CITY UNIVERSITY LONDON

SCHOOL OF MATHEMATICS, COMPUTER SCIENCE & ENGINEERING

RESEARCH CENTRE FOR CIVIL ENGINEERING STRUCTURES

Post-peak behaviour of substandard R/C members subjected to seismic loading

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Outline

1. Introduction
2. Beam-column model development
3. Beam-column model verification
4. Simultaneous shear-axial failure
5. Summary & Future Work

Introduction

Old buildings, not adhering to modern seismic codes

Sub-standard members; shear or flexure-shear critical.

Axial failure of vertical members (disintegration of concrete core with cycles; axial load capacity dropping down to axial load demand)

Initiation of progressive (vertical) collapse of the structure

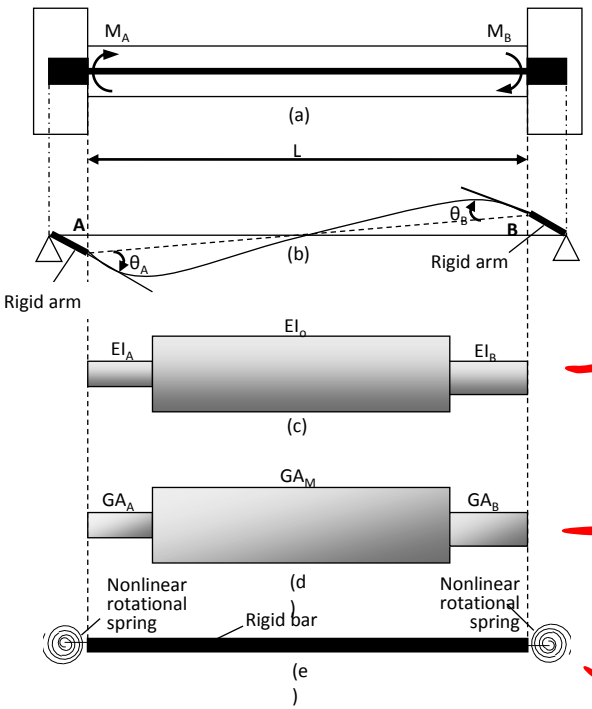
Introduction

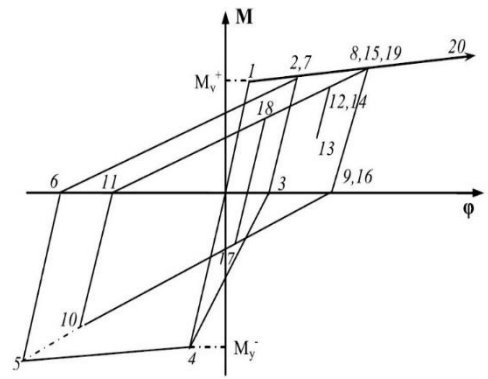
Existing models:

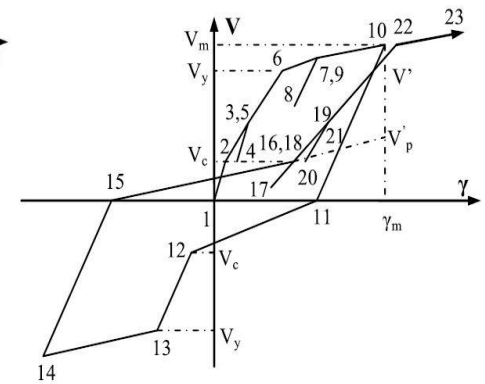
- do not account for (post-peak) shear response,
- lack efficiency for such application (e.g. well-known fibre-models), or
- lack accuracy:
  - in the entire response (e.g. not accounting for bond-slip contribution to deformations or for shear-flexure interaction), or
  - in the post-peak response (not accounting for “shear failure localisation”, adopting unsound assumptions for the post-peak descending branch, the onset of axial failure and the existence of residual strength)

