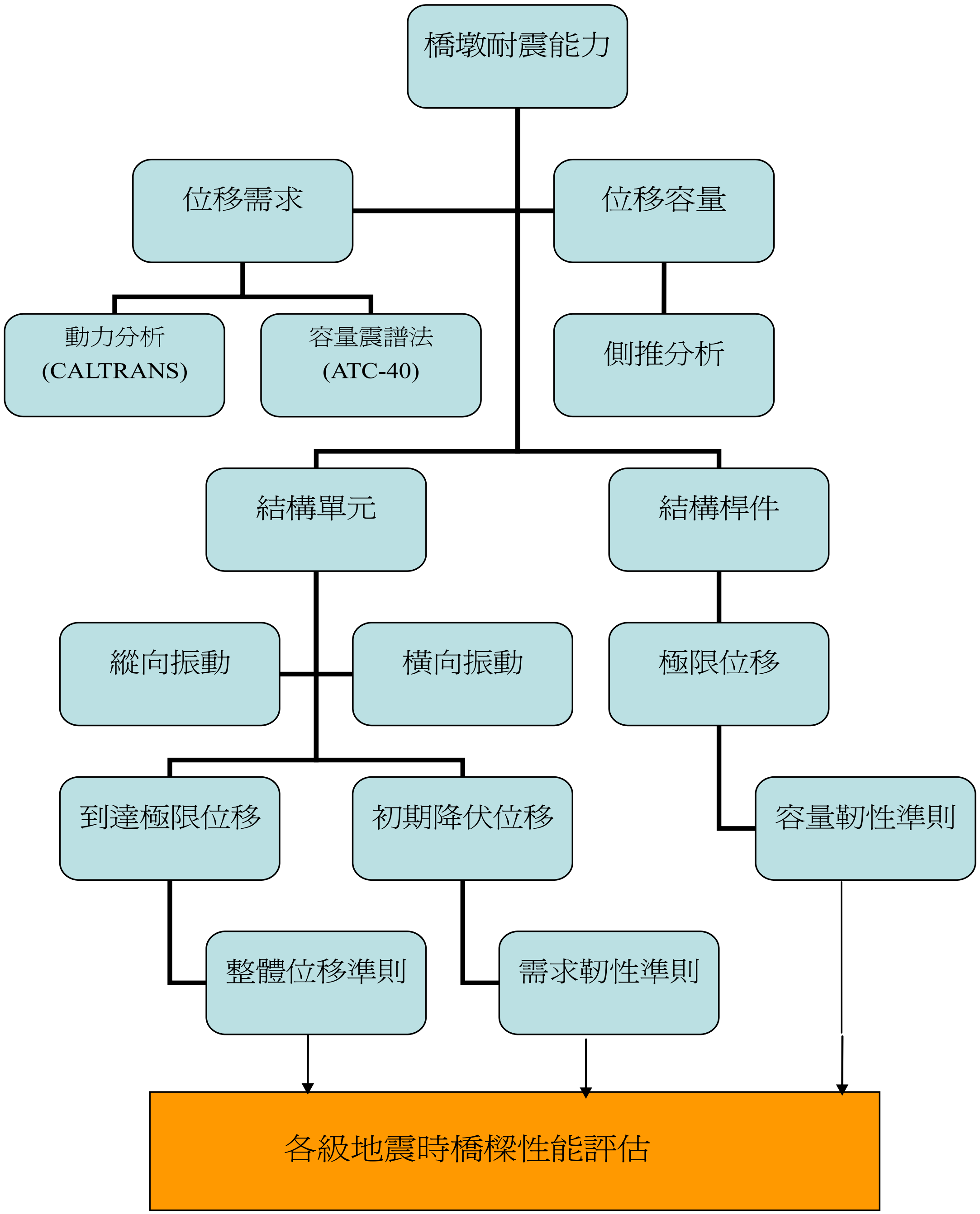
橋墩耐震能力
位移需求
位移容量
動力分析
(CALTRANS)
容量震譜法
(ATC-40)
側推分析
結構單元
結構桿件
縱向振動
橫向振動
極限位移
到達極限位移
初期降伏位移
容量韌性準則
整體位移準則
需求韌性準則
各級地震時橋樑性能評估

SEISMIC PERFORMANCE EVALUATION FOR BRIDGE STRUCTURES

Dr. Ching-Jong Wang

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Chartered Structural Engineer (Taiwan)

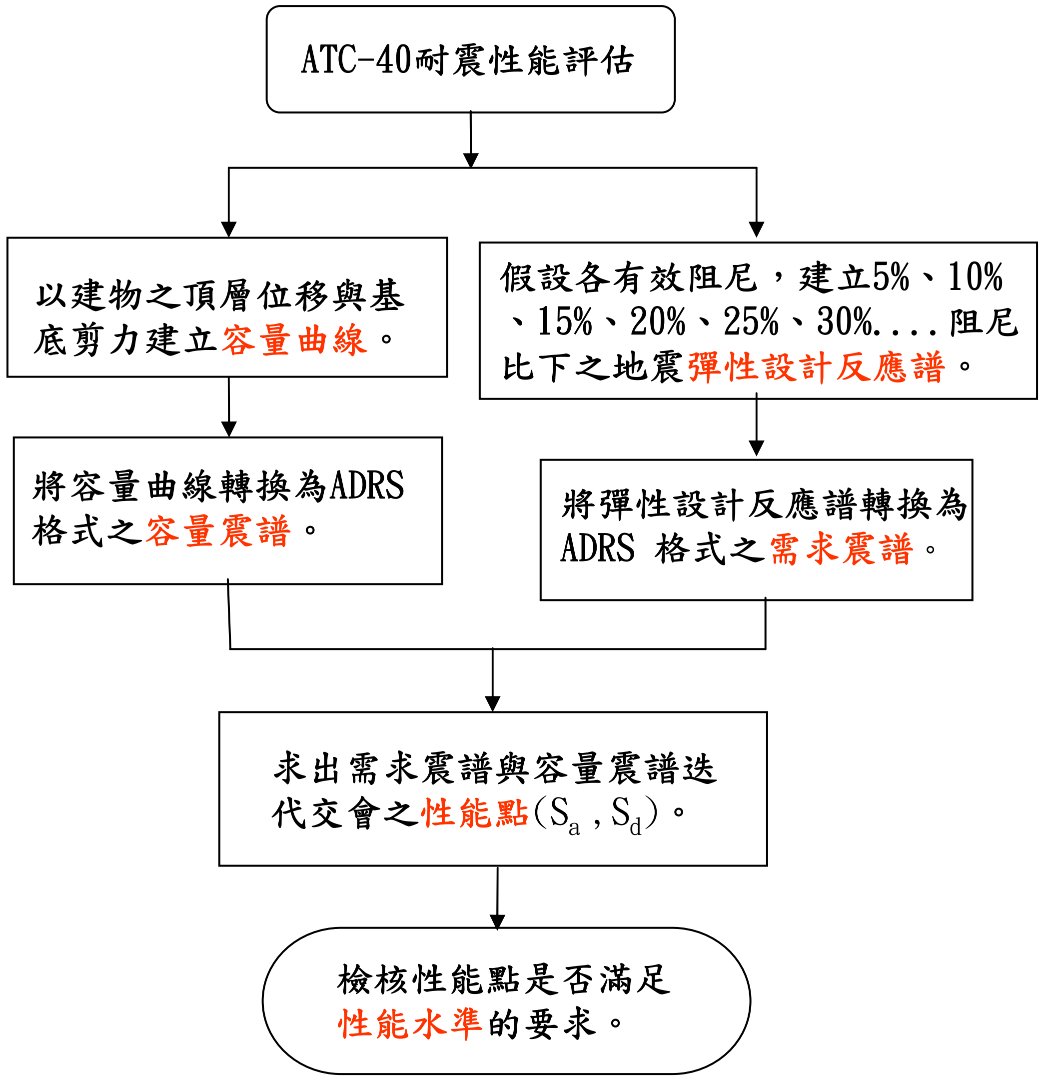
Kaohsiung First U of Science and Tech

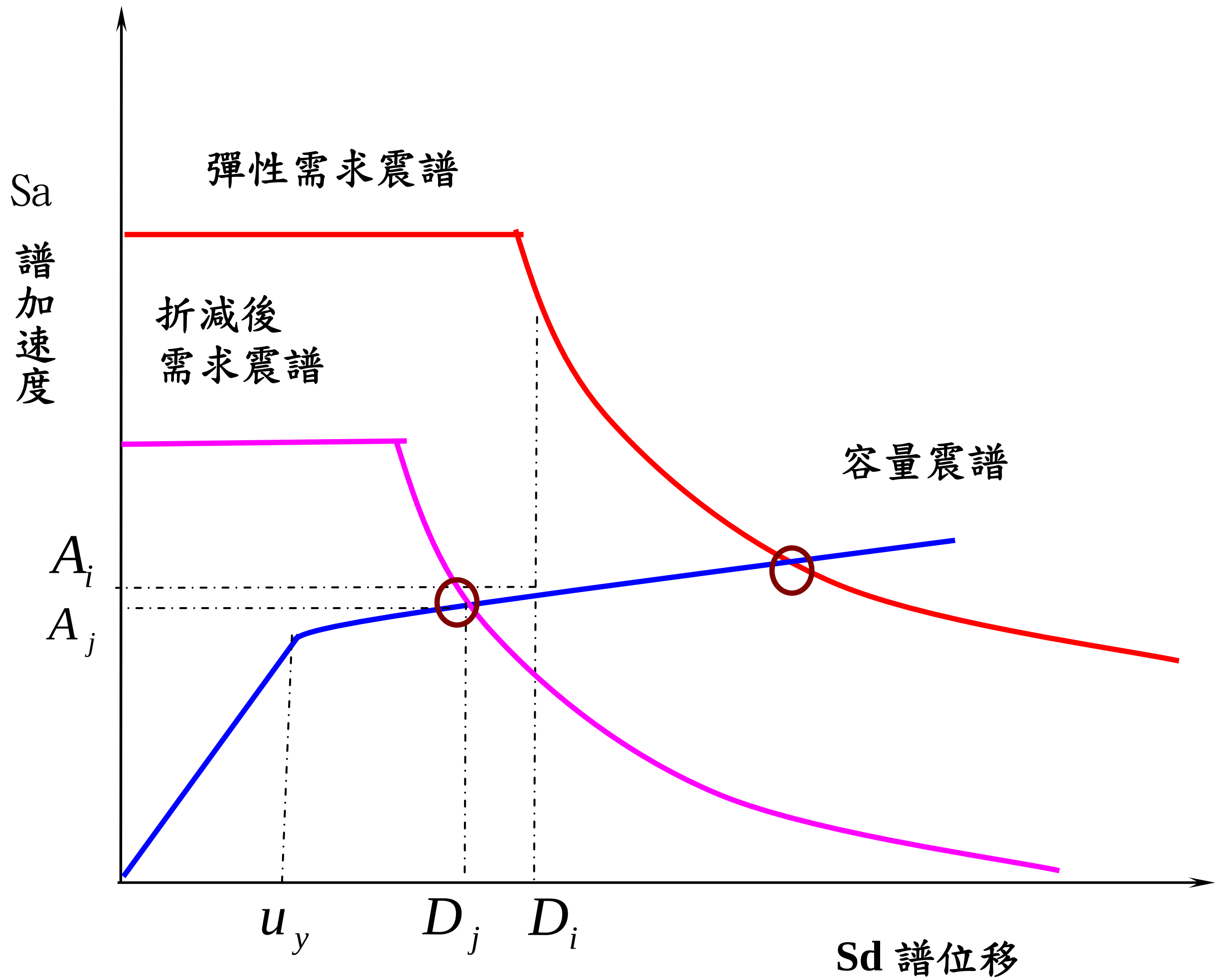
Asian Institute of Technology (visiting)

