交通部臺灣區國道高速公路局
Taiwan Area National Freeway Bureau

國道高速公路橋梁耐震補強
第2期工程(第1優先路段)規劃設計

中華民國地震工程學會-結構耐震補強技術獎

簡報

T·Y·LIN INTERNATIONAL TAIWAN
林同棪工程顧問股份有限公司

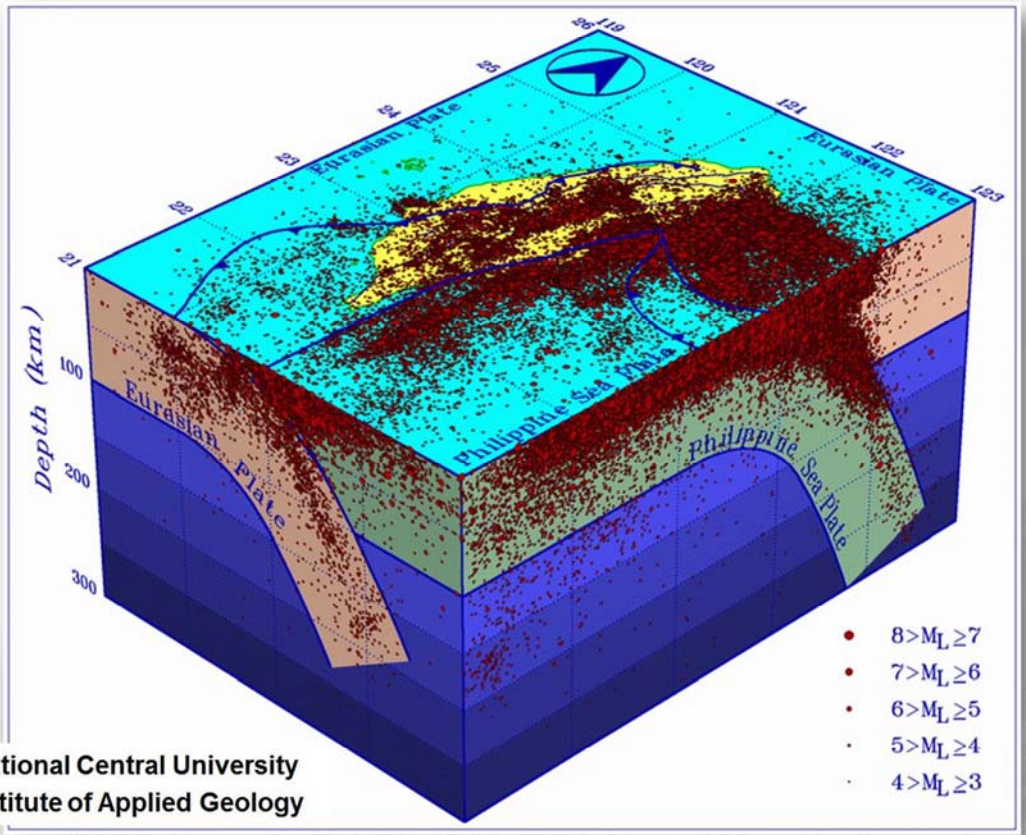
主講人：彭康瑜　計畫主持人

中 華 民 國 105 年 12 月 17 日

簡報大綱

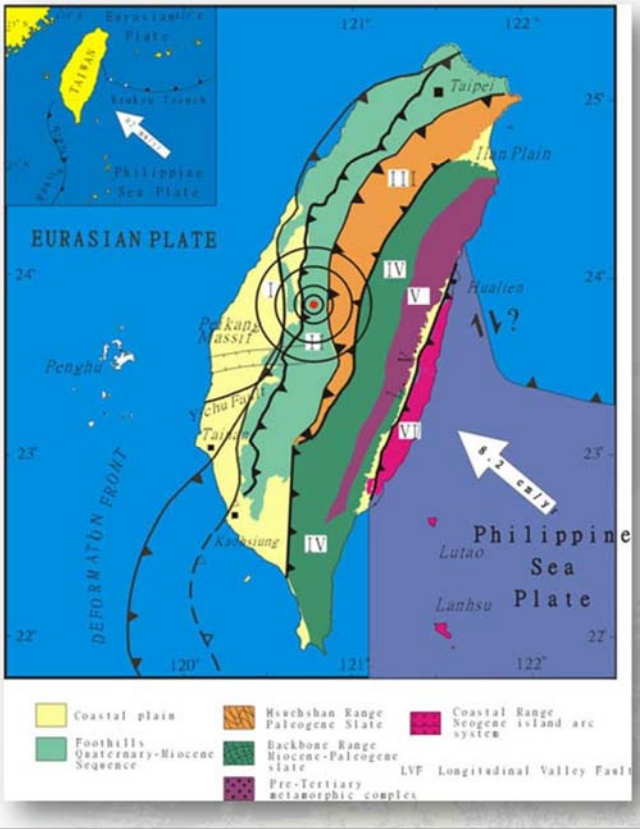
1 國道橋梁耐震補強計畫

Taiwan Tectonics and Seismicity

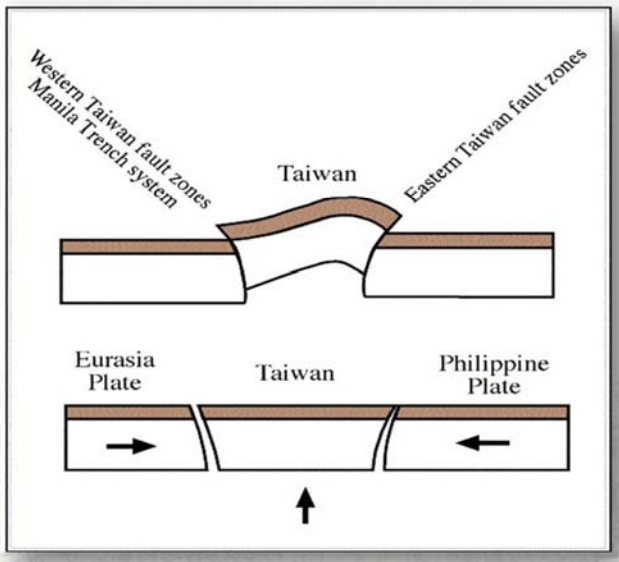


Courtesy: National Central University
Graduate Institute of Applied Geology

Chi-Chi Earthquake



- Chi-Chi Earthquake, Taiwan, 9/21, 1999
- Local Magnitude = 7.3



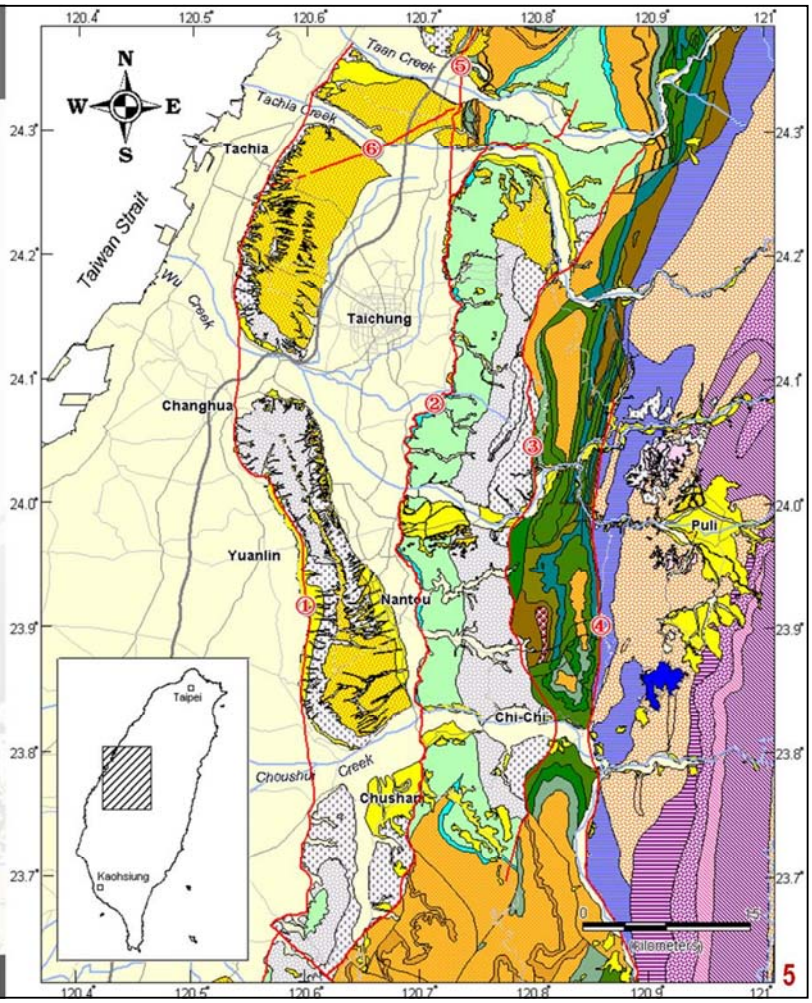
Chi-Chi Earthquake

Geological Map of West Central Taiwan

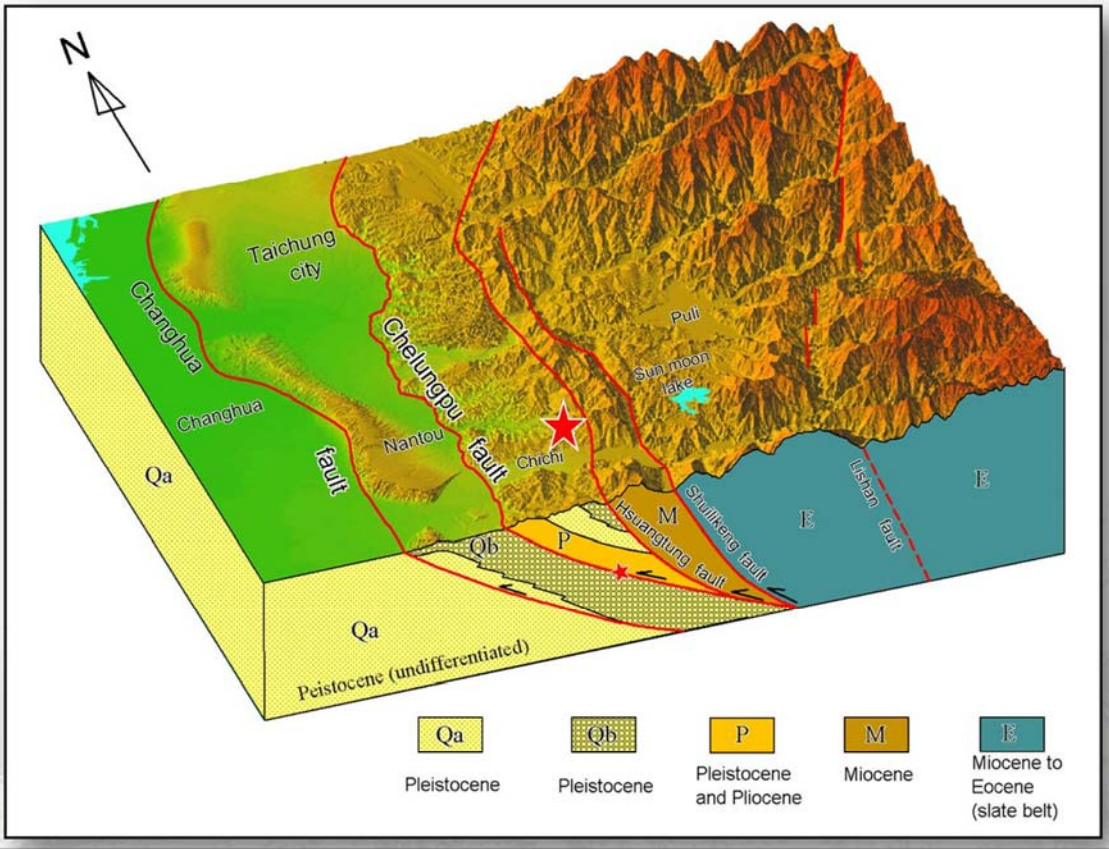
LEGEND

- Alluvium
- Pleistocene
  - Terrace Deposits
  - Lateritic Terrace D.
  - Toukoshan F.
- Pliocene
  - Cholan Formation
  - Chinshui Shale
- Miocene
  - Kueichulin F.
  - Nanchuan F.
  - Nankang Formation
  - Shiti Formation
  - Taliao Formation
  - Mushan Formation
- Oligo.
  - Shuichangliu F.
- Eocene
  - Paileng Formation
  - Chiayang Formation
  - Yuhshan Chufeng F.
  - Dachian Sandstone
  - Shibachungsi F.

① Changhua Fault
② Chelungpu Fault
③ Hsuangtung Fault
④ Shuilikeng Fault
⑤ Sanyi Fault
⑥ Tuntzechiao Fault
Highway



Chi-Chi Earthquake



Chi-Chi Earthquake : Lessons Learned

Summary of damaged highway bridge in Chi-Chi earthquake

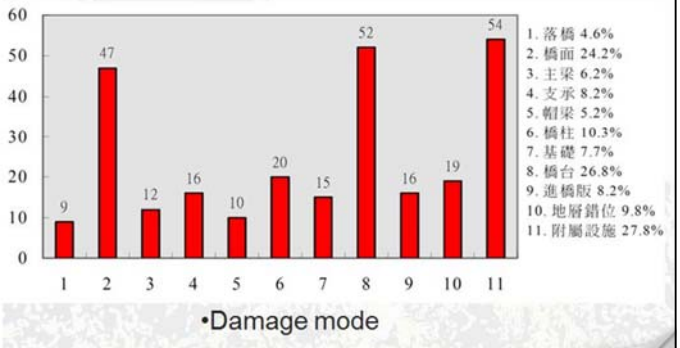
County	Number			
	bridges	Non damaged	Minor-to-moderate damaged	Major damaged
Taichung	196	131	52 (26.5%)	13 (6.6%)
Changhua	199	182	17 (8.5%)	0
Nantou	410	315	82 (20.0)	13 (6.6%)
Tyunlin	176	158	18 (10.2)	0
Summary	981 (100%)	786 (80.1%)	169 (17.2%)	26 (2.7%)

* the percentage is based on the total inspected bridges in each county.

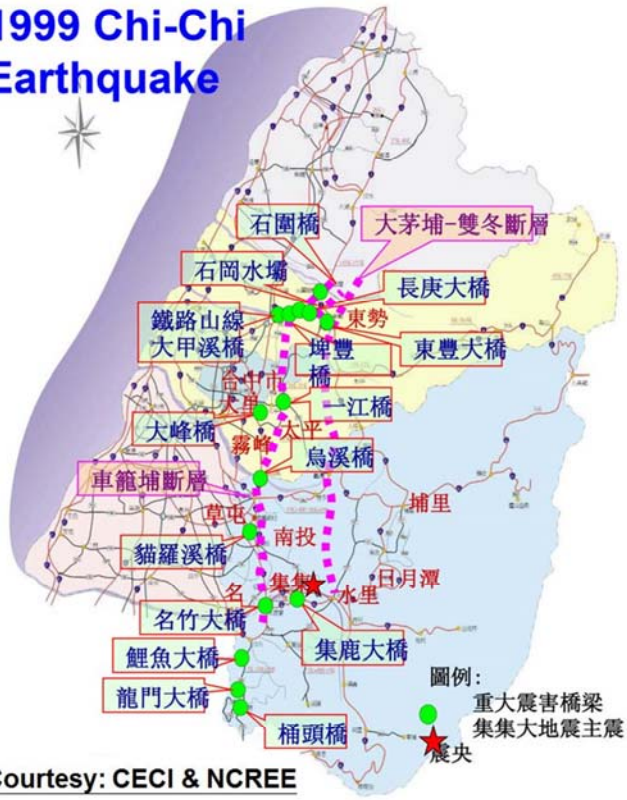
11 different damage modes

Mode	Item	Number	Percentage (%)
1	collapse	9	4.6
2	deck	51	26.2
3	girder	16	8.2
4	bearing	18	9.2
5	pier cap	12	6.2
6	column / pier	21	10.8
7	foundation	14	7.2
8	abutment	63	32.3
9	approaching slab	41	21.0
10	land slide	19	9.7
11	Ancillary facilities	69	35.4

