

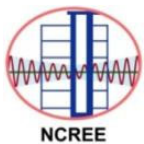
Recent Advances on the Increase of Resilience
and Sustainability of School Infrastructure

NARLabs

February 24, 2021

Seismic Retrofitting Program of School Buildings in Taiwan

Shyh-Jiann Hwang



Director
National Center for Research on Earthquake Engineering



Professor
National Taiwan University

Introduction of NCREE

- Established at National Taiwan University in 1990
- Mission:
 - Pre-quake preparation – Disaster prevention
 - Emergency response – Disaster reduction
 - Post-quake recovery – Disaster relief



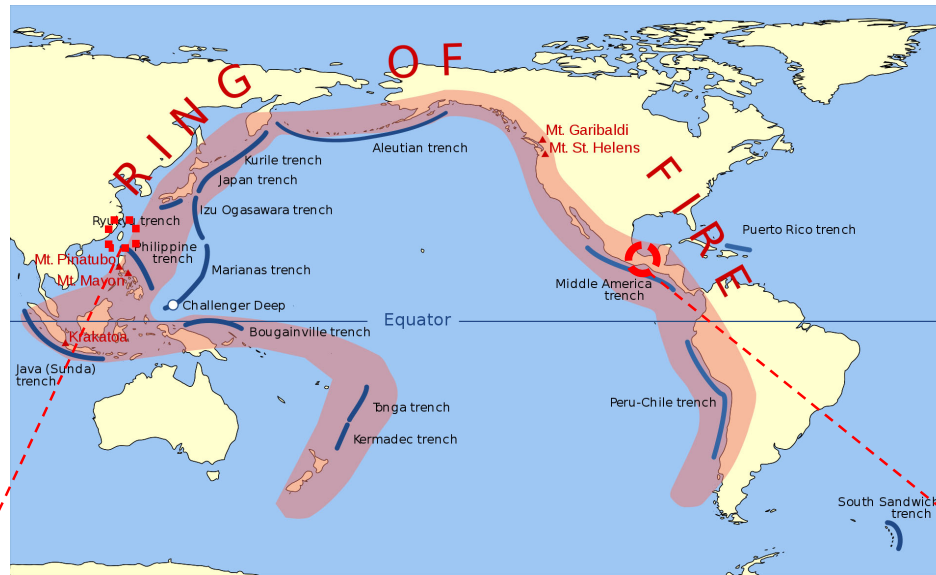
Outlines

- **Introduction**
- **Evaluation and Retrofitting Technologies**
- **School Retrofitting Program**
- **Residential Building Program**
- **Conclusion**

Introduction

Vulnerability of School Buildings

Taiwan 1999
Chi-Chi EQ



Mexico 1985
Mexico City EQ



**Collapse of
school buildings**



School Building Retrofitted by PT Rods

The 14th World Conference on Earthquake Engineering
October 12-17, 2008, Beijing, China



FIELD TEST OF RC SCHOOL BUILDING RETROFITTED BY POST-TENSIONED RODS

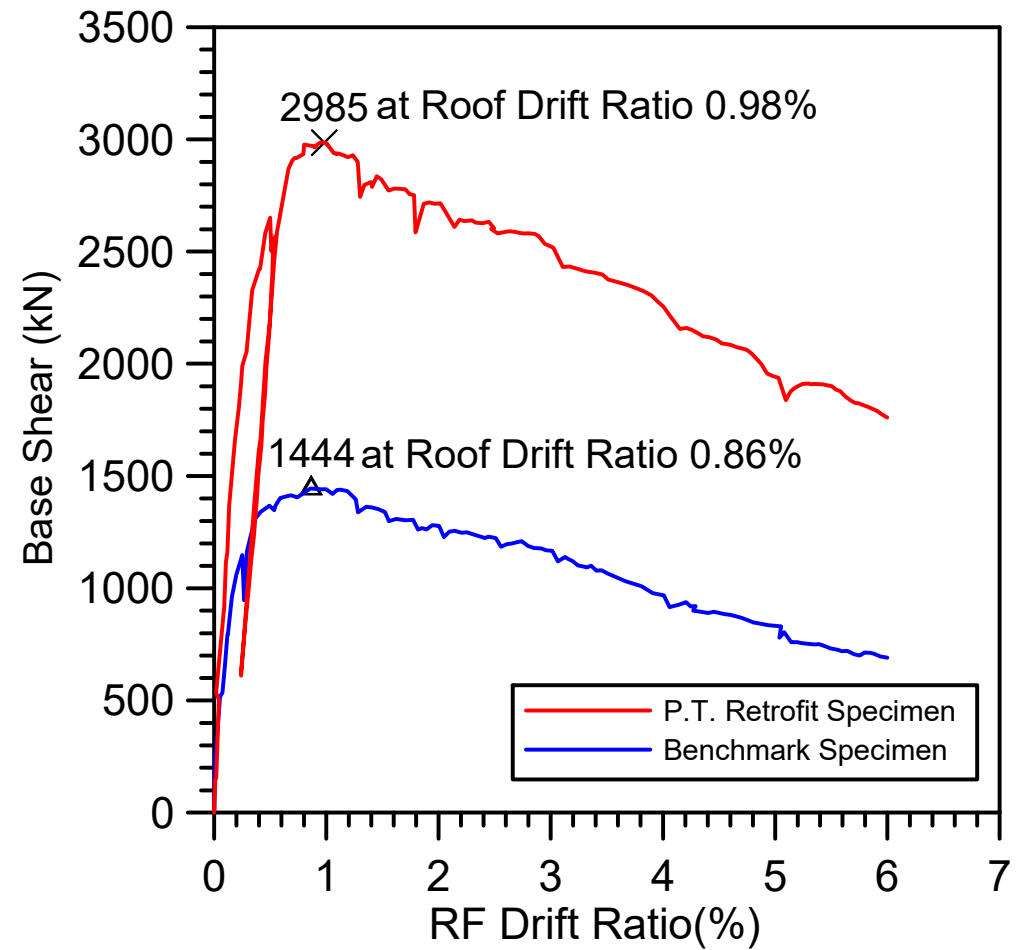
S.J. Hwang¹, T.C. Chiou², F.P. Hsiao³, Y.J. Chiou⁴ and S.M. Alcocer⁵



Effectiveness of PT-Rod Retrofitting

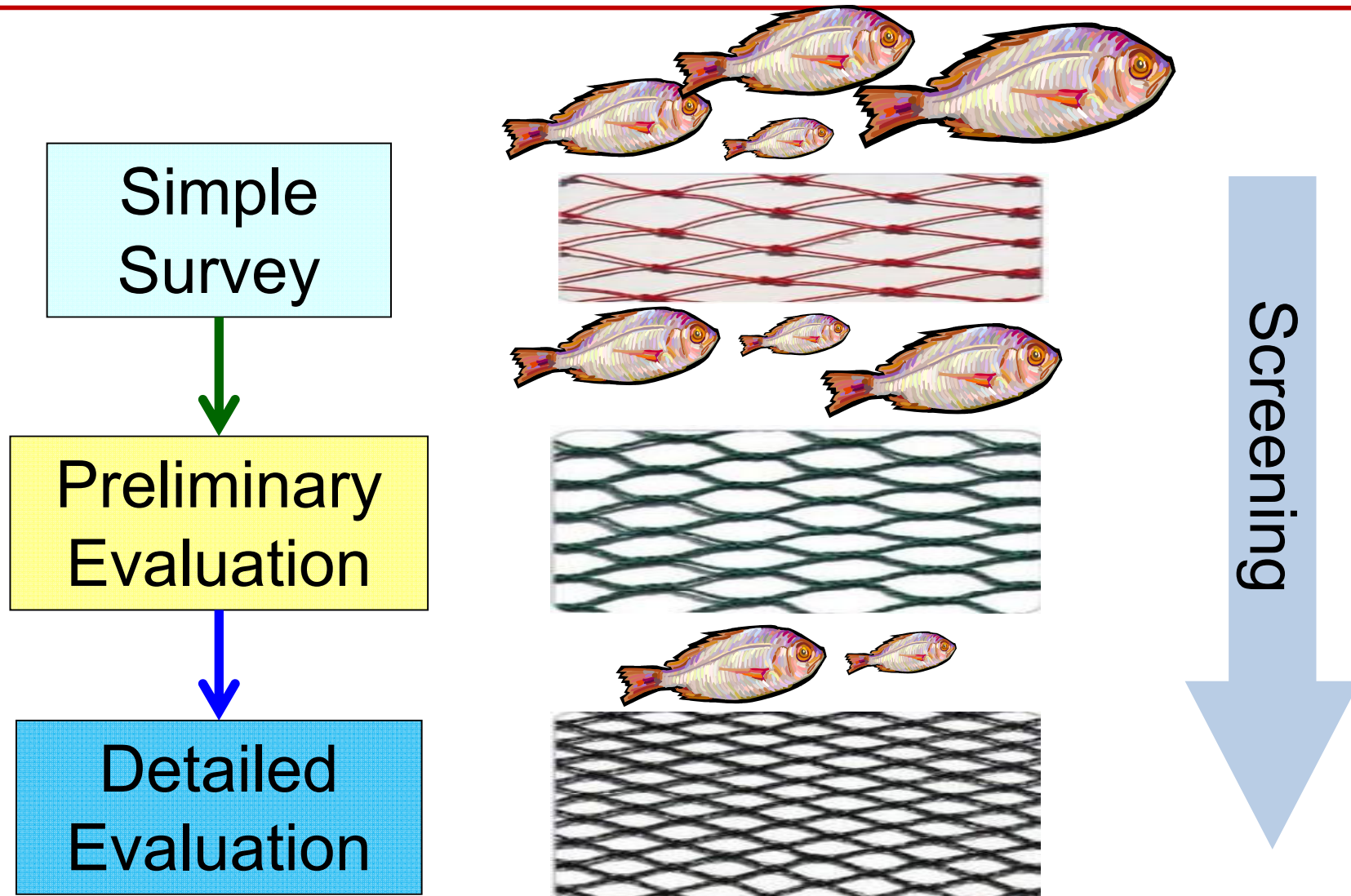


In-situ school testing,
Tainan, Taiwan (2007)



Evaluation and Retrofitting Technologies

Screening Process



Simple Survey (2009-2011)

Field investigation:

- 3,721 public schools
25,843 buildings
- 228 college students
4,426 days per person

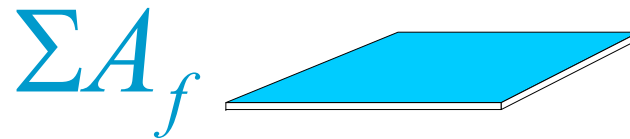
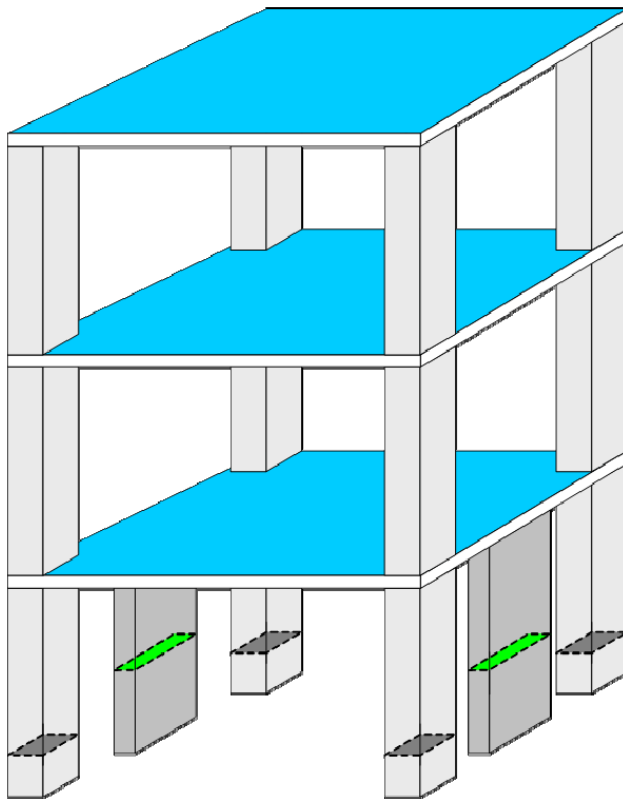
School building included:

- Buildings constructed before 1999
- Buildings occupied by students or teachers

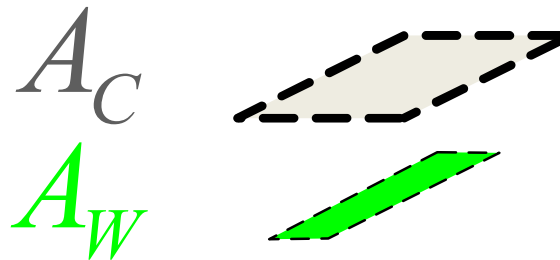


Preliminary Evaluation

Seismic Index:
$$\frac{\text{Capacity}}{\text{Demand}} = \frac{\tau_C A_C + \tau_W A_W}{a_g \times w \times \Sigma A_f}$$



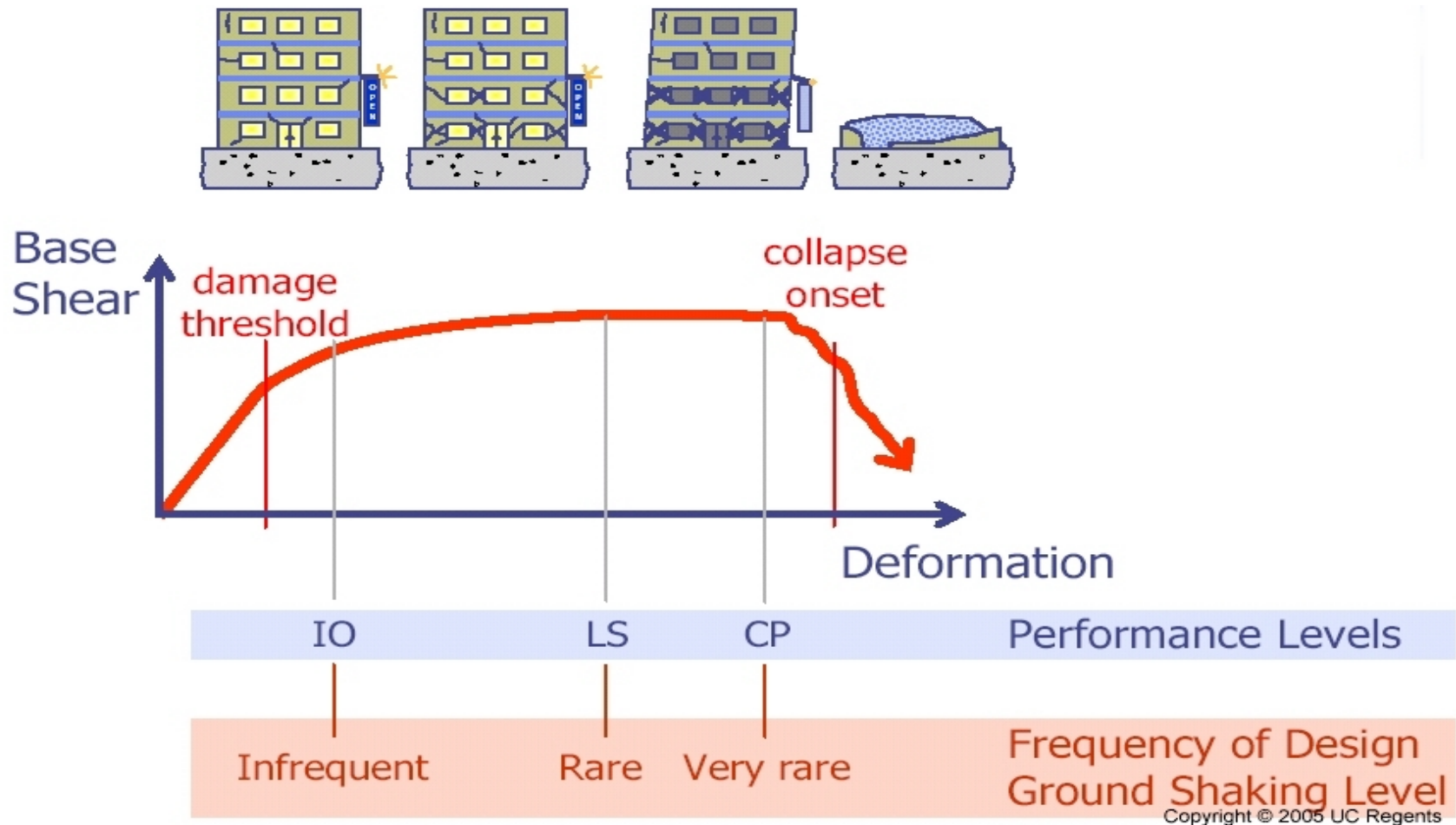
Total Floor Area above 1st Floor



1st Floor Capacity

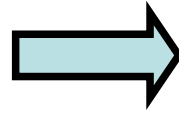
Detailed Evaluation

Performance Based Engineering

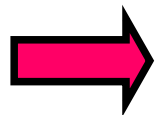
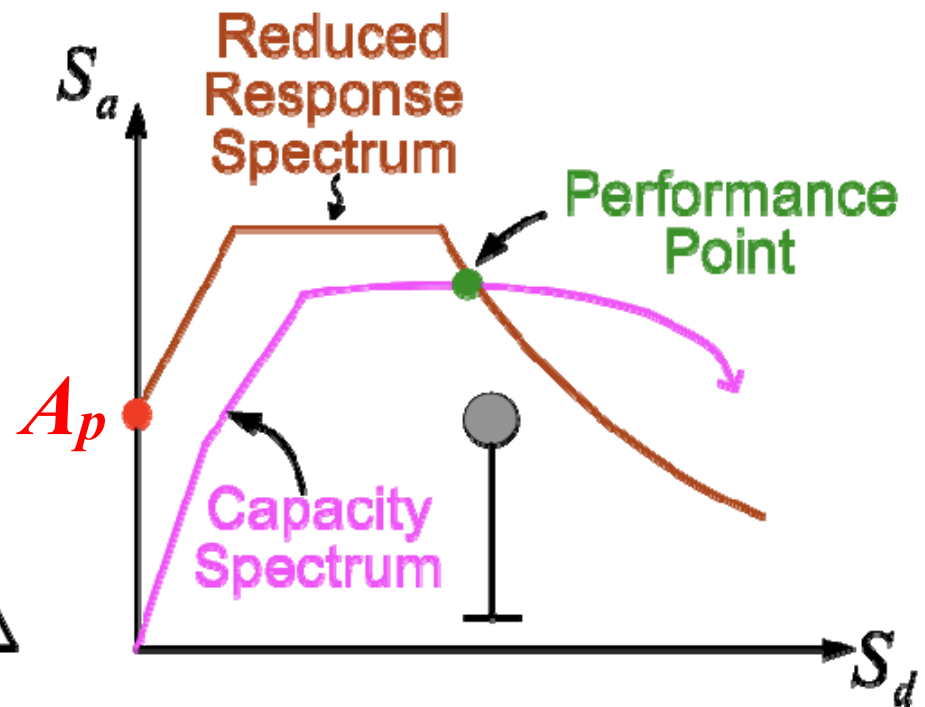
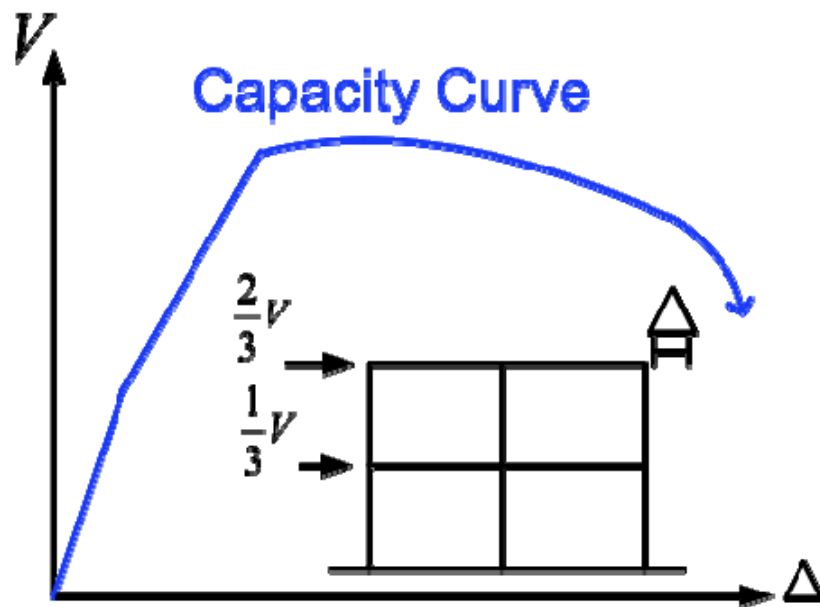


