Influence of Modelling Parameters on the Fragility Assessment of pre-1970's Italian RC Structures

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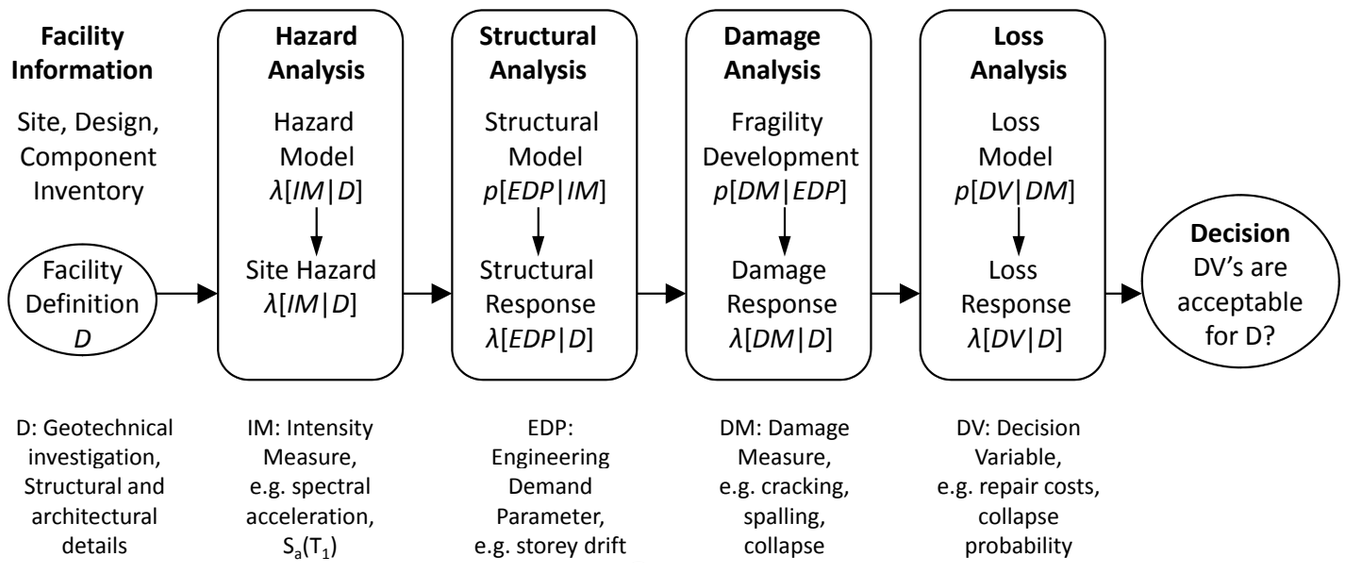
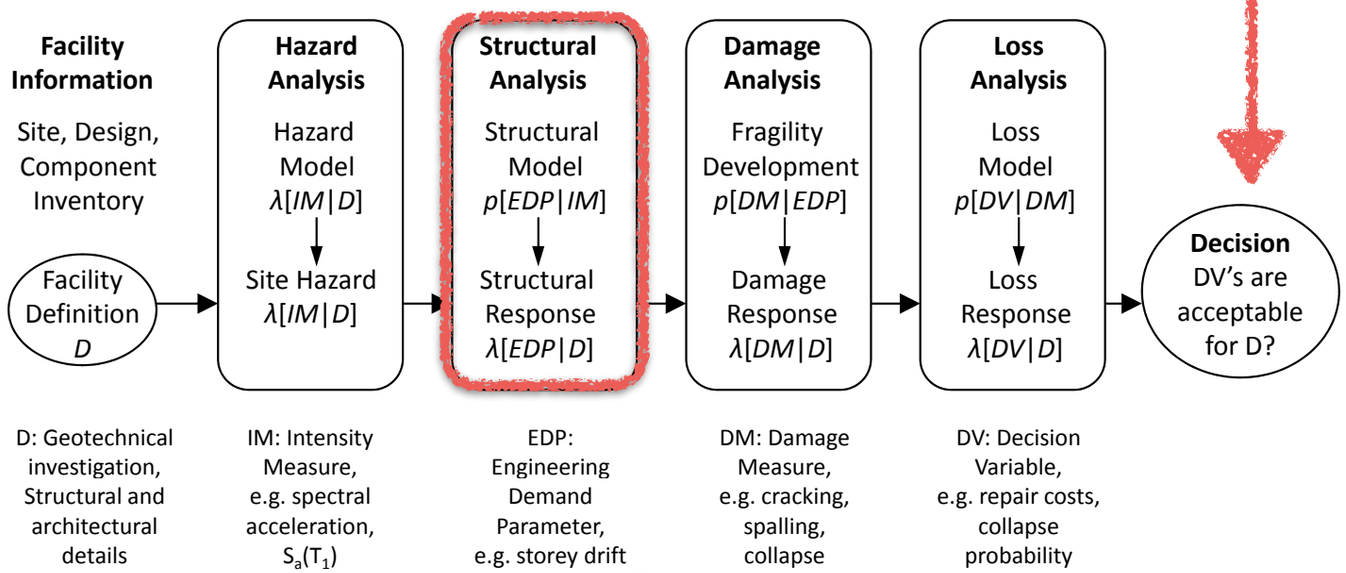
Seismic Assessment of Structures

- PEER performance-based earthquake engineering method is a 4 step convolution of:
  - Hazard Analysis
  - Structural Analysis
  - Damage Analysis
  - Loss Analysis



Seismic Assessment of Structures

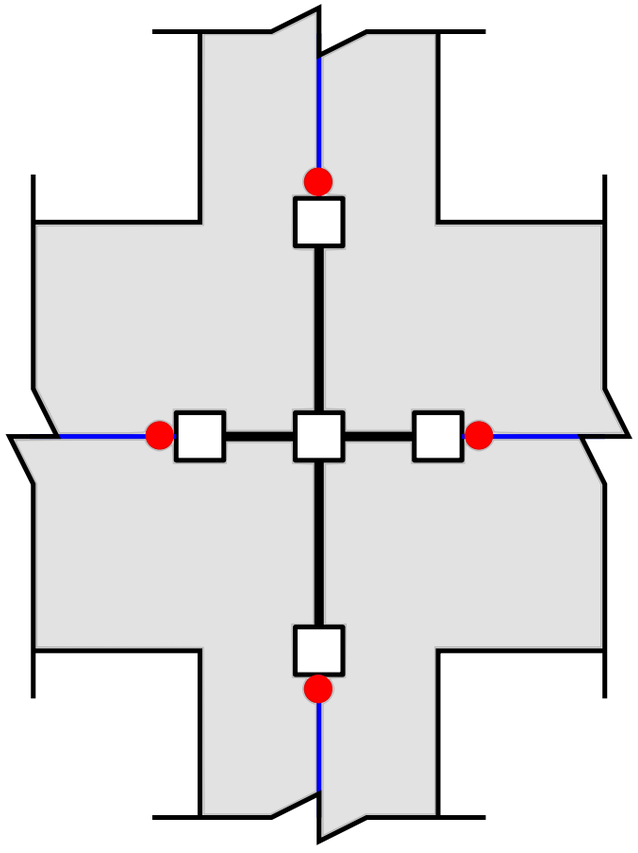
- PEER performance-based earthquake engineering method is a 4 step convolution of:
  - Hazard Analysis
  - Structural Analysis → How do different considerations effect the decision?
  - Damage Analysis
  - Loss Analysis



Relevance of Modelling Decisions in Assessment of RC Structures

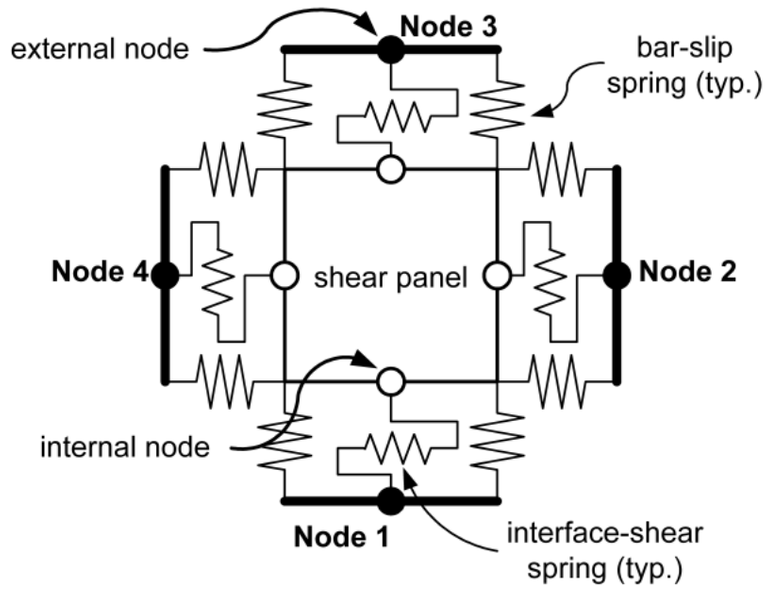
- The modelling of joints as either rigid zones or no consideration at all is now recognised as being grossly inadequate in numerical analysis of structures.

- Paulay & Priestley [1992] reported that joint deformation alone can account for as much as 20% of the inter storey deflection in a structure.



Relevance of Modelling Decisions in Assessment of RC Structures

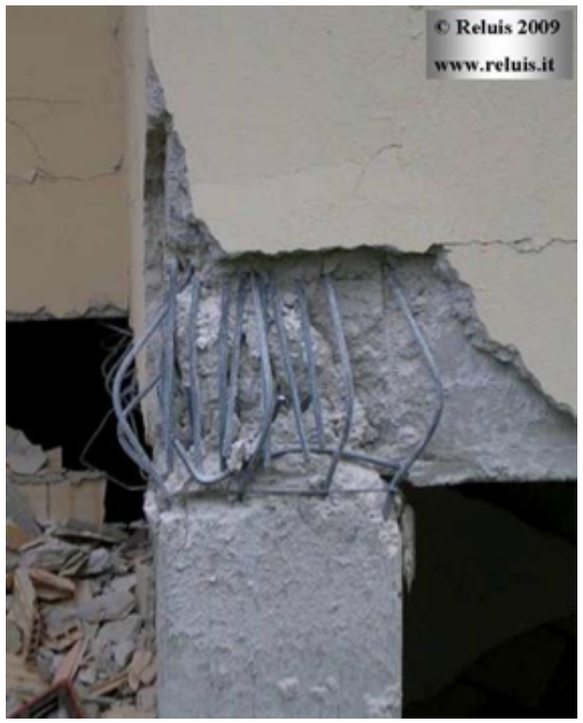
- Models such as Lowes et al. [2003] can be used to consider a joint that is well detailed according to modern design codes.



- Pampanin et al. [2002] noted how RC structures constructed in Italy prior to seismic codes resulted in a lack of shear reinforcement and hence a shear failure mechanism.

Pampanin et al. [2002]

Relevance of Modelling Decisions in Assessment of RC Structures



[Photos from www.reluis.it]

- Past observations of damage in Italy have shown extensive damage to beam column joints due to a lack of shear reinforcement.

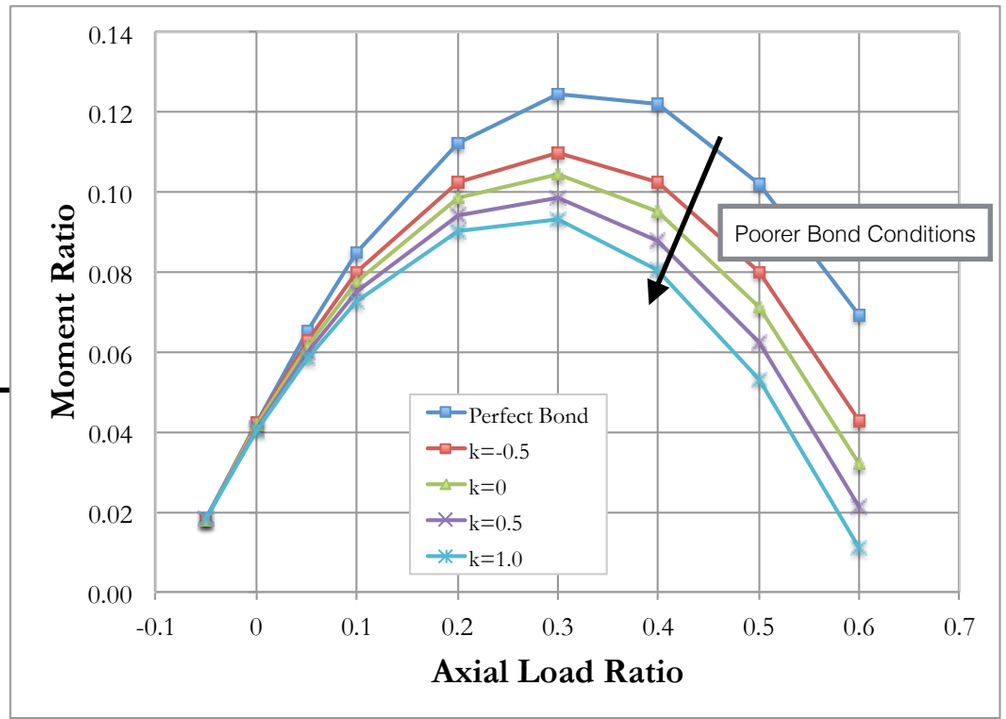
Relevance of Modelling Decisions in Assessment of RC Structures

- Experimental testing of beam-column members with plain bars and poor concrete demonstrates a pinched hysteretic behaviour.

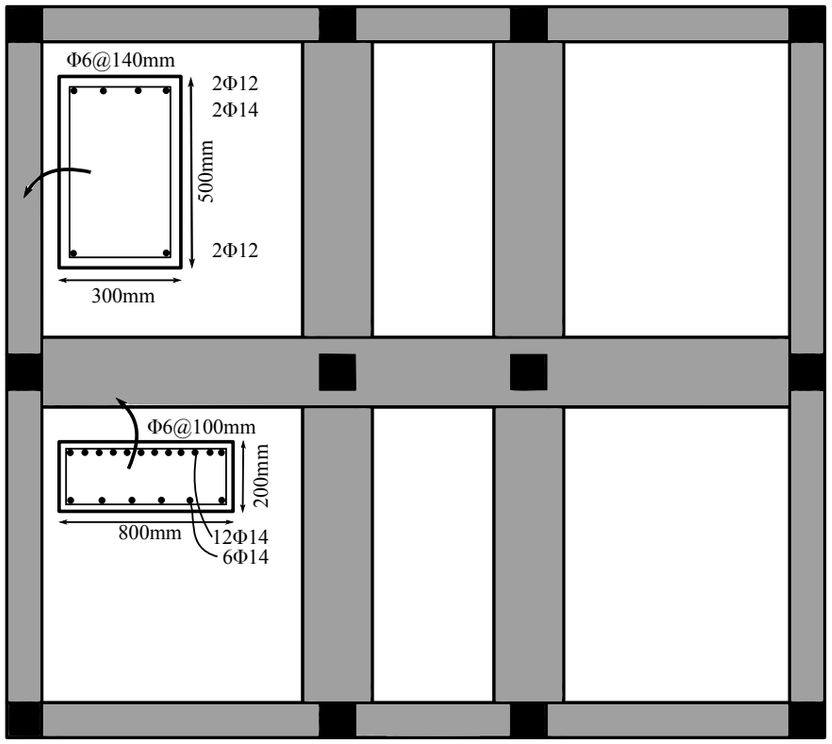
- In addition, the ductility capacity is significantly influenced by the presence of plain bars.

Testing by Di Ludovico et al. showed plain bar members had ~40% more ductility capacity.

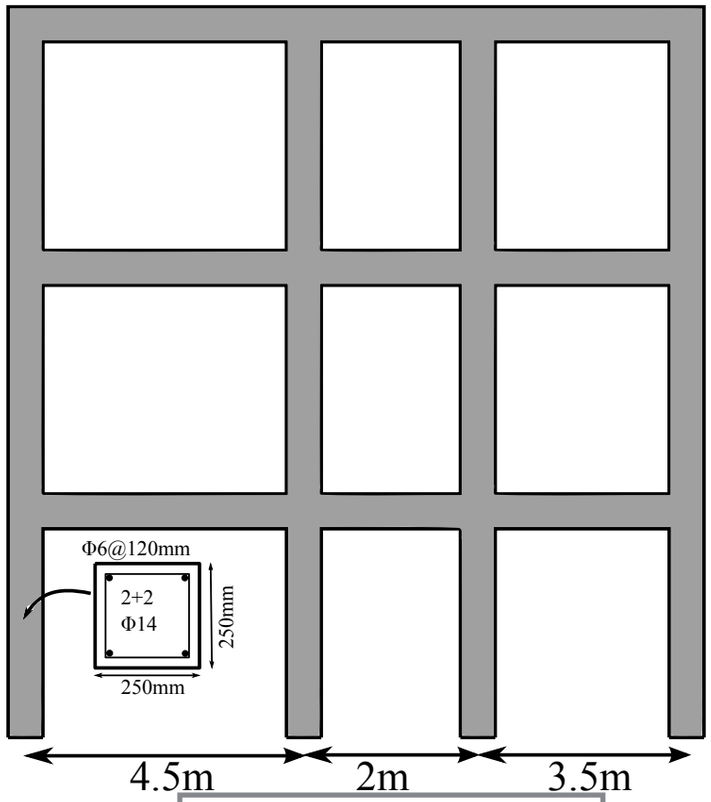
- Calvi et al. [2002] have noted that the presence of smooth bars can result in a reduction is flexural capacity of members.