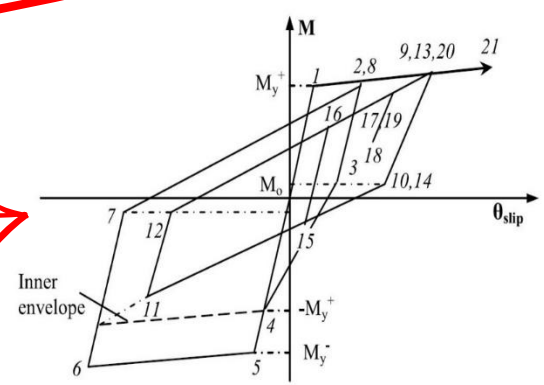
Beam-column model development

Description of previous version









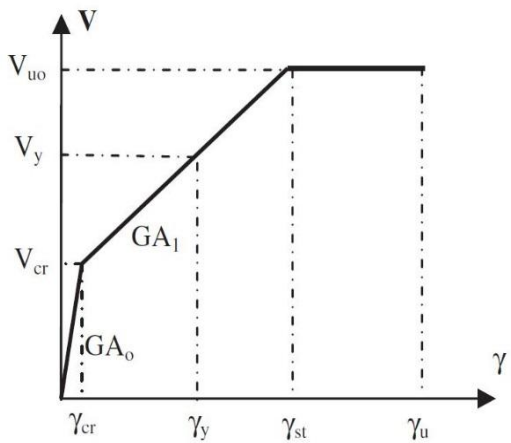
$$F = F^{fl} + F^{sh} + F^{sl}$$

$$K = F^{-1}$$

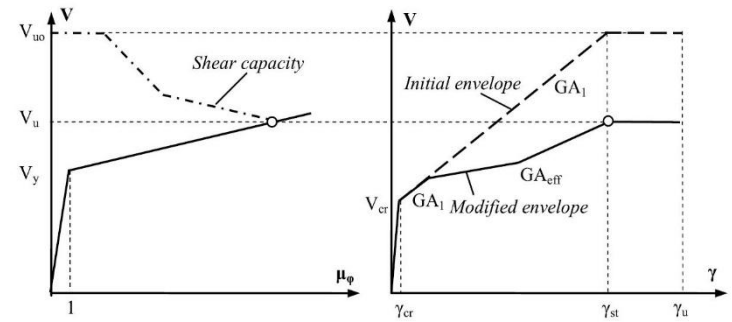
Mergos & Kappos (2008, 2012, 2013)

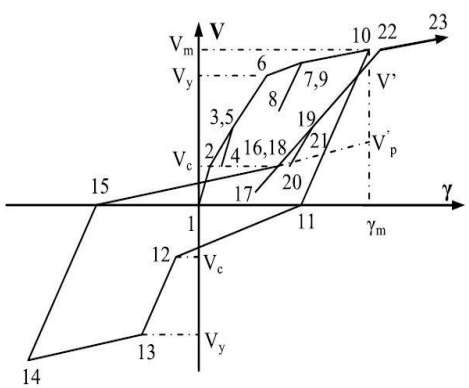
Beam-column model development

Description of previous version - shear component



Shear-flexure interaction



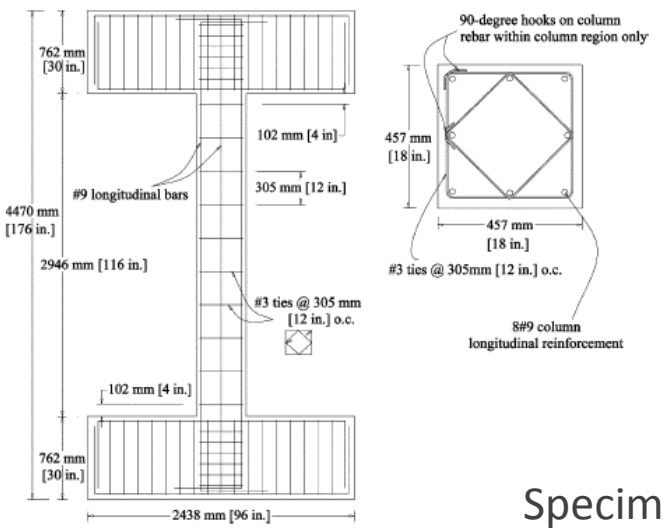


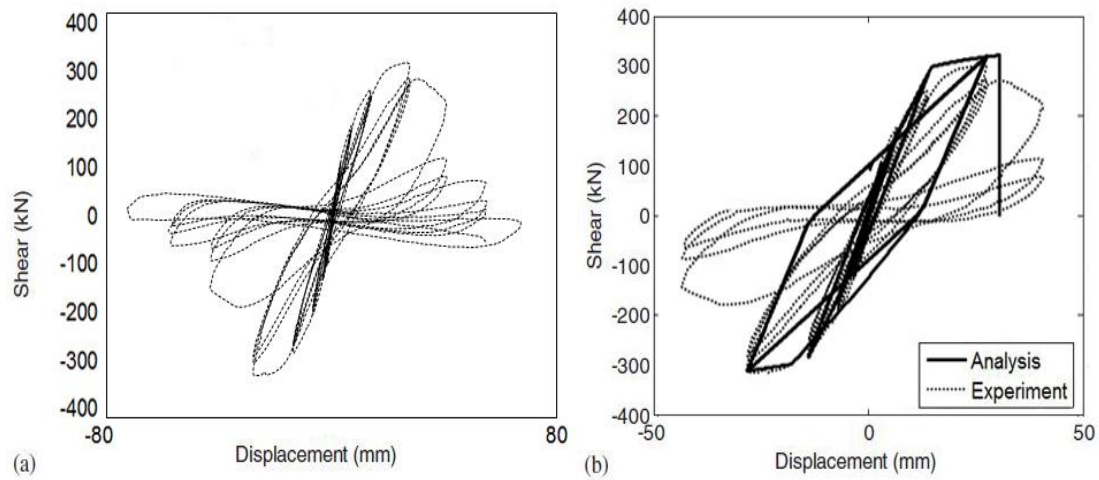
Ozcebe & Saatcioglu (1989) hysteretic rules.

Beam-column model development
Implementation of previous version

Relevant specimen in quasi-static cyclic loading (lightly reinforced, flexure-shear critical):

- Up-to-peak behaviour predicted with decent accuracy.
- Not covering the post-peak part of the response (vital for progressive collapse prediction).