Source: NCREE-99-055 Reconnaissance Report



Chi-Chi Earthquake : Lessons Learned



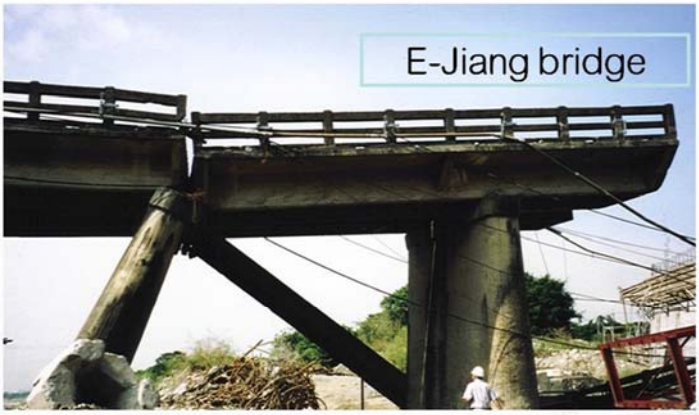
Chi-Chi Earthquake : Lessons Learned

26 Major damaged highway bridges

Source:
NCREE-99-055 Report

Name	Route	Year	Span (m)	Length (m)	Damaged mode
Shi-wei	Provincial 3	1994	25	75	collapse
Chang-geng	local	1987	25	300	collapse
Dong-feng	Provincial 3	1962/1988	26	572	girder/column
Pi-feng	local	1991	25	300	collapse
E-jian	County 129	1972	11	264	collapse
Wu-shi	Provincial 3	1981/1983	34.7	624	collapse/column
Mao-loh-shi	Provincial 3	1999	40~70	500	column
Ming-tsu	Provincial 3	1990	25	700	collapse
Ji-lu	local	1999	150	300	pylon/bearing
Tong-tou	County 149	1980	40	160	collapse
Guang-long	local	1986	28	56	deck/abutment
Guan-de	local	1977	20	60	collapse
Bei-keng	County 129	1959	5.7	5.7	deck/abutment
Long-an	County 129	1986	35	280	column
Cheng-feng	County 136	1986	25.6	184	column/abutment
Yan-feng	Provincial 14	1984	35	455	column
Pu-ji	Provincial 16	1979	35	105	pier cap
Hsing-shi-nan	County 127	1994	50	500	column/bearing
Yan-ping	Provincial 3	1986	13	78	abutment
Hsin-yi	Provincial 21	1981	29	180	column
Long-men	Tou 53	1982	40	480	collapse
Li-yu	Tou 53	1988	39	546	bearing
Ping-lin	Tou 6	1969	25	500	collapse/column
Mo-keng No.1	Provincial 16	1996	14.6	14.6	abutment
Mo-keng No.2	Provincial 16	1996	40	40	abutment
Da-feng	Chung 105	1992	-	-	deck

Chi-Chi Earthquake : Lessons Learned



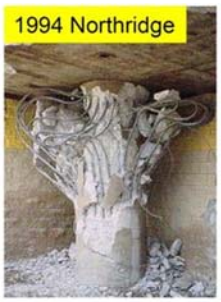
Chi-Chi Earthquake : Lessons Learned

Shear failure in pier of Wu-Shi bridge, Chi-Chi Earthquake, Taiwan, September 1999

Chi-Chi Earthquake : Lessons Learned

Settlement, Unseating and Shear failure of Ming-Tsu bridge, Chi-Chi Earthquake, Taiwan, September 1999

US & Japan Earthquake : Lessons Learned



- Complex Geometry Redistributes Forces
  - Skew, Varied Column Heights
- Accommodate Shear & Flexure
- Post 1989 Designs Reduced Damage
- Retrofit Improves Resistance
  - Joint Restrainers
  - Column Jacketing

- Consider Structural Filters / Fuses
  - Isolation, Energy Dissipation
  - Displacement Control
- Accommodate Forces & Displacements
- Evaluate Ground Motion Amplification/Attenuation
- Consider "Near Field" Effects
- Identify Liquefaction Potential
- Retrofit Improves Performance
- Current Designs Improve Resistance

Chi-Chi Earthquake : Lessons Learned

- **Fault rupture**
- **Near-field ground motions**
- **Ground failures precipitate structural failure**
- **Abutment back-walls and back-fills are essential for continuous bridges**
- **Shear failures must be avoided in piers**
- **Shear keys are required to prevent spans falling transversely**

Taiwan Freeway Bureau (TANFB):
Develop the comprehensive Bridge Retrofit Program

Freeway Bridge Seismic Retrofit Program

Risk management concepts for disaster prevention

- **Upgrade ONE lifeline freeway connecting major response and business centers before 2009**
- Retrofit is a proven method to preserve bridges, slopes, and landslides
- Route selection is critical to success
- Significant reduction in secondary loss of life and long term economic losses can be achieved

Freeway Bridge Seismic Retrofit Program

1. To reduce damage and to avoid casualties of future large earthquakes is the primary objective

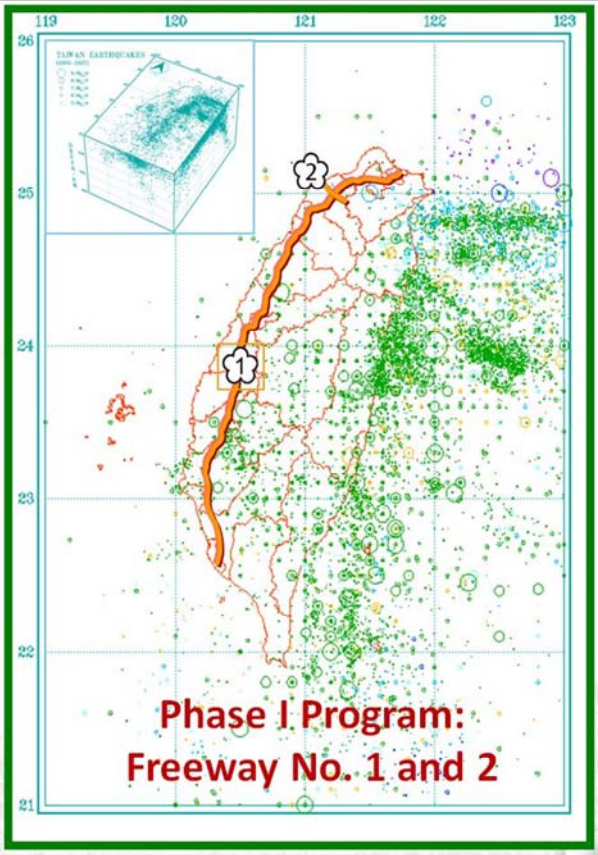
2. To construct Taiwan's high-efficiency lifeline for earthquake disaster relief road network system

3. To ensure high-safety critical transportation infrastructures for Taiwan's economic sustainable development

4. To achieve the overall goal of disaster prevention by adopting the seismic performance concepts
   - Zero damage for frequent earthquakes
   - Reparable damages under moderate earthquakes
   - No collapse in the case of extreme earthquakes

Freeway Bridge Seismic Retrofit Program

- TANFB reviewed the seismic vulnerability of all freeway bridges after the Chi-Chi Earthquake, with the technical support by T.Y. Lin & NCREE
- Bridges inventories are screened to identify structures that are seismically deficient and evaluated for the severity of expected damage and losses by using TELES
- to prioritize in the order of needs for retrofitting



Freeway Bridge Seismic Retrofit Program

Freeway Bridge Seismic Retrofit Program

Project phases	Project Scope	Number of bridges evaluated	Number of bridges retrofitted	Description
Phase I	**Freeway No.1 and No.2** (including the widening projects of freeway No.1 Yuanlin-Kaohsiung section and freeway No.2)	**490**	**412**	**Freeway No.1: completion in December 2009** **Freeway No.2: completion in December 2011**
Phase II	**Freeway No.3 (northern section)**	**190**	**180**	**Completion in June 2016**
Phase III	**Freeway No.3 (central & southern sections) and freeway No.4, 5, 6, 8, 10**	**769**	**Note 1**	**In seismic evaluation and retrofit design stage, scheduled for 2016~2025**

Note 1: according to seismic assessment results to determine the number of bridge retrofitted

Freeway Bridge Seismic Retrofit Program

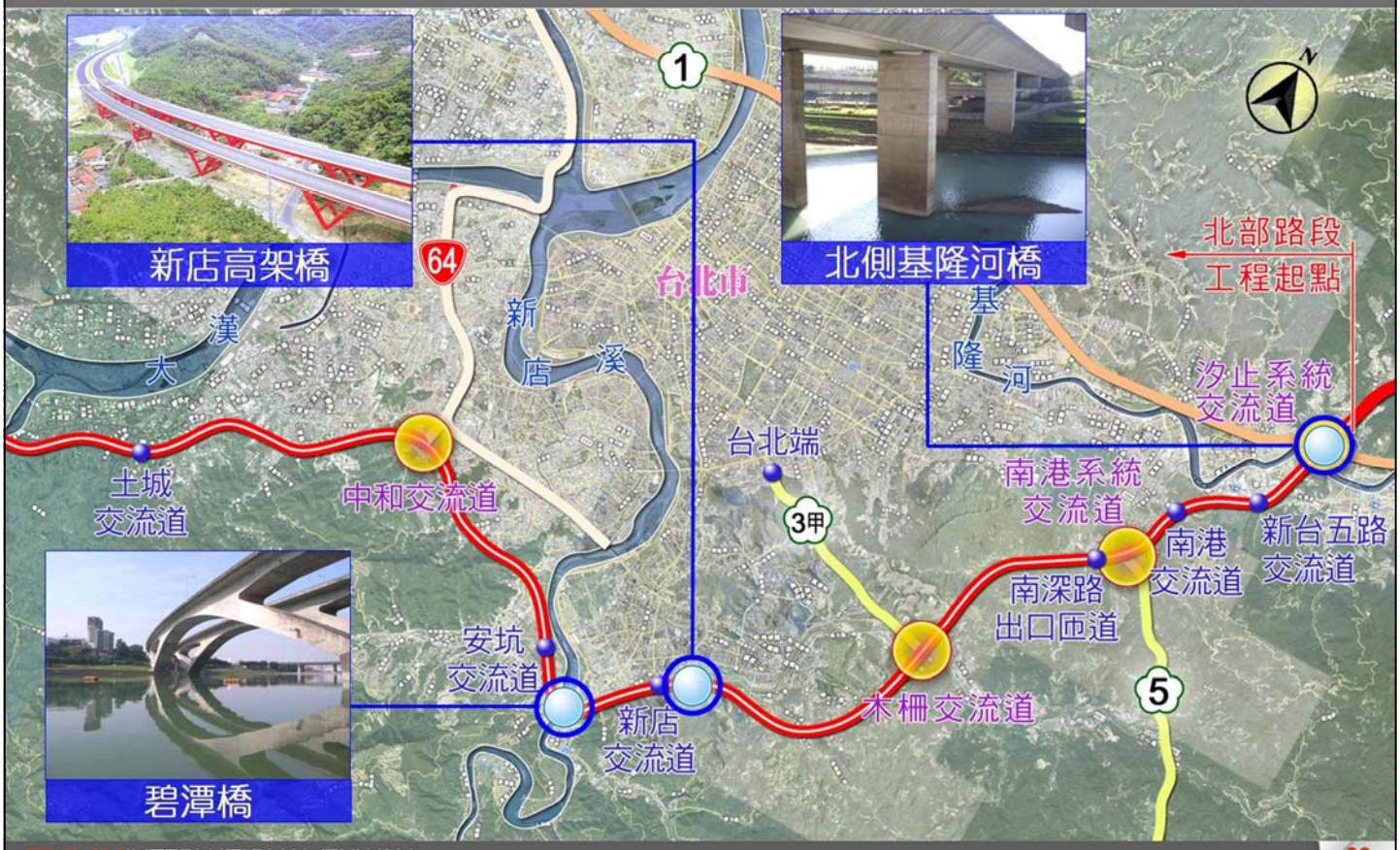
- Dedicate New Funding to Phase III Program
- To avoid NT$144 Billion in economic losses and minimize loss of life:
  - To complete all 3 prioritized sections in 10-years plan
  - Recommended to implement during 2016~2025

2

第2期工程-第1優先路段

第2期工程 - 第1優先路段

北二高主要橋梁現況(1/3)



北二高主要橋梁現況(2/3)

北二高主要橋梁現況(3/3)

