臺北自來水事業處
Taipei Water Department

中興工程顧問股份有限公司
SINOTECH ENGINEERING CONSULTANTS, LTD.

台北市既有水管橋耐震評估與補強

Seismic Evaluation and Retrofit of Existing Water Pipe Bridges in Taipei

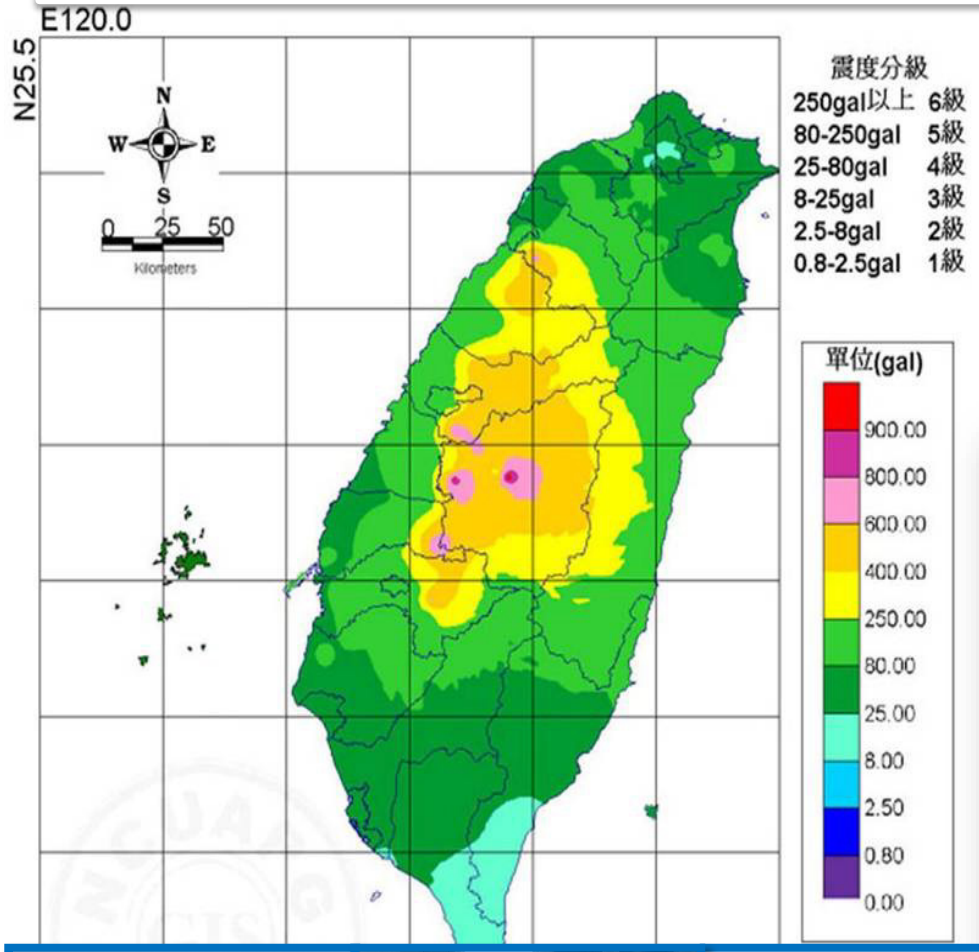
Authors: Wei-Hsiang Lee, Kuan-Hua Lien, Po-Ming Cheng and Chii-Jang Yeh Sinotech Engineering Consultants)

Speaker: Po-Ming Cheng Technical Manager

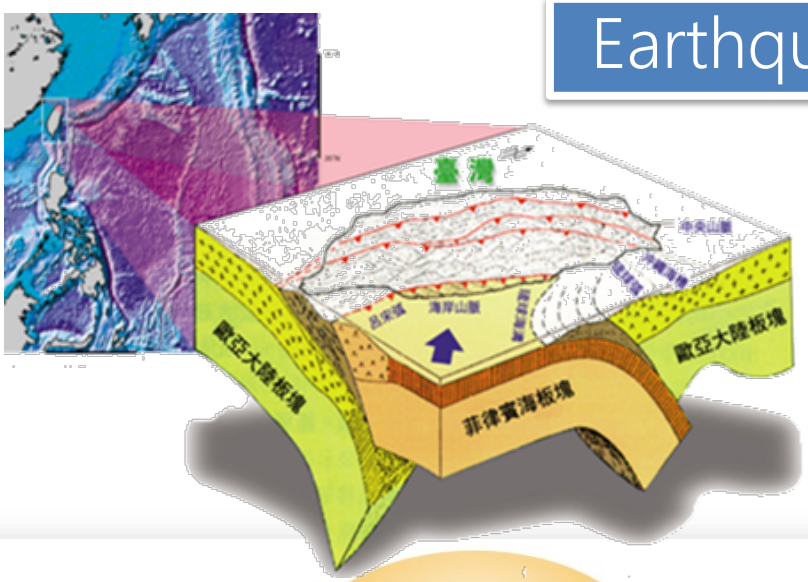
The 10th CTWWA/JWWA/WRF Water System Seismic Conference
October 18-21, 2017 Tainan, Taiwan

Motive

921 ChiChi earthquake



Earthquake



Speaker Introduction

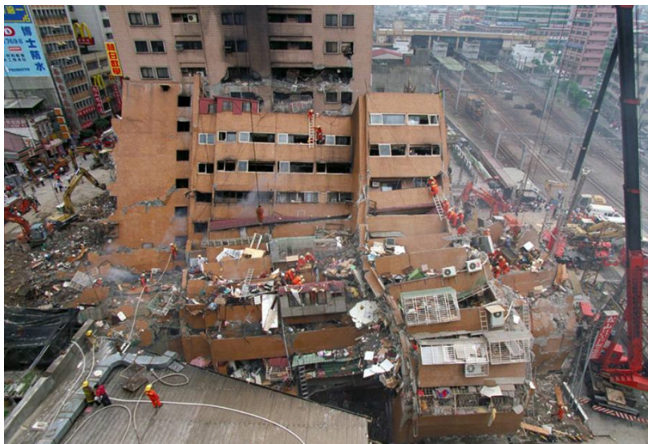
Speaker ： Po-Ming Cheng Structure P.E. ,Technical Manager

Company : Sinotech Engineering Consultant

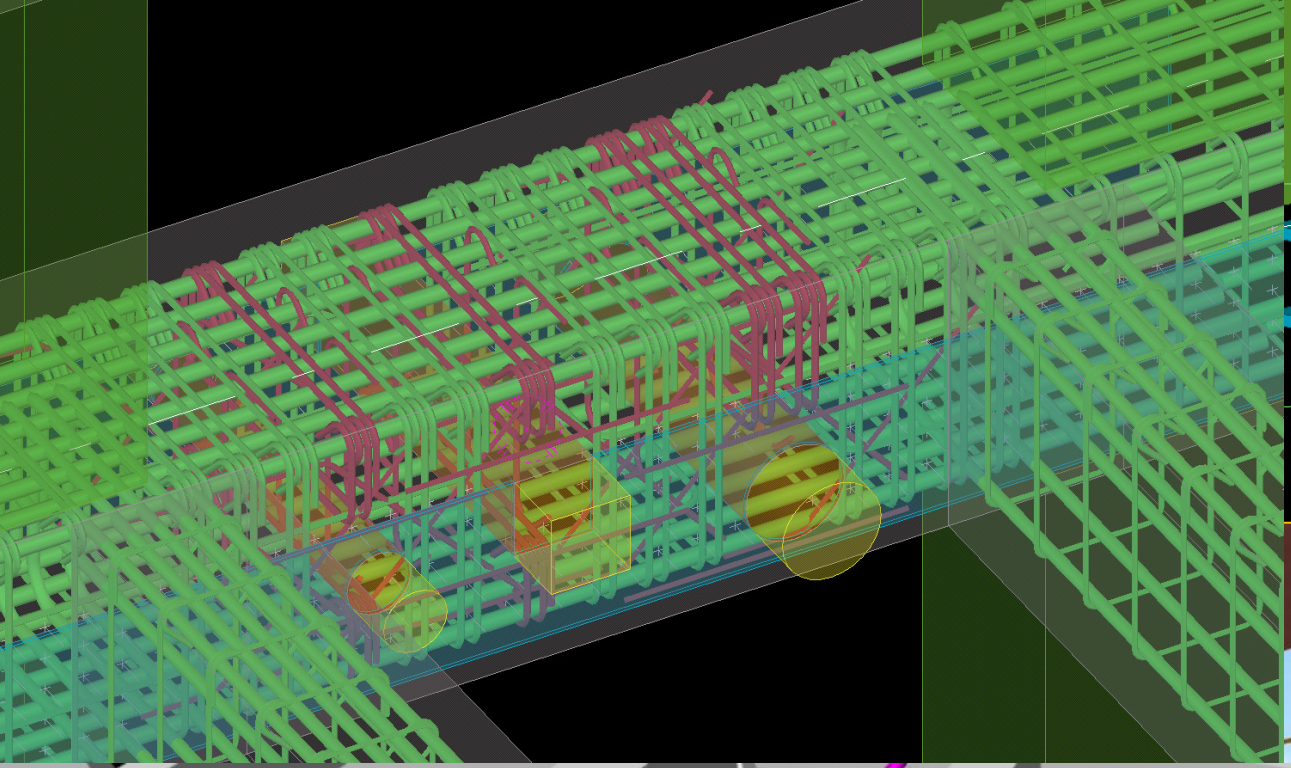
(start from 1991)

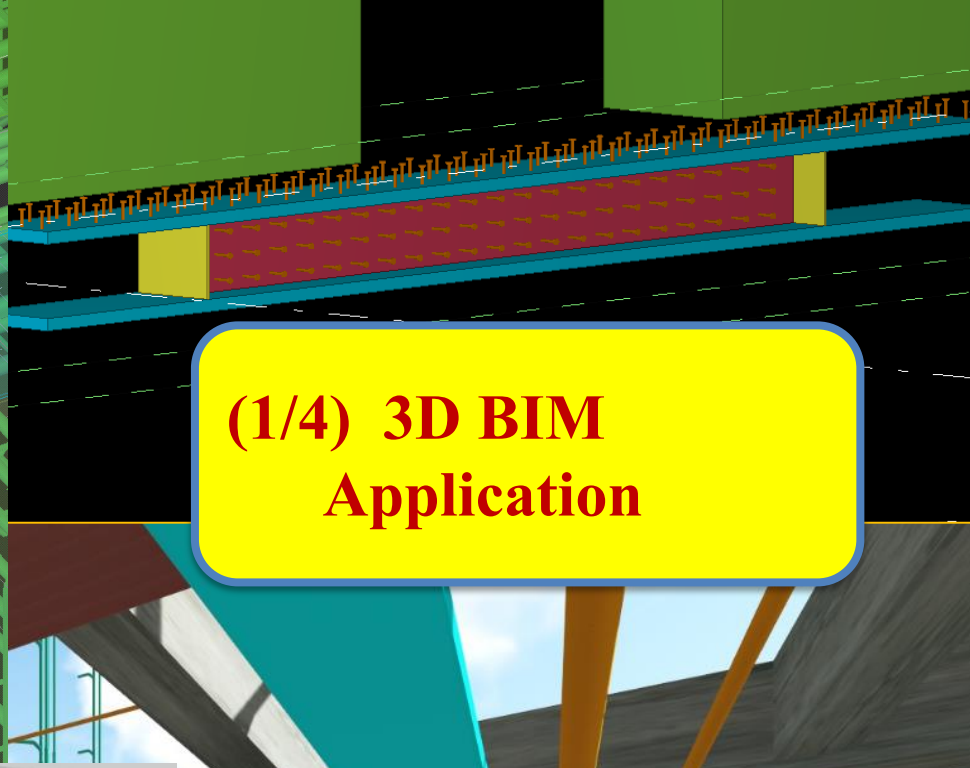
Experience:

1. **Building Design & 3D BIM Application**
2. **(Steel) Plant Design**
3. **New bridge design**
4. **Existing Bridge Evaluation & Retrofit**

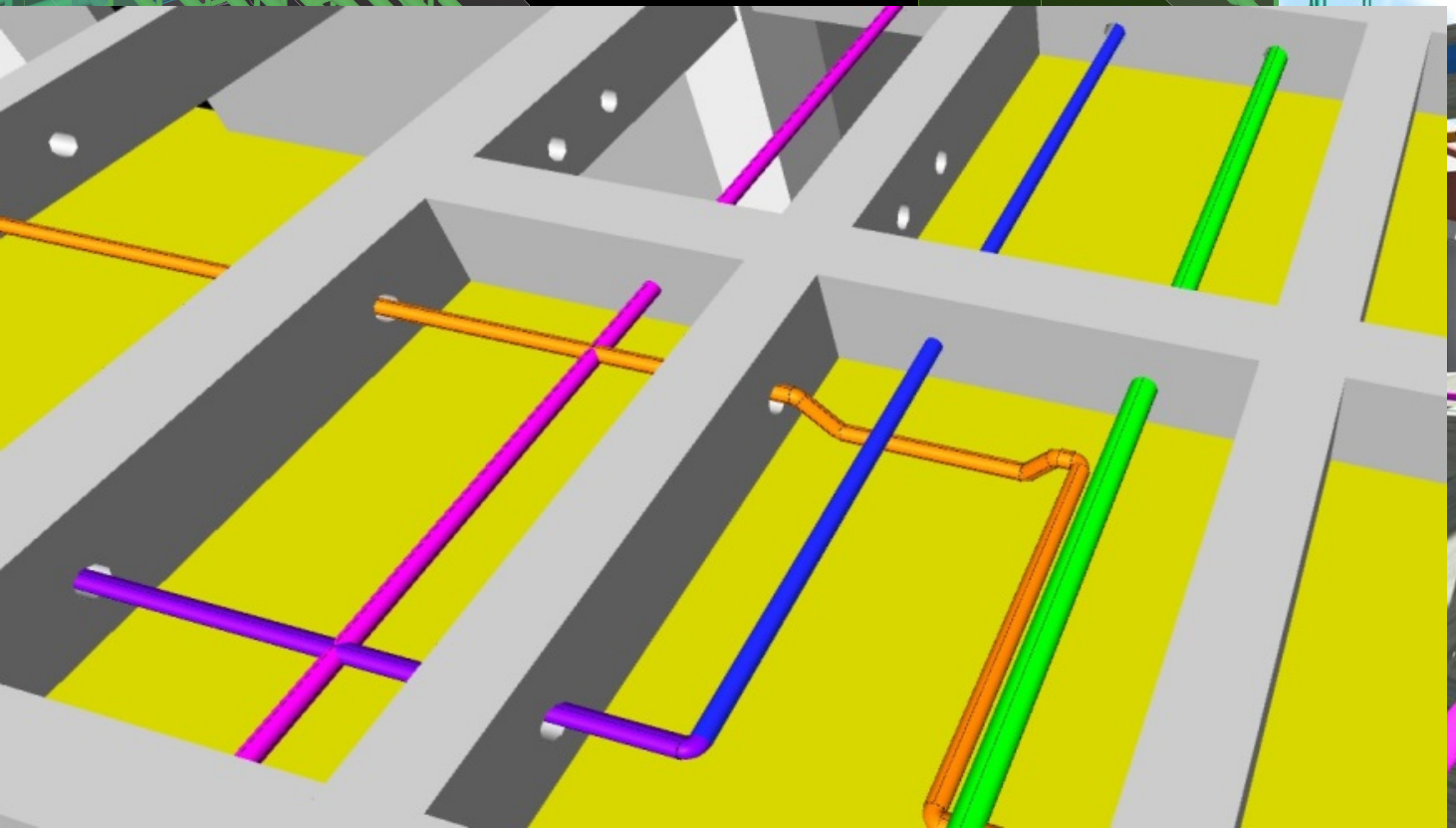


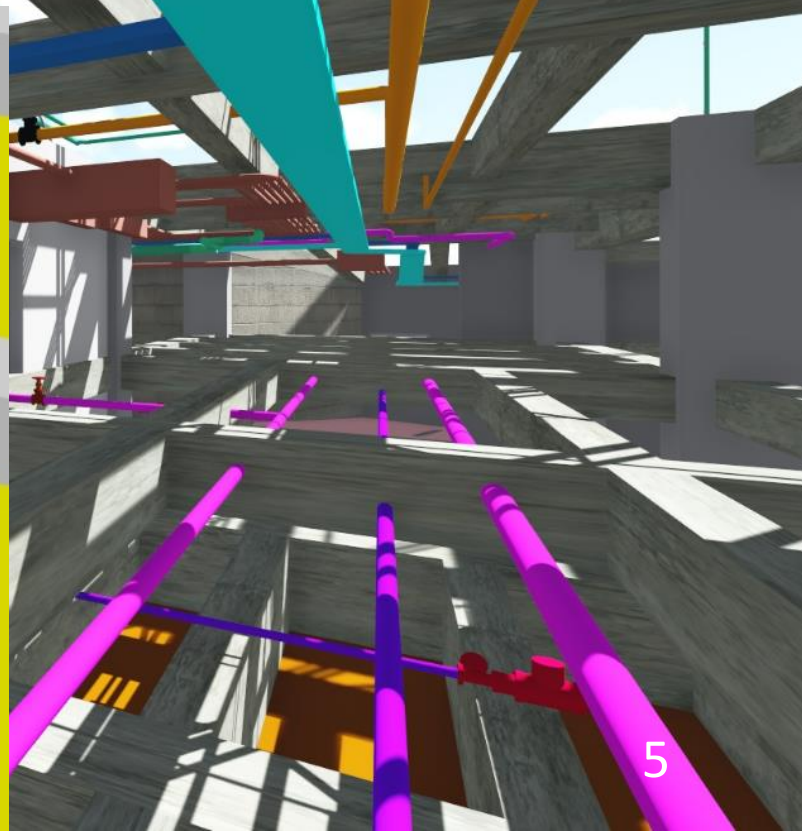
(1/4) 2017 Summer Universiade Athletes' Village of Taipei