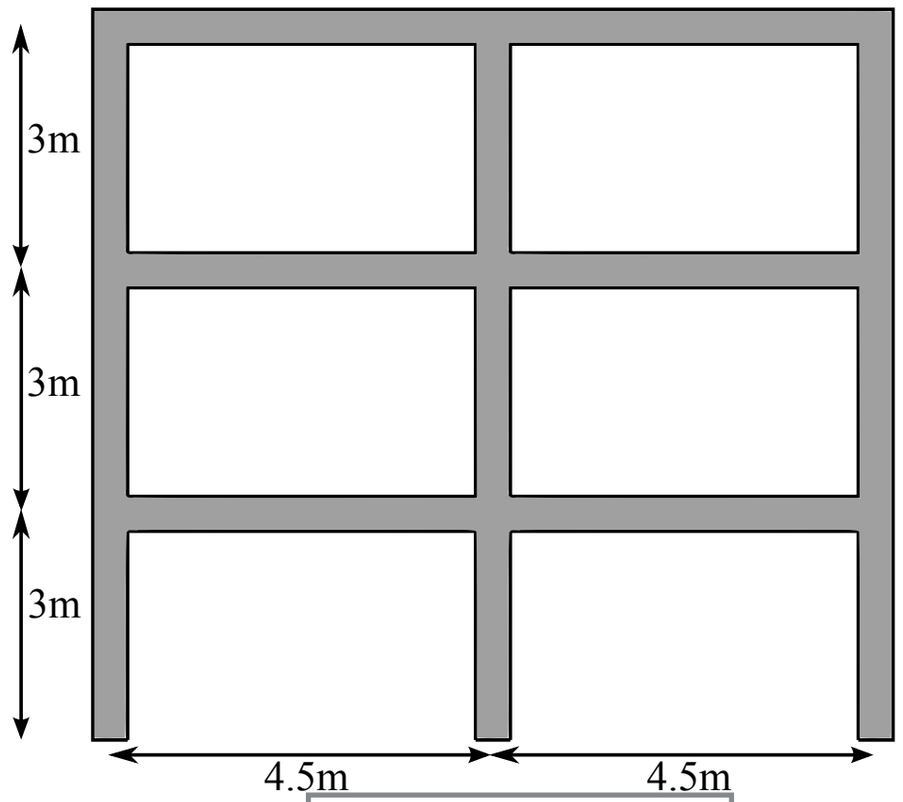
Case Study Structure



Plan View



Front View

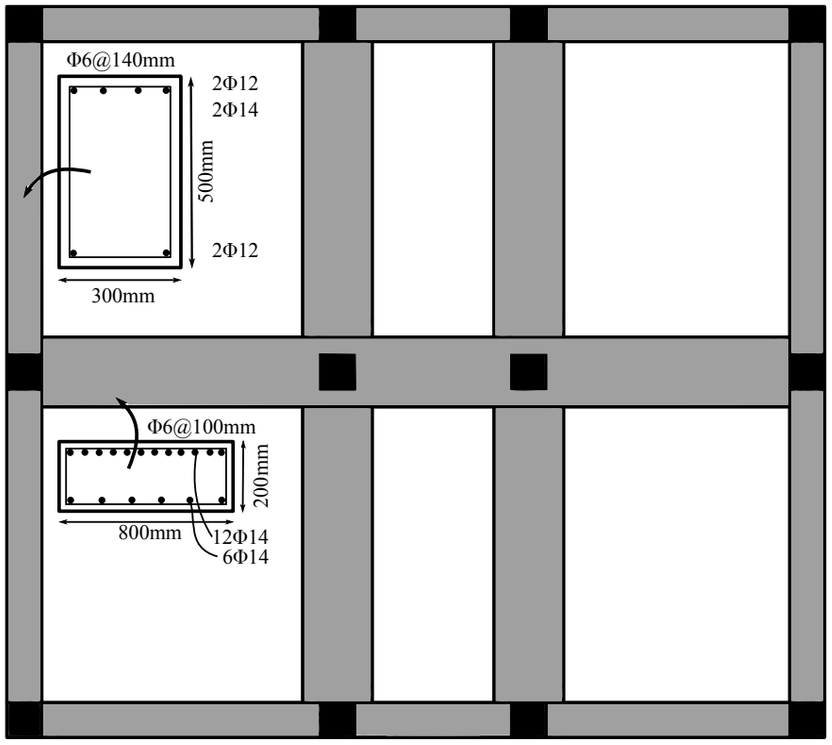


Side View

- RC frame designed according to Regio Decreto 2229/39.
- Full design outlined in Piazza [2013].

- f_c'=12MPa @ 28 days.
- Plain bars with hook-ends.
- Stirrups closed at 90° with large spacing.
- Beam and column sections same at all floors.
- 100mm thick weak clay infill.

Modelling?



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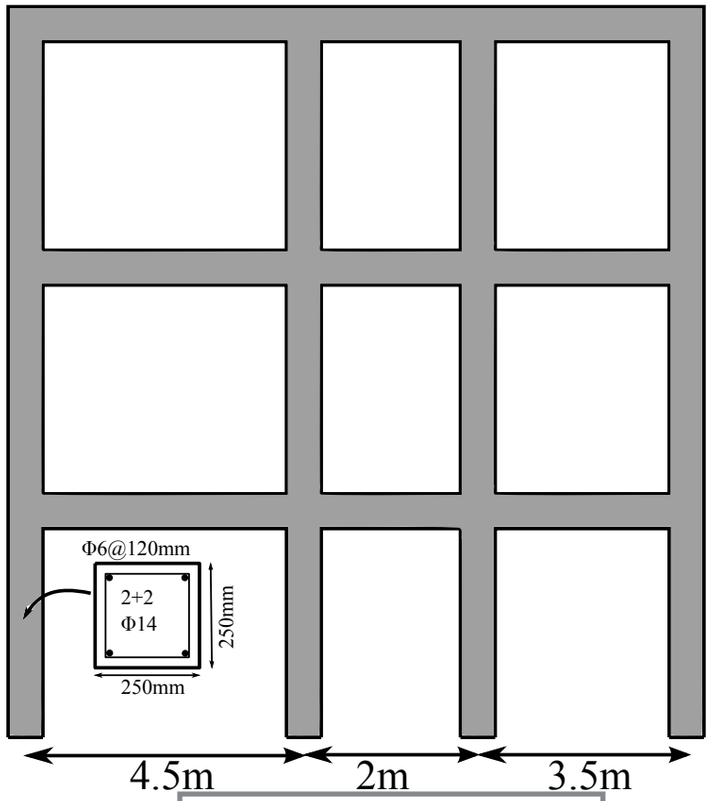
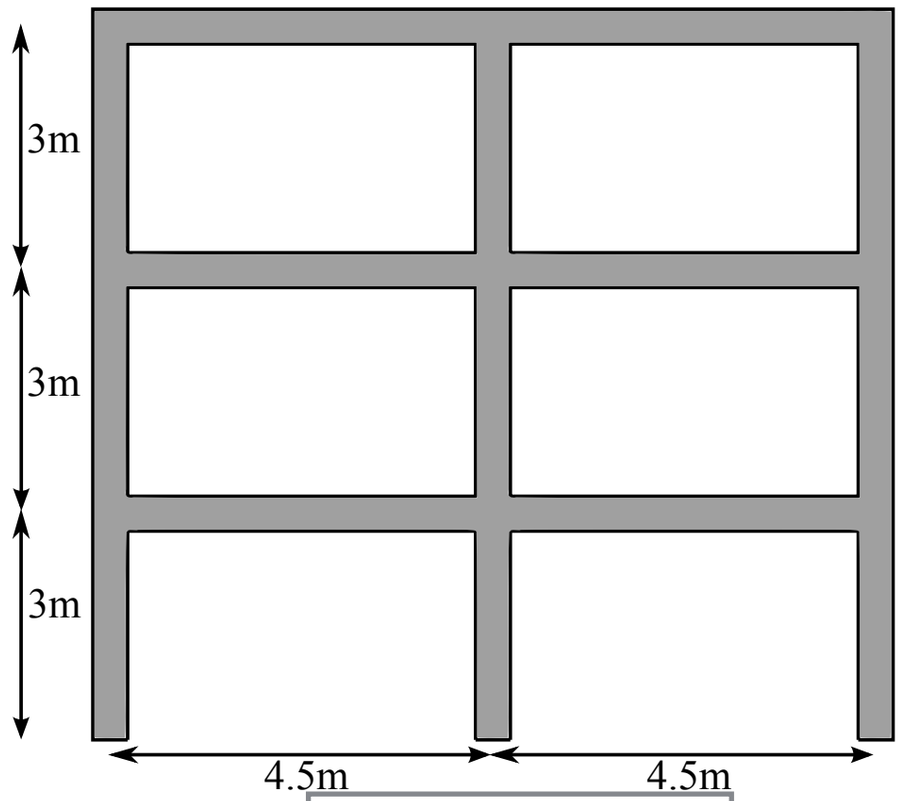


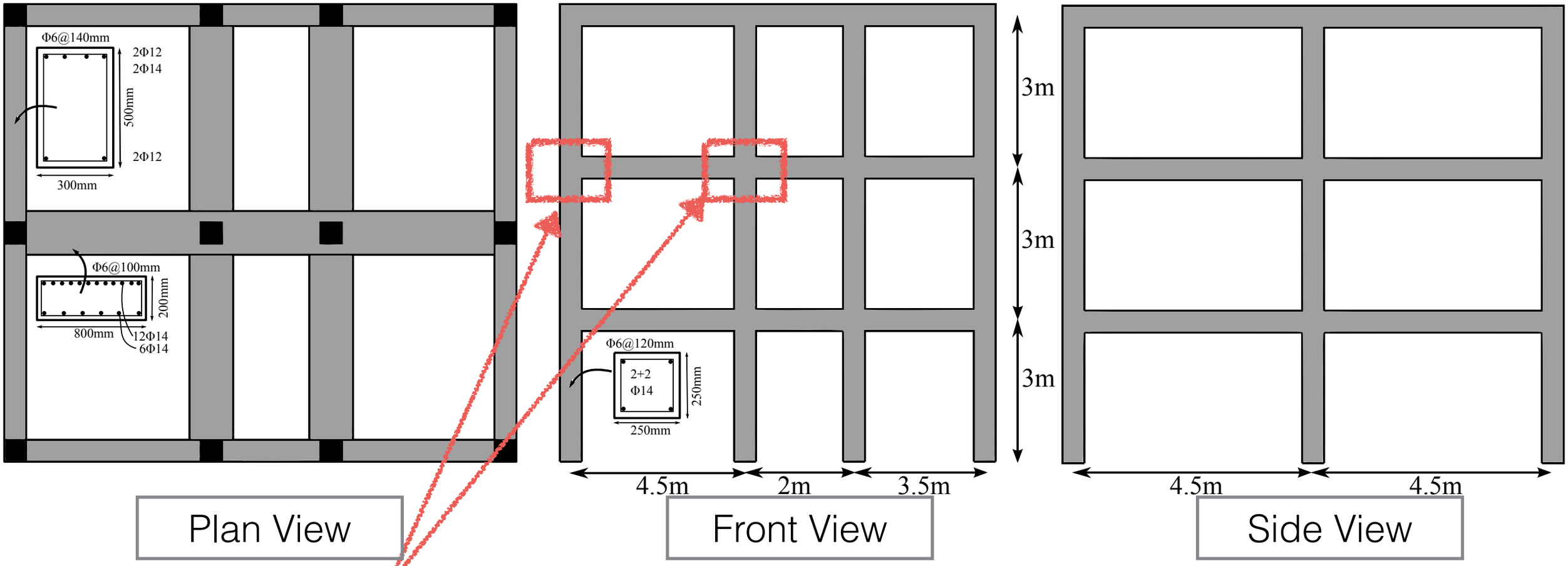
Front View



Side View

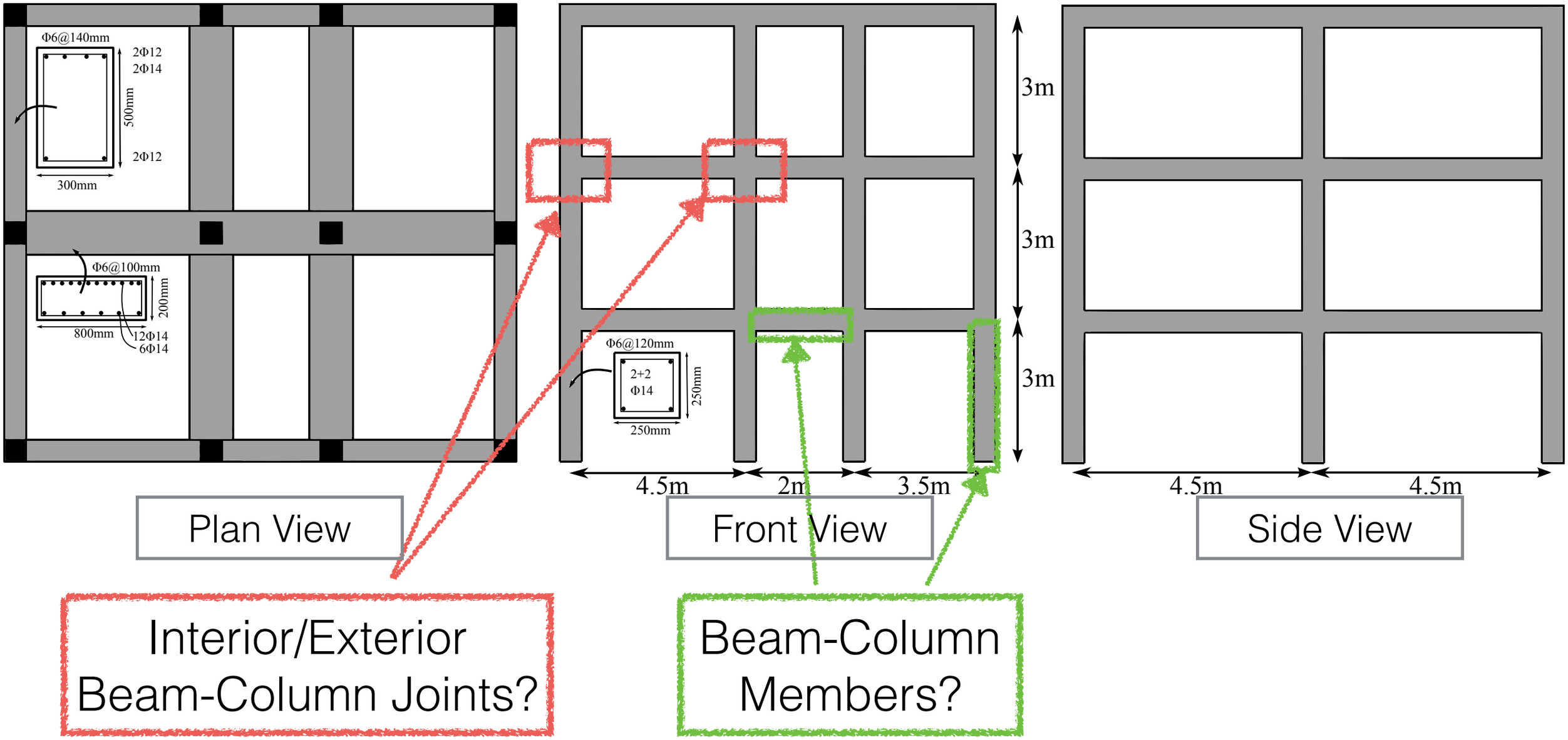
- How are the various components associated with older buildings in Italy modelled?

Modelling?

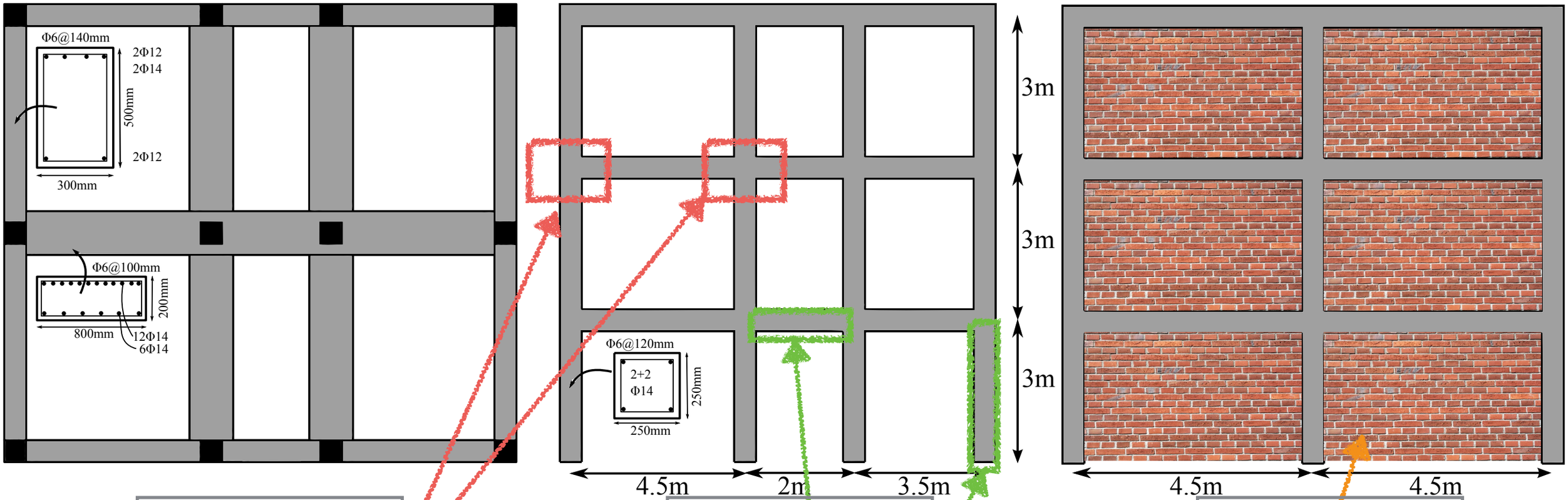


Interior/Exterior
Beam-Column Joints?

Modelling?


Φ6@140mm
2Φ12
2Φ14
500mm
2Φ12
300mm
Φ6@100mm
200mm
800mm
12Φ14
6Φ14
Φ6@120mm
2+2
Φ14
250mm
250mm
3m
3m
3m
4.5m
2m
3.5m
4.5m
4.5m
Plan View
Front View
Side View
Interior/Exterior
Beam-Column Joints?
Beam-Column
Members?

Modelling?



Plan View

Front View

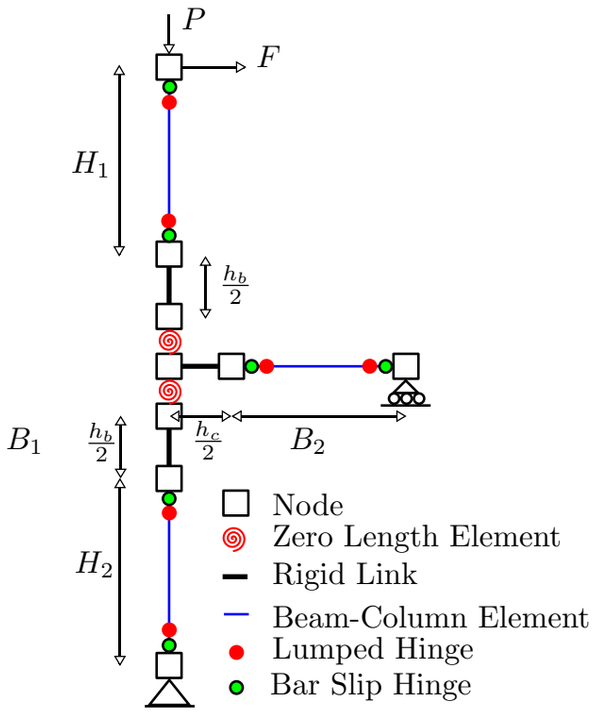
Side View

Interior/Exterior Beam-Column Joints?

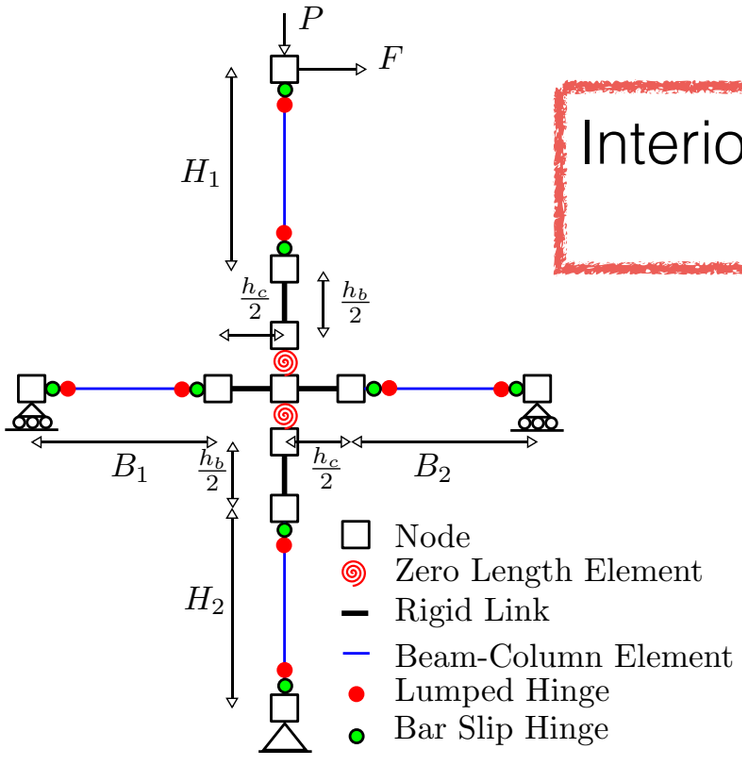
Beam-Column Members?