SEISMIC PERFORMANCE EVALUATION

- Displacement-based evaluation from yield to ultimate states
- Structure converted to an equivalent SDOF:

  ATC-40 Capacity Spectrum Method
- Structure modeled by frames, bents, and MDOF: CALTRANS Performance Criteria


ATC-40耐震性能評估
以建物之頂層位移與基底剪力建立容量曲線。
假設各有效阻尼，建立5%、10%、15%、20%、25%、30%....阻尼比下之地震彈性設計反應譜。
將容量曲線轉換為ADRS格式之容量震譜。
將彈性設計反應譜轉換為ADRS 格式之需求震譜。
求出需求震譜與容量震譜迭代交會之性能點(S_a , S_d)。
檢核性能點是否滿足性能水準的要求。

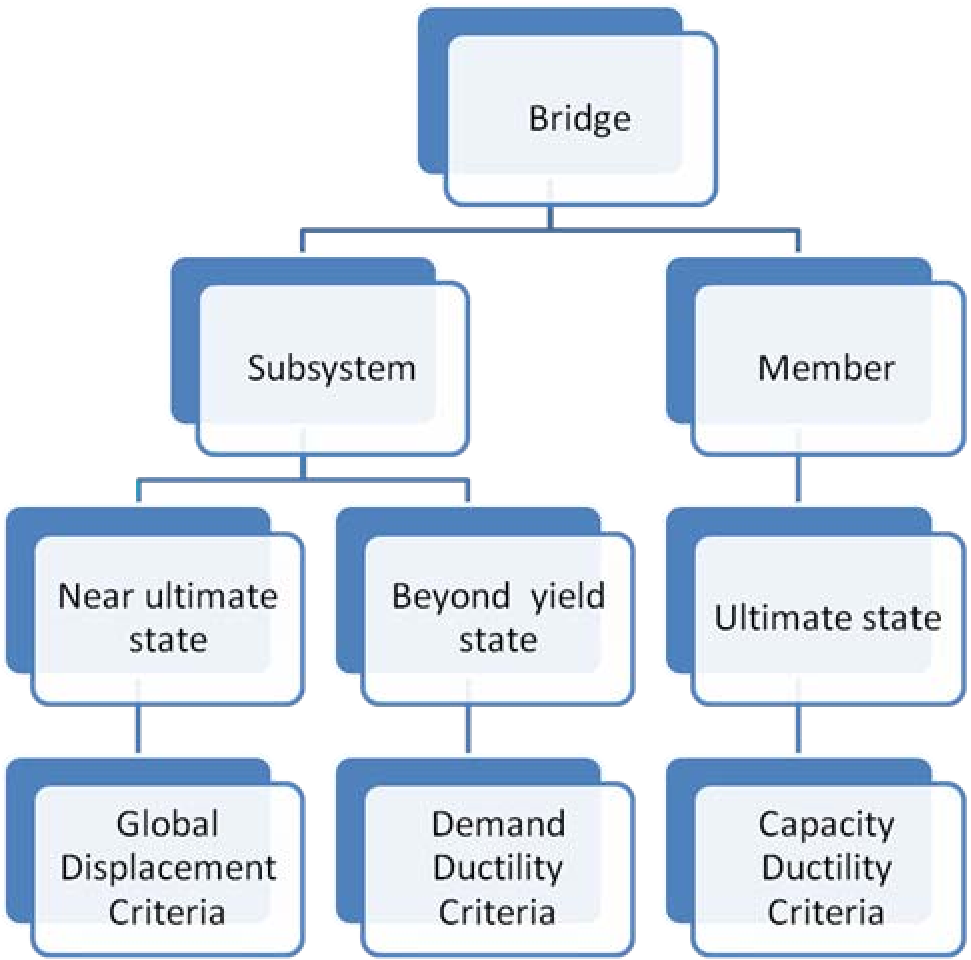


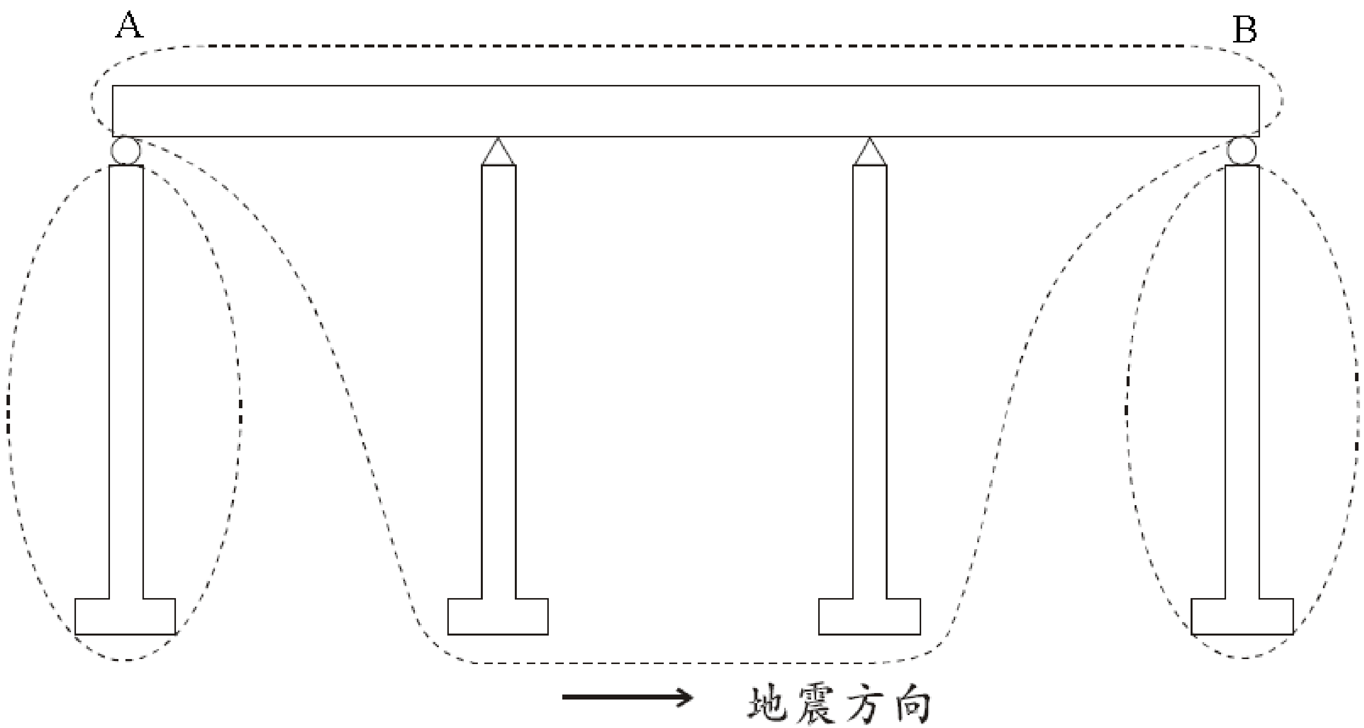
ADRS格式之性能點交會圖

Equivalent SDOF ?

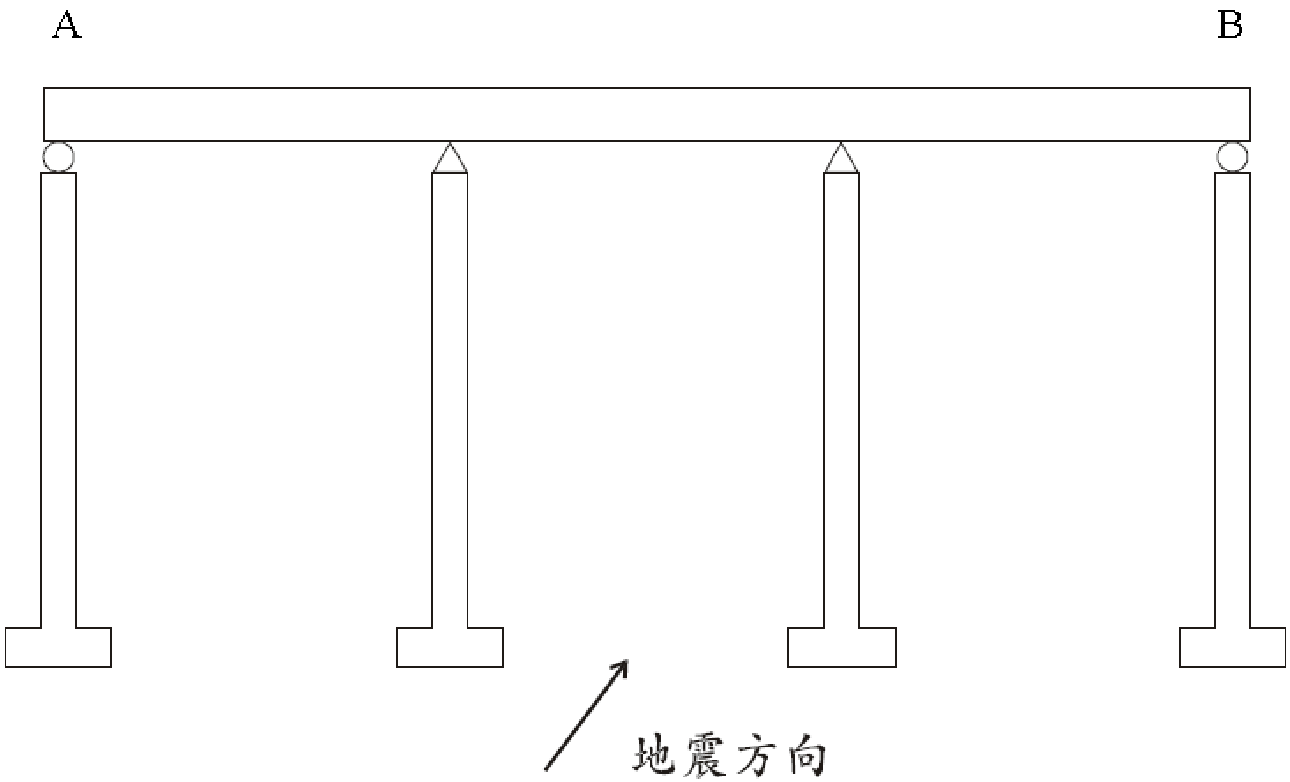
- First mode mass participation < 90% ?
- Period $T_1 > 1.0$ and $T_1 – T_i > 1.0$?
- Ratio PGV/PGA high ?
- Skew and curved bridges ?