北二高橋梁結構特色

上部結構系統、工法演進

中山高	北二高	二高後續

預力I型梁（吊裝工法）

連續預力箱型梁

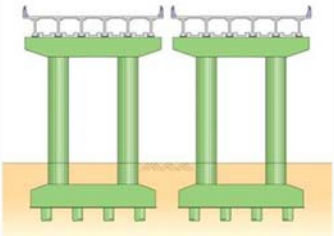
場撐工法	引進歐洲自動化橋梁工法

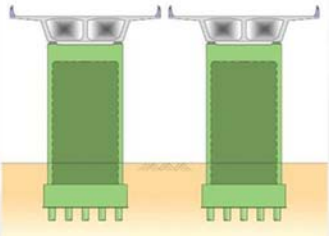
北二高橋梁結構特色

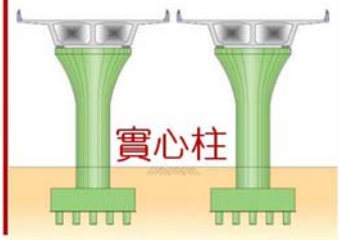
下部結構橋墩型式演進

84年耐震規範

中山高	北二高	二高後續	二高後續
框架式橋墩	直柱式中空橋墩		擴頭式橋墩







PC箱型梁、施工性、節減材料、減輕自重 → 直柱式中空設計

- 基礎須滿足塑鉸發生後之彎矩
- 避免柱尺寸過大影響塑鉸發生
- 滿足承接上構尺寸之幾何需求

→ 縮小墩柱尺寸 採擴頭式設計

計畫目標與理念

計畫目標

國道橋梁：生命線路網

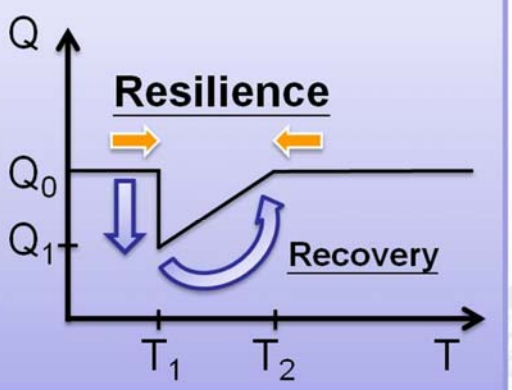
地震侵襲
減少損害、避免傷亡

高安全性
基礎交通建設

中度地震-不壞、設計地震-可修
、最大考量地震-不倒

防災韌性理念
Disaster Resilient Lifelines

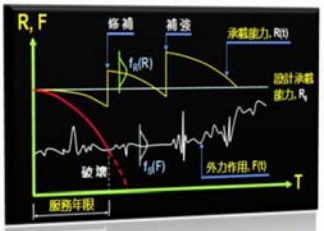
提昇橋梁地震恢復力
Seismic Resilient Bridge



永續思維與作法

全球氣候變遷

生命週期理念



Safer Bridge
山-橋-河共治，確保安全

Faster Bridge
補強更快速
施工更安全

Better Bridge
創新工程技術
友善生態環境

多重防災策略

「山・橋・河」共治理念

山 鄰近橋址順向邊坡

→ 與國道邊坡補強計畫整合

橋 橋梁耐震補強方案

→ 避免增加邊坡擾動與載重

河 高沖刷潛勢之河川

—般沖刷+束縮沖刷+局部沖刷

→ 地震力+50%最大沖刷深度

「山・橋・河」共治理念

預力地錨揚起試驗

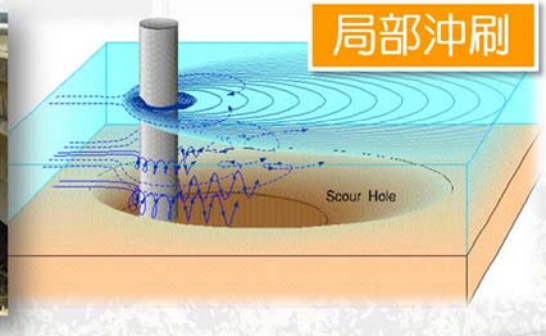
鋼鍵內視鏡檢測

鋼鍵銹蝕狀況

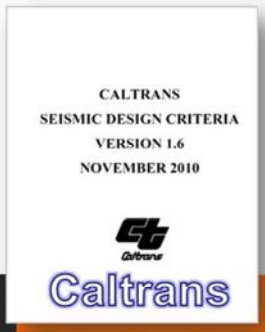
莫拉克風災之啟示

暴雨集中

飄流物掛淤



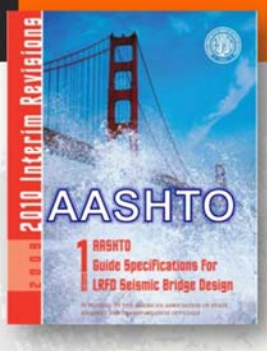
國道橋梁之耐震補強性能標準



耐震補強標準
服務年限50年

Life Line

國道定位：生命線救災道路



補強基本對策

① 系統補強

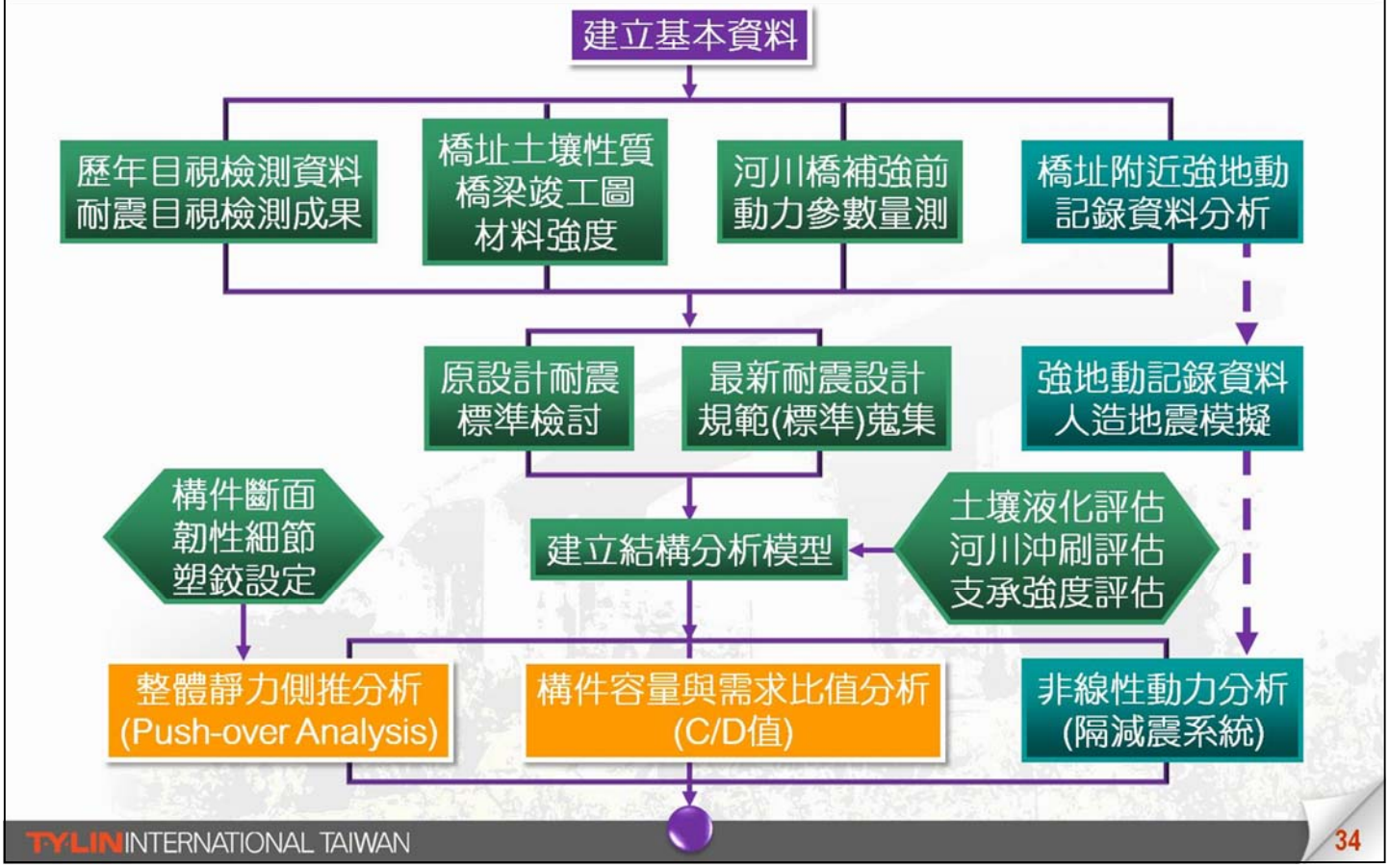
② 構件補強

③ 增加構件

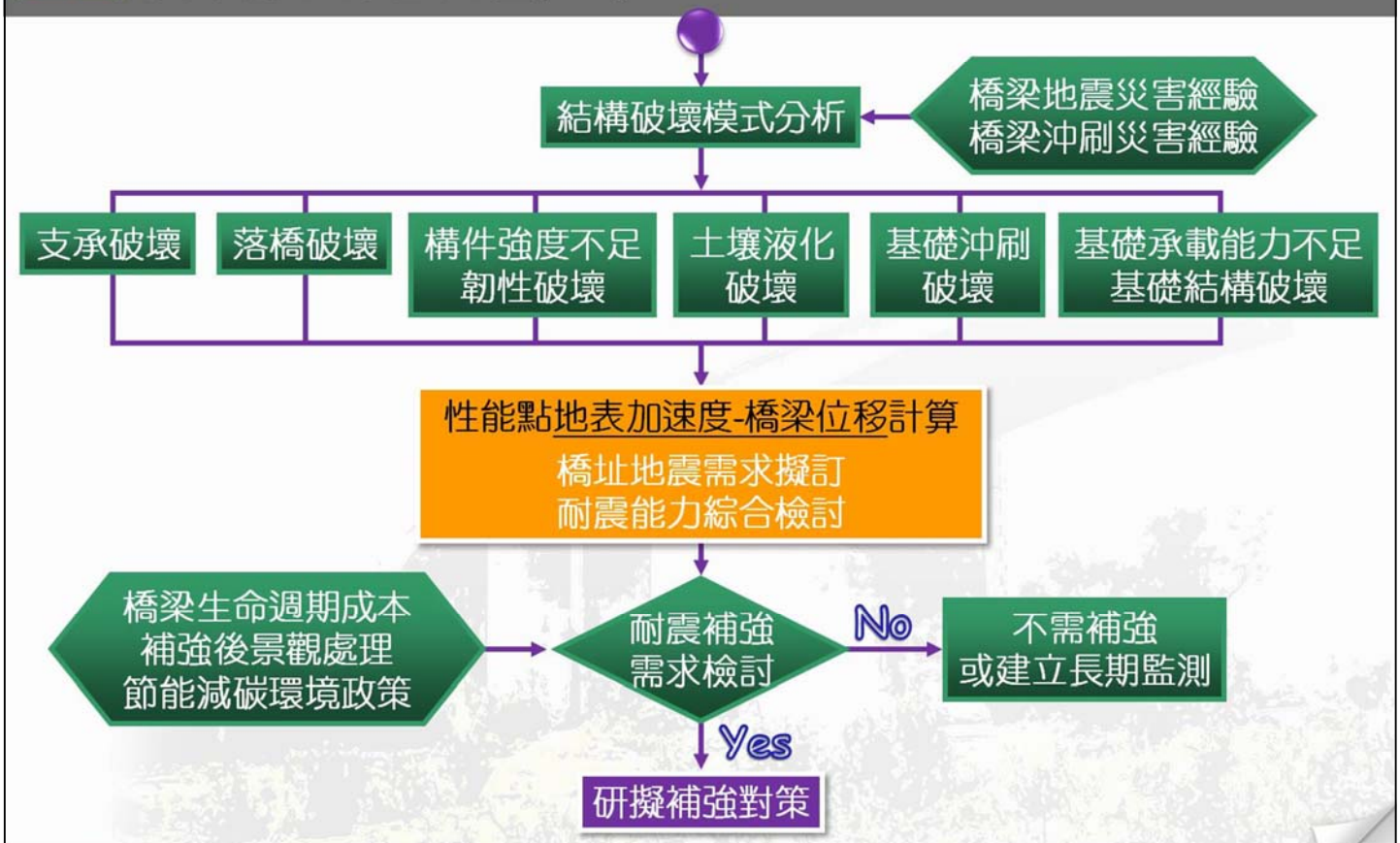
耐震性能準則(Seismic Performance Criteria)

地震力等級	工址水平譜加速度係數		耐震理念	服務性能	損壞等級
中度地震 回歸期：30年	依行政區劃分		結構保持彈性	震後 正常通行	輕 微
	回歸期475年地震之1/3.25				
設計地震 回歸期：475年 50年超越機率: 10%	依行政區劃分		構件產生塑鉸發揮容許韌性容量	震後 有限通行	可修復
	S_S^D	0.80、0.70、0.60、0.50			
	S_1^D	0.45、0.40、0.35、0.30			
最大考量地震 回歸期：2500年 50年超越機率: 2%	依行政區劃分		結構韌性容量完全發揮，但橋梁避免落橋、崩塌	震後 緊急通行	嚴 重
	S_S^M	1.00、0.90、0.80、0.70			
	S_1^M	0.55、0.50、0.45、0.40			

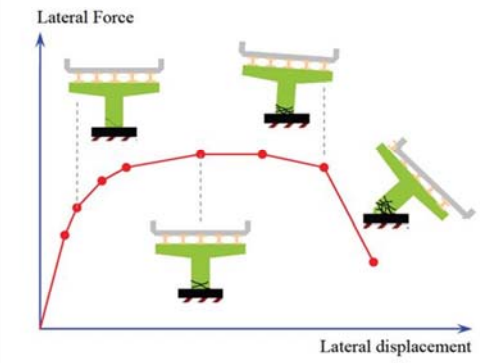
橋梁耐震評估流程(1/2)



橋梁耐震評估流程(2/2)