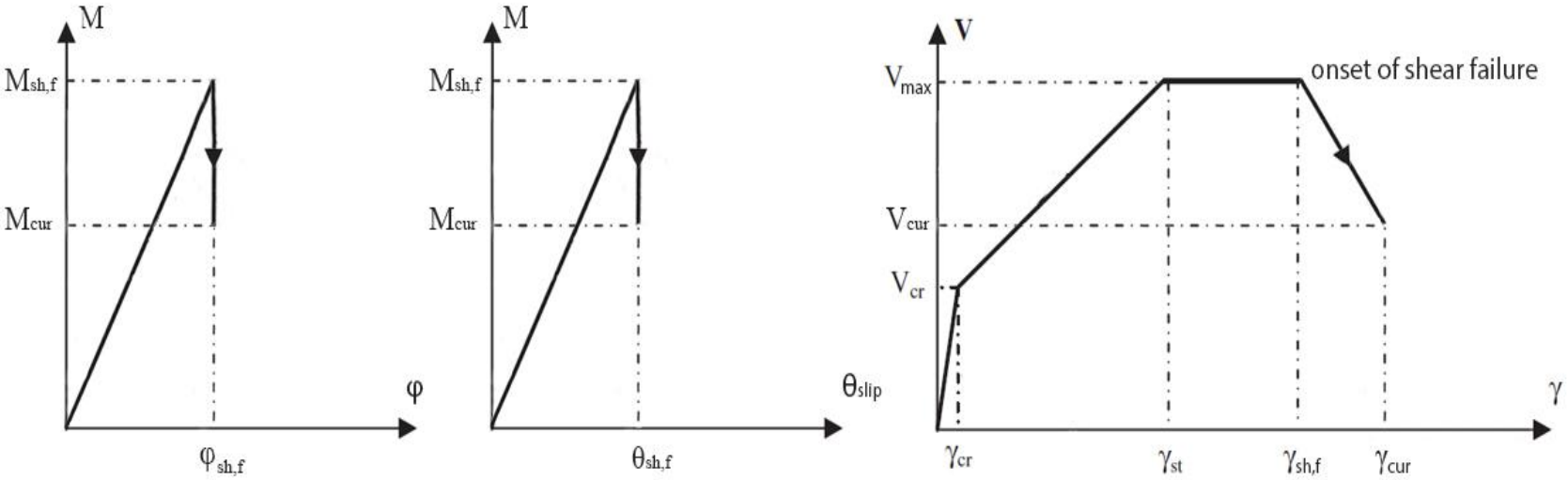


Specimen 1 (Sezen & Moehle, 2006) (figures adapted from Sezen & Moehle,2006 and Mergos, 2010)

Beam-column model development
Modelling highlights

Flexural and bond-slip components “locking” at the respective deformations at the onset of shear failure. (like some similar models; experimentally observed)

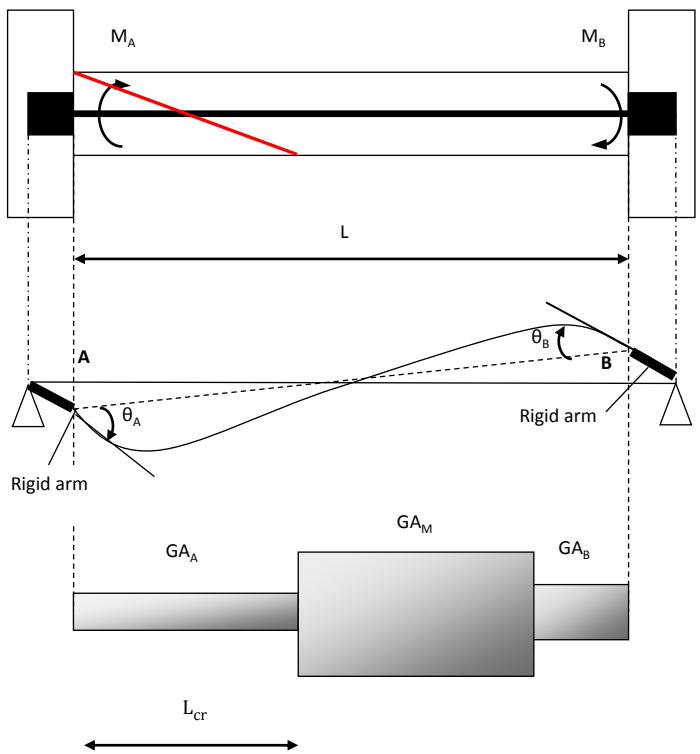
- Element becomes shear-dominated after the peak.
- Other sub-models unloading with very high stiffness simultaneously with the shear model’s descent.