CALTRANS Performance Criteria





(a) 軸向地震時



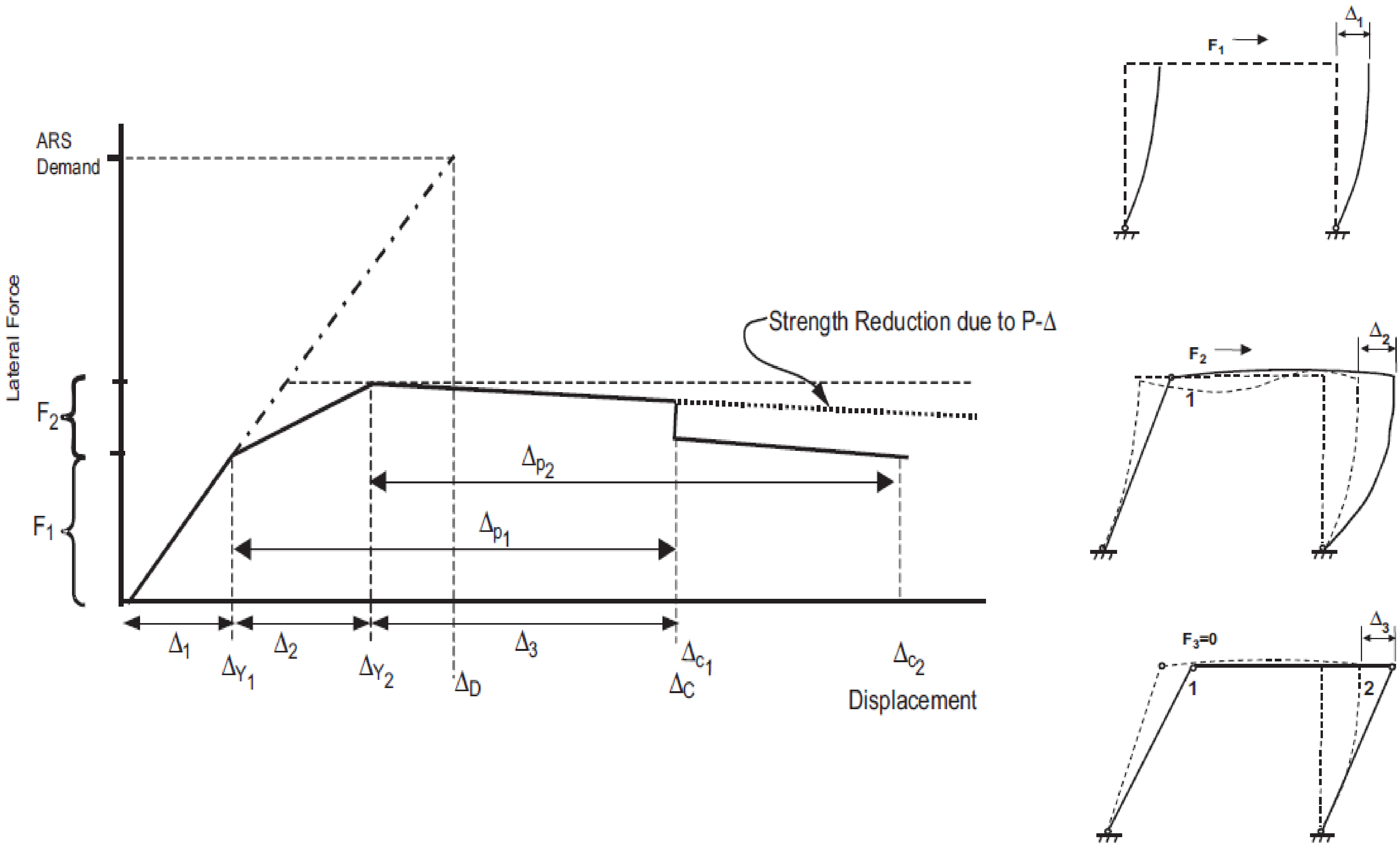
(b) 橫向地震時

圖 C1-1 橋梁之振動單元

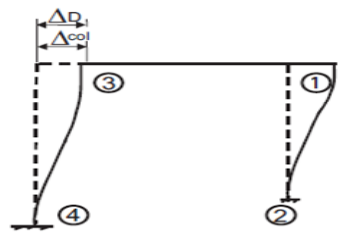
Global Displacement Criteria--subsystem

- $\Delta_D < \Delta_C$ for bridge subsytems
- Δ_D -- **demand** displacement, by elastic static or dynamic analysis.
- Δ_C -- **capacity** displacement, by push over analysis, taken as $\Delta_c(i)$ (when i-th ductile column approaching ultimate state)

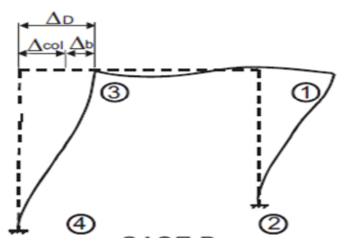
Capacity Vs. Demand[1]



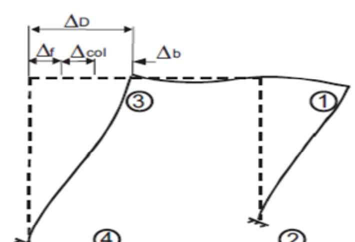
Demand displacements



CASE A
Rigid Bent Cap



CASE B
Flexible Bent Cap



CASE C
Flexible Bent Cap & Flexible Foundation

Demand Ductility Criteria-- subsystem

- **$\mu_D = \Delta_D/\Delta_Y(i)$**

  Single Column Bents $\mu_D \leq 4$

  Multi-Column Bents $\mu_D \leq 5$

  Pier Walls (weak axis) $\mu_D \leq 5$

  Pier Walls (strong axis) $\mu_D \leq 1$

- $\Delta_Y(i)$ -- yield displacement when i-th column was at yield state

Ductile Member Δ_c

- Measured from fixed end to inflection point--
- **$\Delta_c = \Delta_Y + \Delta_p$**