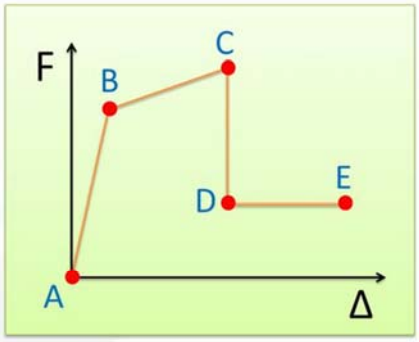
Freeway Bridge Seismic Evaluation



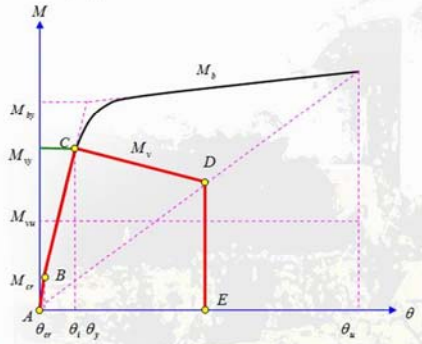
Pushover Analysis

Characteristics of plastic hinge for RC member

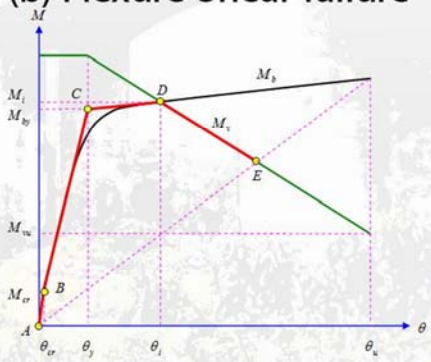
M3-hinge model in SAP2000



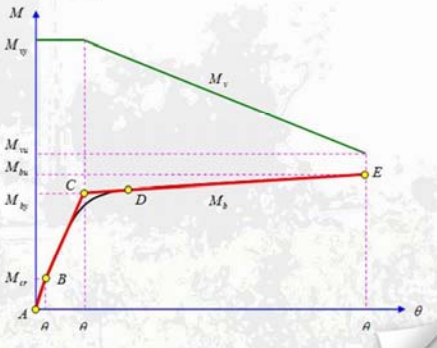
(a) Shear failure



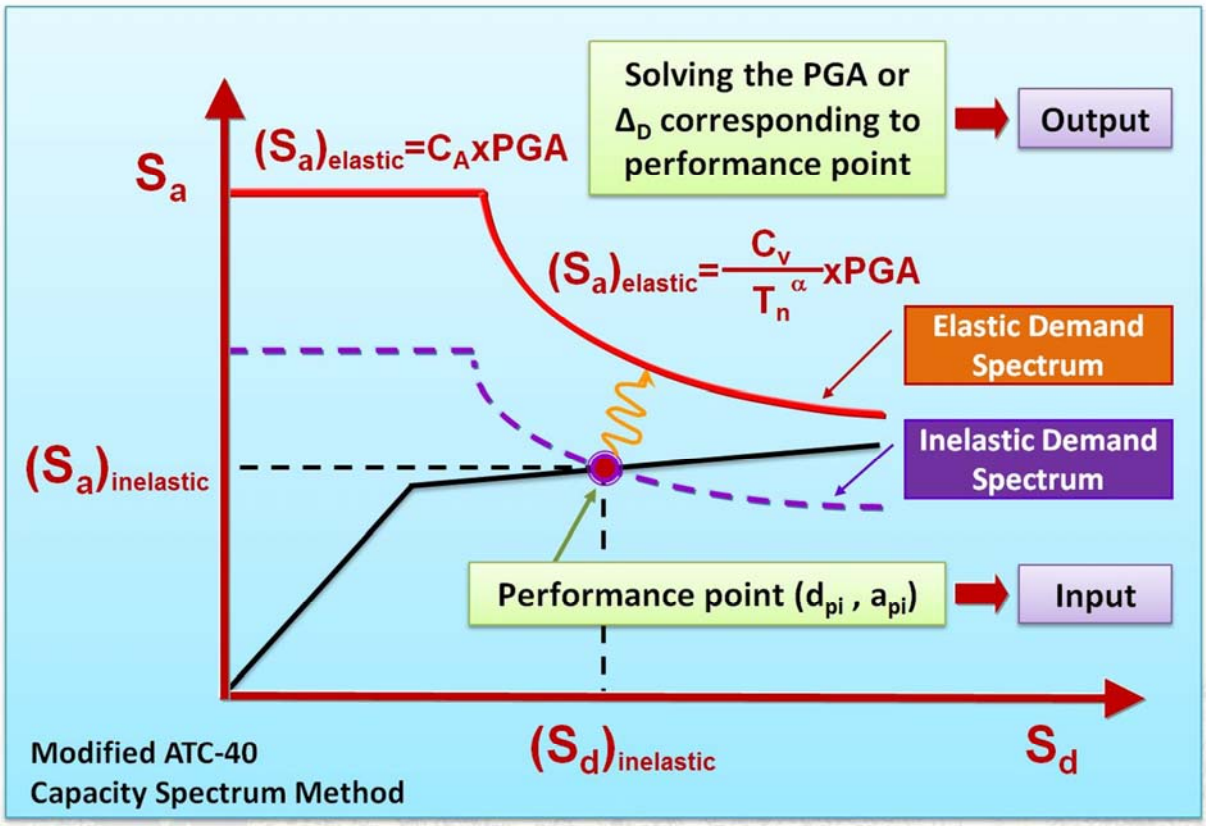
(b) Flexure-Shear failure



(c) Flexure failure



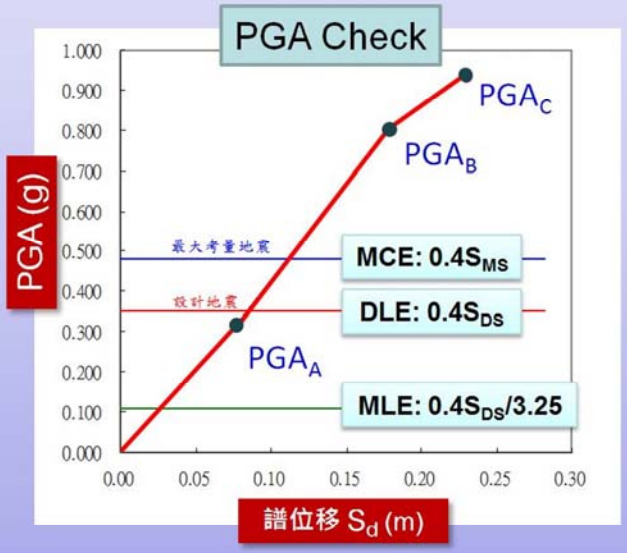
Freeway Bridge Seismic Evaluation

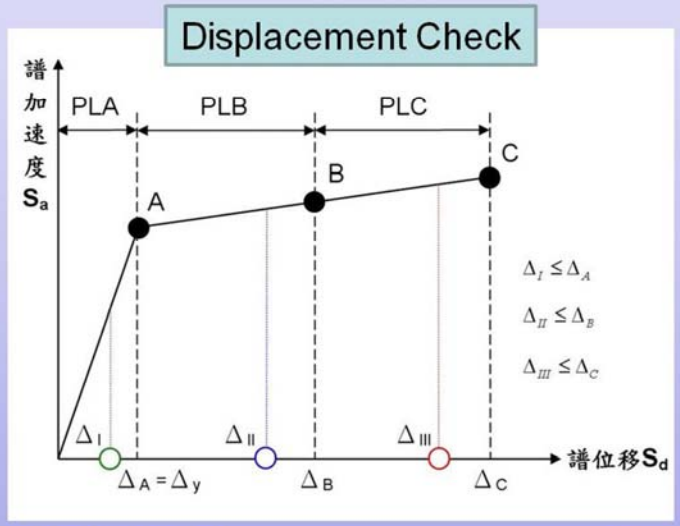


Freeway Bridge Seismic Evaluation

Seismic check for qualification requirement

$PGA_{Demand} < PGA_{Capacity}$ $\quad \Delta_{Demand} < \Delta_{Capacity}$

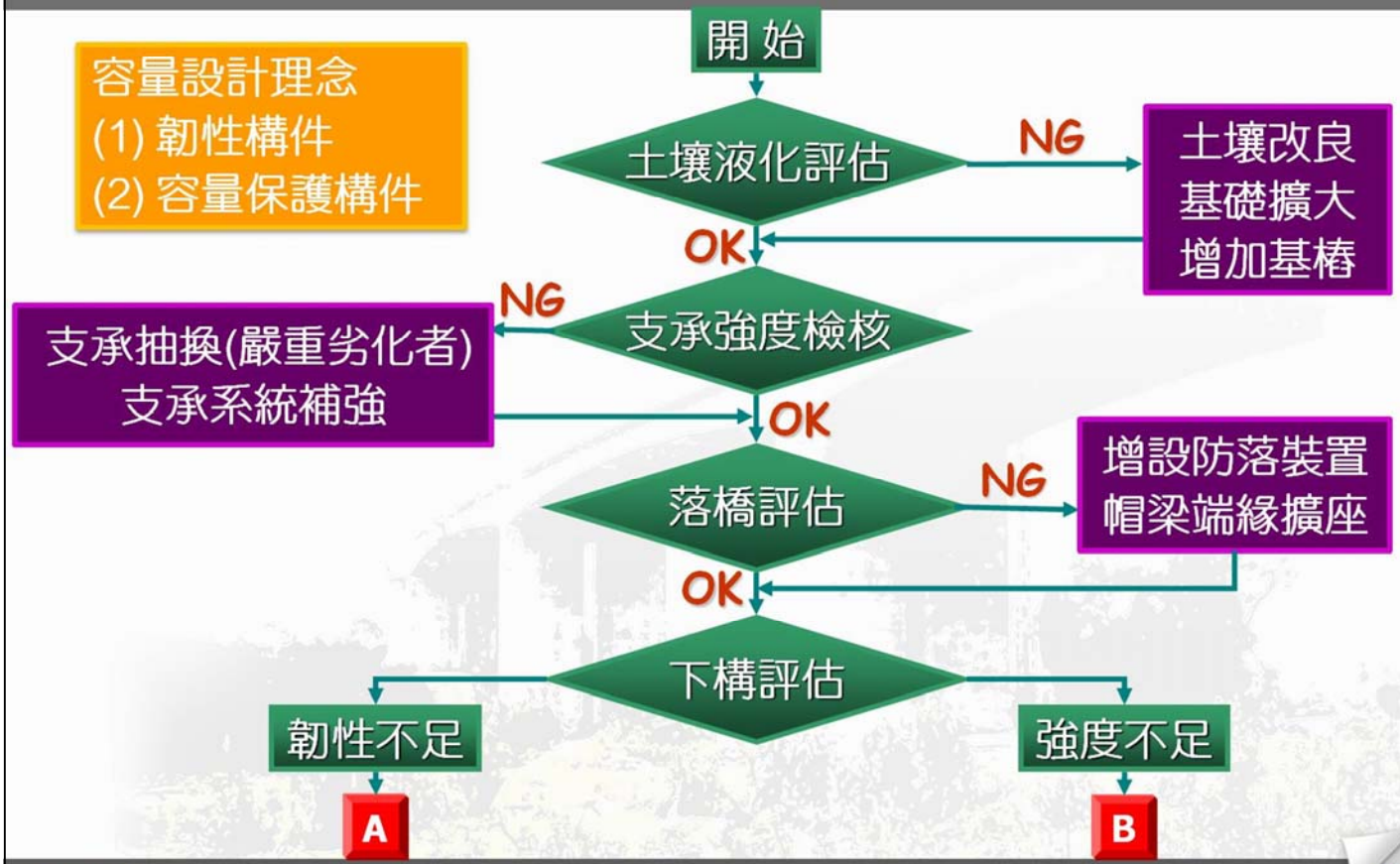




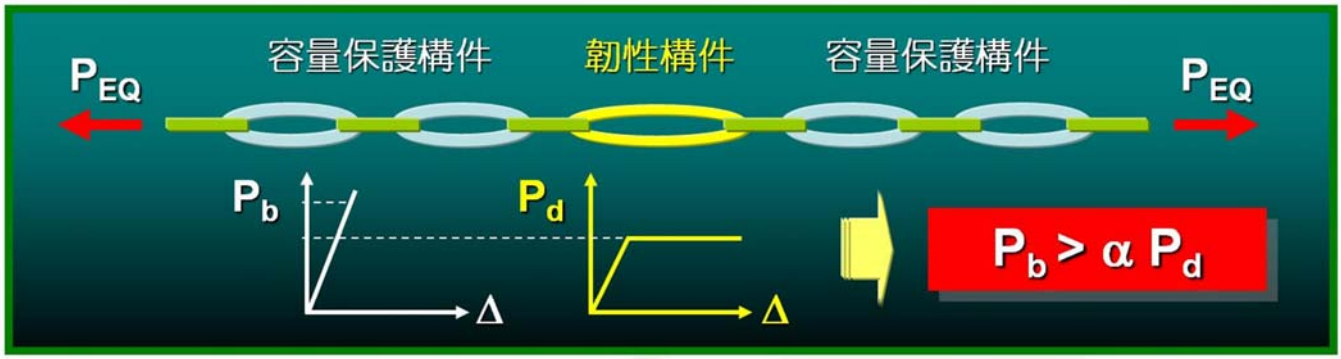
AASHTO/Caltrans : $\Delta_{Demand} = \Delta_{Elastic} \times R_d$

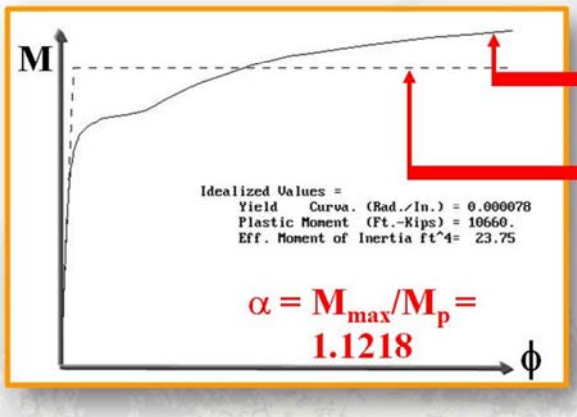
土壤液化、支承及落橋補強對策

容量設計理念
(1) 韌性構件
(2) 容量保護構件



容量設計理念



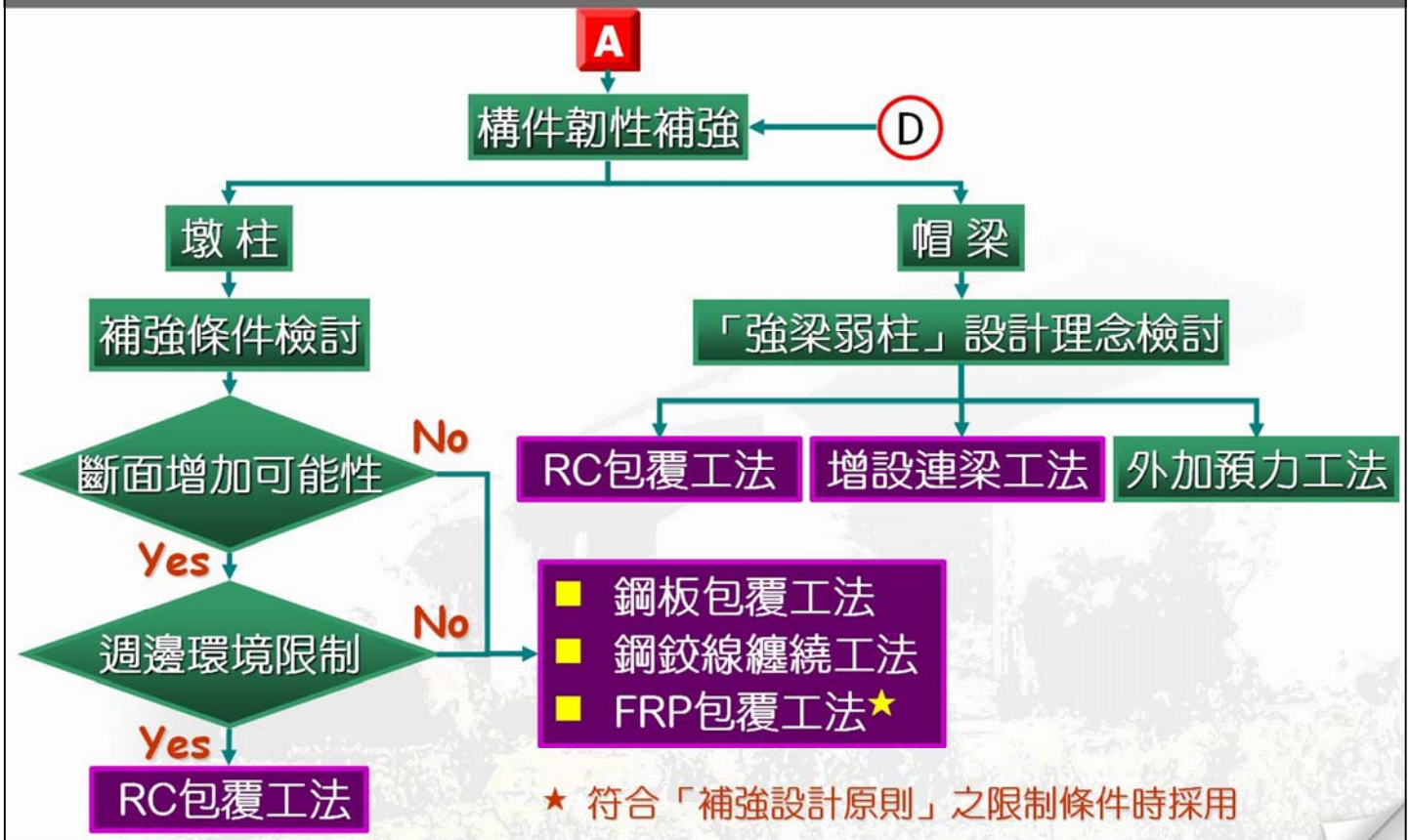


最大彎矩 M_{max}

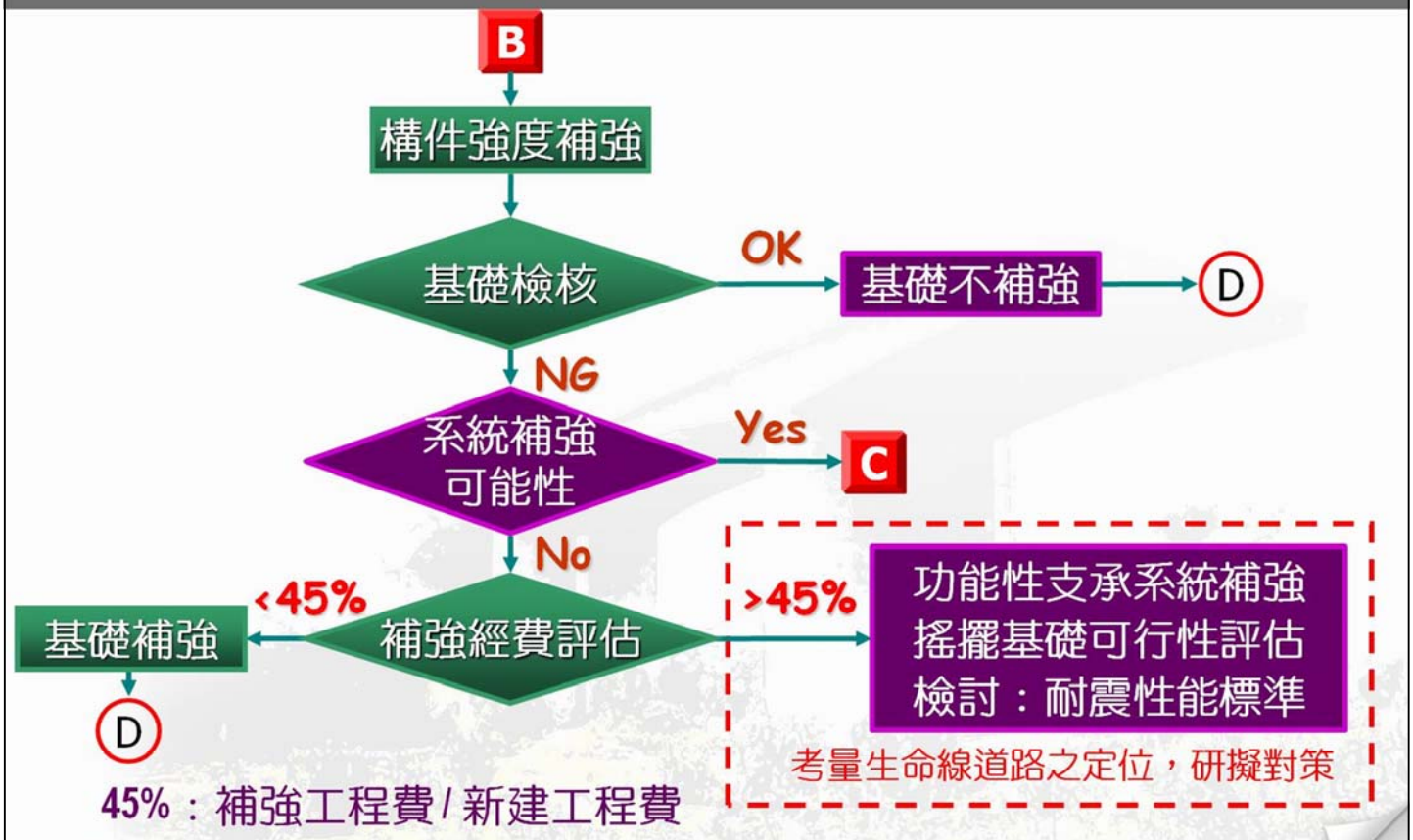
塑鉸彎矩 M_p

◀ 中山高大林新營段評估案例

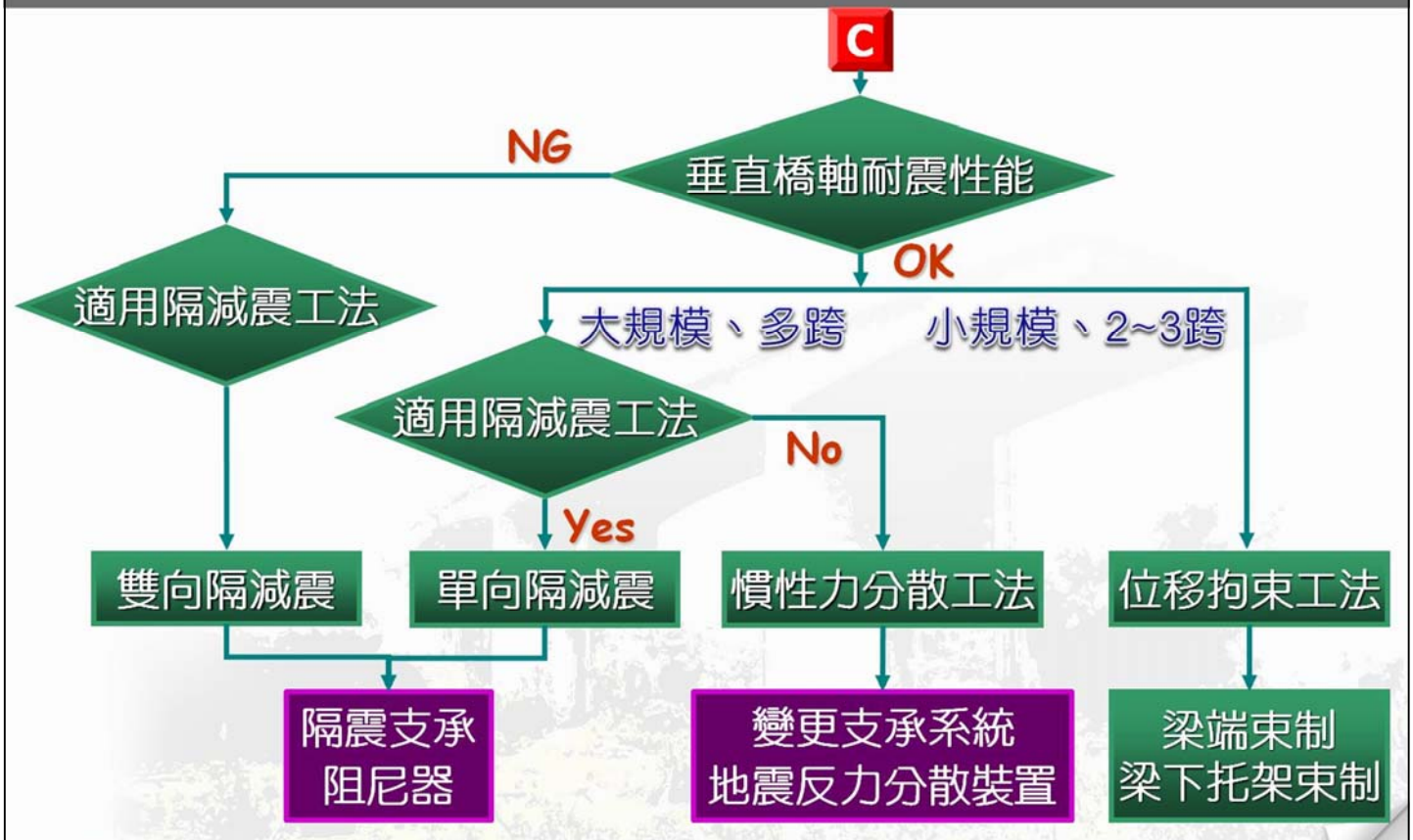
橋柱及帽梁補強對策



基礎補強對策



系統補強對策



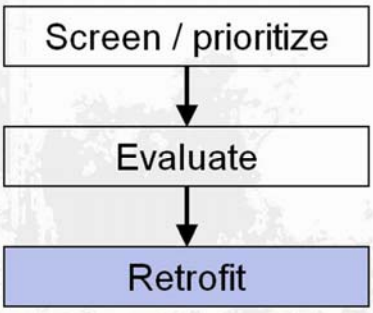
Freeway Bridge Seismic Retrofit

Retrofit Strategy

- One or more approaches used together to achieve desired level of improvement in performance
- Partial or full replacement
- Do-nothing (retrofitting not justified)