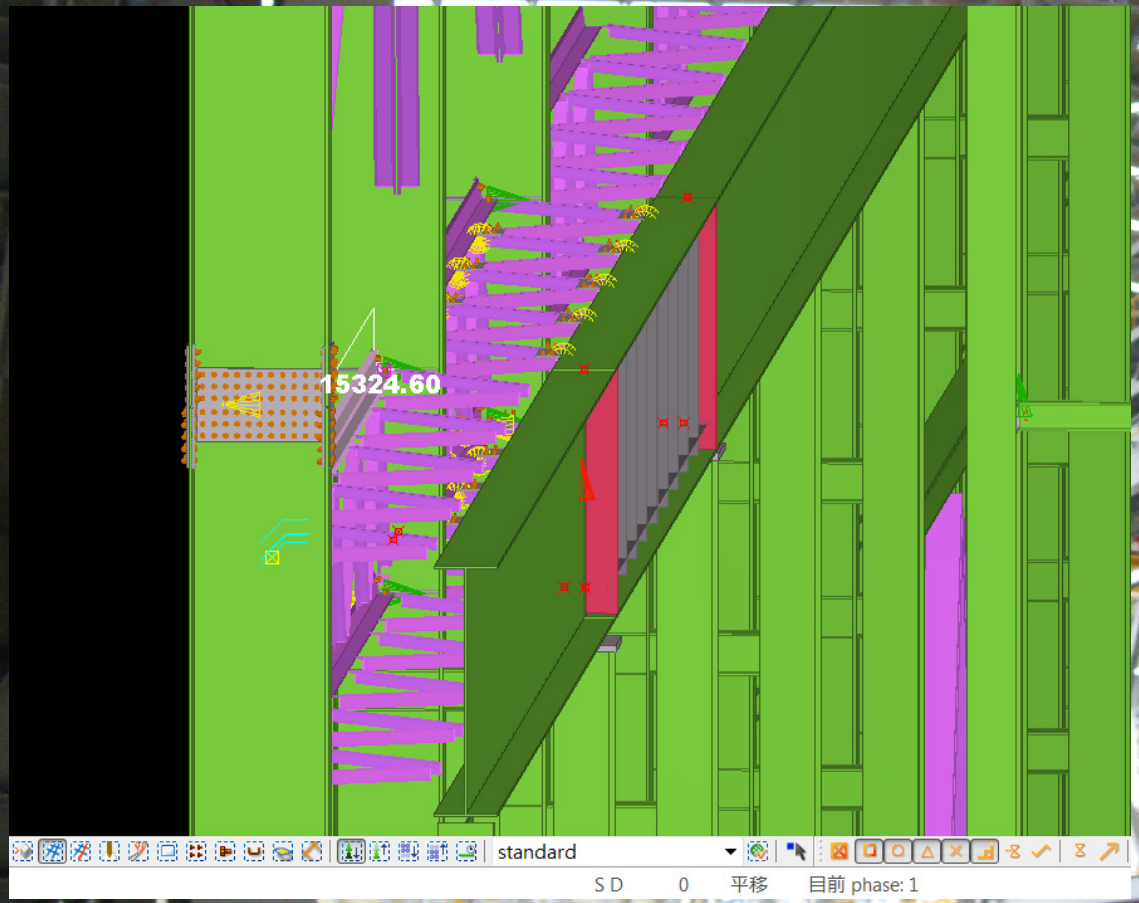


(1/4) 3D BIM Application





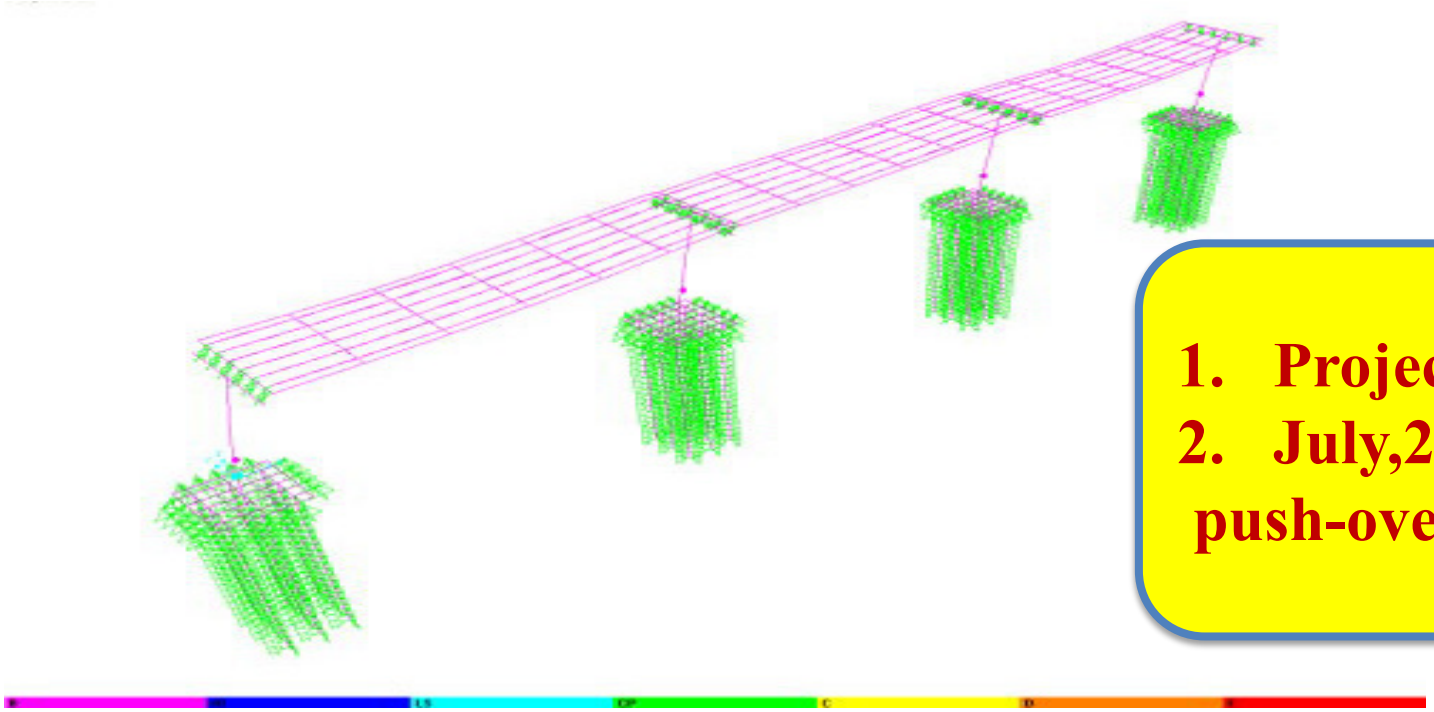
(2/4) (Steel) Plant Design



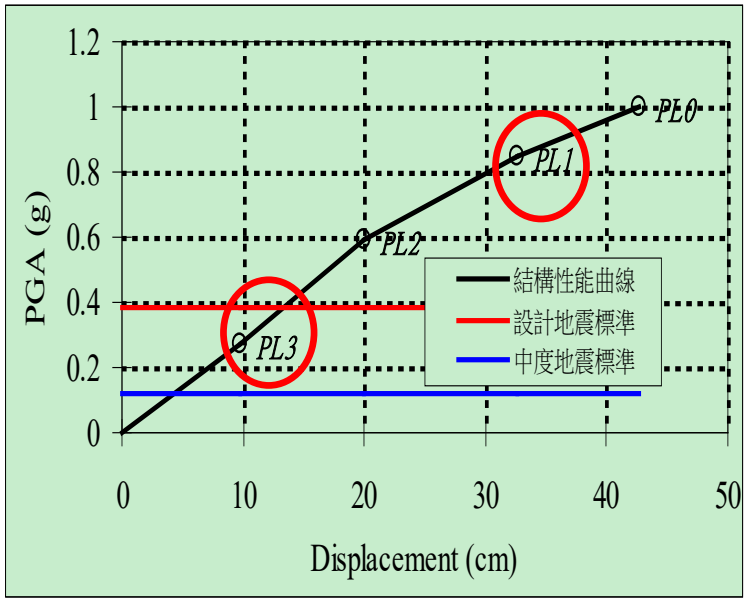
2013/05/22

(3/4)New bridge design

(4/4) Existing Bridge Evaluation & Retrofit



1. Project begin from 2009
2. July,2010 NCREE Drawed up push-over Draft



PL0~PL3 performance points PGA (after retrofit)			(before retrofit)
PGA_{PL0}=	0.997	g	0.548
PGA_{PL1}=	0.848	g	0.440
PGA_{PL2}=	0.593>0.387	g	0.304
PGA_{PL3}=	0.271	g	0.114

Existing Bridge Evaluation & Retrofit(4A/4)

$$V=Kh\cdot W=Z\ S\ I\ C_0\cdot W=0.8\times 1.1\times 1.2\times 0.15\cdot W=0.16W$$

1 Column Vert.	0.16W
2 Column Hori.	0.16W
3 Bearing & E.J.	0.16W
4 Foundation	0.16W

Old Code

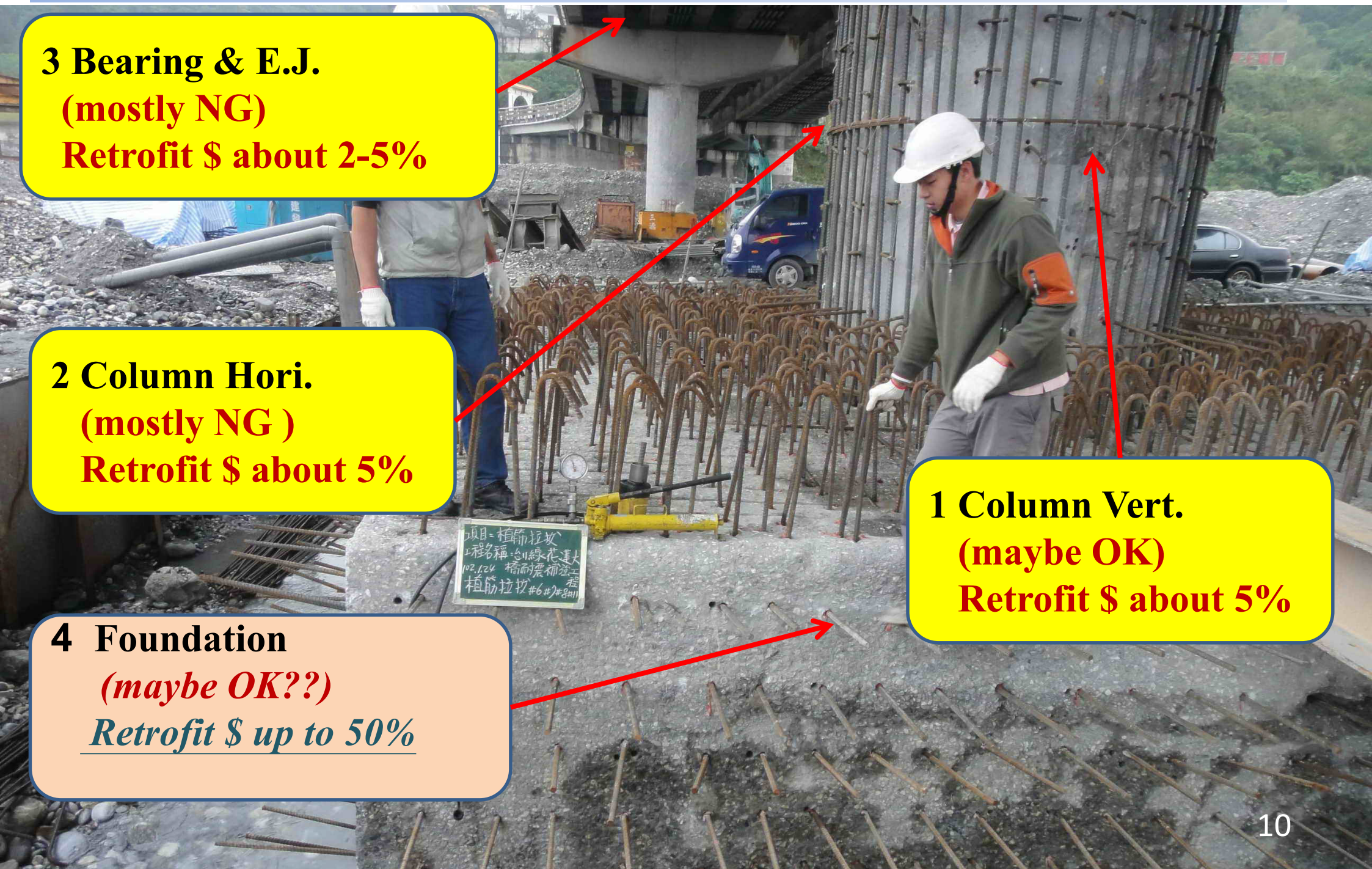
Year 1995

$$V=\frac{ZI}{1.2\alpha_y}\left(\frac{C}{F_u}\right)_m W=0.607/3.96\cdot W=0.153W$$

New Code

1 Column Vert.	0.153W
2 Column Hori.	0.607W (or Vp)
3 Bearing & E.J.	0.607W (or Vp)
4 Foundation	0.607W (or Mp,Vp)

Existing Bridge Evaluation & Retrofit(4B/4)



Existing Bridge Evaluation & Retrofit (4C/4)

Push-Over not on safe side ??

1. **30 % other direction not considered**
2. **Vertical E.Q. not considered**
3. **Temp. & CR&SH not considered (Continuous Bridge)**
4. **Soil Spring makes stiffness soft (Period increase)**

   but Soil Spring makes E.J. safe

Outline

- Introduction
- Seismic Evaluation of Water Pipe Bridge
- Evaluation results and retrofit strategy
- Conclusion

01

Introduction

Location map of water pipe bridges

Water pipe bridge A

Water pipe bridge B

Water pipe bridge C

Water pipe bridge D

劍潭水管B橋
Water pipe bridge B

圓山水管A橋
Water pipe bridge A

Hsiang-t'ou-p'o

清一永福水管橋台北市
Water pipe bridge C

新北市

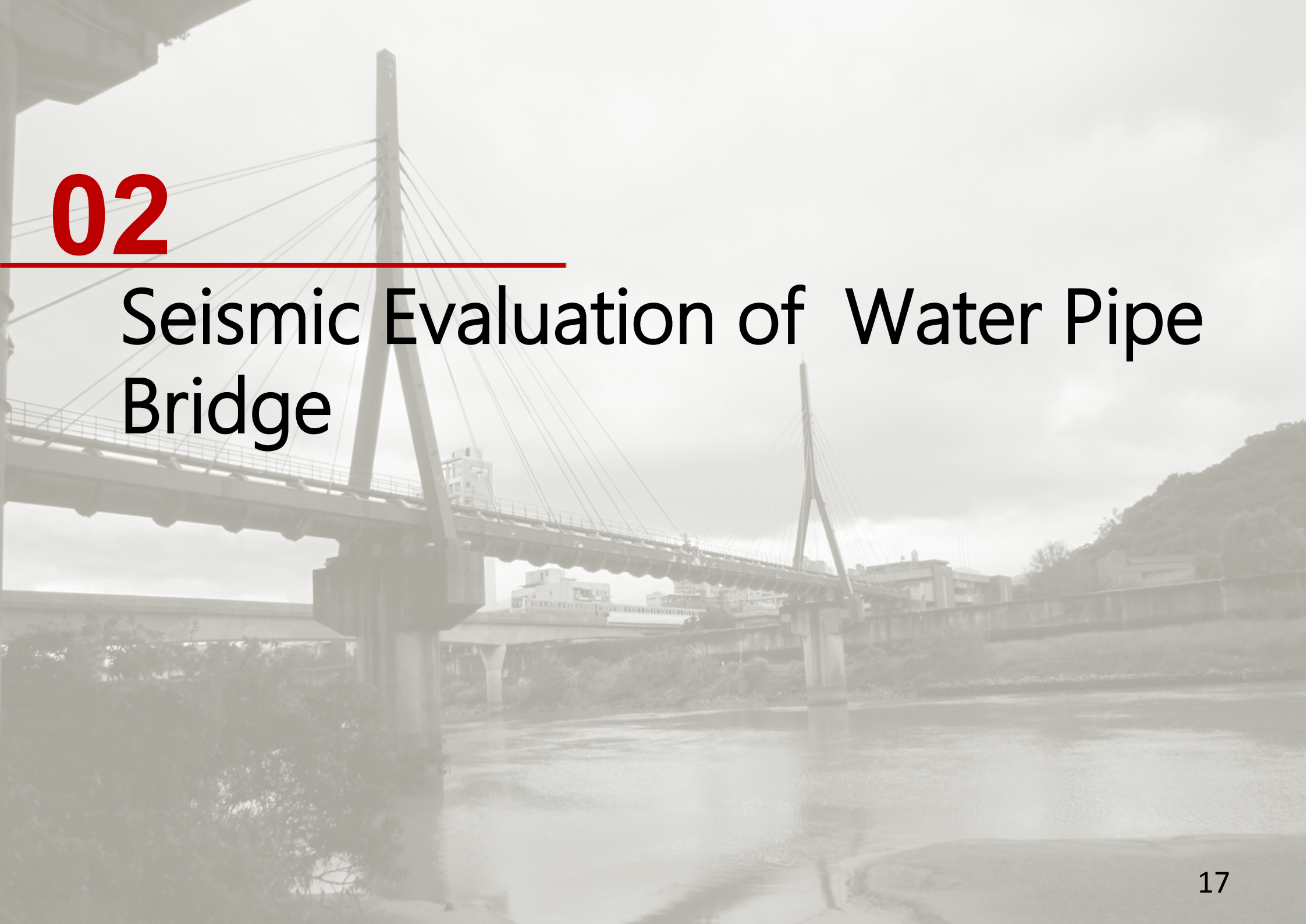
清二新店溪水管橋
Water pipe bridge D

Basic information of water pipe bridges

Bridge name	Type (Completion year)	Span, Pipe length and diameter	Condition
Water pipe bridge A (Yuanshan)	Arch steel bridge (1988) **Old Code**	§ 2000mm steel pipe length :100.6 m 1 span:100.6 m	
Water pipe bridge B (Jiantan)	Cable-stayed steel bridge (1988) **Old Code**	§ 2000mm steel pipe length :140 m 3 spans: 34+72+34 m	
Water pipe bridge C (Yongfu)	Arch steel bridge (1987) **Old Code**	2- § 2400mm steel pipe Length: 360 m 7 spans: 28.2+35+3@80 steel arch+30.16+26.2 m	
Water pipe bridge D (Hsintien)	Arch steel bridge (1998) **New Code**	2- § 2400mm steel pipe Length: 290 m 5 spans: 25+3@80 steel arch+25 m	

Basic information of water pipe

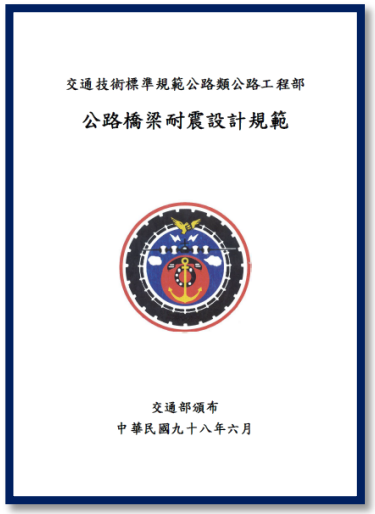
Bridge name	Diameter	Length	Unit length	Elongation	Shrinka-ge	Eccentri-city
Water pipe bridge A (Yuanshan)	2000 mm	98 m	1600 mm	190 mm ×2	220 mm	61 mm
Water pipe bridge B (Jiantan)	2000 mm	140 m	1600 mm	190 mm ×2	220 mm	61 mm
Water pipe bridge C (Yongfu)	2400 mm	360 m×2	1400 mm 1500 mm	80 mm ×2 140 mm ×2	100 mm 160 mm	40 mm 40 mm
Water pipe bridge D (Hsintien)	2400 mm	290 m×2	1600 mm	80 mm ×2	100 mm	40 mm

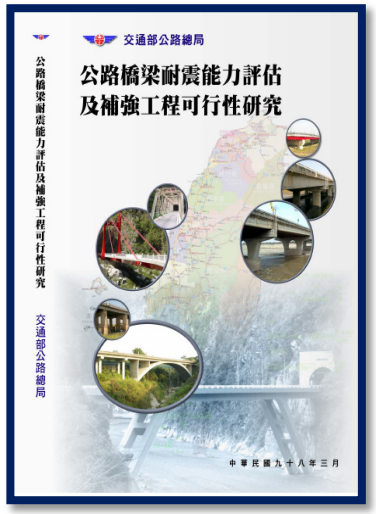


02

Seismic Evaluation of Water Pipe Bridge

Standard of seismic **Evaluation and Retrofit**



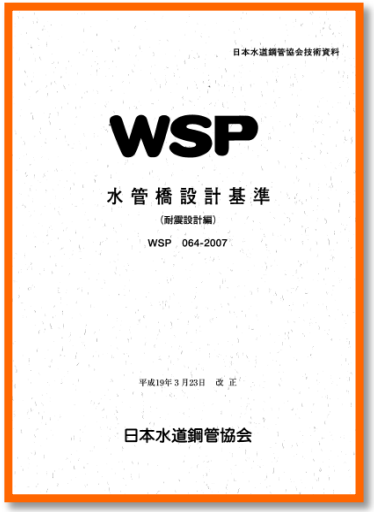


MOTC

Seismic retrofit standard: 50-year service life

Bridge objective

Normal water supply after earthquake



Retrofit strategy

- System reinforcement
- Component reinforcement
- Component increase

Seismic retrofit performance criteria & objective

Performance criteria (Site : Taipei 1, 2 and 3 district)

Earthquake level	Horizontal acceleration coefficient		Seismic restraint concept	Service performance	Damage grade
Moderate earthquake	Divided by administrative region 1/3.25 of earthquake of 475-year return period		Structure keeps elastic	Normal water supply after earthquake	Slight
Design earthquake (I=1.2) Return period:975years 50-year exceeding probability:5%	Divided by administrative region		Component has plastic hinge, exerting admissible toughness capacity	Limited water supply after earthquake	Repairable
	S_S^D	0.72			
	S_1^D	1.60、1.30、1.05			

