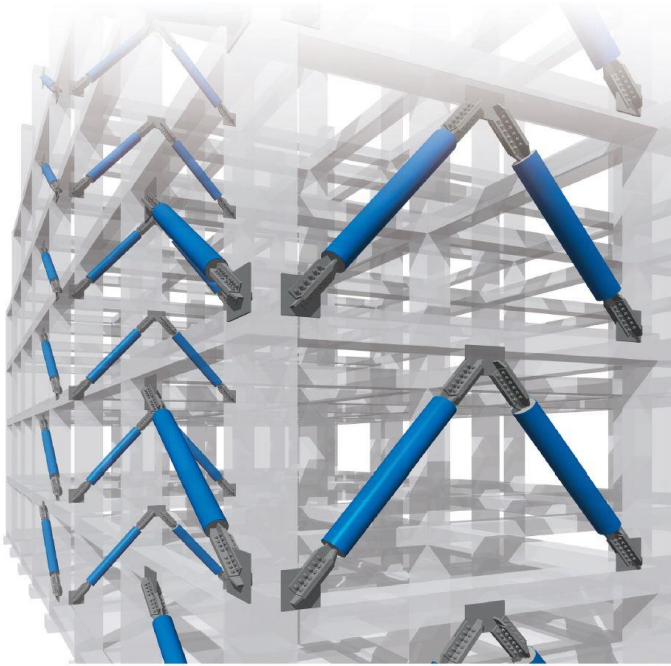
Seismic Performance of Buckling Restrained Braced Frames Subjected to Combined In-plane and Out-of-plane Loading

PhD candidate: Jian Cui & Saul Vazquez Colunga

Supervisor: Dr. Chin-Long Lee

Co-supervisor: Assoc. Prof. Gregory A. MacRae



24, May, 2018

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

NATURAL HAZARDS RESEARCH PLATFORM

[1] Introduction

BRB member & BRBF

Applications in Chch

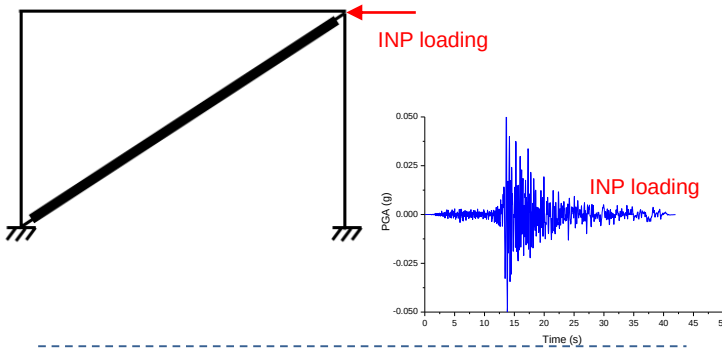
BNZ Centre

The Crossing Carpark

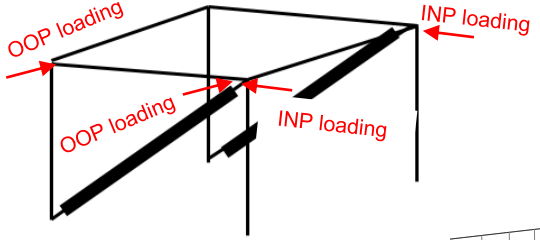
BRB & BRBF in this research

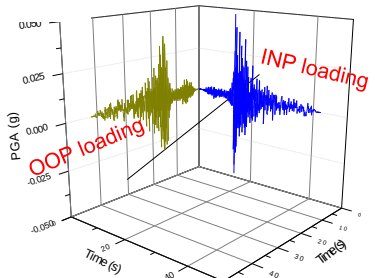
- BRB & BRBF
  - Cross-section
    - Circular
    - Rectangular
  - BRB-GP Connection
    - Bolted connection
    - Pinned connection
    - Welded connection
  - BRB layout
    - Diagonal bracing
    - (Inverted) V bracing

