



COUPLED SHEAR WALL

耦合剪力牆系統

鄭敏元 MIN-YUAN CHENG

ASSOCIATE PROFESSOR

DEPARTMENT OF CIVIL AND CONSTRUCTION ENGINEERING
NATIONAL TAIWAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

OUTLINE

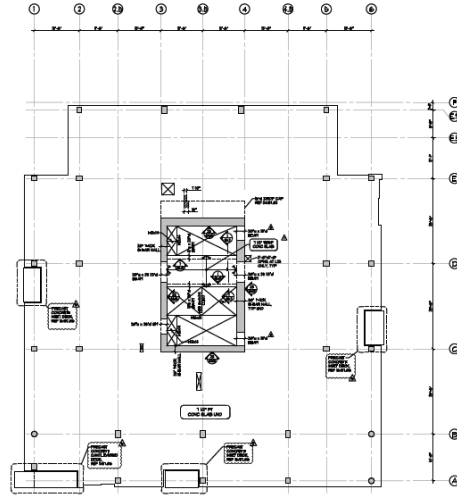
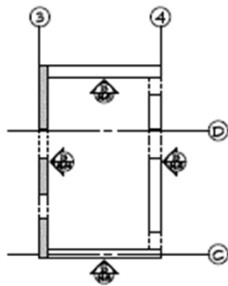
- **Introduction**
 - Shear wall
 - Coupled Shear Wall
 - Coupling Beam
- **Tests Conducted in 2012**
 - RC Coupled Shear Wall
 - Hybrid Coupled Shear Wall
- **Finite Element Analysis**
- **Design Recommendations**
- **Conclusion**



INTRODUCTION: SHEAR WALL

鋼筋混凝土剪力牆經常被當作建築物主要的側向力抵抗系統

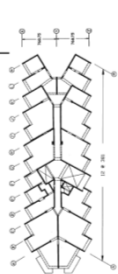
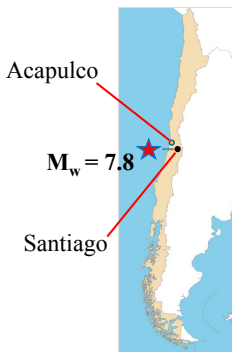
- 提供建築物良好側向勁度
- 對低或中高樓層，使用鋼筋混凝土剪力牆較為經濟且有效 (Moele et al., 2012)



INTRODUCTION: SHEAR WALL

Past Earthquake Experience: The 1985 Chile Earthquake

Building : Acapulco
 Number of Stories : 15
 Wall Area/Floor Area : ~ 6%



Before Earthquake



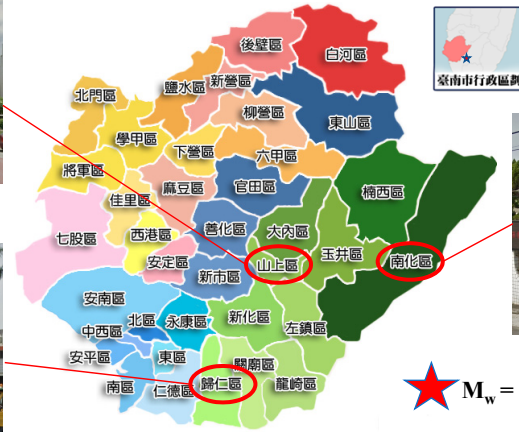
After Earthquake



Wood et al., 1987, "The 1985 Chile Earthquake Observations on Earthquake-Resistant Construction in Vina Del Mar," Report to the National Science Foundation, University of Illinois.

