# Earthquake Hazard Mitigation Research and Practice: 10 years after Chi-Chi Earthquake

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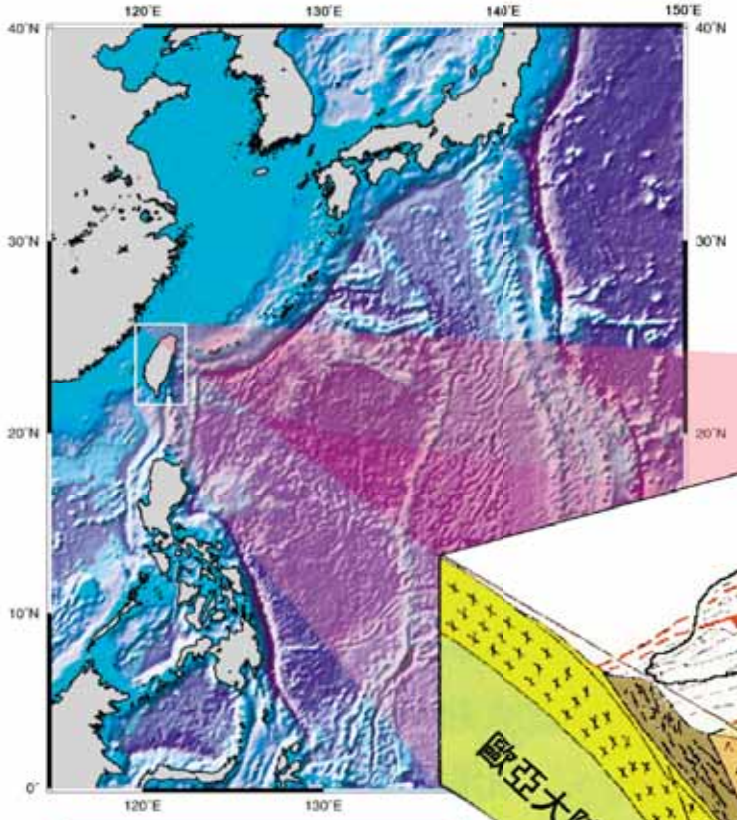
國家地震工程研究中心
National Center for Research on Earthquake Engineering

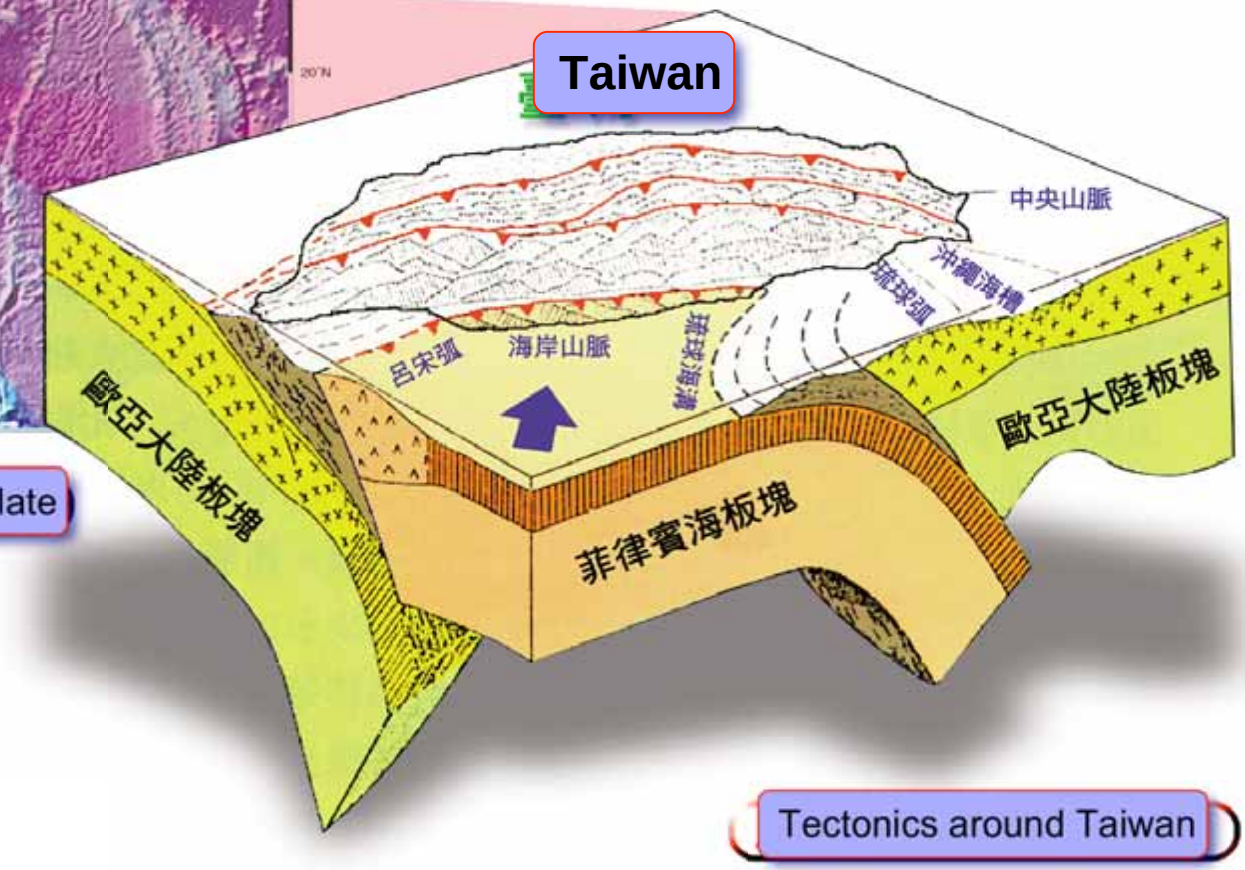
# Overview of Presentation

- Revision of seismic force requirements for building structures.
- Seismic safety improvement of school buildings in compulsory, senior high and occupational schools.
- Some example implementations.