Nonlinear Static Analysis

Pushover
Analysis

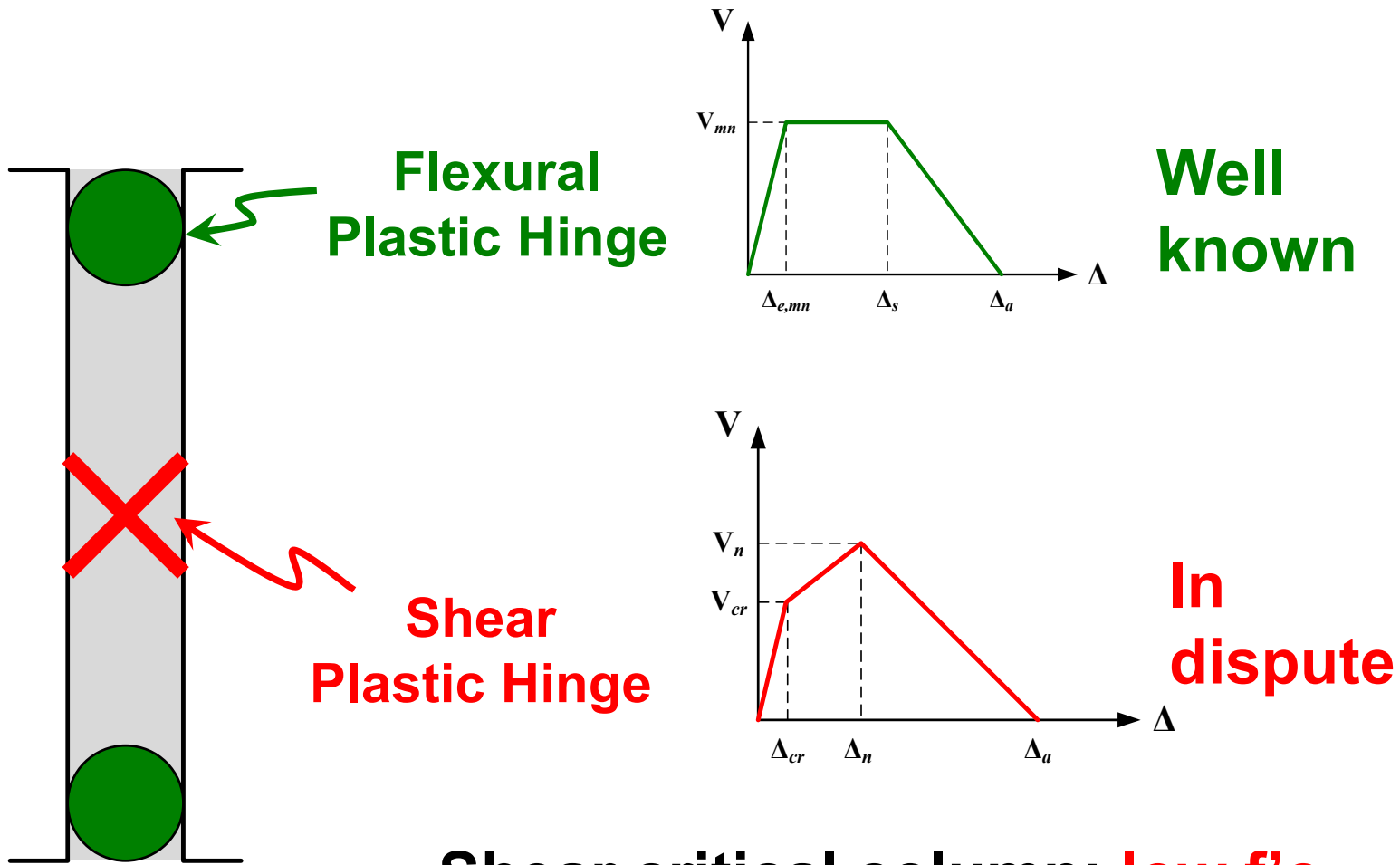


Capacity Spectrum
Analysis



Performance-Target Ground Acceleration A_p

Modeling of Vertical Members



Shear critical column: **low f'_c** ,
less transverse reinforcement

Shear-Critical Vertical Members



Short column



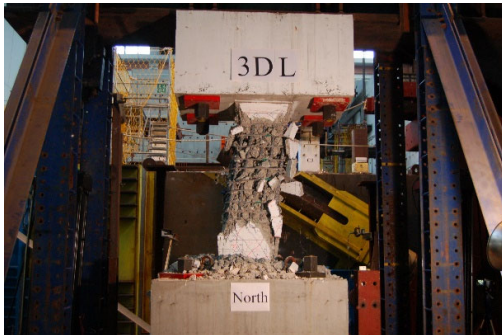
Column



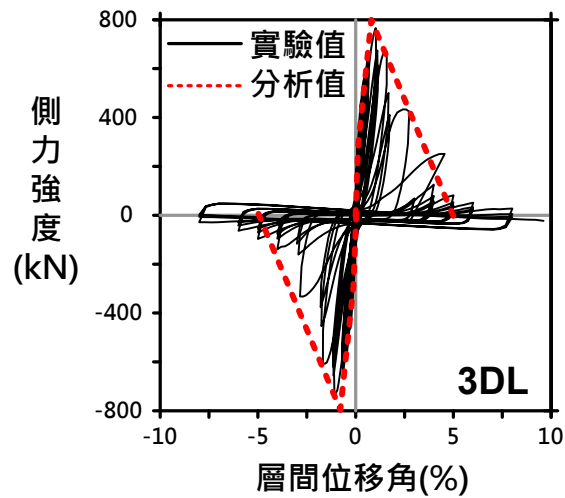
Shear wall

Research on Seismic Capacity of Members

Static Test



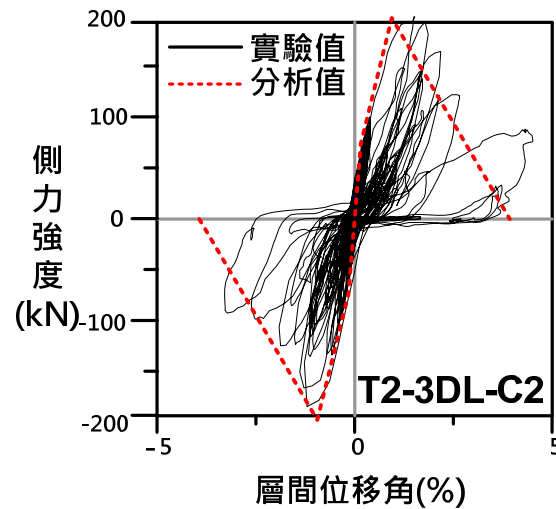
Column



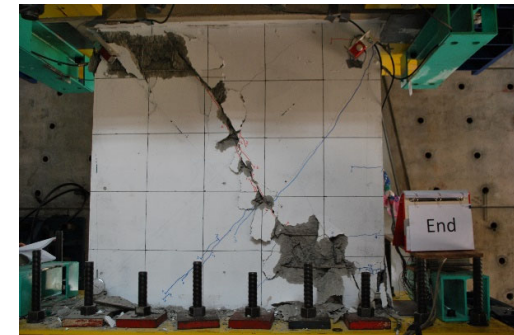
Shaking Table Test



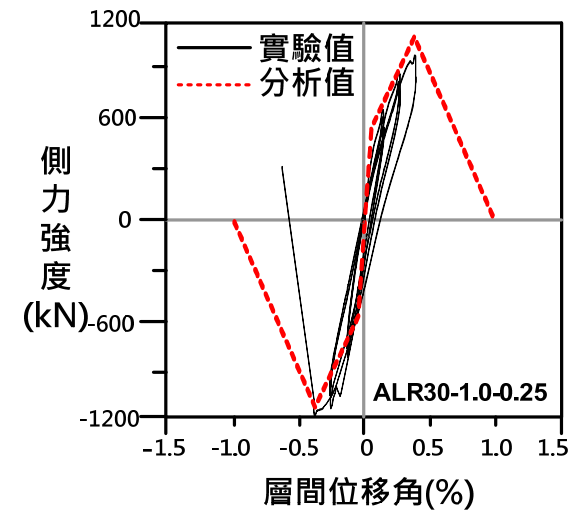
Columns



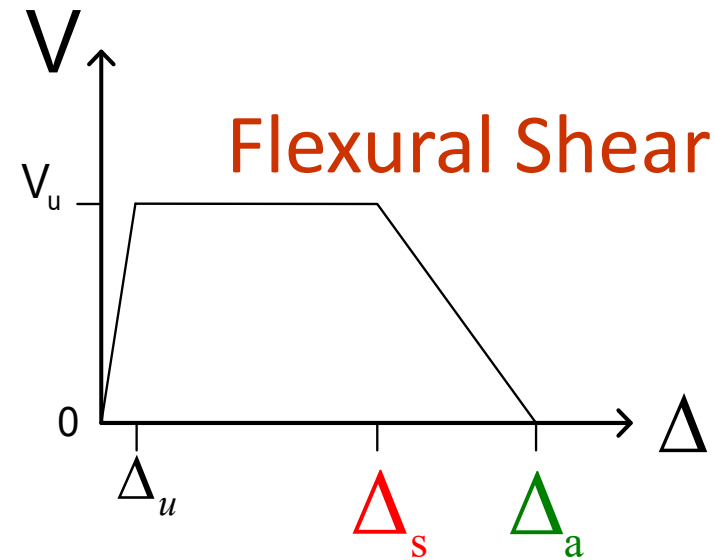
Static Test



Wall



Collapse Behavior of RC Column

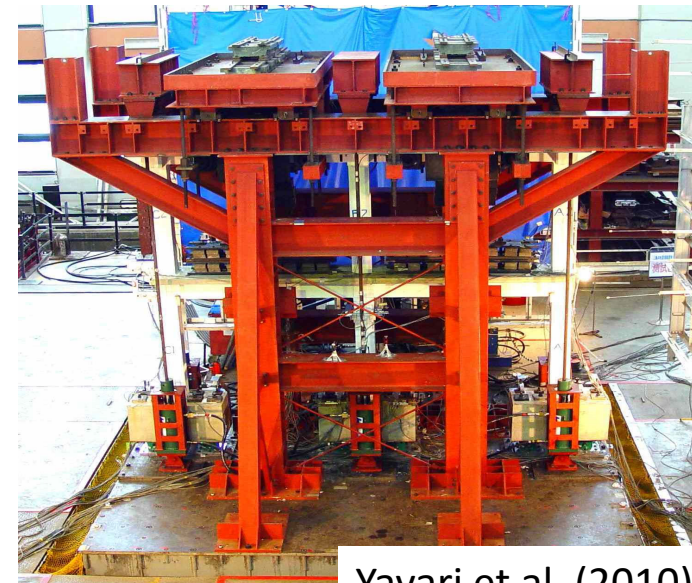
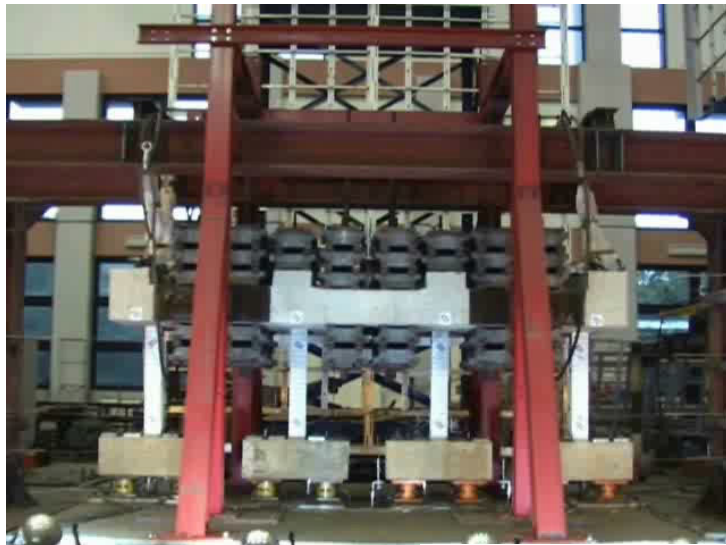
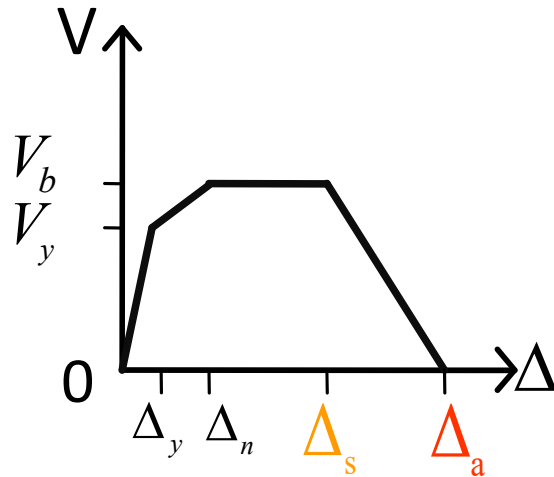


Elwood & Moehle (Spectra 2005; ACI 2005)