Retrofit Approaches

- Strengthening
- Displacement capacity enhancement
- Force limitation
- Response modification
- Site remediation
- Partial replacement
- Damage acceptance or control



Bearing seat extension, restrainer and shear key

Seismic Restrainer

Bearing seat extension and RC shear key

Bearing RC shear key

Longitudinal & transverse steel aseismic device

Concrete, Steel and FRP jacketing for columns



Concrete jacketing (rectangular/circular column)

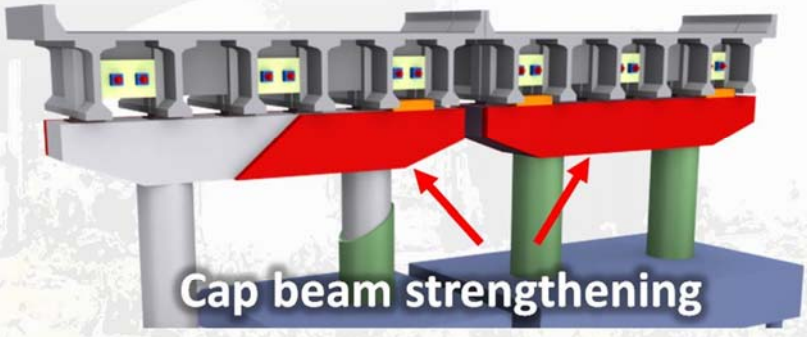
CFRP jacketing



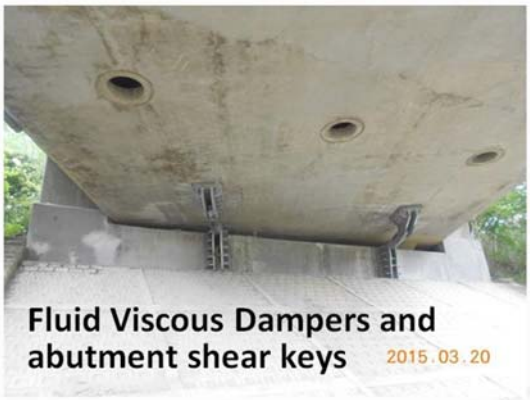
Steel jacketing and welding inspection

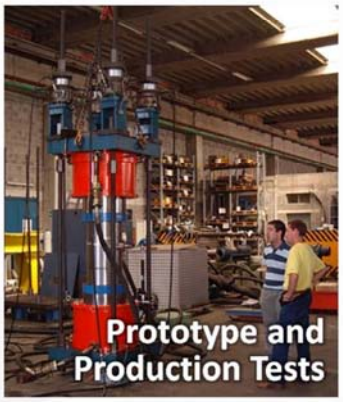
Steel jacketing construction

Cap beam strengthening and link beam in bents

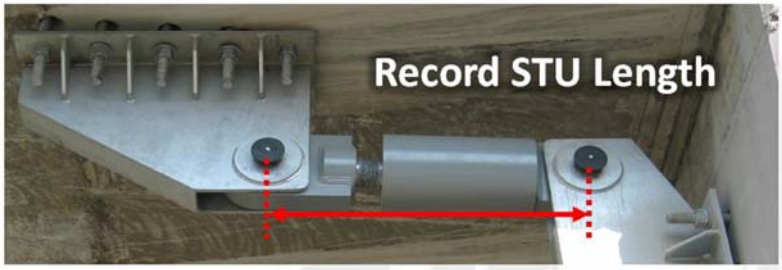



Fluid Viscous Damper & Shock Transmission Unit





FVDs and STUs Inspection and Maintenance



Footing retrofit and replacement

Footing retrofit with supplemental piles (CIDH, CISS piles)

High-Capacity Micropile

Steel jacketing on scoured piles and riverbed protection

3 結構系統補強技術

結構系統補強技術之應用

液態黏滯性阻尼器
(Fluid Viscous Damper)

- 降低地震受力，減少基礎補強
- 維持主線交通，控制補強經費


安坑交流道(匝道5)跨越橋


安坑交流道(匝道6)跨越橋

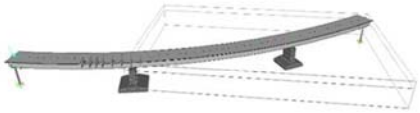

安坑交流道連絡道跨越橋


鳳山溪河川橋


頭前溪河川橋

$F = C|V|^{\alpha}\,\mathrm{sgn}(V)$

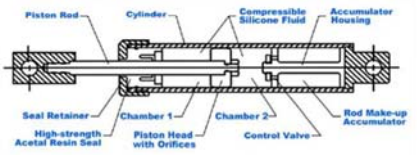
橋梁結構分析模型


安坑交流道(匝道5)跨越橋


安坑交流道(匝道6)跨越橋

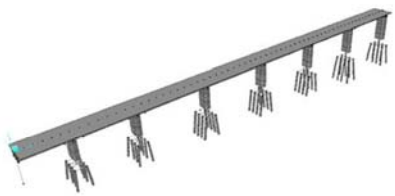

安坑交流道連絡道跨越橋


鳳山溪河川橋



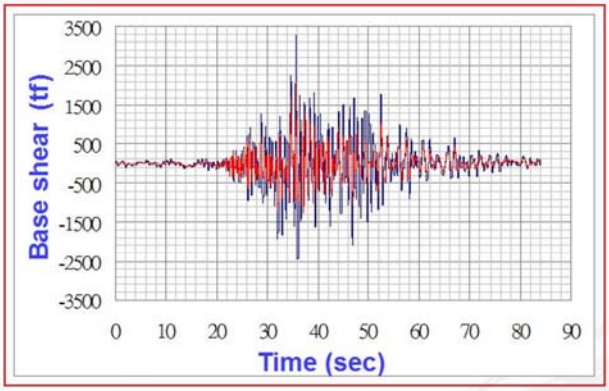
$F = C|V|^{\alpha}\,\mathrm{sgn}(V)$

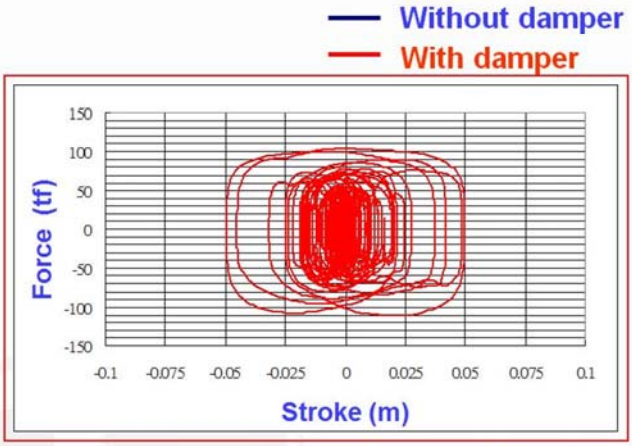
阻尼指數α = 0.1~0.5

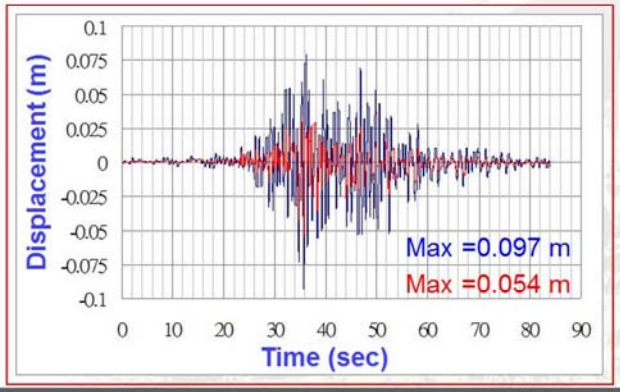

頭前溪河川橋

安坑交流道(匝道5)跨越橋 - 歷時分析結果

減震效益



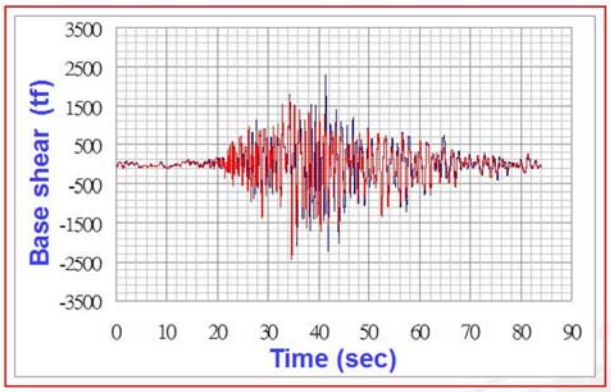


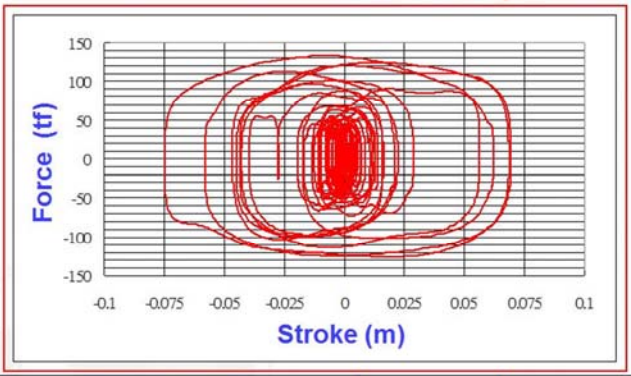


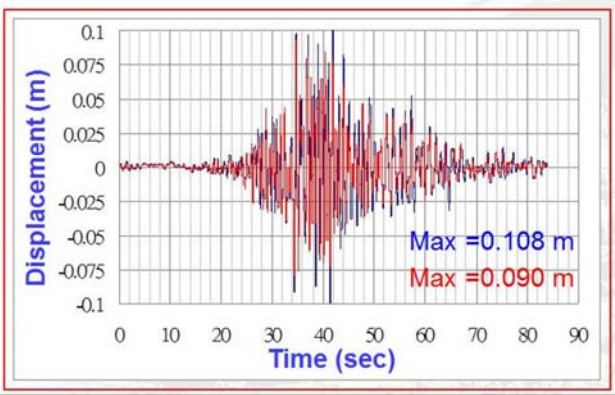
橋墩柱剪力		P1	P2
TAP033	增設阻尼器 原始結構	59%	47%
TAP034	增設阻尼器 原始結構	52%	47%
TAP053	增設阻尼器 原始結構	55%	45%

安坑交流道(匝道6)跨越橋 - 歷時分析結果

減震效益



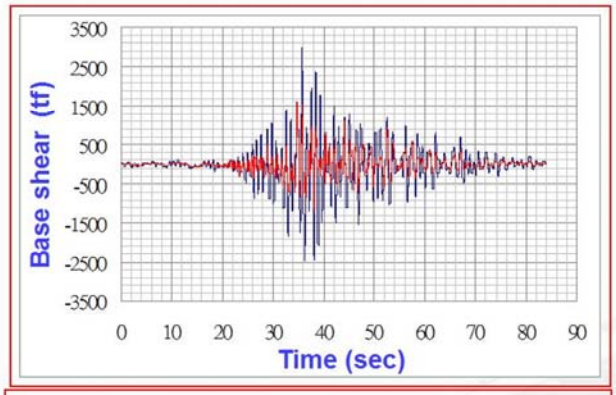


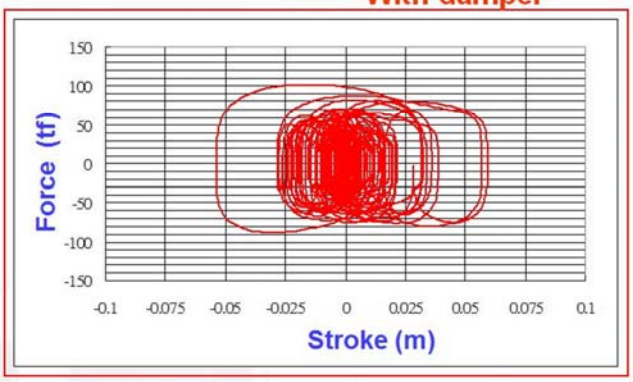


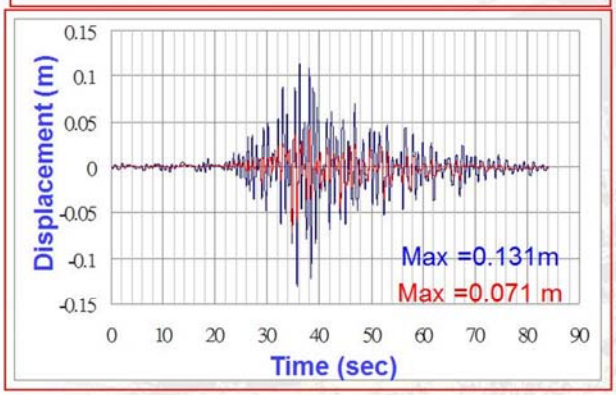
橋墩柱剪力		P1	P2
TAP033	增設阻尼器 原始結構	66%	63%
TAP034	增設阻尼器 原始結構	56%	52%
TAP053	增設阻尼器 原始結構	60%	60%

安坑交流道連絡道跨越橋 - 歷時分析結果

■ 減震效益







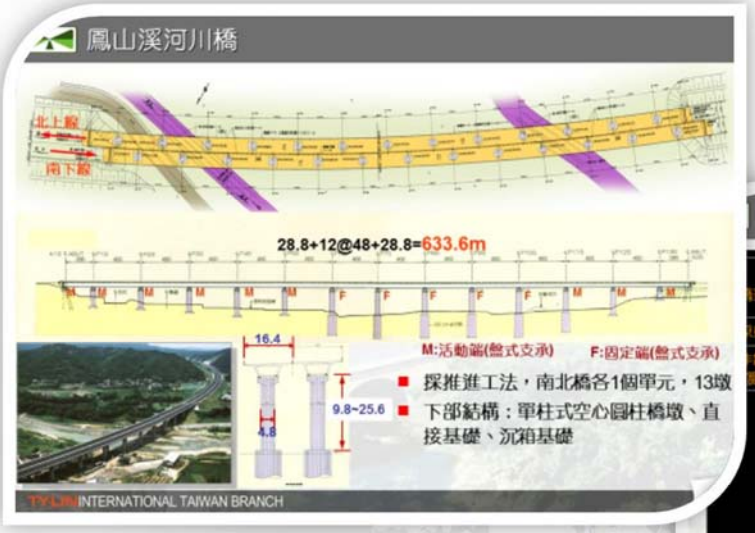
橋墩柱剪力		P1	P2
TAP033	增設阻尼器 原始結構	57%	76%
TAP034	增設阻尼器 原始結構	35%	79%
TAP053	增設阻尼器 原始結構	49%	88%

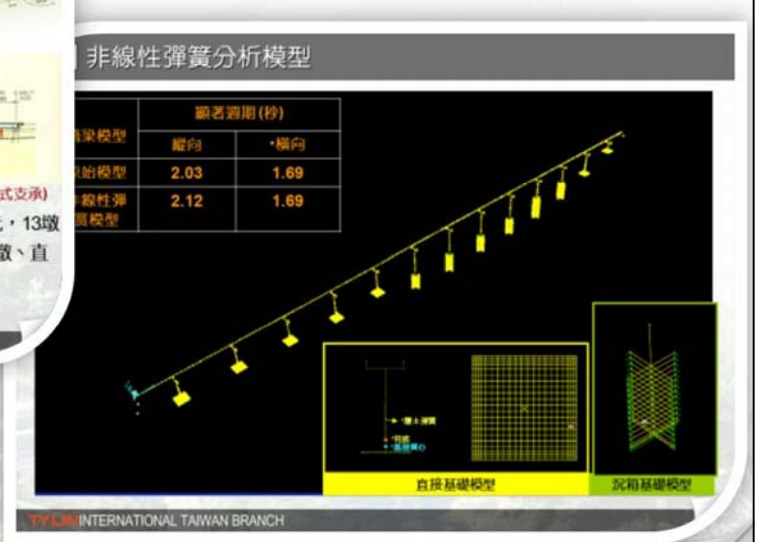
4 基礎非線性評估技術

基礎非線性評估技術

鳳山溪河川橋 (案例)

非線性彈簧應用 - 沉箱基礎及直接基礎



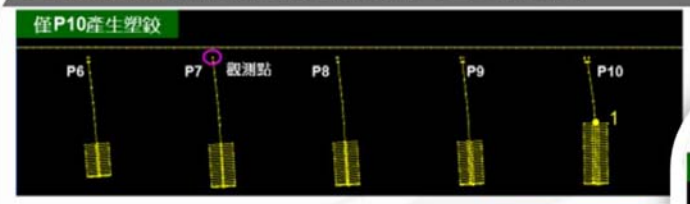


鳳山溪河川橋 (案例)

整體橋梁側推分析成果

耐震能力評估結果-強度韌性分析（垂直行車向）

僅P10產生塑鉸



耐震性能標準		耐震需求(地表加速度,g)	耐震容量(地表加速度,g)	C/D
中度地震等級	SP1	0.108	0.279	2.58
設計地震等級	SP2	0.352	0.411	1.17
最大考量地震等級	SP3	0.480	0.436	0.91

縱向強度韌性不足

穩定性評估P-Delta Effect △=0.2*Mu/P=2.01 m

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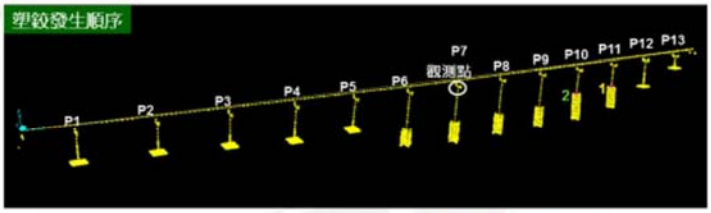
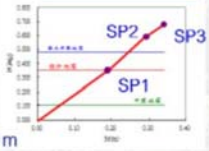
耐震能力評估結果-強度韌性分析（垂直行車向）

塑鉸發生順序



耐震性能標準		耐震需求(地表加速度,g)	耐震容量(地表加速度,g)	C/D
中度地震等級	SP1	0.108	0.347	3.20
設計地震等級	SP2	0.352	0.585	1.66
最大考量地震等級	SP3	0.480	0.676	1.41

橫向強度韌性足夠



穩定性評估P-Delta Effect △=0.2*Mu/P=3.39 m

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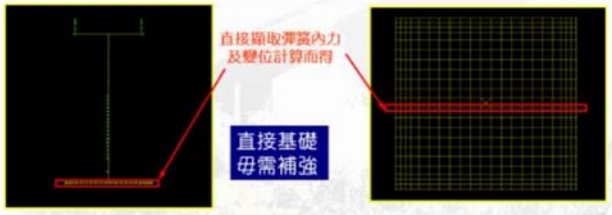
鳳山溪河川橋 (案例)

橋梁基礎評估成果

耐震能力評估結果

■ 直接基礎穩定性評估

橫向	P1	P2	P3	P4	P5	P12	P13
最大變位(m)	-0.015	-0.022	-0.026	-0.030	-0.037	-0.013	-0.011
接觸面積	1	0.764	0.597	0.533	0.445	1	1
土壓降伏比	0.000	0.000	0.000	0.000	0.000	0.000	0.000
評估結果	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.