# Seismic Hazards of Taiwan

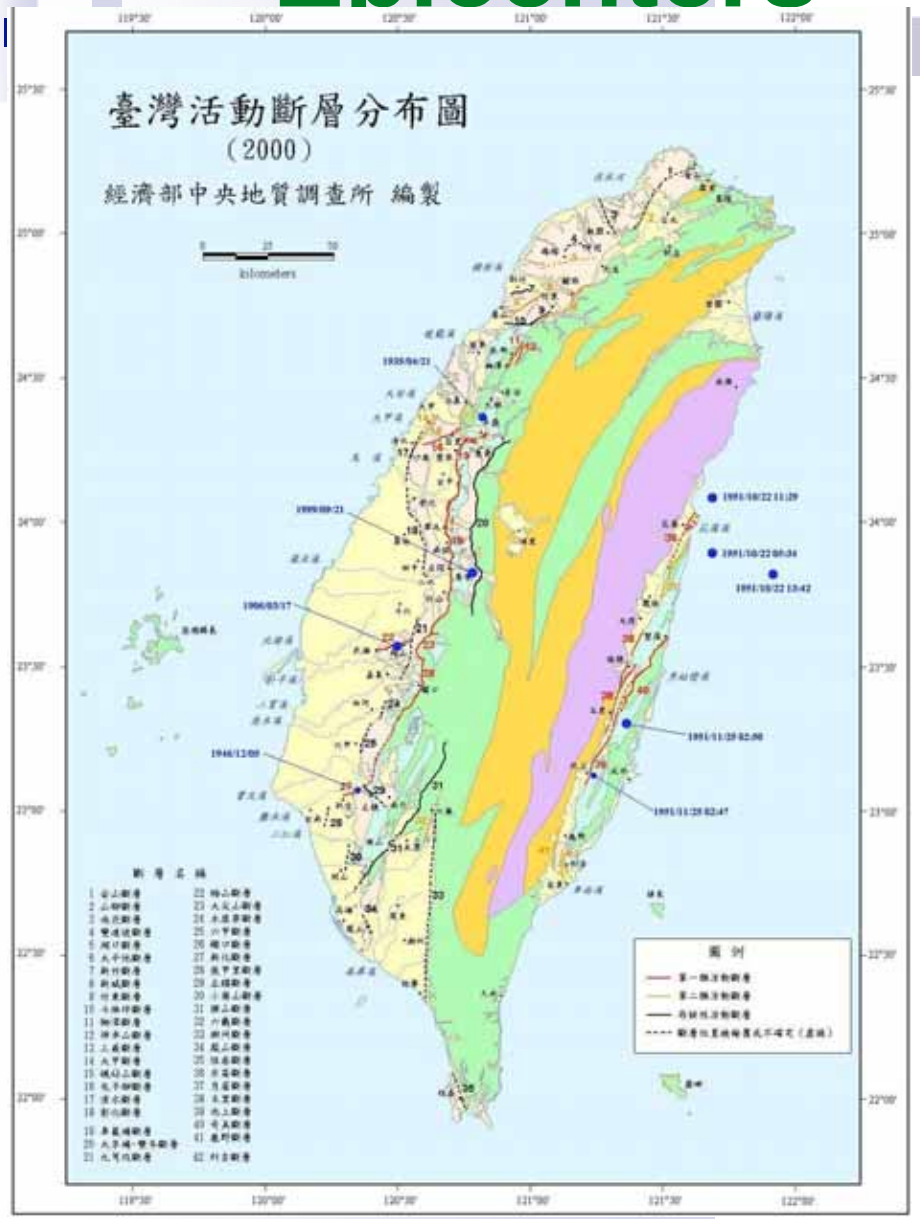


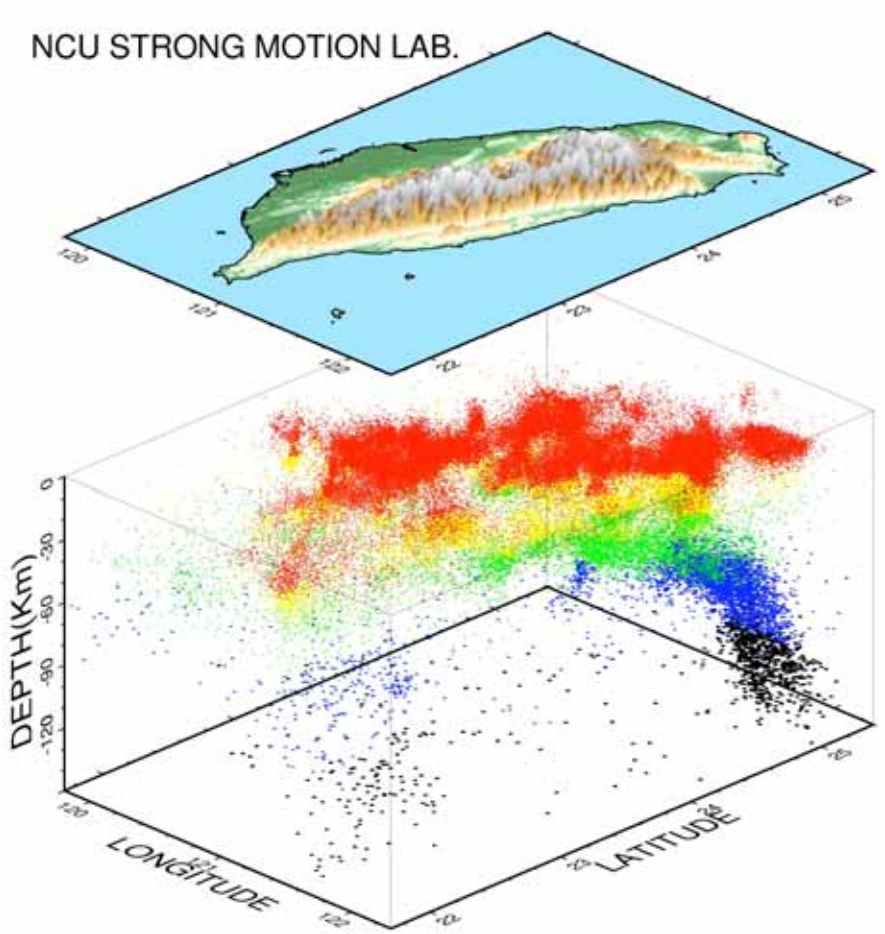

% Philippine Sea Plate




Tectonics around Taiwan

# Faults and Historical Epicenters

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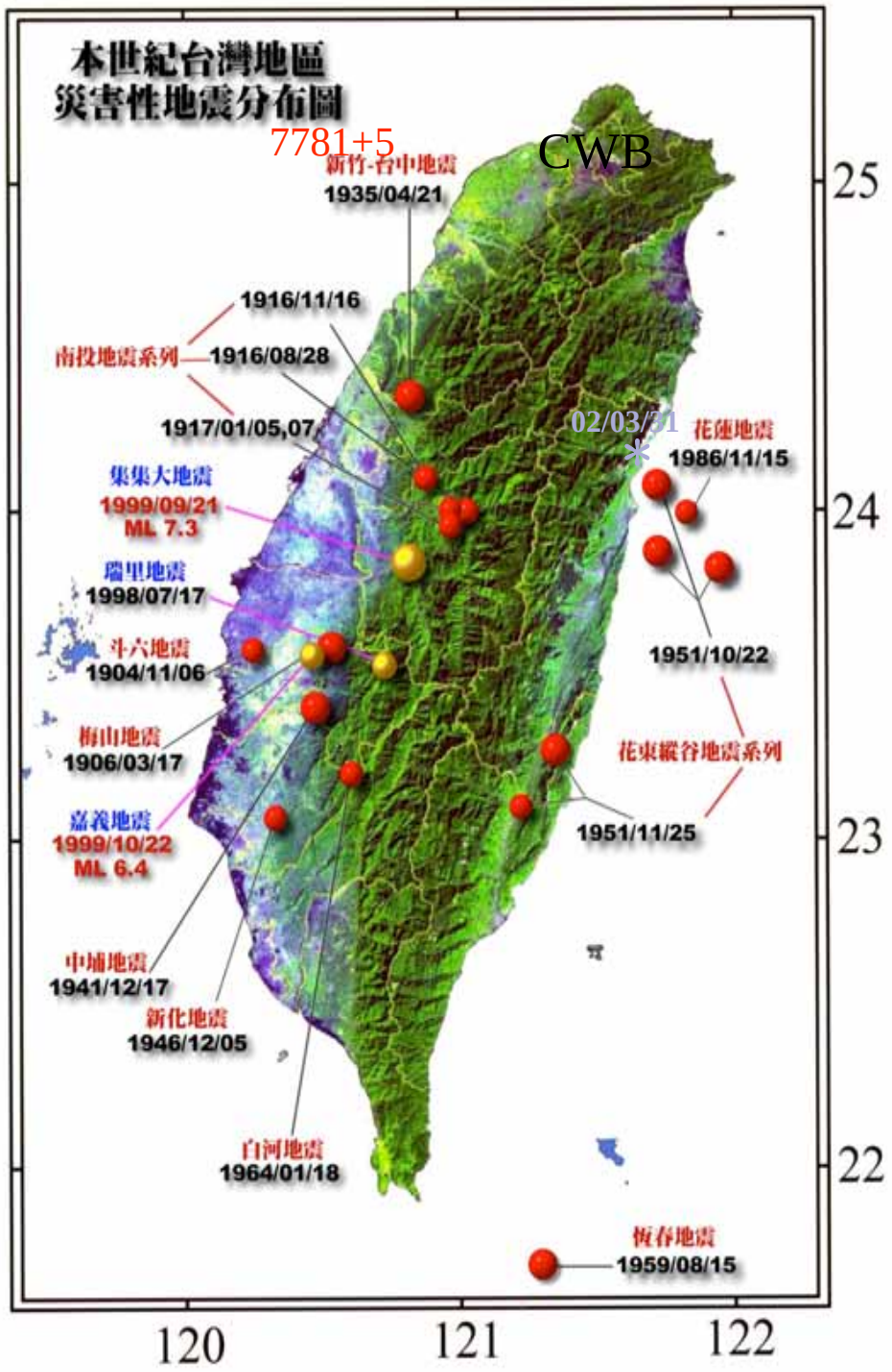
# Historical damaging earthquakes

表0001、台灣十大災害地震和地震系列震源參數一覽表

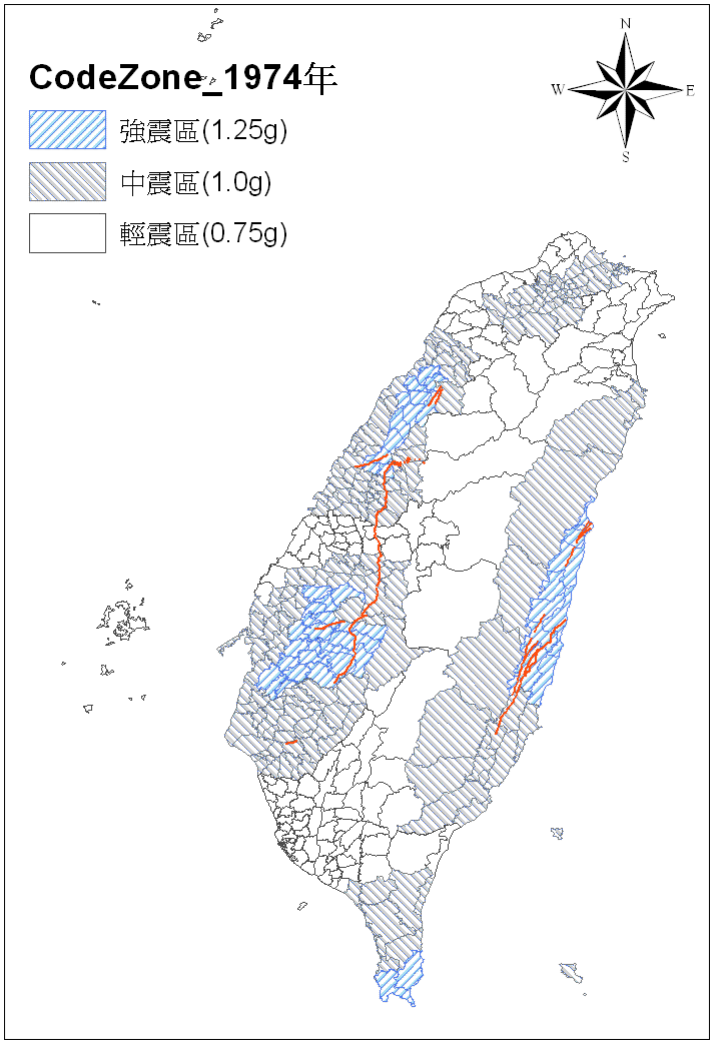
| 編號 | 地震名稱 | 發震時間 (120°E) | 震央位置 北緯(N) | 震央位置 東經(E) | 震源深度 (公里) | 地震規模 ($M_L$) |
|---|---|---|---|---|---|---|
| 1 | 斗六地震 145 | 1904/11/06 04:25 | 23.575 | 120.250 | 7.0 | 6.1 |
| 2 | 梅山地震 | 1906/03/17 06:43 | 23.550 | 120.450 | 6.0 | 7.1 |
| 3 | 南投地震系列 1258+17 16+1+53 | 1916/08/28 15:27 | 24.000 | 121.025 | 45.0 | 6.8 |
| | | 1916/11/15 06:31 | 24.100 | 120.875 | 3.0 | 6.2 |
| | | 1917/01/05 00:55 | 24.000 | 120.975 | 很淺 | 6.2 |
| | | 1917/01/07 02:08 | 23.950 | 120.975 | 很淺 | 5.5 |
| 4 | 新竹－台中地震 3279 | 1935/04/21 06:02 | 24.350 | 120.817 | 5.0 | 7.1 |
| 5 | 中埔地震 360 | 1941/12/17 03:19 | 23.400 | 120.475 | 12.0 | 7.1 |
| 6 | 新化地震 74 | 1946/12/05 06:47 | 23.070 | 120.330 | 5.0 | 6.1 |
| 7 | 花東縱谷地震系列 68+17 | 1951/10/22 05:34 | 23.875 | 121.725 | 4.0 | 7.3 |
| | | 1951/10/22 11:29 | 24.075 | 121.725 | 1.0 | 7.1 |
| | | 1951/10/22 13:43 | 23.825 | 121.950 | 18.0 | 7.1 |
| | | 1951/11/25 02:47 | 23.100 | 121.225 | 16.0 | 6.1 |
| | | 1951/11/25 02:50 | 23.275 | 121.350 | 36.0 | 7.3 |
| 8 | 恆春地震 17 | 1959/08/15 16:57 | 21.700 | 121.300 | 20.0 | 7.1 |
| 9 | 白河地震 106 | 1964/01/18 20:04 | 23.200 | 120.600 | 18.0 | 6.3 |
| 10 | 花蓮地震 15 | 1986/11/15 05:20 | 23.992 | 121.833 | 15.0 | 6.8 |
| 11 | 集集地震(2403) | 1999/09/21 01:47 | 23.85 | 120.78 | 10.0 | 7.3 |