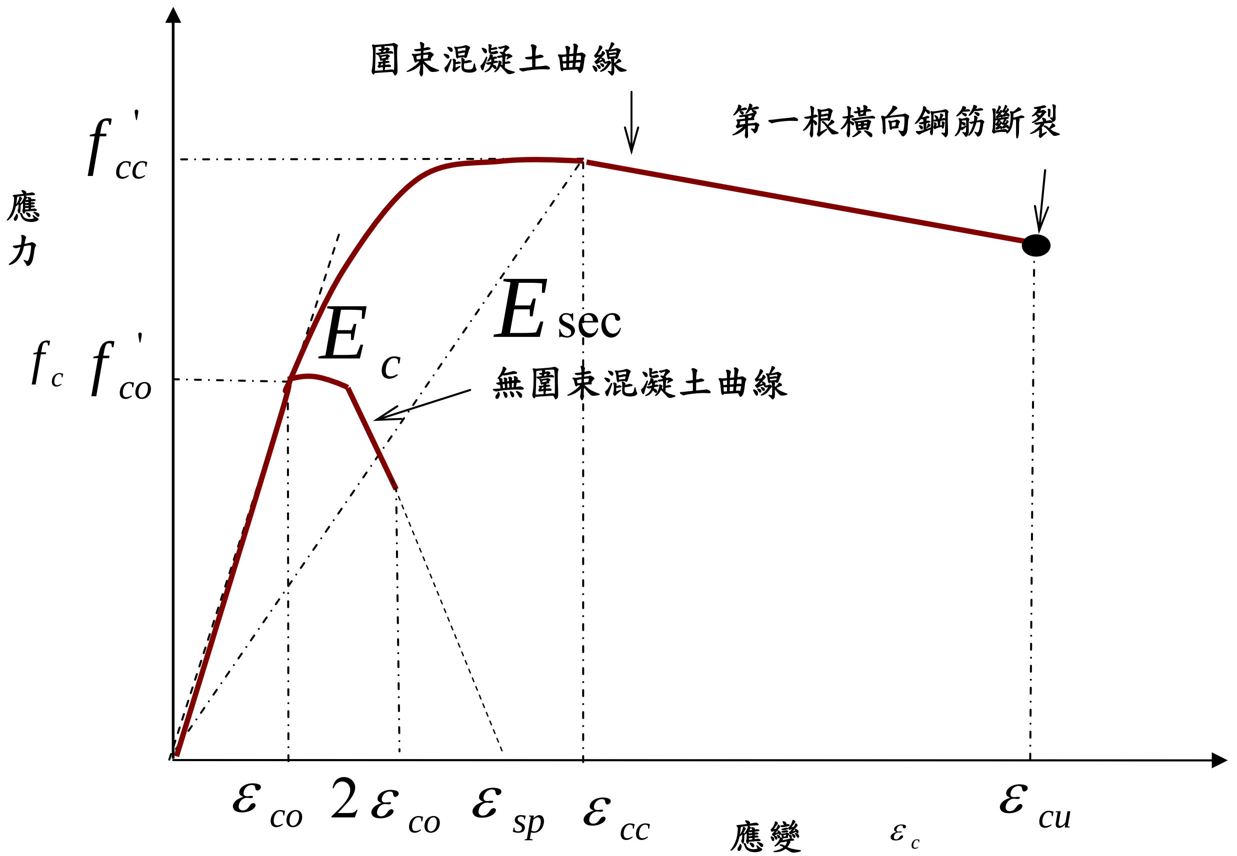
$$\Delta_Y = L^2/3 \times \phi_Y$$

$$\Delta_p = (L - L_p/2) \times \theta_p$$

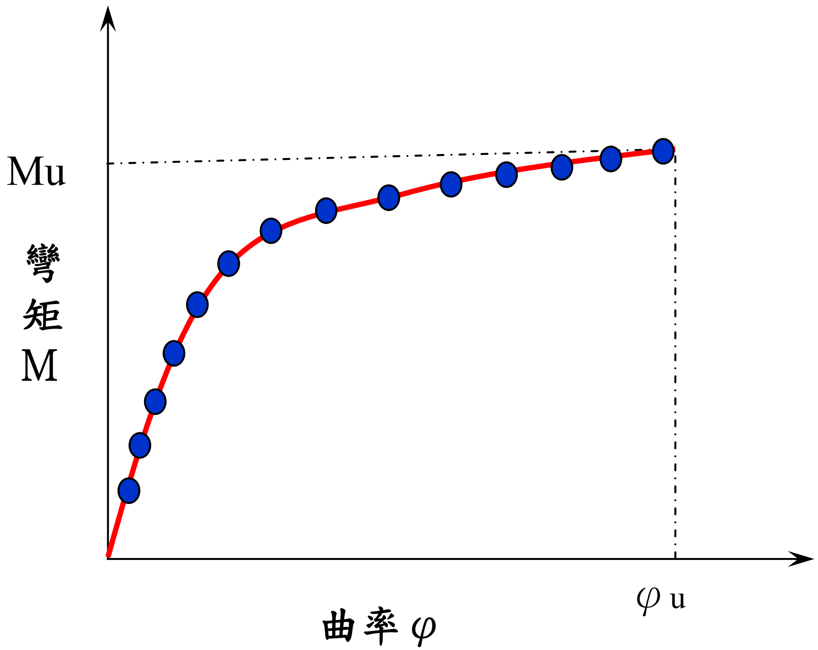
$$\theta_p = L_p \times \phi_p$$

$$\phi_p = \phi_u - \phi_Y$$

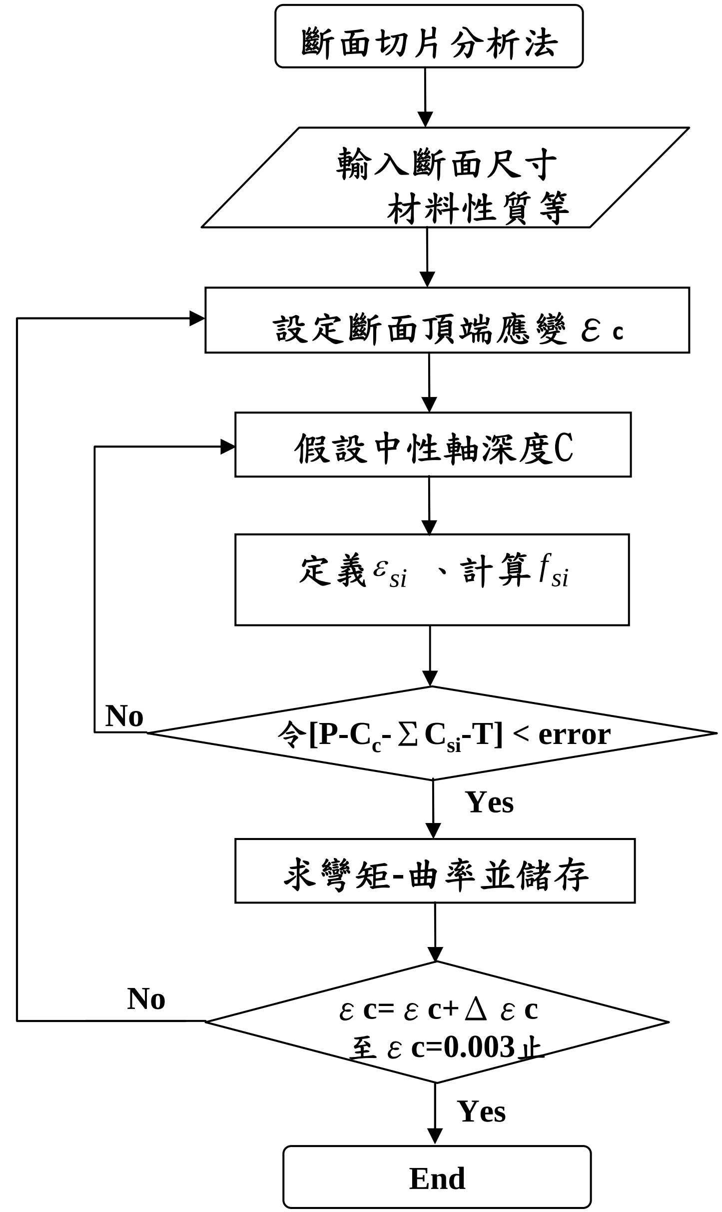
建立Mander材料組成律

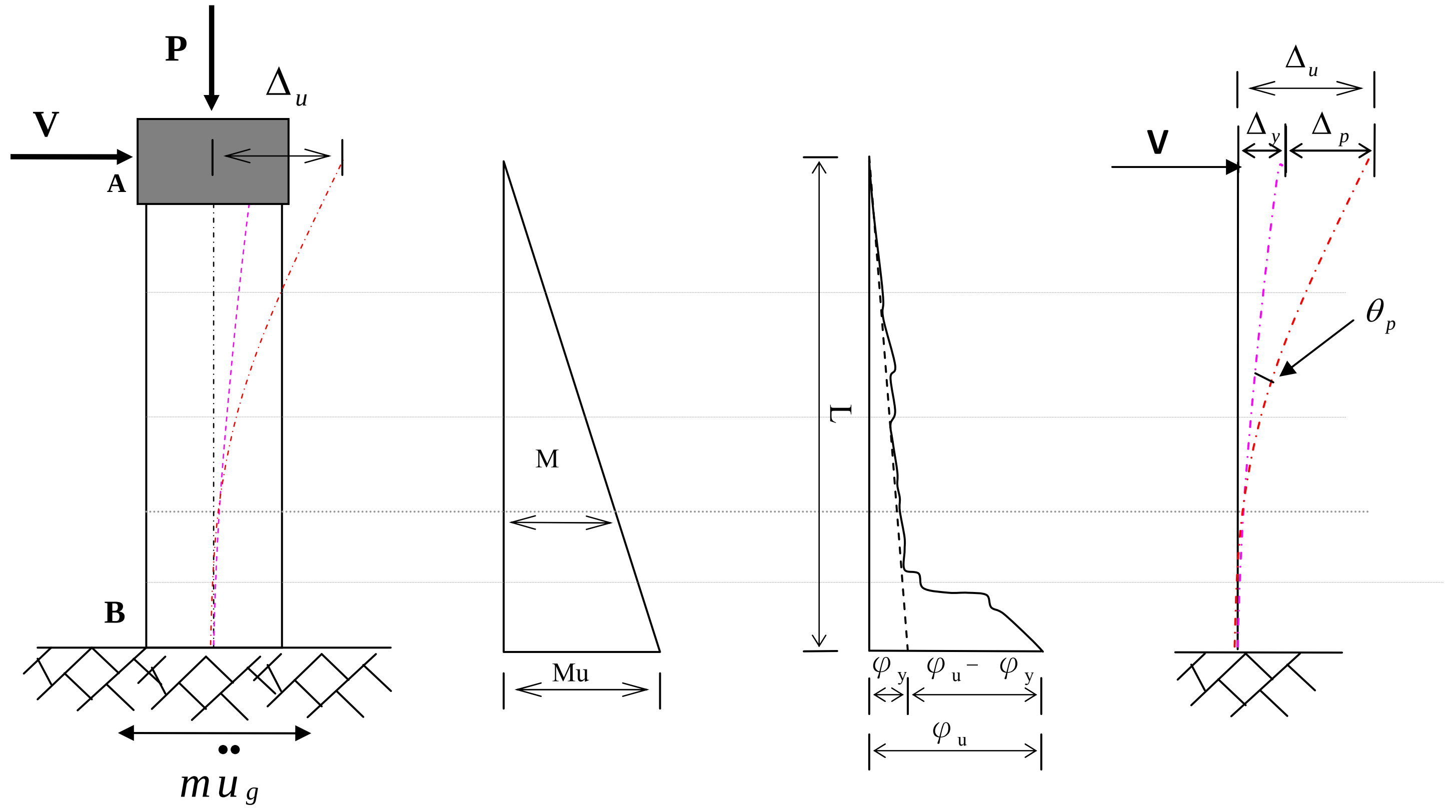


混凝土應力-應變關係曲線示意圖

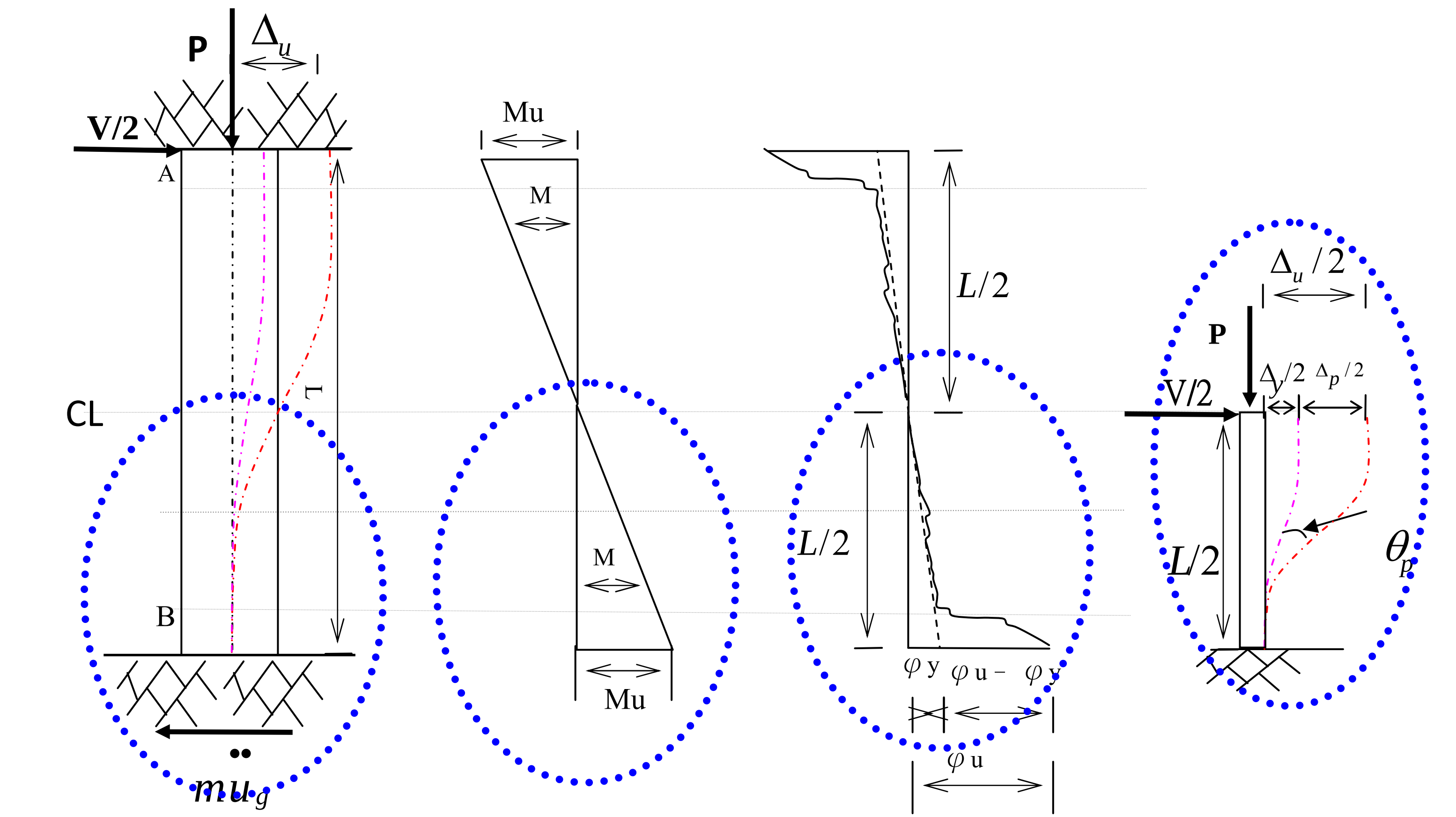


斷面之彎矩-曲率關係全曲線示意圖





(a)單柱橋墩受力示意圖　(b)彎矩示意圖　(c)真實曲率示意圖　(d)位移示意圖

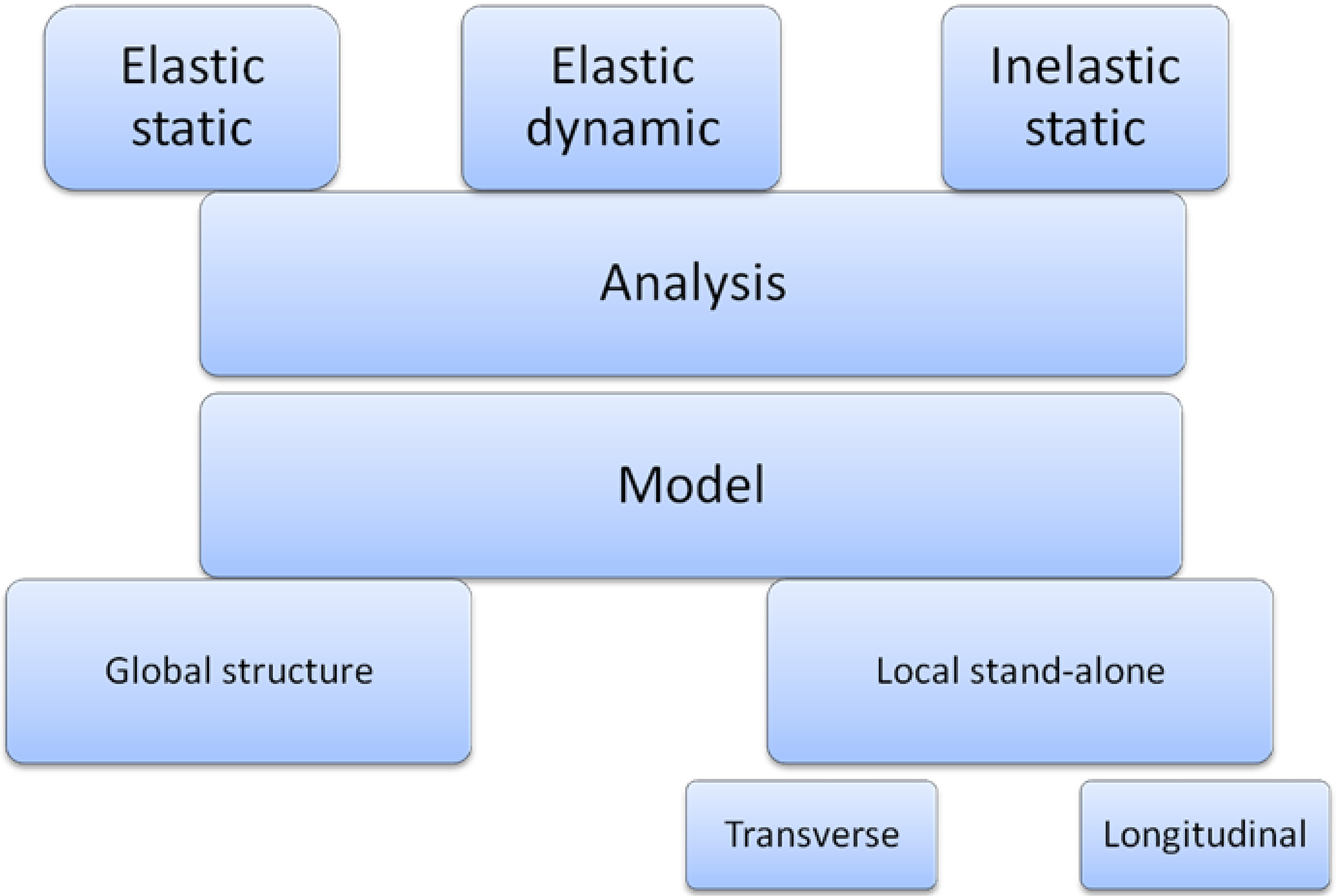


(c) 橋墩分析示意圖 (d)彎矩示意圖 (e)真實曲率示意圖 (f) 位移示意圖

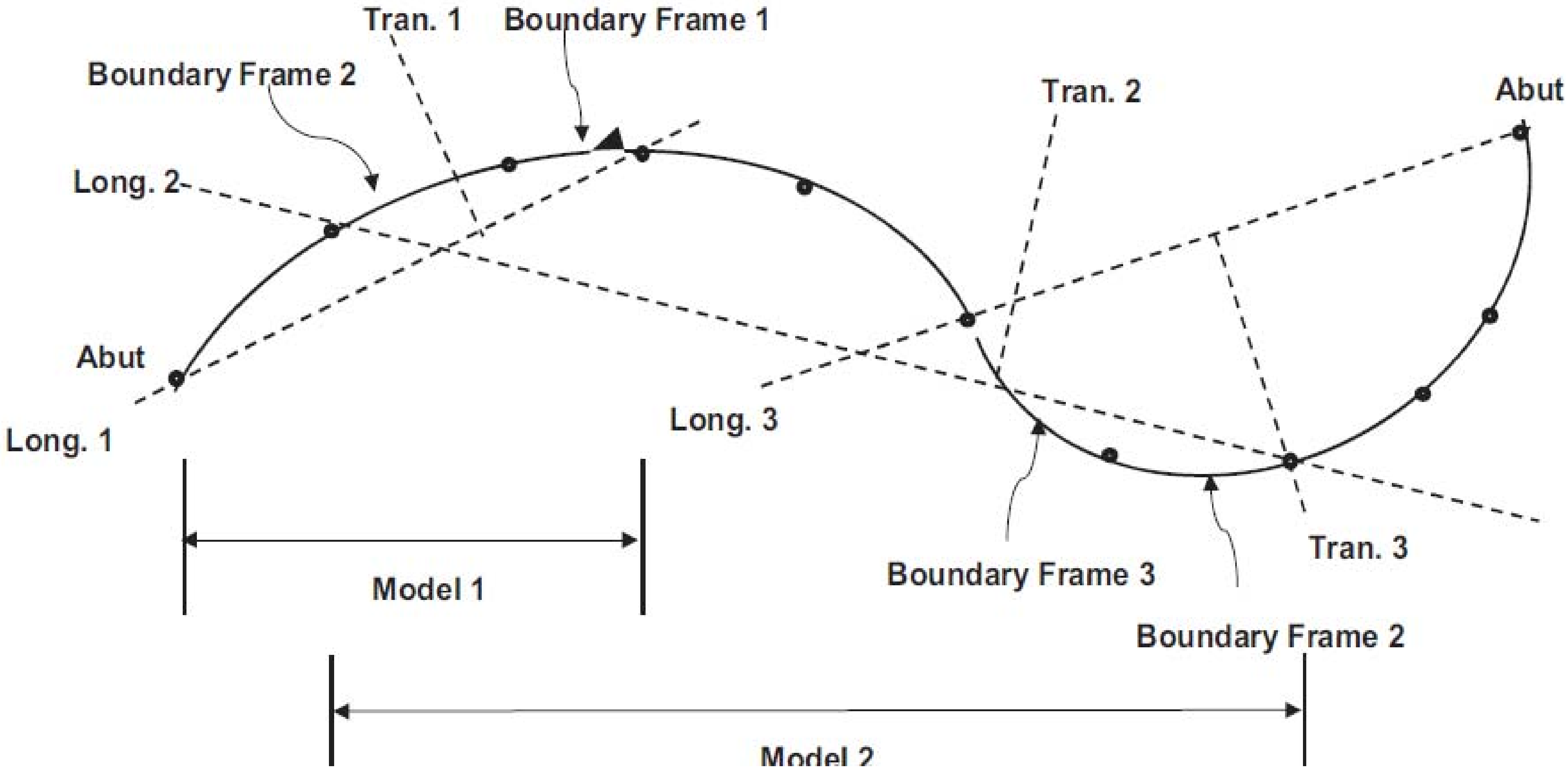