Seismic performance level

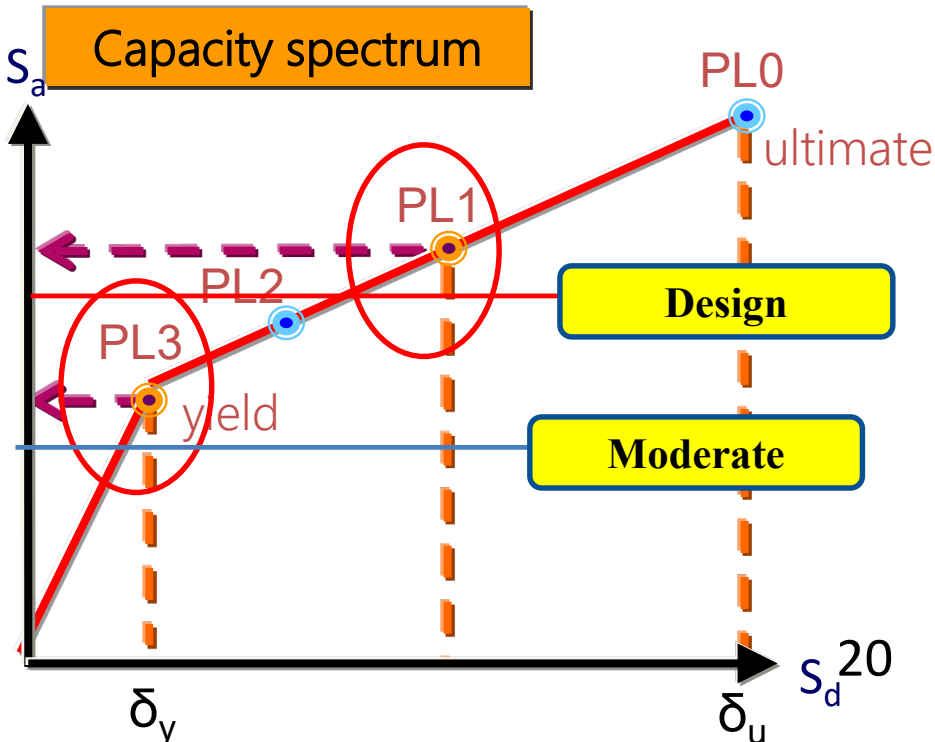
Performance level	Safety		Serviceability	Reparability	
	structure	foundation		Short period	Long period
PL3	Structure remains elastic	elastic	As same as prior to the earthquake	none	
PL1(2)	limited damages	elastic	Normal water supply	Partially repair or replace damaged member	

Seismic retrofit performance criteria & objective

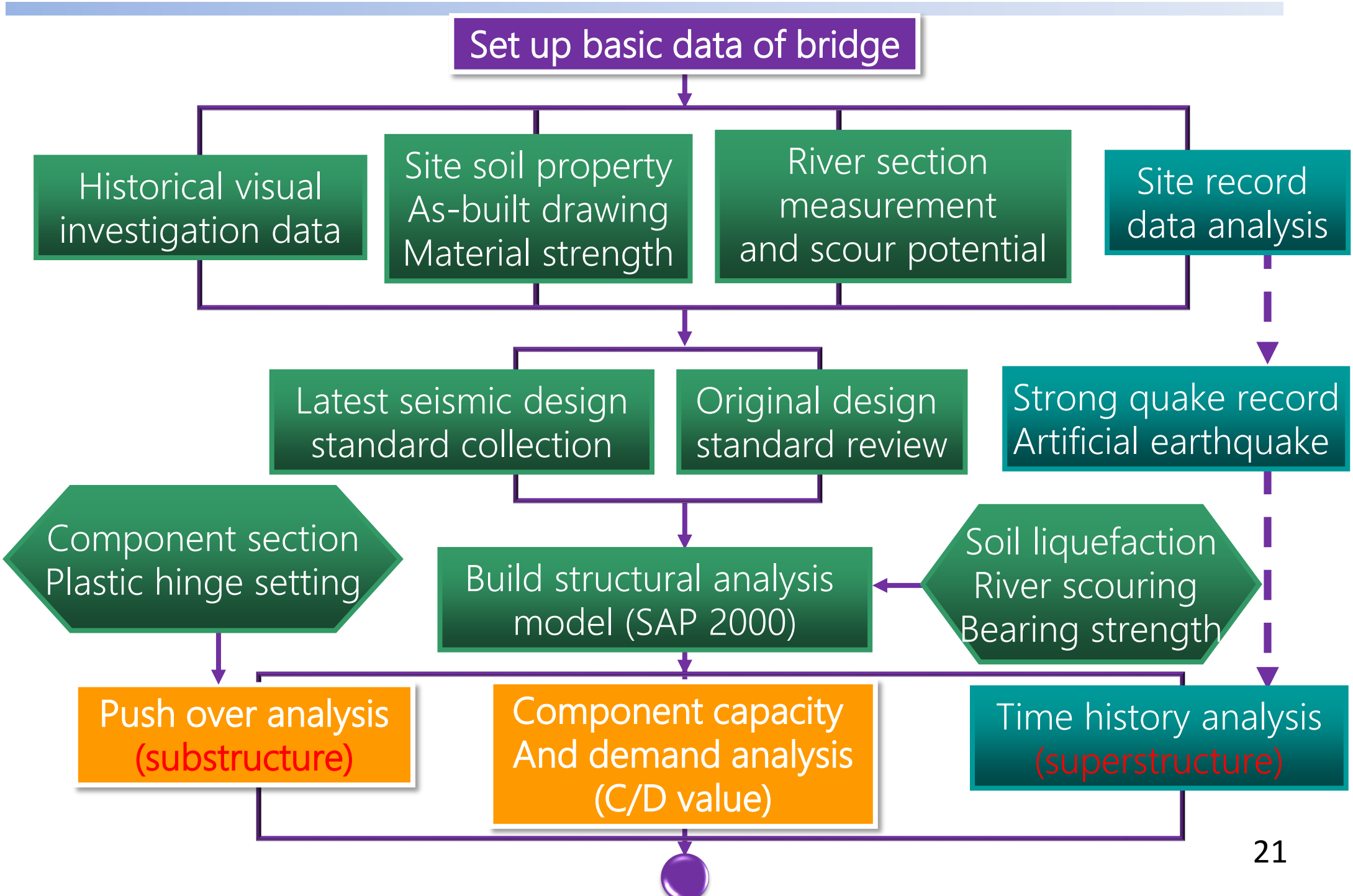
Seismic performance objective

Earthquake level		Design specification version					
		2000及1995 year		1987 and 41960year		Before 1960 year	
		Ordinary	Important	Ordinary	Important	Ordinary	Important
Moderate		PL3	PL3	PL3	PL3	PL3	PL3
Design	Ordinary(I=1.0)	PL2	-	PL1	-	PL0	
	Important(I=1.2)	-	PL2	-	PL1		PL1

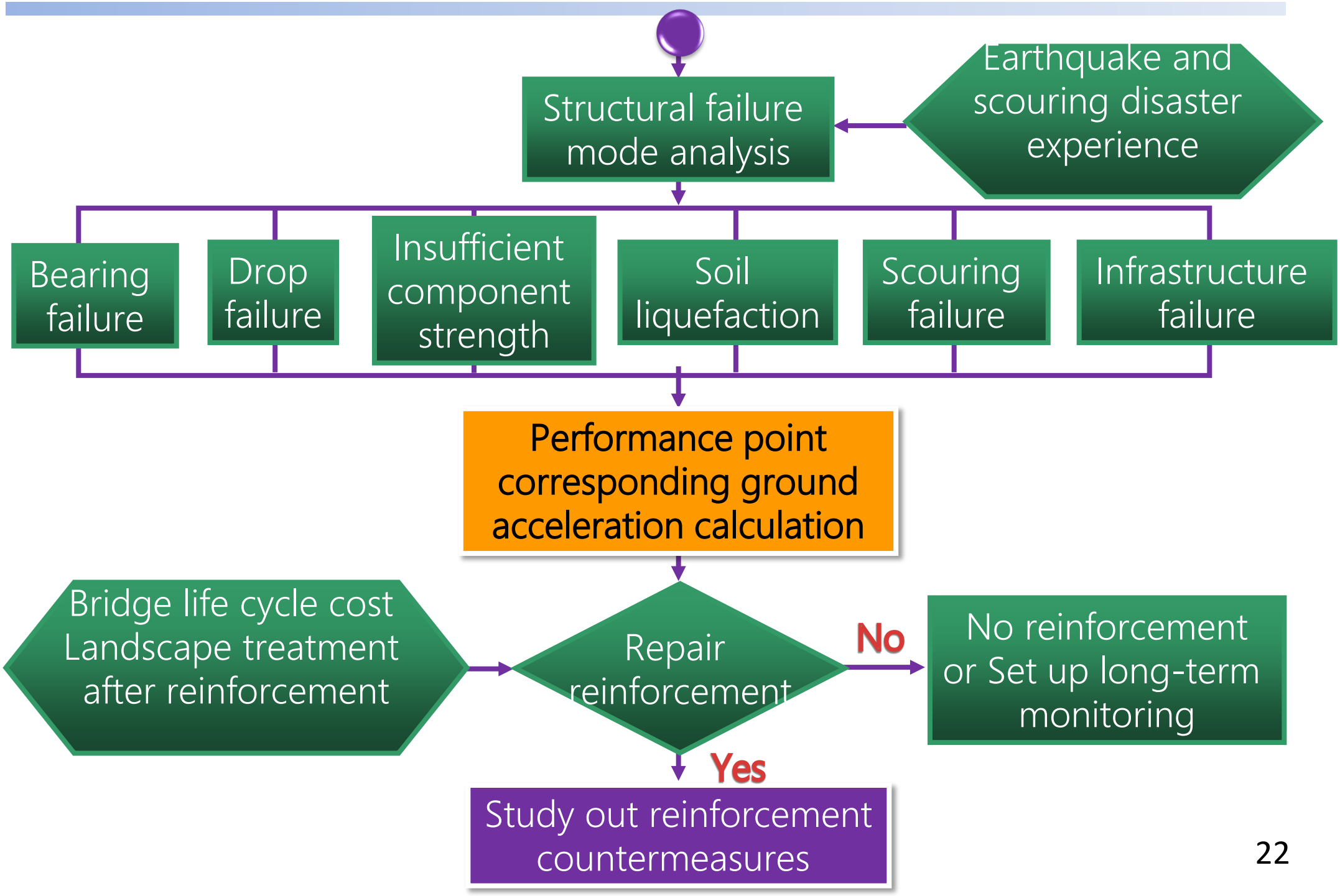
Earthquake level	Seismic performance level	Structural response condition
Moderate	PL3	Structure remains elastic
Design	PL2	Structure into inelastic and 1/4 capacity developed
Max. considered	PL1	Structure into inelastic and 2/4 capacity developed
—	PL0	Structure into inelastic and all capacity developed



Seismic evaluation of water pipe bridge



Seismic evaluation of water pipe bridge



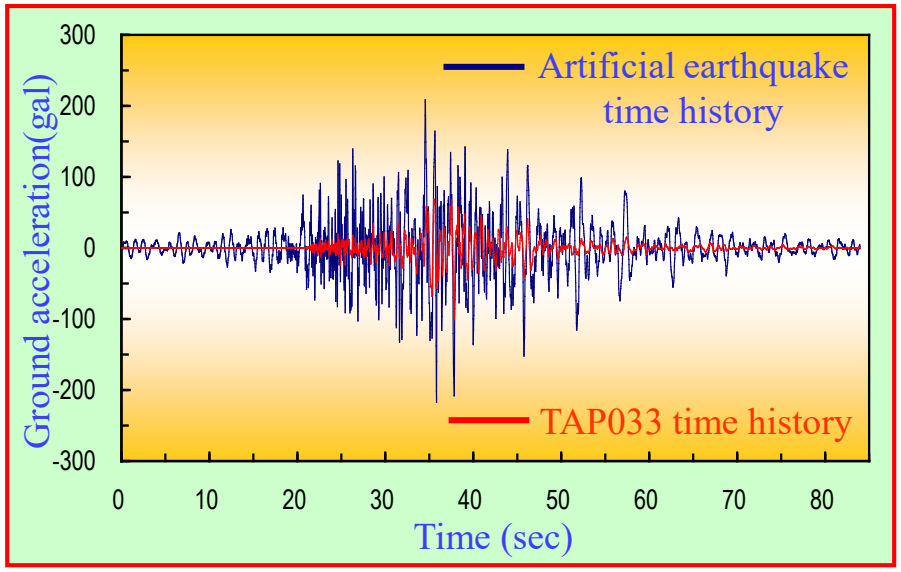
Time history analysis for superstructure

Pipe expansion joint

Bearing

Beam splicing

Artificial earthquake time history



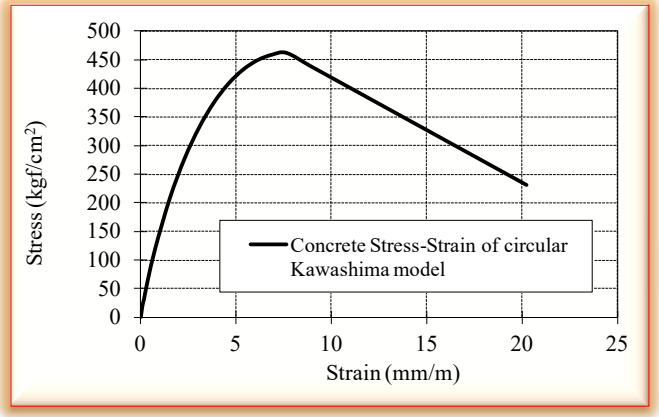
Spandrel column splicing

Girder splicing

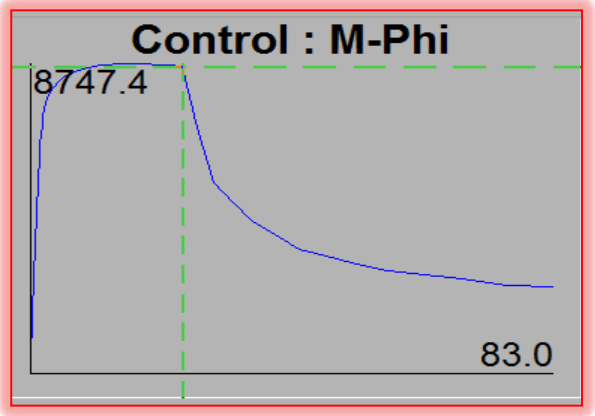
Check whether the component capacity meet the current design code