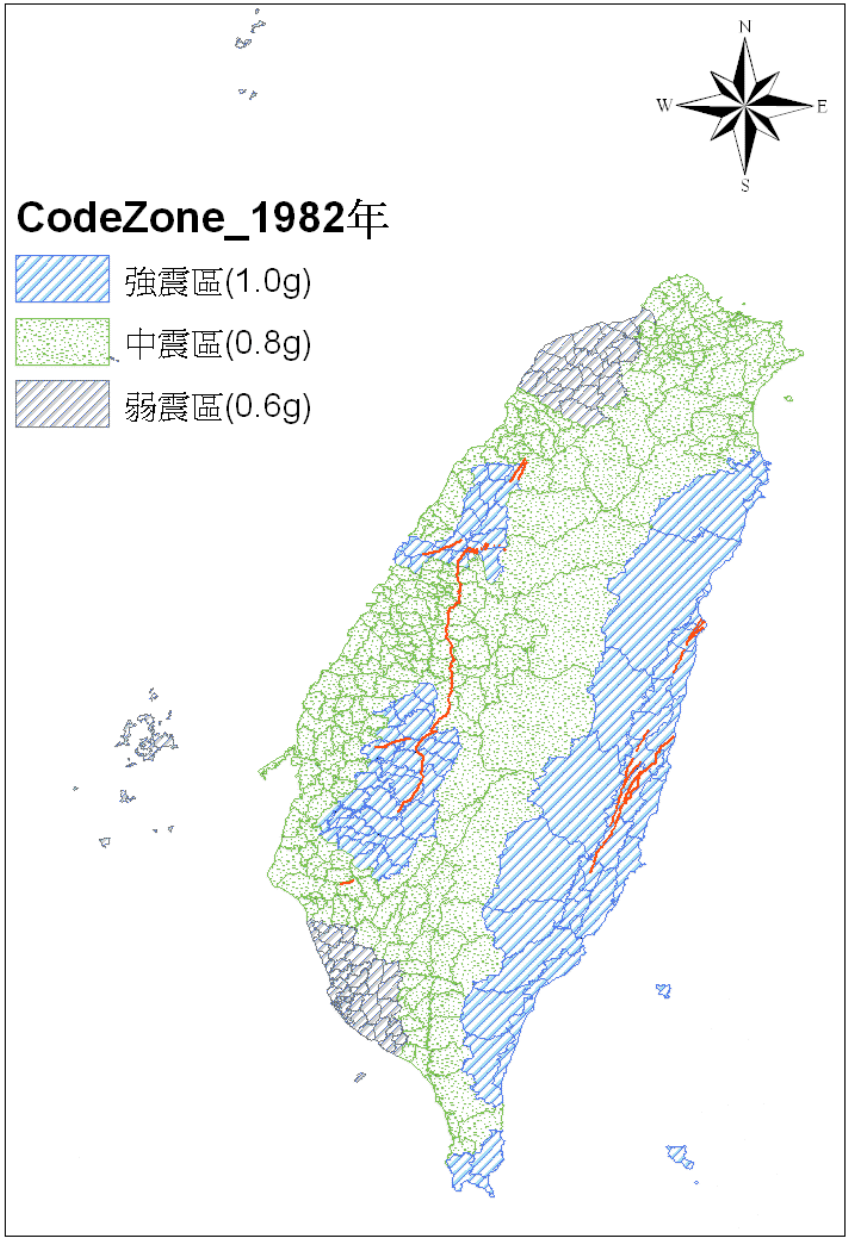
- **Developments of Seismic Design Code for Building in Taiwan before 1999 Chi-Chi Earthquake：**
  - **Before 1974**
  - **1974**
  - **1982**
  - **1989 (minor modification)**
  - **1997**

# Seismic Force Requirements in Taiwan

- **Before 1974**
  - Base shear: V=0.1W
- **1974**
  - Base shear: V=ZKCW
    - Z = 1.25, 1.0, 0.75
    - K = 0.67, 0.8, 1.0, 1.33
    - C = 0.1/$\sqrt{\blacksquare}$ ≤ 0.1
    - W = D+0.25L
  - Remarks
    - Seismic hazard
    - Structural ductility
    - Structural period



- 1982
  - Base shear: V=ZKCIW
    - Z = 1.0, 0.8, 0.6
    - K = 0.67, 0.8, 1.0, 1.33
    - C = 1/8$\sqrt{T}$ ≤0.15
    - I = 1.0, 1.25, 1.5
    - W = D
  - Remarks
    - Importance factor



- **Basin Effect**
  - **Mexico EQ (1985)**
  - **Hwa-lian EQ (Taiwan, 1986)**
- **1989 (minor modification)**
  - **Base shear: V=ZKCIW**
    - **Taipei Basin**
      **$C = 0.248/T \leq 0.15$**
      **with $T_0$=1.65 sec.**
  - **Remarks:**
    - **Basin effect for Taipei Basin**

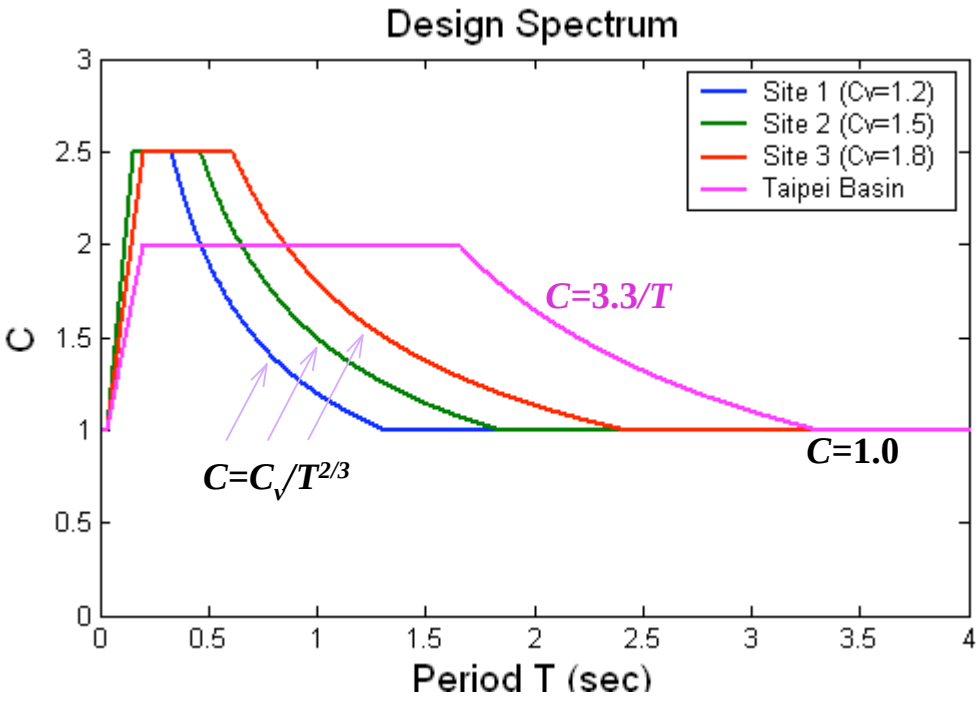
**A building collapsed in Taipei Basin with ED >100 km (Hwa-lian EQ, 1986)**