Infills?

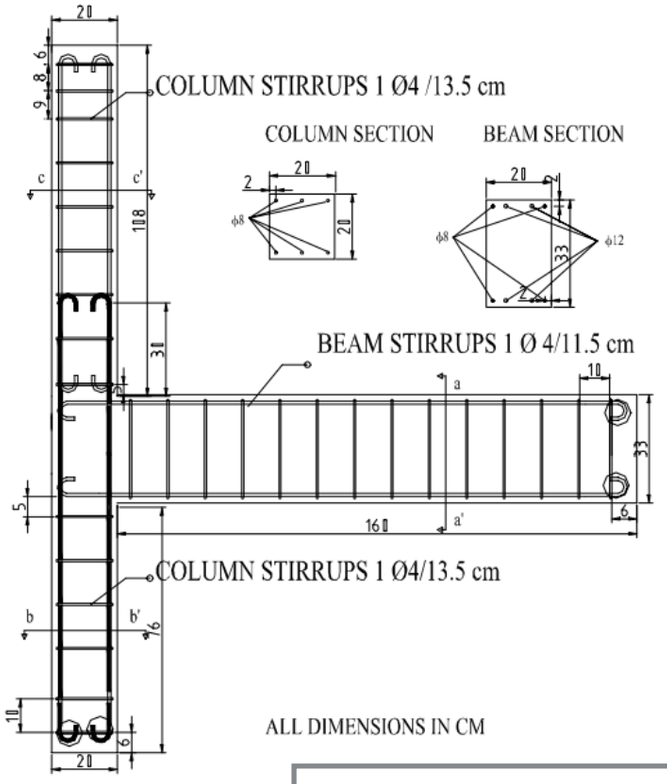
Beam-Column Joints



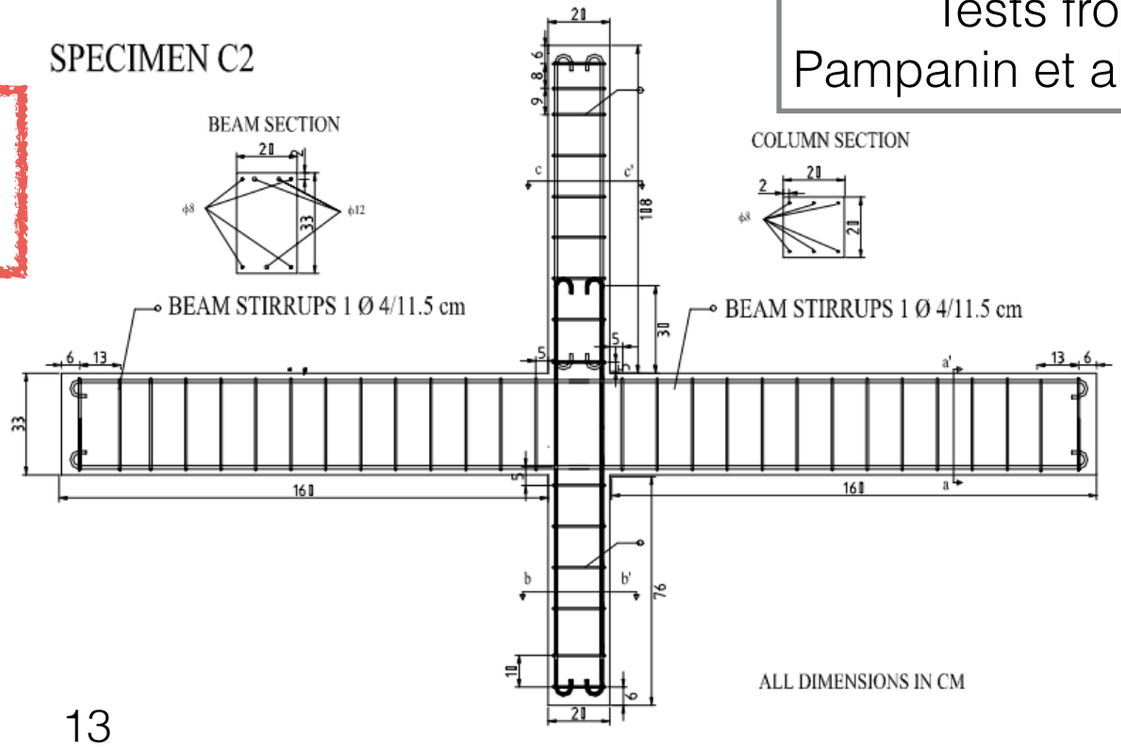
Exterior Beam-Column Joints



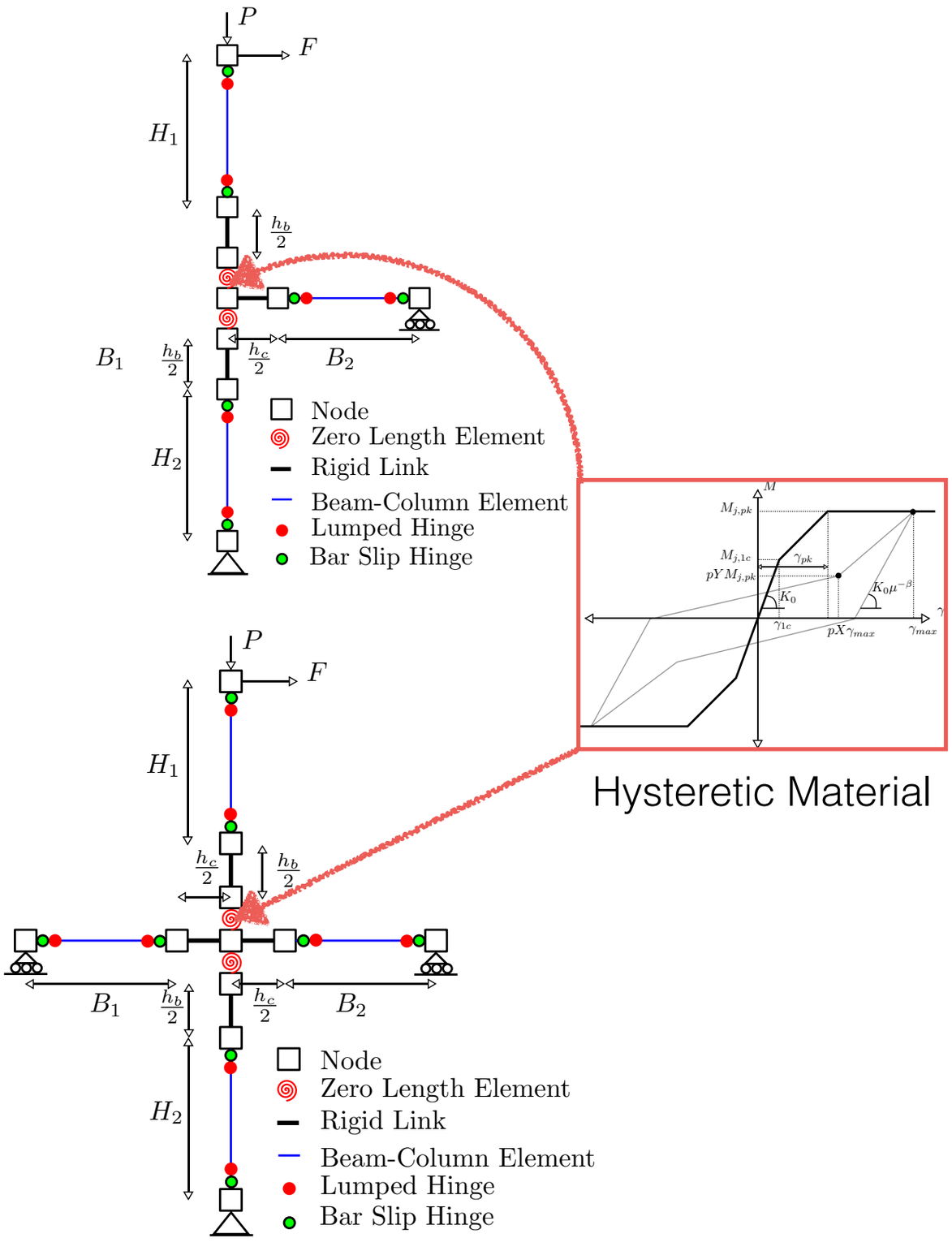
Interior Beam-Column Joints



Tests from Pampanin et al. [2002]



Beam-Column Joints

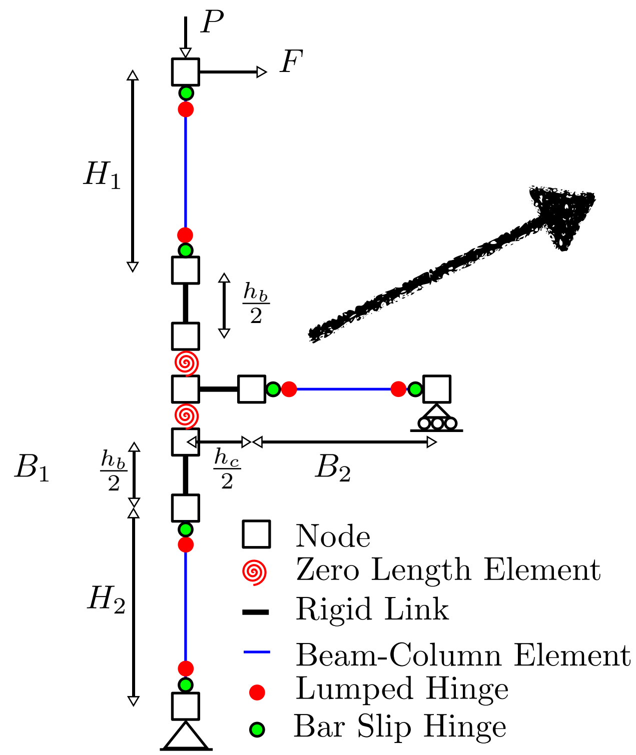


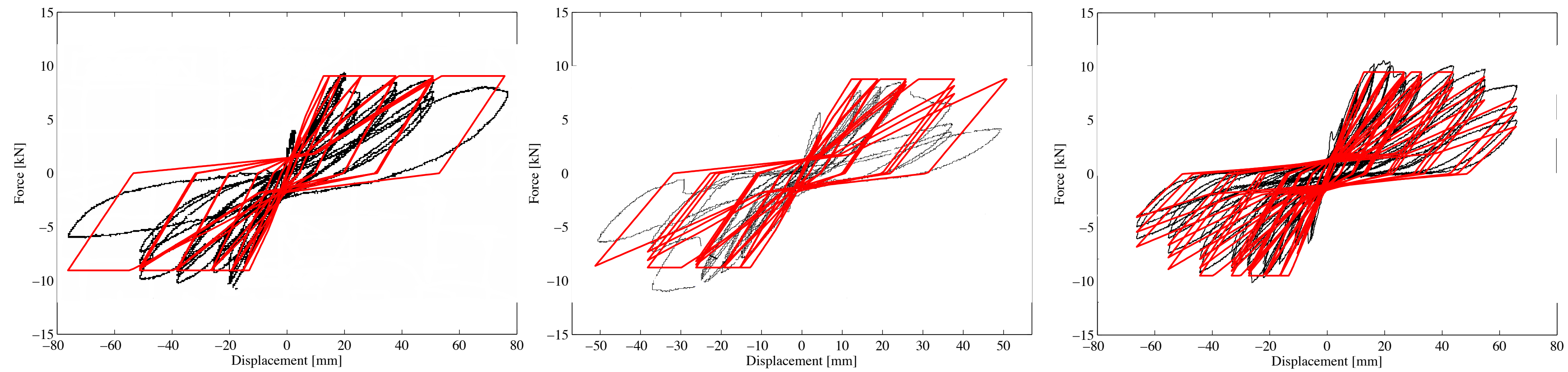
- Model developed using OpenSees and is based on previous modelling approach by Pampanin et al. [2002].

- Shear hinge parameters calibrated considering principle tensile stress observed in test data for both exterior (18 tests) and interior joints (9 tests).

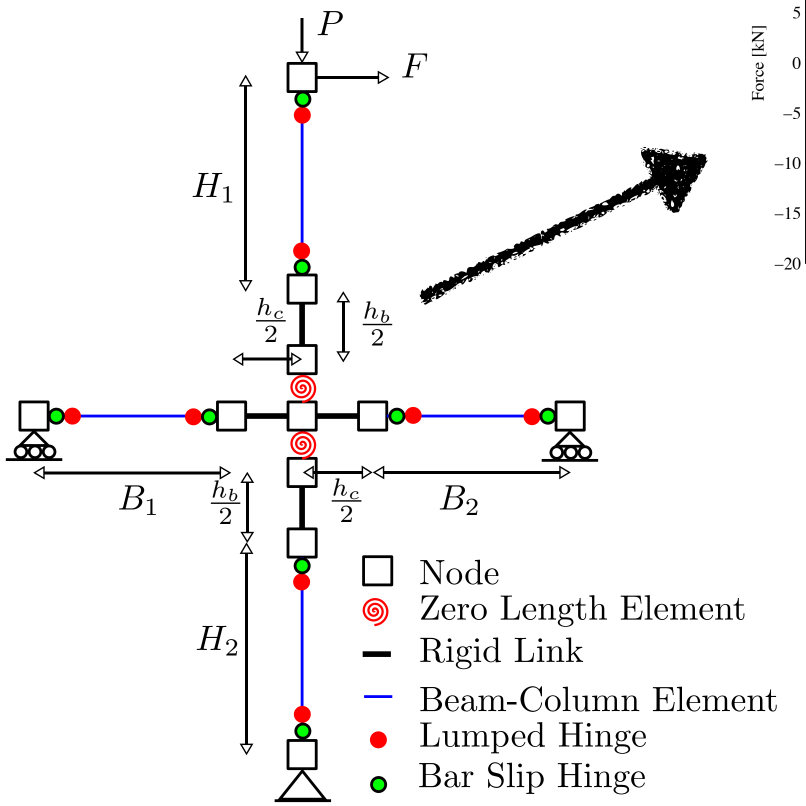
- Cyclic degradation parameters matched with experimental data.