Pushover analysis for substructure

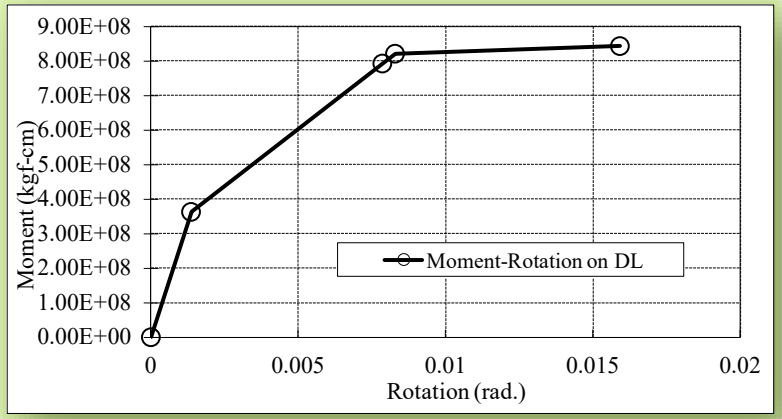
Concrete of pier Stress-strain relation



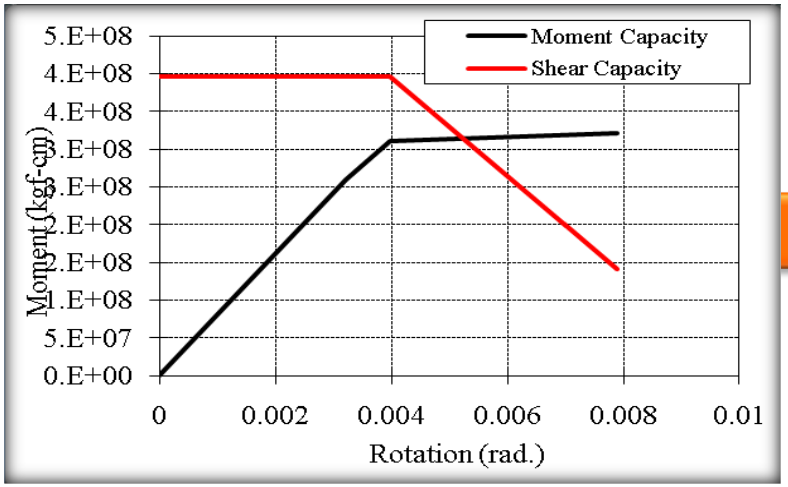
Pier moment-curvature relation



Pier moment-rotation relation

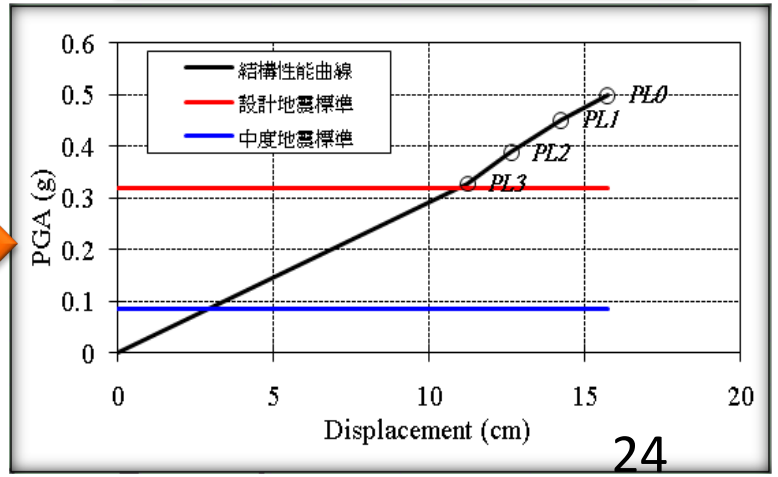


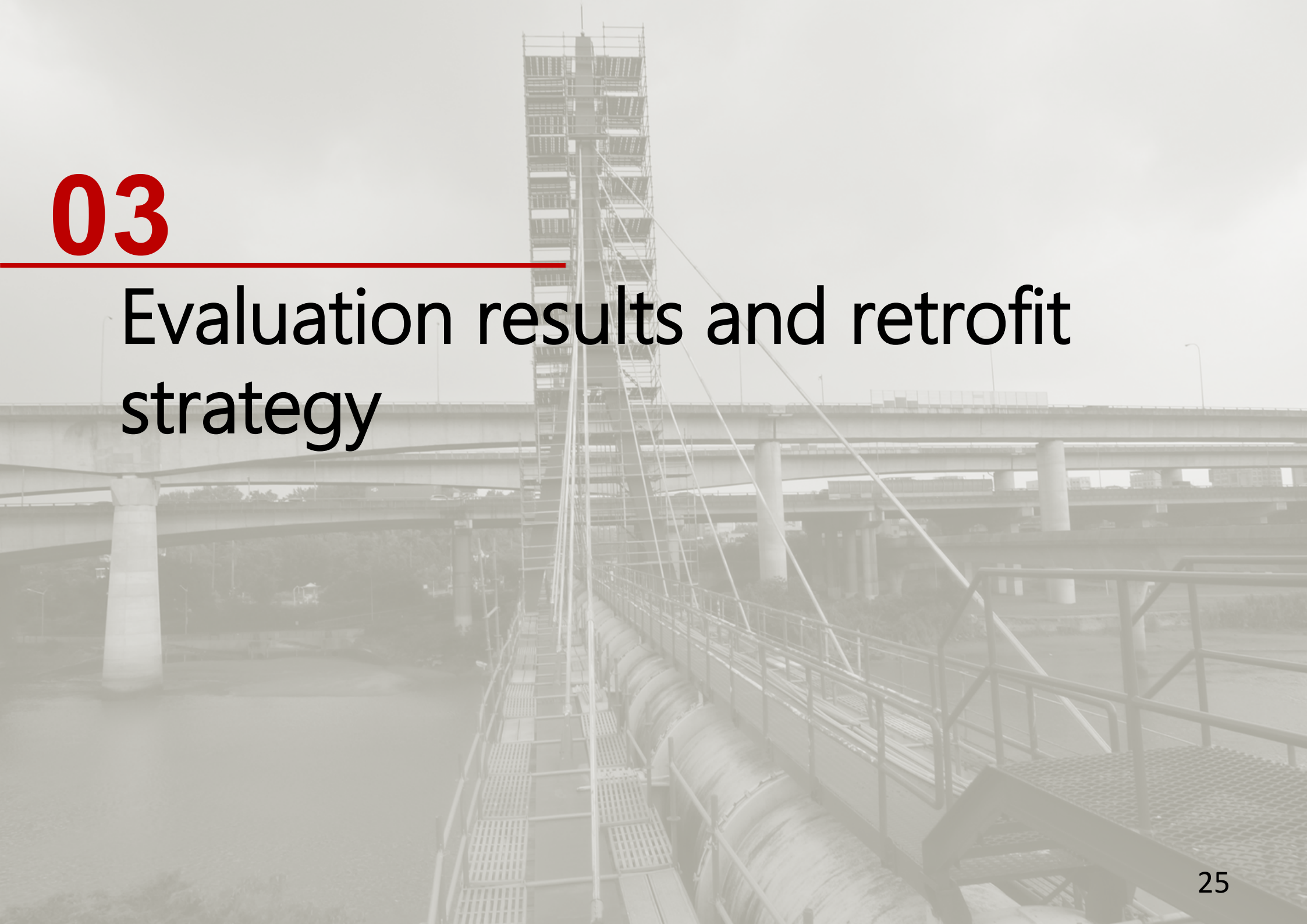
Pier hinge curve



Push-over Analysis

Bridge seismic performance curve

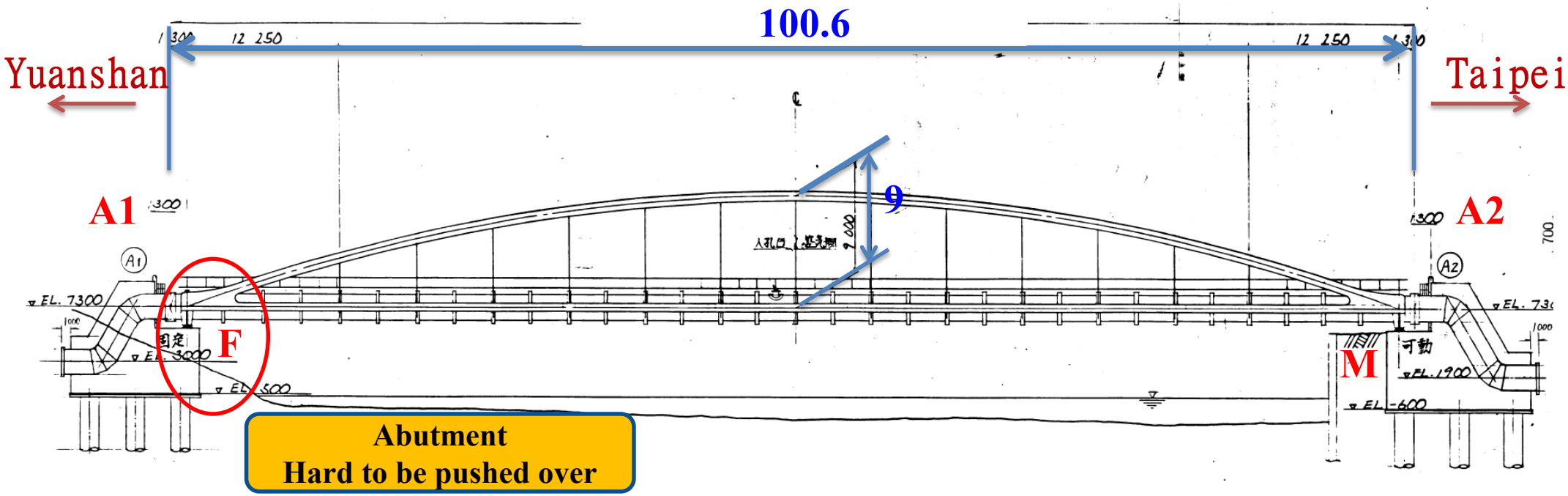




03

Evaluation results and retrofit strategy

Water pipe bridge A-structure description

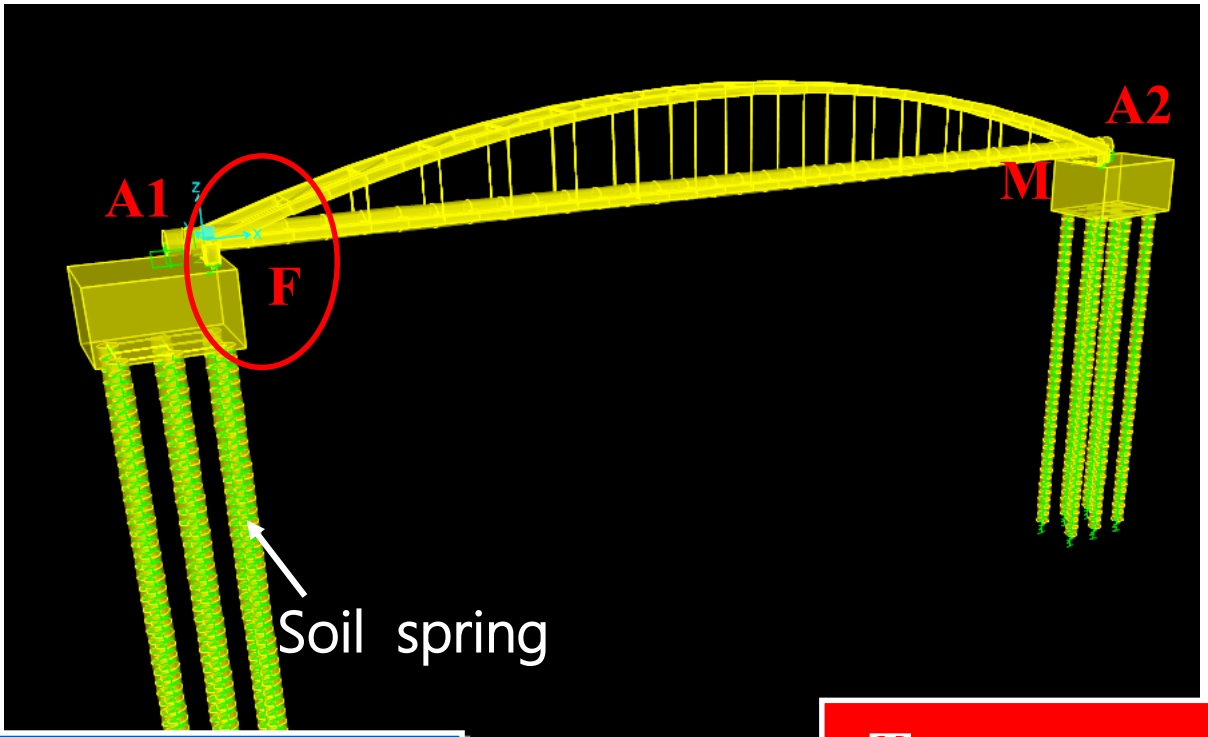


Structure description

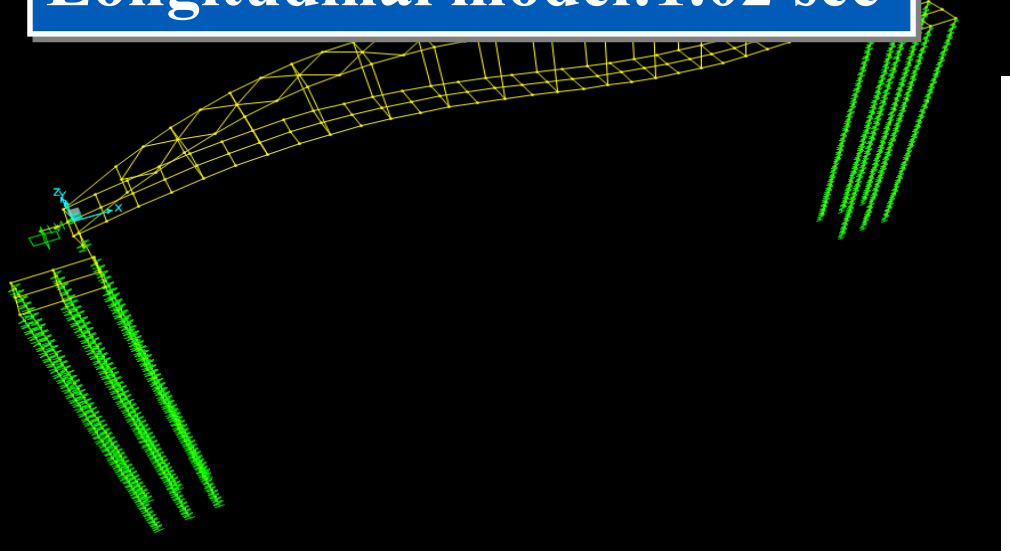
Old Code

- Single-span arch steel bridge; completion year in 1988
- Bridge length: 100.6 m; arch height: 9 m
- Steel pipe diameter: 2000 mm; two steel box girder
- Concrete: fc'=240 kgf/cm^2; steel: A36

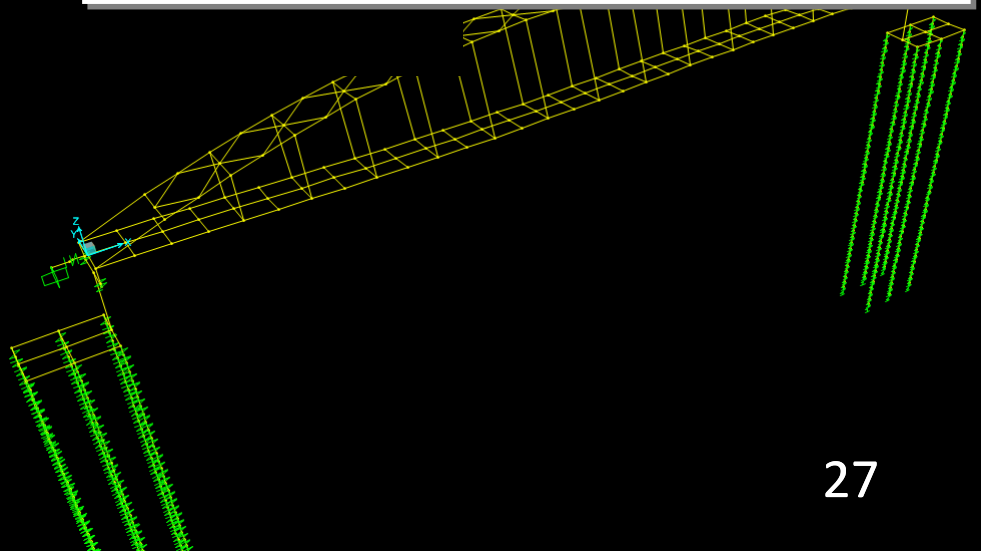
Water pipe bridge A-SAP2000 model and modal analysis



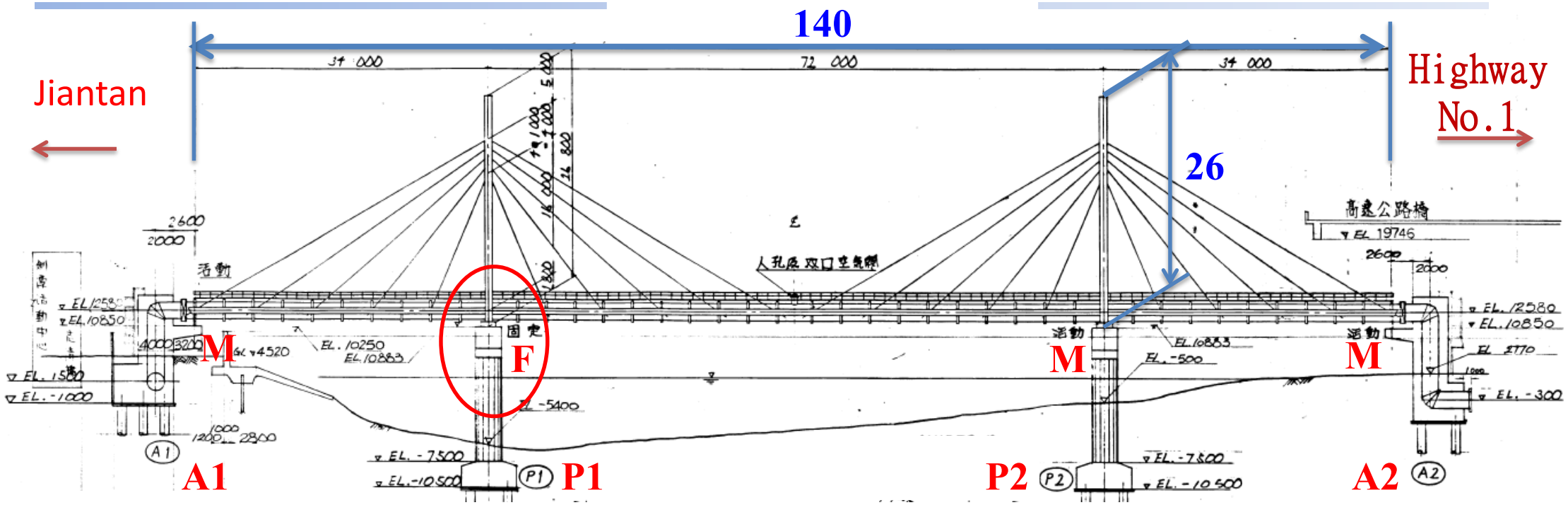
Longitudinal model:1.02 sec



Transverse model:0.52 sec



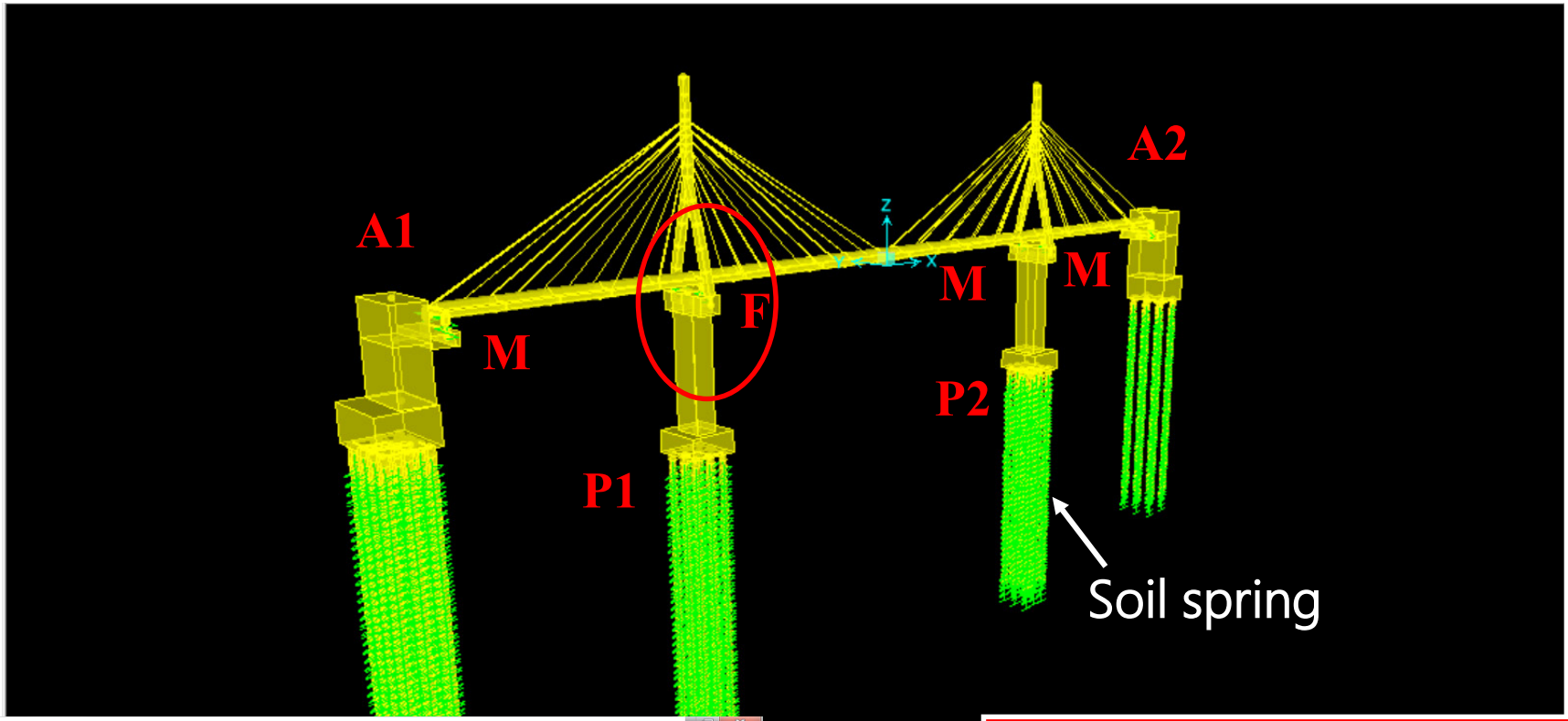
Water pipe bridge B-structure description



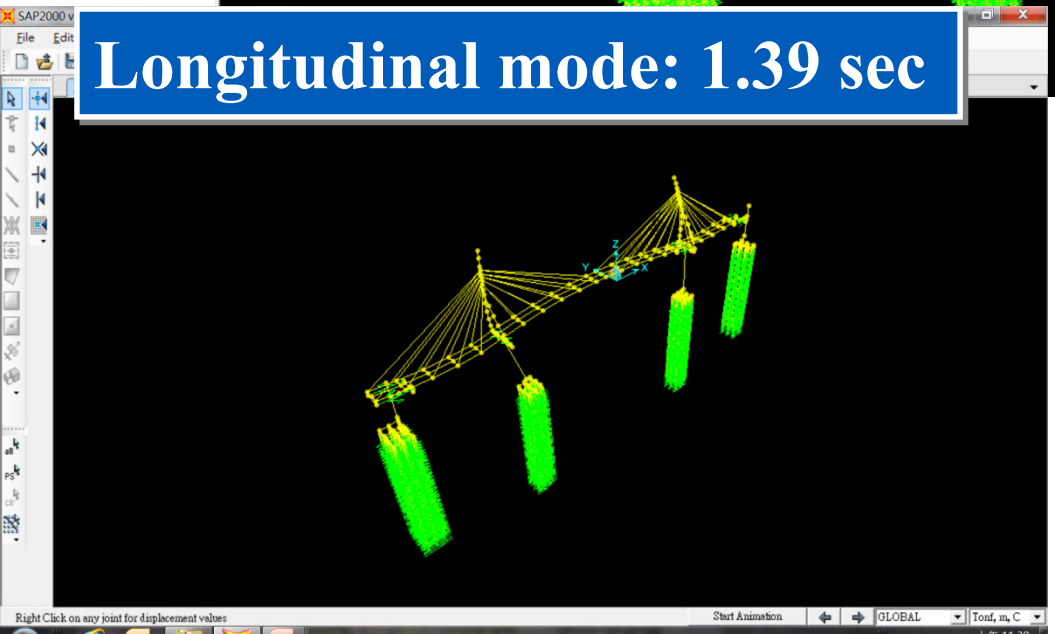
Structure description

- **multi-span simply supported cable-stayed steel bridge; completion year in 1988** Old Code
- **Bridge length: 140 m; tower height: 26 m; 20 pair cables**
- **Steel pipe diameter: 2000mm; two steel box girder**
- **Concrete: fc'=240 kgf/cm^2; steel: A36**

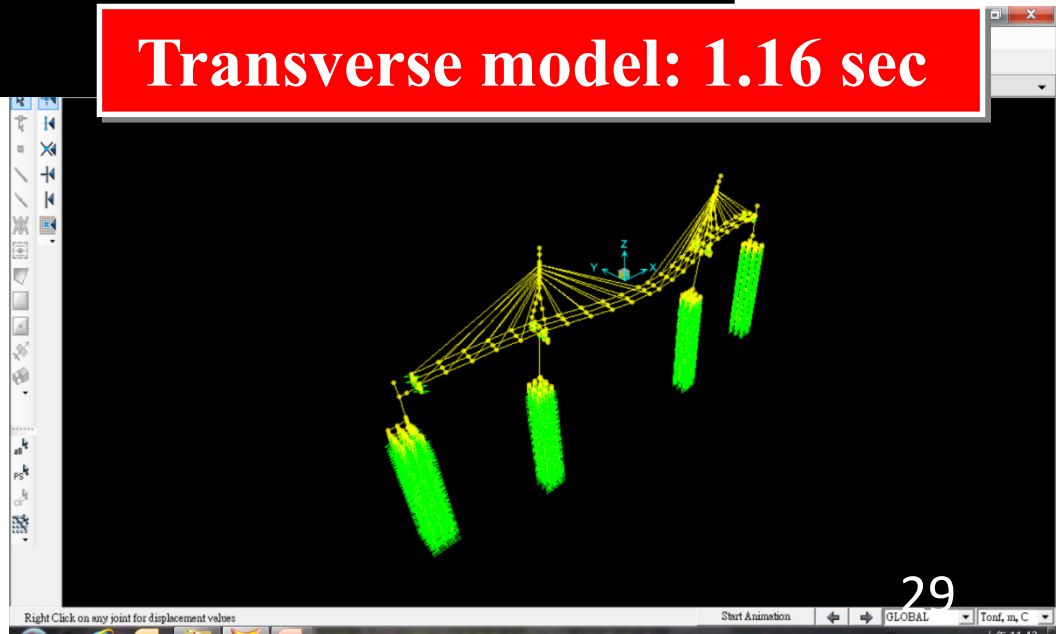
Water pipe bridge B-SAP2000 model and modal analysis