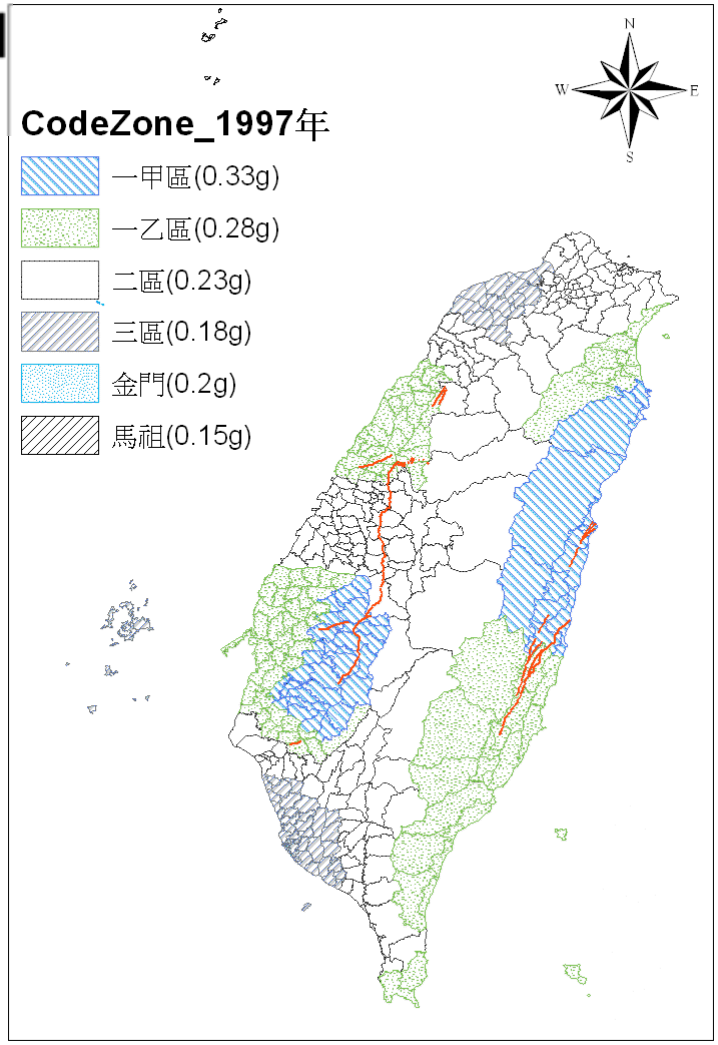
## ❒ 1997

- **Base shear:**

$$V = \frac{ZI}{1.4\alpha_y}\left(\frac{C}{R}\right)W$$

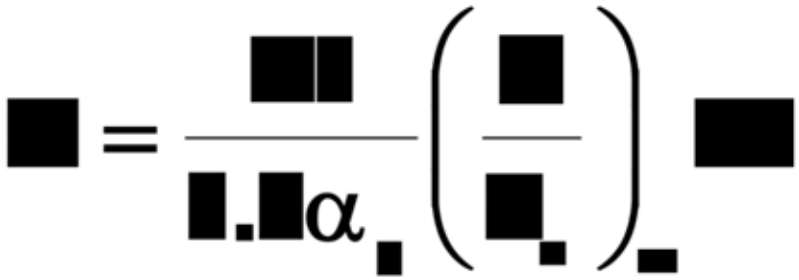
  - **Z = 0.33, 0.28, 0.23, 0.18**
  - **C: for 3 site classification and Taipei Basin**



## 1997

- **Base shear:**

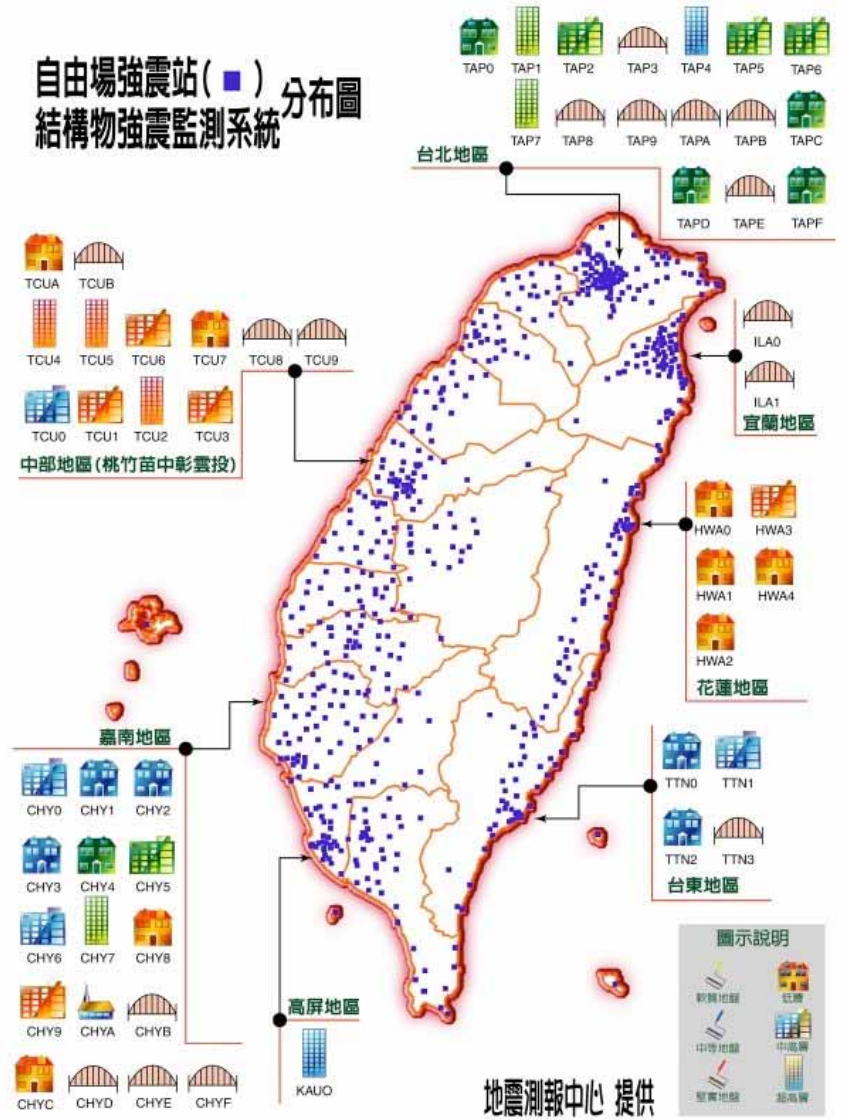


  - I = 1.0, 1.25, 1.5
  - W = D
  - $\alpha_y$ = 1.2 for WSD, 1.5 for USD
  - $F_u(R_a) \approx$ 2.1, 2.5, 2.9

- **Remarks**
  - Zoning factor Z: design PGA (10%/50 years)
  - Site classification (S1, S2, S3 and Taipei Basin)
  - Reduction factor $F_u$: Newmark-Hall recommendations
  - Dynamic analysis procedures (response spectrum method)

# Taiwan Strong Motion Instrumentation Program (TSMIP): A 20-year Plan (1990-2010)

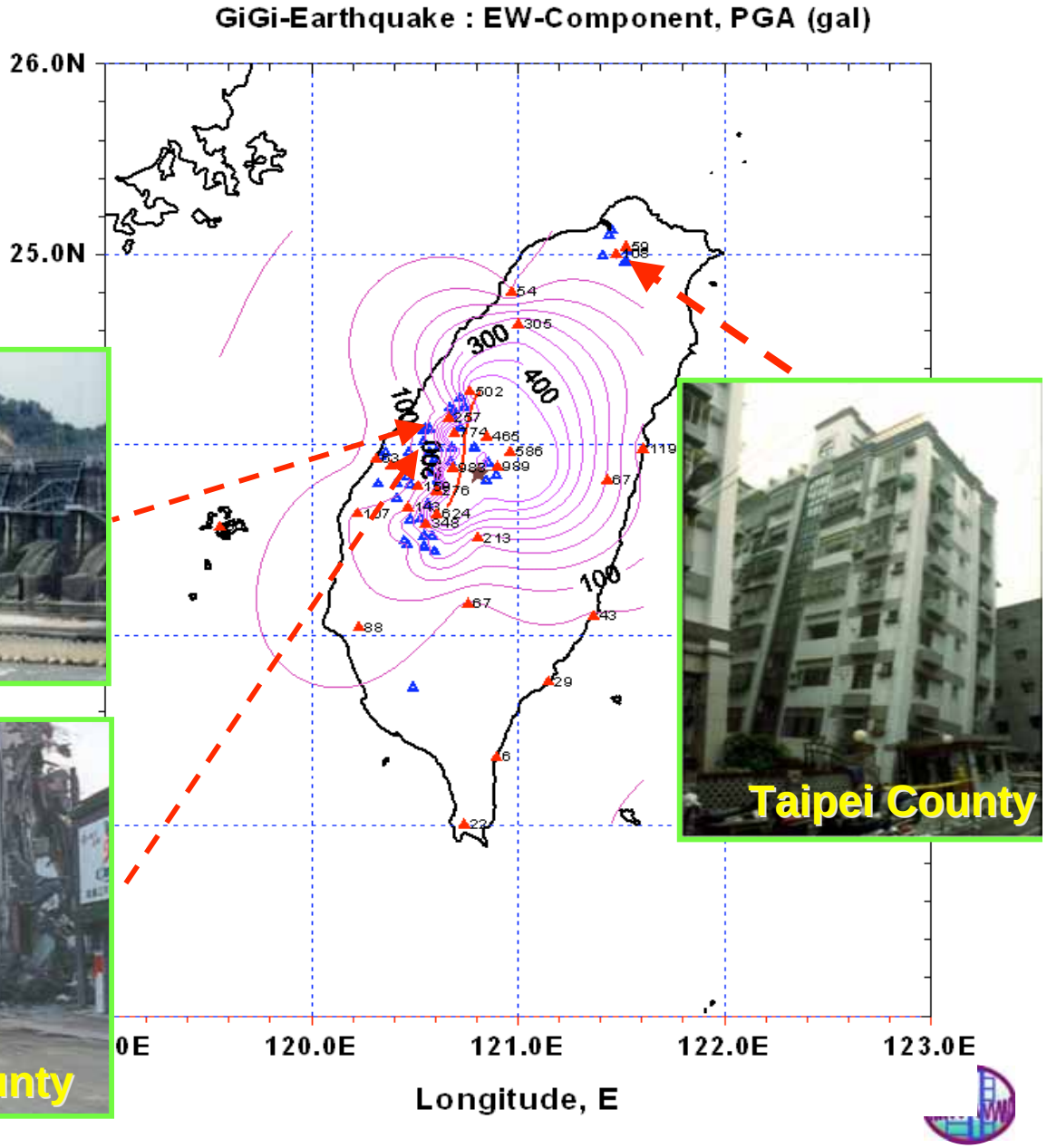
- Started from 1990
- Being installed and maintained by CWB
- Target: 1000 strong motion stations
- 109 real-time stations
- 800+ strong motion stations
- 50+ monitored structures
- All are digital Instrumentation