In previous studies



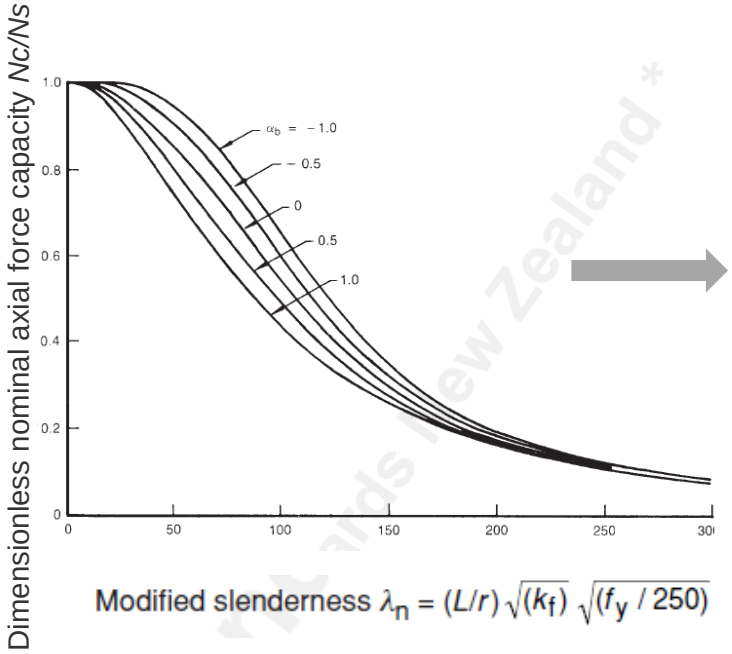
In this study



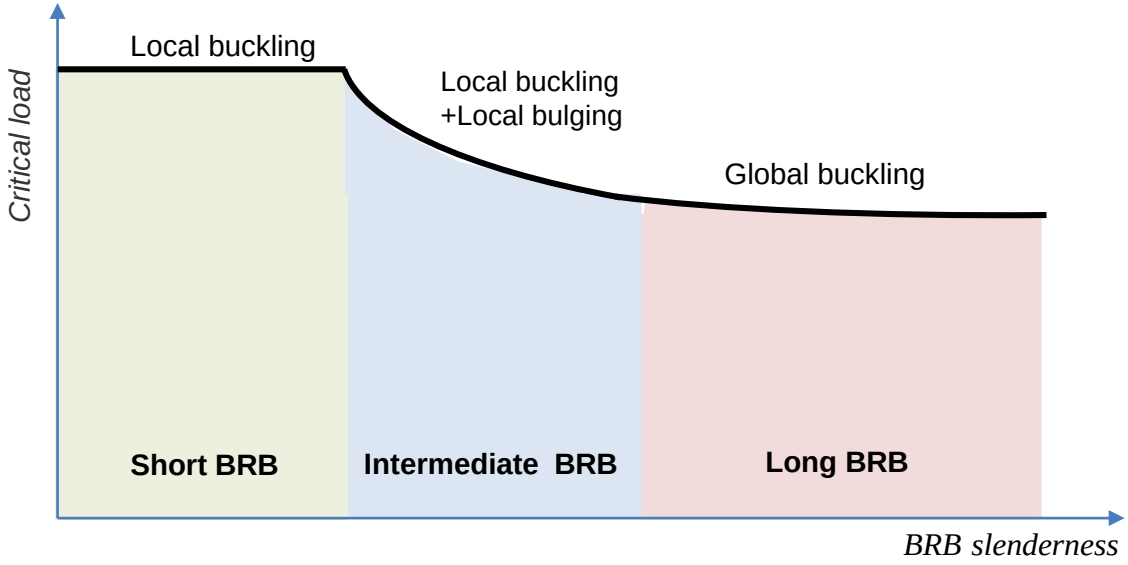


Research summary

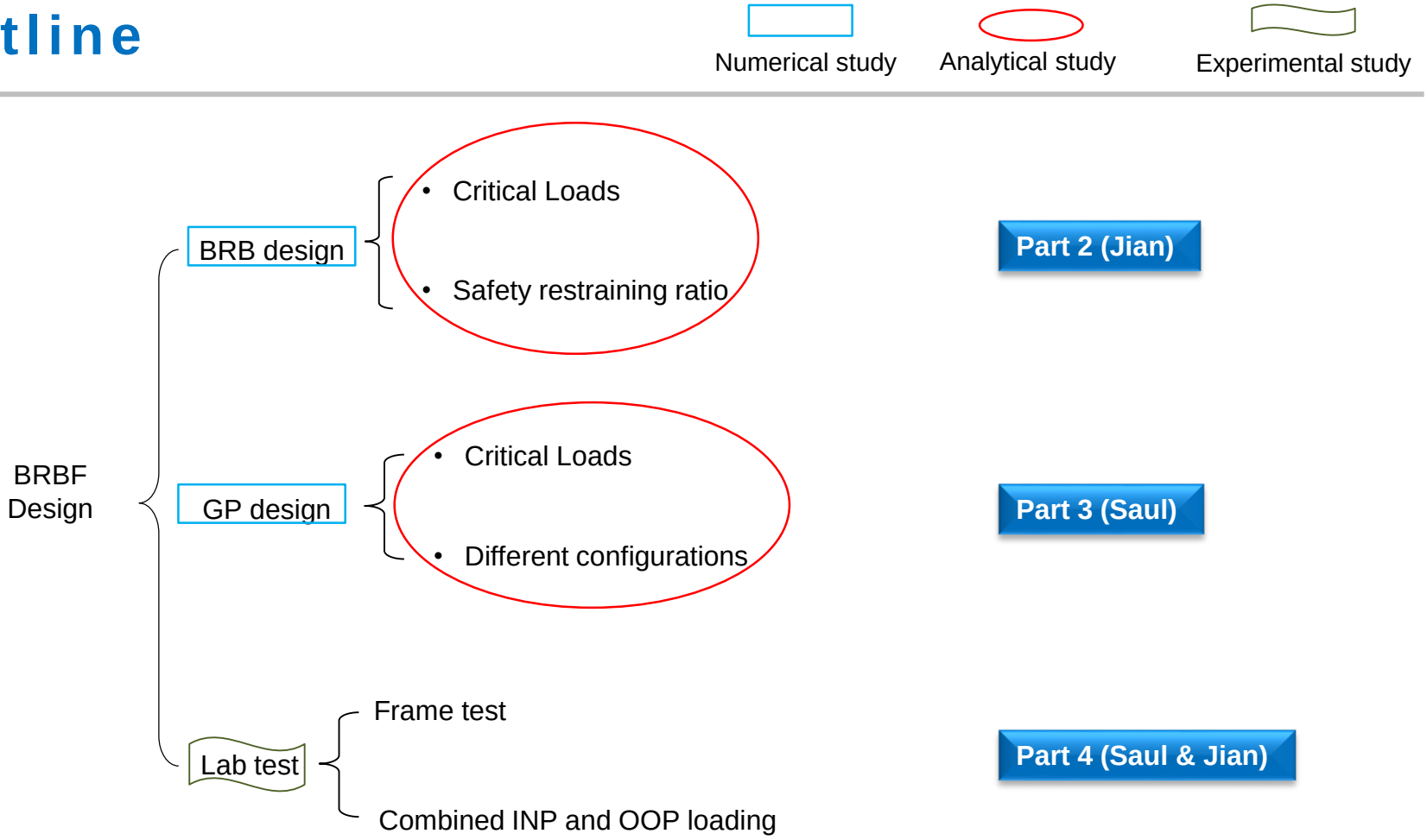
Column curve (Clause C6.3 ,NZ3404)



