Analysis of Infilled Reinforced Concrete Frames Strengthened with Fiber Reinforced Polymers

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Contents

- FRP retrofit scheme
- Behavior and failure modes
- Analytical modeling
- Experimental verification
- Case study
- Conclusions

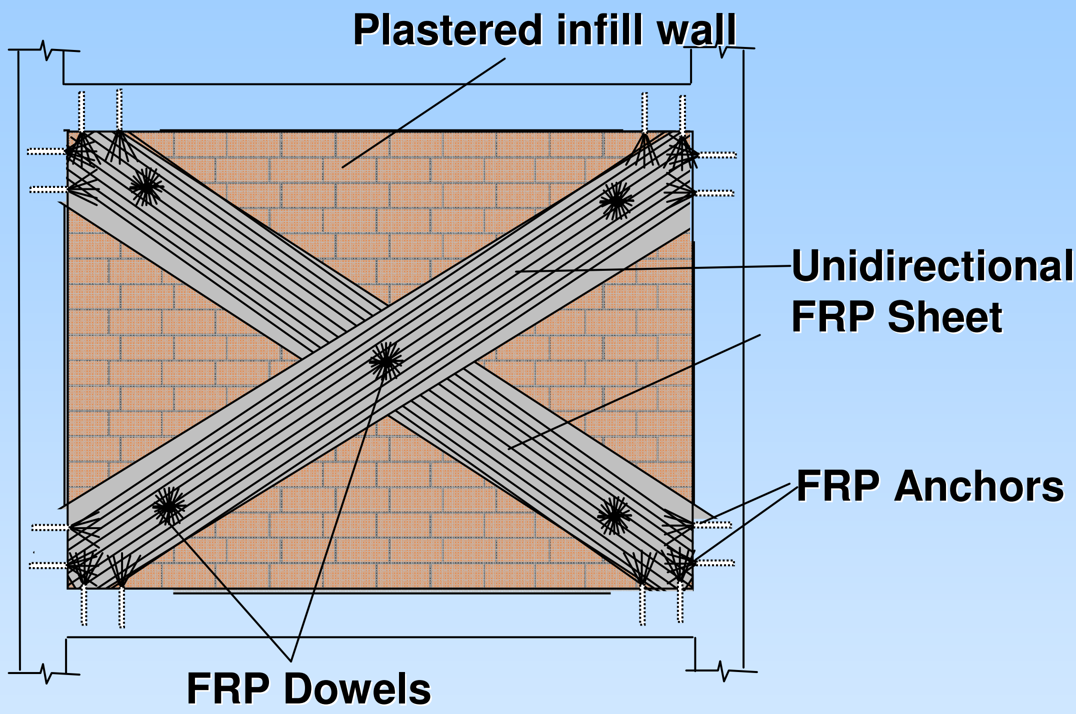
- Large building stock requiring upgrades
- Common method: Addition of shear walls
- Alternatives are needed

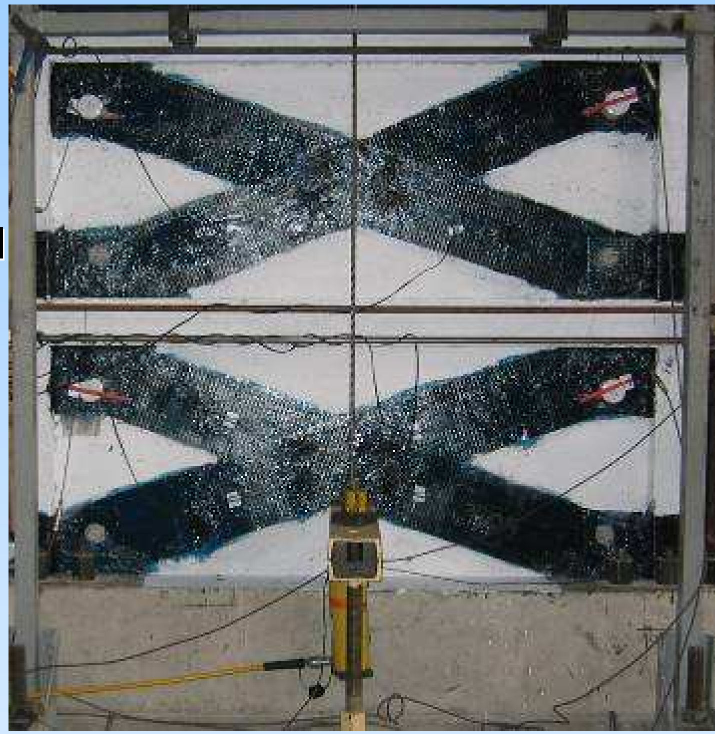
  (rapid, economical, less disturbance)
- Significant amount of infill walls

  - Not accounted in the design

  - Susceptible to out of plane failure

FRP Retrofit of Infill Walls





Advantages:

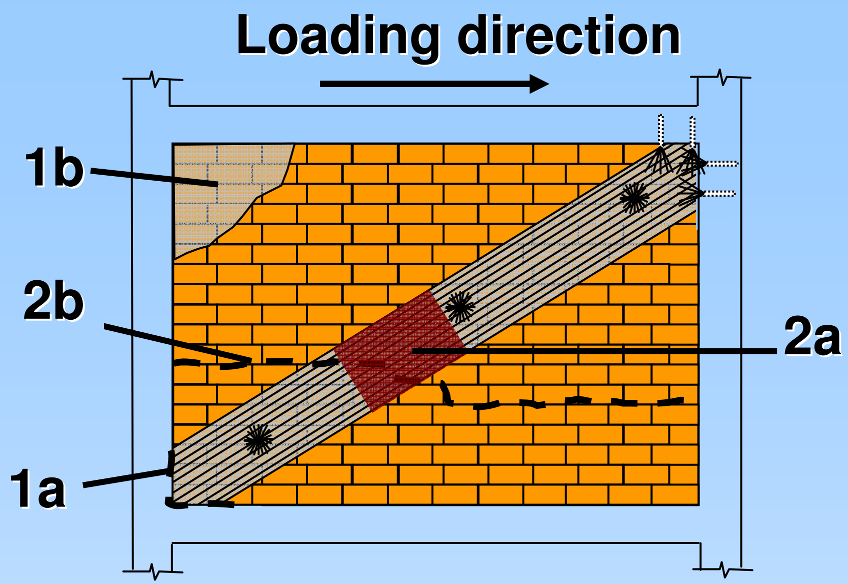
- Rapid retrofit
- Little disturbance

Disadvantages:

-Material Cost

-Requires infill walls

How to analyze (NSP) and design FRPs in building retrofit?