直接擷取彈簧內力及變位計算而得

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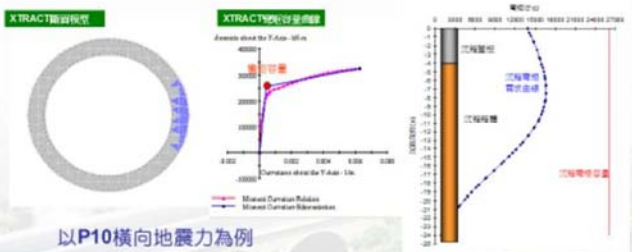
耐震能力評估結結果

■ 沉箱結構強度評估



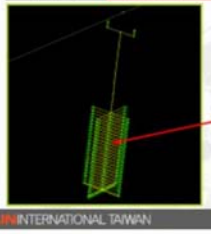
以P10橫向地震力為例

容量>需求=>O.K.

耐震能力評估結果

■ 沉箱基礎穩定性評估（>0.6為N.G.）

沉箱評估	P6	P7	P8	P9	P10	P11
側面土壓降伏比（縱向）	0.85	0.82	0.82	0.82	0.59	-
側面土壓降伏比（橫向）	0.77	0.71	0.71	0.65	0.38	0.45
評估結果	N.G.	N.G.	N.G.	N.G.	O.K.	O.K.



直接擷取彈簧內力及變位計算而得

橋墩P6~P9受沖刷影響，穩定性不足

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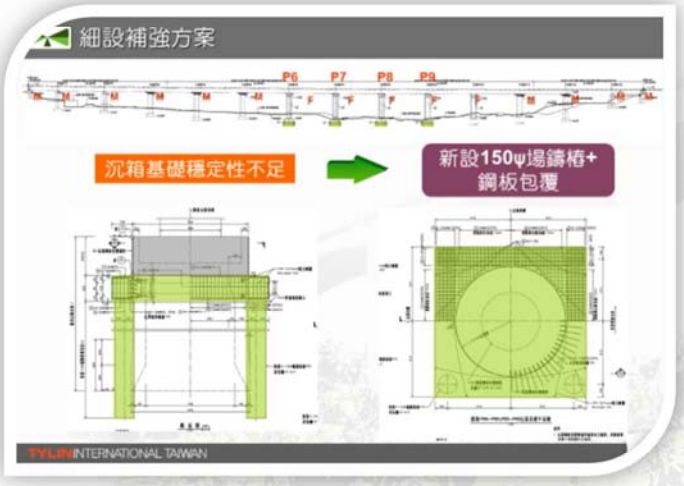
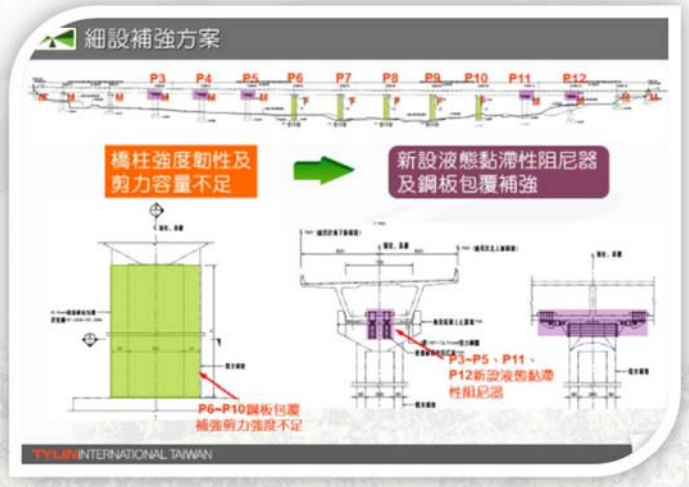
鳳山溪河川橋 (案例)

橋梁耐震補強策略

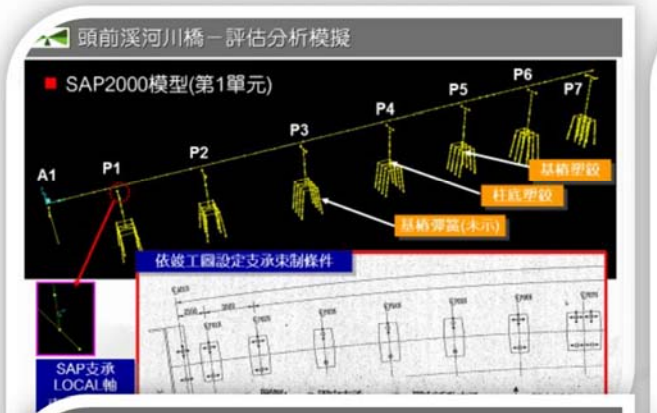
- 增設液態黏滯性阻尼器：有效提升整體橋梁耐震性能
- 深槽區橋墩：沉箱基礎沖刷補強 + 橋柱鋼板包覆補強

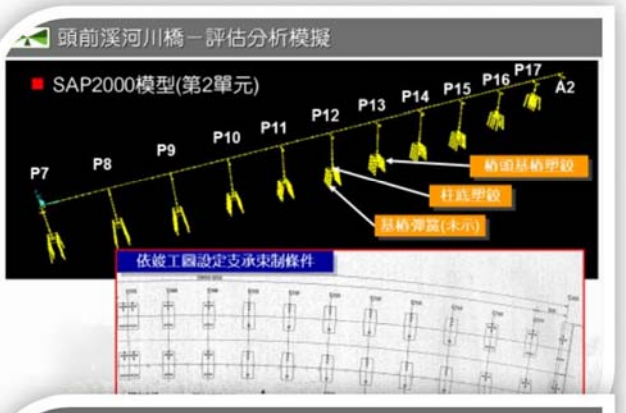


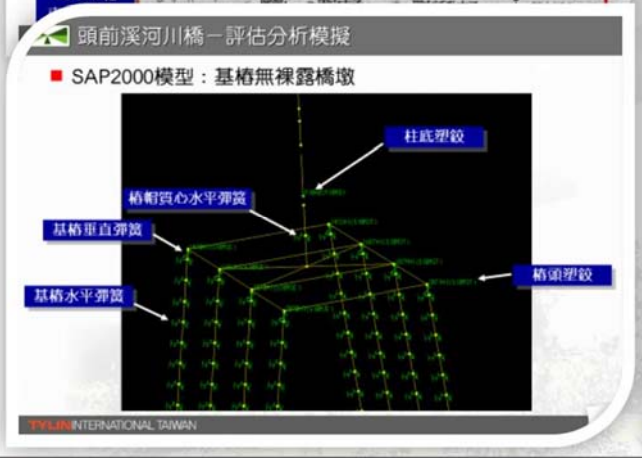


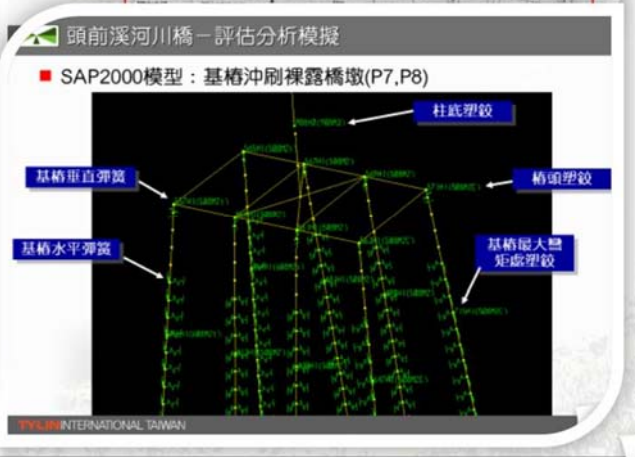
頭前溪河川橋 (案例)

非線性分析模型







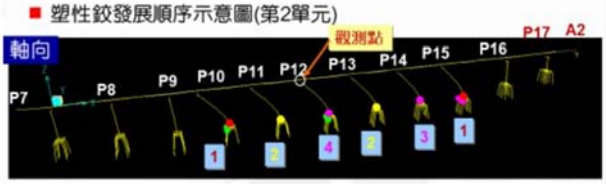


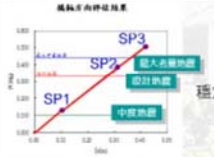
頭前溪河川橋 (案例)

以第二單元為例

頭前溪河川橋－橋柱強度韌性評估

■ 塑性鉸發展順序示意圖(第2單元)





				C/D
平面地震單元	SP1	0.103	0.126	1.22
設計地震單元	SP2	0.336	0.385	1.14
最大考量地震單元	SP3	0.440	0.511	1.16

穩定性評估P-Delta Effect △=0.2*Mu/P =1.74 m

➡ 軸向強度韌性足夠

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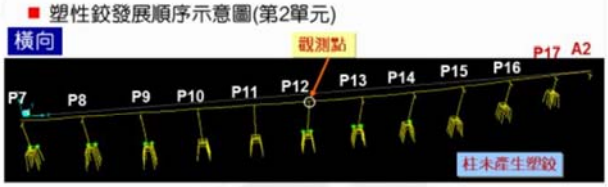
頭前溪河川橋－橋柱強度韌性評估

■ 塑性鉸發展順序示意圖(第2單元)



				C/D
平面地震單元	SP1	0.103	0.181	1.75
設計地震單元	SP2	0.336	0.437	1.30
最大考量地震單元	SP3	0.440	0.555	1.26

穩定性評估P-Delta Effect △=0.2*Mu/P =2.39 m

➡ 橫向強度韌性足夠

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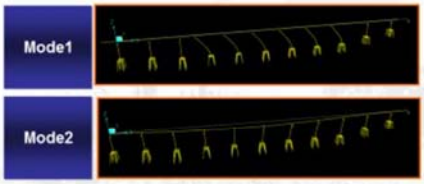
■ 模型週期

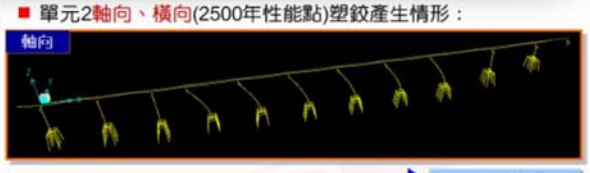
❖ 第2單元

方向	模態	顯著週期
		橋柱勁度0.5EI
軸向	Mode1	3.03
橫向	Mode2	1.68



TYLININTERNATIONAL TAIWAN

■ 單元2軸向、橫向(2500年性能點)塑鉸產生情形：



➡ 基樁皆未產生塑鉸

➡ P7~P9、P12~P14樁頭拉力側產生塑鉸

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頭前溪河川橋 (案例)

評估成果

頭前溪河川橋—基樁檢核

■ 單元2軸向(2500年性能點力量)

樁頭處

立承	樁號	軸拉	M	V	塑鉸My	C/D	檢核	軸壓	M	V	塑鉸My	C/D	檢核
F	P10	6	432	34	667	1.54	OK	-780	678	84	741	1.09	OK
F	P11	48	381	32	657	1.72	OK	-824	591	35	837	1.42	OK
F	P12	29	393	38	652	1.66	OK	-765	653	98	715	1.09	OK
F	P13	37	392	38	660	1.68	OK	-812	620	47	763	1.23	OK
F	P14	53	381	40	656	1.72	OK	-833	599	29	806	1.35	OK
F	P15	37	401	55	638	1.59	OK	-824	652	61	731	1.12	OK

➡ 軸向樁頭檢核OK

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頭前溪河川橋—基樁檢核

■ 單元2橫向(2500年性能點力量)

樁頭處

立承	樁號	軸拉	M	V	塑鉸My	C/D	檢核	軸壓	M	V	塑鉸My	C/D	檢核
M	P7	506	177	61	60	0.34	NG(塑鉸後)	-1184	218	74	444	2.04	OK
M	P8	520	135	49	63	0.47	NG(塑鉸後)	-1242	153	58	448	2.94	OK
M	P9	482	210	50	63	0.30	NG(塑鉸後)	-1162	317	16	444	1.40	OK
F	P10	443	503	33	570	1.13	OK	-1124	449	121	871	1.94	OK
F	P11	564	469	61	539	1.15	OK	-1259	397	160	887	2.23	OK
F	P12	620	590	39	522	0.88	NG(塑鉸後)	-1301	516	149	892	1.73	OK
F	P13	732	573	57	491	0.86	NG(塑鉸後)	-1413	489	169	901	1.84	OK
F	P14	628	563	43	521	0.93	NG(塑鉸後)	-1327	492	144	895	1.82	OK
F	P15	362	492	13	587	1.19	OK	-1071	471	63	864	1.83	OK
M	P16	325	108	58	235	2.18	OK	-936	85	88	430	5.09	OK
M	P17	-14	65	32	202	3.11	OK	-648	64	32	302	4.70	OK

➡ P7~P9、P12~P14橫向樁頭檢核NG ➡ 樁頭鋼板包覆補強

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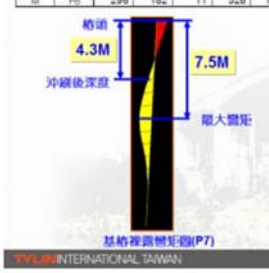
頭前溪河川橋—基樁檢核

■ 單元2橫向(2500年性能點力量)

最大彎矩處深7.5處(基樁裸露橋墩)

立承	樁號	軸拉	M	V	塑鉸My	C/D	檢核	軸壓	M	V	塑鉸My	C/D	檢核
M	P7	287	198	11	326	1.64	OK	-933	218	36	311	1.42	OK
M	P8	296	182	11	328	1.80	OK	-995	199	35	314	1.58	OK



➡ 最大彎矩處檢核OK

非線性模擬：
掌握基樁塑性鉸
發展順序及位置

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頭前溪河川橋—基樁檢核

■ 整理：基樁檢核結果

	軸向	橫向
單元1 (A1~P7)	O.K.	P7
單元2 (P7~A2)	O.K.	P7~P9、P12~P14

➡ 樁頭鋼板包覆補強

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5 CFRP包覆補強技術

CFRP包覆耐震補強

- M31標：共18墩

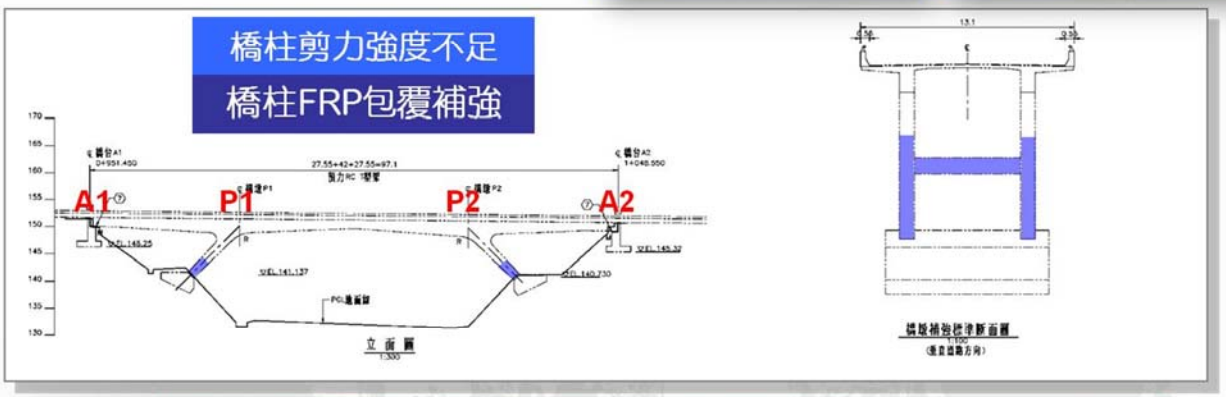
橋 名	里 程	補強墩數	補強原因
四分里坑高架橋N	17K+502	3	剪力
四分里坑高架橋S	17K+528	2	剪力
安坑溪橋N	32K+138	7	剪力
安坑溪橋S	32K+145	6	剪力