BRB curve



Outline


Numerical study
Analytical study
Experimental study
BRBF Design
BRB design
Critical Loads
Safety restraining ratio
Part 2 (Jian)
GP design
Critical Loads
Different configurations
Part 3 (Saul)
Lab test
Frame test
Combined INP and OOP loading
Part 4 (Saul & Jian)

[2] Current Research on BRBs

PhD candidate: Jian Cui

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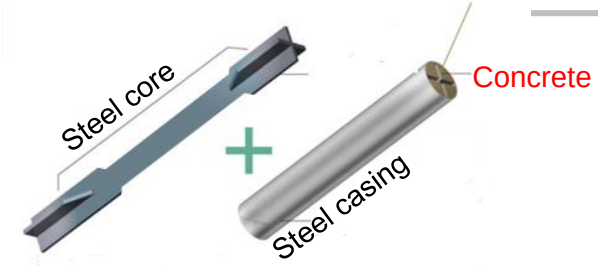
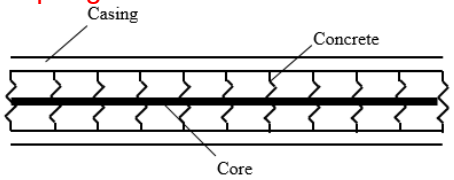
Numerical modelling



Analogies :

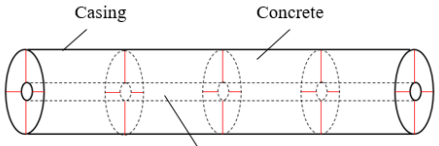
Free body diagram:

Spring constant



Numerical model:

Connector (spring) elements?

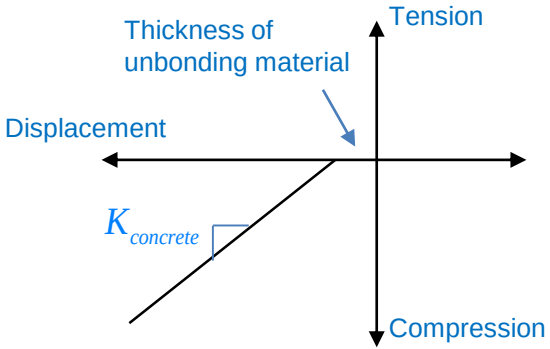


Advantages :

- Increasing computational efficiency

  Avoid contact problem

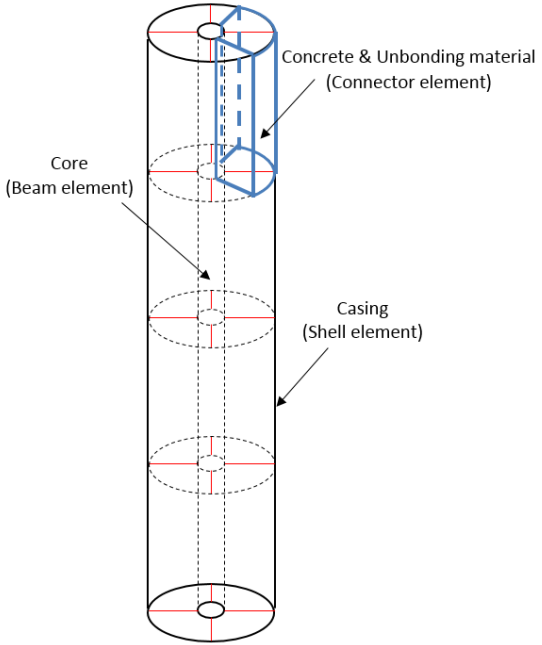
- Incorporating non-linear response characteristics