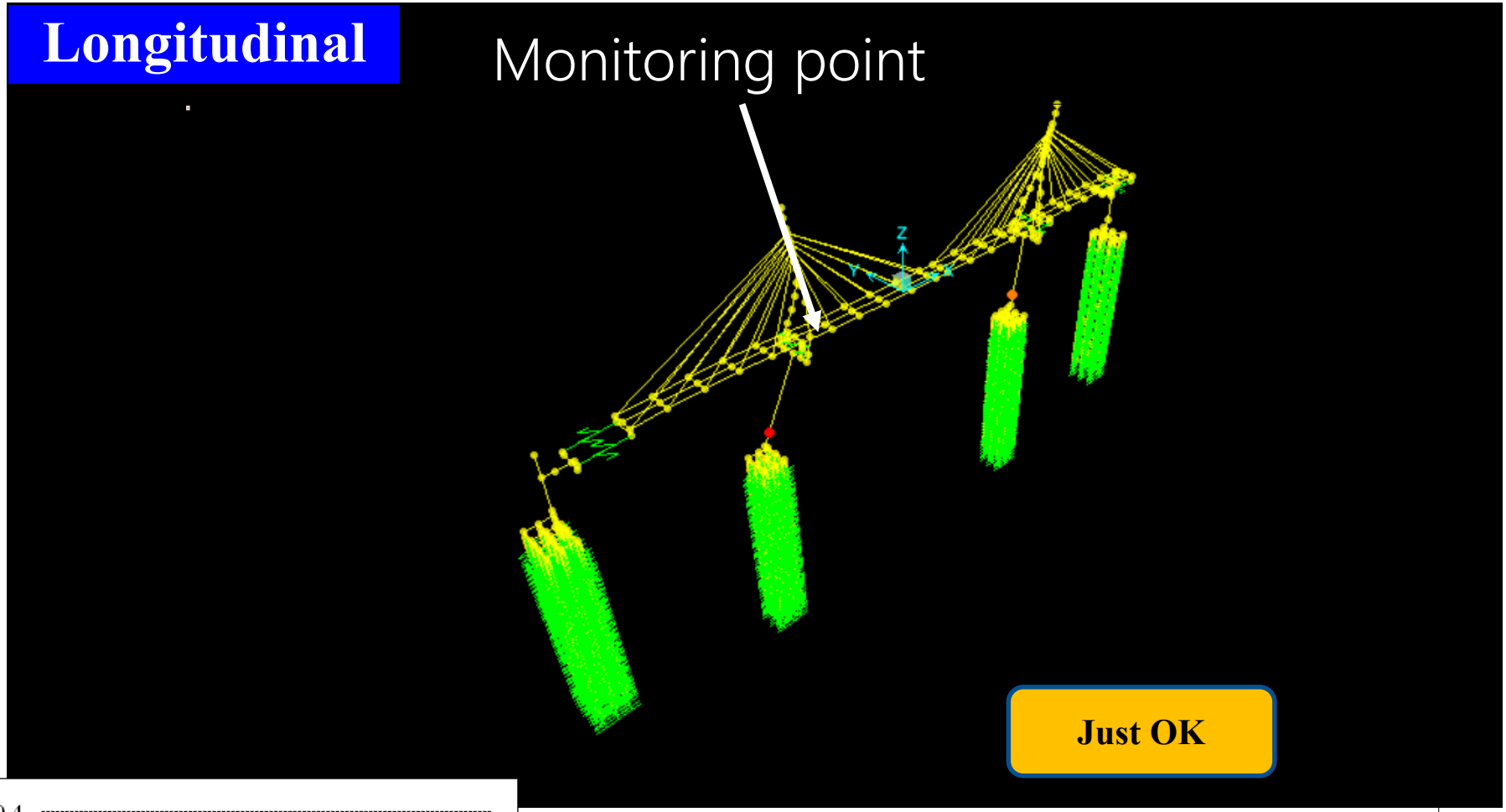
Longitudinal mode: 1.39 sec

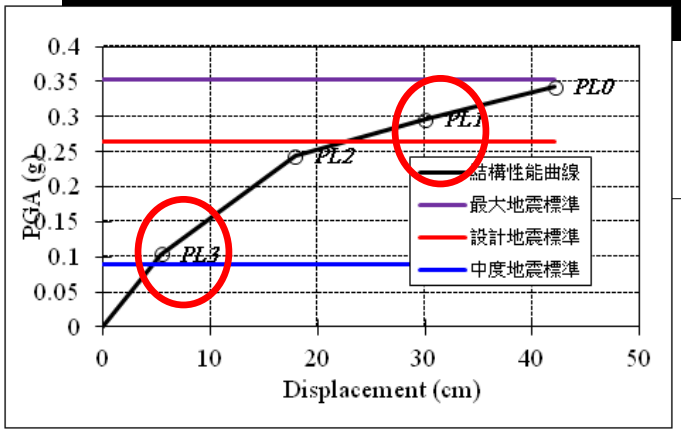


Transverse model: 1.16 sec



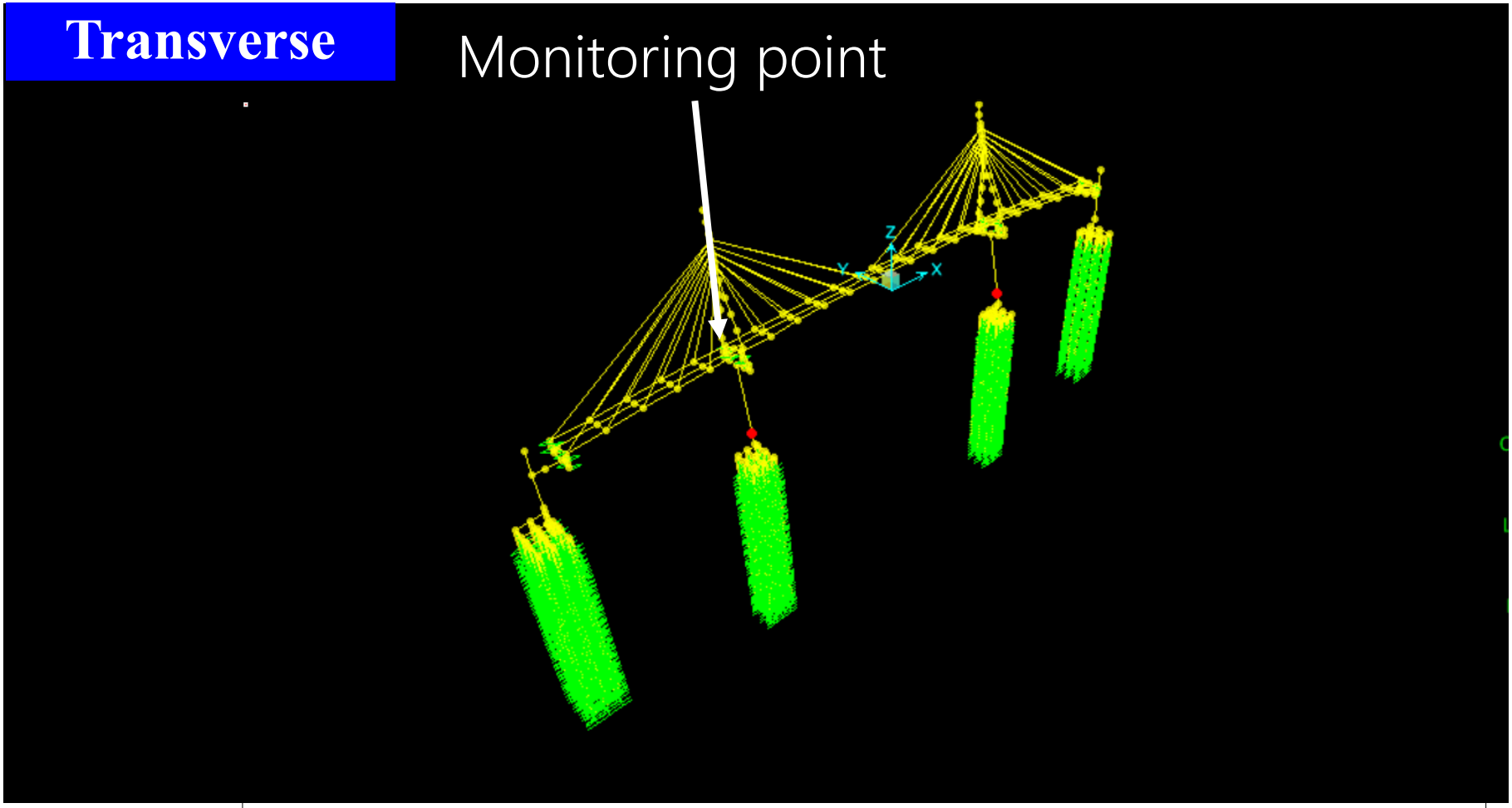
Pushover analysis(1/2)

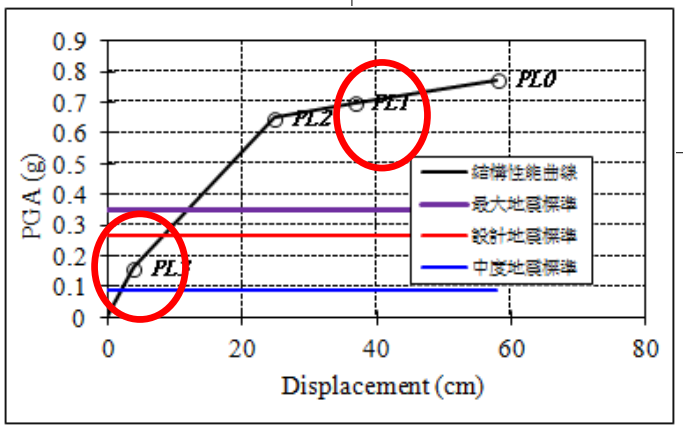




Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	performance	PGA (g)	Seismic demand check
Moderate	0.074 g	PL3	0.104	OK
Design	0.240 g	PL1	0.296	OK

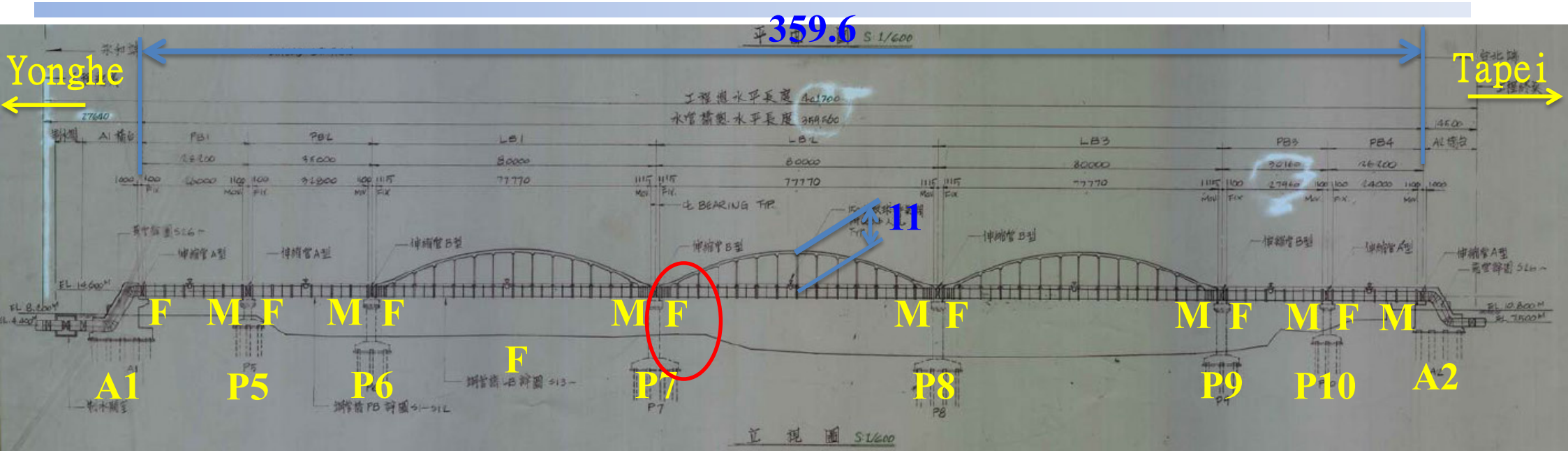
Pushover analysis(2/2)





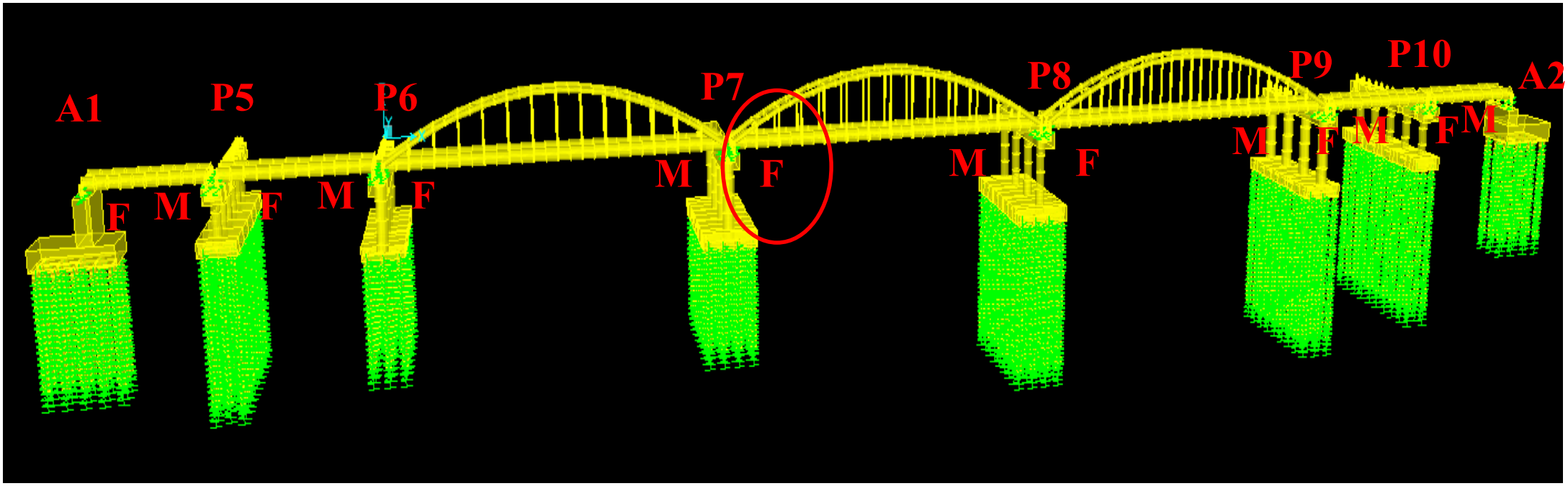
Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	perform ance	PGA (g)	Seismic demand check
Moderate	0.074 g	PL3	**0.160g**	**OK**
Design	0.240 g	PL1	**0.698 g**	**OK**

Water pipe bridge C-structure description

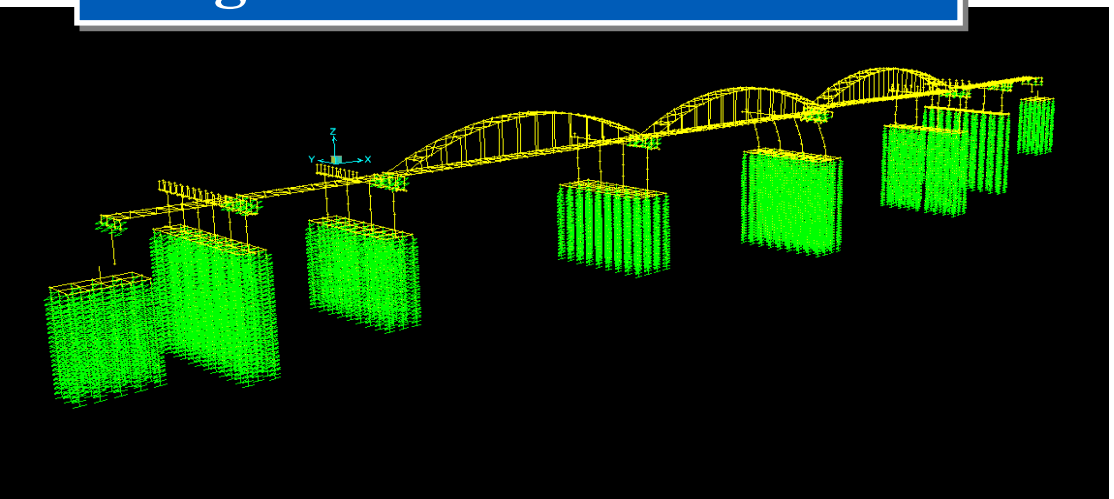


- Structure description
  - **multi-span simply supported arch steel bridge; completion year in 1984** Old Code
  - **Bridge length: 359.60 m; arch height: 11 m**
  - **Steel pipe diameter: 2400mm;**
  - **Concrete: fc'=240 kgf/cm^2; steel: A36**

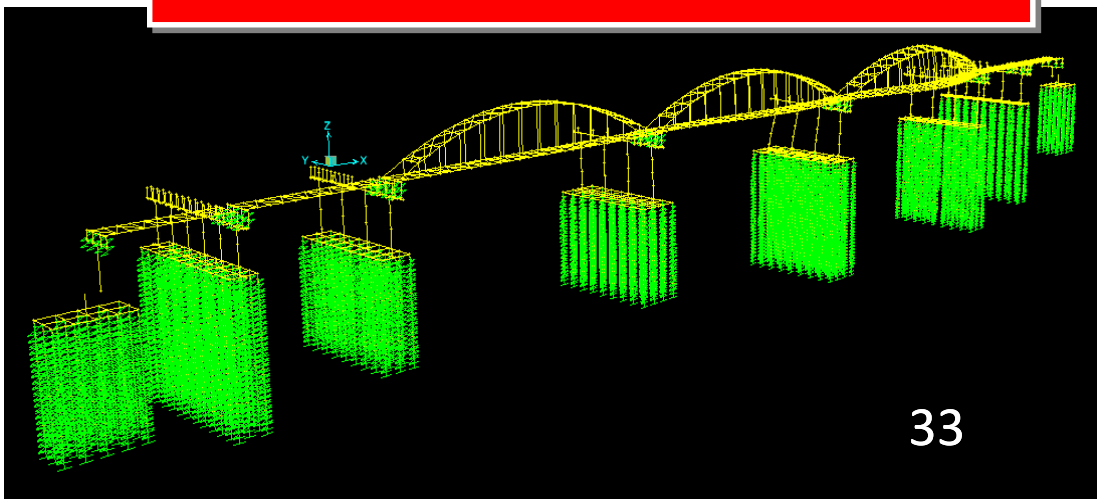
Water pipe bridge C-SAP2000 model and modal analysis