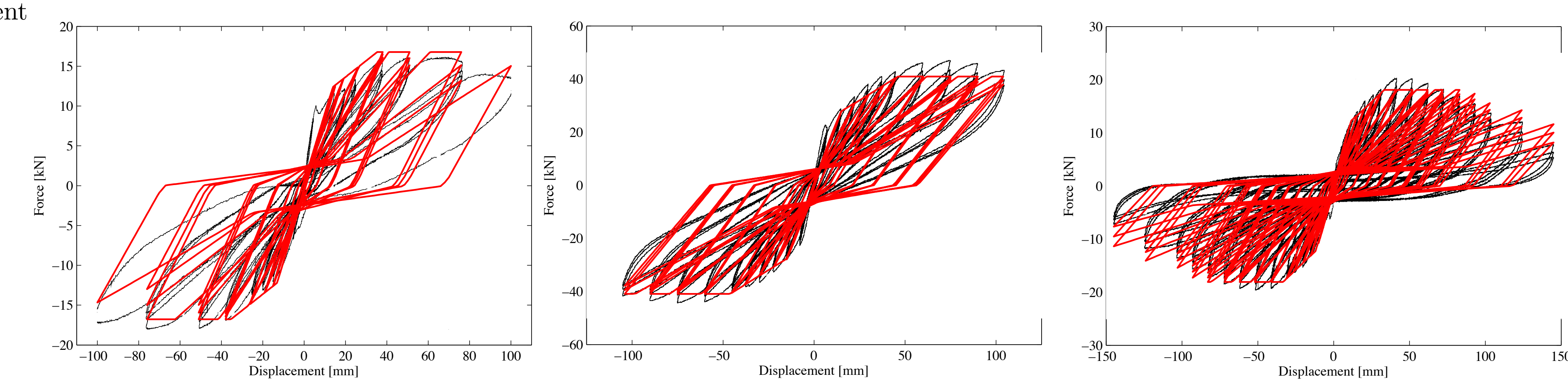
Beam-Column Joints





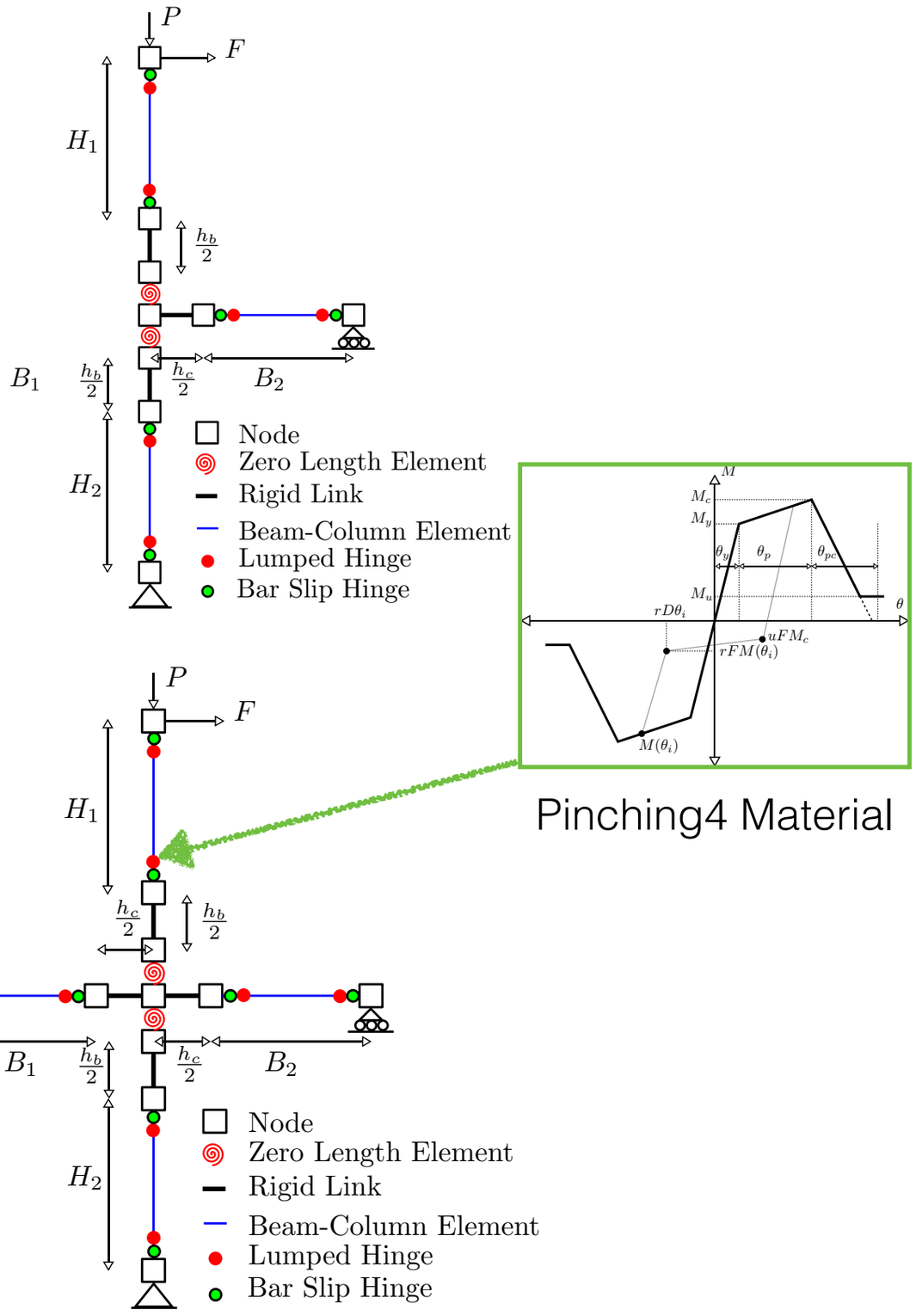
Experiment | Model





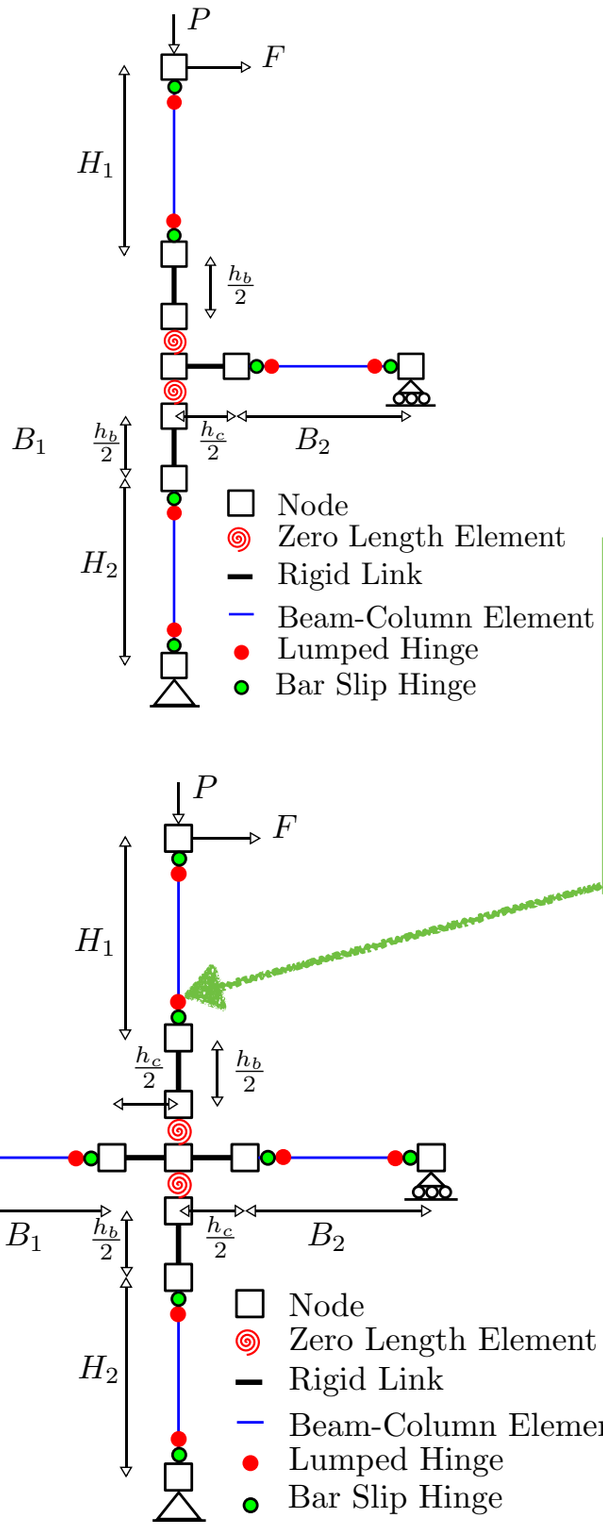
- Calibrate with tests available in literature.
- Strength, stiffness and degradation well represented by joint model.

Beam-Column Members



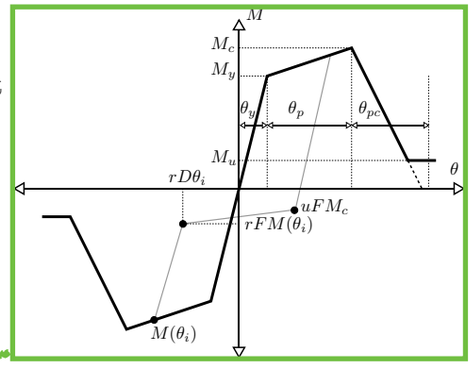
- Modelling using lumped plasticity beamWithHinges element in OpenSees.
- Hinge modelled using Pinching4 hysteretic material.
- Plastic hinge length as per Paulay & Priestley [1992].
- Bar slip hinge as per Metelli et al. [2015].

Beam-Column Members

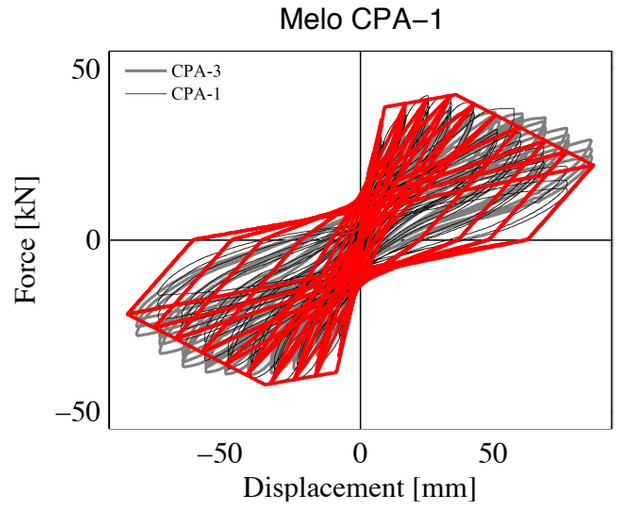


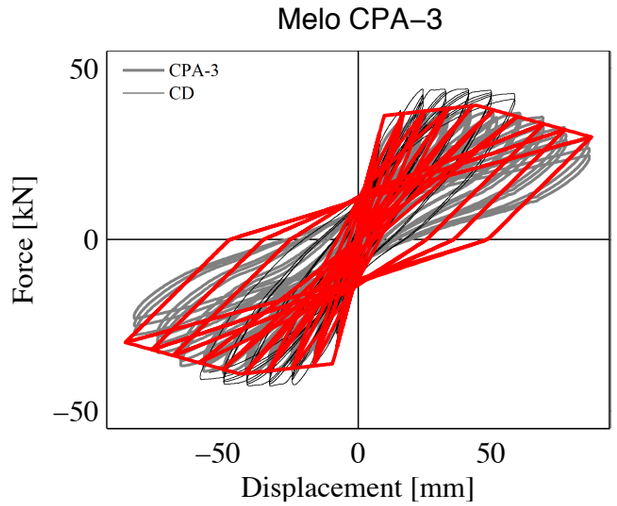
Experiment

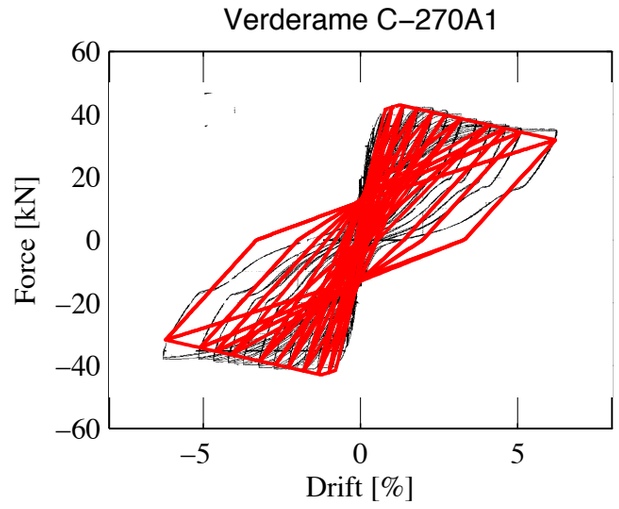
Model

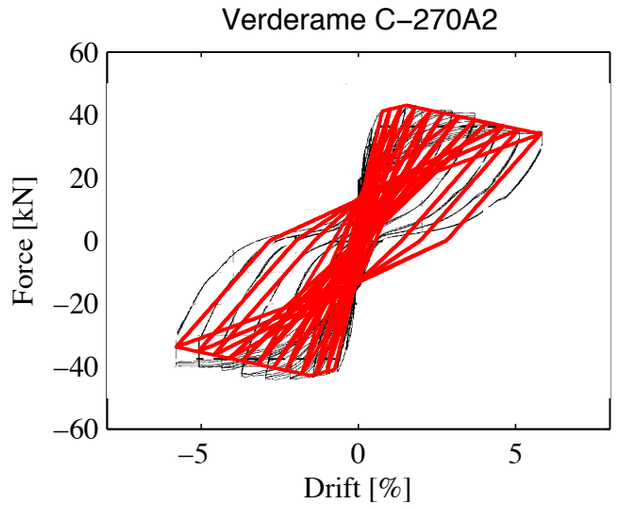


Pinching4 Material



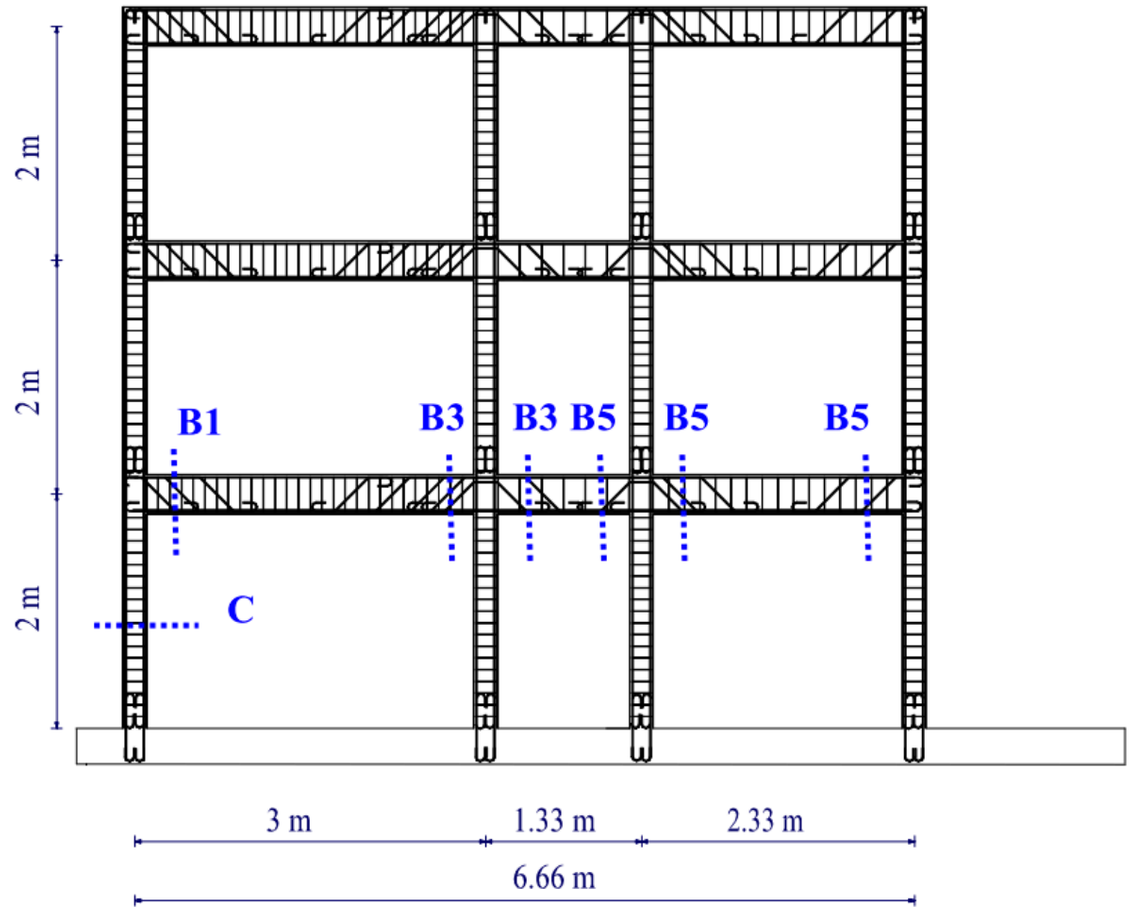






- Calibrate with available test data in literature.

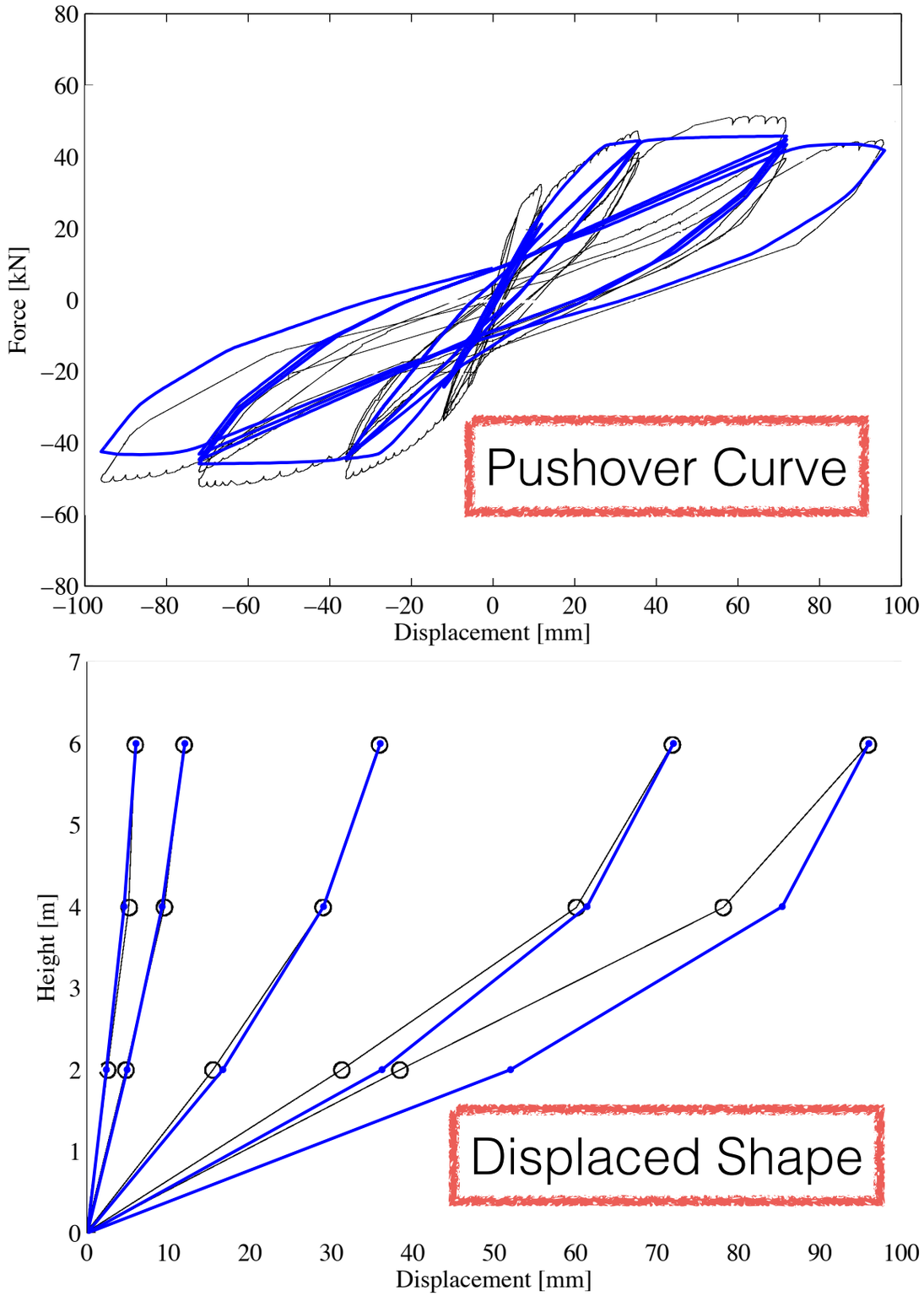
Model Validation



- 2/3 scale 3 storey RC frame tested by Calvi et al. [2002] used to validate modelling.

- Frame subject to quasi-static pushover cycles of increasing

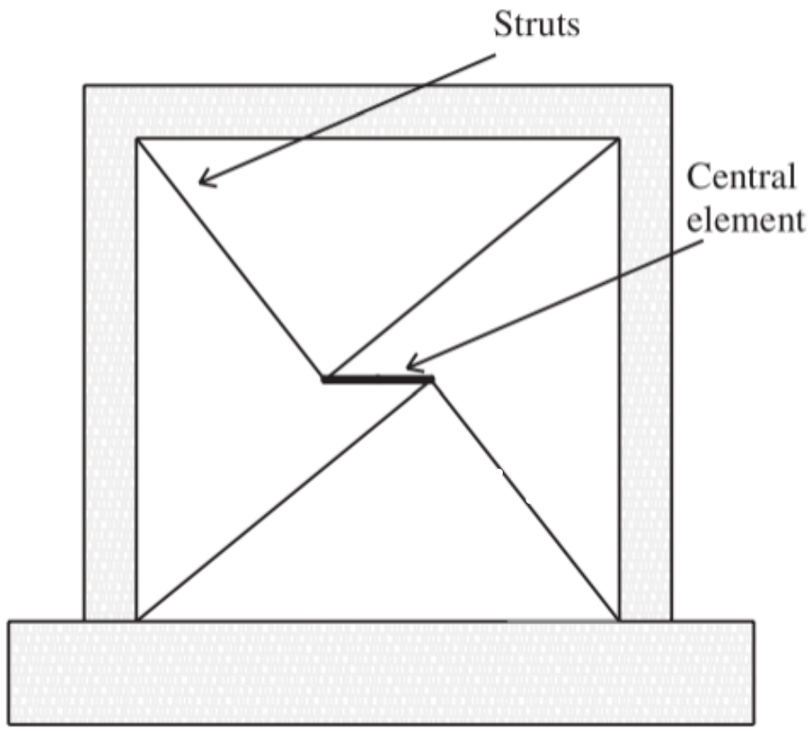
Model Validation

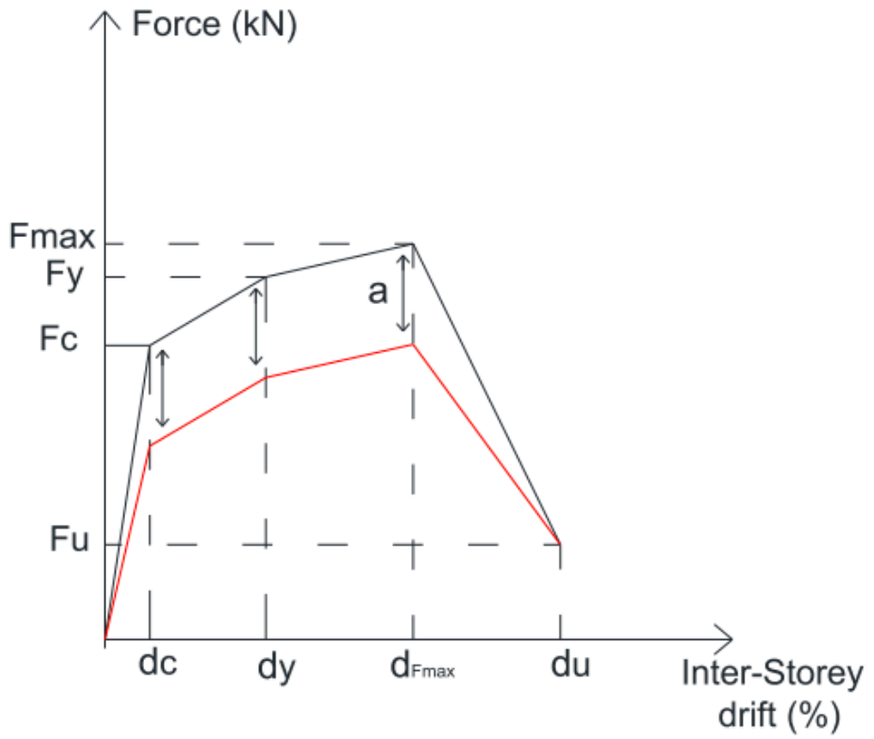


Model | Experiment

- Numerical model matches the observed response very well.
- Seen through the match in lateral capacity, stiffness and hysteretic behaviour.
- Displaced shape matched very well also, where the shear mechanism in the joints at the first floor is captured.