Assumptions

: Concrete hoop stress and axial stress are ignored for this preliminary study

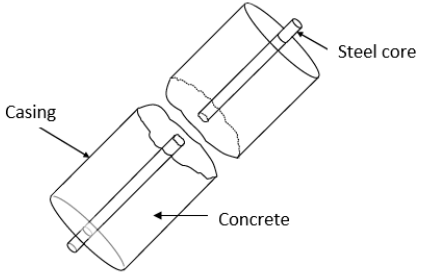
Numerical model :



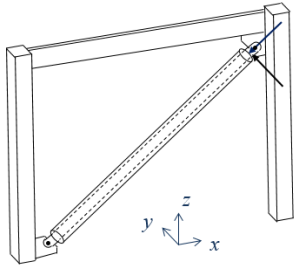
Numerical simulation

Experiment model:

Palazzo et al. (2011)



Loading method:

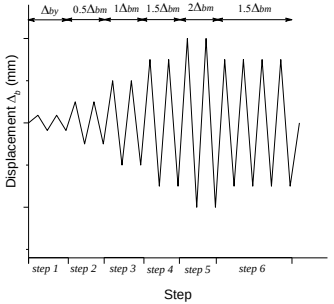


Axial In-plane (xz plane) loading

Pined-pined connection

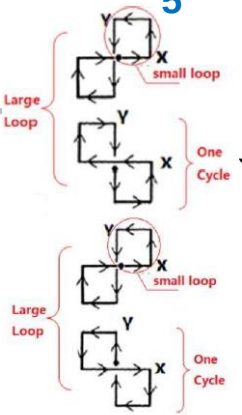
Out-of-plane (yz plane) loading

Fixed-fixed connection



INP loading

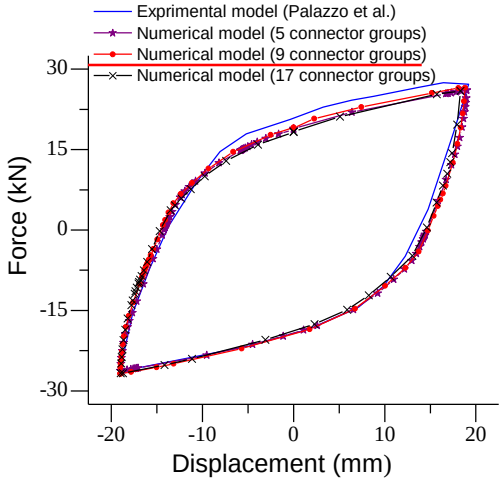
(AISC 341-16)



OOP loading

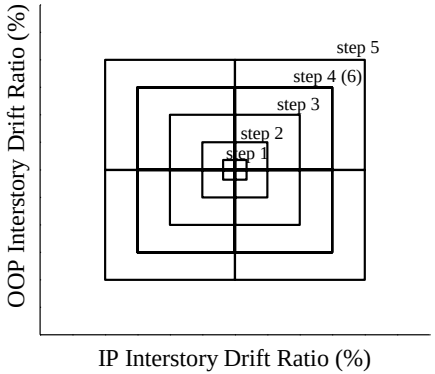
(Wei & Bruneau, 2015)

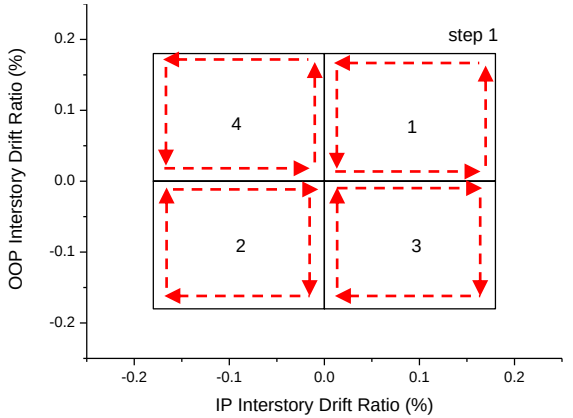
Model calibration:



Loading protocol:

=





Combined INP and OOP loading (estimated loading time: 1636 step time)

Results

Energy dissipation capability:

Cumulative plastic deformation (CPD)

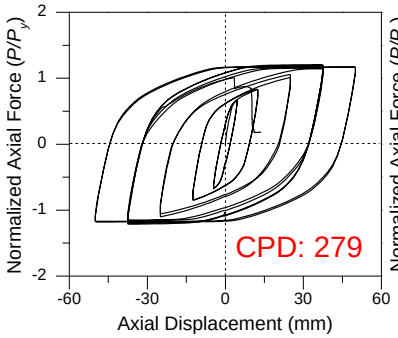
$$CPD = \sum_i \frac{\left| u_C^{\max} - u_T^{\max} \right|}{u_y}$$