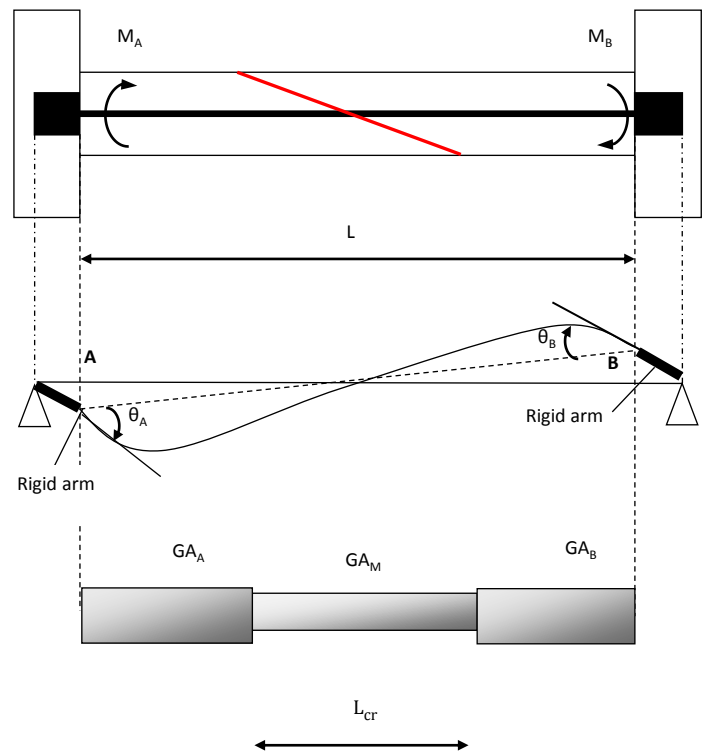


Beam-column model development
Modelling highlights

"Shear failure localisation": Post-peak shear deformations concentrated at "critical length", defined by the "shear crack critical angle".

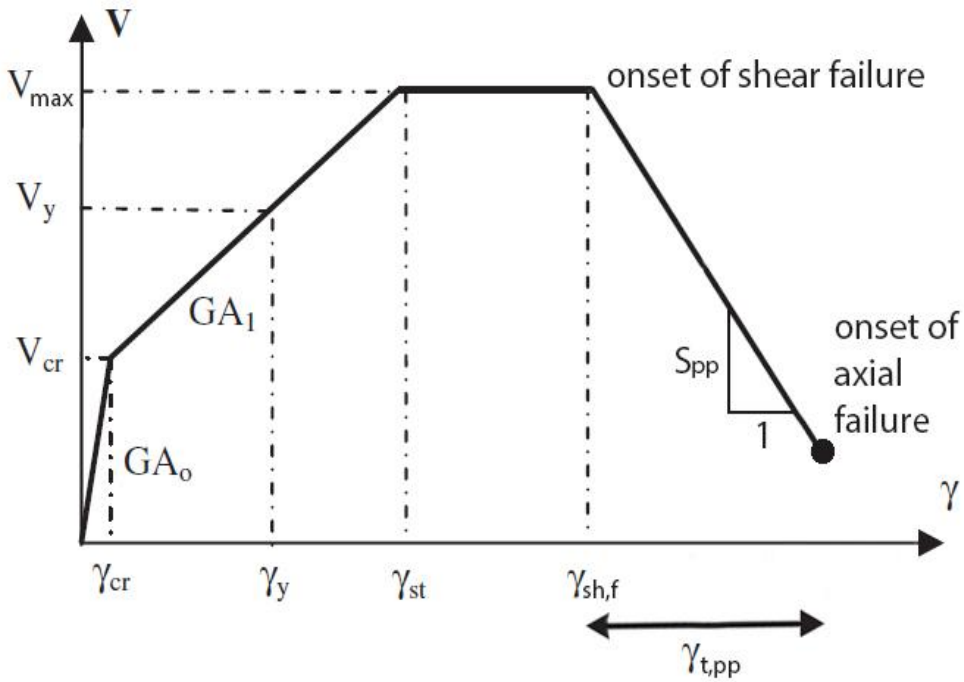
- Setting L_{cr} as the length of the respective inelastic zone in the spread inelasticity model
- "Detecting" diagonal plane region (accounting correctly for flexibility/stiffness)