Infill Modelling



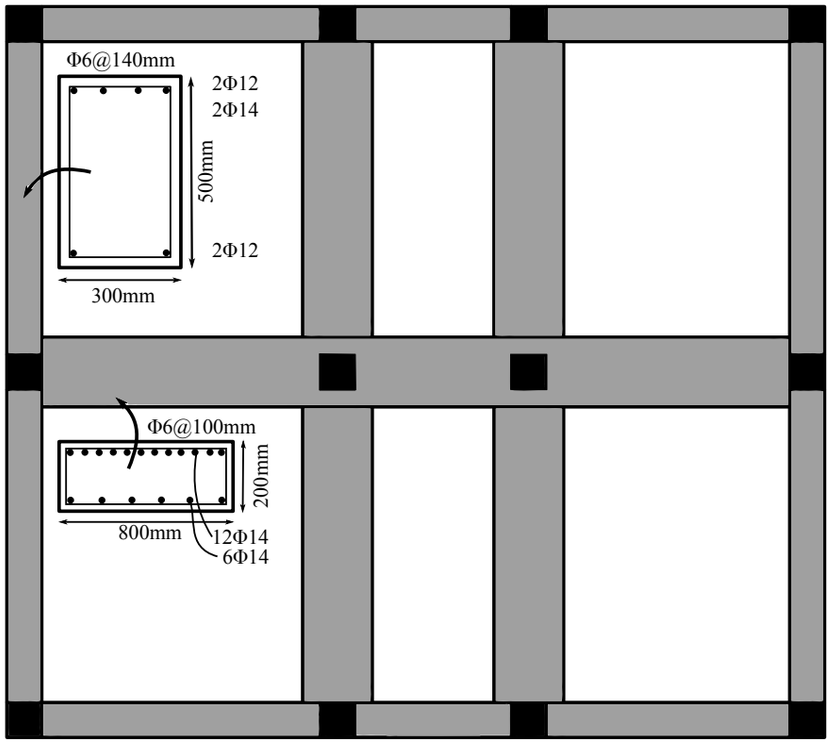


- Model is based on equivalent strut model proposed by Rodrigues et al. [2010].

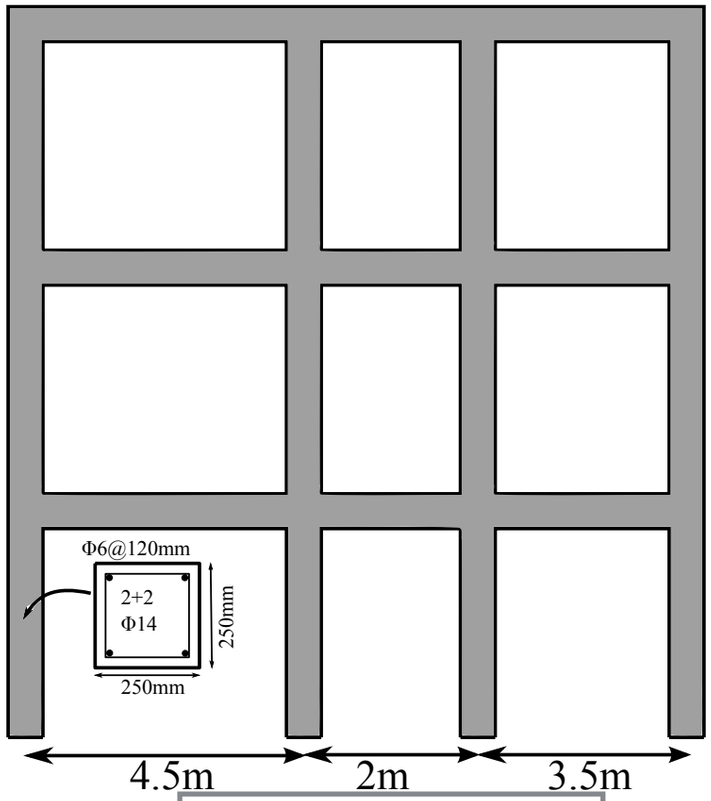
- Hysteretic parameters determined from expression proposed by Dolsek & Fajfar [2008].

- Openings for doors and windows are accounted for by a reduction in

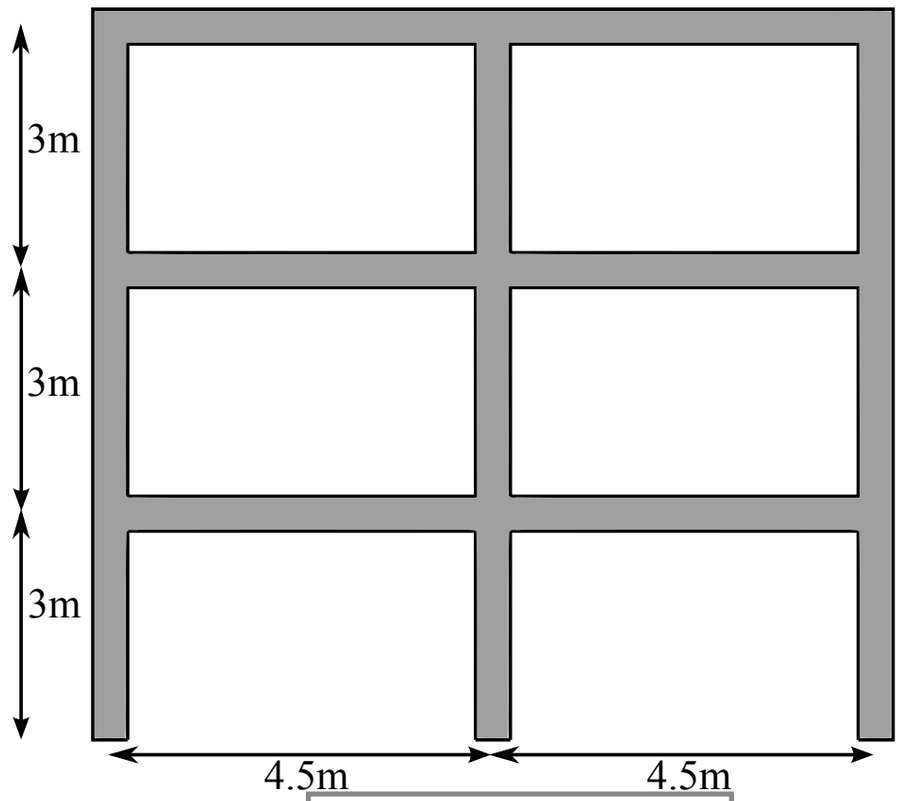
Fragility Analysis



Plan View



Front View

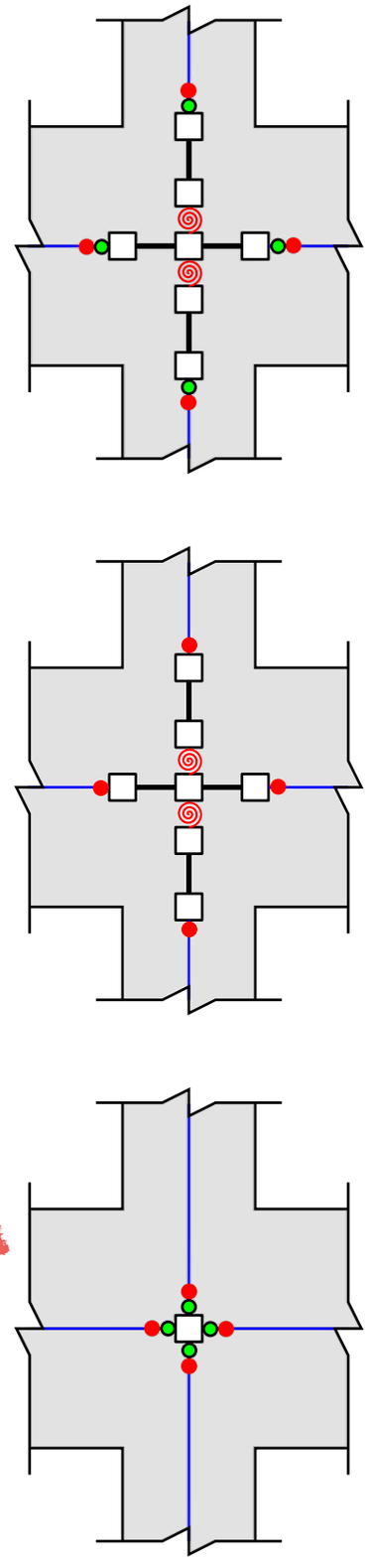


Side View

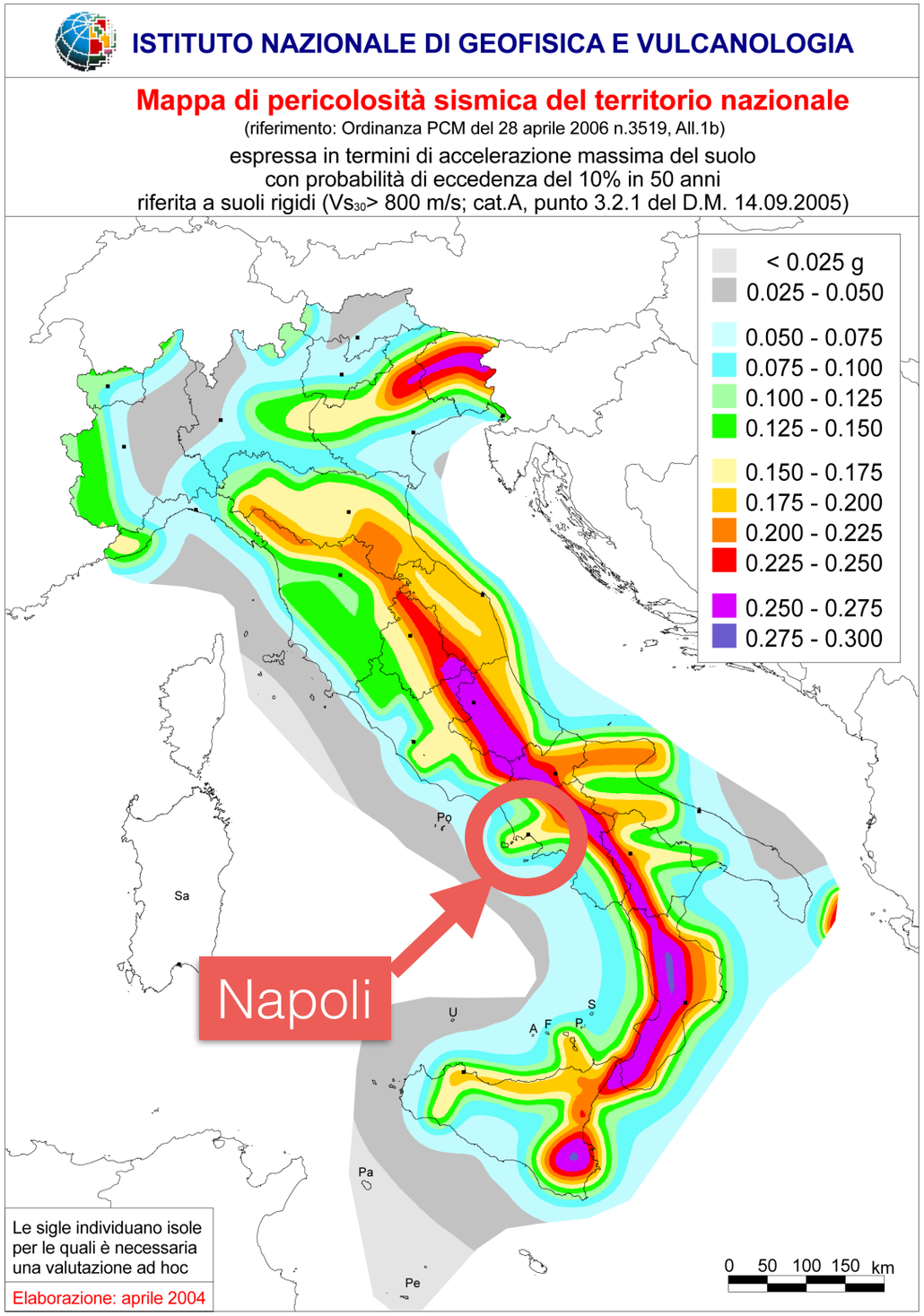
- Conduct a stripe analysis at 2 different return periods for a range of model variations to examine their affect on typical response parameters.

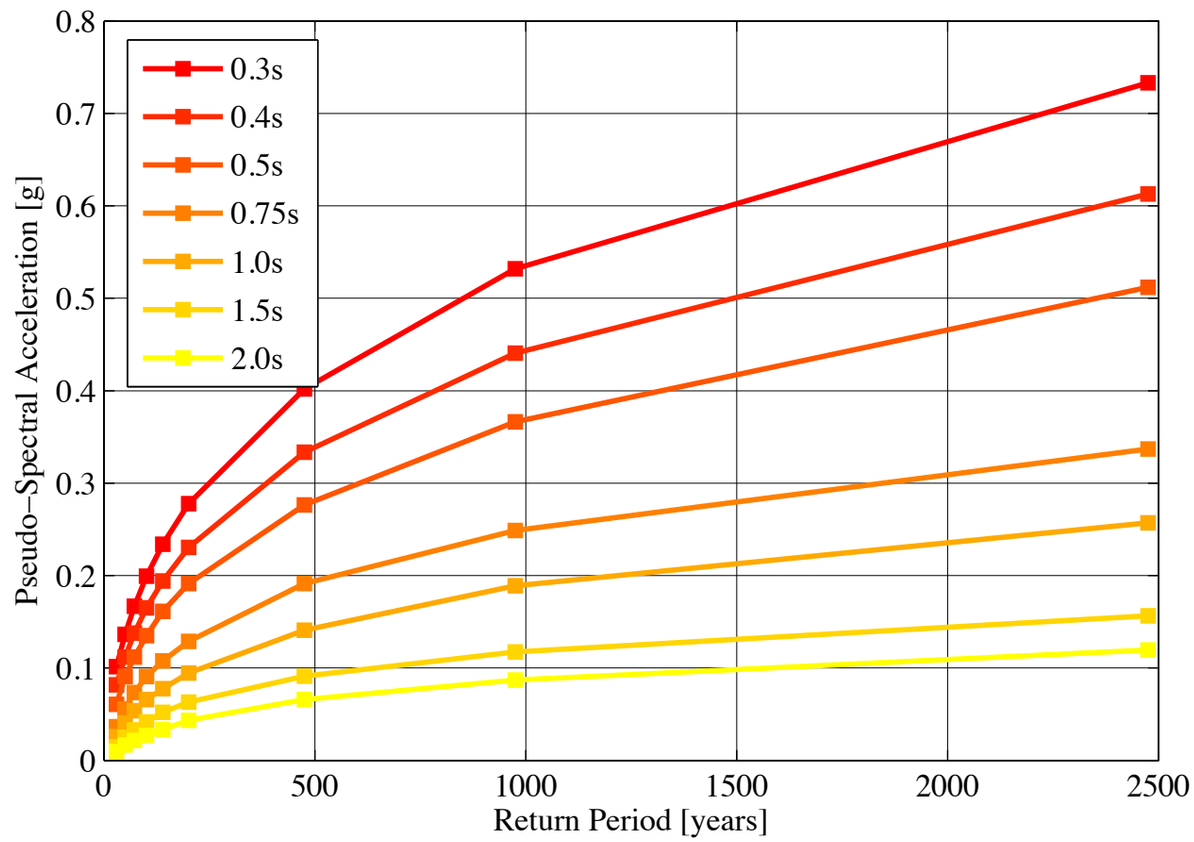
Variations in Structural Model

- **Reference Model** - Full modelled.
- **Ductile Members** - Use BC member parameters by Haselton et al. [2008] for ductile members.
- **No bar slip effects** - Bar slip elements removed and capacity of members reduced according to Calvi et al. [2002].
- **No Joint Detail** - No aspects of the joints are modelled.
- **Elastic Damping** - Damping is varied between 2, 3 and 5%.
- **Masonry Infills** - The above both with & without infill modelling.



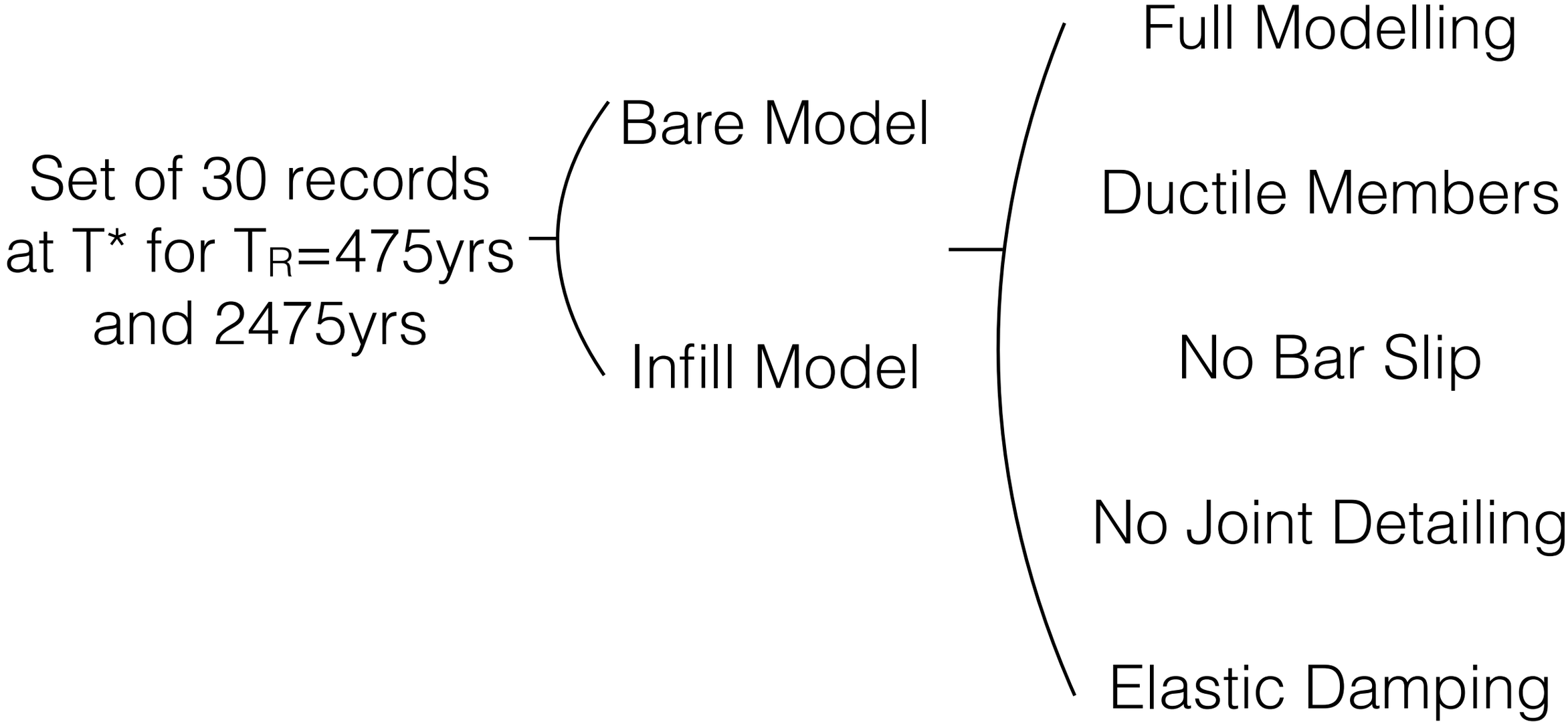
Seismic Hazard & Ground Motions





- Site considered is in Napoli, Italy.
- Conditional Mean Spectra developed by Ay et al. [2015] for sets of conditioning period (T*) and return period (T_r).
- Ground motion set selected in relation to first mode T_1 of the structure