# 1999 Chi-Chi Earthquake

$M_L$=7.3
Sept. 21, 1999





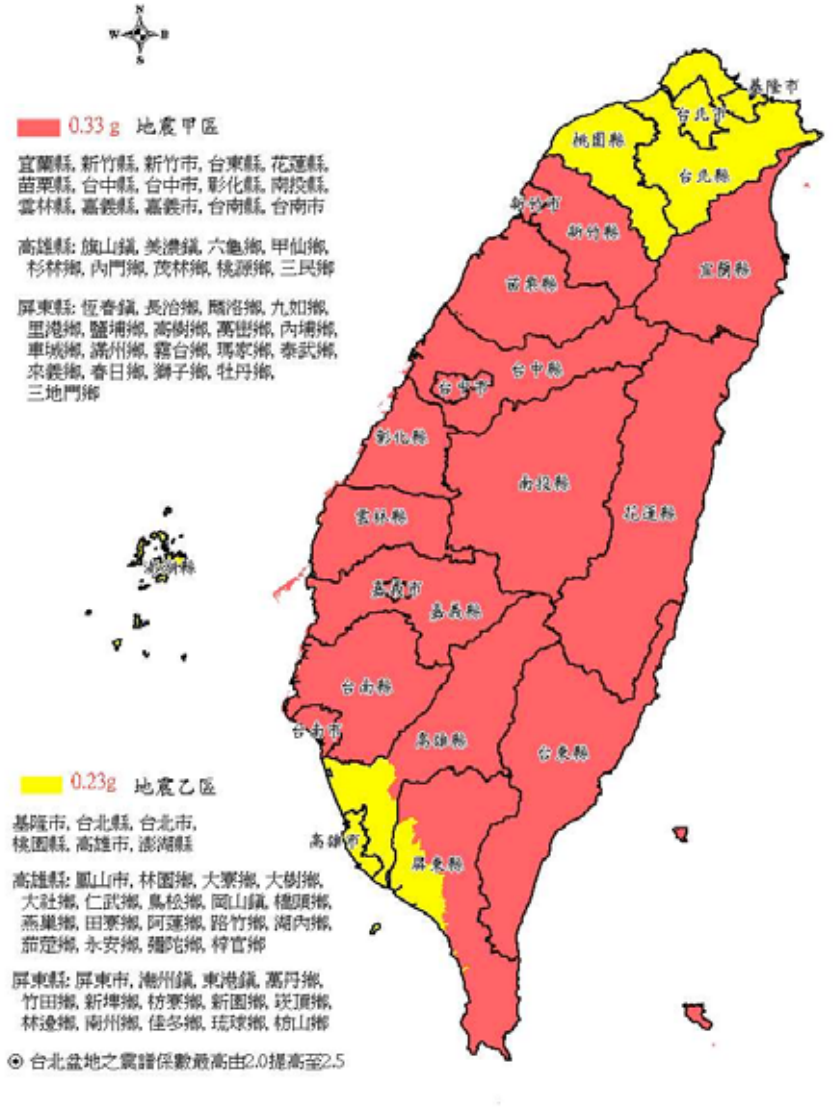
## ㄱ 1999 (after Chi-Chi EQ)

- **Base shear:**

$$\blacksquare = \frac{\blacksquare\blacksquare}{\blacksquare.\blacksquare\alpha_{\blacksquare}}\left(\frac{\blacksquare}{\blacksquare_{\blacksquare}}\right)_{\blacksquare}\blacksquare$$

  - **Z = 0.33, 0.23**
  - **$C_{max}$= 2.5 for Taipei Basin**

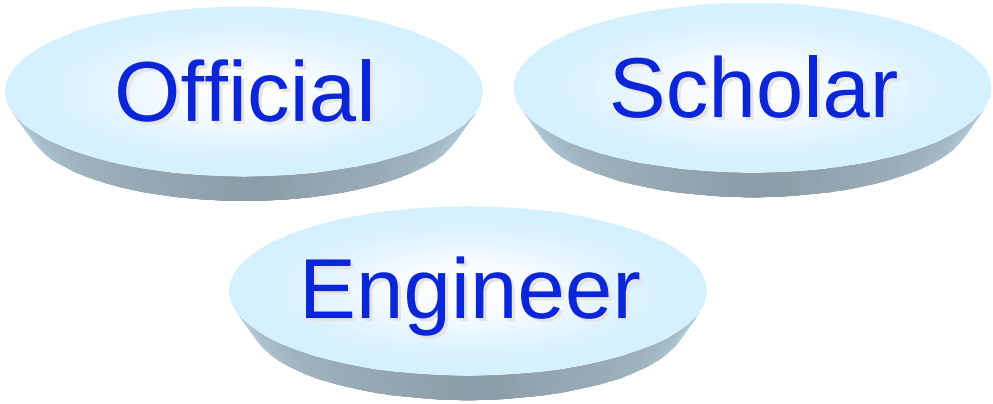
- **Remarks:**
  - **Emergency response: released three months after the event temporarily**




臺灣地區震區劃分建議圖

# Research & Development Committee for Seismic Design Code

- Organized by NCREE in 2005



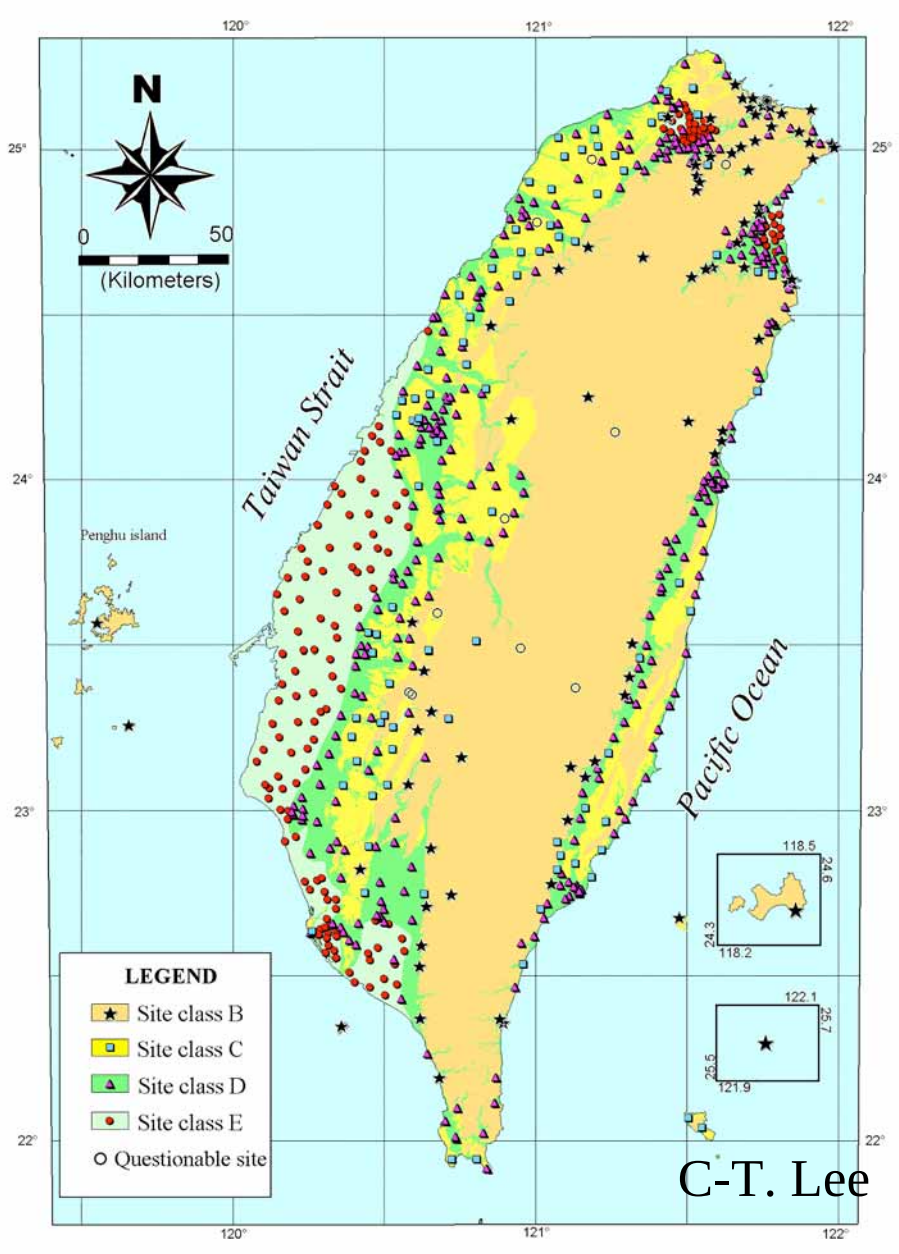

- Objectives
  - Continued modification of existing seismic design code
  - Development of next version of seismic design code (Performance based Seismic Design)

# Site Classification for Taiwan Strong Motion

4 classes

The correlation between the site classification and the site amplification is not good.