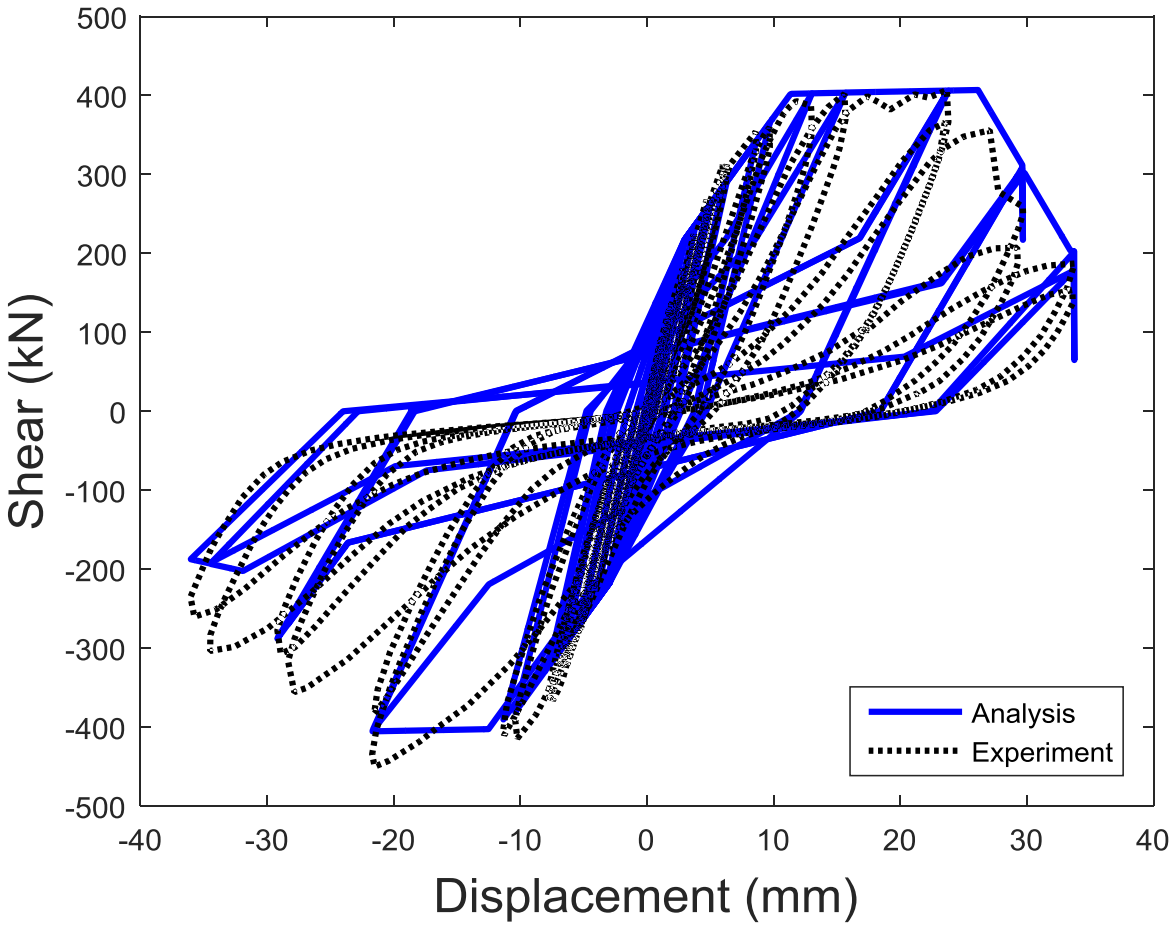
Beam-column model development
Modelling highlights

Envelope of proposed shear sub-component hysteresis model:



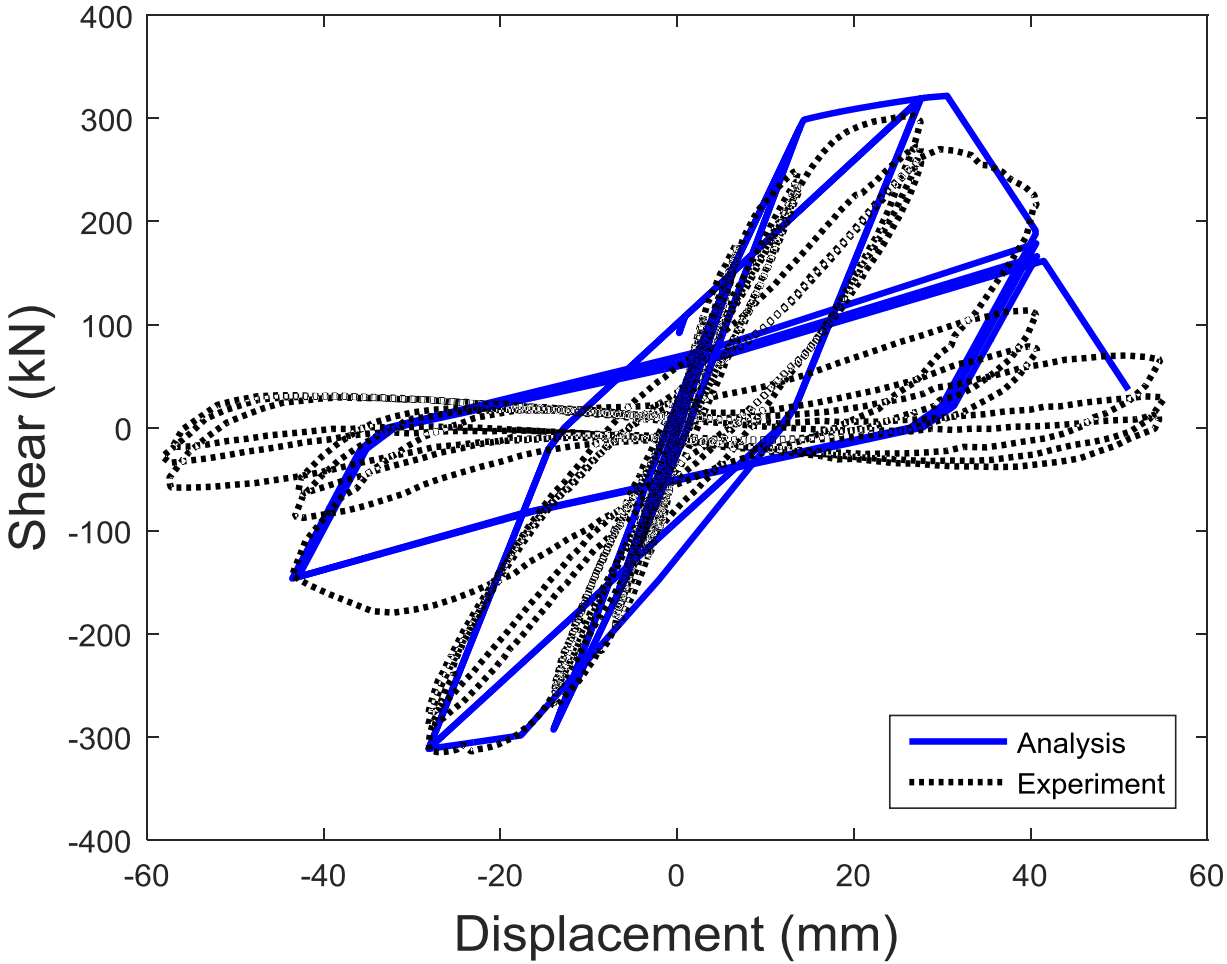
Beam-column model development
Verification