CFRP包覆耐震補強

■ M34標：雲南路跨越橋

橋柱剪力強度不足

橋柱FRP包覆補強



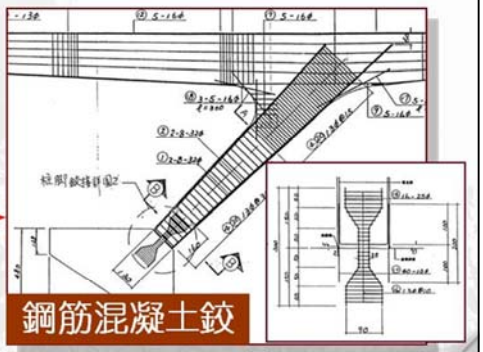
橋址位於敏感性邊坡，避免重機械施工擾動邊坡

傾斜橋墩，考量施工彈性及對高速公路影響最小

雲南路跨越橋 (耐震前)

■ 橋台

■ 橋墩



CFRP包覆耐震補強

減少斜柱補強增加之重量

降低景觀衝擊

降低主線交通維持之壓力

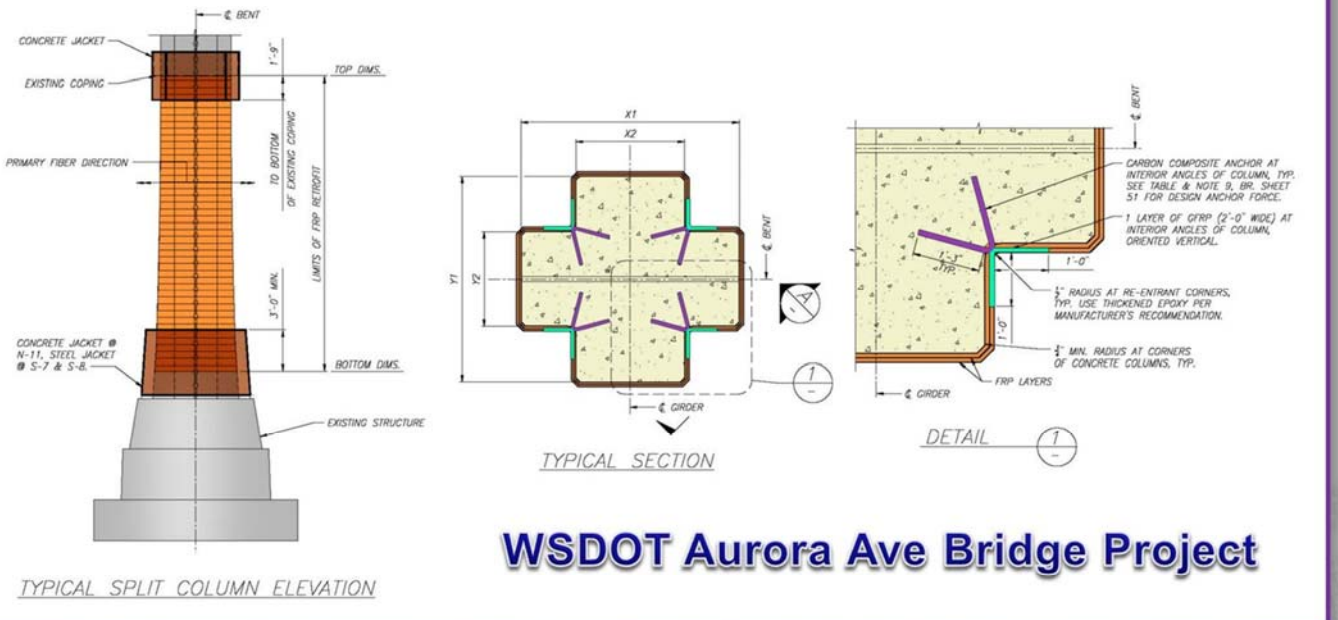
CFRP包覆耐震補強施工

施工流程

墩柱CFRP包覆補強

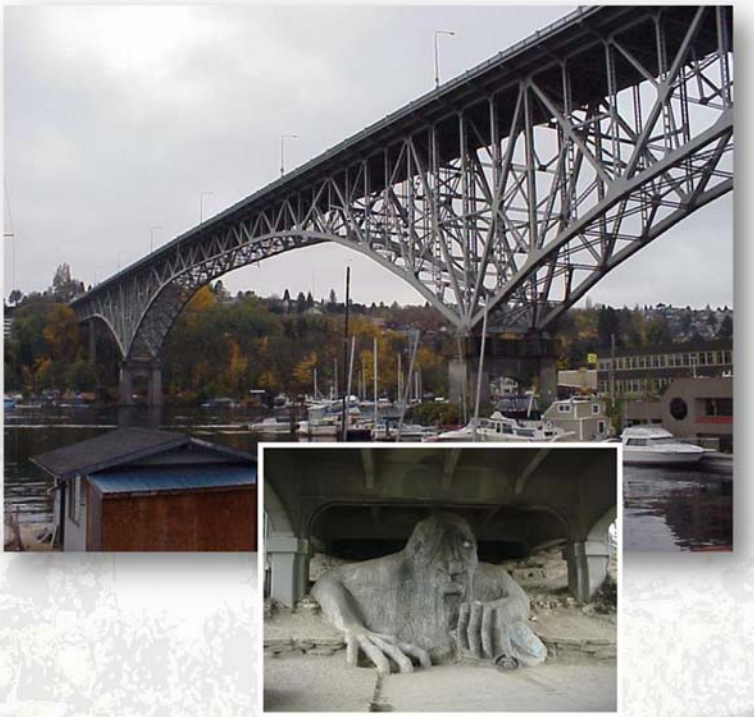
FRP包覆補強工法

- 十字造形(Cruciformu shape)橋柱FRP Anchor錨碇技術



WSDOT Aurora Ave Bridge Project

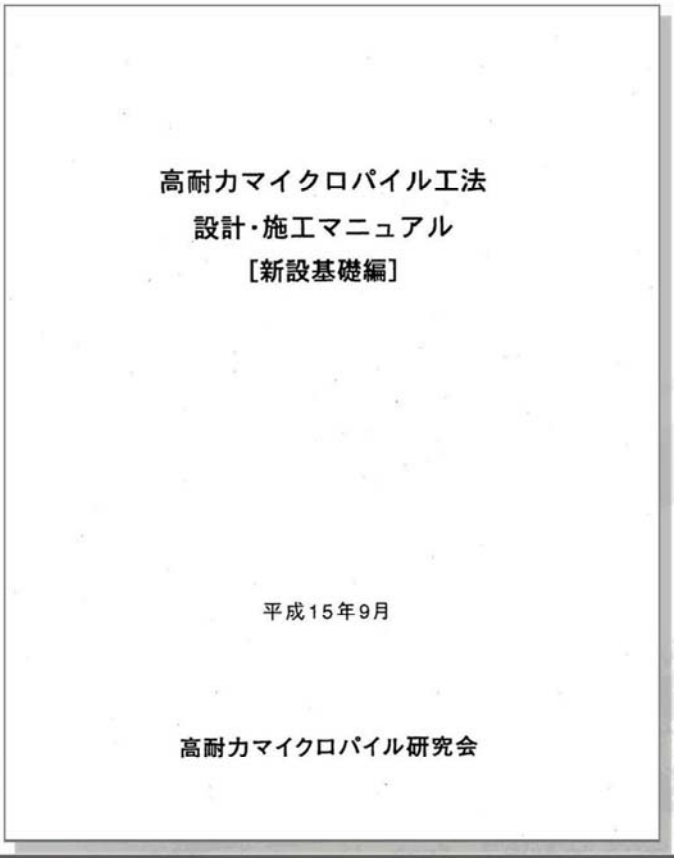
WSDOT Aurora Ave Bridge Project



6 高強度微型樁補強技術

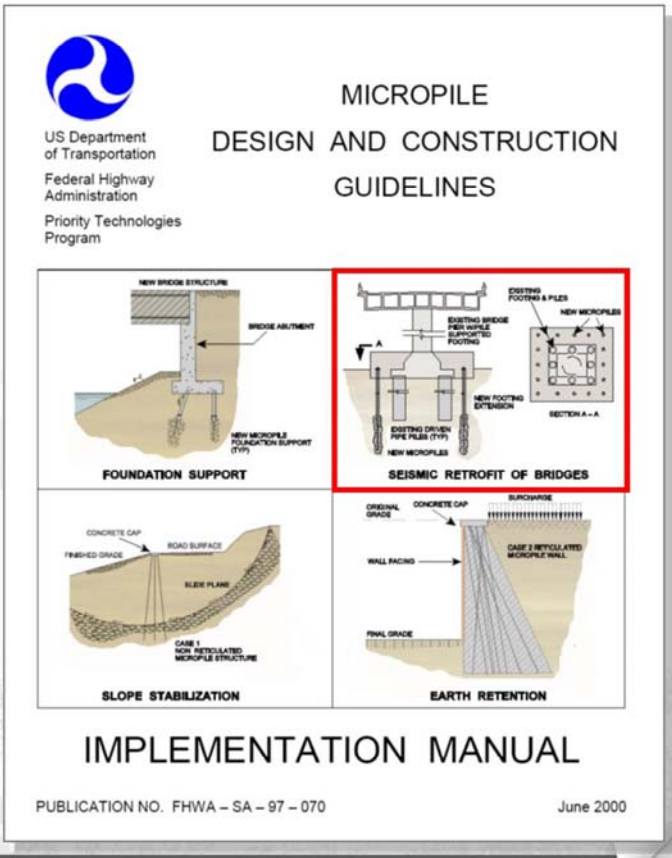
高強度微型樁 (High-Capacity Micropile)

- 本工程部份橋墩基礎考量施工空間限制與降低交通衝擊，採增設高強度微型樁補強
- 採用之高強度微型樁，於直徑約200~300mmϕ高強度鋼管(API鋼管)內，設置高拉力螺紋鋼棒(ASTM A722)，利用內部及底部之壓力灌漿，形成具抵抗拉力及壓力之高強度樁體
- 高強度微型樁已成功應用於美國加州及日本之基礎耐震補強工程，並已有設計施工手冊可供參考
  - 美國FHWA Micropile Design and Construction Guidelines Implementation Manual, 2000
  - 美國FHWA Micropile Design and Construction-Reference Manual, 2005
  - 日本「高耐力微型樁工法設計施工手冊」, 平成15年9月


高耐力マイクロパイル工法
設計・施工マニュアル
［新設基礎編］

平成15年9月

高耐力マイクロパイル研究会


US Department of Transportation
Federal Highway Administration
Priority Technologies Program

MICROPILE
DESIGN AND CONSTRUCTION
GUIDELINES

FOUNDATION SUPPORT

SEISMIC RETROFIT OF BRIDGES

SLOPE STABILIZATION

EARTH RETENTION

IMPLEMENTATION MANUAL

PUBLICATION NO. FHWA – SA – 97 – 070

June 2000

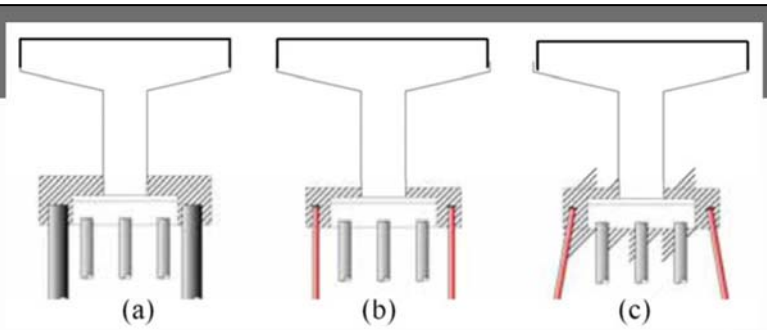
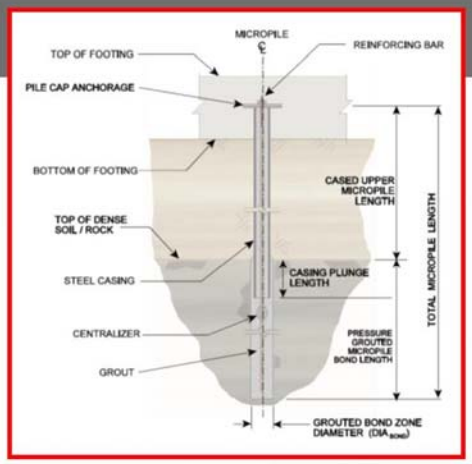


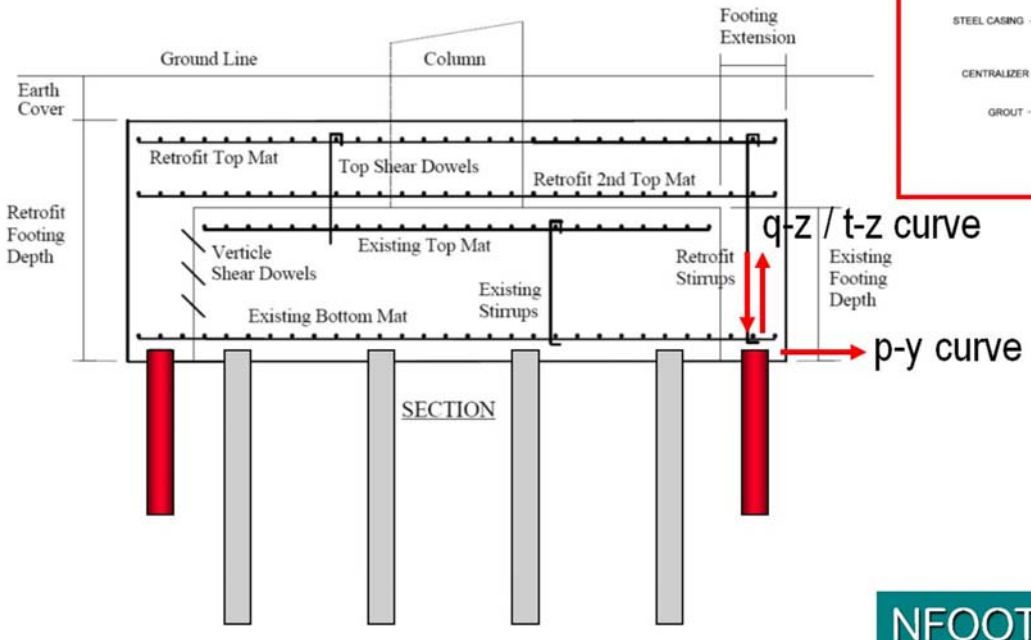
Table 11.2 Cost evaluation of retrofit using micro piles

Properties and cost	Cast-in-place piles	Straight micro piles	Inclined micro piles
Radius of piles	1000mm	178mm	178mm
Number of piles	8	26	14
Length of piles	16m	21m	21m
Cost of piles relative to cast-in-place piles	100%	90%	80%
Total cost of retrofit including dry-up and footing retrofit	100%	81%	72%
Construction period relative to cast-in-place piles	100%	80%	65%

FIB TG 7.4 Seismic Design and Assessment Procedure for Bridges 2005

基礎補強設計之非線性分析

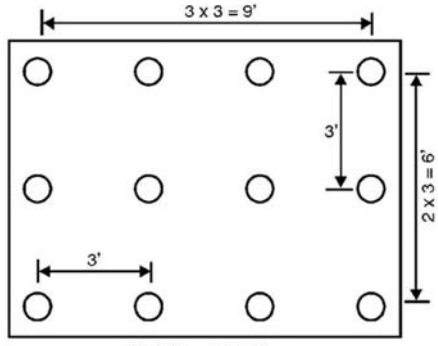




q-z / t-z curve

p-y curve

NFOOT程式



3 x4 Pile Footing

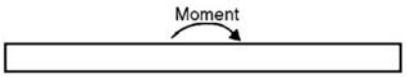
12 — 45-ton Concrete Piles

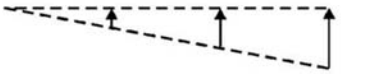
50-ft-long
12-in Concrete Pile
Embedded in
Uniform Medium Sand