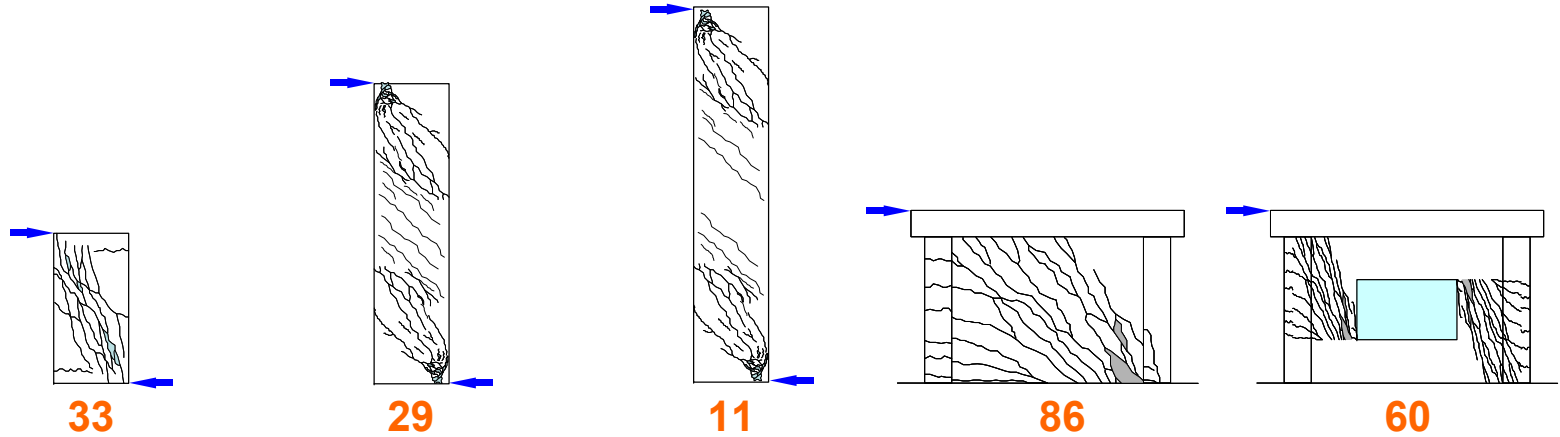
$$\frac{\Delta_s}{H_n} = \frac{3}{100} + 4\rho'' - \frac{1}{40} \frac{v}{\sqrt{f'_c}} - \frac{1}{40} \frac{N_u}{A_g f'_c} \geq \frac{1}{100}$$

$$\frac{\Delta_a}{H_n} = \frac{4}{100} \frac{1 + (\tan \theta)^2}{\tan \theta + N_u \left(\frac{s}{A_{st} f_{yt} d_c \tan \theta} \right)}$$

Shaking Table Tests for Column Collapse Behavior



Experimental Verification of Shear Strength



AVG = 1.20
COV = 0.10

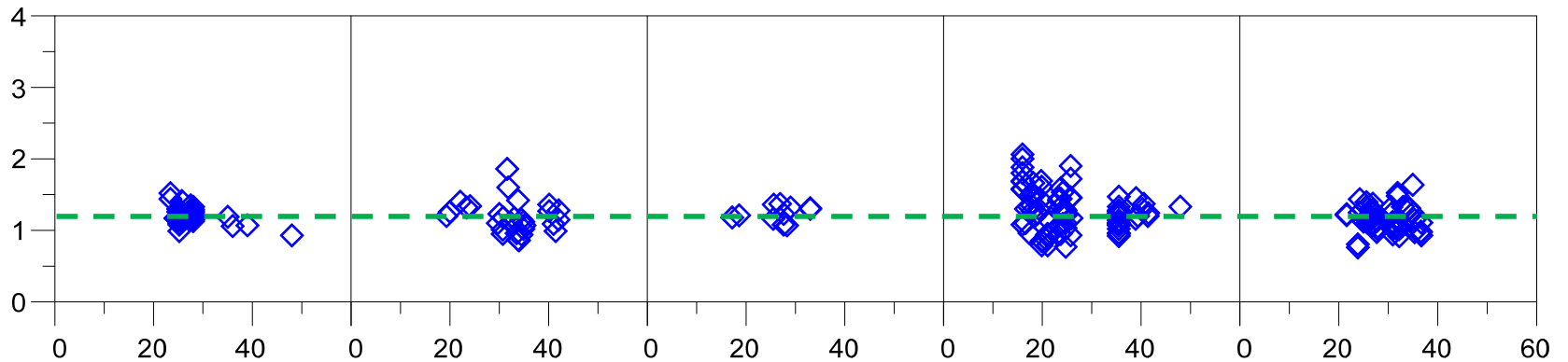
1.18
0.18

1.24
0.08

1.27
0.22

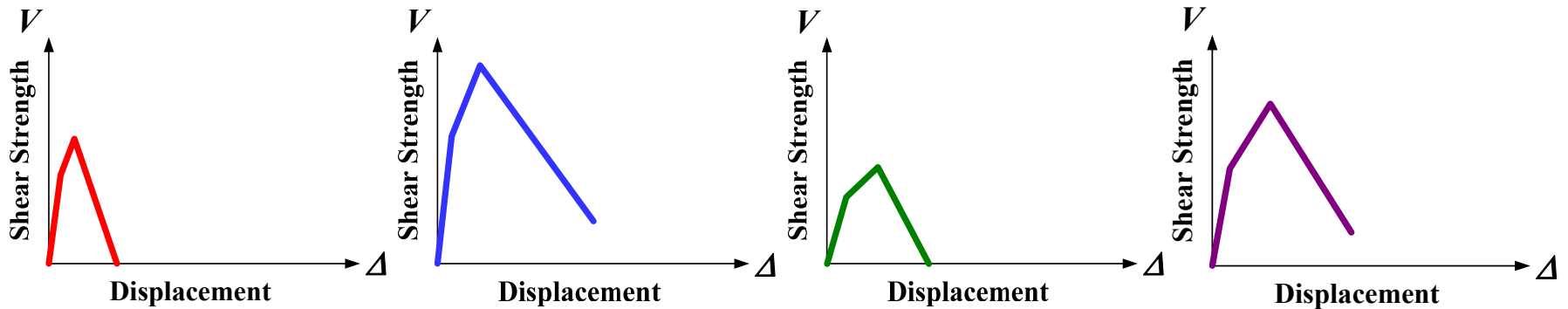
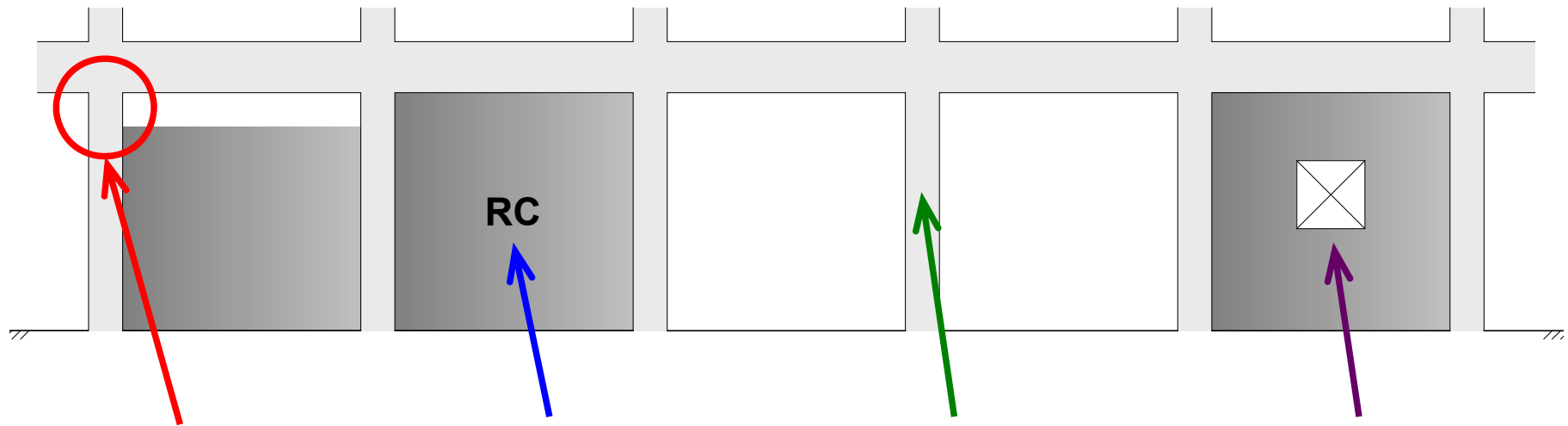
1.15
0.14

V_{test} / V_n



f'_c (MPa)

Backbone Curves for Shear Critical Members



Short Column

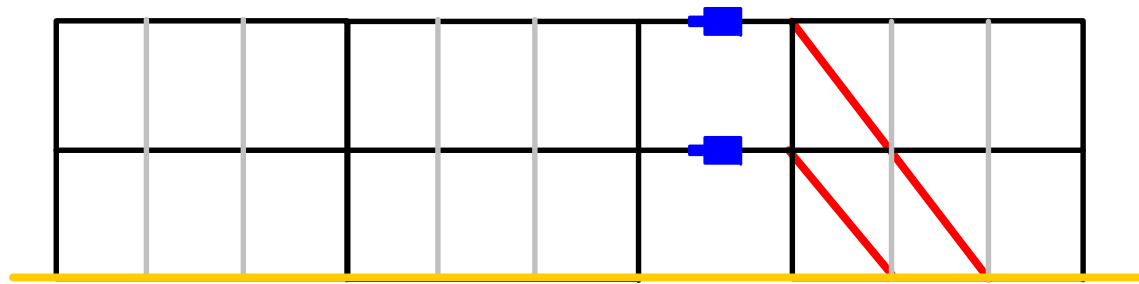
Shear Wall

Typical Column

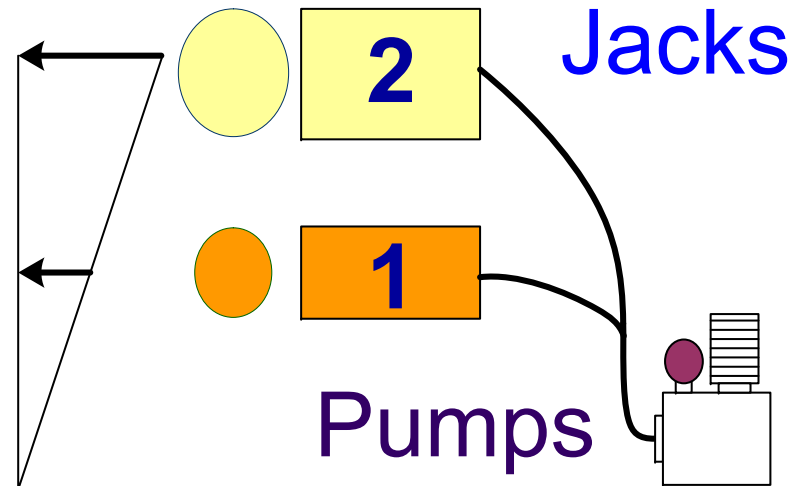
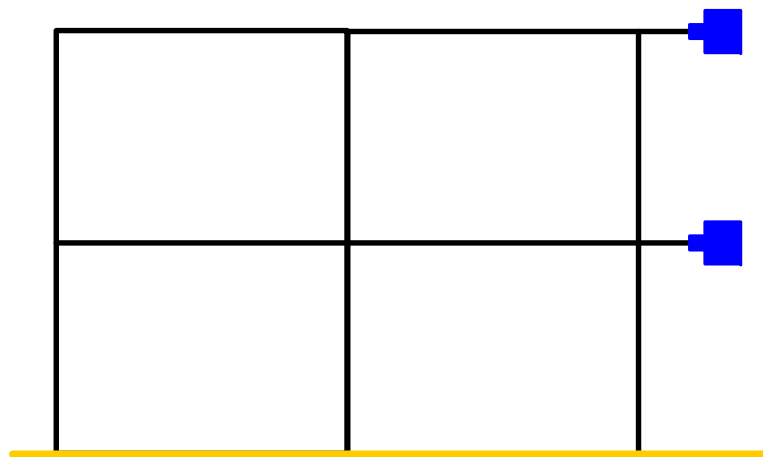
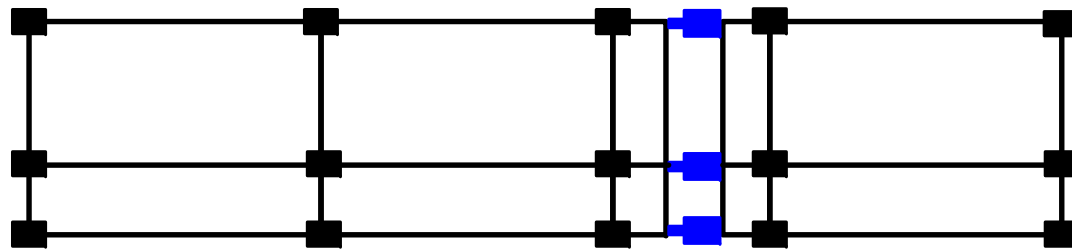
Wall with Opening