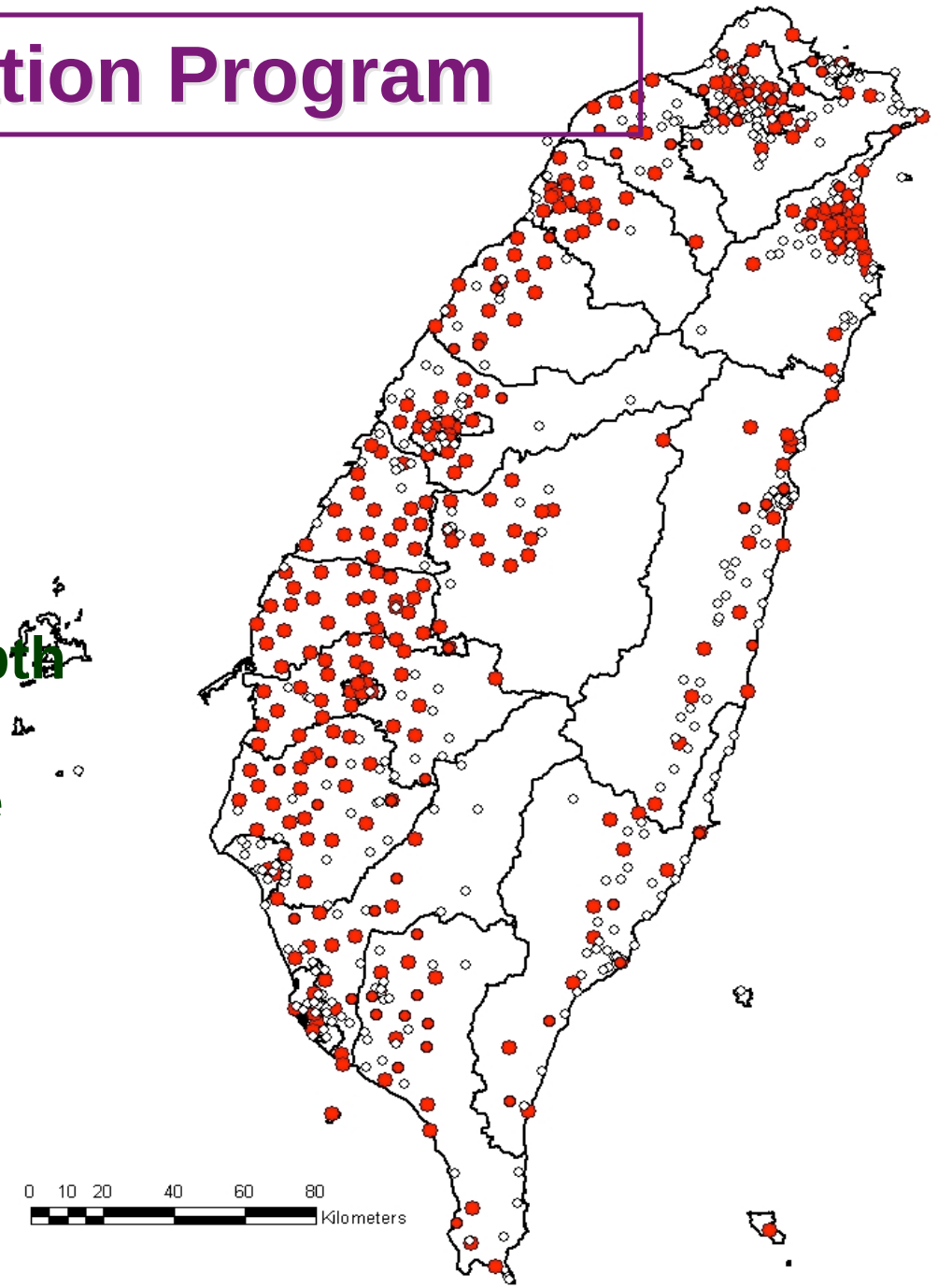
Another approach is needed.



# Site Investigation Program

- NCREE and CWB cooperated a long term project to investigate the site conditions for the strong motion arrays.

- 333 stations were completed (red stars, depth = 30 m);
- 22 stations, the bore hole depth > 50 m.

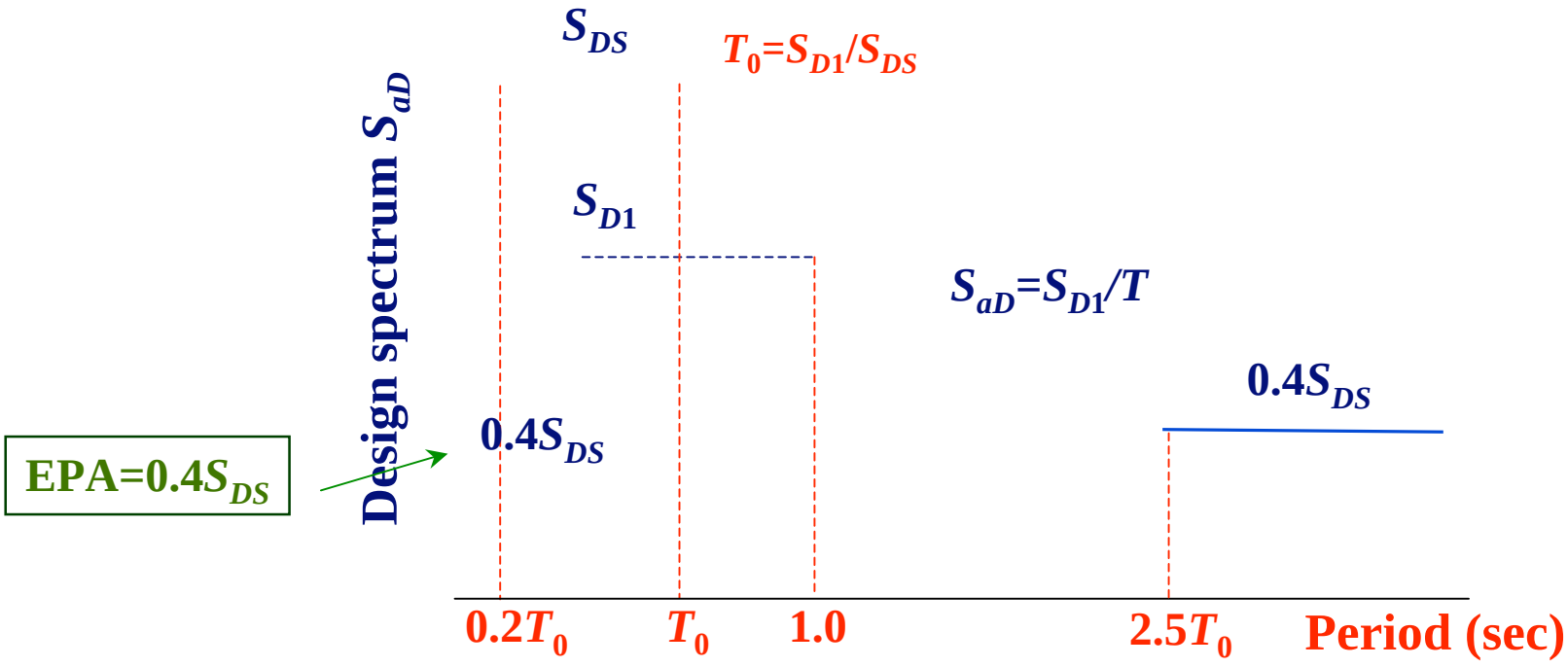



http://geo.ncree.org.tw/

- **Site-adjusted spectral response acceleration parameters**
  - **Include local site effects by site coefficients $F_a$ and $F_v$**

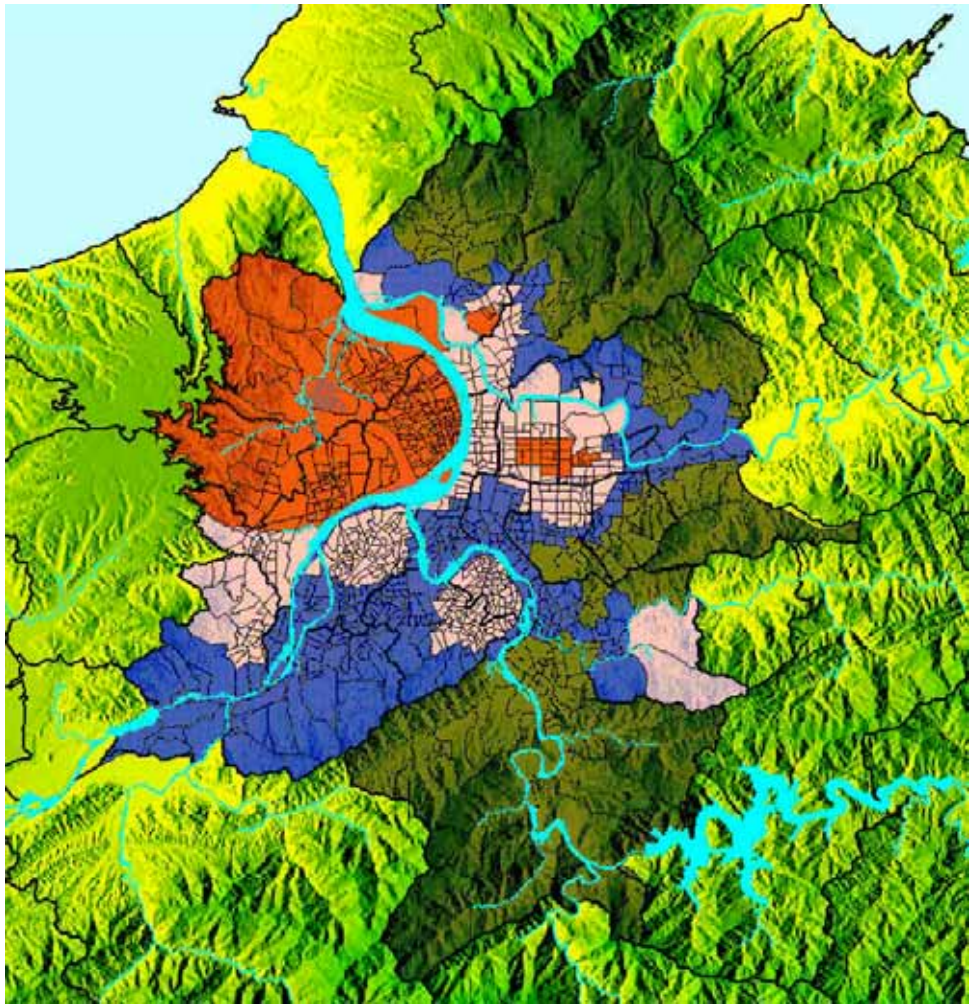
$$S_{MS} = F_a S_S \quad ; \quad S_{M1} = F_v S_1$$