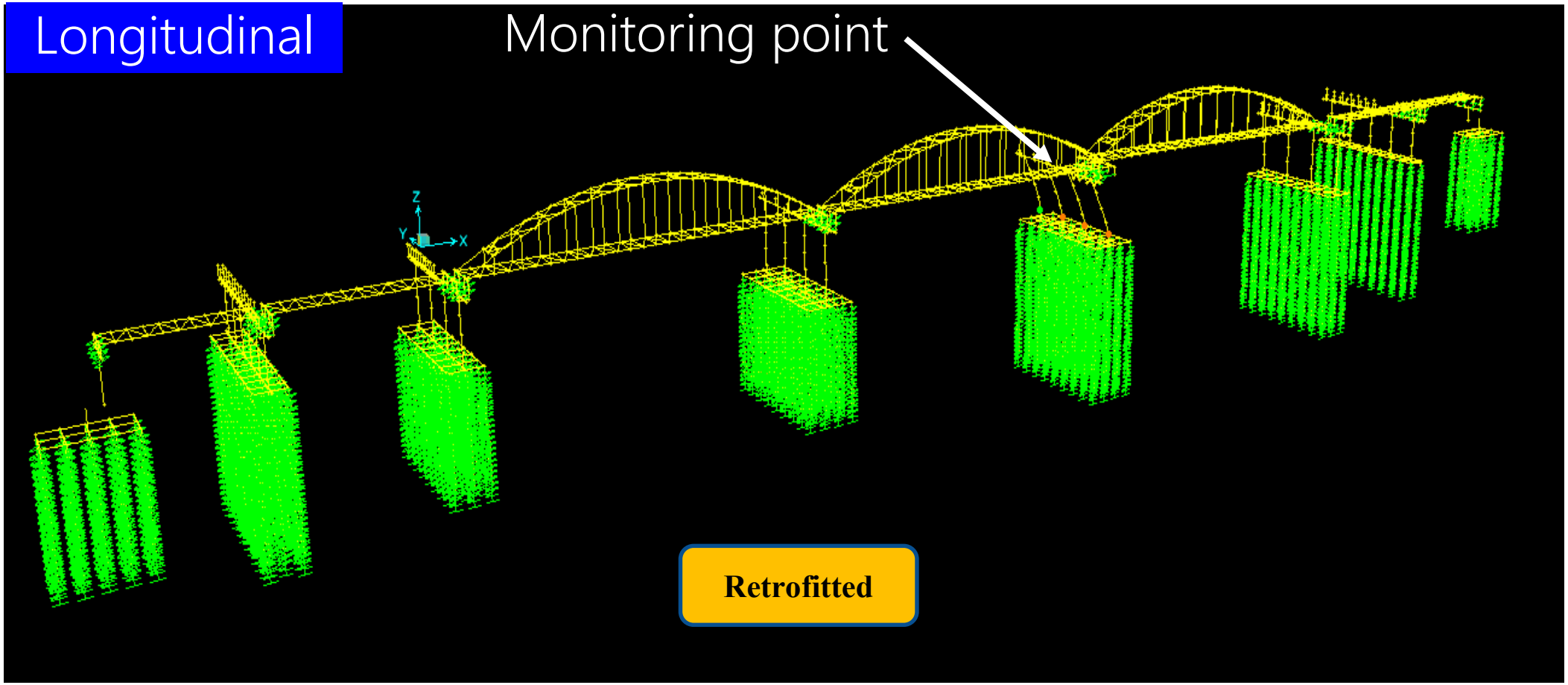
Longitudinal model:1.55 sec

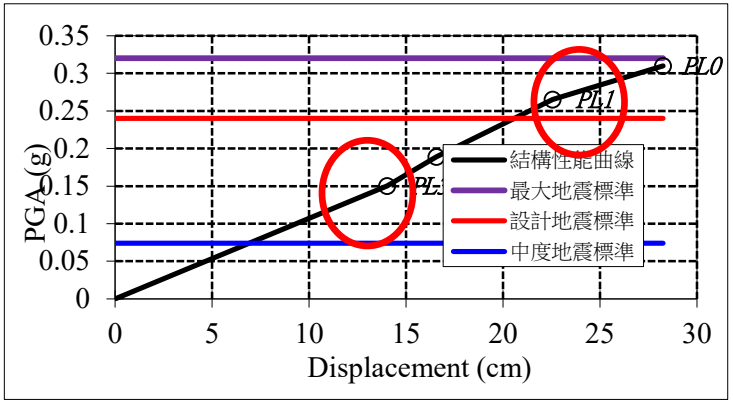


Transverse model:0.87 sec



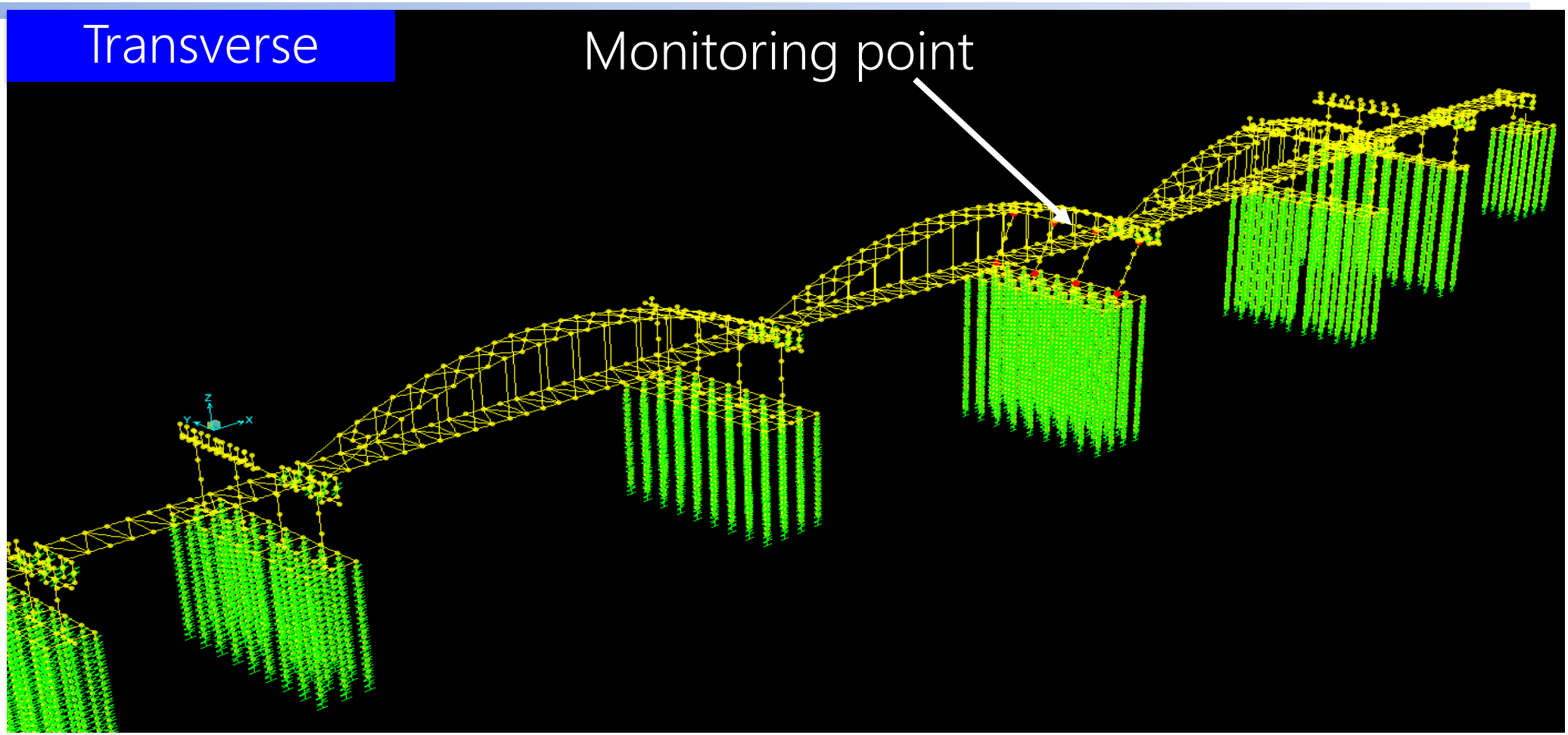
Pushover analysis(1/2)

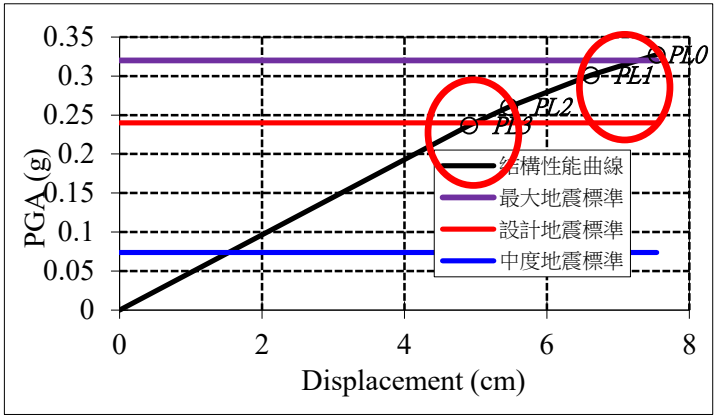




Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	performance	PGA (g)	Seismic demand check
Moderate	0.074 g	PL3	0.150	OK
Design	0.240 g	PL1	0.265	OK

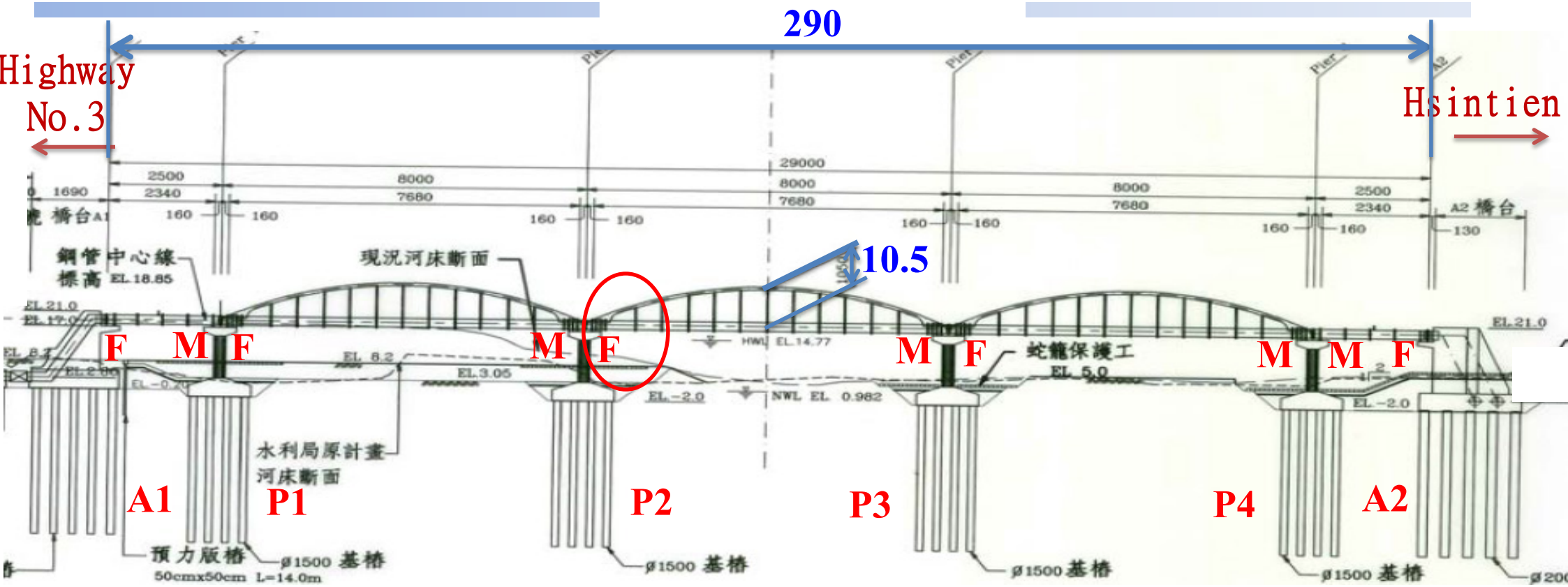
Pushover analysis(2/2)





Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	performance	PGA (g)	Seismic demand check
Moderate	0.074 g	PL3	0.237	OK
Design	0.240 g	PL1	0.301	OK

Water pipe bridge D-structure description

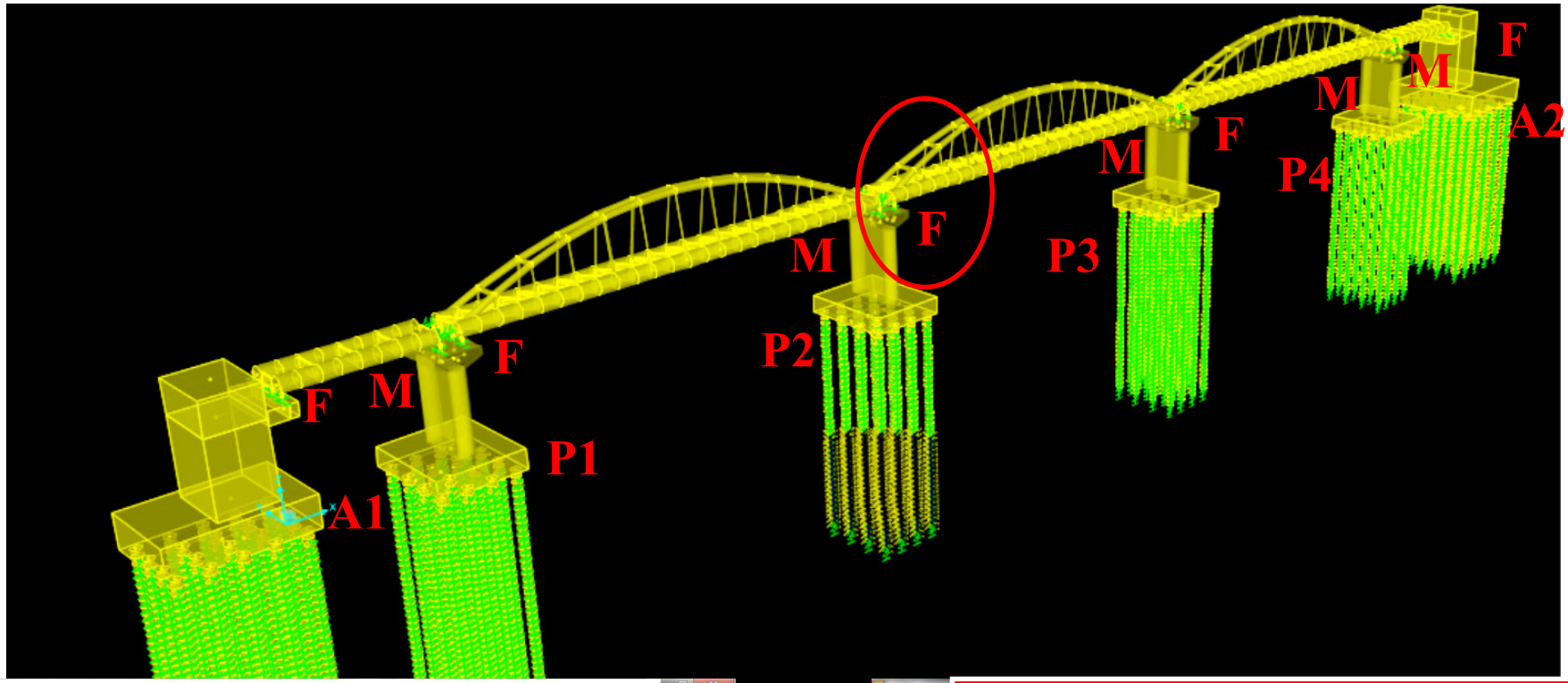


- Structure description

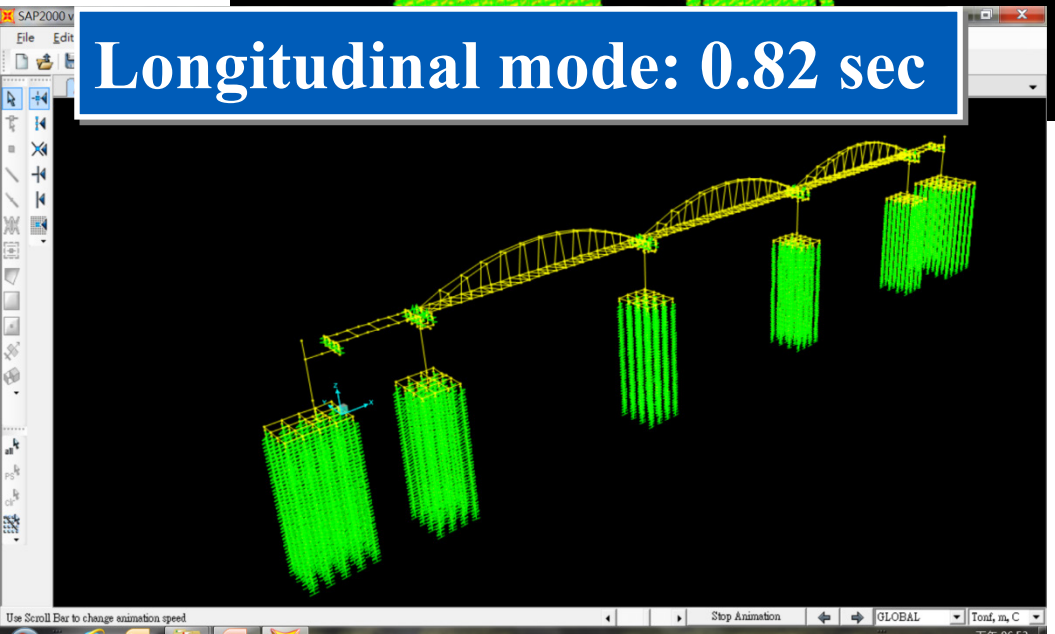
New Code

- **multi-span simply supported arch steel bridge; completion year in 1998; Bridge length: 290 m; arch height: 10.5 m**
- **Steel pipe diameter: 2400mm;**
- **Concrete: fc'=240 kgf/cm^2; steel: A36**

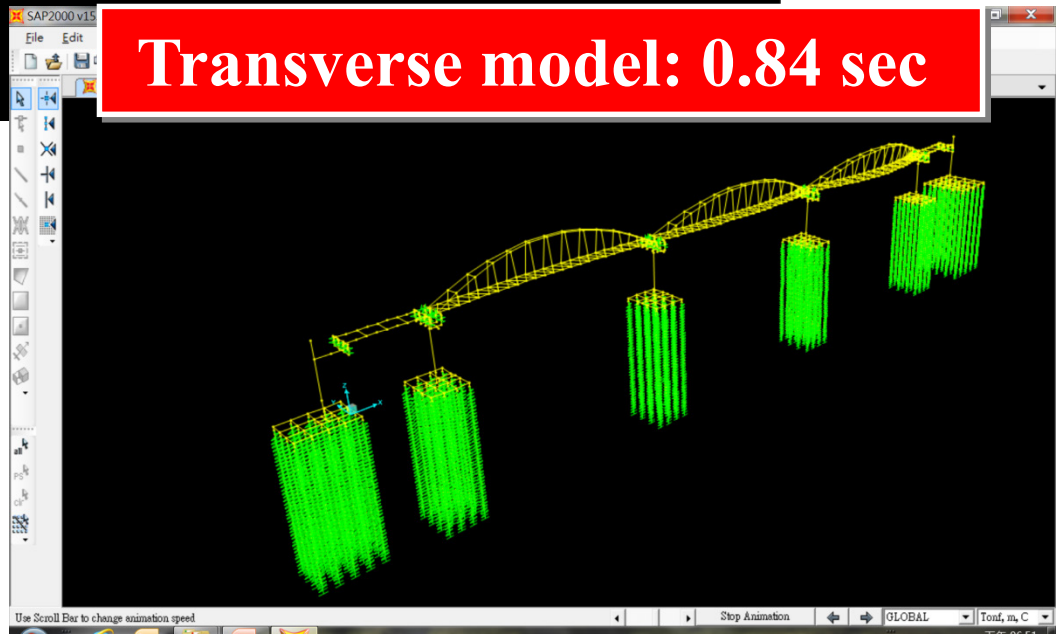
Water pipe bridge D-SAP2000 model and modal analysis