Softened Strut-and-Tie Model

Test Setup of Monotonic Loading



Brace



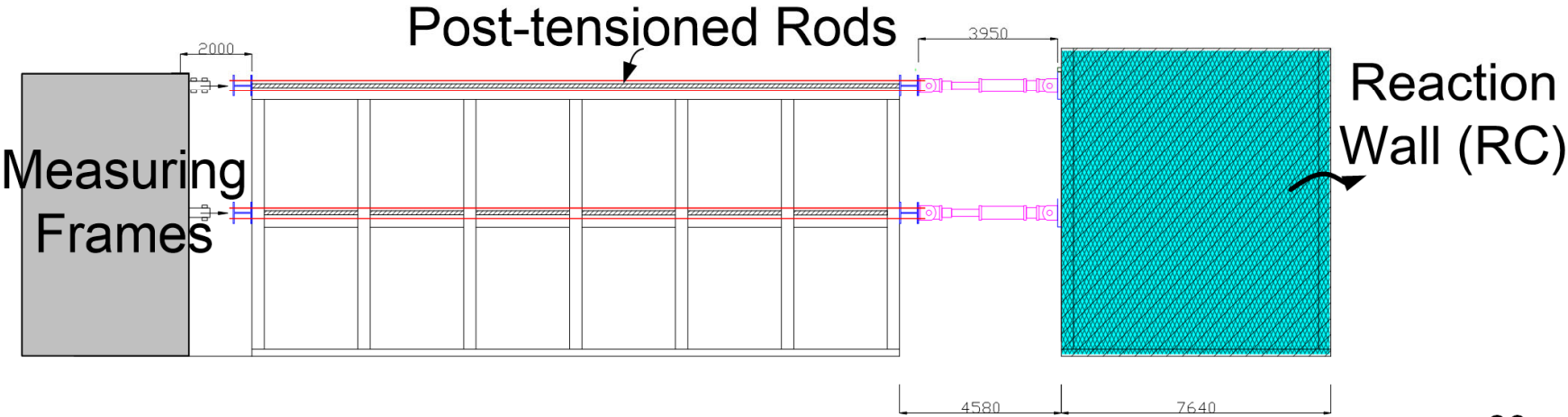
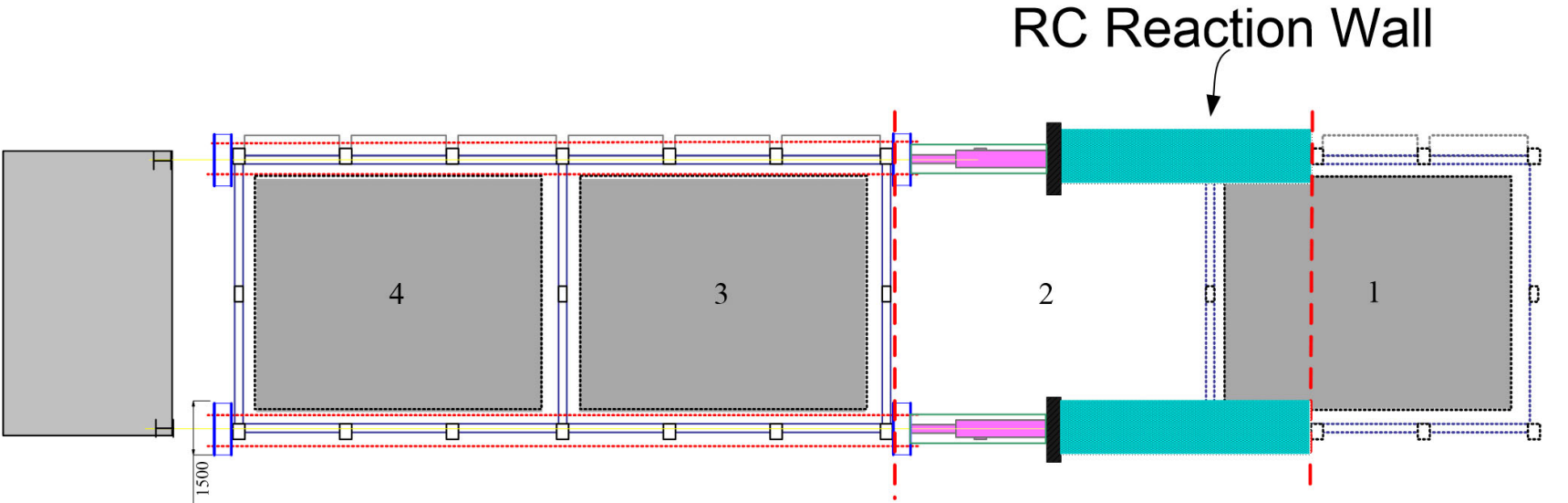
Jacks

Pumps

Test Video of Monotonic Loading



Pseudo-Dynamic and Cyclic Tests Setup

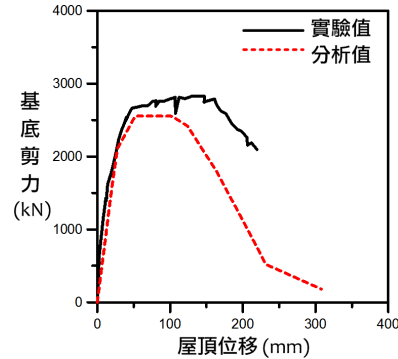




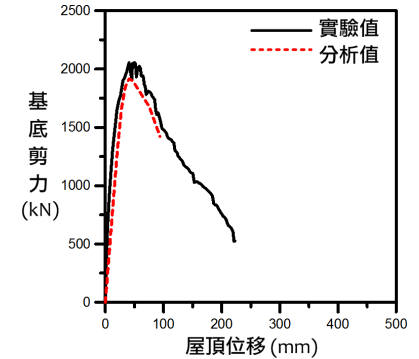
Pseudo Dynamic Test (# 3), Courtesy of Dr. Min-Lang Lin

In-Situ Tests of School Buildings – Verification of Pushover Analysis

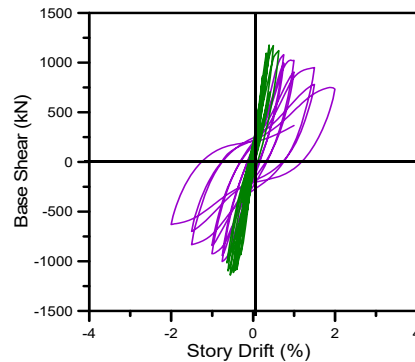
Hua-Lien (2005)



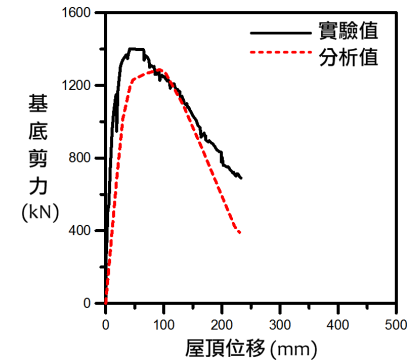
Yun-Lin (2005)



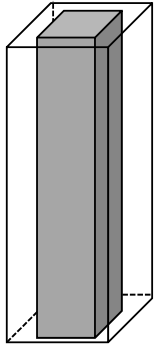
Tao-Yuan (2006)



Tainan (2007)



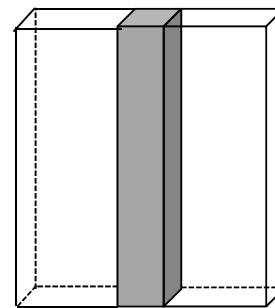
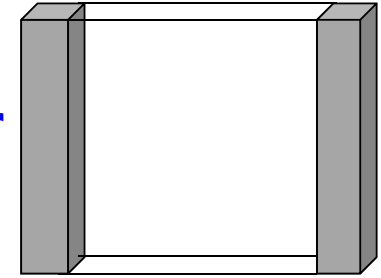
Common Retrofitting Techniques



Jacketed column



Shear wall

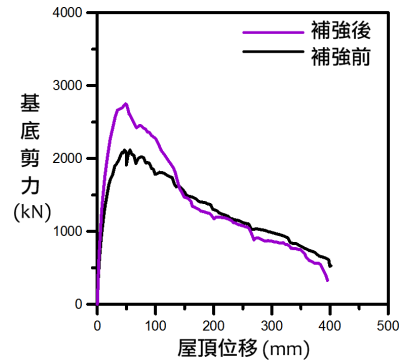


Wing wall

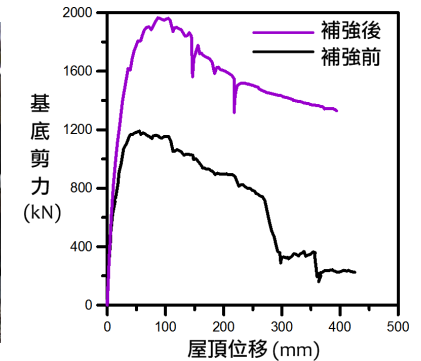


In-Situ Tests of School Buildings – Verification of Retrofitting Methods

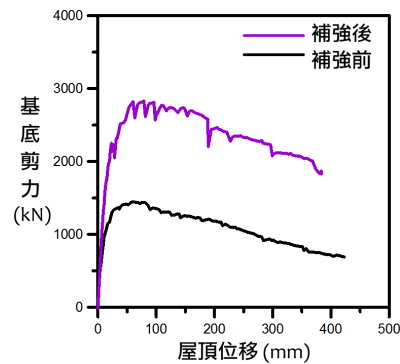
RC Wing Wall (2005)



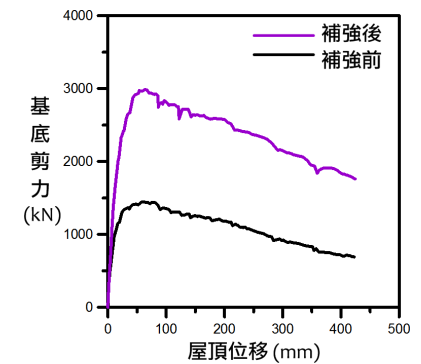
Composite Column (2006)



RC Jacketing (2007)