Capacity Ductility Criteria-- member

- **$\mu_c = \Delta_c/\Delta_Y$** > 3 for ductile members.
- Use cracked flexural stiffness for ductile members = $E_c\, I_{eff}$ or M_y/ϕ_y

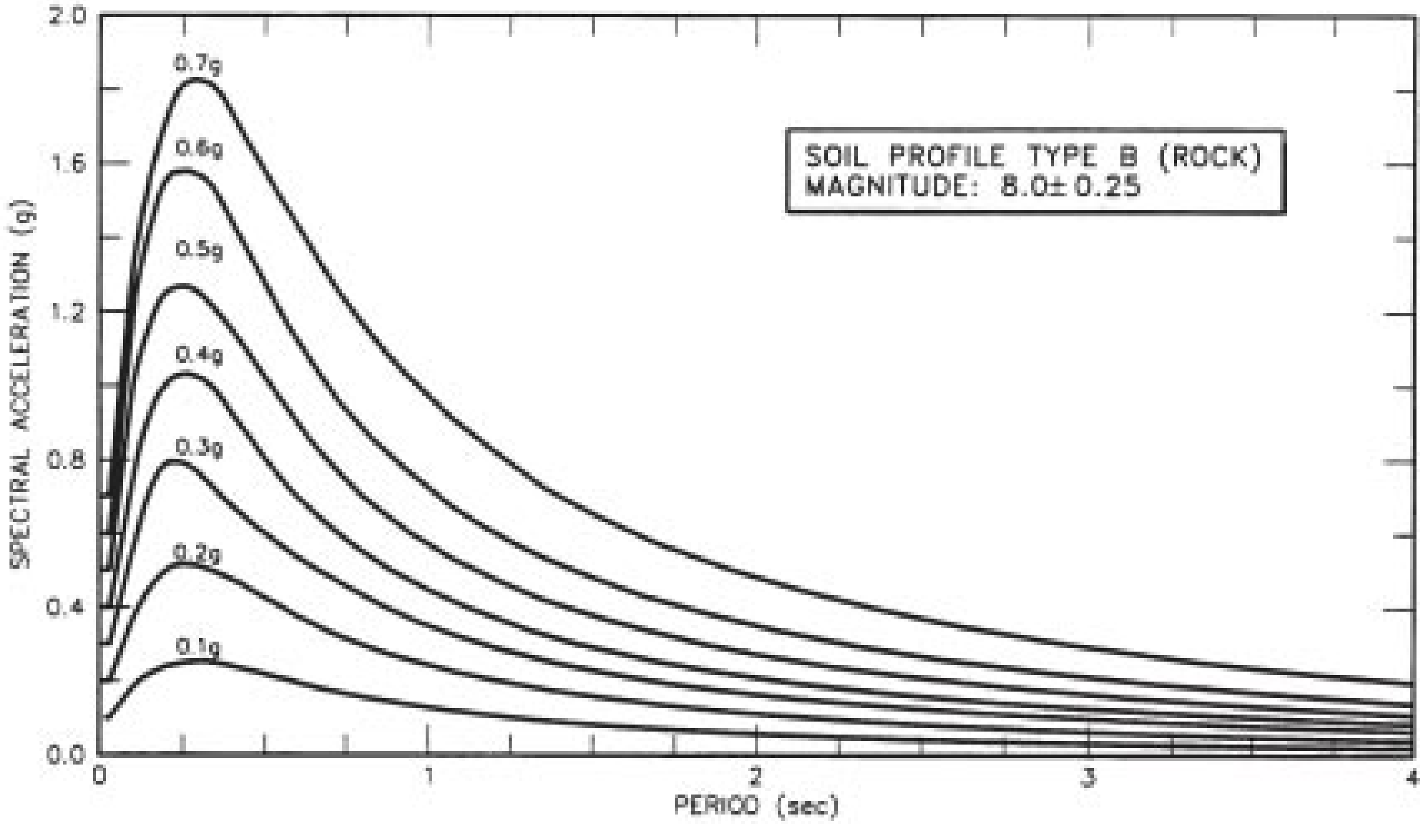
Bridge Models



Multi-frame Analysis[1]



Acceleration Response Spectrum[1]



Elastic Static Analysis (ESA)

- Obtains Δ_D demand displacement.
- Global analysis; stand-alone analysis.
- Requires balanced spans; uniform stiffness.
- SDOF acceleration response spectrum.
- Equivalent static load to MDOF = ARS x W
- Use effective moments of inertia.