Mode 1:

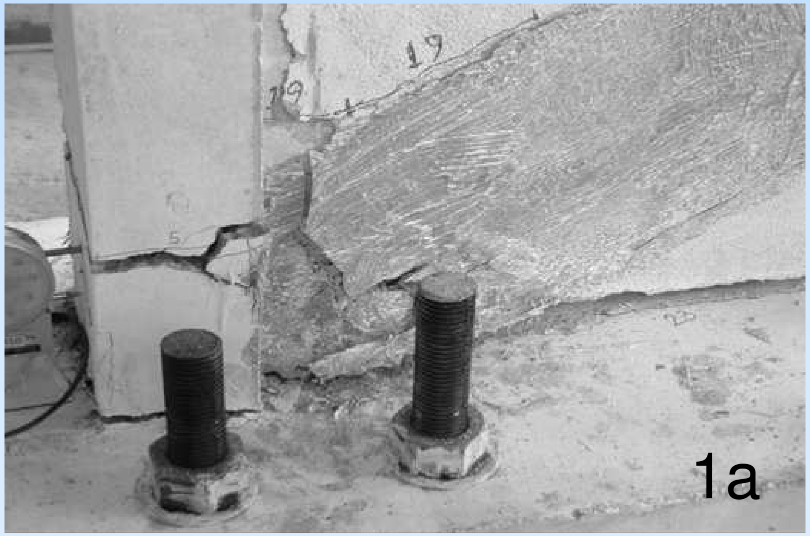
a) FRP anchor pullout

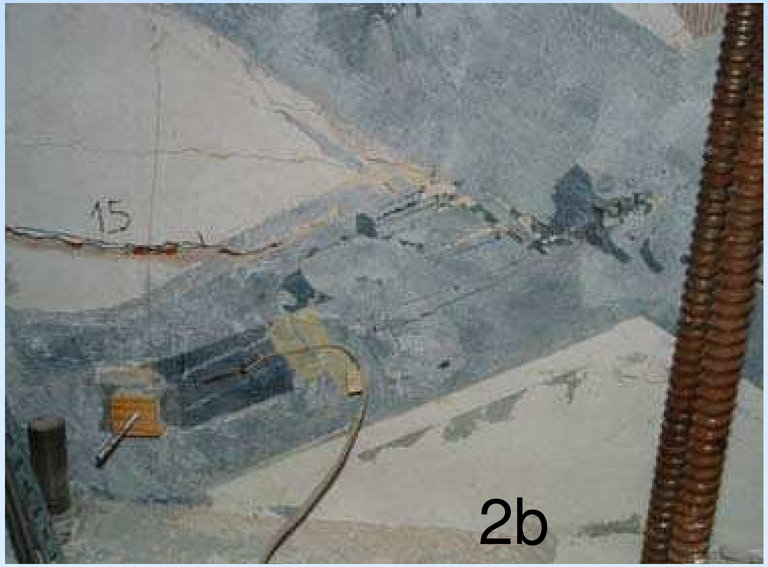
b) Corner crushing (CC)

Mode 2:

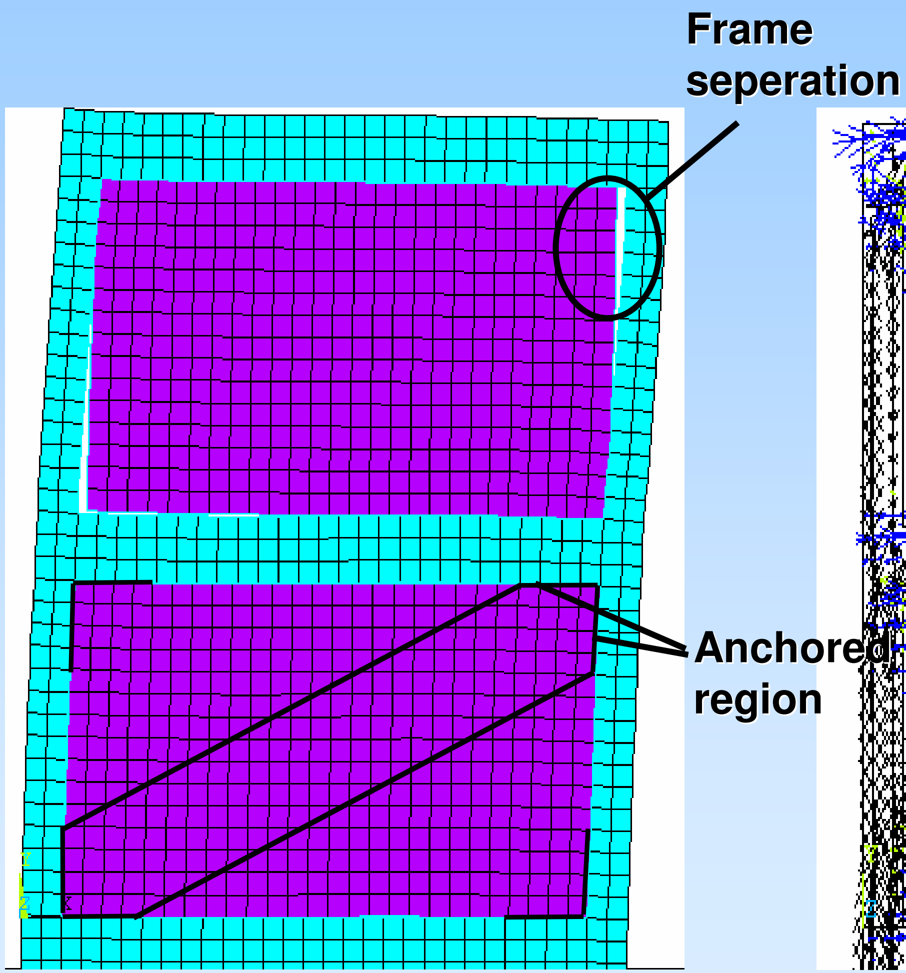
a) FRP debonding

b) Sliding /CC

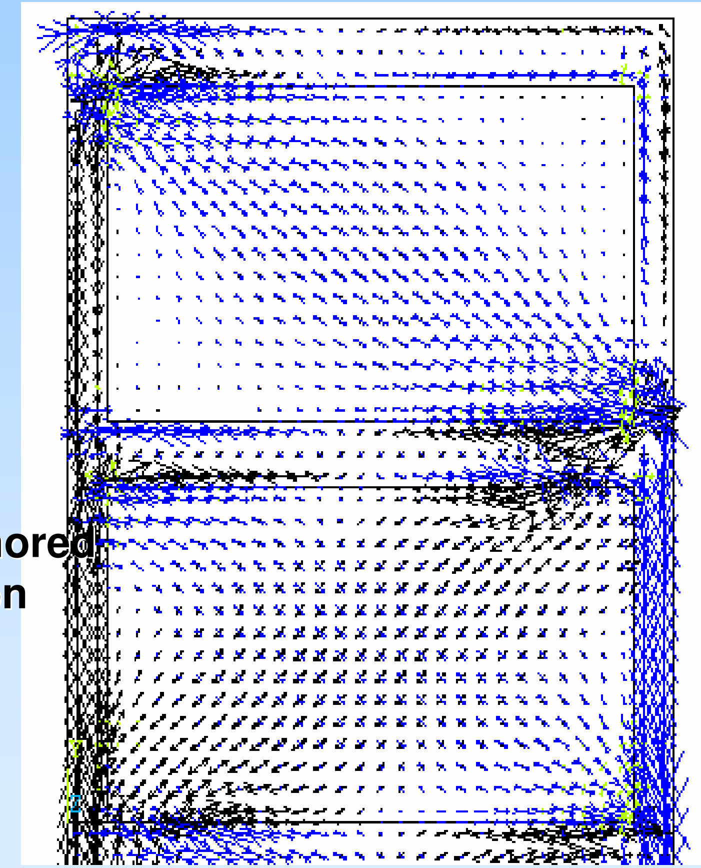




Finite Element Analyses

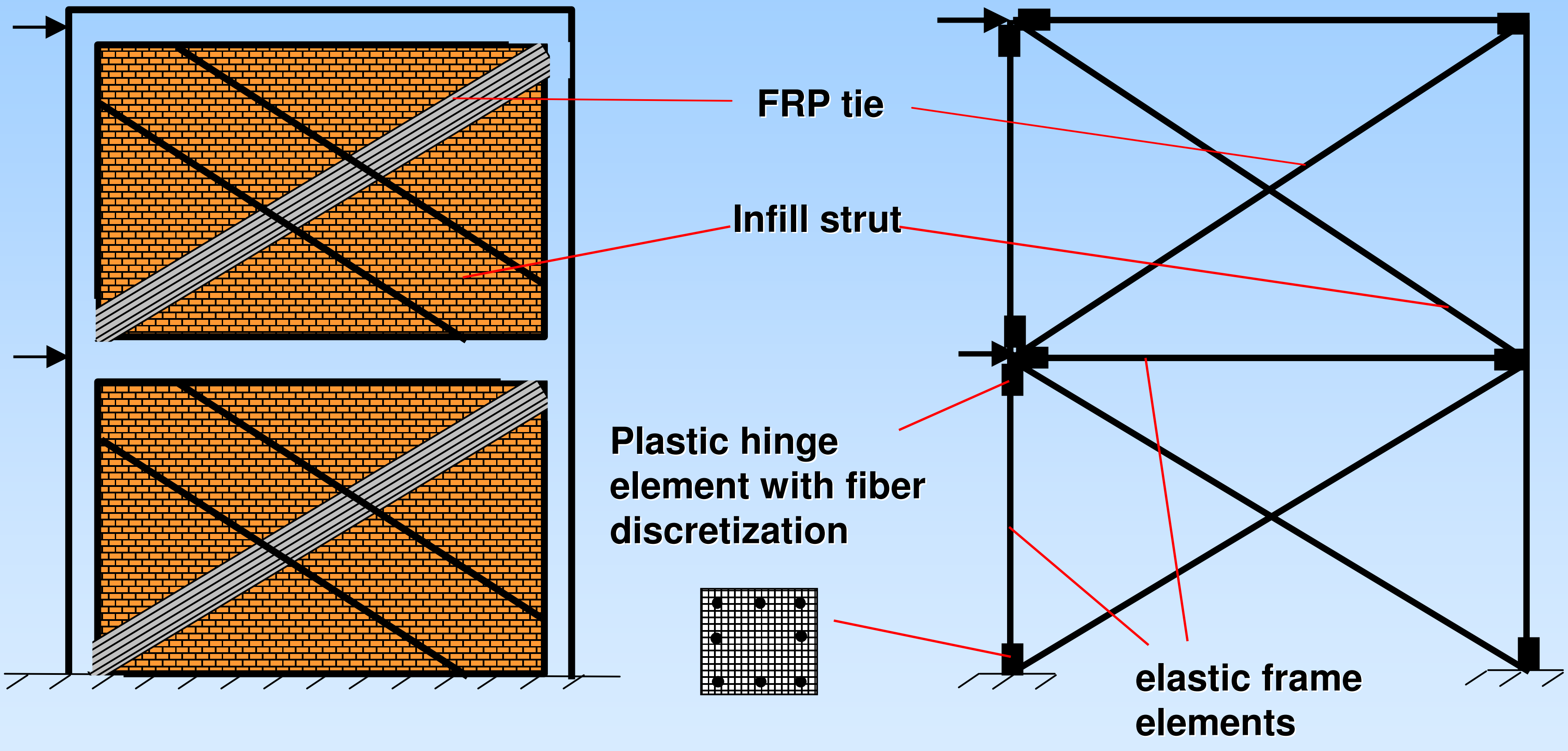


Deformed Shape



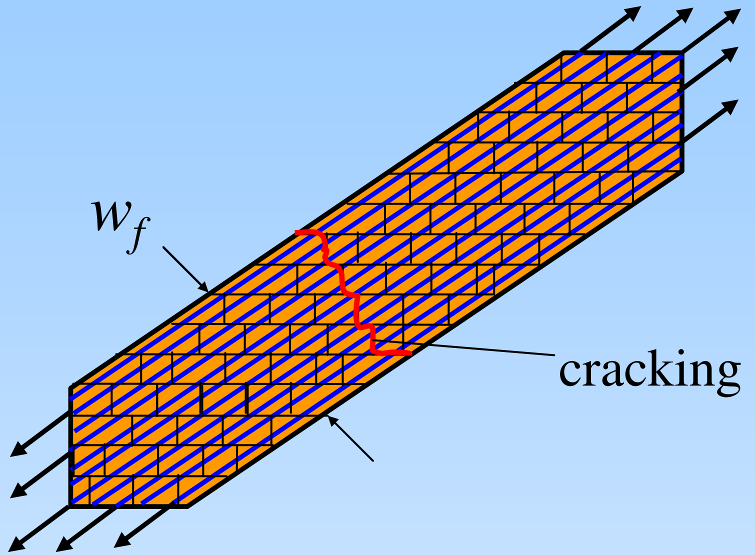
Principal Stresses

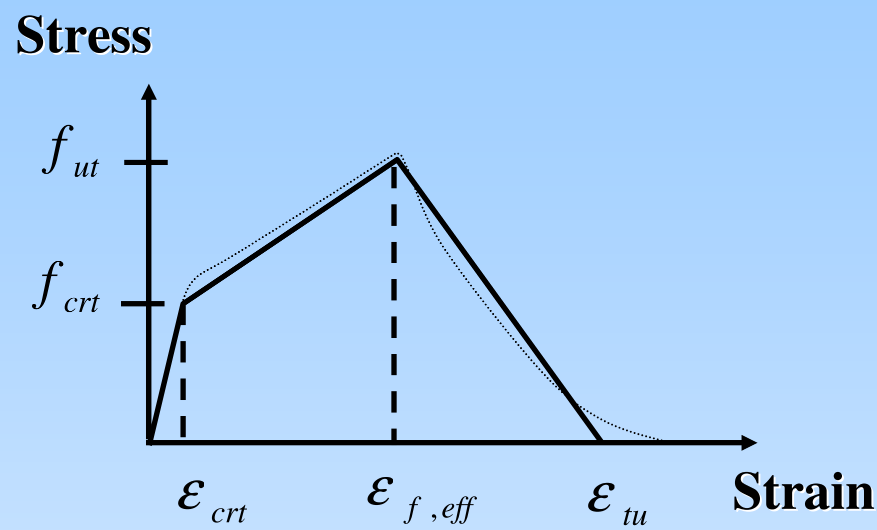
Analytical Model (STM)



OPENSEES Platform

FRP Ties





$$A_{tie} = w_f t_{tie}$$

$$f_{crt} = \frac{V_{crt}}{A_{tie}}$$

$$t_{tie} = t_f + t_p + t_{in}$$

$$f_{ut} = \frac{E_f \varepsilon_{f,eff} w_f t_f}{A_{tie}}$$

Measured $\varepsilon_{f,eff}$:

- Anchor failure: 0.002- 0.003

-Debonding : 0.004 - 0.006

$\varepsilon_{tu} \approx 3\, \varepsilon_{f,eff}$

Infill Struts

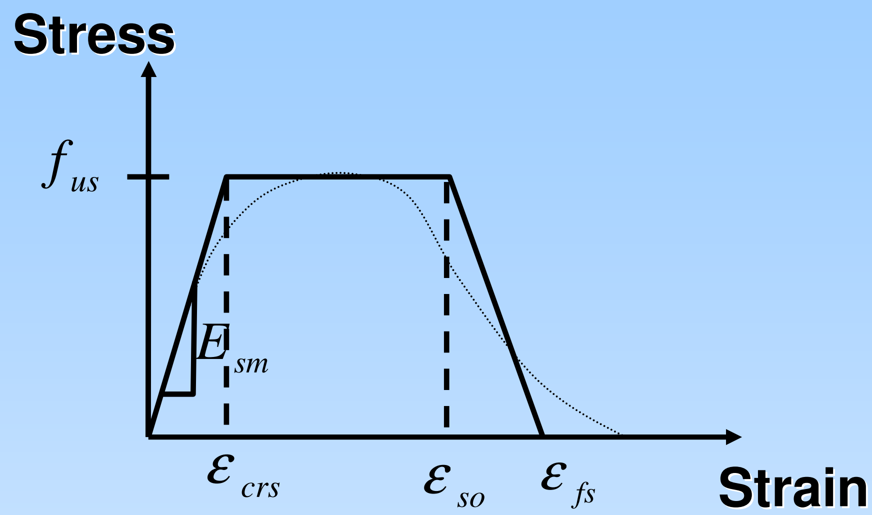
(Saneinejad and Hobbs 1995, El-Dakhakhi et. al. 2003)

Incorporates:

-Frame-infill contact length

- Relative flexibility of members