Dynamic Analysis of Structures



Dynamic Analysis of Structures

Set of 30 records at T* for T_R=475yrs and 2475yrs

- Bare Model
- Infill Model

- Full Modelling
- Ductile Members
- No Bar Slip
- No Joint Detailing
- Elastic Damping

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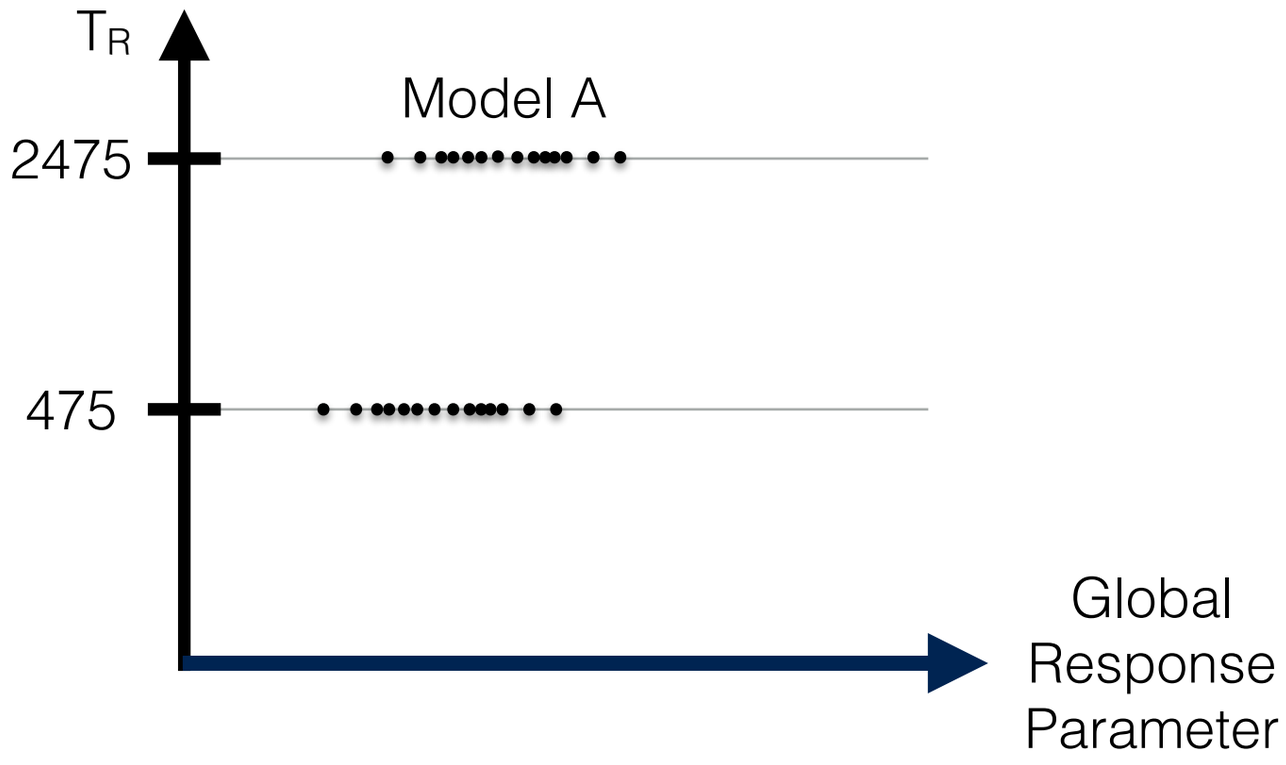

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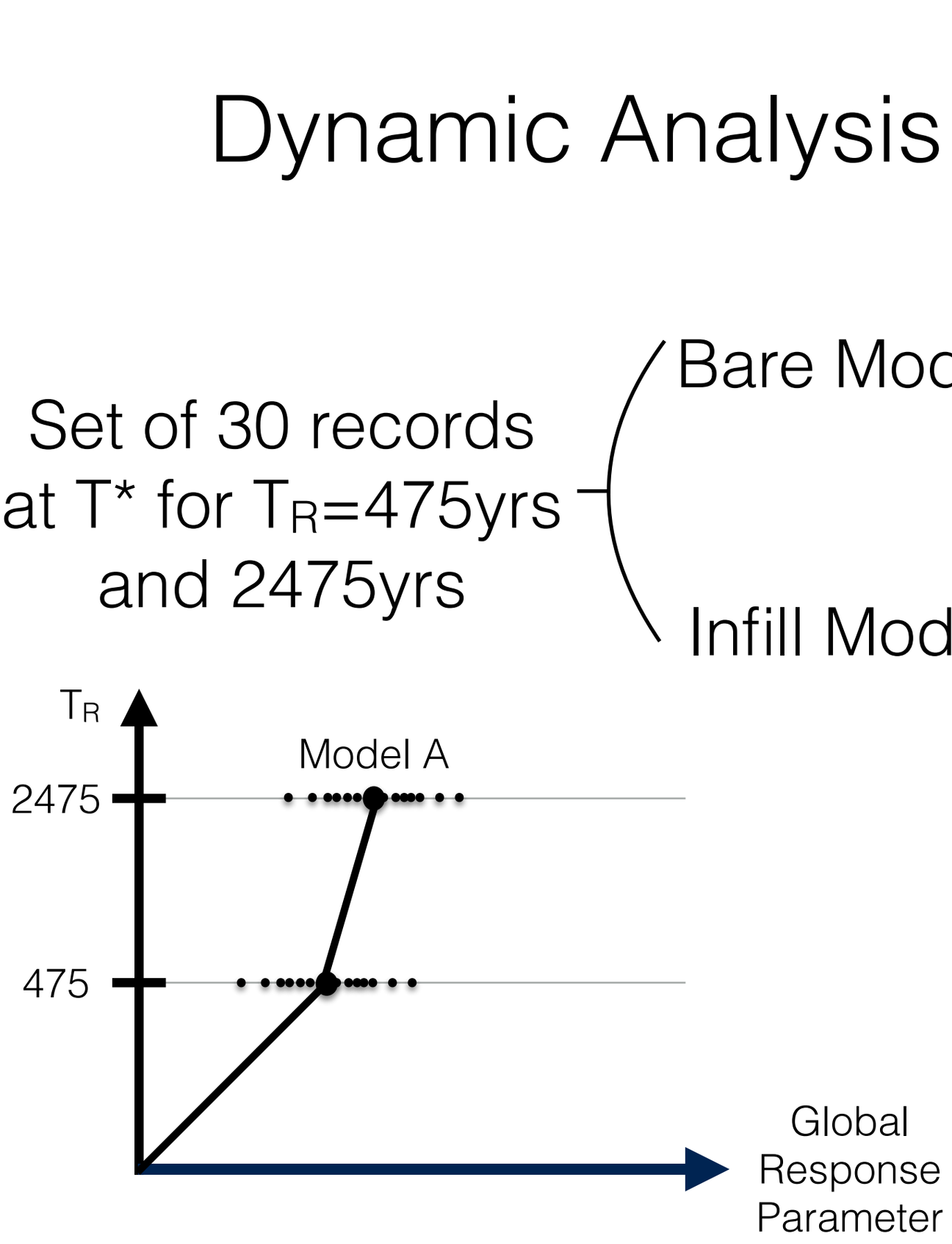

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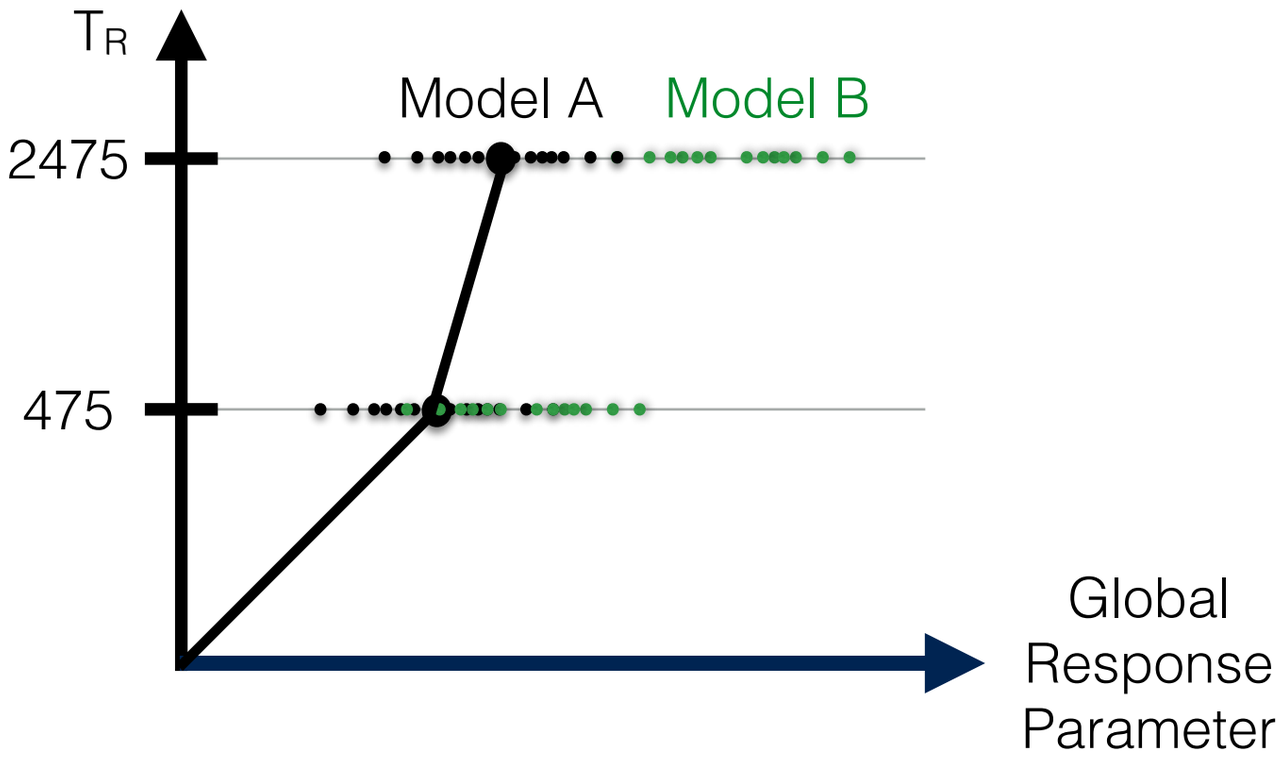

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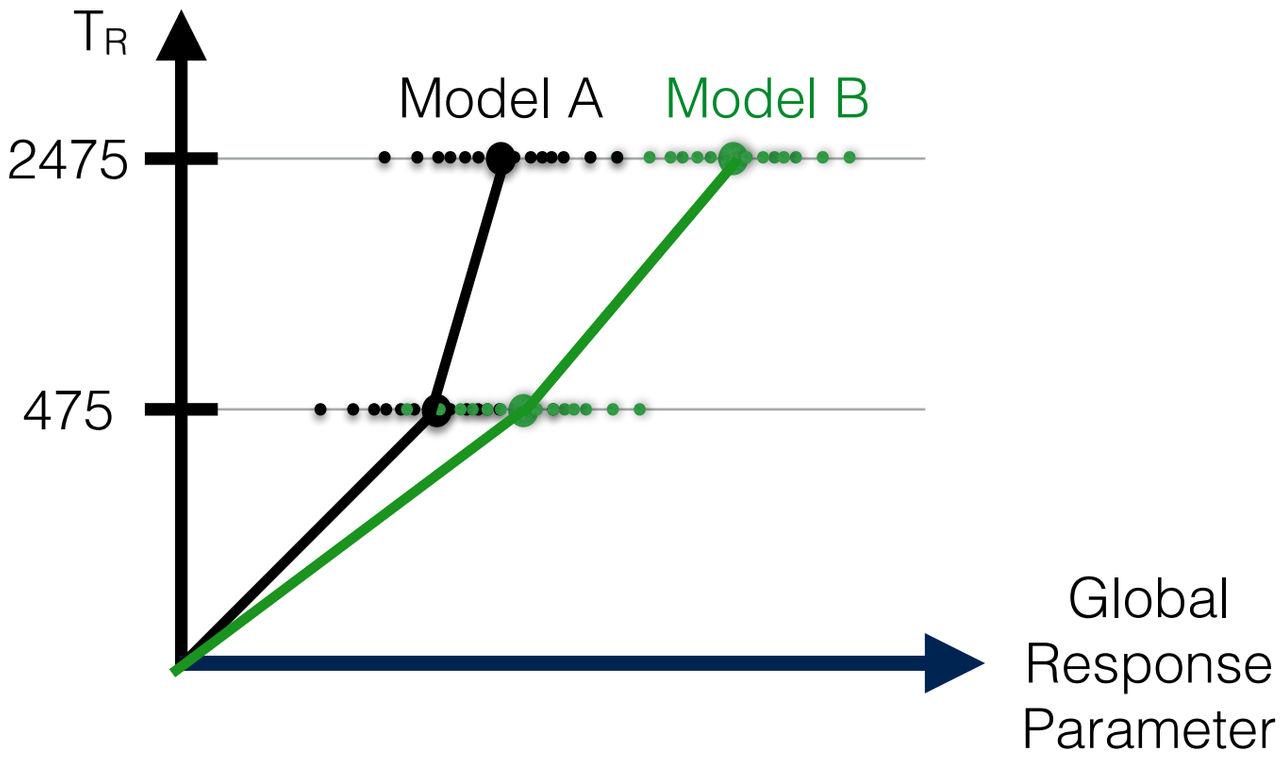
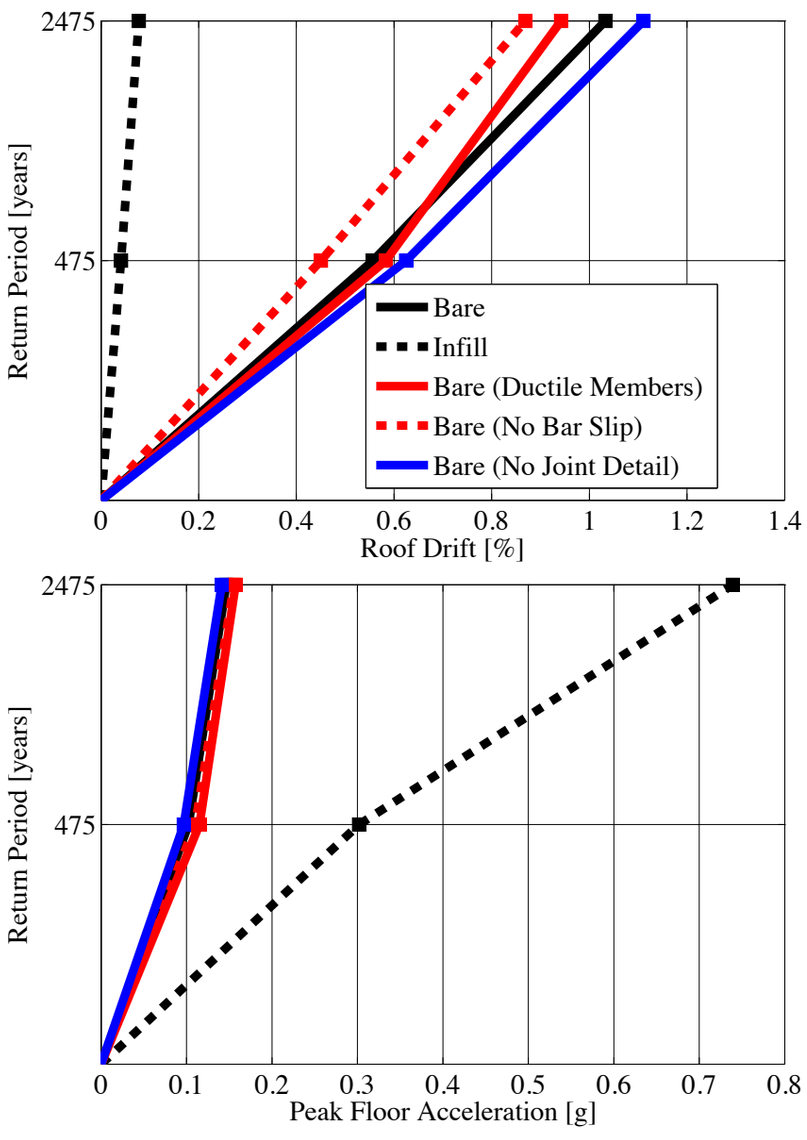
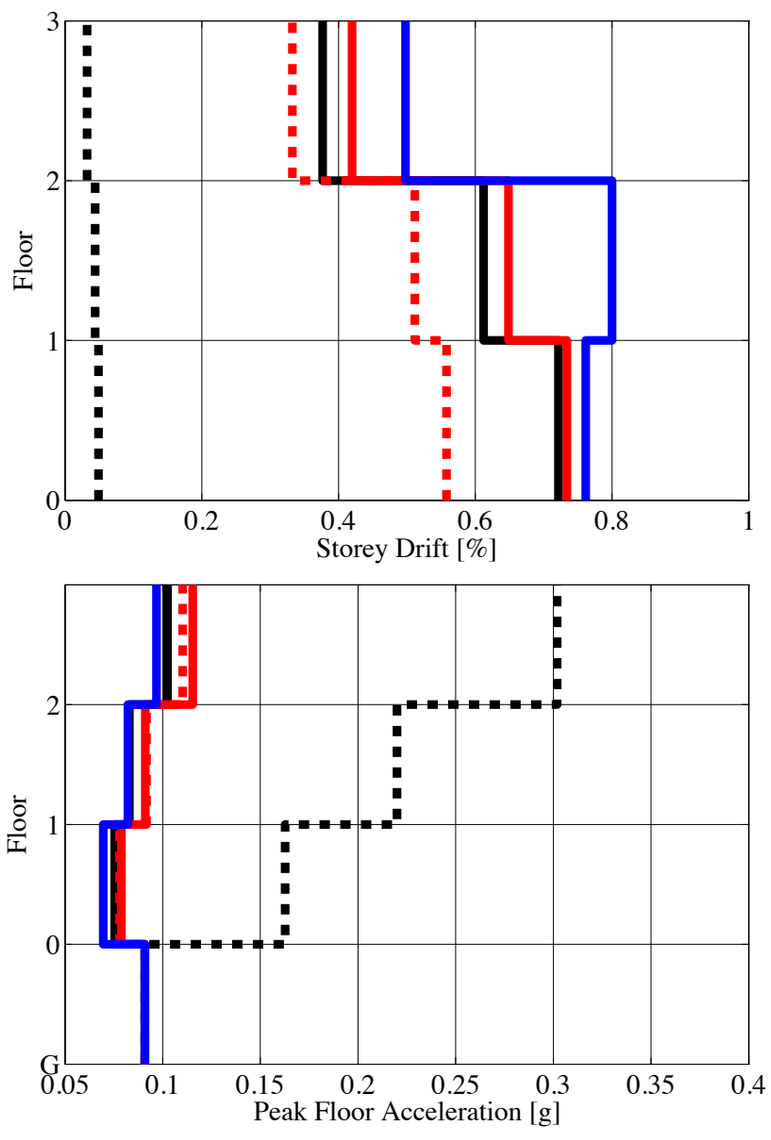