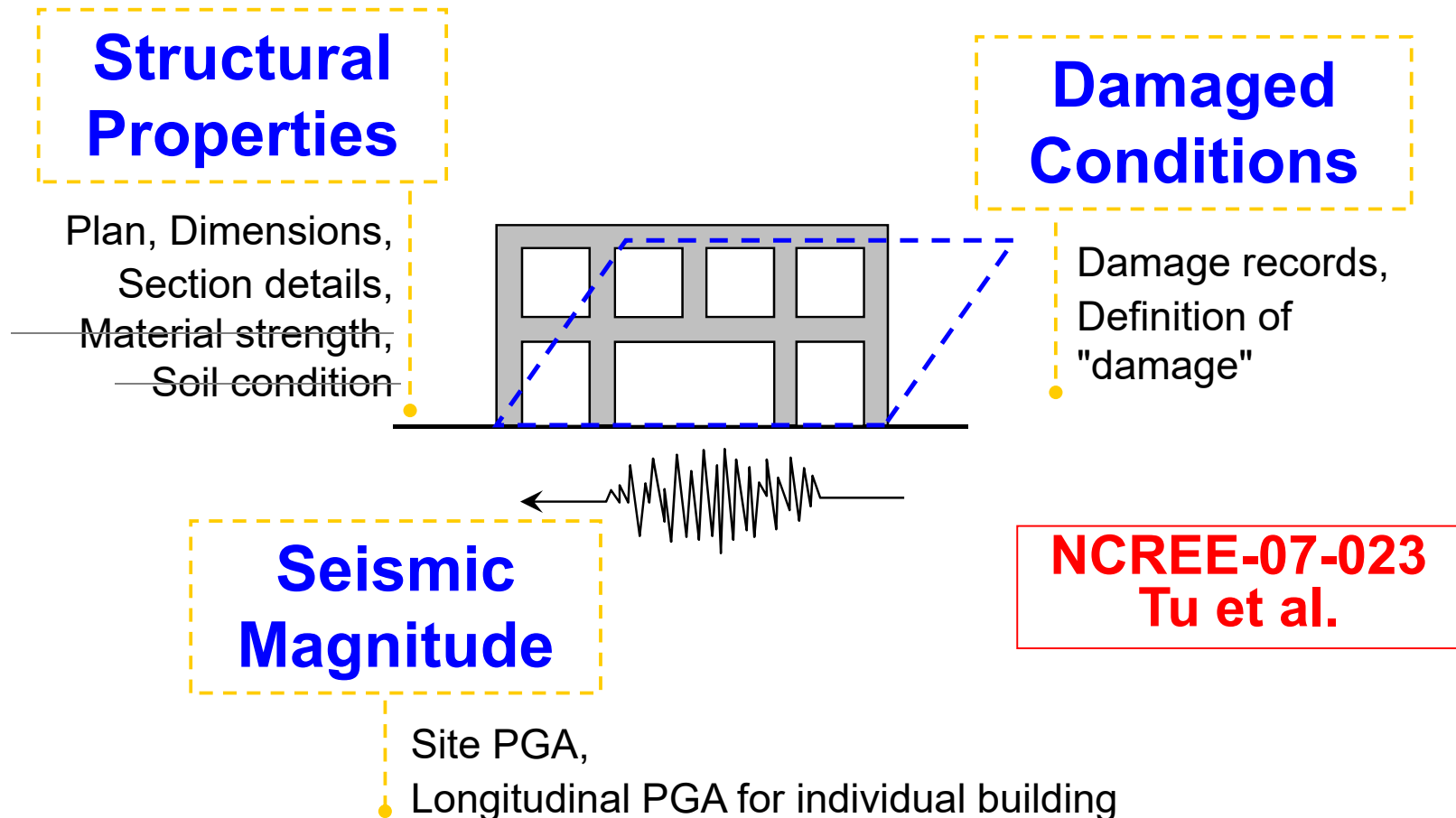


Steel Jacketing (2007)

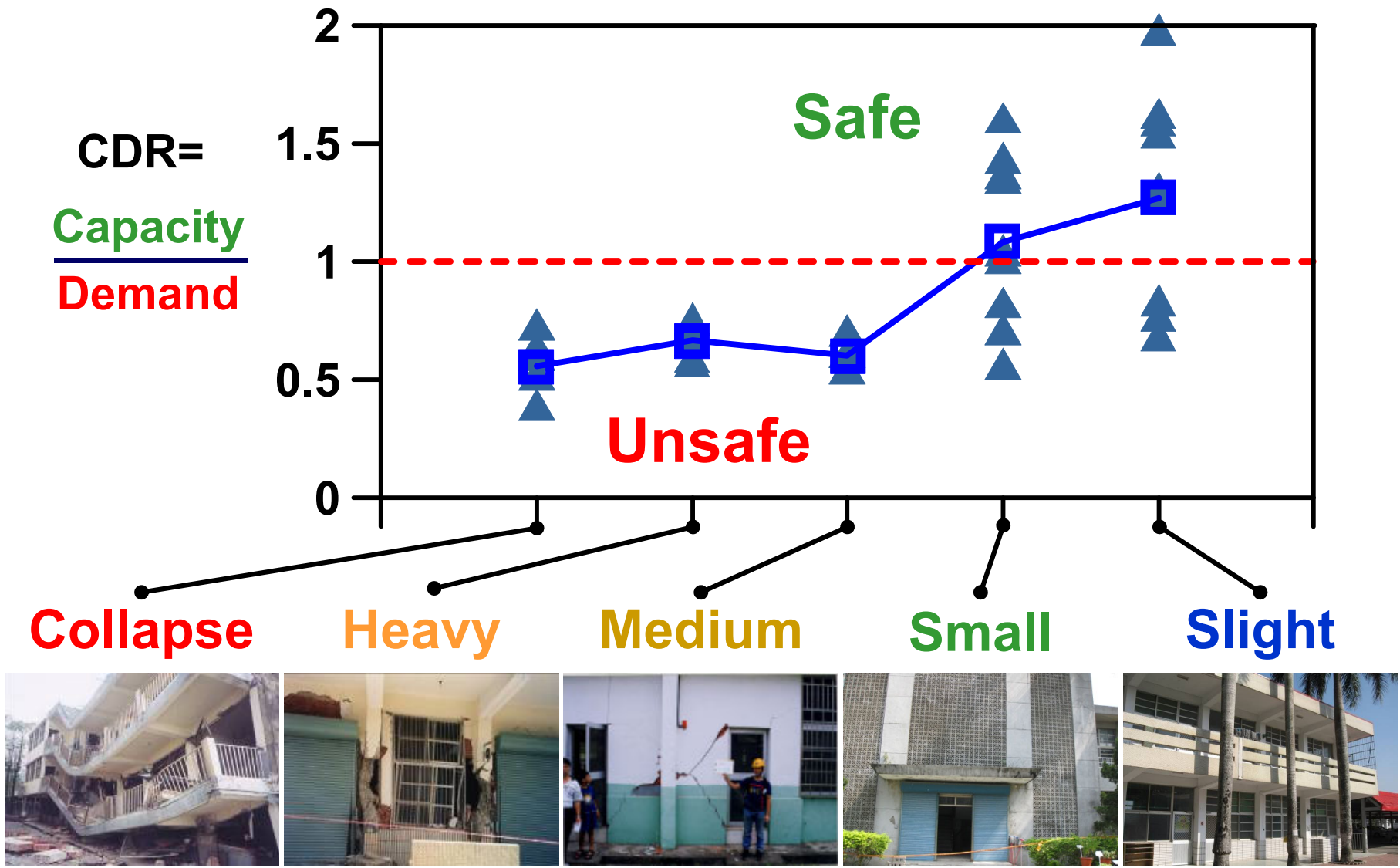


Chi-Chi Earthquake Damage Database of School Buildings in Taiwan

Basic Methodology from ATC-13

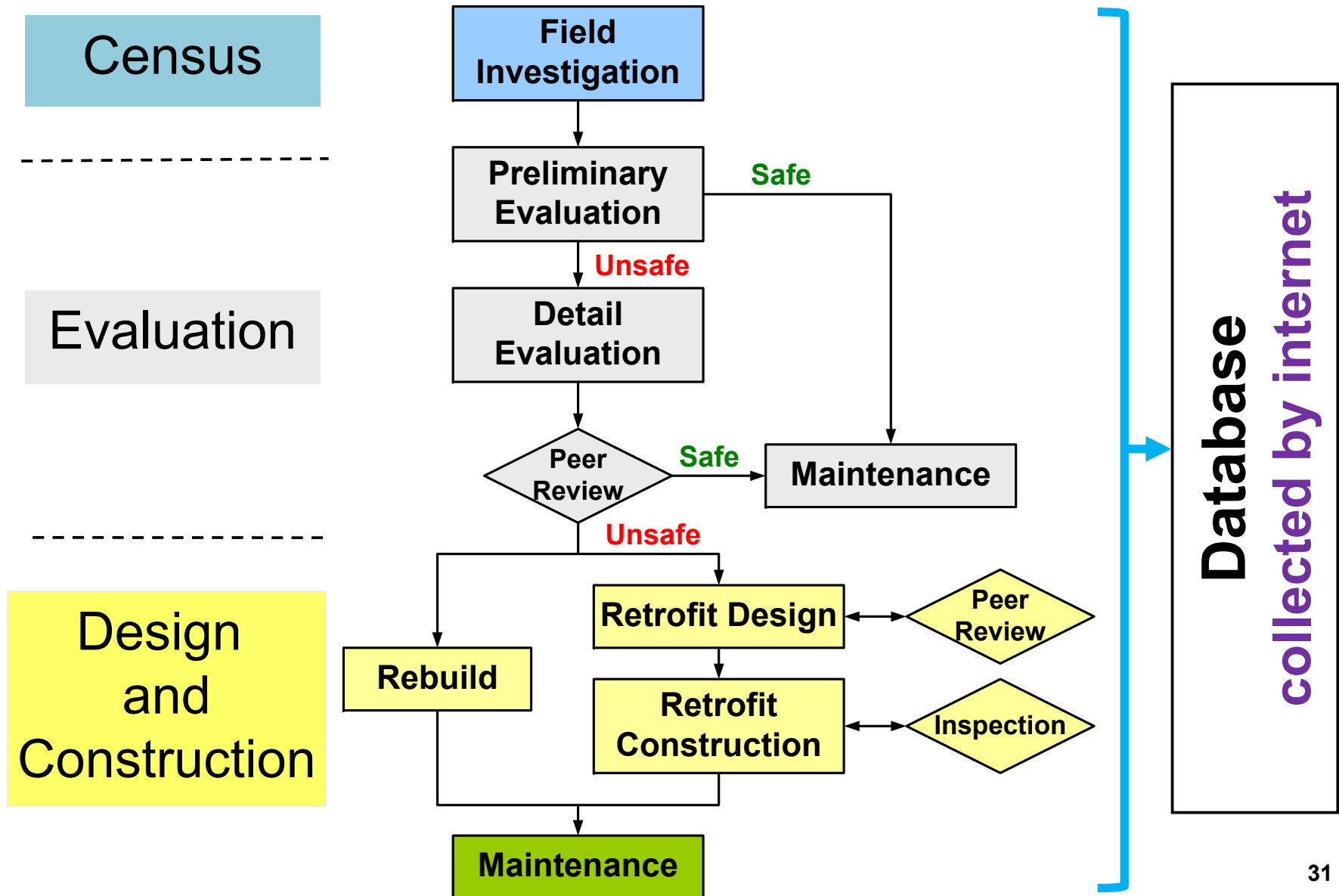


Verification of Acceptance Criteria (35 Buildings)