Elastic Dynamic Analysis (EDA)

- Obtains Δ_D demand displacement.
- Global analysis; stand-alone analysis.
- MDOF response spectra with CQC.
- Elements: 3/column; 4/span.
- Forces/stresses are over-estimated.
- Uses effective moments of inertia.

Inelastic Static Analysis (ISA)

- Obtains Δ_C capacity displacement by push over analysis.
- Captures the overall nonlinear behaviors.
- Includes effects of cracking and yielding.
- Up to a collapse mechanism.

Global Analysis

- Captures responses for entire bridge system.
- Curved bridges; skew bridges.
- Joints; soft soil.
- Long multi-frame bridges shall be analyzed with multiple elastic models overlapping each other.

COMPUTER CODES

- Capabilities: inelastic modeling and analysis beyond the requirements of ATC-40, CALTRANS, or Taiwan code.

- Pushover: MKREC; MKCIR; MKHOLW; PUSHO.

  Reinforced concrete column's M-ϕ and P-Δ curves for rectangular, circular, or hollow sections.
- Capacity spectrum: ATC-INTER, TAI-INTER, SPEC-GEN.

  Demand spectrum for California, Taiwan, or site-specific ground motions, then intersected with capacity spectrum for performance point.
- SDOF inelastic dynamic: DOF6-PL; DOF6-BK.

  Incremental nonlinear time stepping solutions for elastic-plastic, or elastic-fracture responses of single-degree model.

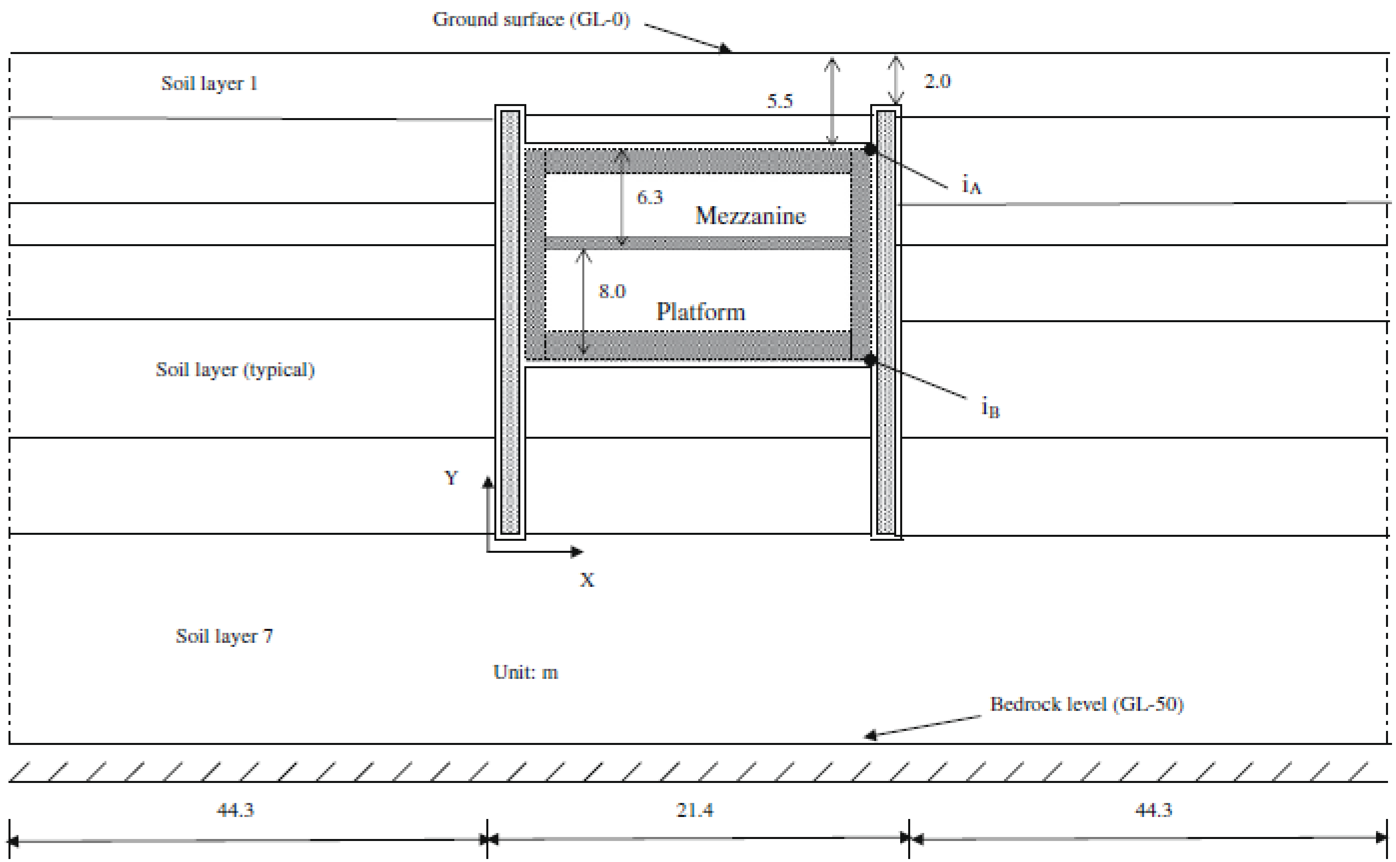
(COMPUTER CODES)

- MDOF inelastic dynamic: SHAKE6; SHEAR6.

  Incremental nonlinear time stepping solutions for elastic-plastic responses of multi-layered soil strata, or multi-story shear frame.

- 2D MDOF Finite elem inelastic dynamic: DISMA9.

  Nonlinear time history solutions for general purposes: e.g. seismic racking analysis of subway structures in soft ground; failure study of bridge considering deck pounding during earthquake; impact load resistance for pipes embedded in soil.


Ground surface (GL-0)
Soil layer 1
5.5
2.0
6.3
Mezzanine
i_A
8.0
Platform
Soil layer (typical)
i_B
Y
X
Soil layer 7
Unit: m
Bedrock level (GL-50)
44.3
21.4
44.3

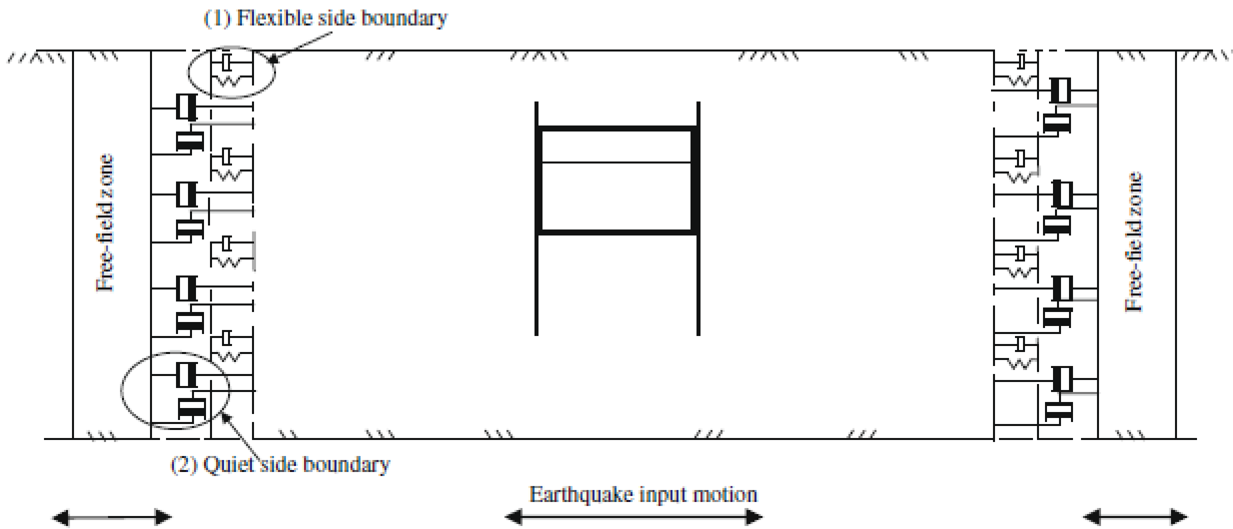
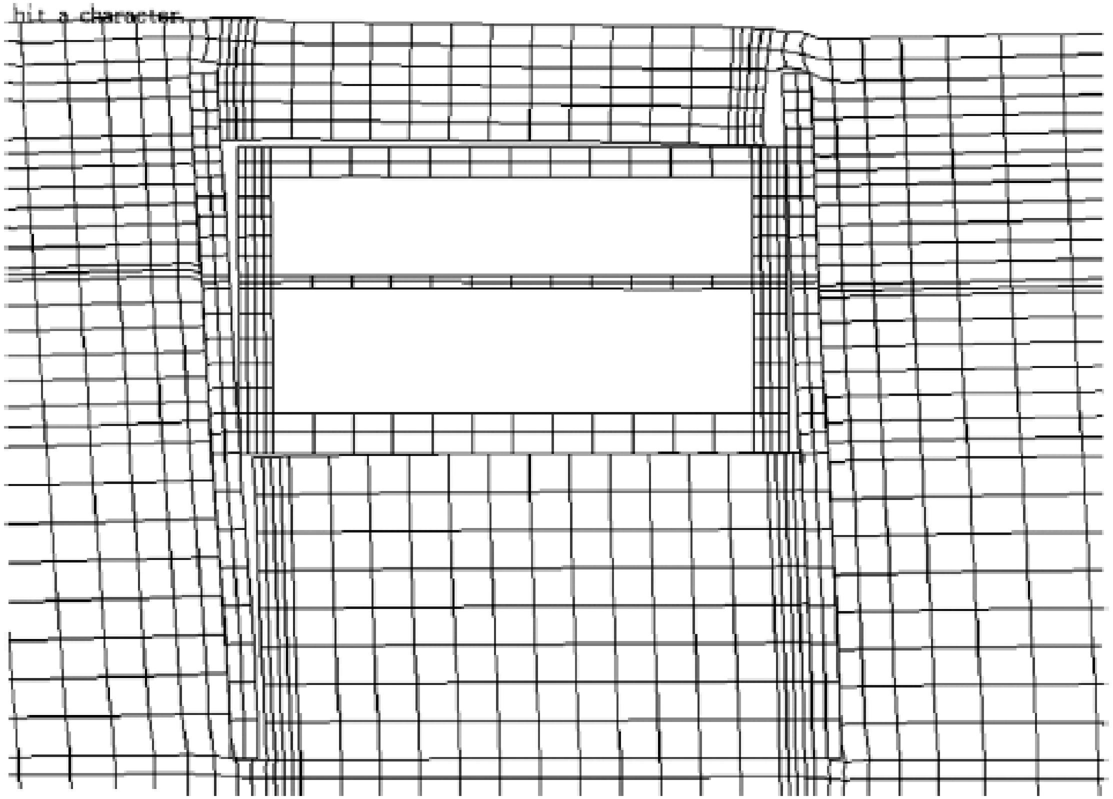
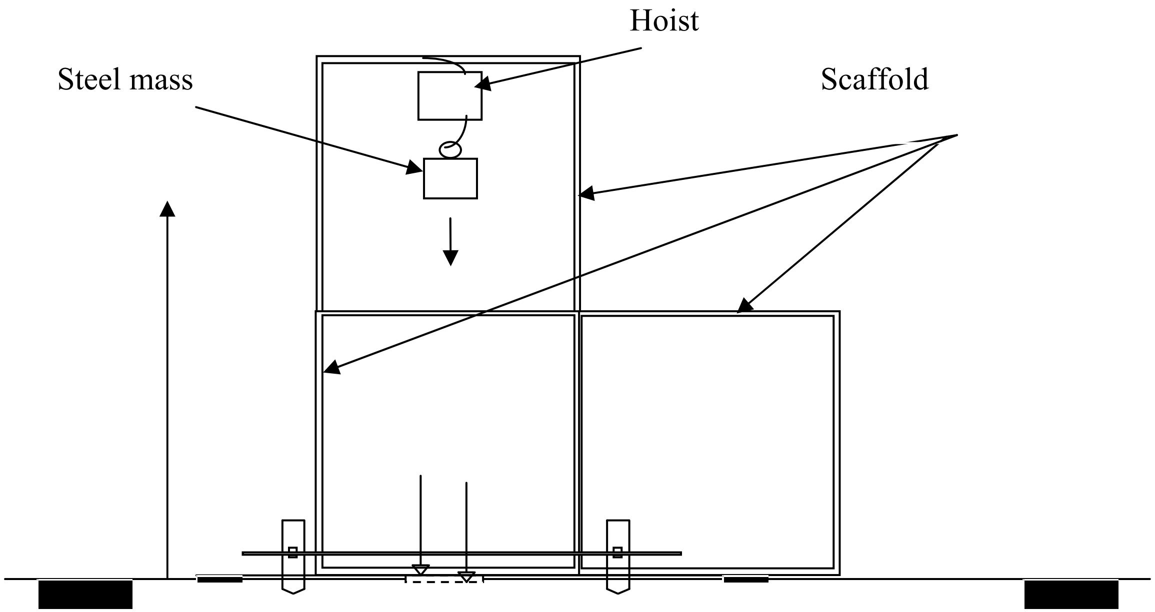