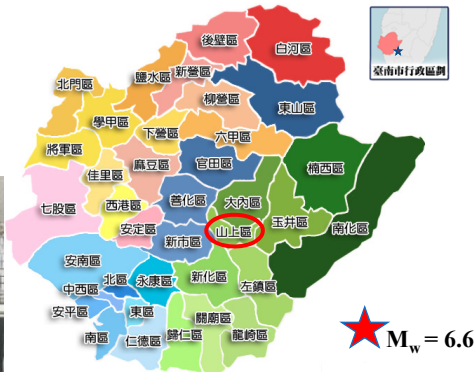
INTRODUCTION: SHEAR WALL

Past Earthquake Experience: The 2016 Kaohsiung Earthquake



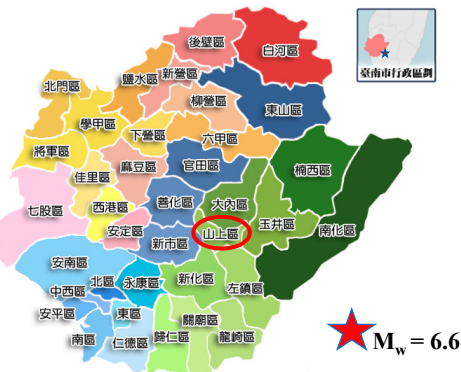
★ $M_w = 6.6$

INTRODUCTION: SHEAR WALL

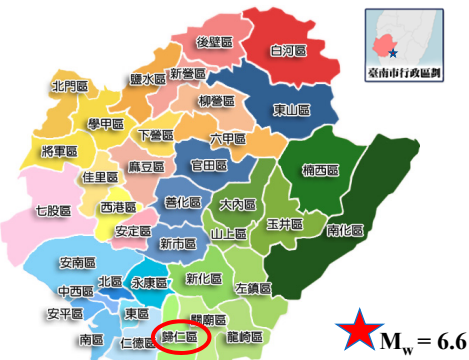


★ $M_w = 6.6$

INTRODUCTION: SHEAR WALL



INTRODUCTION: SHEAR WALL



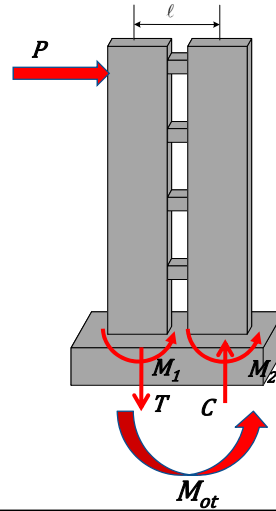
INTRODUCTION: COUPLED SHEAR WALL

耦合剪力牆系統：因建築或使用需求，在剪力牆上作規則開孔



Coupling Beam
Shear Wall

耦合剪力牆系統

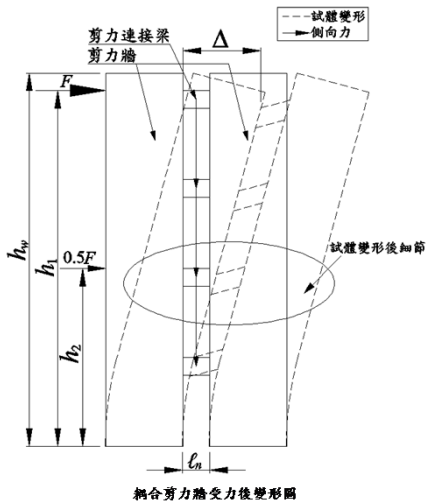


$$M_{Ot} = M_1 + M_2 + (C \text{ or } T)\ell$$

$$\text{耦合效應比 (CR)} = \frac{(C \text{ or } T)\ell}{M_{Ot}}$$

INTRODUCTION: COUPLING BEAM

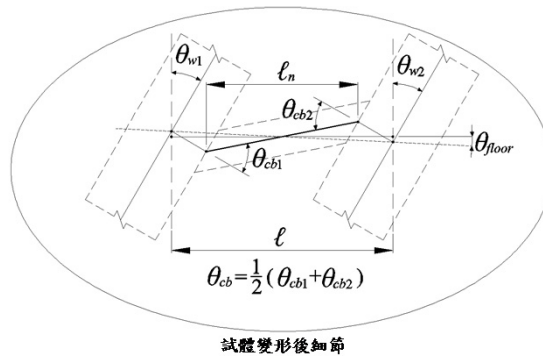
剪力連接梁需要具有足夠韌性以維持耐震機制



耦合剪力牆受側力後變形圖

$$\text{System drift} = \frac{\Delta}{h_1}$$

Wall deformation

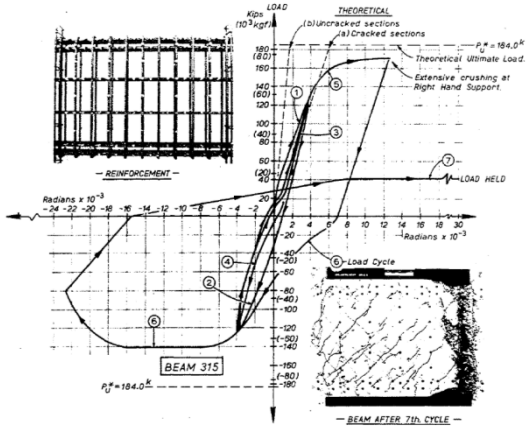


試體變形後細節

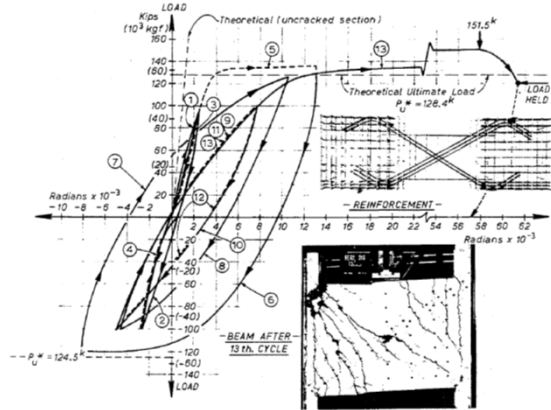
Beam deformation

INTRODUCTION: COUPLING BEAM

剪力連接梁需要具有足夠韌性以維持耐震機制



Conventional Reinforcement



Diagonal Reinforcement

(Paulay and Binney, 1971)

INTRODUCTION: COUPLING BEAM

剪力連接梁實際施作情形



(www.sukamta.com/service/view/10)



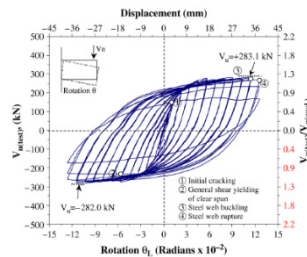
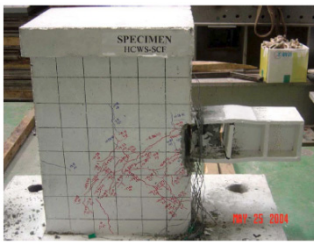
(.....)

(http://sitemaker.umich.edu/nees.hpfr/c.project/the_motivation, July 2012)