  - **Site coefficients $F_a$ and $F_v$ are functions of site class (S1, S2 or S3) and mapped spectral response acceleration parameters**
- **Design spectral response acceleration $S_{aD}$**
  - **Based on $S_{DS}$ and $S_{D1}$**



# ❒ Taipei Basin (design level)

- **Four microzones (issued in 2005)**
  - **Representative corner period $T_0$ for each microzone**

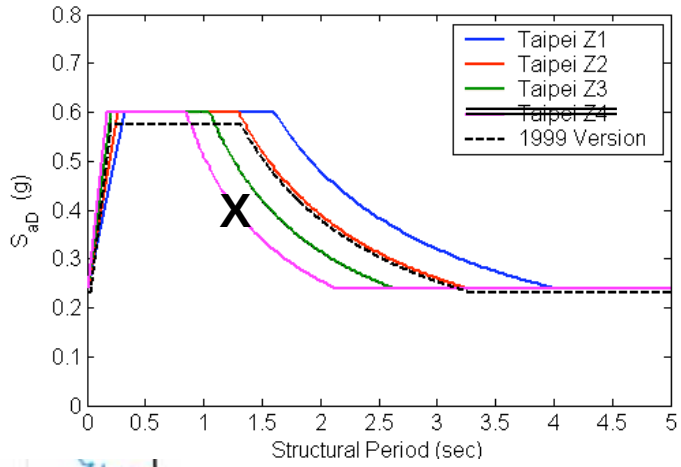


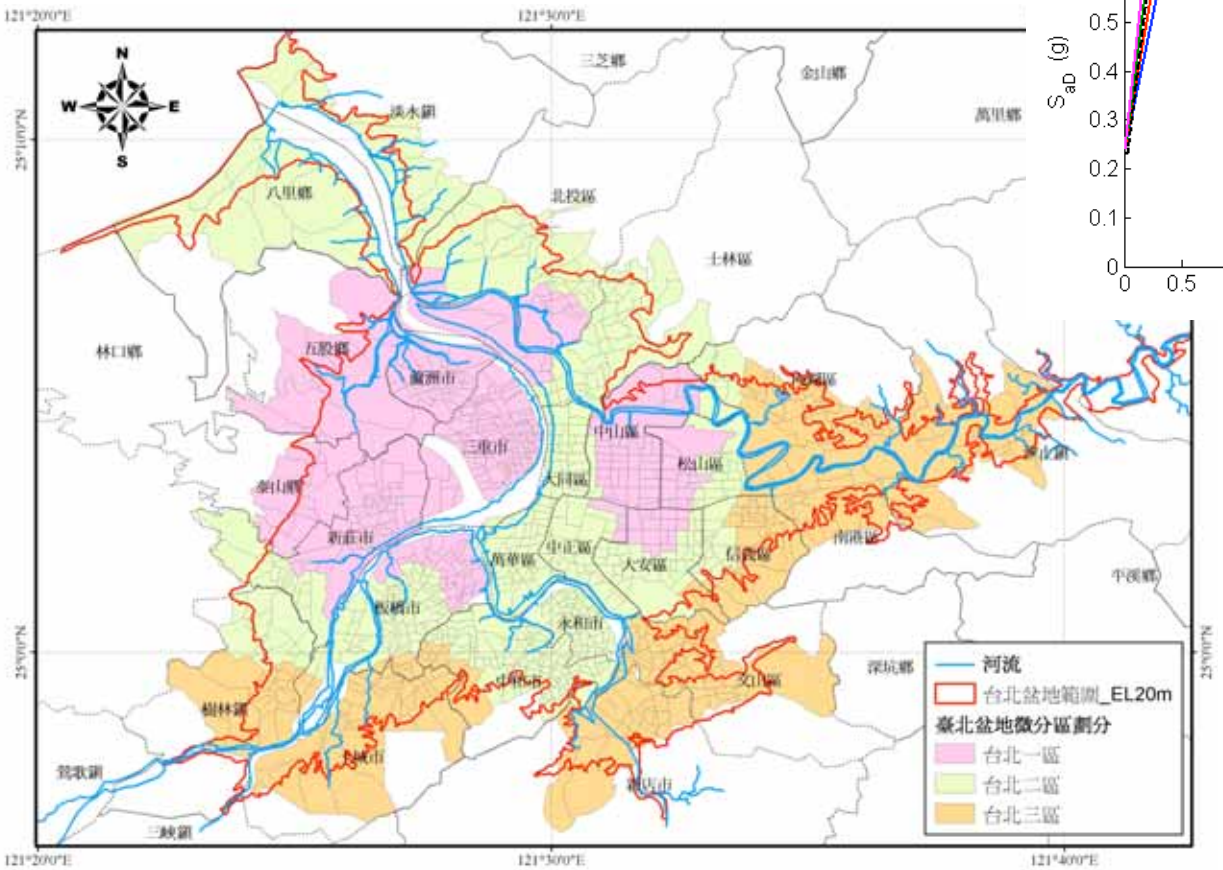
**Taipei Z1 ($T_0$=1.6 sec.)**
**Taipei Z2 ($T_0$=1.3 sec.)**
**Taipei Z3 ($T_0$=1.05 sec.)**
**Taipei Z4 ($T_0$=0.85 sec.)**

**The distribution is in accordance to the basin shape and reflects the thickness of the sedimentary soil layers in Taipei Basin**

# ❒ Three microzones (revised in 2008)

- **Boundary of Taipei Basin (EL 20m)**
- **Cancellation of Taipei Z4**



# 921 Chi-Chi Earthquake

**At 01:47AM Sept. 21, 1999. Magnitude of 7.3 About 2,500 deaths.**

**Buildings in 293 compulsory and secondary schools collapsed in Chi-Chi earthquake.**

# Typical School Buildings

## Vulnerable in longitudinal direction

Brick Wall

Classroom

Corridor

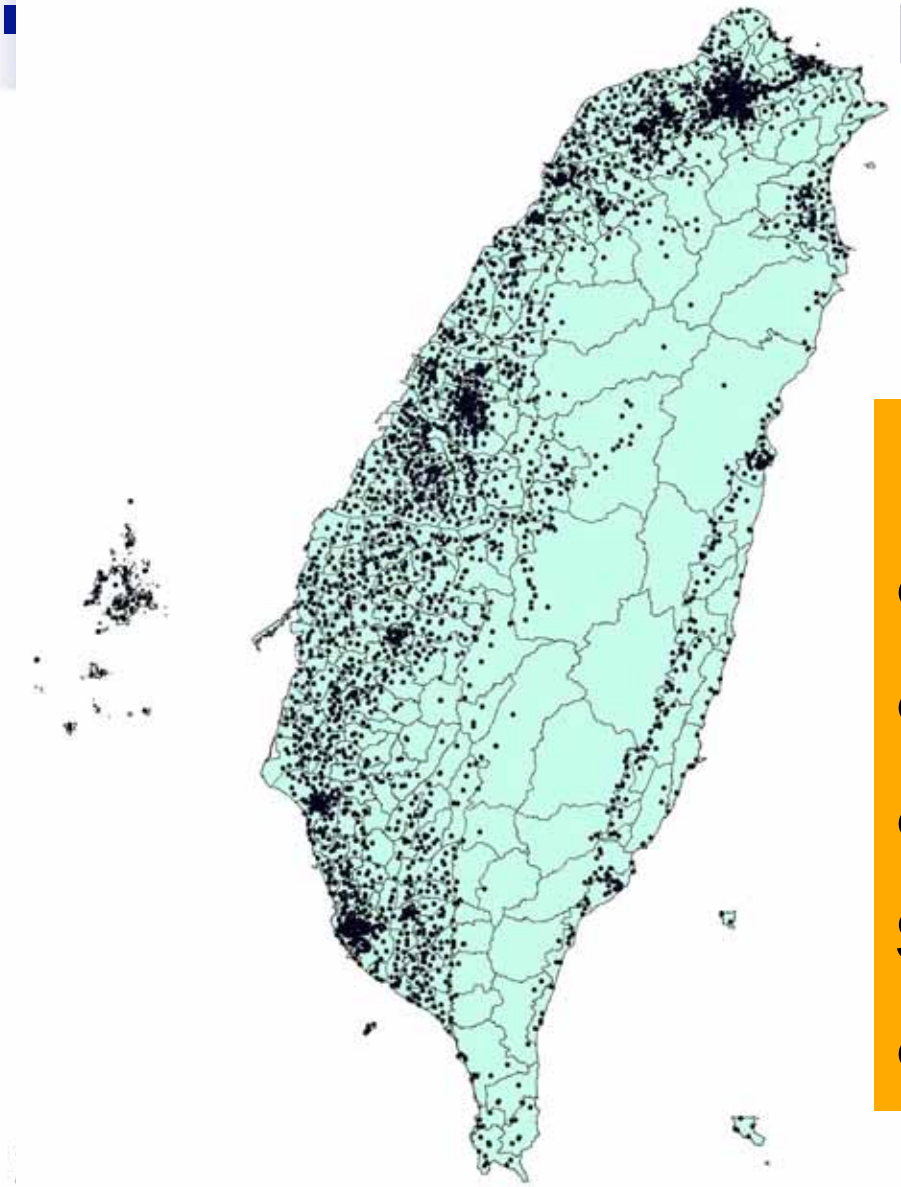
Weak Direction

Vulnerable along Corridor Direction

# Column Failures at First Floors

# The number of school buildings in compulsory and se

**10,746 school buildings**



**Needs!**

- **Nation-wide effort**
- **Prioritization**
- **Efficiently enhance seismic capacity**
- **Budget**