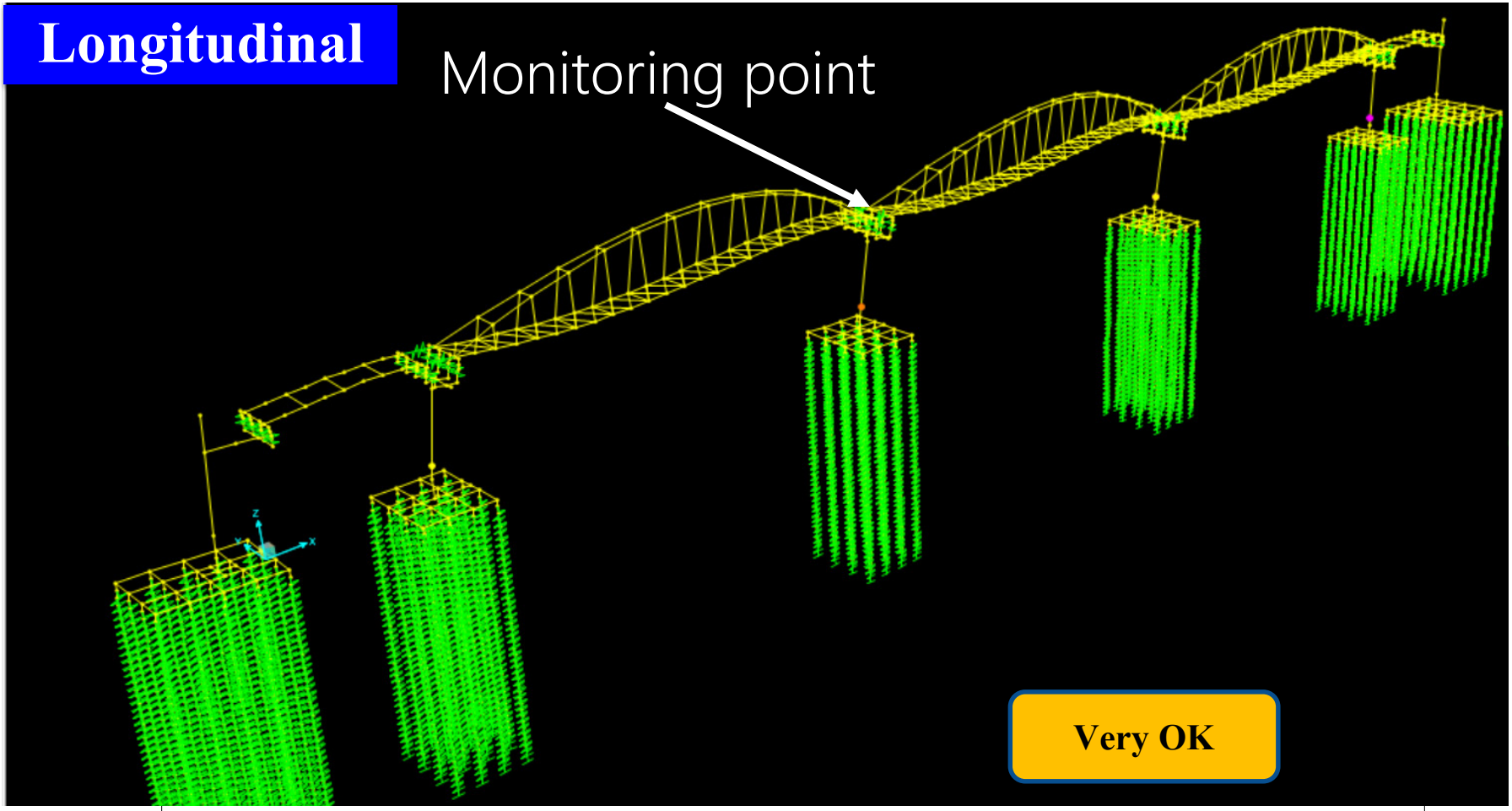
Longitudinal mode: 0.82 sec

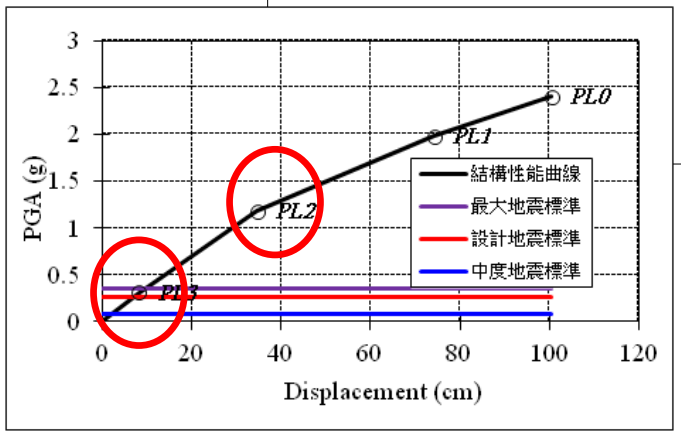


Transverse model: 0.84 sec



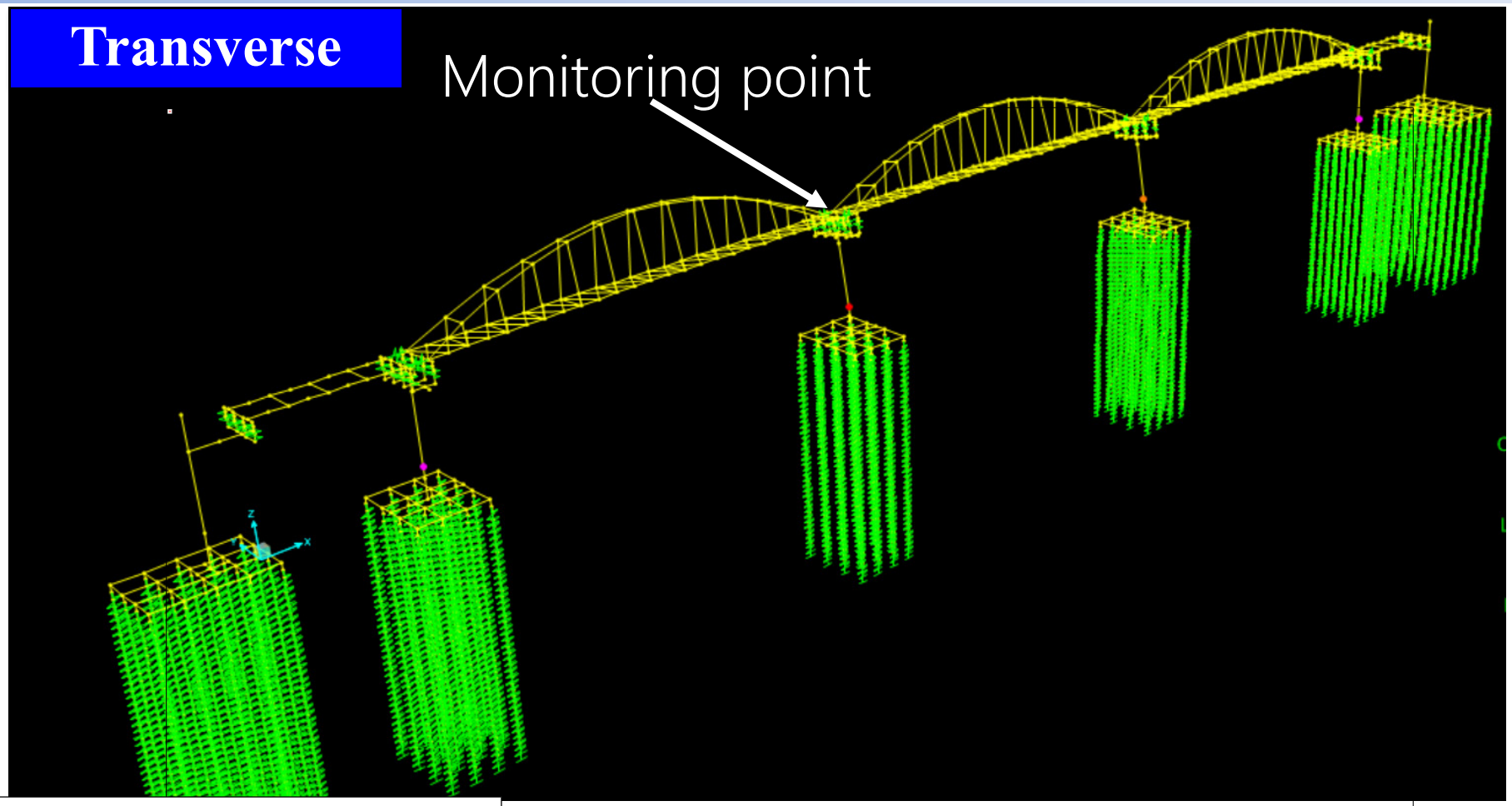
Pushover analysis(1/2)

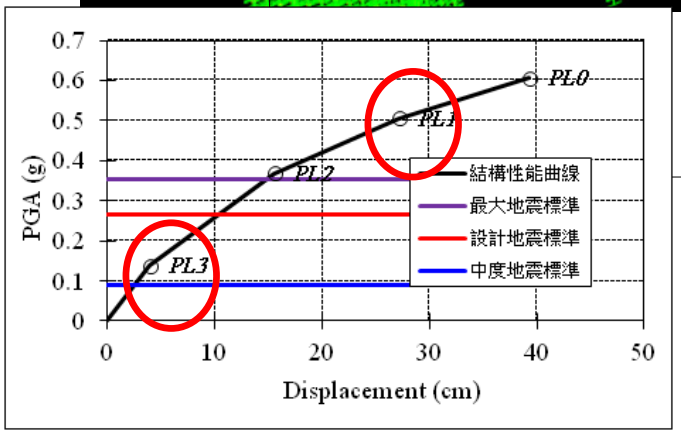




Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	perform ance	PGA (g)	Seismic demand check
Moderate	**0.074**	**PL3**	**0.313**	**OK**
Design	**0.240**	**PL2**	**1.181**	**OK**

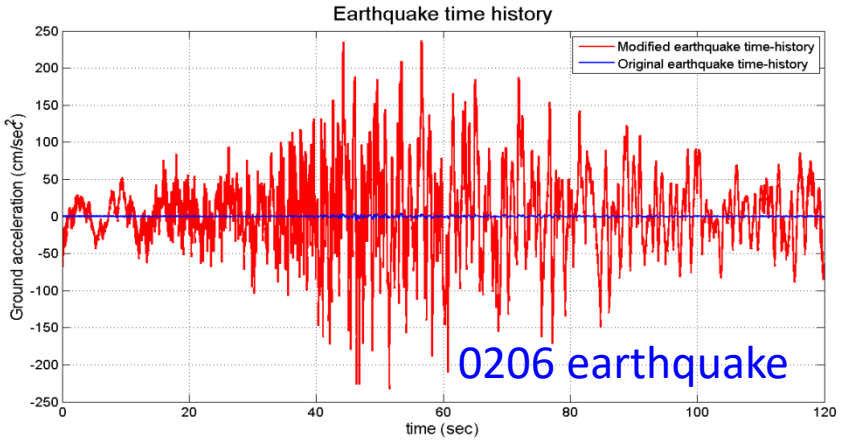
Pushover analysis(2/2)

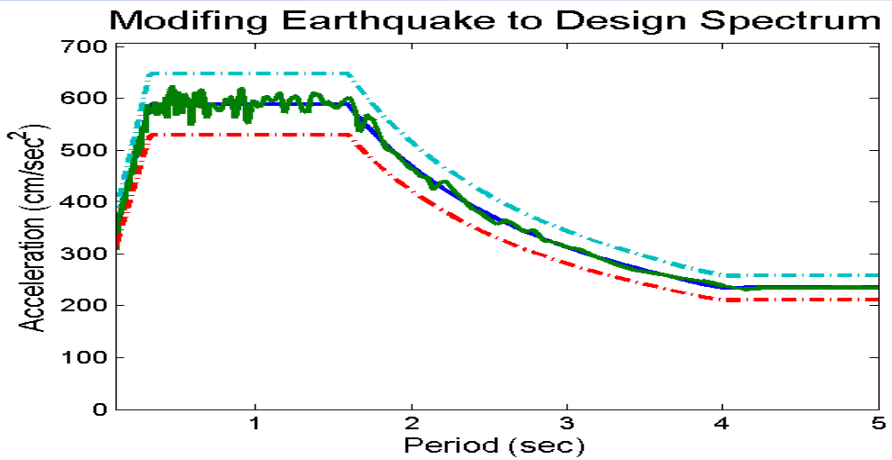


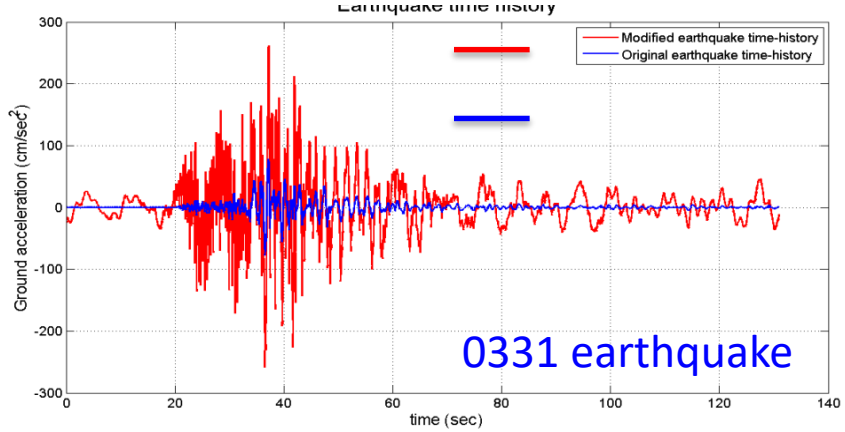


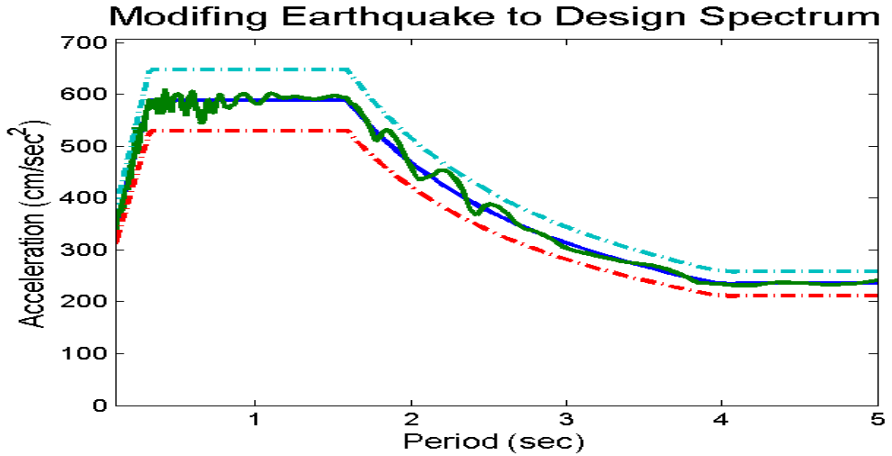
Performance objective		Analysis unit		
Earthquake level	Ground Acc. (g)	perform ance	PGA (g)	Seismic demand check
Moderate	**0.074**	**PL3**	**0.138**	**OK**
Design	**0.240**	**PL2**	**0.369**	**OK**

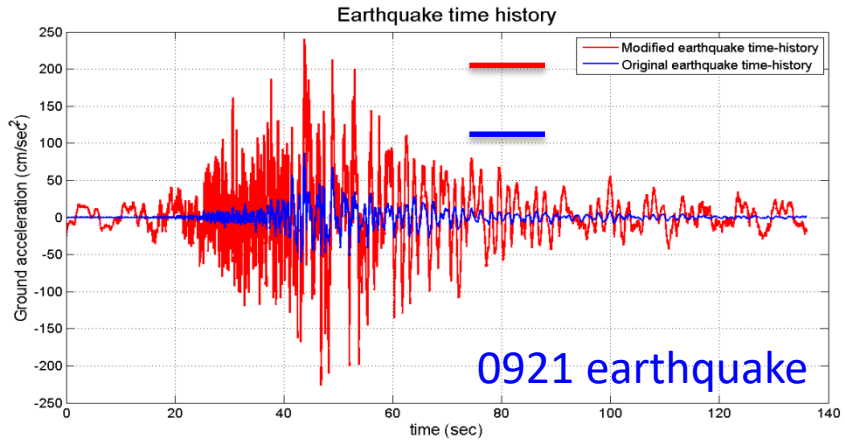
Time history analysis-Artificial time history

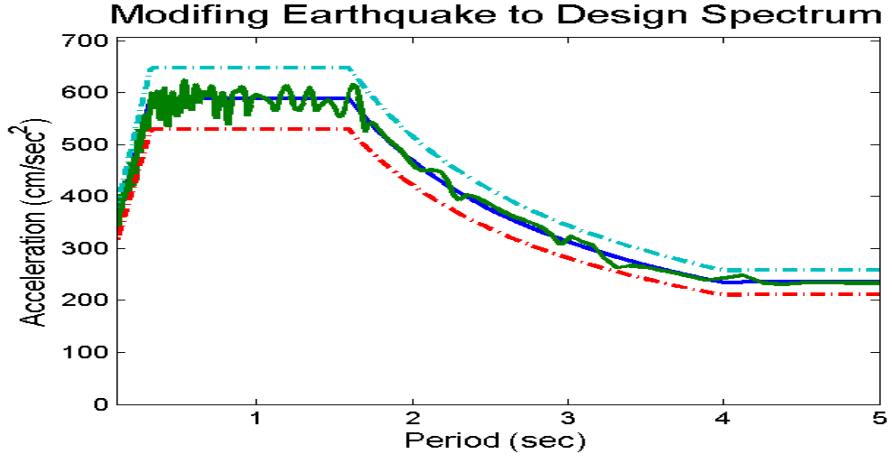












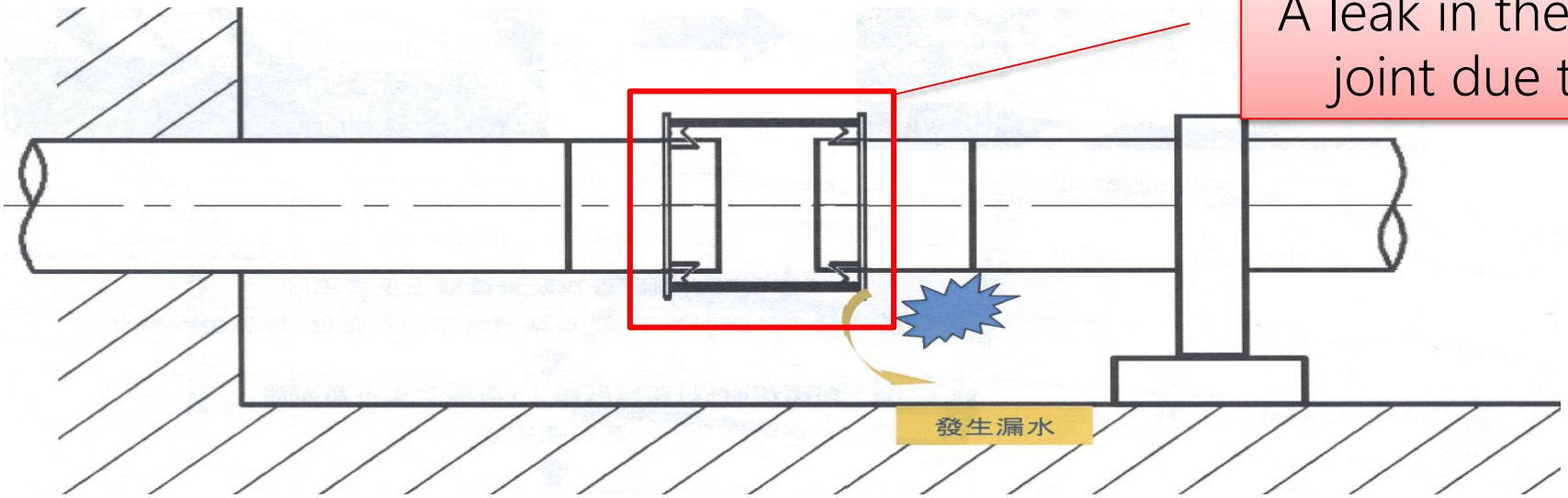
Pipe expansion joint check

Bridge	Earthquake station/record	Axial displacement (Demand)	Bridge	Earthquake station/record	Axial displacement (Demand)
A	TAP007/0206	4.37 cm	B	TAP007/0206	11.83 cm
	TAP008/0331	5.01 cm		**TAP008/0331**	**23.48 cm**
	TAP013/0921	4.35 cm		TAP006/0921	15.86 cm
C	**TAP029/0206**	**22.0 cm**	D	TAP033/0331	5.71 cm
	TAP028/0331	**23.8 cm**		TAP053/0401	2.24 cm
	TAP028/0921	**21.2 cm**		TAP034/0921	4.35 m