INTRODUCTION: COUPLING BEAM

利用鋼梁取代鋼筋混凝土剪力連接梁

- 鋼梁於現場定位困難
- 預埋鋼梁細部現場施作困難
- 設計建議大多根據構件實驗與有限元素分析



Park and Yun, 2005

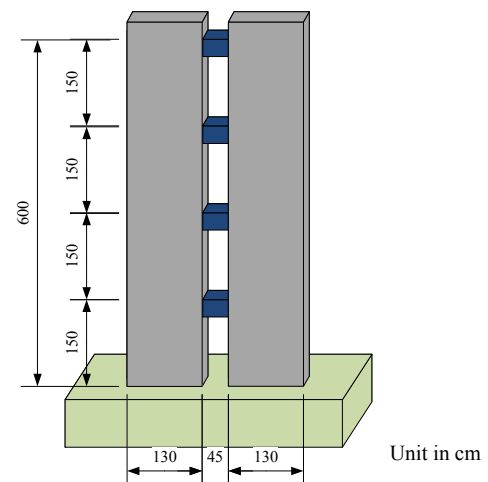


Lehmkuhl, 2002

TEST CONDUCTED IN 2012

兩組四層樓高試體於建研所實驗室測試

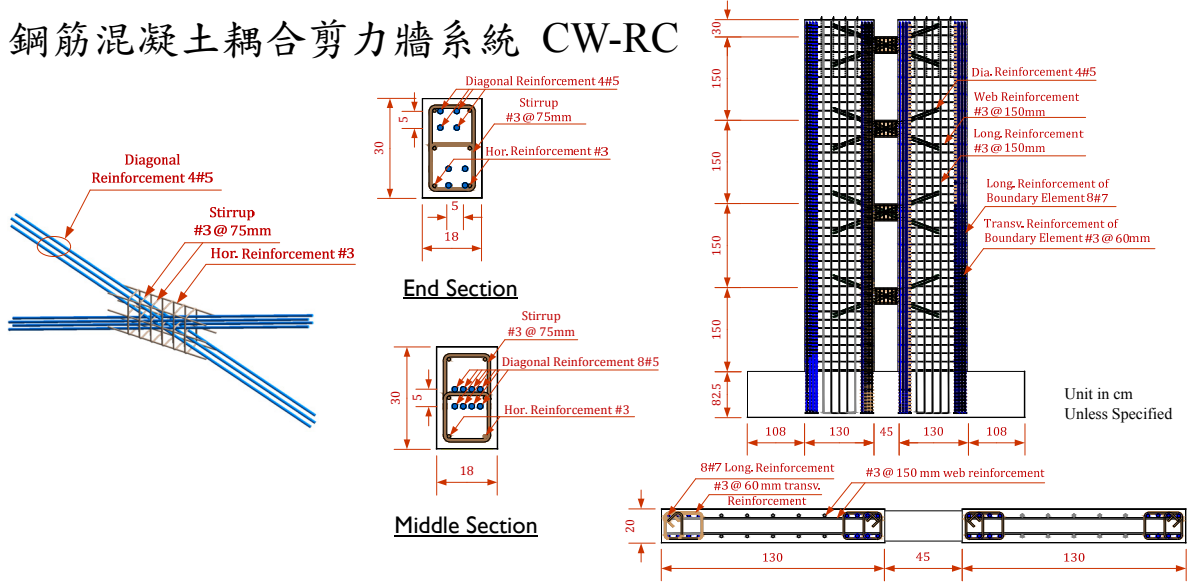
- 試體總高 4 @ 1.50 m = 6.00 m
- 試體總寬約 3.05 m
- 牆寬 1.30 m
- 剪力連接梁淨跨 0.45 m
- 剪力連接梁跨深比 1.5



Unit in cm

TEST CONDUCTED IN 2012

鋼筋混凝土耦合剪力牆系統 CW-RC



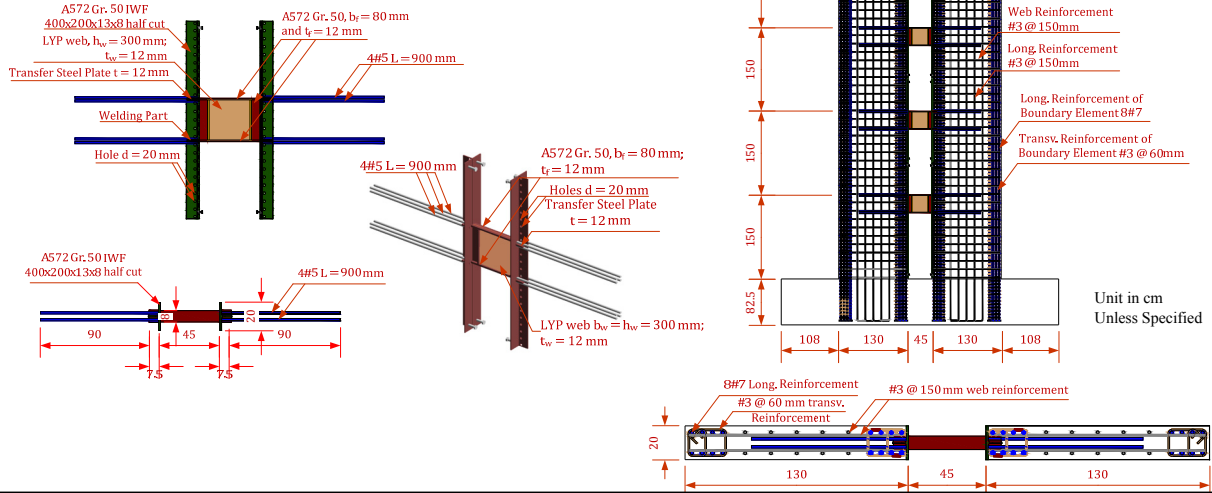
TEST CONDUCTED IN 2012

鋼筋混凝土耦合剪力牆系統 CW-RC



TEST CONDUCTED IN 2012

複合型耦合剪力牆系統 CW-S



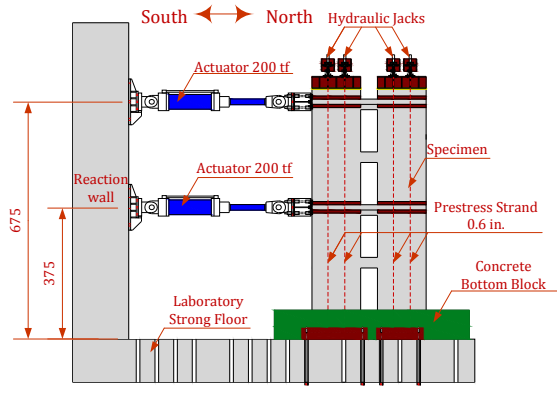
TEST CONDUCTED IN 2012

複合型耦合剪力牆系統 CW-S



TEST CONDUCTED IN 2012

測試佈置



TEST CONDUCTED IN 2012

CW-RC測試結果



At the end of the test (walls)