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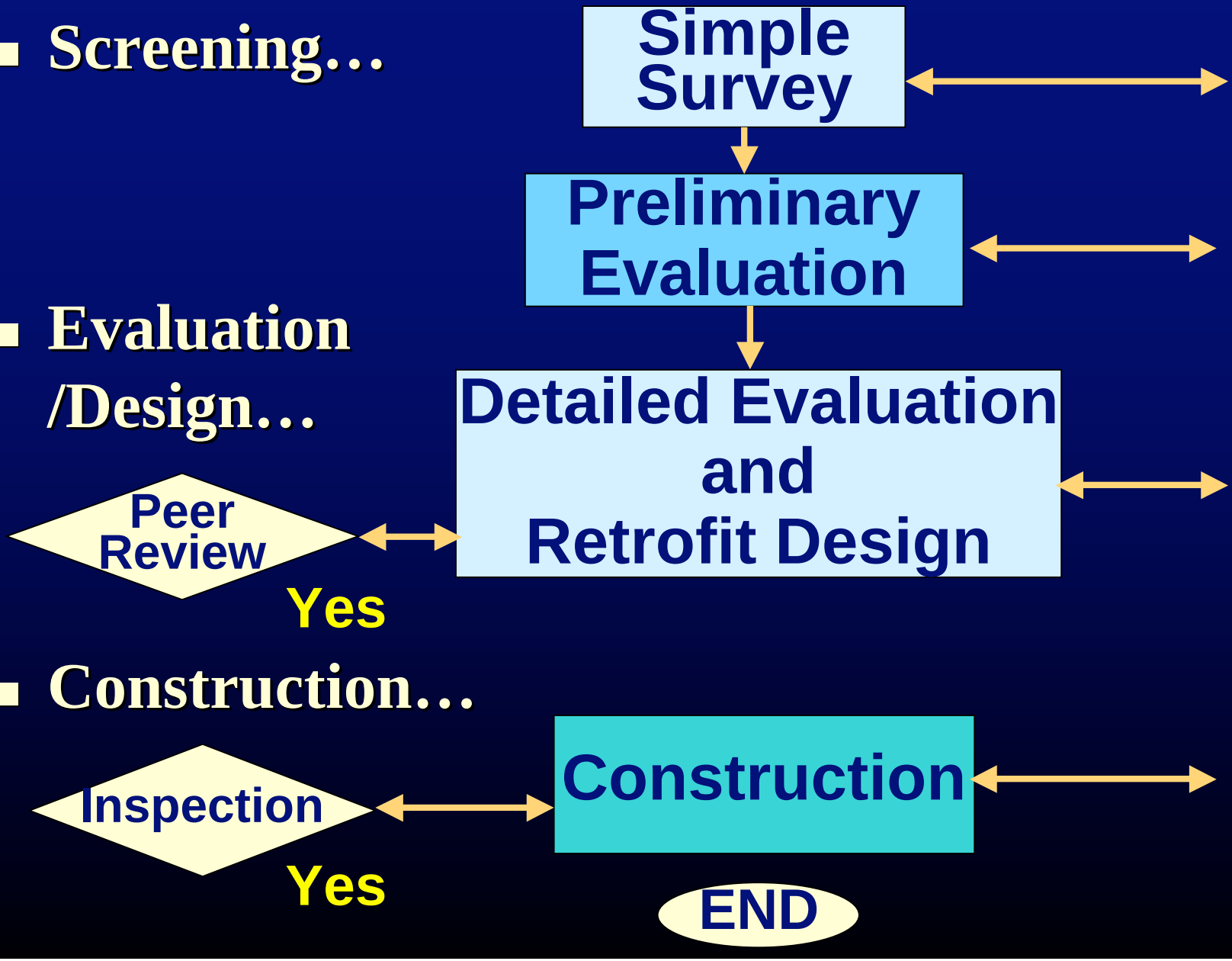
# Stages for School Upgrading

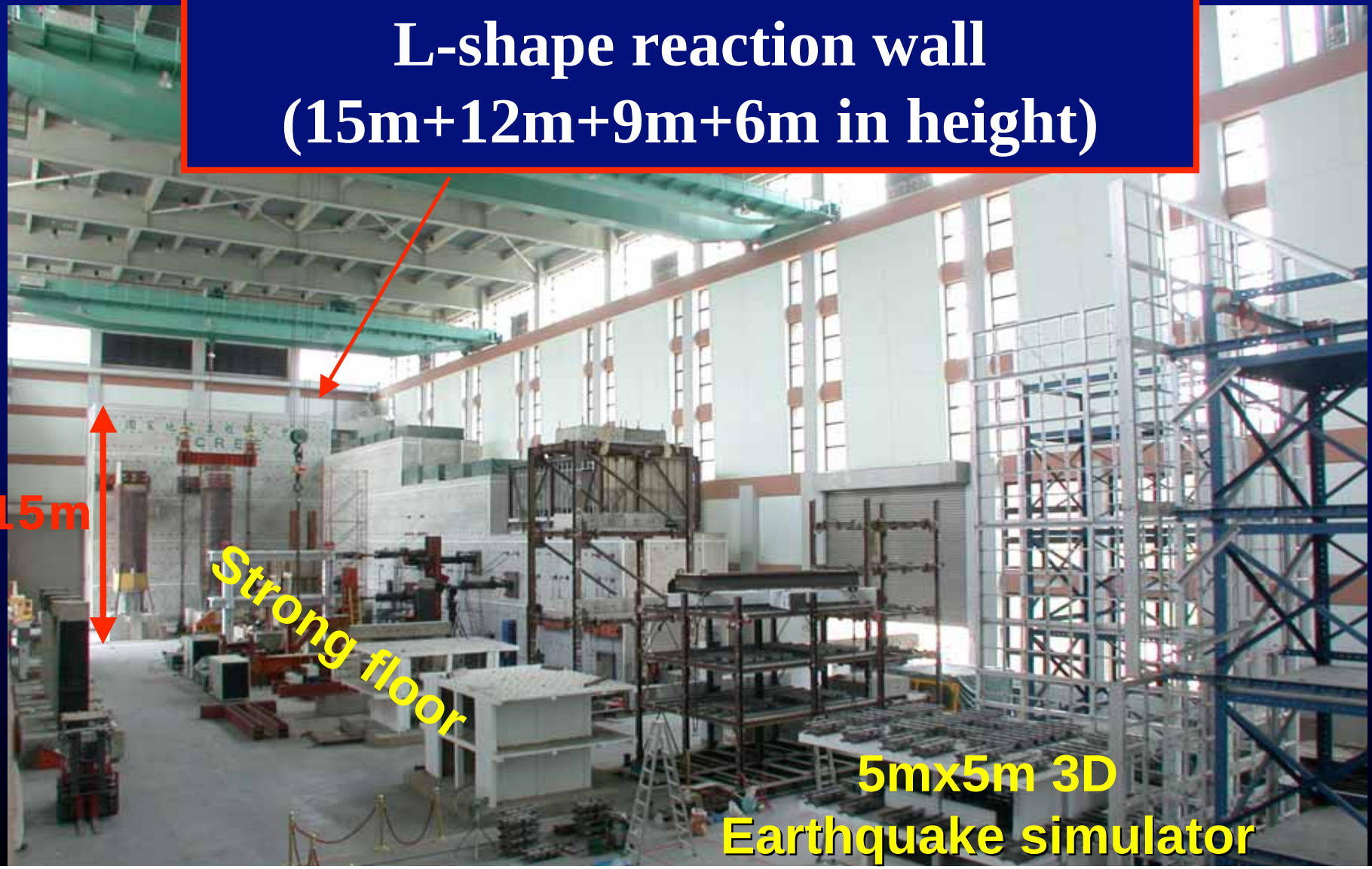
- Screening…
- Evaluation /Design…
- Construction…



# Stages for School Upgrading

- **Simple Survey by school administration through internet**
- **Preliminary Evaluation by P.E.'s through filling templates**
- **Detailed Evaluation and Retrofit Design by P.E.'s**
  **cost effective methods are verified**

# Experimental Facilities in NCREE



# Test Result– Wing Walls

$V_{retrofit}$= 63.1 t

$V_{prototype}$= 48.2 t

**Failure Modes：Beam – Flexural Failure**

**Joint – Shear Failure**

# Kou-Hu

## Specimen 2

**Frames retrofitted with RC Wing Walls**

Collapse

# Window of Opportunities

- Research on Seismic Retrofit Since 2003.
- Devastating EQ Occurred in China, May 2008.
- Global Economic Crisis - Stimulus Plan
- Legislative Yuan approved “Special Act for Developing Economy and Expending Public Development” on Jan.13, 2009.
- Legislative Yuan approved “New Scheme for Developing Economy” on Apr.10, 2009.
- A total of budget of US$1.6 billion dollars has been approved for 2009-2012 for school seismic retrofit project

# Organization of Project Office

# Mission of the Project Office

- Provide standard contracts for seismic evaluation and retrofit design
- Construct reviewer resource data bank
- Assist in review on retrofit design
- Provide seminar and technical training
- Construct and maintain data bank
- Collect and publish results of the project
- Visit outstanding seismic retrofit cases

# Progress and Technical Training

- Manual for seismic retrofit of school building completed in Oct. 2008
- 13 seminars and 82 courses since 2008 for 960 practitioners (seismic evaluation and design procedures)
- 19 coordination meeting held among school administrators, Professional Engineers and reviewers. (reference unit cost, review process, procurement)
- Additional 23 seminars and 71couses for 1582 engineers on prescribed evaluation procedures procurement since March 2009.
- A data base for the evaluation, design and review works

# Seismic Retrofit Example: Wanfang Elementary School in Taipei


## Adding Wing Walls


Thanks for Your Attention
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National Applied Research Laboratories
國家地震工程研究中心
National Center for Research on Earthquake Engineerir