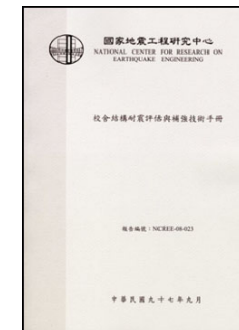
School Retrofitting Program

Strategy for School Upgrading in Taiwan



Unification of Process

- **Complex Parties:** governmental official, school teacher, engineer, constructor, student, parent
- **Tight Schedule:** annual budget, short construction period
- **Unification Document:** operation specification, contract document, design manual



Budget Control - Service Payment

New
Construction



Seismic
Retrofitting

Design Payment =
Rate × Construction Fee

Design Payment =
Rate × Floor Area

Payment per
Quantity

Innovation for
Quality

Budget Control - Economic Methods

✓ Traditional Retrofitting Method ⇒ Encouraged

RC Column Jacketing



RC Wing Wall

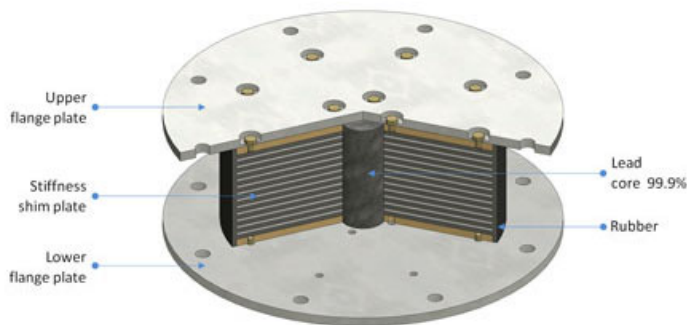


RC Shear Wall

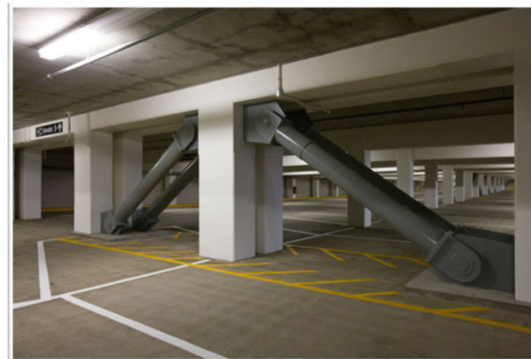


⊘ Seismic Devices with Patents ⇒ Prohibited

Isolated Device

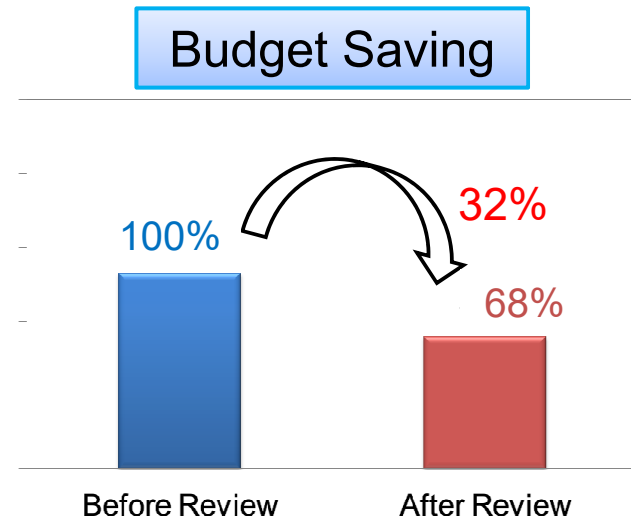
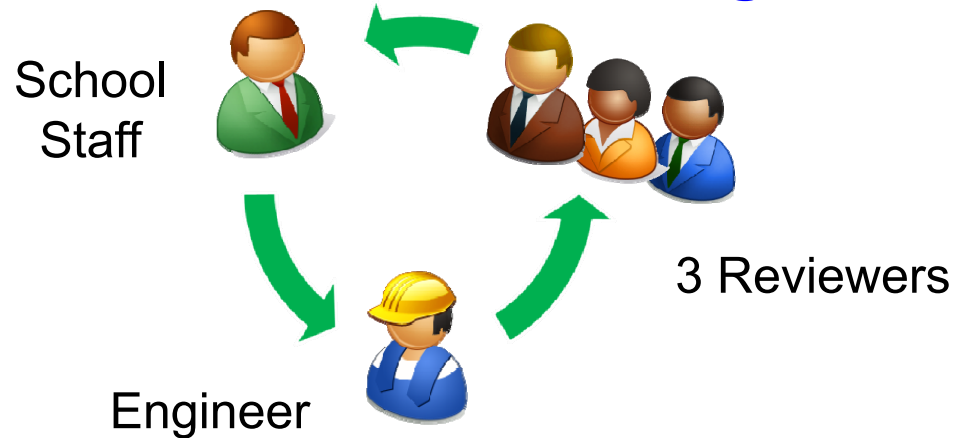


Damper

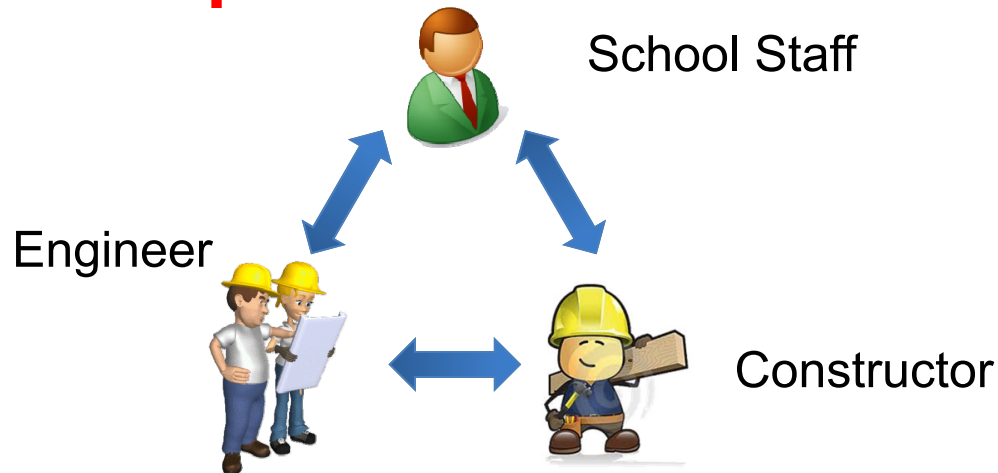


Quality Control - Review and Inspection

- **Peer Review for Design**



- **Inspection for Construction**



Quality Control - Workshops

- Workshops for Engineers, School Administrators, Educational Officials



- Case Study



Website and Database

校舍耐震資訊網
Information Website for Seismic Assessment and Retrofit of School Buildings

首頁 | 編輯個人資料 | 登出

功能選單

- 最新消息
- 耐震補強小知識
- 最新現地記錄
- 系統管理 >
- 資料查詢 >
- 進度管控 >
- 評估與補強資料上傳 >
- 評估與補強資料下載 >
- 補強設計審查會 >
- 補強成果彙整表
- 成果彙整表
- 文件及影片下載 >
- 研討會與講習會
- 相關網站
- 聯絡我們

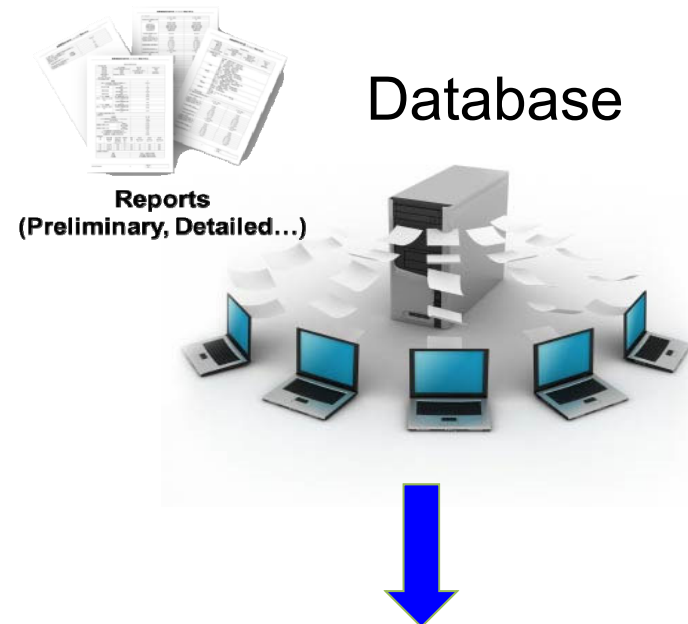
最新消息公告

2018-05-14	2018-06-20 校舍耐震補強成果上傳說明會(高雄場)【網路報名已截止, 謝謝您!】	(點閱 264 次)
2018-05-04	2018-06-07 校舍耐震補強工程施工廠商作業講習會【報名已截止, 謝謝您!】	(點閱 515 次)
2018-04-26	2018-05-24 校舍耐震補強案例現地觀摩研習活動【網路報名已截止, 謝謝您!】	(點閱 323 次)
2018-04-09	2018-05-04 校舍結構耐震能力評估與補強作業講習會【網路報名已截止, 謝謝您!】	(點閱 552 次)
2018-03-21	2018-04-26 校舍耐震補強工程施工廠商作業講習會(高雄場)【報名已截止, 謝謝您!】	(點閱 408 次)
2018-02-26	2018-03-29 校舍結構耐震能力評估與補強作業講習會【網路報名已截止, 謝謝您!】	(點閱 694 次)
2018-01-10	2018-02-08 校舍耐震補強成果上傳說明會(下午場)【報名已截止, 謝謝您!】	(點閱 359 次)
2018-01-10	2018-02-08 校舍耐震補強成果上傳說明會(上午場)【報名已截止, 謝謝您!】	(點閱 322 次)

所有消息

TWCA 18/06/18

建議使用IE 9.0以上瀏覽器或Chrome瀏覽器 | © 2009-2018 NCREE 若舊校舍補強專案辦公室 All Rights Reserved.