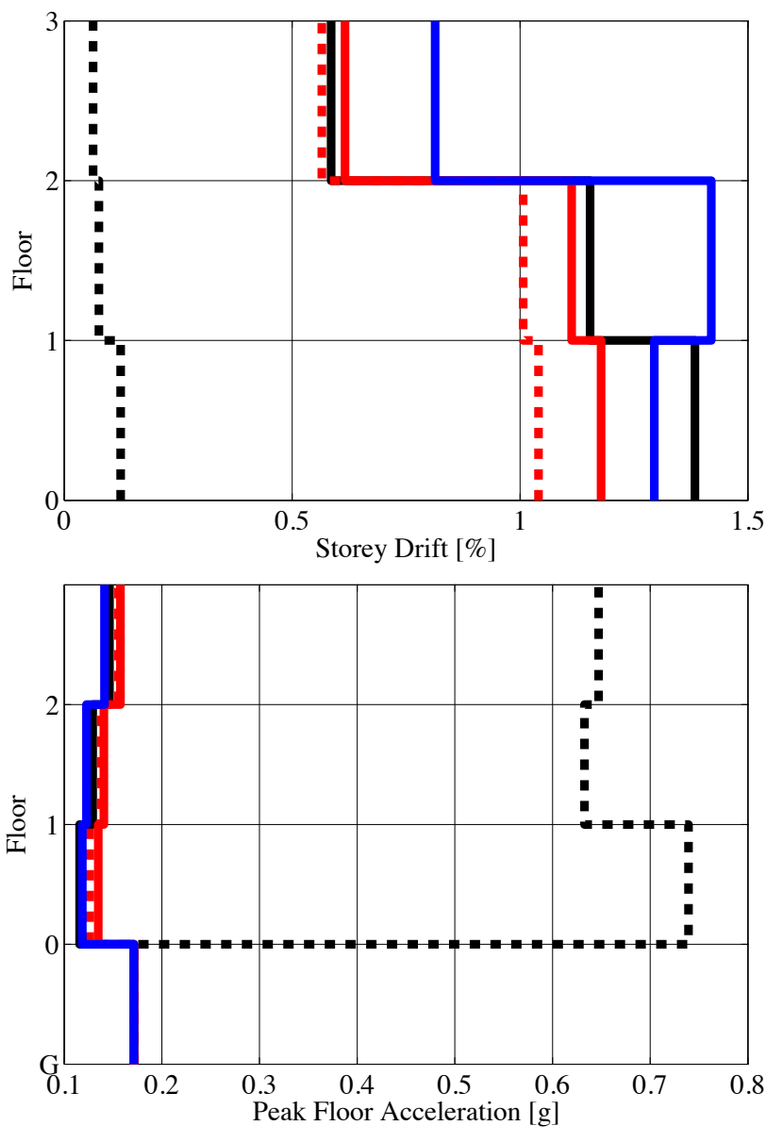
Bare Frame Model Results

475yrs



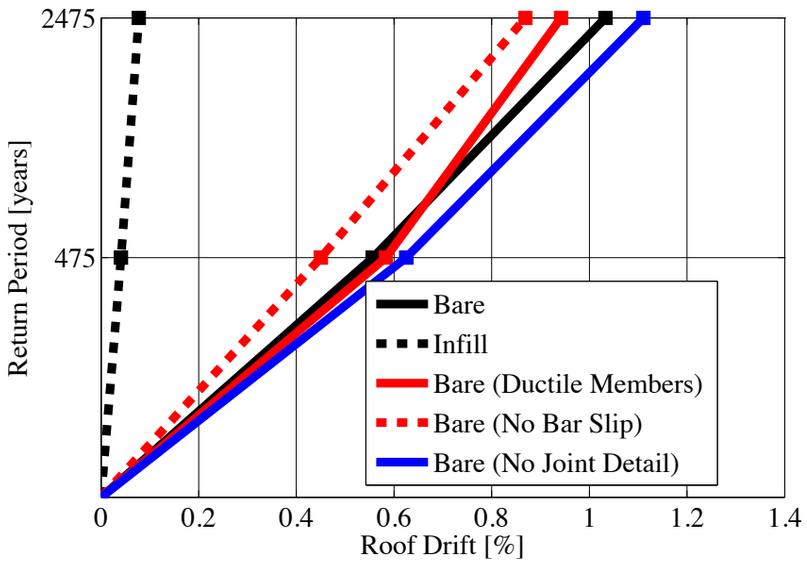


2475yrs

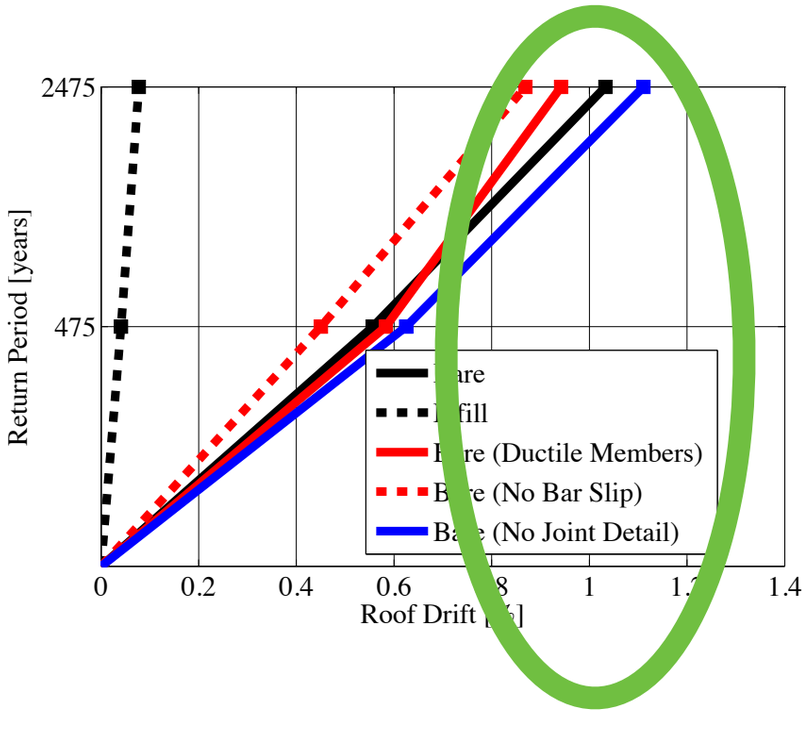


- Lack of joint detail results in increased storey drift. ▬
- Addition of infills is by fare the most influential parameter. ▪▪▪

Bare Frame Model Results



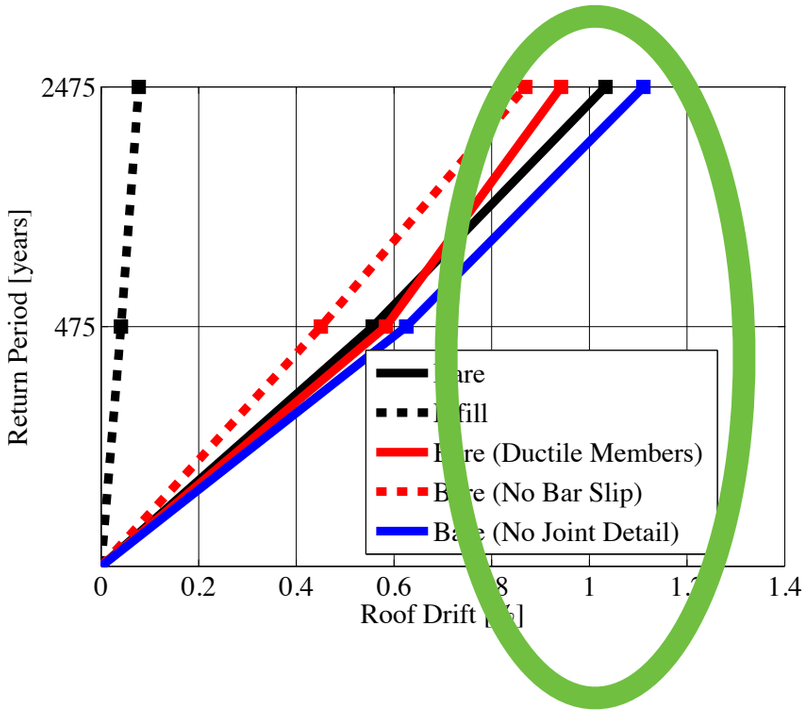
Bare Frame Model Results

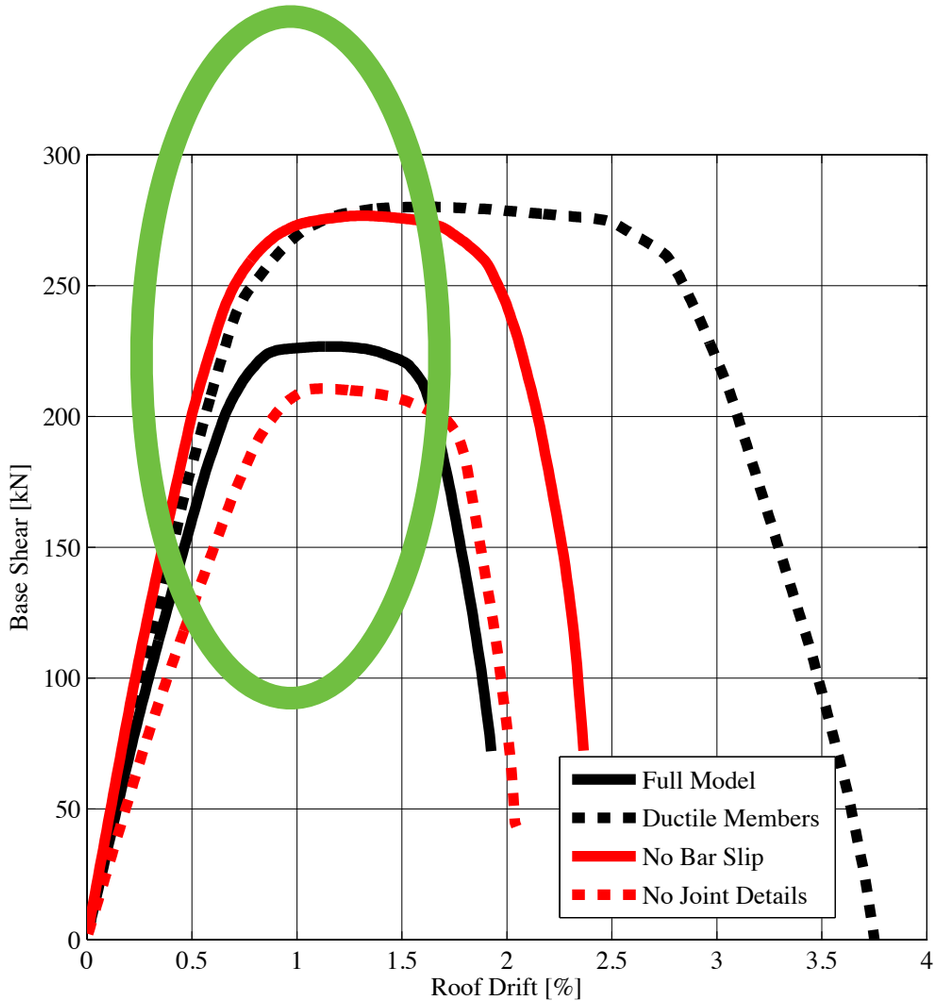


- At the 2475 year return period, roof drift is close to yield drift.

- Structure is exhibiting limited ductility.