- Presence of plaster



$$f_{us} = \frac{V_{us}}{A_{st}}$$

$$V_{us} = \min\left(V_{ss}, V_{cc}\right)$$

$$\varepsilon_{so} = \begin{cases} \varepsilon_{crs} \; no\ FRP \\ 2\varepsilon_{f,eff} \; with\ \ FRP \end{cases}$$

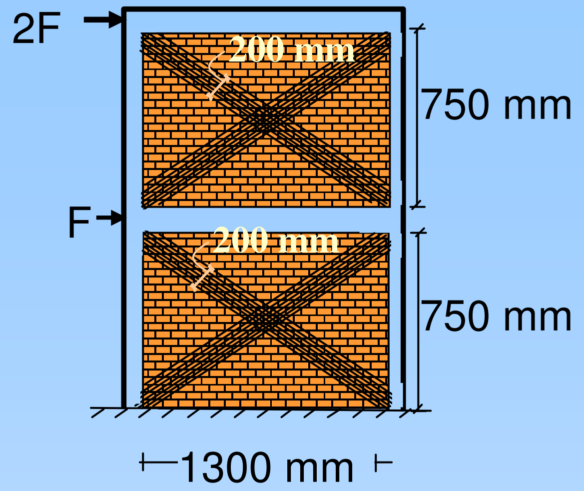
$$A_{st} = w_s t_{st}$$

$$E_{sm} = \frac{E_{in} t_{in} + E_m t_p}{t_{st}}$$

$$\varepsilon_{fs} = \begin{cases} 0.01 \; no\ FRP / Mode\,1 \\ 0.02 \qquad\qquad Mode\,2 \end{cases}$$

Experimental Verification

- Studies: Akgüzel (2000), Erduran (2002), Erdem (2003)
- Typical details of construction
  - Plain bars
  - Insufficient stirrup spacing
  - Lap splices
  - Low concrete strength (10 - 15 MPa)
  - Infills with plaster ($f_{cm} \approx 2$MPa , $f_{cp} \approx 4$MPa)
- Carbon fiber reinforced polymers ($f_{CFRP} = 3450$ MPa)



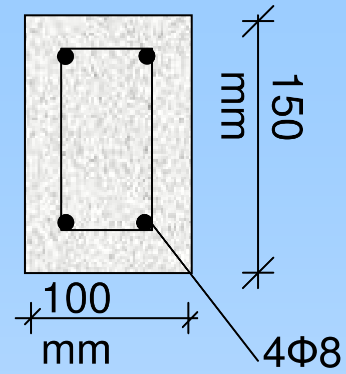
Columns Details:

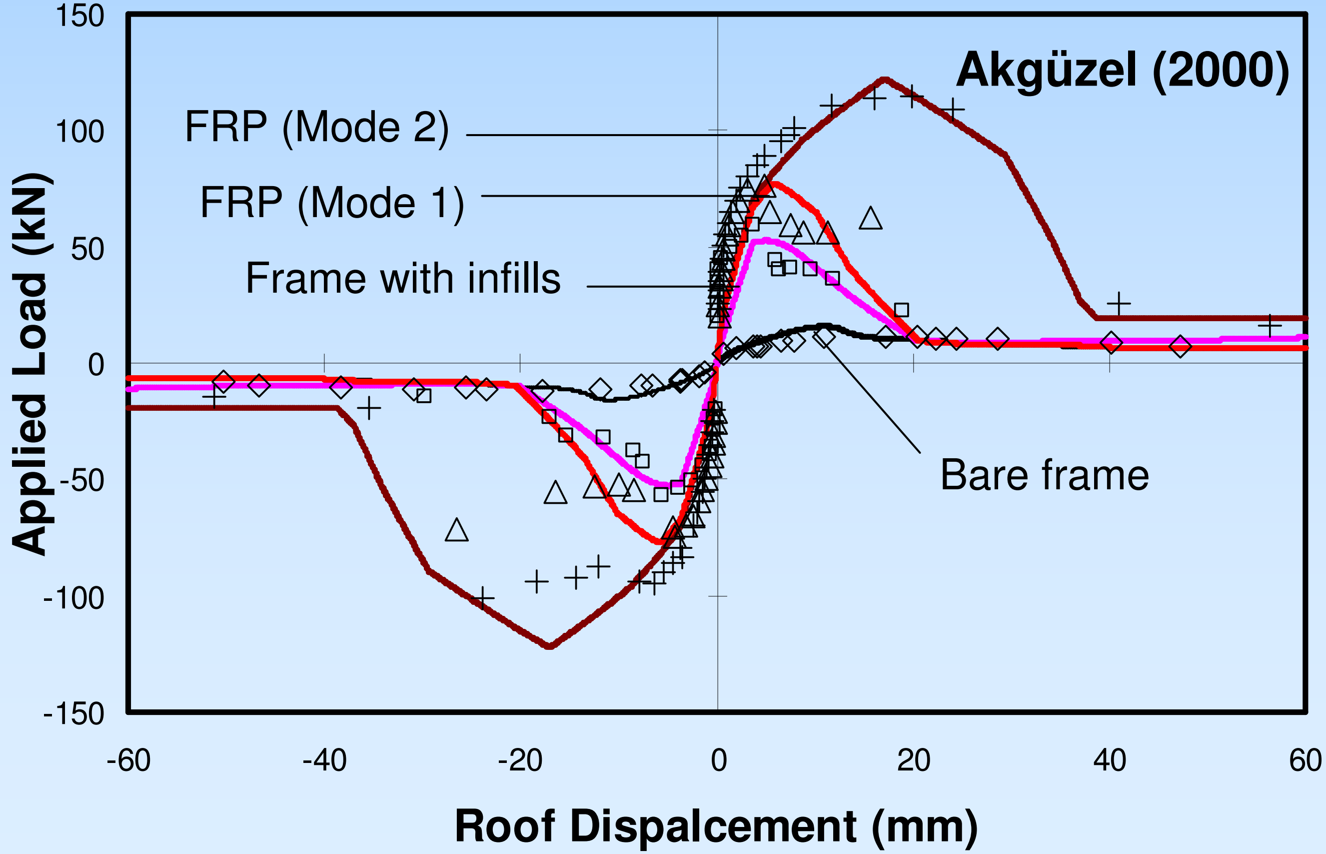
100 mm x 150 mm

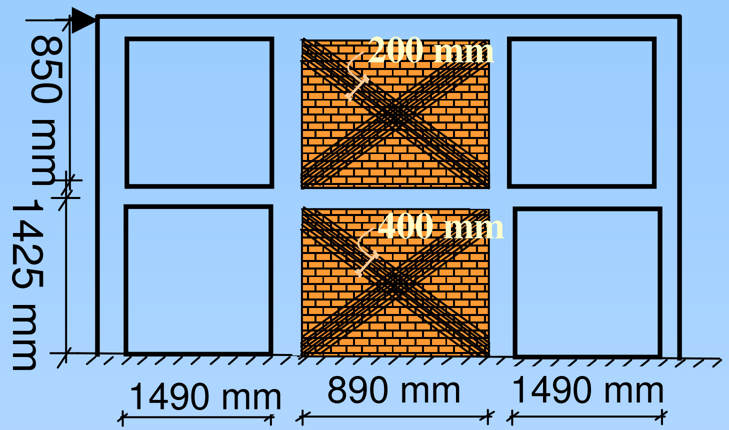
$\rho = 1.3\ \%$

$N/N_o \approx 0.1$

s = 95 mm







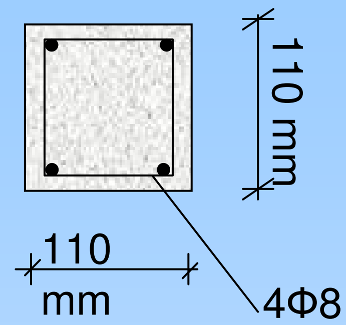
Columns Details:

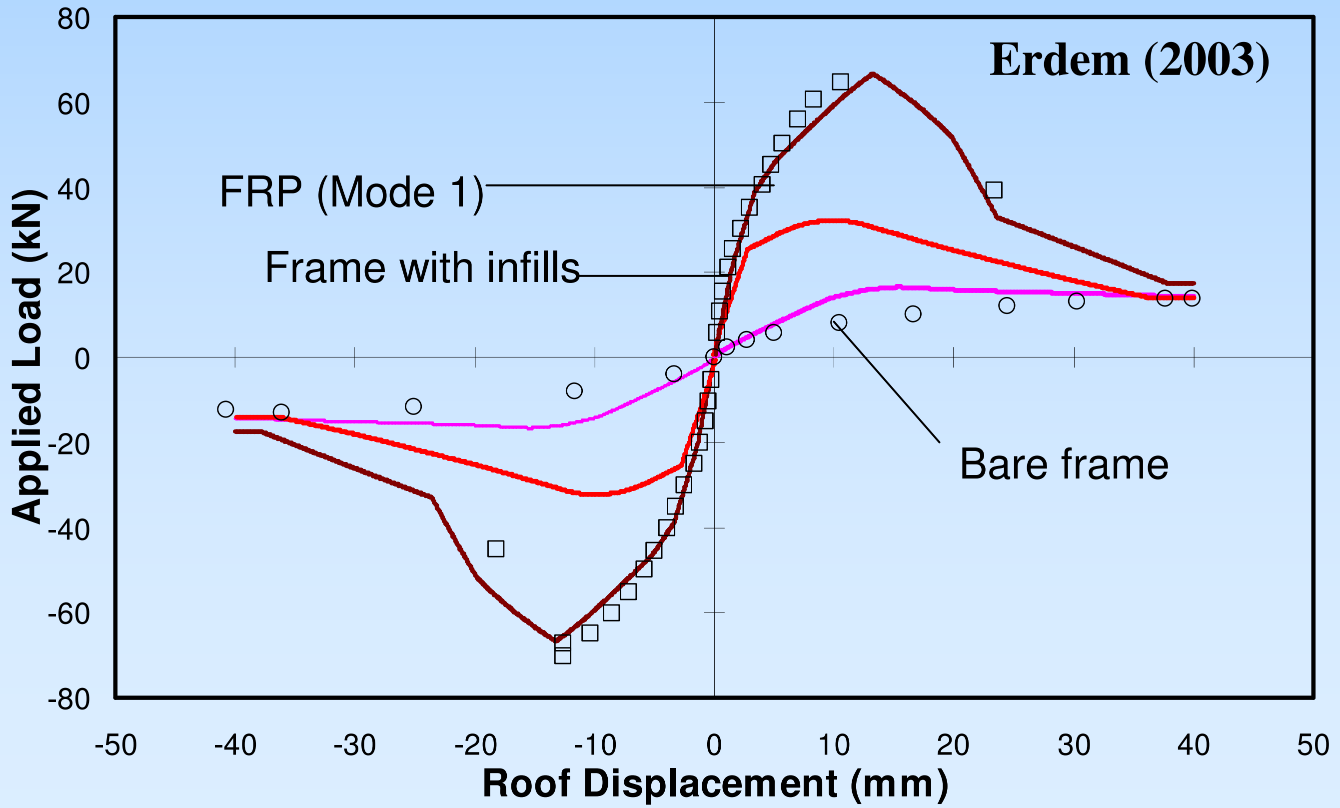
110 mm x 110 mm

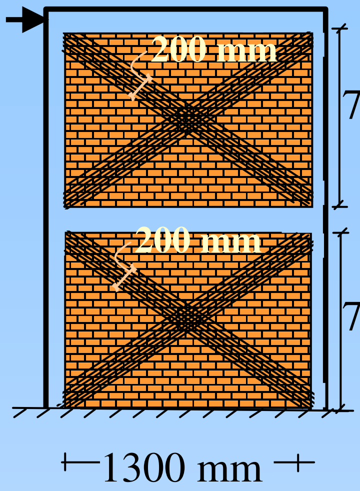
$\rho = 1.6\ \%$

$N/N_o \approx 0.1$

s = 100 mm







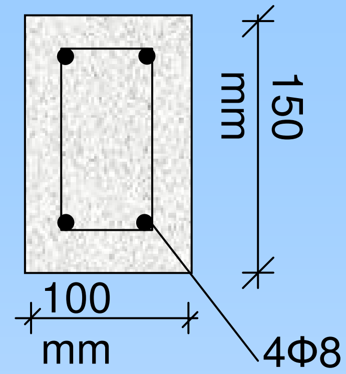
Columns Details:

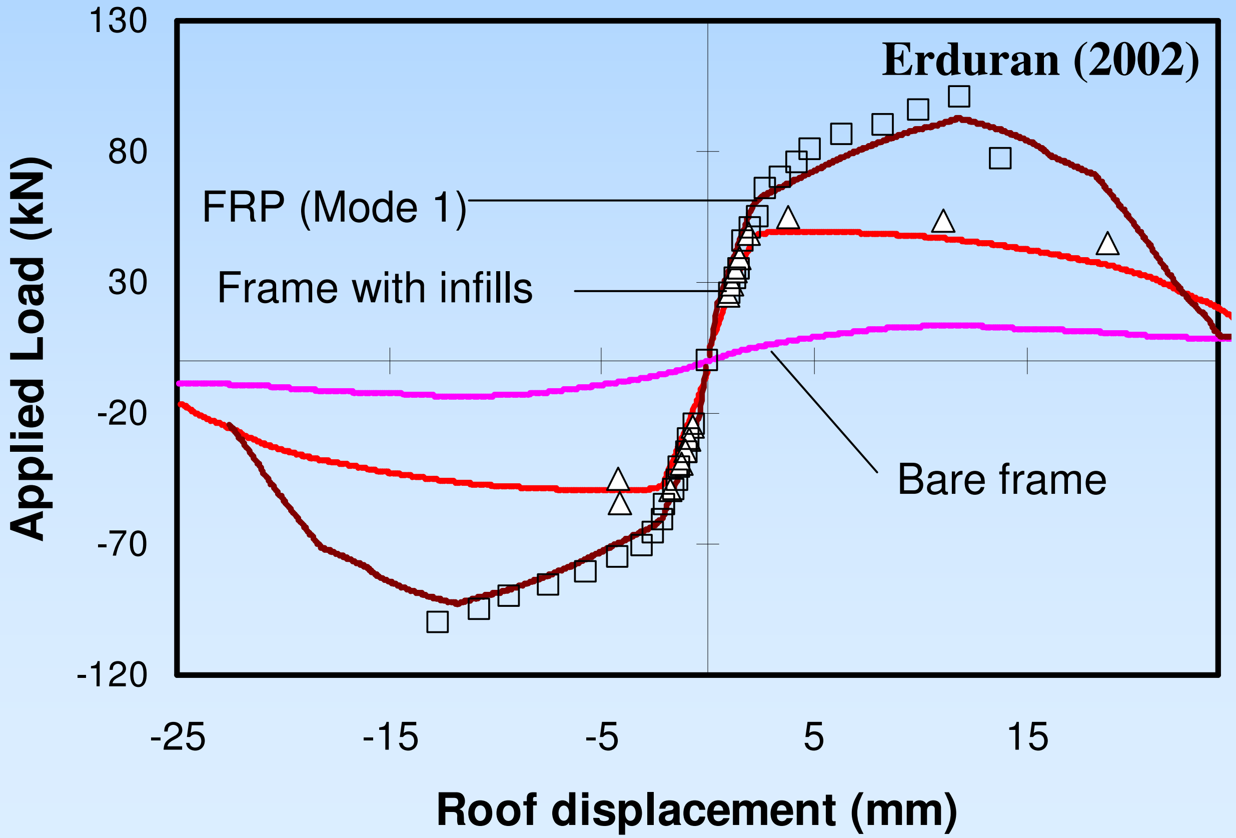
100 mm x 150 mm

ρ = 1. 3 %

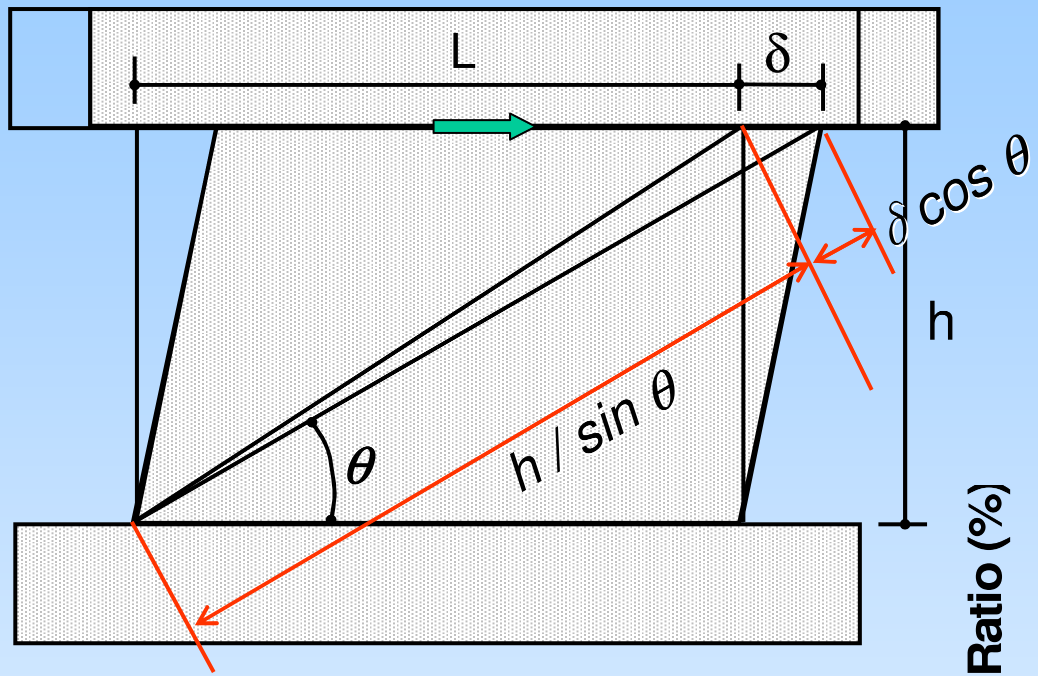
$N/N_o \approx 0.25$

s = 90 mm



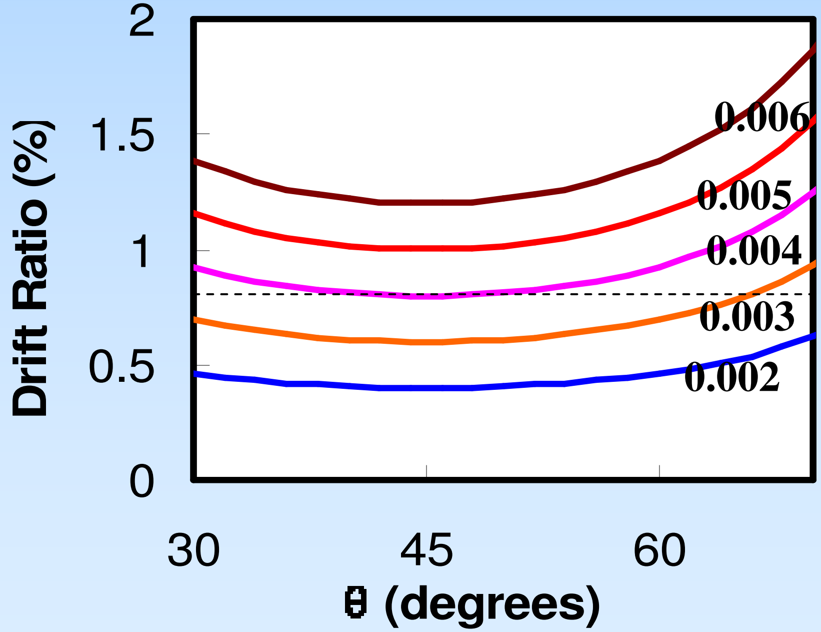


Evaluation of Deformations



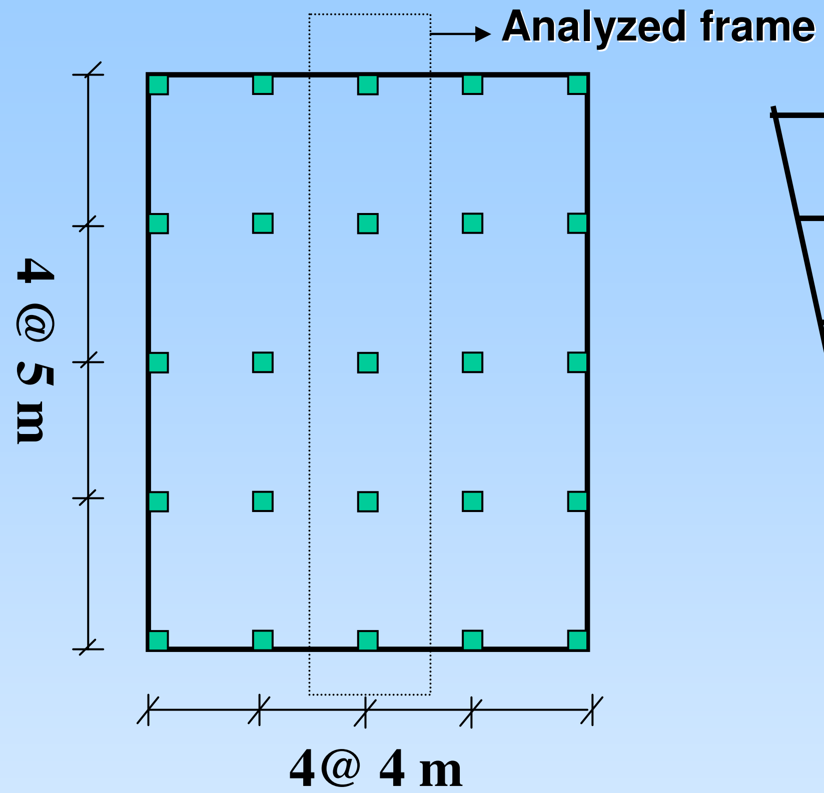
Assumed deformation of a wall
and FRP strain