$u_C^{\max}$: maximum inelastic compressive displacement

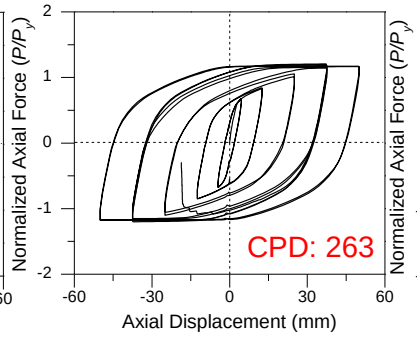
$u_T^{\max}$: maximum inelastic tensile displacement

u_y : yield displacement

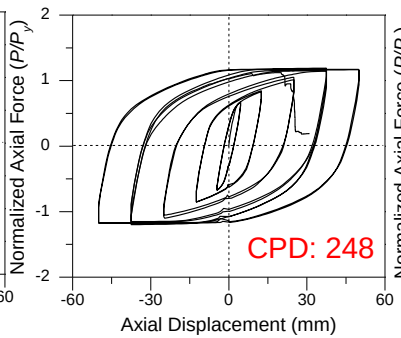
Case 1:
INP loading only



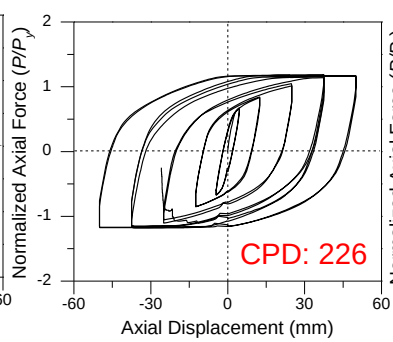
Case 2:
OOP/INP loading=0.5



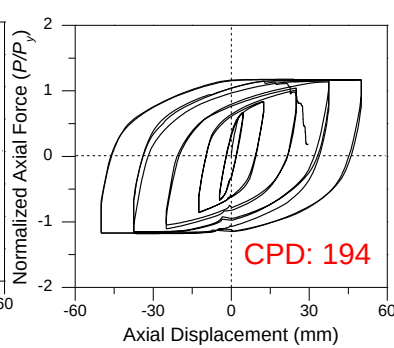
Case 3:
OOP/INP loading=1



Case 4:
OOP/INP loading=1.5

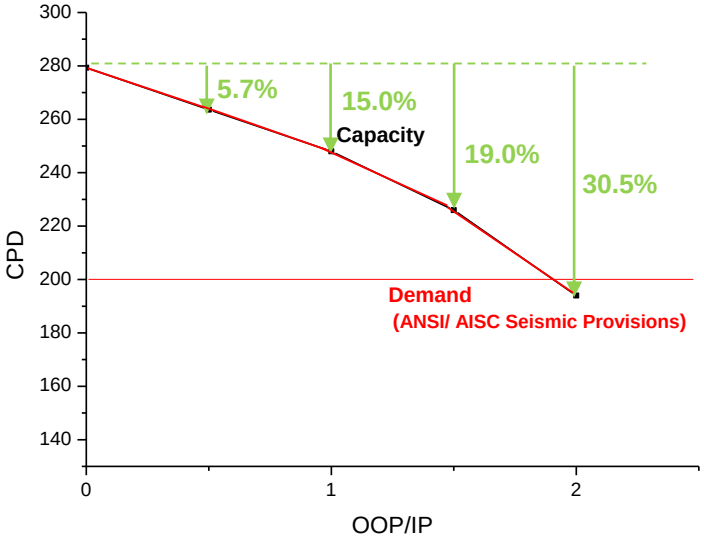


Case 5:
OOP/INP loading=2



- OOP/INP loading ↑, CPD ↓

Conclusions



Conclusions:

- The shell model with **connectors** is a good option for BRB modelling
- The OOP loading **reduces** the energy dissipation ability of BRBs.
  OOP/INP loading=0.5, CPD 5.7% ↓
  OOP/INP loading=1, CPD 15% ↓
  OOP/INP loading=1.5, CPD 19% ↓
  OOP/INP loading=2, CPD 30.5% ↓, less than 200, unsafe
- BRBF design method should consider the **effect of OOP loading**