Shear critical specimen SC9 (Aboutaha et al., 1996), rectangular section, quasi-static cyclic loading:



Beam-column model development
Verification

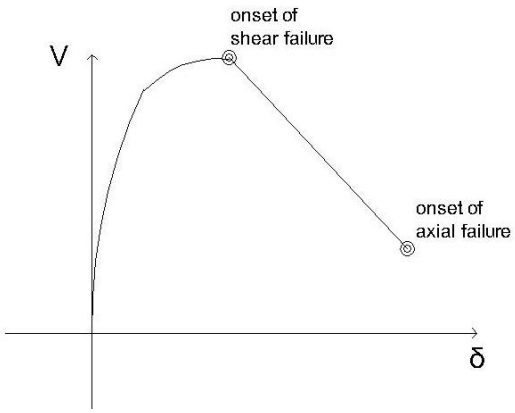
Flexure-shear critical specimen No. 1 (Sezen & Moehle, 2006):



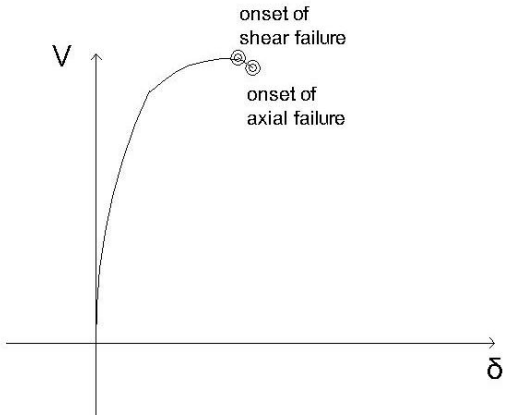
Simultaneous shear-axial failure
Introduction

Indicative response:

Flexure-shear specimen with post-peak behaviour



Flexure-shear specimen with simultaneous shear and axial failure



Simultaneous shear-axial failure
Introduction

Definition?

- Conventionally chosen:
  Post-peak Inter-storey Drift Ratio ($IDR_{,pp}$) < 0.2 %

Database:

- 133 rectangular R/C columns exhibiting post-peak response and/or axial failure:
  - 89 specimens sustaining axial failure (44 exhibiting at least 30% strength degradation)
  - 12 specimens sustaining simultaneous shear and axial failure

Simultaneous shear-axial failure
Existing observations

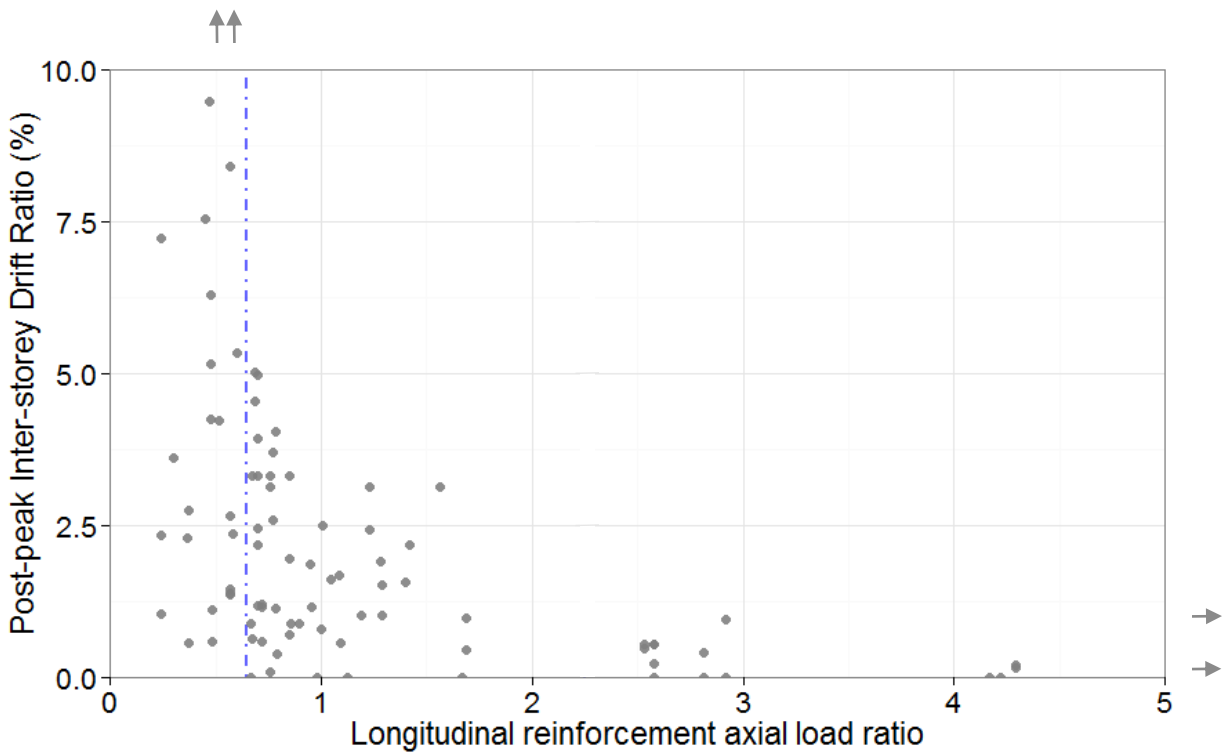
1. Flexure-shear critical specimens fail simultaneously, shear critical do not (Yoshimura et al., 2008):