2nd Floor



4th Floor



3rd Floor

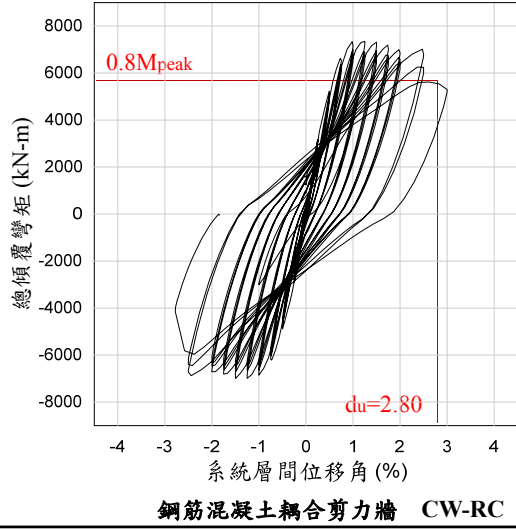


Roof Floor

鋼筋混凝土耦合剪力牆系統

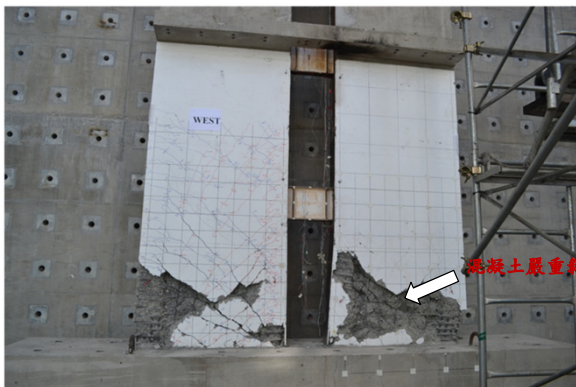
TEST CONDUCTED IN 2012

CW-RC測試結果



TEST CONDUCTED IN 2012

CW-S測試結果



At the end of the test (walls)



鋼梁無發生挫曲與斷裂

2nd Floor



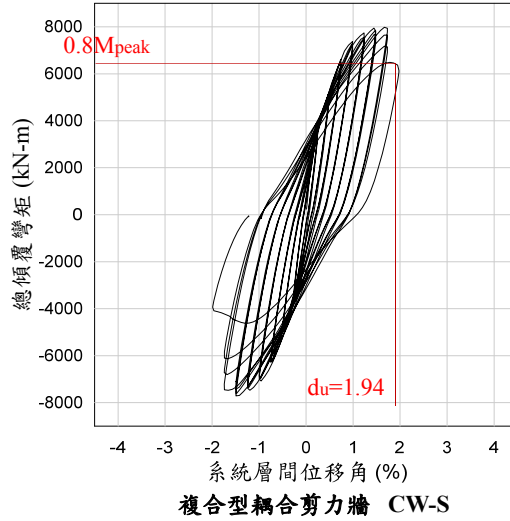
3rd Floor

混凝土嚴重剝落

複合型耦合剪力牆系統

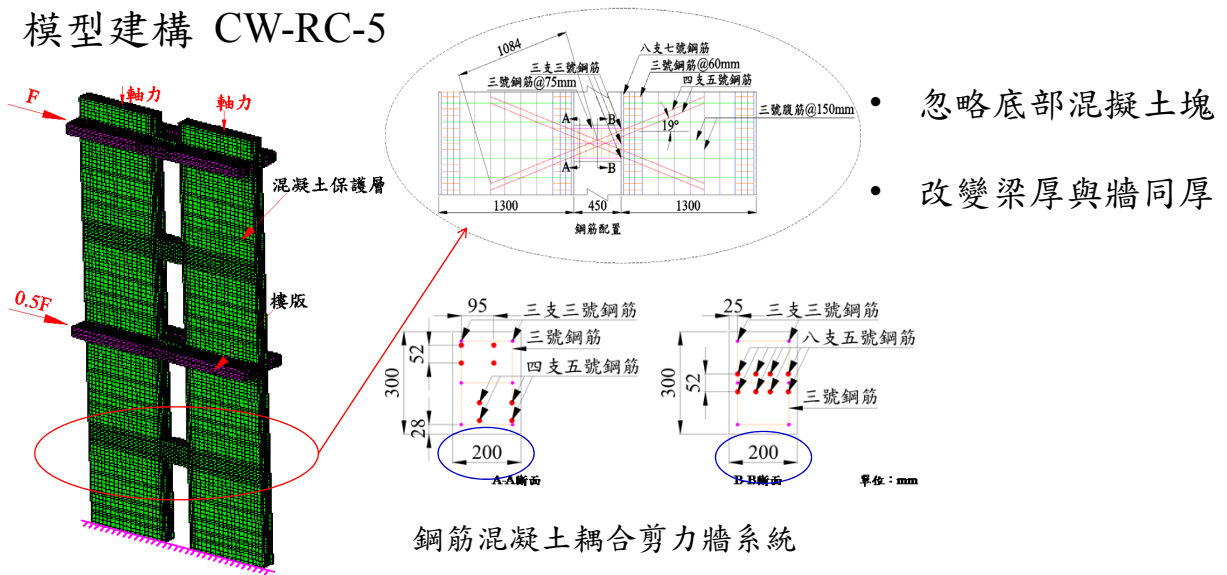
TEST CONDUCTED IN 2012

CW-S測試結果



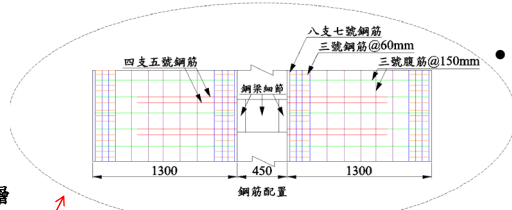
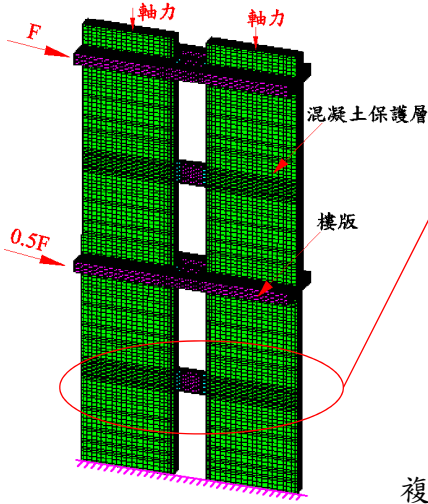
FINITE ELEMENT ANALYSIS