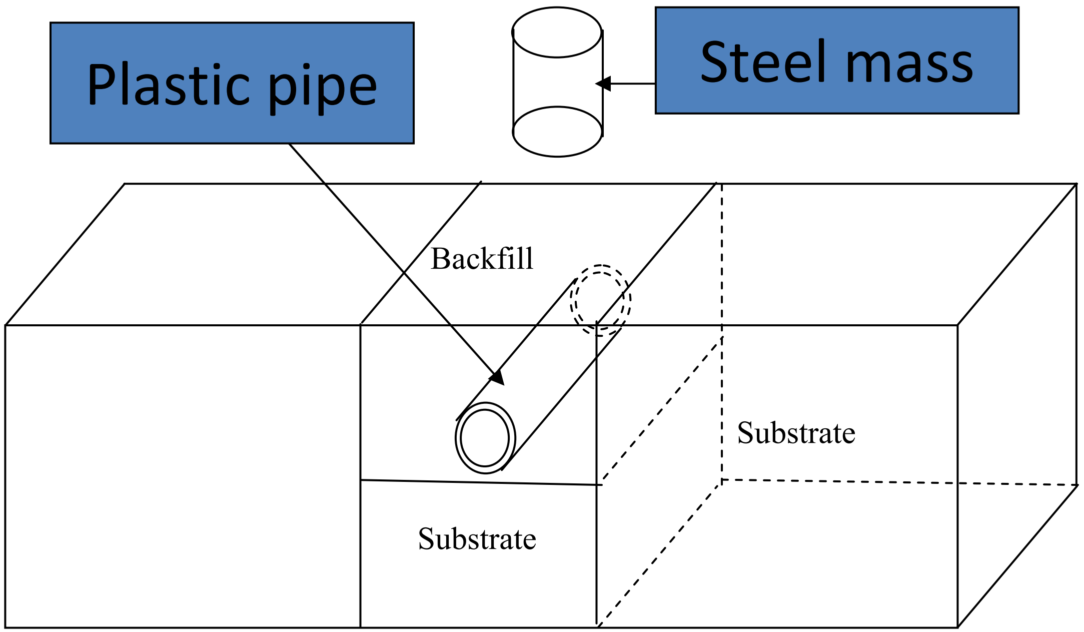
Fig. 4. Two options for side boundaries of a soil half-space.


hit a character

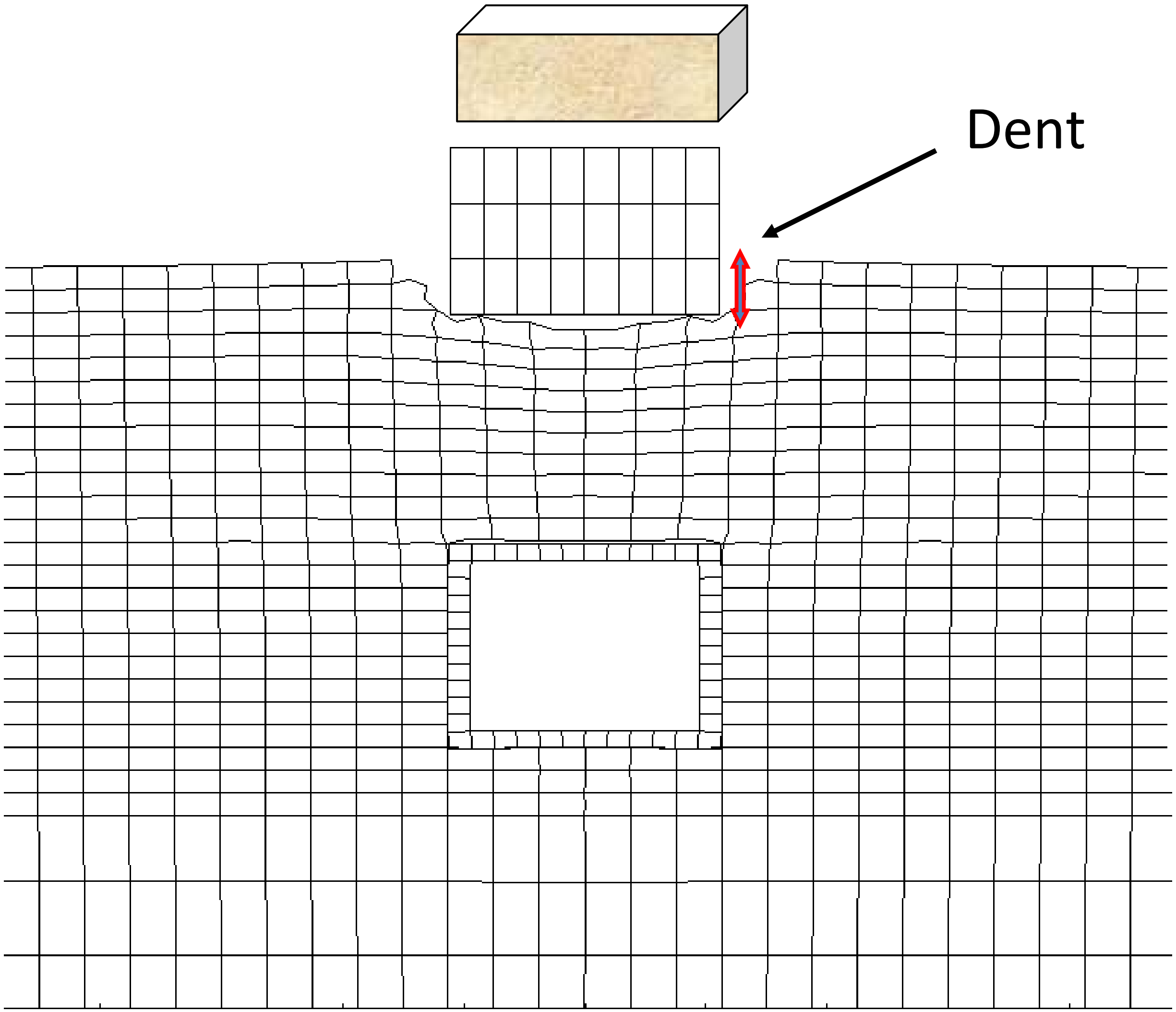


Model parameters-- calibrated with field test data

Mass-soil-pipe dynamic interactions



KST



2D model; soil dent

$$F(\{\sigma\}, c, \varphi) = 0 \qquad \{\bar{a}\} = \{\partial F / \partial \sigma\}$$

$$\{d\sigma\} = [D]\{d\varepsilon\} \longrightarrow \{d\sigma\} = [Dep]\{d\varepsilon\}$$

$$[Dep] = [D] - \left([D]\{\bar{a}\}\{\bar{a}\}^T [D]\right) / \left(\{\bar{a}\}^T [D]\{\bar{a}\}\right)$$

$$G(\{\sigma\}, c, \psi) = 0 \qquad \{\bar{b}\} = \{\partial G / \partial \sigma\}$$

$$[Dep] = [D] - \left([D]\{\bar{b}\}\{\bar{a}\}^T [D]\right) / \left(\{\bar{a}\}^T [D]\{\bar{b}\}\right)$$

Yield function and flow rule

KST

Finite element with erosion

- Large strains-- Lagrangian formulation
- Crumpled elements-- Erosion scheme
- Collision interface-- Contact search algorithm