- half shear-axial specimens are shear-critical.
- 88% of flexure-shear critical specimens in the database have not failed simultaneously.

Simultaneous shear-axial failure
Existing observations

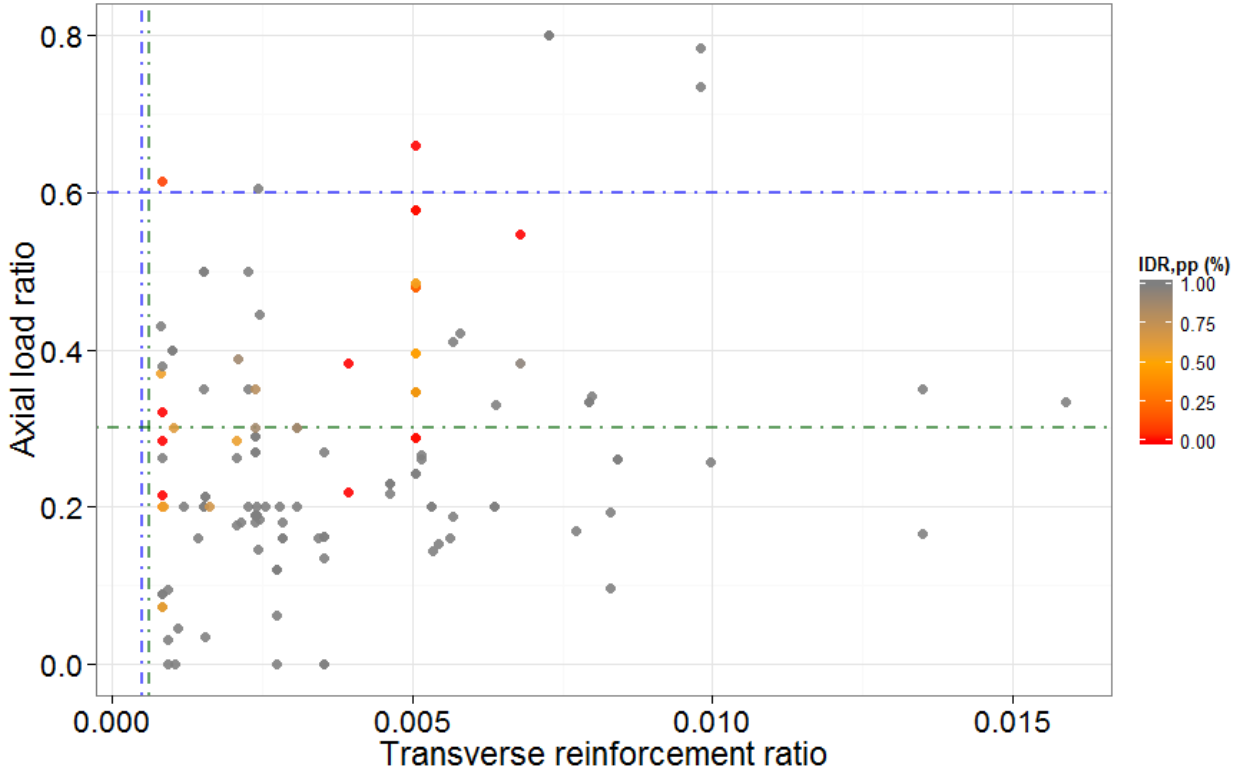
2. "Longitudinal reinforcement axial load ratio" [$v_l = N / (A_{sl} \times f_{yl})$]

- > 1.0 → simultaneous failure (Matchulat, 2009)
- < 0.65 → no simultaneous failure (Matamoros & Woods, 2010)