模型建構 CW-RC-5



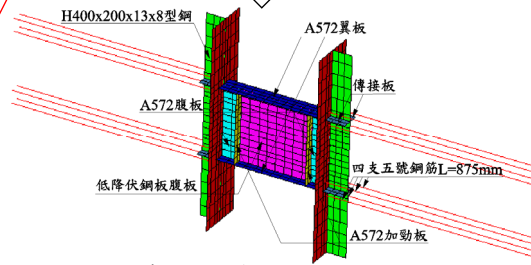
FINITE ELEMENT ANALYSIS

模型建構 CW-S-12



• 忽略底部混凝土塊

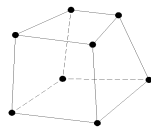
鋼梁元素劃分



複合型耦合剪力牆系統

FINITE ELEMENT ANALYSIS

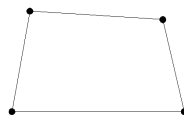
元素與材料卡設定



實體元素

MAT159
非線性模型

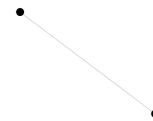
混凝土



殼元素

MAT3
雙線性模型

鋼板



桿元素

MAT24
多線性模型

鋼筋

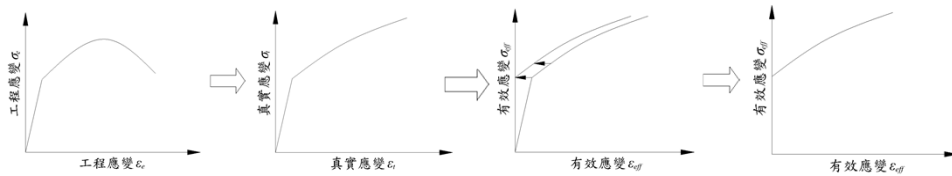
FINITE ELEMENT ANALYSIS

低降伏鋼板試片拉伸試驗模擬(MAT24材料模型)

- 材料參數設置

低降伏鋼板材料模型參數設置

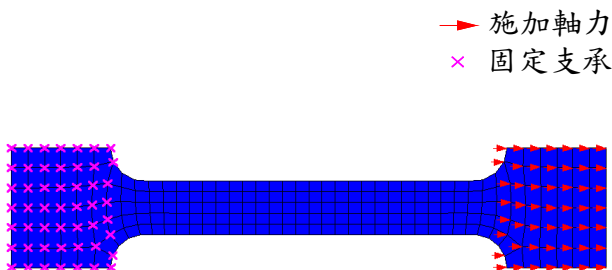
鋼板	材料 模型	密度 RO(ton/mm ³)	彈性模數 E (MPa)	浦松比 PR	材料失效應變 FAIL	有效應力-塑性應變曲線 LCSS
低降伏 鋼板	MAT24	7.644E-09	200000	0.3	0.45	材料曲線



FINITE ELEMENT ANALYSIS

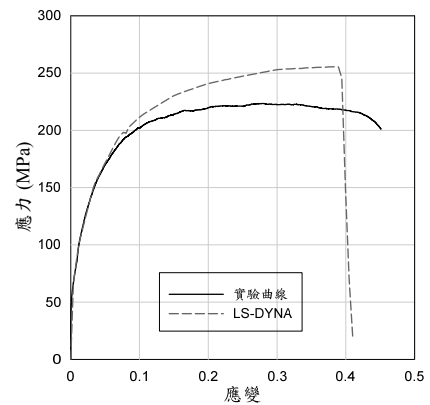
低降伏鋼板試片拉伸試驗模擬(MAT24材料模型)