Allowable Capacity
= 90 k/pile
Ultimate Compressive
Capacity = 180 k/pile

Ultimate Uplift
Capacity = 90 k/pile

Weight = 1,080 kips

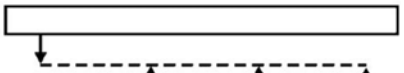




3 x 60 k = 180 k | 3 x 120 k =360 k | 3 x 180 k = 540 k

Conventional
Design Criterion

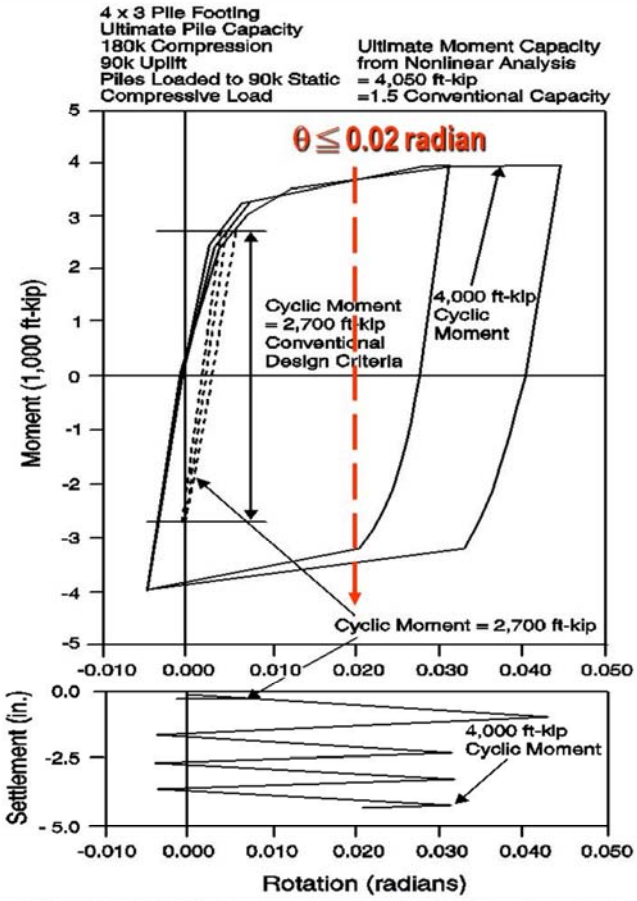
Moment Capacity
= 2,700 ft-kip



3 x -90 k = -270 k | 3 x 90 k = 270 k | 3 x 180 k = 540 k | 3 x 180 k = 540 k

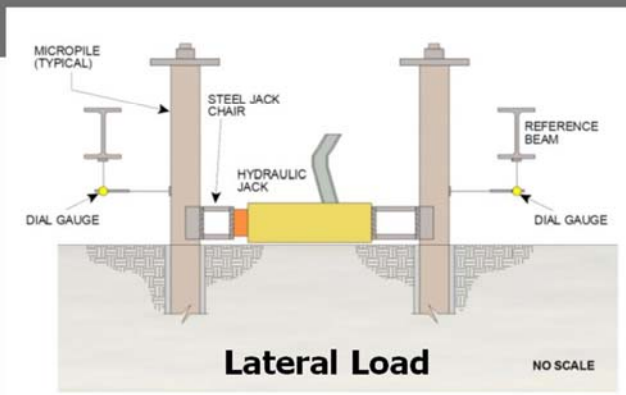
Ultimate Moment
Capacity from
Moment-Rotation
Analysis

Moment Capacity
= 4,050 ft-kip

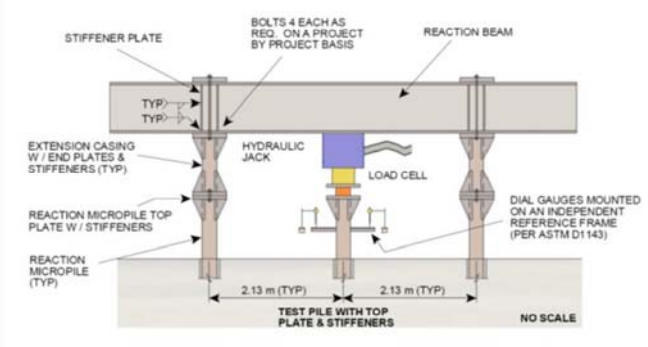


現場載重試驗 (Load Test)

- 確認試驗 (Verification Test)
- 驗收試驗 (Acceptance Test)

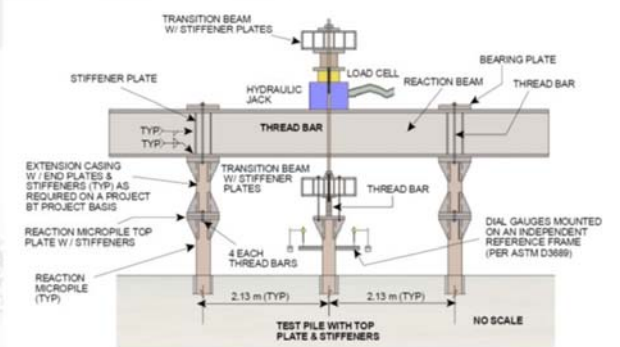


Compression Load (ASTM D1143)



Note: 2.13 m = 7 ft

Tension Load (ASTM D3689)

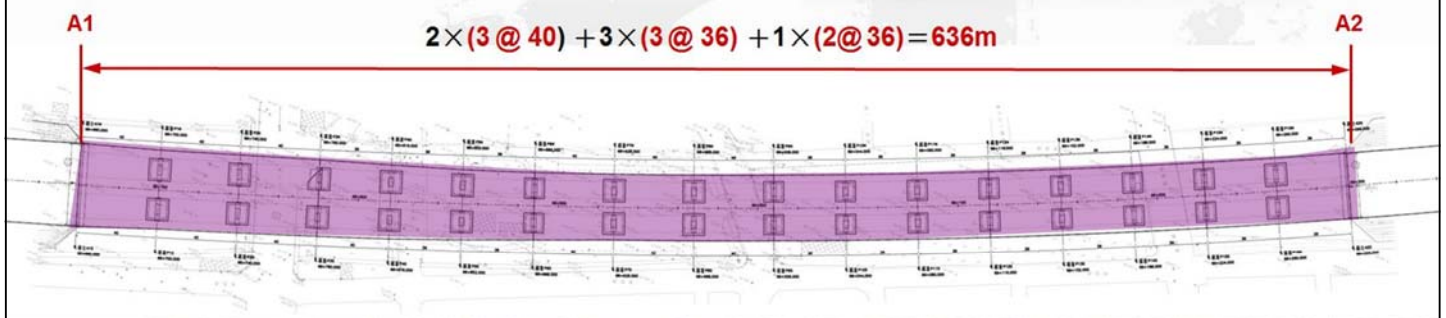


Note: 2.13 m = 7 ft

現場載重試驗 (Load Test)

龍潭高架橋 (直基補強案例)

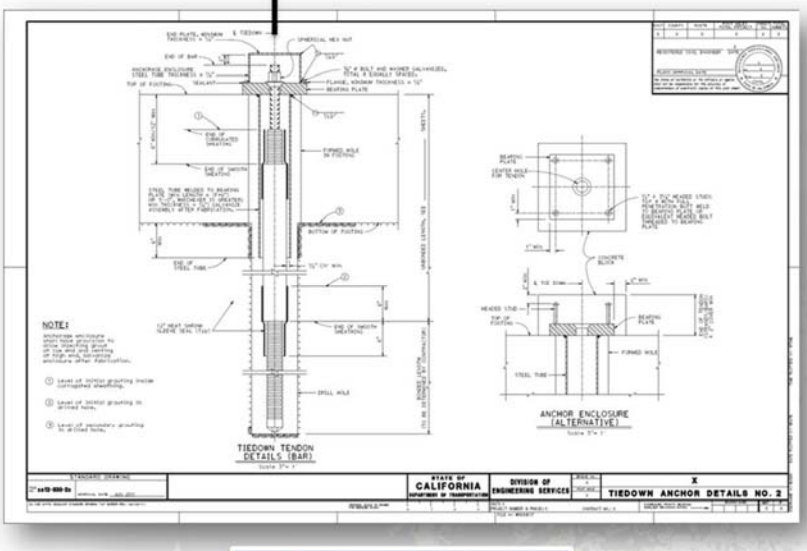
- **結構配置**
  - 預力箱型梁橋
  - 南北向橋寬20.74~16.4m
  - 南北橋各17跨，共16橋墩
  - 下部結構：單柱式矩形橋墩、直接基礎



直接基礎穩定性補強工法

僅承受地震時拉力

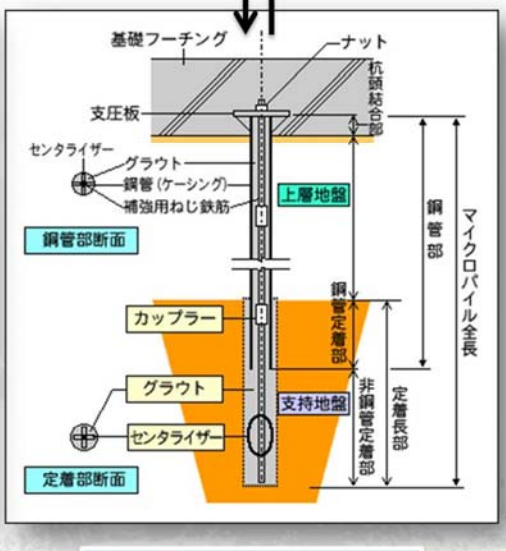
T



基礎抗拉地錨

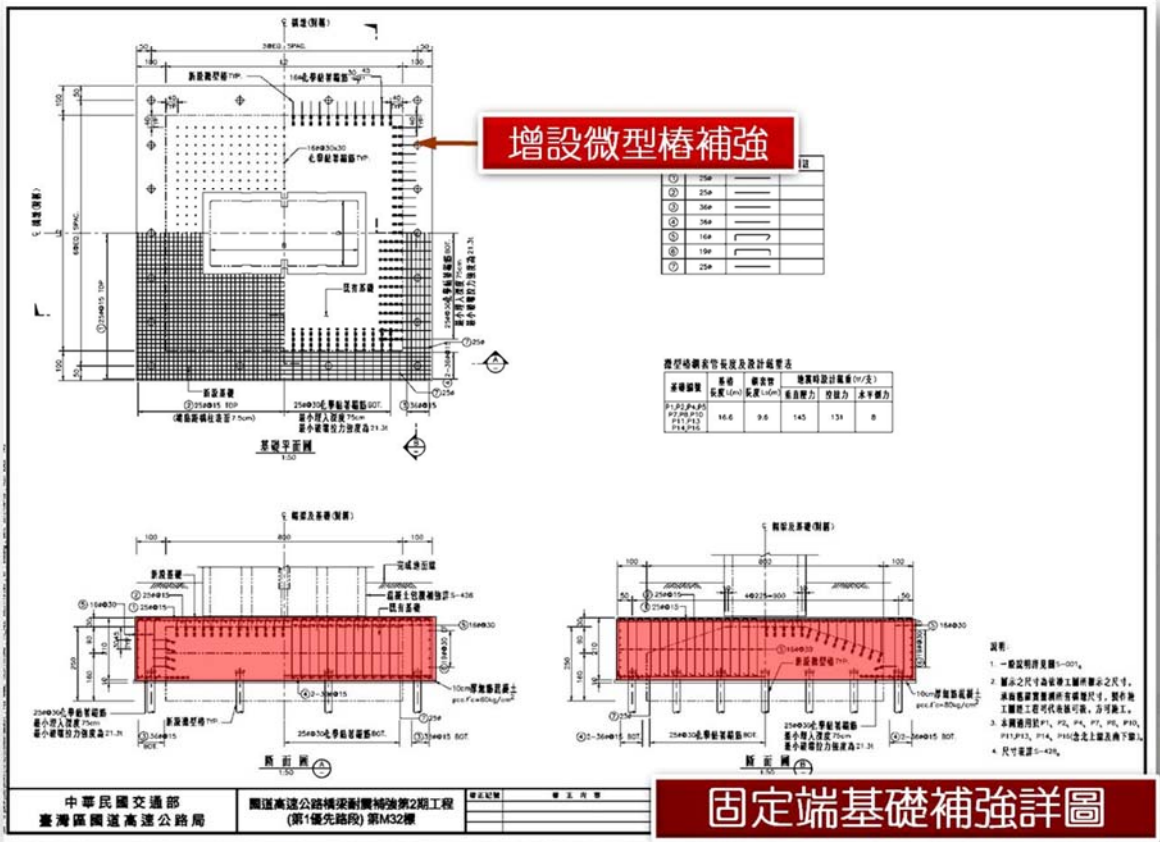
承受地震時拉力及壓力

T & C



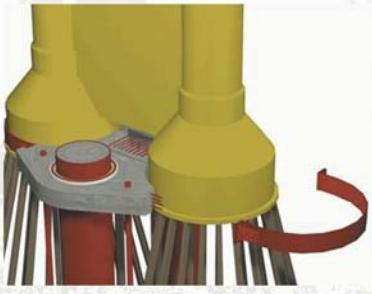
高強度微型樁

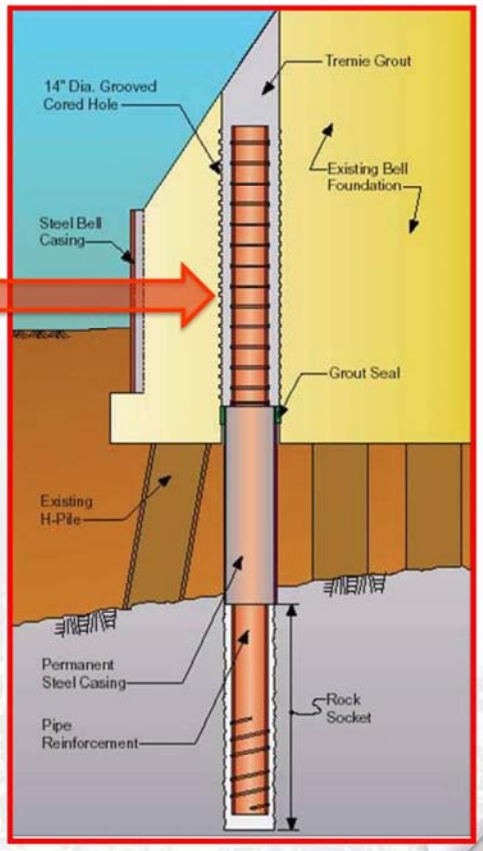
龍潭高架橋 (直基補強案例)



日本宮崎縣平成13年地方道路整備工事(耐震補強)

Seismic Retrofit of Richmond/San Rafael Bridge, CA





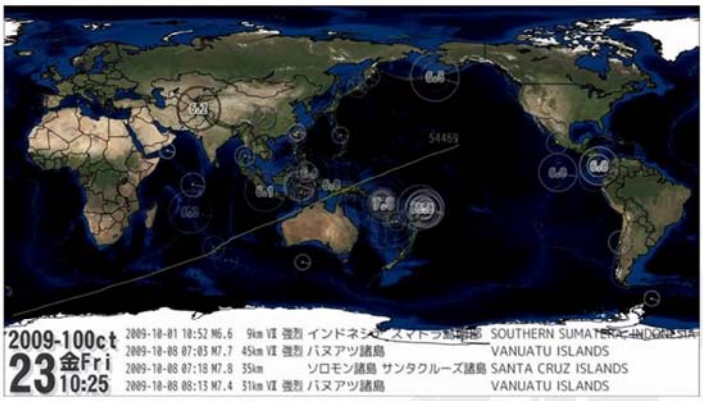
7 結語：持續的挑戰

結語：持續的挑戰

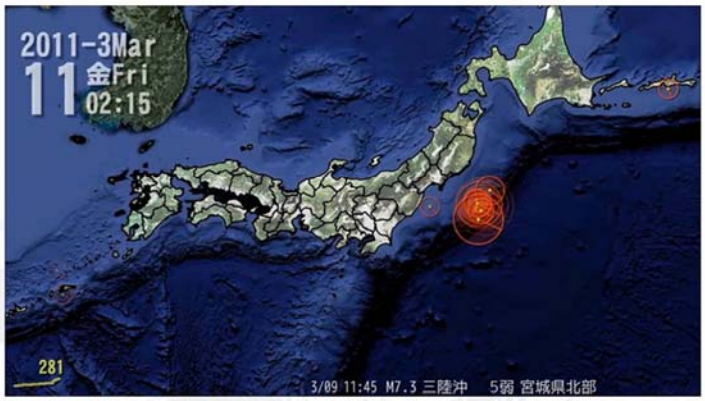
- 高公局於921集集大地震後，已建立25年的長期國道橋梁耐震補強計畫，持續有效率的穩定推動
  - 第一期：集集大地震後，於10年內完成首條生命線救災道路(中山高速公路、國二)橋梁耐震補強
  - 第二期：接續一期計畫，於5年完成台灣北部生命線救災路網(北二高)橋梁耐震補強
  - 第三期：現正積極推動後續路段橋梁耐震補強，分為三個區段，預定115年完成
- 本工程的順利完成，感謝高公局、技術組、工務組與拓建處參與工程司的努力與協助；此外，對於國震中心張國鎮主任、美國FHWA顏文輝博士與Caltrans前總工程司James E. Roberts的指導與建議，特別表示誌謝

Competing Against Time

2001.1~2014.5 World Earthquakes



311 Japan Tohoko Earthquake (2011)



The Race To Seismic Safety
The Continuing Challenge
Competing Against Time

我們正在與時間賽跑

Prof. Joseph Penzien, Chairman, Caltrans Seismic Advisory Board

簡報完畢
敬請指教

For further information,
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kypeng@tylin.com.tw