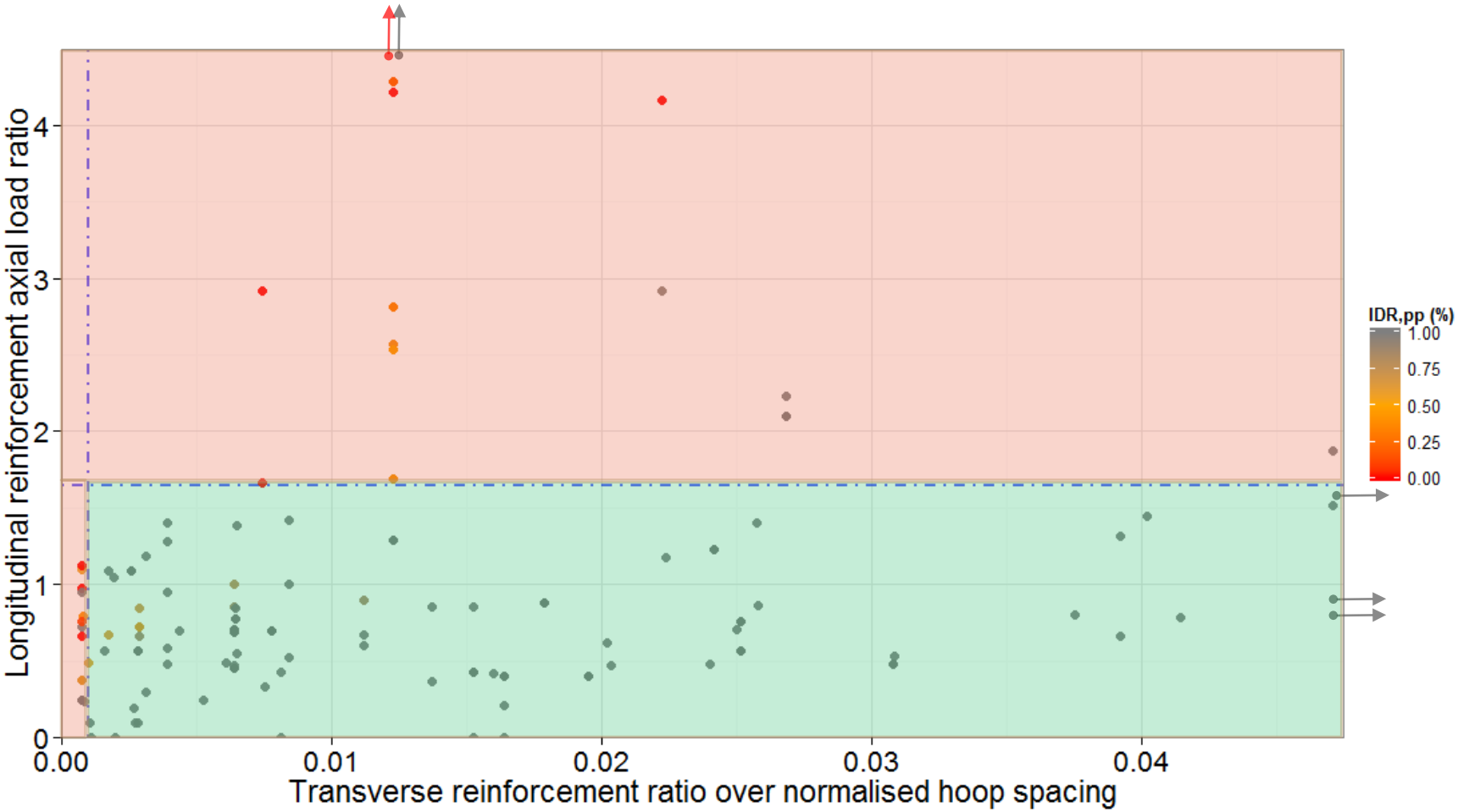
Simultaneous shear-axial failure
Existing observations

3. ASCE/SEI 41-06 limits of $\rho_w \geq 0.05\%$ and $v \leq 0.6$ do not guarantee that no simultaneous failure will occur; in their (more limited) database, specimens that failed simultaneously had $\rho_w \geq 0.06\%$ and $v \leq 0.3$ (Henkhaus et al., 2009).



Simultaneous shear-axial failure
2-parameter classification criterion

Limits to consider a column "safe": $v_l \leq 1.65$ and $\rho_w / (s/d) \geq 0.1\%$



Summary

- Development of a beam-column macro-model , predicting post-peak response of (flexure-)shear critical specimens up to the onset of axial failure, accounting for shear failure localisation.
  Verifications show good agreement with experimental results.

- Observations regarding simultaneous shear-axial failure were tested and shown not to provide a reliable criterion.
  A 2-parameter criterion for the classification of a column as “safe” from this type of failure or “not safe” is proposed.

Future Work

- Extension of the model beyond the onset of axial failure, so as to capture the inelastic axial response of a column and the redistribution of vertical loads to neighbouring columns.

- More experiments with specimens near the “limits” of the 2-parameter criterion, in order to further refine or reinforce the proposed criterion.

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Thank you very much for your attention!

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