- 模型元素劃分



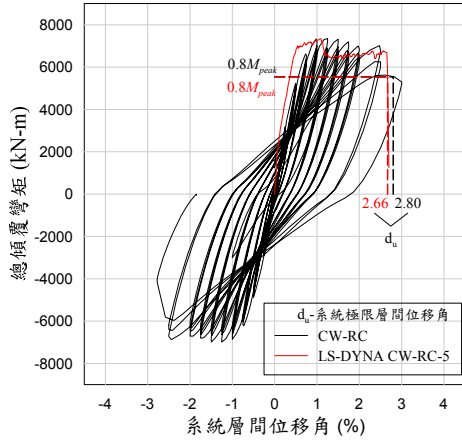
→ 施加軸力
× 固定支承

- 模擬結果

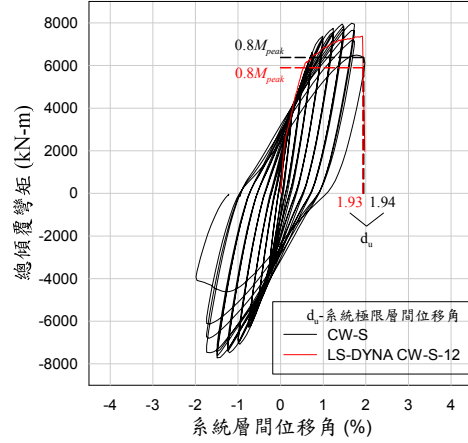


FINITE ELEMENT ANALYSIS

分析結果驗證



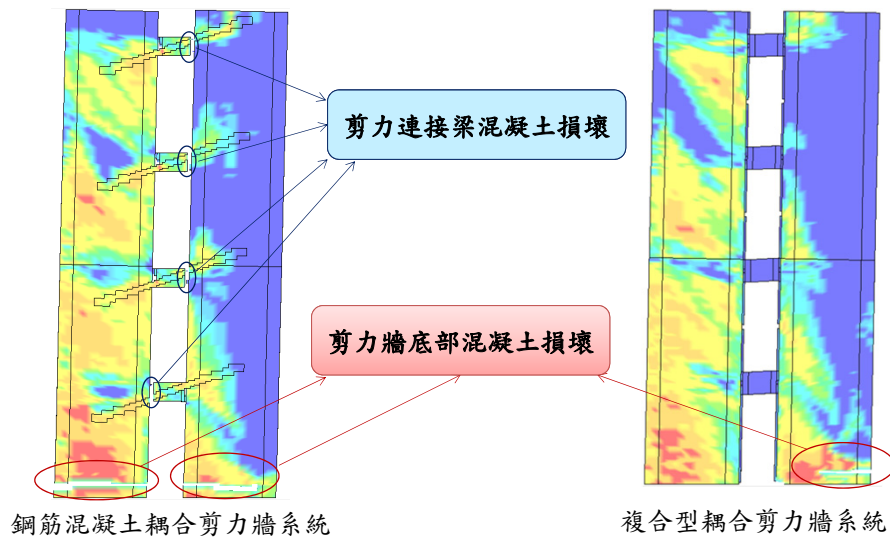
CW-RC 與 CW-RC-5



CW-S 與 CW-S-12

FINITE ELEMENT ANALYSIS

分析結果驗證



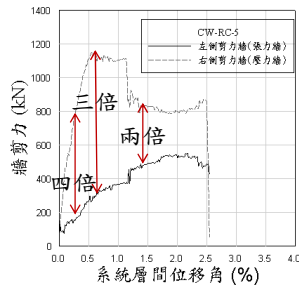
鋼筋混凝土耦合剪力牆系統

複合型耦合剪力牆系統

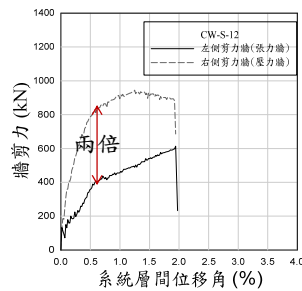
FINITE ELEMENT ANALYSIS

耦合剪力牆系統

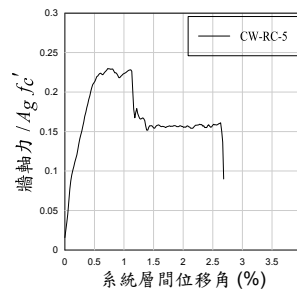
• 剪力牆基底剪力



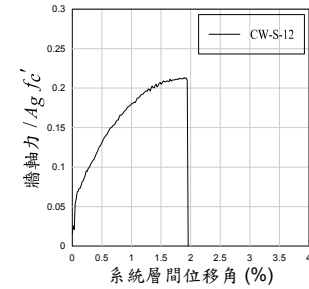
鋼筋混凝土耦合剪力牆系統



複合型耦合剪力牆系統



鋼筋混凝土耦合剪力牆系統



複合型耦合剪力牆系統

• 耦合效應比作用下-壓力牆軸力

FINITE ELEMENT ANALYSIS

改變剪力連接梁設計參數

• 鋼筋混凝土剪力連接梁

改變對角線鋼筋號數

四號(CW-RC-4)、五號(CW-RC-5)、六號(CW-RC-6)、七號(CW-RC-7)、

八號(CW-RC-8)

• 低降伏鋼板剪力連接梁

改變低降伏鋼板厚度

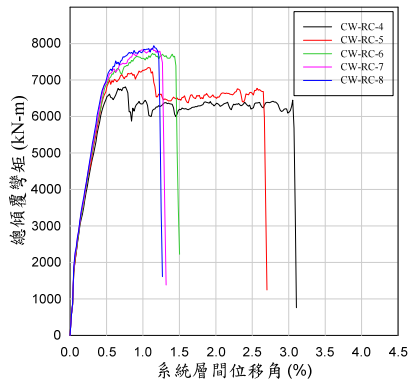
6mm(CW-S-6)、9mm(CW-S-9)、12mm(CW-S-12)、15mm(CW-S-15)、

18mm(CW-S-18)

FINITE ELEMENT ANALYSIS

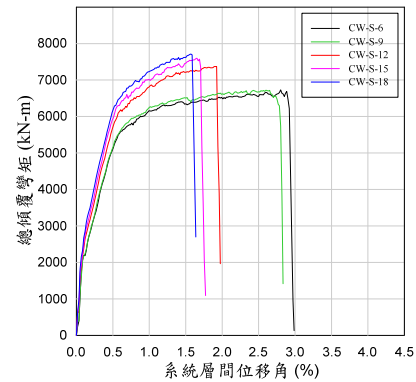
分析結果

改變對角線鋼筋號數



鋼筋混凝土耦合剪力牆系統

改變低降伏鋼板厚度

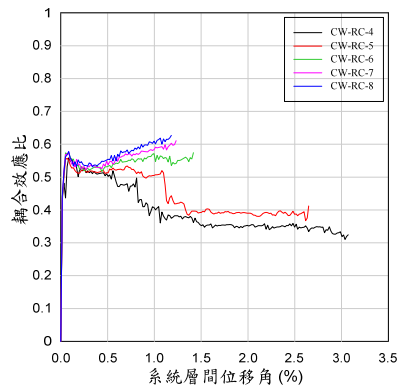


複合型耦合剪力牆系統

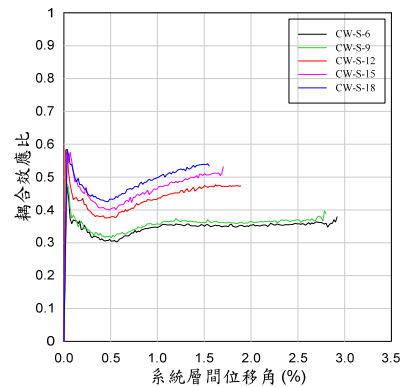
FINITE ELEMENT ANALYSIS

分析結果

- 耦合剪力牆系統 - 耦合效應比



鋼筋混凝土耦合剪力牆系統



複合型耦合剪力牆系統

FINITE ELEMENT ANALYSIS

分析結果

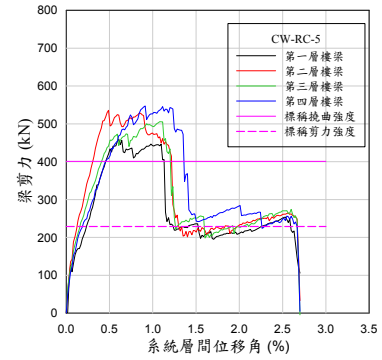
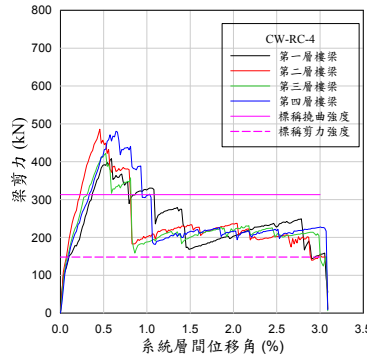
- 剪力連接梁之剪力容量預測