[3] Current Research on Gusset Plates

PhD candidate: Saul Vazquez Colunga

Supervisor: Dr. Chin-Long Lee

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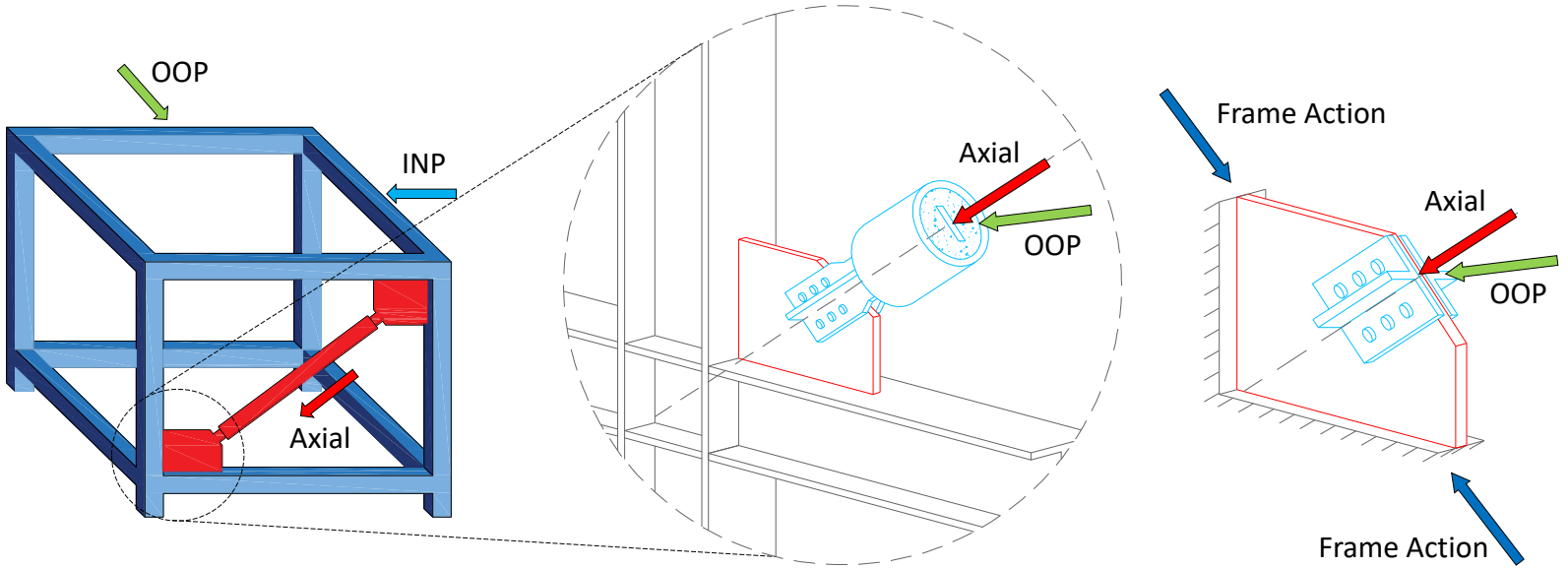
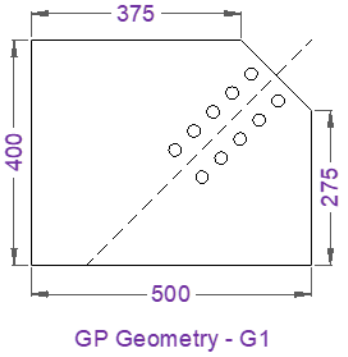
Out-of-plane displacements

- Influence of OOP displacements on load capacity of Gusset plates (GPs).
- Relationship between reduced load capacity of GPs and the their slenderness ratio (elastic and inelastic buckling).

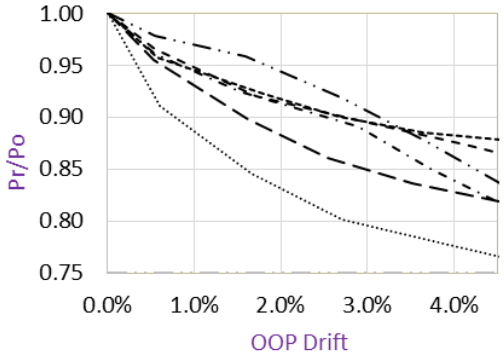


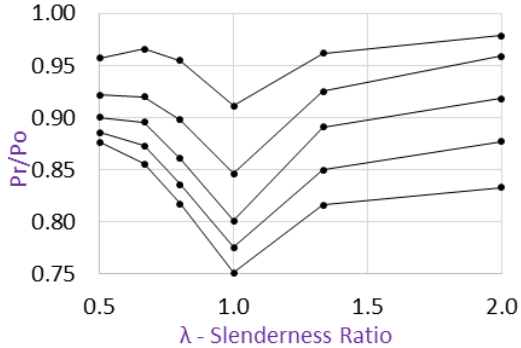
Conclusions

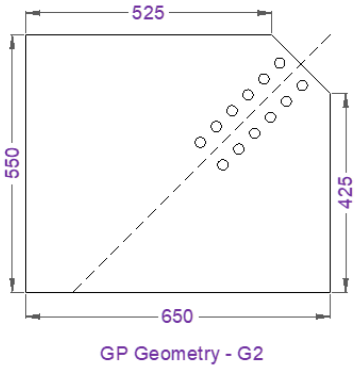
- Local models to account for the effect of OOP displacements



