.32	3.222	5.51	3.49	4.41	2.98	5.89	3.36
P3柱底扭矩(MN-m)	13.75	0.002	153.26	0.003	24.60	0.002	192.21	0.002
P4柱底扭矩(MN-m)	13.88	0.012	153.03	1.050	27.92	0.83	191.36	1.22
P3柱底塑性變形比	4.45	2.11	162.69*	4.89	10.28	1.57	213.39*	3.83
P4柱底塑性變形比	4.03	1.93	192.02*	4.56	13.05	1.54	270.37*	3.47

結論與討論

NARLabs

- ✓ 對於跨越斷層橋梁，分析若未考慮同一座橋相鄰橋柱間之斷層錯動，將低估支承剪力，柱底變形和柱底所受扭矩，但高估柱頂加速度反應。
- ✓ 尚須更多橋型比較、支承非線性模擬...不同斷層錯動方向...等等之分析比較，以作為未來擬定跨越斷層橋梁相關設計或減災方案之參考