—— 標稱撓曲強度

$$V_{n,Mn} = \frac{2M_n}{\ell_n}$$

- - - 標稱剪力強度

$$V_n = 2A_{vd} f_y \sin \alpha$$



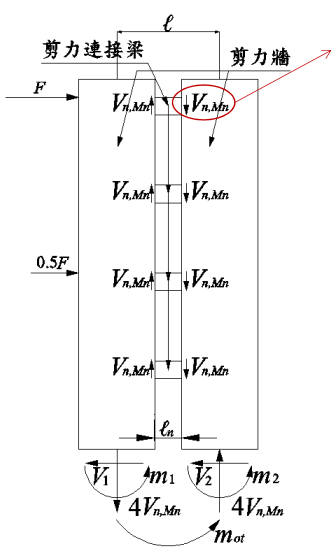
CW-RC-4

CW-RC-5

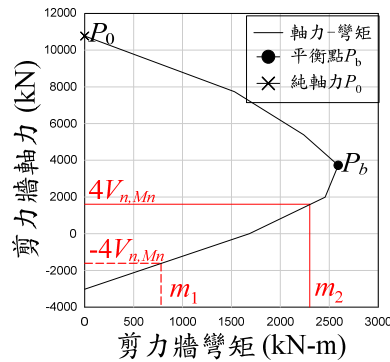
鋼筋混凝土耦合剪力牆系統

DESIGN RECOMMENDATIONS

RC 耦合剪力牆系統



$$V_{n,Mn} = \frac{2M_n}{\ell_n}$$



剪力牆軸力彎矩互制圖

$$m_{ot} = m_1 + m_2 + 4V_{n,Mn} \times \ell$$

$$\text{設計耦合效應比} = \frac{4V_{n,Mn} \times \ell}{m_{ot}}$$

DESIGN RECOMMENDATIONS

RC 耦合剪力牆系統

斷面分析

(LS-DYNA 數值分析)

模型編號	CW-RC-4	CW-RC-5	CW-RC-6	CW-RC-7	CW-RC-8
剪力梁連接梁撓曲強度 $V_{n,Mn}$ (kN)	312	401	501	619	756
剪力牆軸力比 $4V_{n,Mn}/A_{wall}f'_c$	0.13 (0.10-0.20)	0.17 (0.14-0.23)	0.21 (0.20-0.26)	0.26 (0.27-0.28)	0.32 (0.28-0.29)
耦合效應比	0.40 (0.32-0.47)	0.46 (0.39-0.51)	0.53 (0.55-0.57)	0.59 (0.58-0.61)	0.66 (0.60-0.62)
極限層間位移角 d_u (%)	(3.07%)	(2.66%)	(1.45%)	(1.26%)	(1.21%)

剪力連接梁強度-
斷面撓曲強度評估

$$V_{n,Mn} = \frac{2M_n}{\ell_n}$$

建議軸壓大小控制在
 $0.15A_{wall}f'_c$ 以下

DESIGN RECOMMENDATIONS

複合型耦合剪力牆系統

- 剪力連接梁之剪力容量預測

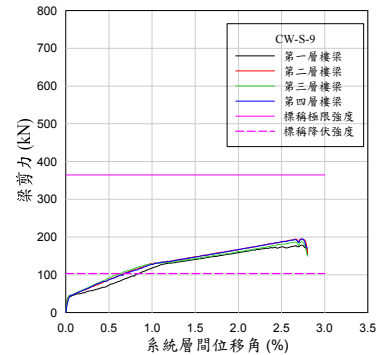
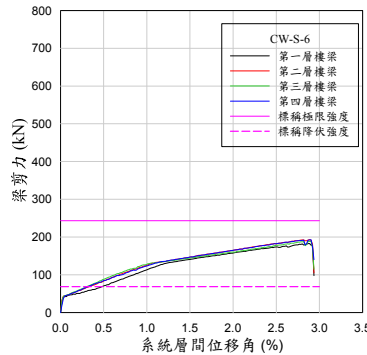
—— 標稱極限強度

$$V_u = 0.6 f_u A_w$$

- - - 標稱降伏強度

$$V_n = 0.6 f_{yp} A_w$$

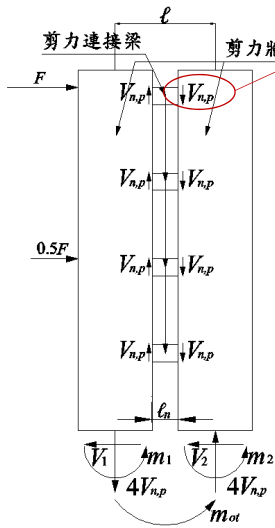
$$f_u / f_{yp} \cong 3.5$$



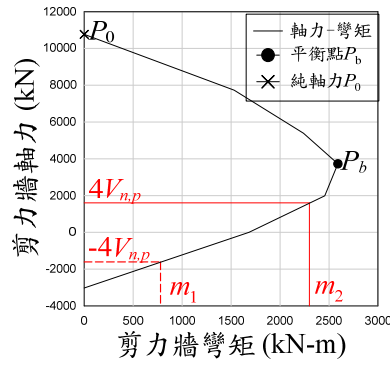
複合型耦合剪力牆系統

DESIGN RECOMMENDATIONS

複合型耦合剪力牆系統



$$V_{n,p} = 3V_n = 3 \times 0.6 f_{yp} A_w$$



剪力牆軸力彎矩互制圖

$$m_{ot} = m_1 + m_2 + 4V_{n,p} \times l$$

$$\text{設計耦合效應比} = \frac{4V_{n,p} \times l}{m_{ot}}$$

DESIGN RECOMMENDATIONS

複合型耦合剪力牆系統

斷面分析

(LS-DYNA 數值分析)