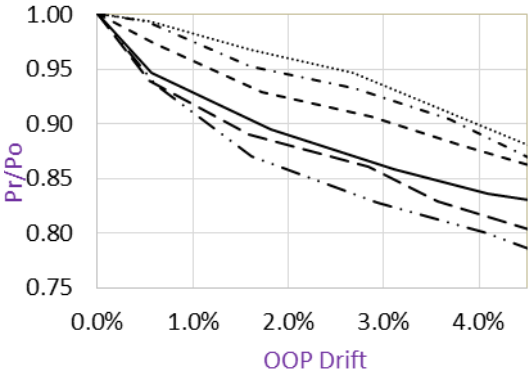
GP Geometry - G1

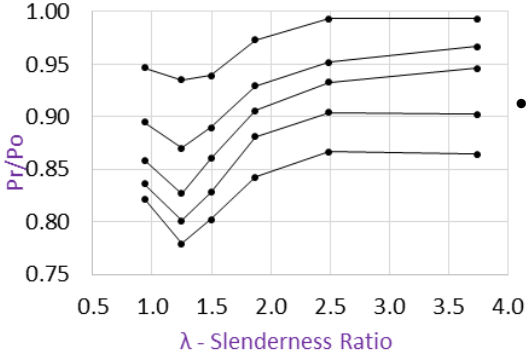






GP Geometry - G2





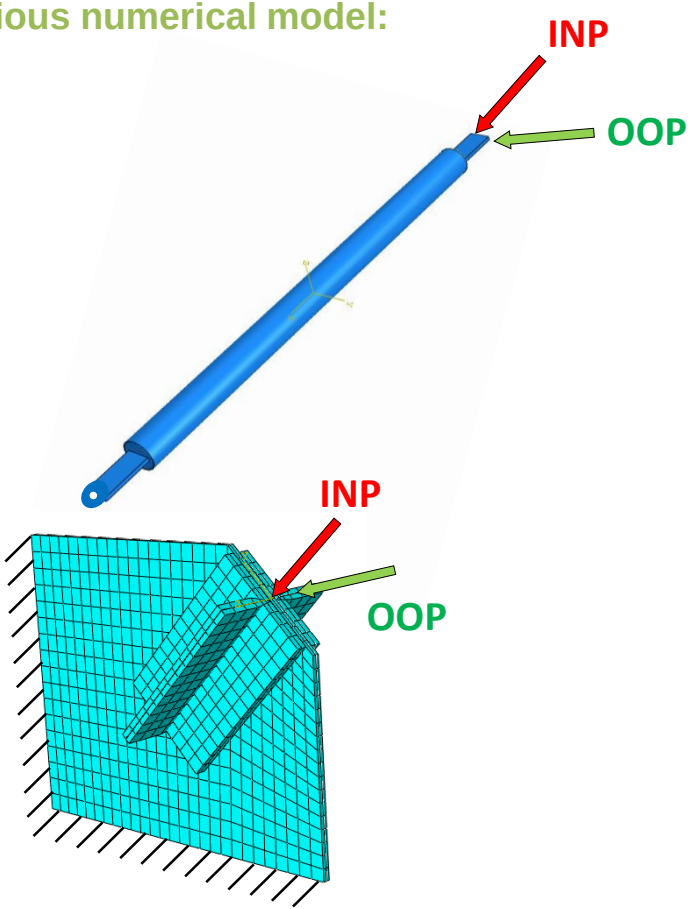
Conclusions:

- The load capacity of GP is further reduced as OOP displacements are increased
- The trend in the reduction changes depending on elastic and inelastic buckling

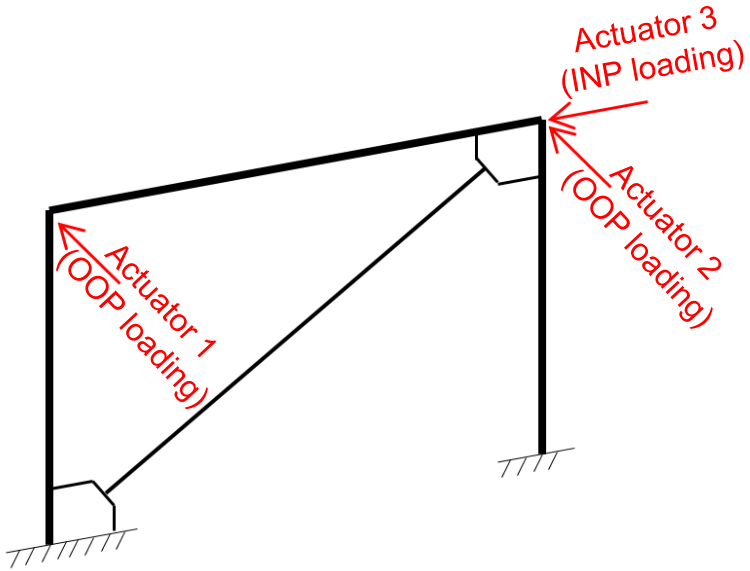
[4] Future Research

Experimental test

Previous numerical model:



Proposed experimental testing:



Strong floor, Wing Lab, University of Canterbury, Christchurch, New Zealand

Experimental test —— BRBs

Object of study:

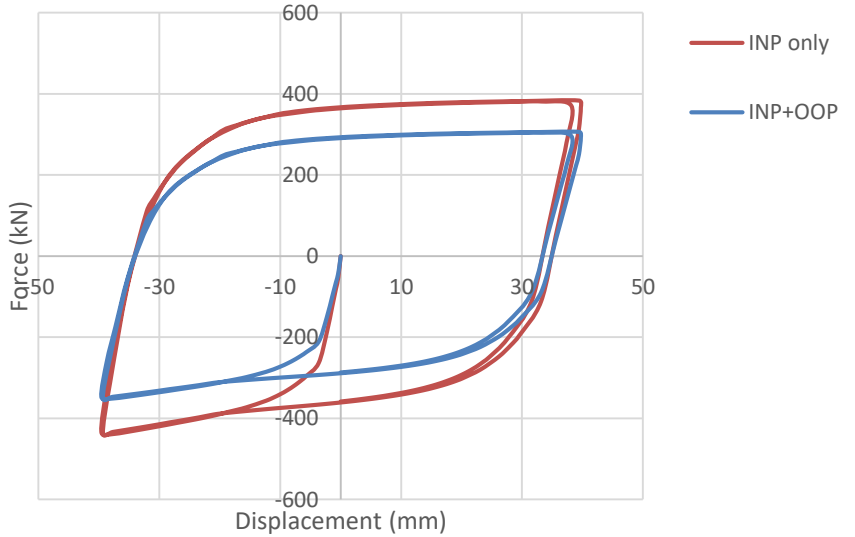
1. Restraining ratio for BRBs with circular cross-section

2. BRBF performance under combined INP and OOP loading

Restraining ratio: $\zeta = \frac{P_{cr}}{P_y}$

- *Watanabe et al., (1988)* $\zeta = 1$
- *Nader & Behzad (2012)* $\zeta = 1.4$
- *JGJ 99-2015 (2015)* $\zeta = 1.95$

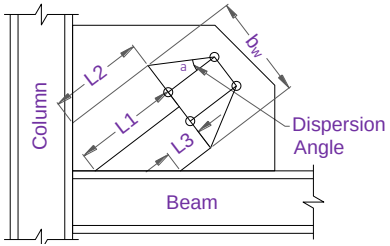
BRB's energy dissipation capability reduced by X%



Experimental test —— GPs

Load capacity of Gusset Plates:

- Obtained using AISC Standards



(a) When $\frac{KL}{r} \le 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} \le 2.25$)

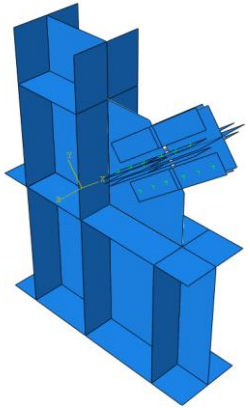
$$F_{cr} = \left[0.658^{\frac{F_y}{F_e}}\right] F_y$$

(b) When $\frac{KL}{r} > 4.71\sqrt{\frac{E}{F_y}}$ (or $\frac{F_y}{F_e} > 2.25$)

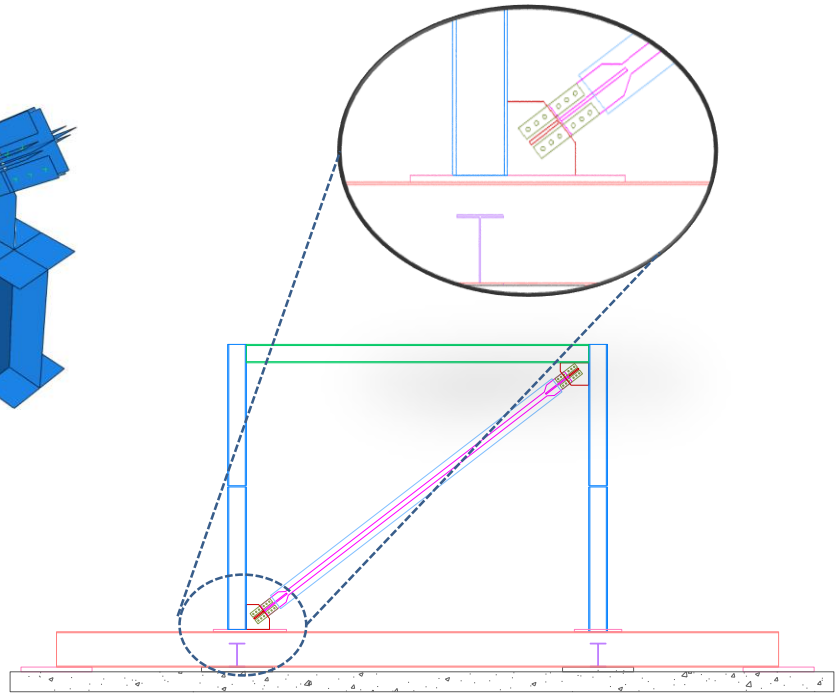
$$F_{cr} = 0.877 F_e$$

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2}$$

- Predicted using FEM models



- Test Results



Summary

2017:
Identifying and quantifying the effects of OOP loading on BRBs and GPs

2018,2019:
- Refined FE models
- Design equations
- ……

2018, 2019:
Experimental test on BRBF under combined INP and OOP loading

2019, 2020:
Design recommendations for BRBs and GPs