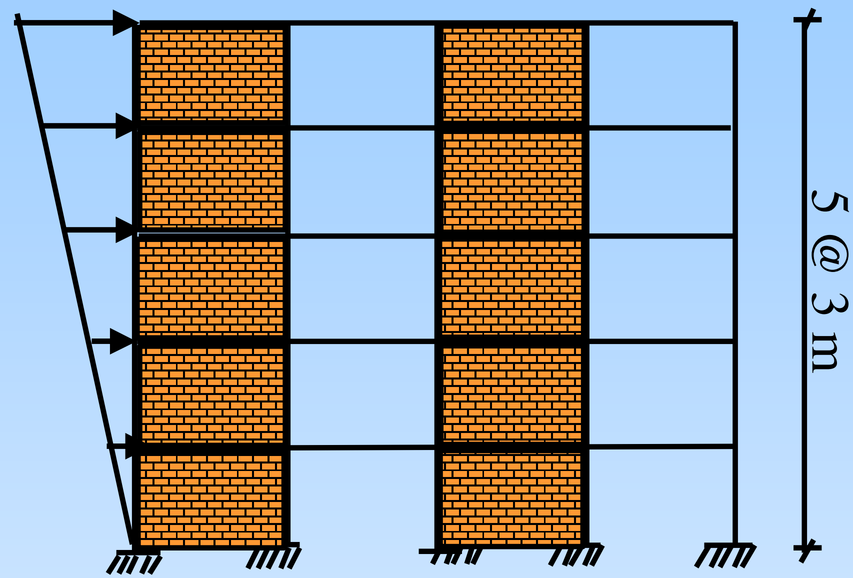
$$DR = \frac{\delta}{h} = \frac{\varepsilon_{f,eff}}{\cos\theta \sin\theta}$$



$IDR_{max} \approx 2\ \varepsilon_{f,eff}$

Case Study





Columns: 400 mm x 400 mm , ρ = 1% , s = 350 mm

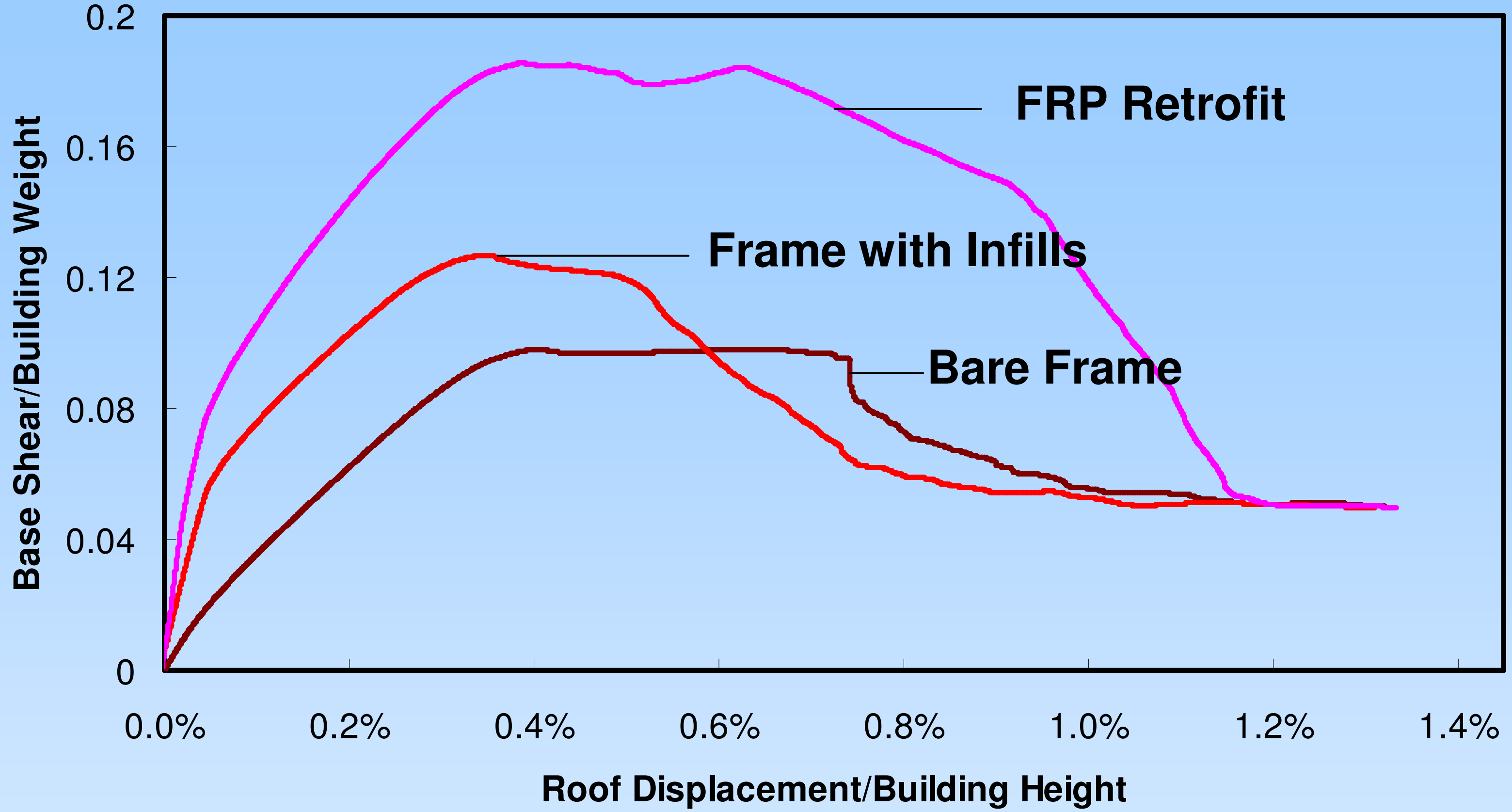
Beams : 300 mm x 600 mm , ρ = 0.5%

f_c' = 10 MPa , f_y = 420 MPa,

f_{mc} = 2 MPa, t_{in} = 100 mm

f_{cp} = 2 MPa, t_p = 40 mm

f_{CFRP} = 3450 MPa, w_f =750 mm (similar to compression strut width !)



- Limited ductility gain
- Strength increase (50 %)

Concluding Remarks

• A simple model is proposed for FRP retrofitted infilled RC frames.

• Comparisons of model estimations and experiments are in agreement.

• Strength increases with limited ductility can be achieved with the proposed retrofit scheme.

Check :

- FRP anchor design

-Significant uplift rotations due to splice deficiencies

(welding of splices for plain bars !)

- Foundation capacity