模型編號	CW-S-6	CW-S-9	CW-S-12	CW-S-15	CW-S-18
剪力梁連接梁撓曲強度 $V_{n,p}$ (kN)	241	361	482	602	723
剪力牆軸力比 $4(V_{n,p})/A_{wall}f'_c$	0.10	0.15	0.20	0.25	0.30
耦合效應比	0.30	0.40	0.48	0.55	0.61
極限層間位移角 d_u (%)	(2.91%)	(2.80%)	(1.93%)	(1.72%)	(1.58%)

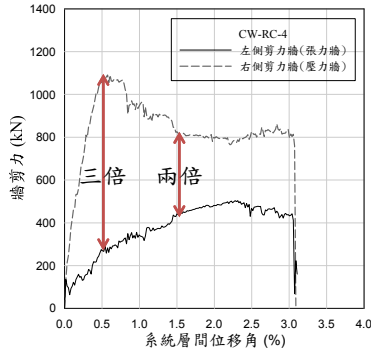
剪力連接梁強度-
三倍標稱降伏強度評估剪力
 $V_{n,p} = 3V_n = 3 \times 0.6 f_{yp} A_w$

建議軸壓大小控制在
 $0.15A_{wall}f'_c$ 以下

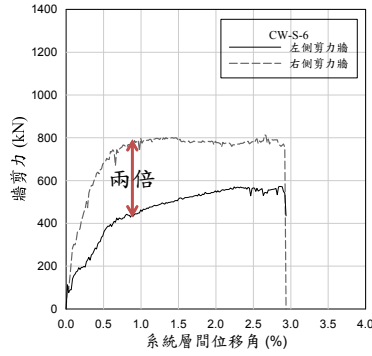
DESIGN RECOMMENDATIONS

剪力分佈

- 剪力牆基底剪力



CW-RC-4



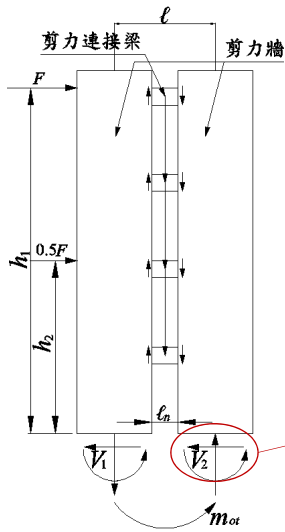
CW-S-6



假設壓力牆底剪力佔總基底剪力70%

DESIGN RECOMMENDATIONS

剪力分佈



$$m_{ot} = F \times h_1 + 0.5F \times h_2$$

$$\text{總基底剪力 } 1.5F = V_1 + V_2$$

$$70\% \text{ 總基底剪力 } \Rightarrow 0.7(1.5F) = V_2 \text{ (壓力牆底剪力)}$$

DESIGN RECOMMENDATIONS

剪力分佈

斷面分析

(LS-DYNA數值分析)

壓力牆底剪力

模型編號	CW-RC-4	CW-RC-5	CW-RC-6	CW-RC-7	CW-RC-8
壓力牆正規化剪力(分配到70%總基底剪力) $V_2/A_{wall}\sqrt{f'_c}$	0.49 (0.48-0.69)	0.54 (0.57-0.73)	0.60 (0.67-0.76)	0.66 (0.67-0.76)	0.72 (0.70-0.78)
耦合效應比	0.40 (0.32-0.47)	0.46 (0.39-0.51)	0.53 (0.55-0.57)	0.59 (0.58-0.61)	0.66 (0.60-0.62)
極限層間位移角 d_u (%)	(3.07%)	(2.66%)	(1.45%)	(1.26%)	(1.21%)

鋼筋混凝土耦合剪力牆系統

DESIGN RECOMMENDATIONS

剪力分佈

斷面分析

(LS-DYNA數值分析)

壓力牆底剪力

建議壓力牆剪應力

0.50 $\sqrt{f'_c}$ MPa 以下

模型編號	CW-S-6	CW-S-9	CW-S-12	CW-S-15	CW-S-18
壓力牆正規化剪力(分配到70%總基底剪力) $V_2/A_{wall}\sqrt{f'_c}$	0.43 (0.48-0.51)	0.49 (0.52-0.53)	0.54 (0.56-0.60)	0.59 (0.58-0.63)	0.64 (0.59-0.66)
耦合效應比	0.30 (0.35-0.37)	0.40 (0.36-0.39)	0.48 (0.47-0.47)	0.55 (0.51-0.53)	0.61 (0.53-0.54)
極限層間位移角 d_u (%)	(2.91%)	(2.80%)	(1.93%)	(1.72%)	(1.58%)

複合型耦合剪力牆系統

CONCLUSION

- 耦合剪力牆系統耦合效應比可由構件標稱強度合理評估，在該耦合效應作用下，受壓牆面假設可佔總基底剪力70%，並控制受壓剪牆面之軸力低於 $0.15A_{wall}f'_c$ ，且限制牆內剪力需求控制在 $0.50\sqrt{f'_c}$ MPa以下以得到理想的系統極限層間位移變形能力。
- 系統在極限層間位移量下之耦合效應比可由桿件標稱強度保守的評估，其中使用對角線鋼筋之鋼筋混凝土剪力連接梁標稱剪力強度建議由斷面撓曲強度決定，低降伏鋼剪力連接梁標稱剪力強度則建議使用三倍標稱降伏強度去評估。