<https://school.ncree.org.tw>



- Data Collecting
- News Announcement
- Download Service
- Exchange of Information



- Process monitoring
- Decision making

Retrofitting Effectiveness

Kaohsiung Jia-Xian EQ
 $M_L = 6.4$, March 4, 2010



Junior High S.
No retrofitting
30km from epicenter



Vocational S.
Retrofitted
31km from epicenter



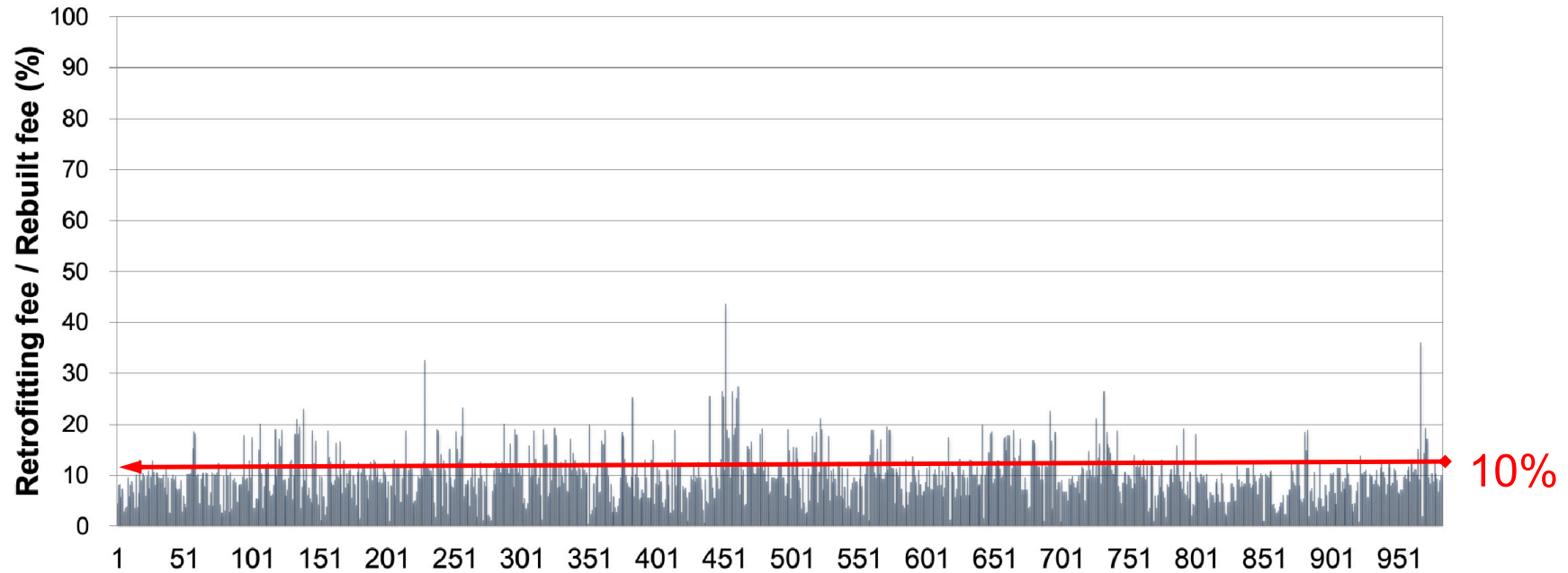
Wing Wall

RC Wall



Epicenter

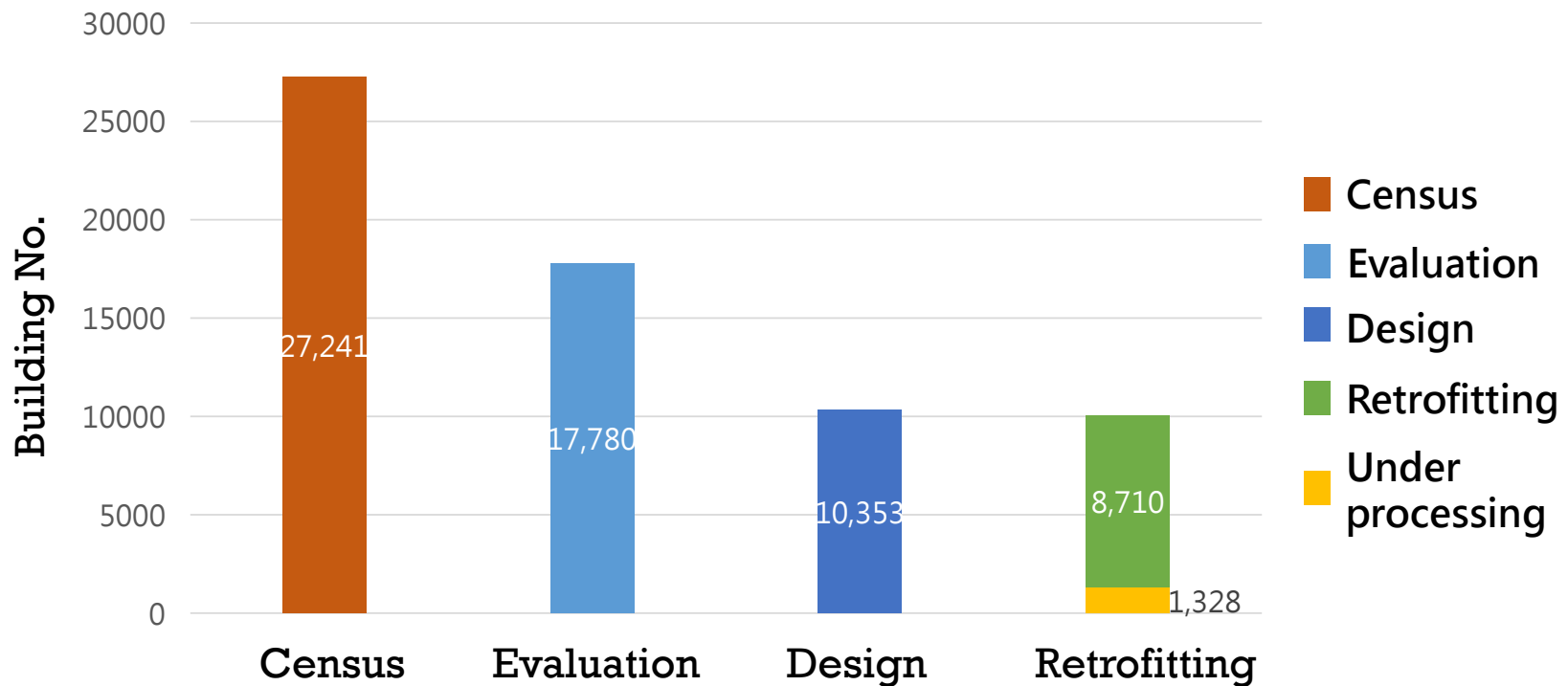
Cost of School Retrofitting in Taiwan



$$\text{Actual Cost: } \frac{\text{Retrofitting fee}}{\text{Rebuilt fee}} = \frac{\text{NT\$ 2,250 /m}^2}{\text{NT\$ 22,000 /m}^2} = 10\%$$

School Buildings Upgrading Projects

- Project span from 2009 to 2022
- Upgrading rate by construction up to 37%



Data deadline : 2020.03.31

Residential Building Program

Earthquake Damages of Buildings with Soft and Weak First Story



14-story Condominium
2016 Meinong EQ



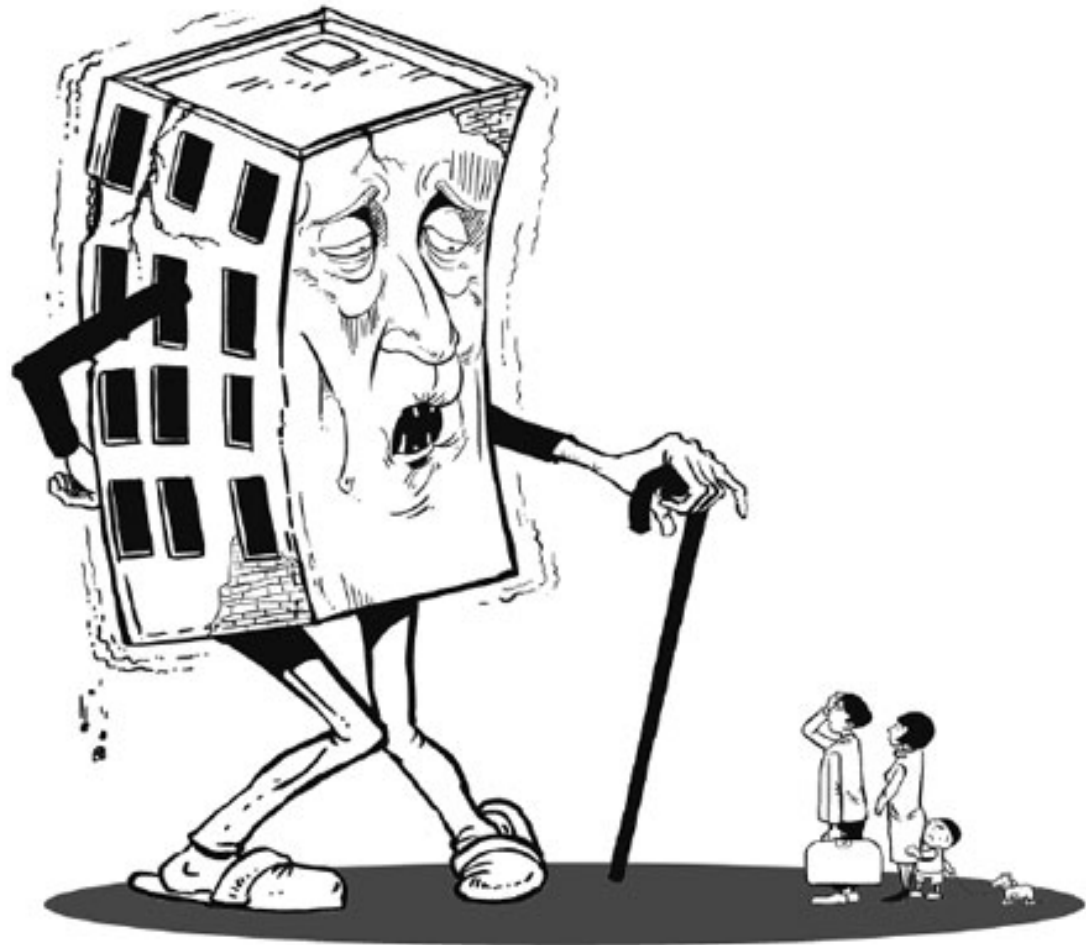
12-story Condominium
2018 Hualien EQ



11-story Hotel
2018 Hualien EQ

Characteristics of Damaged Buildings

- Older RC building
- Soft and weak first story

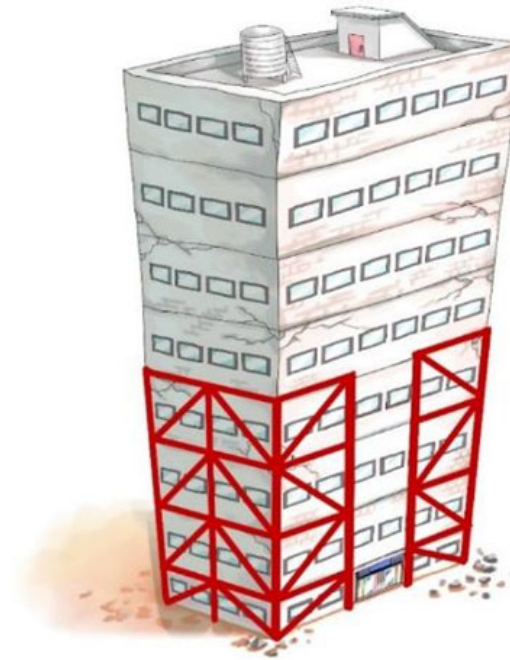


Source : DEGENKOLB RECONNAISSANCE TEAM
2016 MEINONG TAIWAN EARTHQUAKE DEBRIEF

Interim Seismic Retrofit



Building with soft first story



Removal of seismic deficiency

Prevent Building Collapse Immediately during Earthquake

Interim Retrofitting Case – External Frames

City	Building type	Process	Method
Tainan	7-story Condominium + 1F market	Open bidding	Addition of external frames



Conclusion

Features of Project

Compulsory

- Field investigation

Technology

- Advanced evaluation method
- Screen and prioritization

Administration

- Unified procedure
- Budget and quality control

Monitoring

- Website and database



Central
Government



NCREE

Local
Governments



Acknowledgement

- Ministry of Education (**MOE**)
- Ministry of Science and Technology (**MOST**)
- National Applied Research Laboratories (**NARLabs**)
- **Schools** of Cheng Junior High, Kou-Hu Elementary, Ruei-Pu Elementary and Guan-Miao Elementary
- **County Governments** of Hualien, Yunlin, Taoyuan and Tainan
- **Universities** of NTU, NTUST, NYUST, NCKU, NKFUST, NCTU, etc.

Thank you for your attention