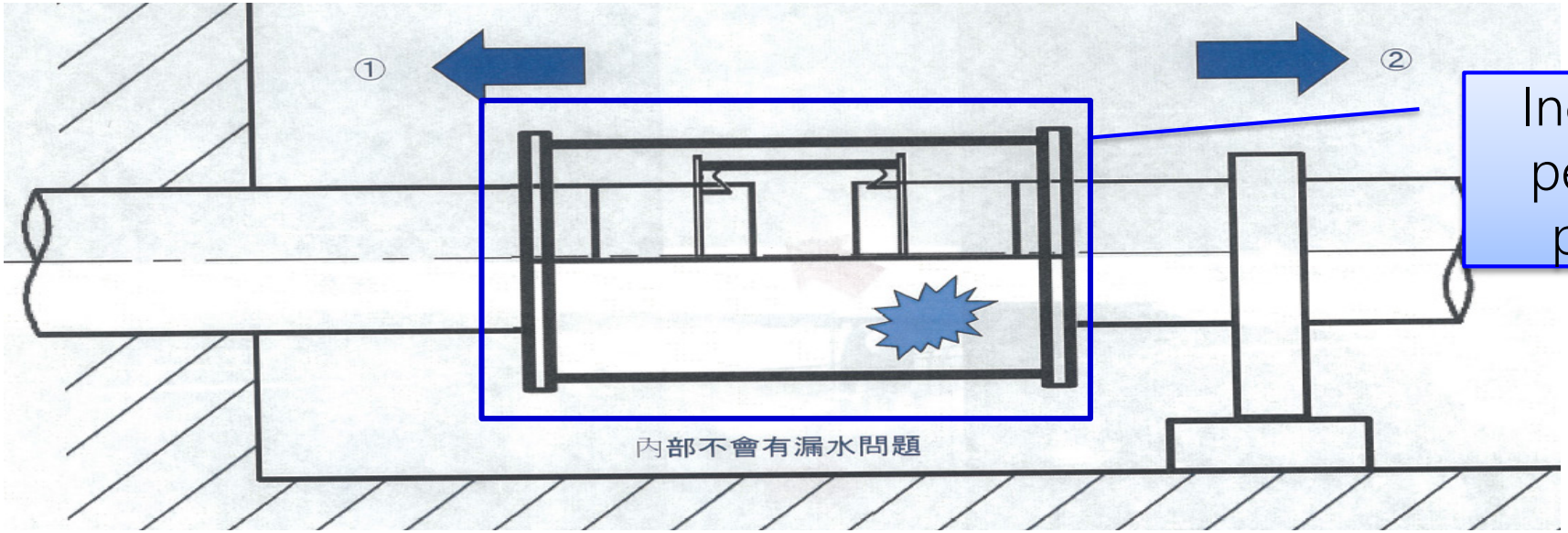
Pipe expansion joint demand are larger than flexible capacity

Additional Outer flexible expansion joint

Retrofit scheme-Outer flexible expansion joint



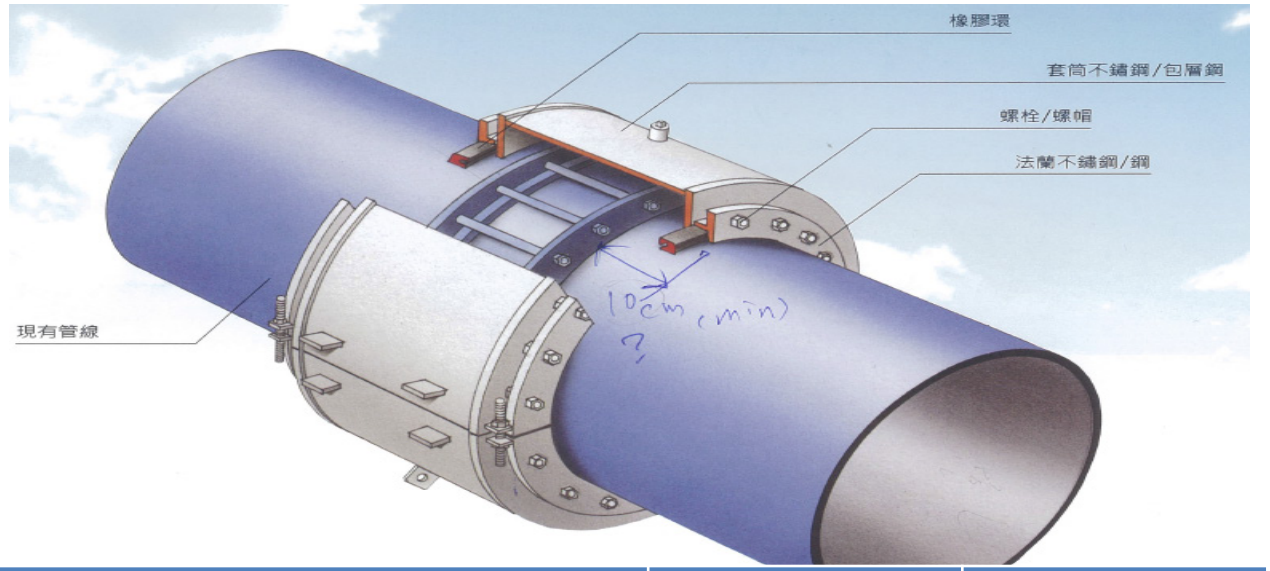
A leak in the pipe expansion joint due to earthquake

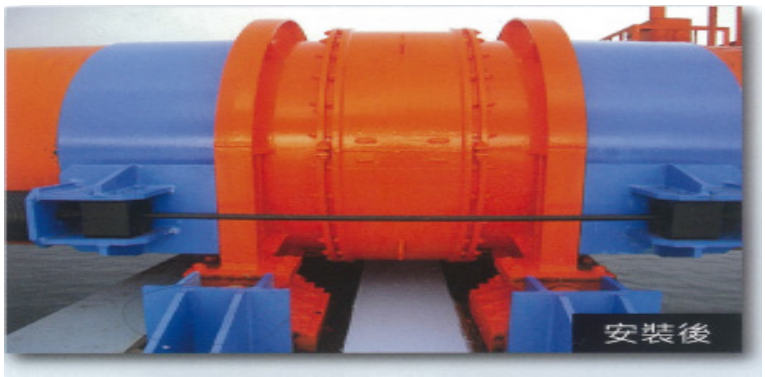


Increasing seismic performance and preventing leak

Reference: THE VICTAULIC COMPANY OF JAPAN LIMITED

Retrofit scheme-Outer flexible expansion joint





Item	Unit	prices(NT)
Flexible expansion joint	lump sum	4,050,000
Tariff (including transport)	--	432,000
Technical support	22 man-day	400,000
Installation and construction	lump sum	480,085

Small installation space

About 5,362,085 (NT)

Reference: THE VICTAULIC COMPANY OF JAPAN LIMITED

Bearing strength check

Bridge		A		B	
Abutment		A1/A2		A1/A2	
Direction		Longitudinal	Transverse	Longitudinal	Transverse
Demand	ton	126.6/--	128.2/128.2	--/--	48/76
Capacity	ton	34.2/--	41.0/41.0	--/--	41.0/41.0
C/D value		0.27/--	0.31 /0.31	--/--	0.85 /0.54
Check		N.G.	N.G.	--/--	N.G.

Bridge		C		D	
Abutment		A1/A2		A1/A2	
Direction		Longitudinal	Transverse	Longitudinal	Transverse
Demand	ton	126.6/--	128.2/128.2	106/89	19.8/35.5
Capacity	ton	34.2/--	41.0/41.0	34.2/34.2	41.0/41.0
C/D value		0.27/--	0.31 /0.31	0.32/0.38	2.0 /1.15
Check		N.G.	N.G.	N.G.	OK

Bearing seismic demand are larger than Bearing capacity

Bearing Retrofit scheme - steel anti-shock devices

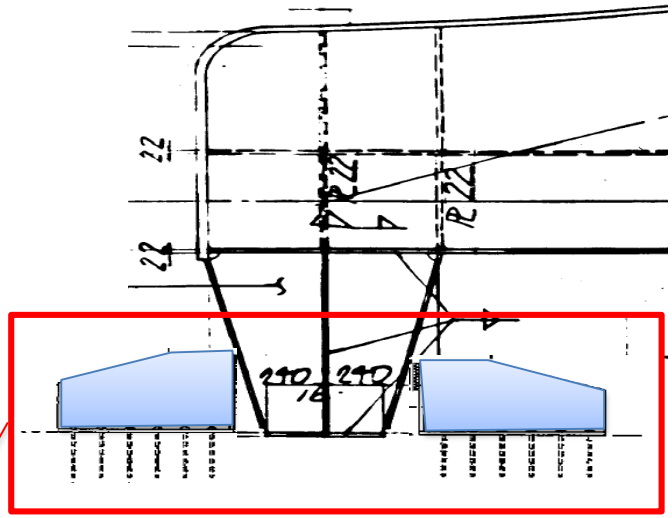
Retrofit scheme		Function Impact	Construction	Costs	**Duration**	**Maintain**
Scheme 1	Replace-ment bearing	Acceptable	Acceptable	Acceptable	Acceptable	Excellent
Scheme 2	Steel anti-shock devices	Excellent	Excellent	Excellent	Excellent	Acceptable

Retrofit scheme 2 is proposed

Retrofit scheme - steel anti-shock devices

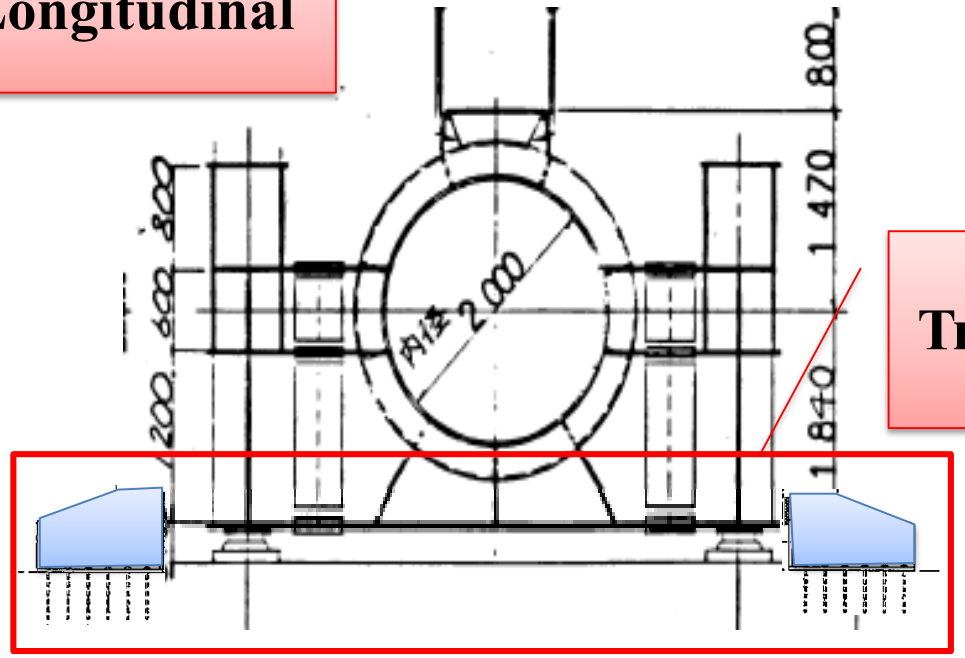
Steel anti-shock devices

Bearing Side elevation



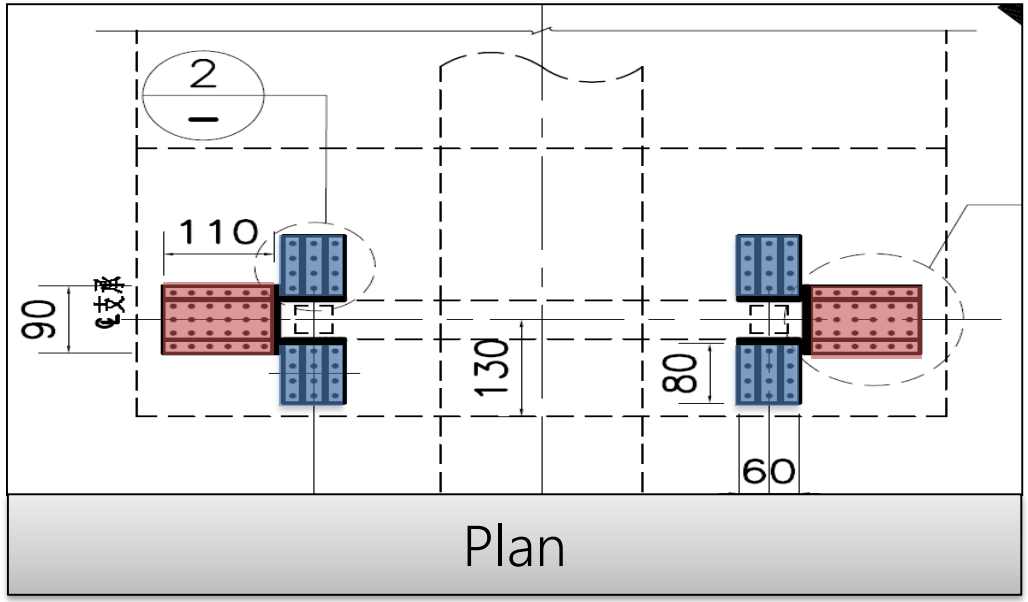
Bearing elevation

Longitudinal

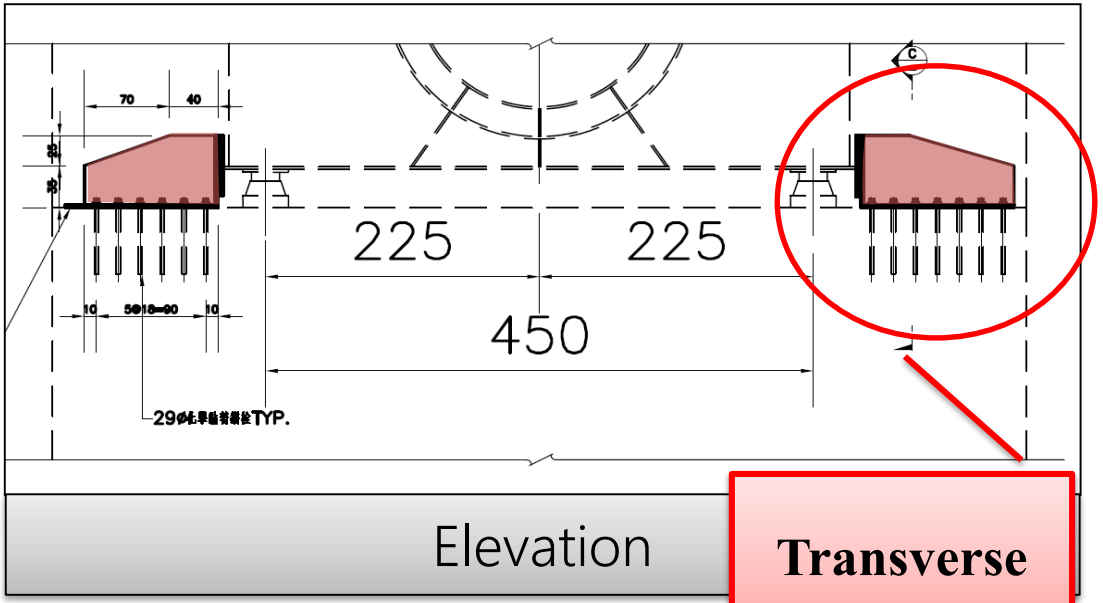


Transverse

Retrofit scheme - steel anti-shock devices

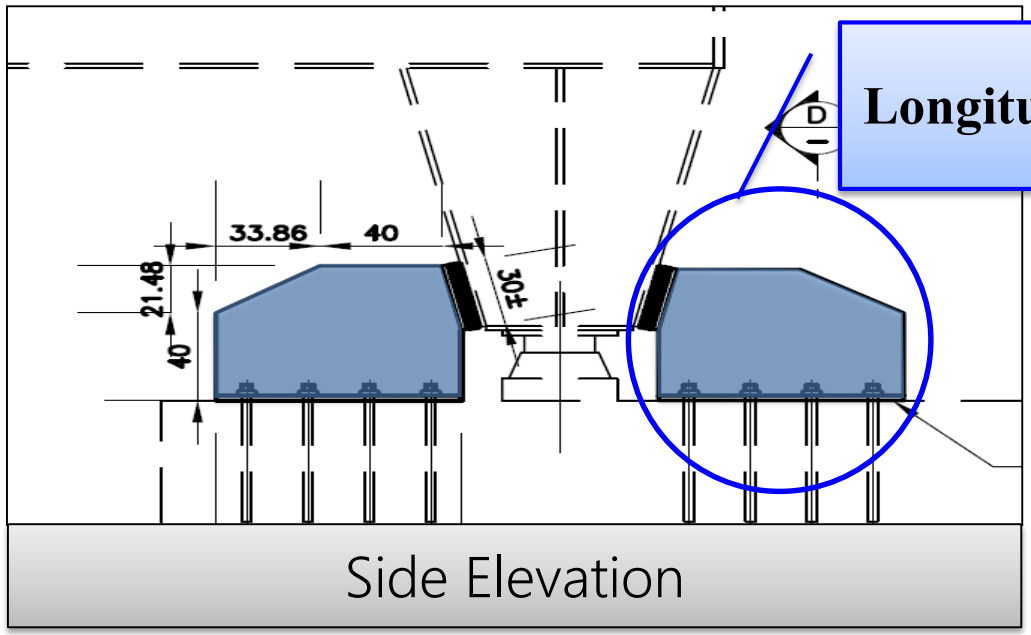


Plan



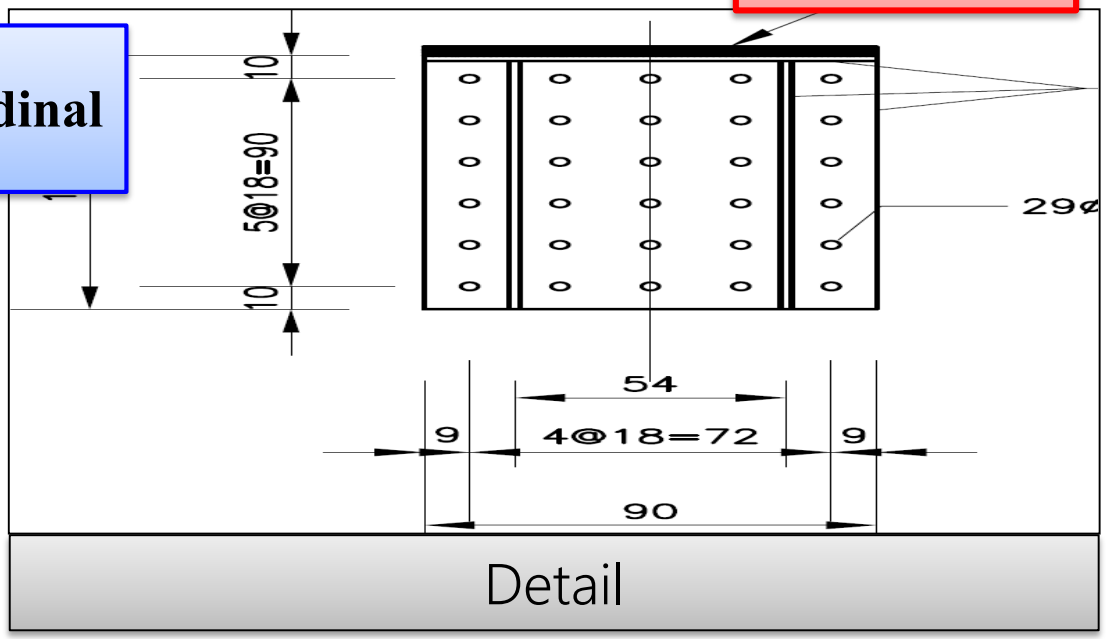
Elevation

Transverse



Side Elevation

Longitudinal



Detail

04

Conclusion

Conclusion

Seismic Evaluation Results & NG parts will be retrofitted

Bridge	Superstructure		1.2 Column Vert. & Hori.	3.Pipe expansion joints	4.Foundation
	Main Girder	3.Bearing			
A Old Code	OK	NG	Abutment ,OK	OK	OK
B Old Code	OK	NG	Just OK	NG	OK
C Old Code	OK	NG	Retrofitted,OK	NG	OK
D New Code	OK	NG	Very OK	OK	Very OK

Not as safe as Bridges designed by New code

Seismic Retrofit Schemes

- **The pipe expansion joints:**

  One is the replacement pipe expansion joint scheme, the other is the additional Outer flexible expansion joint scheme.

Water pipe bridge C

- **The bearings:**

  One is the replacement bearings scheme, the other is the additional RC or steel anti-shock devices scheme.


Thanks for your attention!
I'll appreciate your comments!
臺北自來水事業處
Taipei Water Department
中興工程顧問股份有限公司
SINOTECH ENGINEERING CONSULTANTS, LTD.