Equations of motion

$$\int (\{\delta u\}^T \rho \{u''\}) dV_0 + \int (\{\delta E\}^T \{S\}) dV_0 = \int (\{\delta u\}^T \{f_c\}) dA_c + \int (\{\delta u\}^T \{b\}) dV_0$$

$$[M]\{U''\} = \{P_e\} + \{F_c\} - \{F_s\}$$

Contact force

Internal force

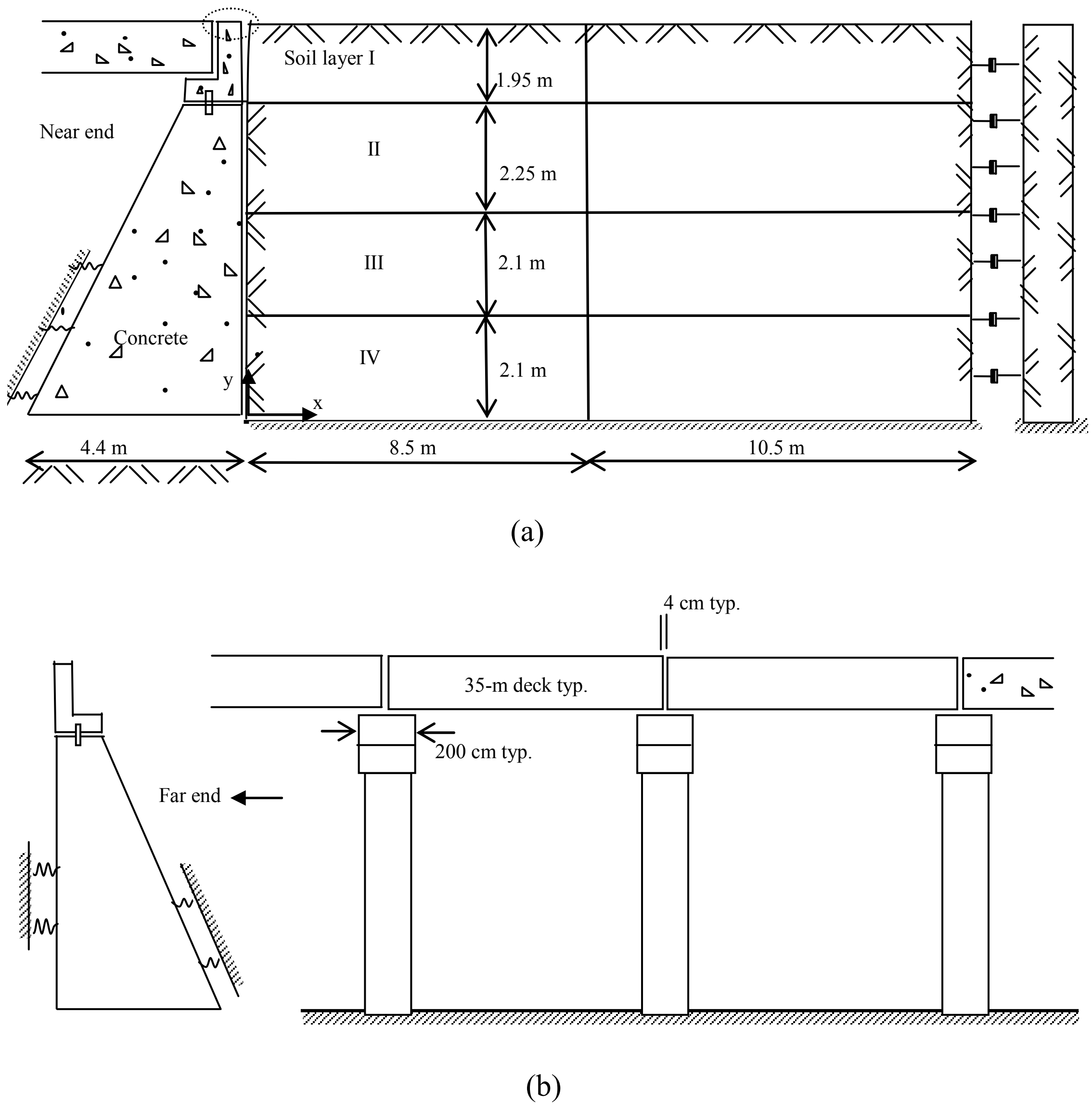


Figure 1. Disjoined models: (a) concrete-soil regions; (b) deck-pier-abutment masses.

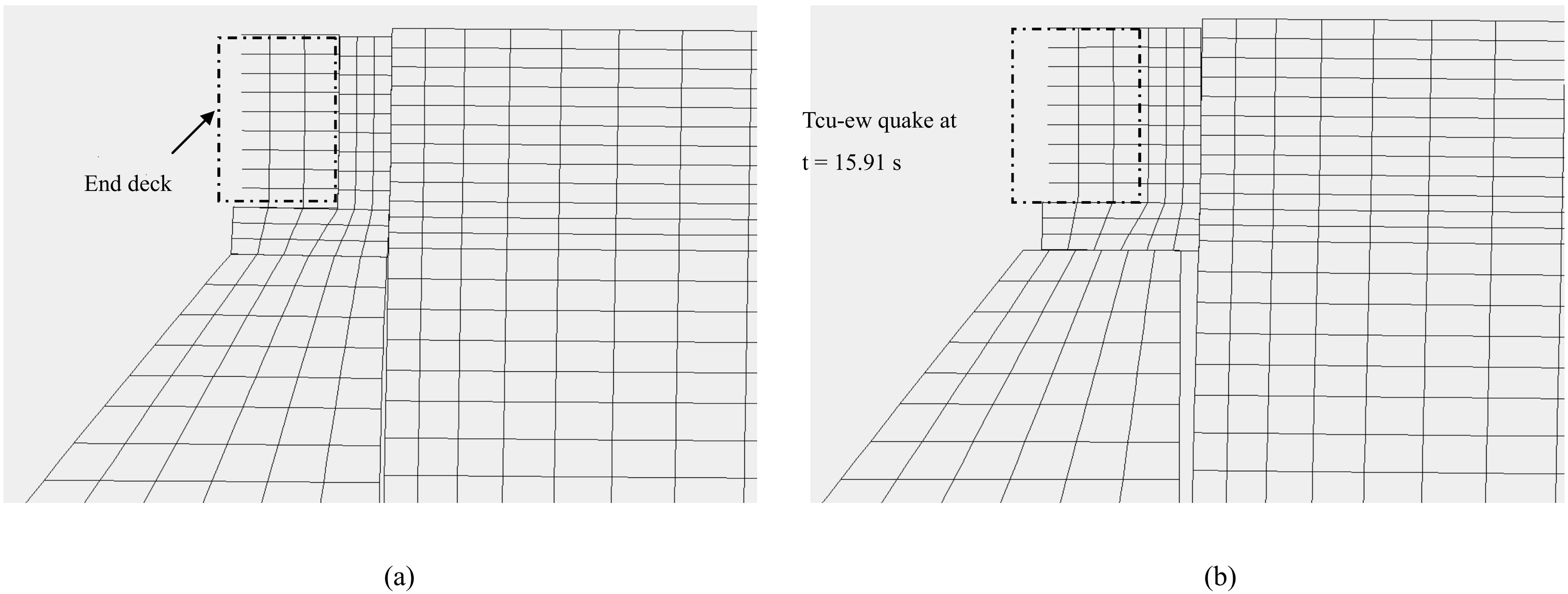


Figure 8. Abutment-backfill interaction: (a) rigid back wall; (b) flexible back wall.

EQUIVALENT SDOF
Inelastic Static Analysis

Models

- Transverse stand-alone
  - Pushover analysis
  - Capacity spectrum method
- Longitudinal Stand-Alone
  - Pushover analysis
  - Capacity spectrum method

Subsystems

- Pier bent
  - Single column
  - Twin column
- Pier wall
- Frame

EQUIVALENT SDOF
Inelastic Dynamic Analysis

Models

- Transverse Stand-Alone
  - Pushover analysis
  - Elastic-plastic
  - Elastic –fracture

- Longitudinal Stand-Alone
  - Pushover analysis
  - Elastic-plastic
  - Elastic -fracture

Subsystems

- Pier bent
  - Single column
  - Twin column
- Pier wall

- Frame

2-DIMENSIONAL MDOF
Inelastic Dynamic Analysis

Models

- Finite elements
  - plane strain/stress
  - elastic-plastic
- Discrete elements
  - contact/friction
  - elastic-plastic
  - elastic-fracture

Subsystems

- Superstructures
- Bearing supports
- Substructures
- Foundations
- Soils

THANKS FOR YOUR ATTENTION

Contact: cjw@nkfust.edu.tw; wang-cj@ait.ac.th

Bibliography:

- [1] CALTRANS Seismic Design Criteria, 2006, California Department of Transportation, Sacramento, CA.
- [2] ATC-40 Seismic Evaluation and Retrofit of Concrete Buildings, 1996, Applied Technology Council.
- [3] Mander JB, Priestly MJN, Park R, Theoretical Stress–strain Model for Confined Concrete, ASCE J Struct Eng 1988,114(8).
- [4] 鋼筋混凝土橋墩柱性能法耐震評估,曾柏碩,民國九十四年, 碩士論文, 國立高雄第一科技大學.
- Seismic Performance Evaluation of Reinforced Concrete Pier Columns, Tseng BS, 2005, Master Thesis, National Kaohsiung First University of Science and Technology, Taiwan ROC.

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Asian Institute of Technology (visiting)

Academic Qualifications

Ph.D Civil Engineering and Engineering Mechanics, 1985
University of Arizona
M. Science in Civil Engineering
Wayne State University, Detroit, Michigan
B. Science Civil Engineering
National Central University, Chung Li, Taiwan

Field of Expertise

Seismic performance evaluation of buildings and bridges
Finite element applications in soil-structure interactions
Structural design for MRT and HSR structures

Current Designations

Visiting Faculty, School of Engineering and Technology, AIT
Chartered Civil Engineer, Taiwan
Chartered Structural Engineer, Taiwan

Professional Experience

Forensic engineering analysis of building/bridge failures (1999 Chi-Chi Earthquake)
Assessing and categorizing damage state of buildings (Chi-Chi quake)
Leading field investigation trips and preparing reconnaissance reports (Chi-Chi quake)
Responsible for structural design of underground subway stations (Kaohsiung MRT’s Orange line O7 and part of O8 stations)
Responsible for design checking for underground concourse and mall (Taipei MRT’s Taipei main station and Chung-Hwa Road)
Responsible for structural design of long-span continuous viaduct bridges (Taiwan High Speed Rail Tainan-Chayi elevated section)
Responsible for MRT technology transfer and quality management (Kaohsiung MRT International Consultants)
Specializing in finite element software development

國立高雄第一科技大學教師升等研究成果資料表

		名稱	作者姓名(含合著者)	出版社或發表刊物名稱、題目、期別	出版或發表地點及年月
申請人自填	代表著作	(SCI) Seismic racking of a dual-wall subway station box embedded in soft soil strata	Wang CJ	Tunnelling and Underground Space Technology	2010 Accepted
	其他著作	A 期刊論文 (SCI) Failure study of a bridge subjected to pounding and sliding under severe ground motions	Wang CJ	International Journal of Impact Engineering, Vol. 34, pp. 216-231.	2007
		(SCI) Performance study of a bridge involving sliding decks and pounded abutment during a violent earthquake	Wang CJ, Shih MH	Engineering Structure, Vol. 29, pp.802-812.	2007
		(SCI) Simulation of collision contacts among disjoined soil-structure bodies under seismic motions	Wang CJ	International Journal of Modern Physics B, Vol. 22, pp.1544-1551.	2008
		(SCI) A model for signal processing and predictive control of semi-active structural control system	Shih MH, Sung WP, Wang CJ	Sadhana, Vol. 34, Part 3, pp. 421–437.	2009