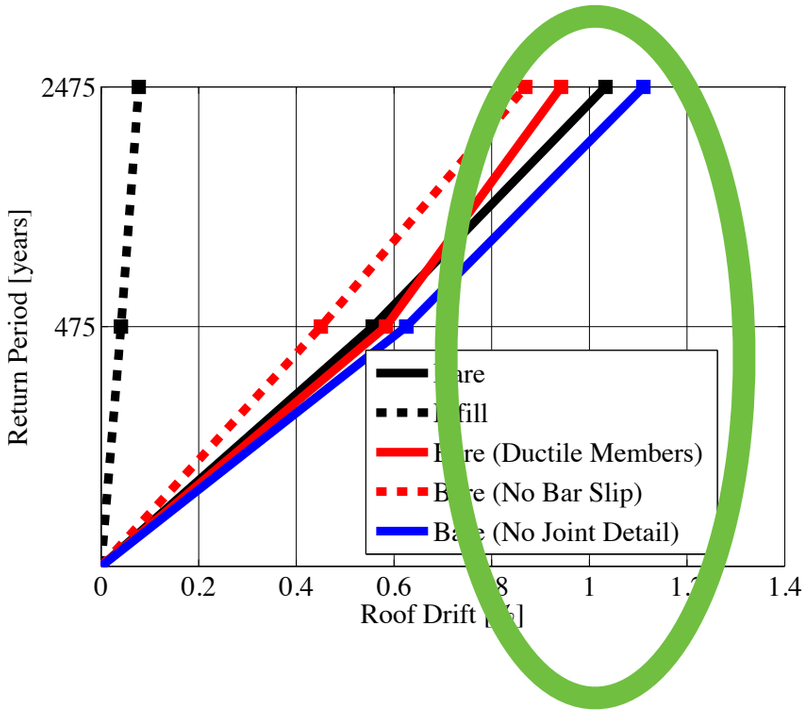
Bare Frame Model Results

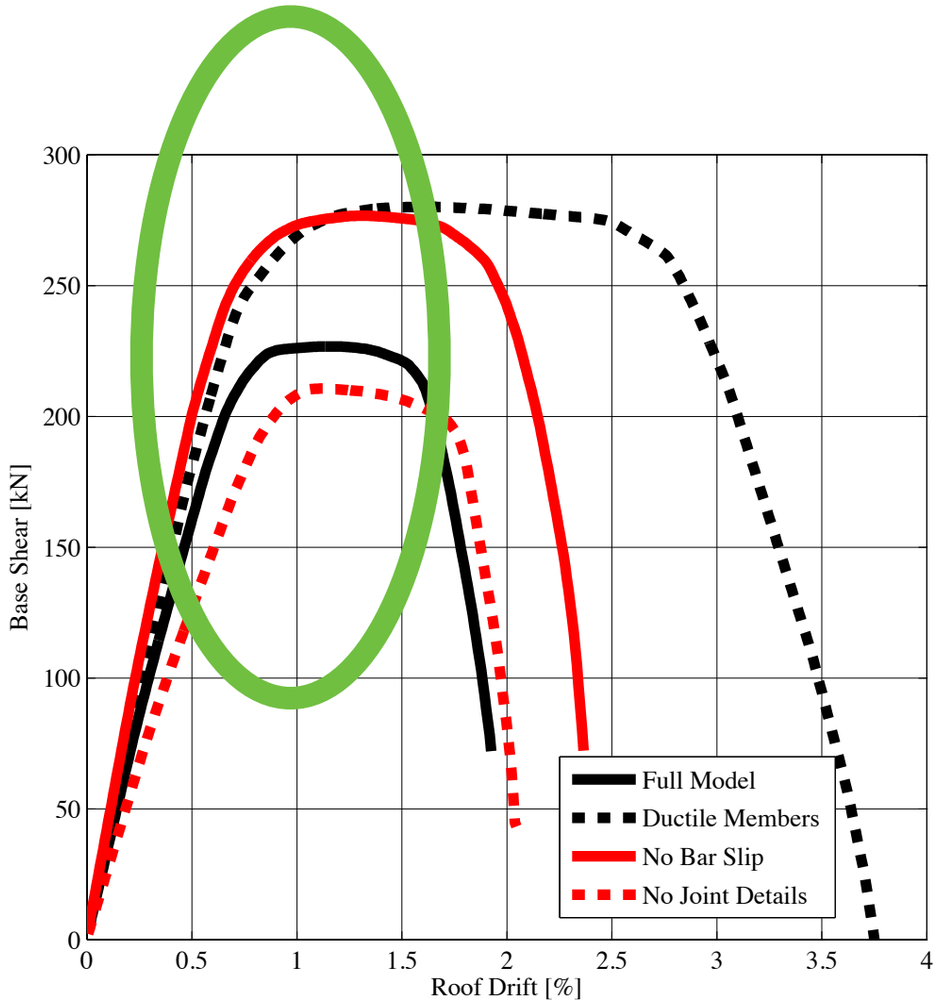




Pushover

Bare Frame Model Results





Pushover

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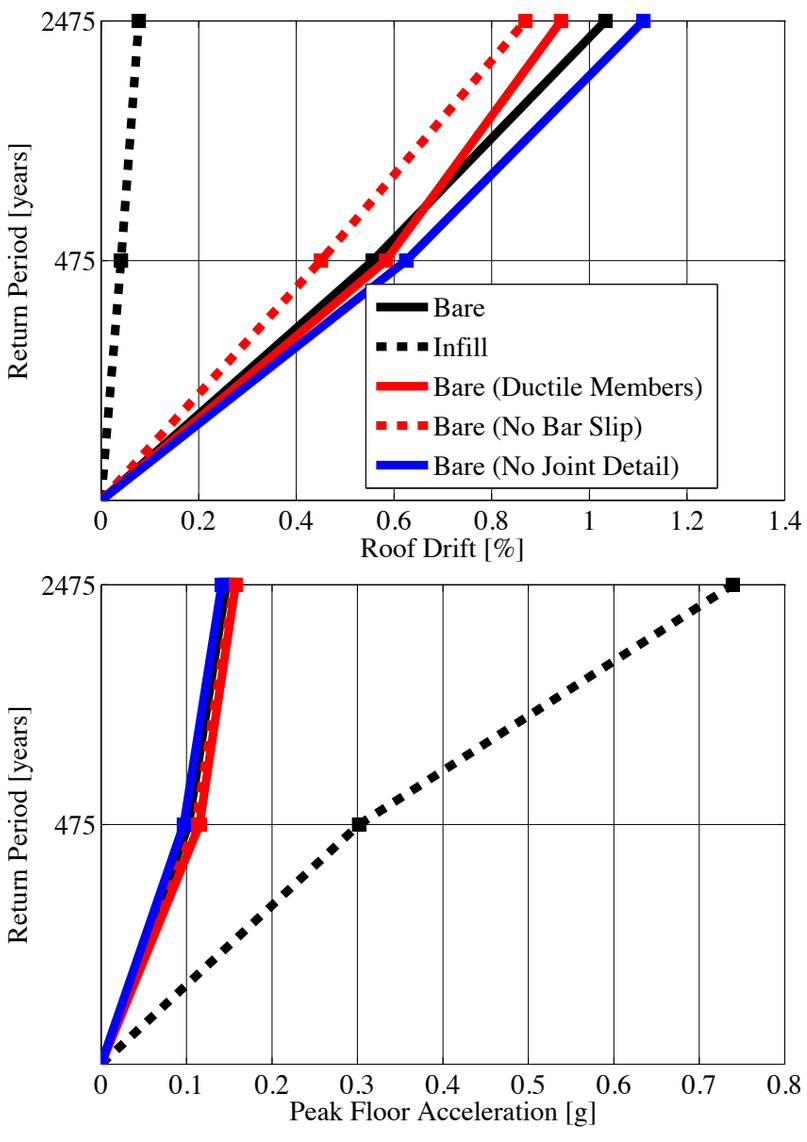
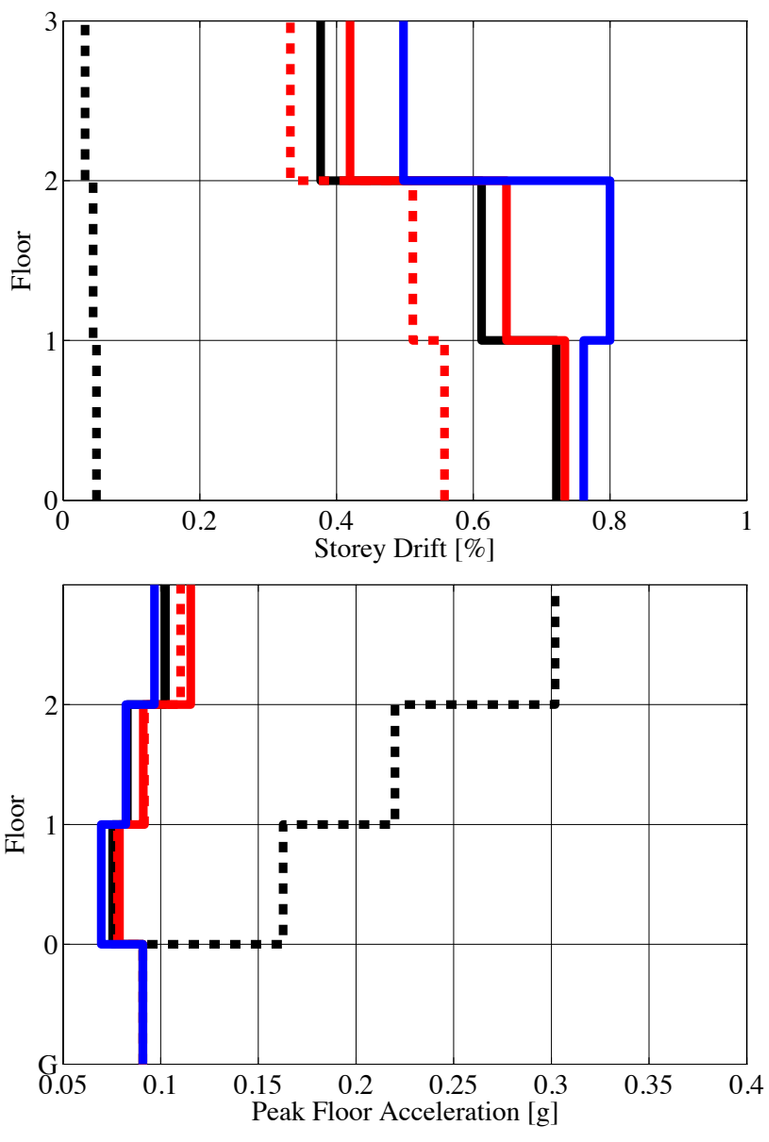
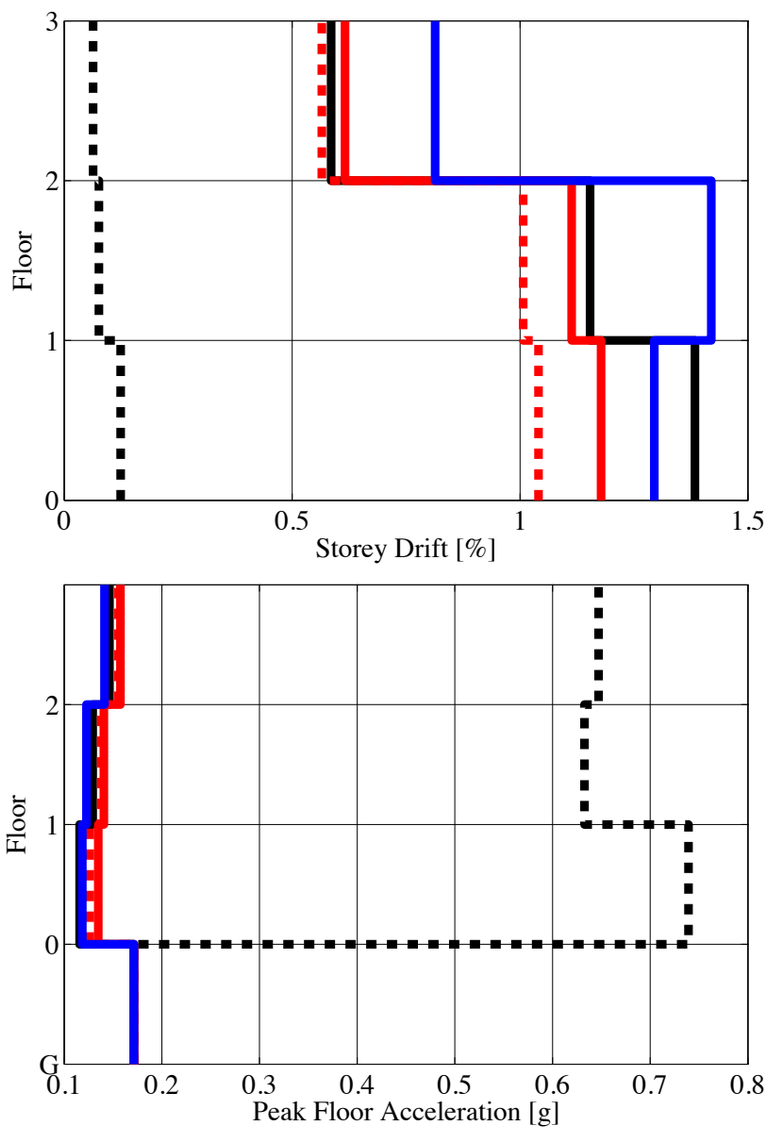
Bare Frame Model Results



475yrs



2475yrs

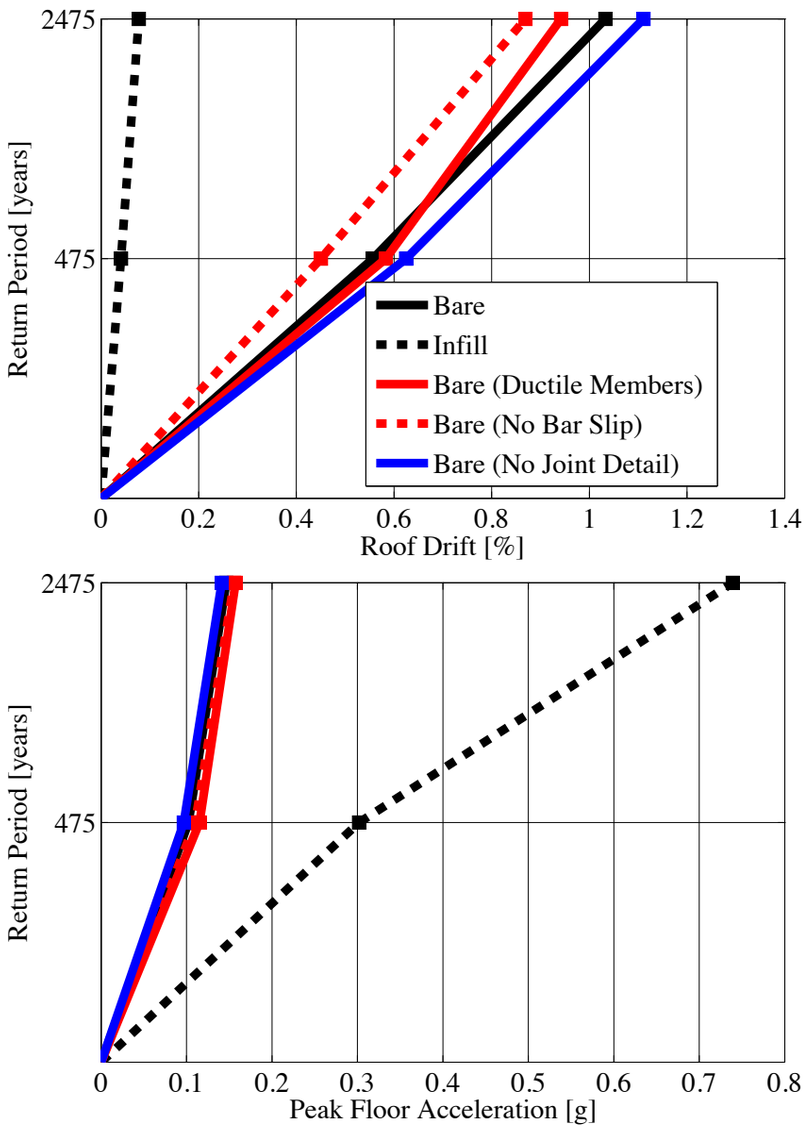


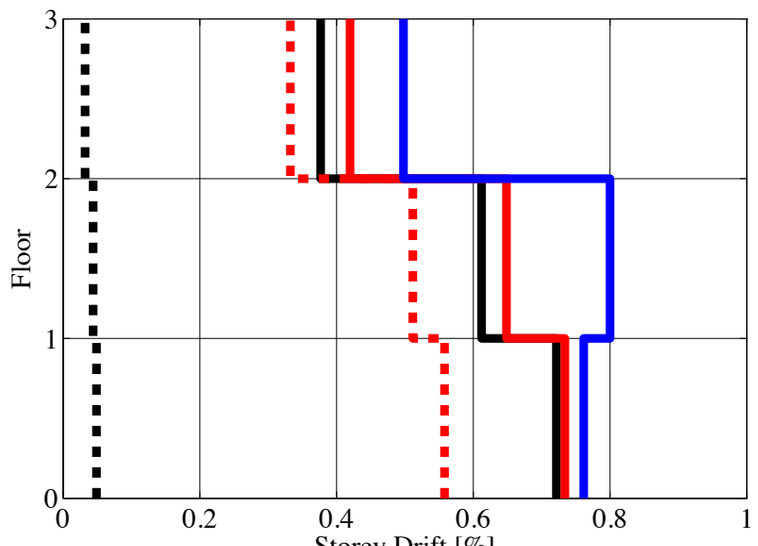
- Ignoring the effects of bar slip leads to a decrease in drift. ▪▪▪▪

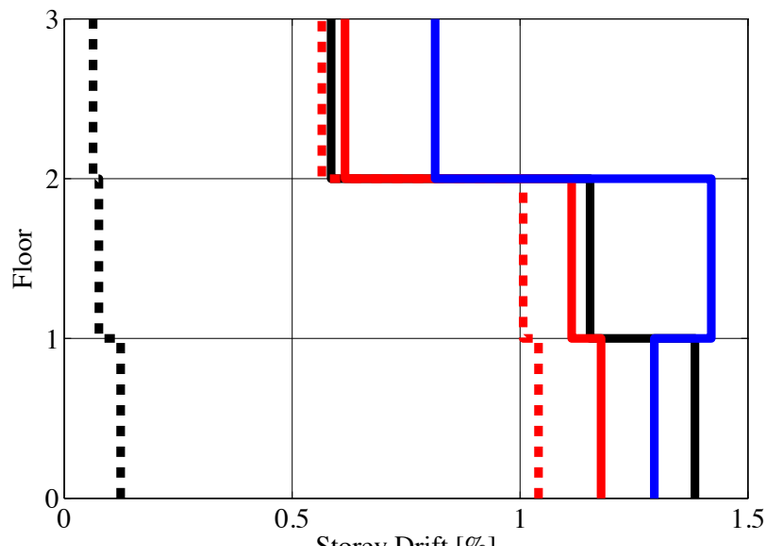
Bare Frame Model Results

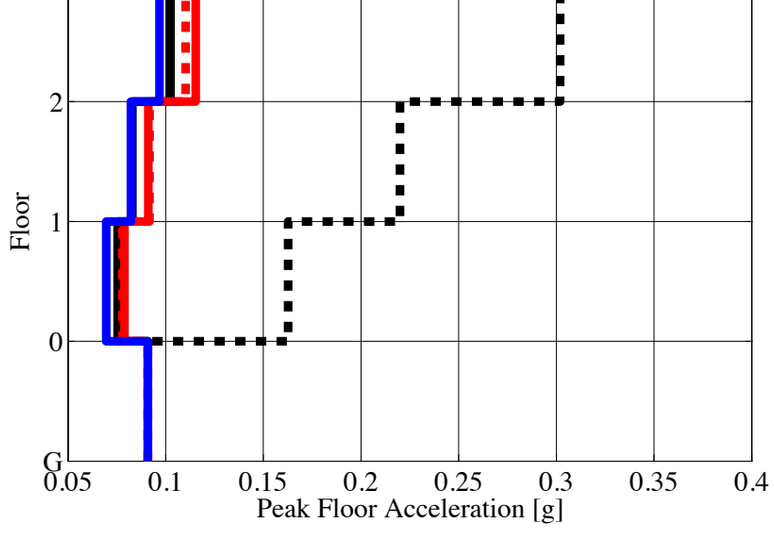
475yrs

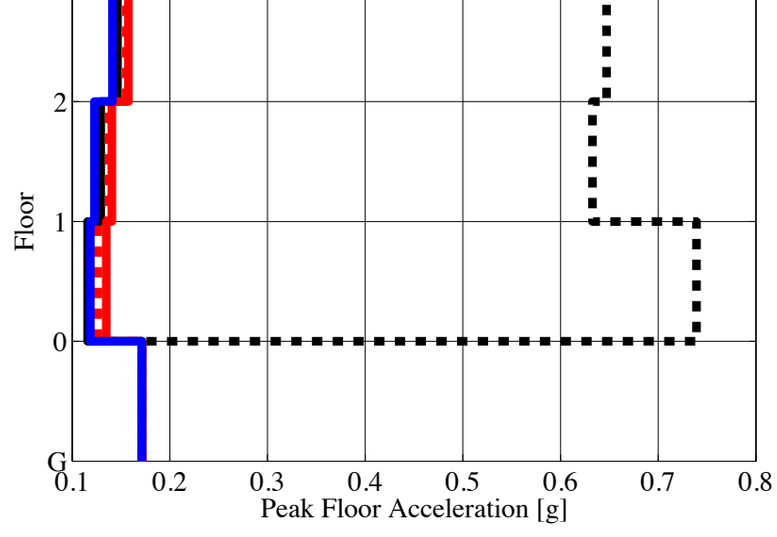
2475yrs





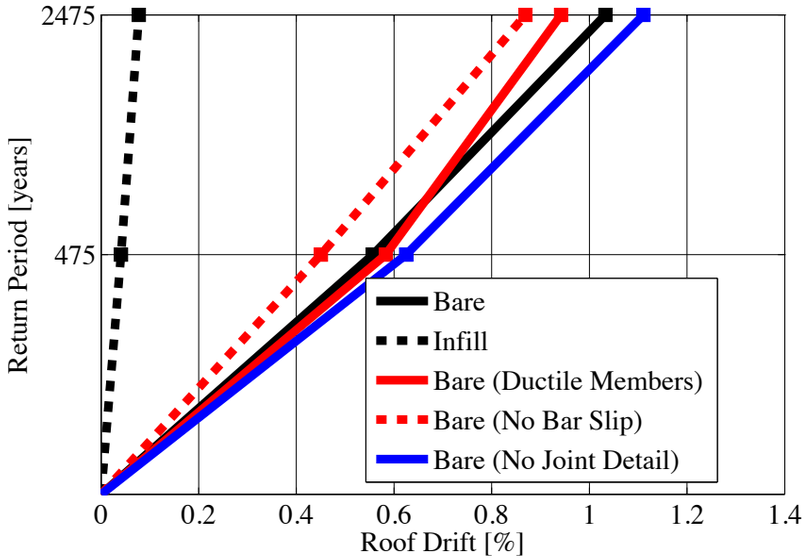


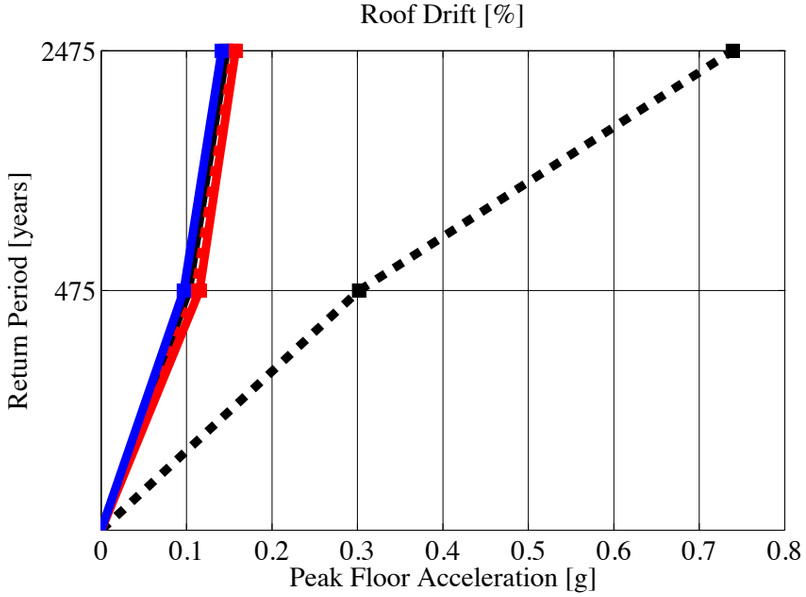


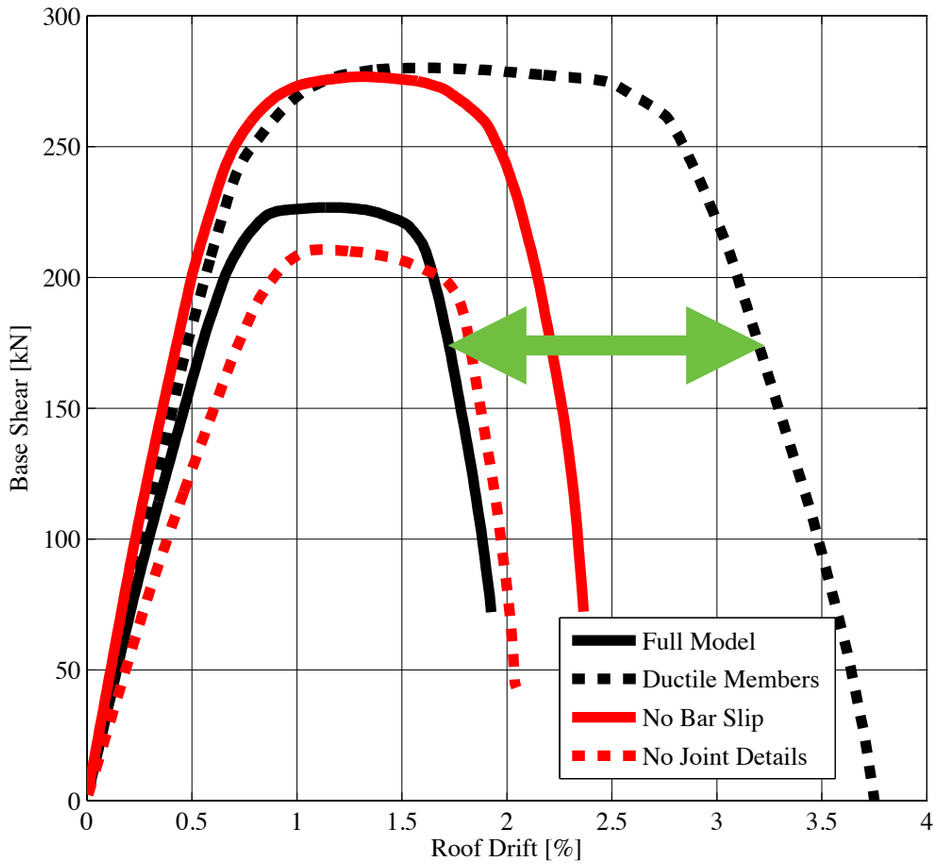


- Influence of ductile members not so apparent since this difference was in ductility capacity. Low ductility here. —

Bare Frame Model Results





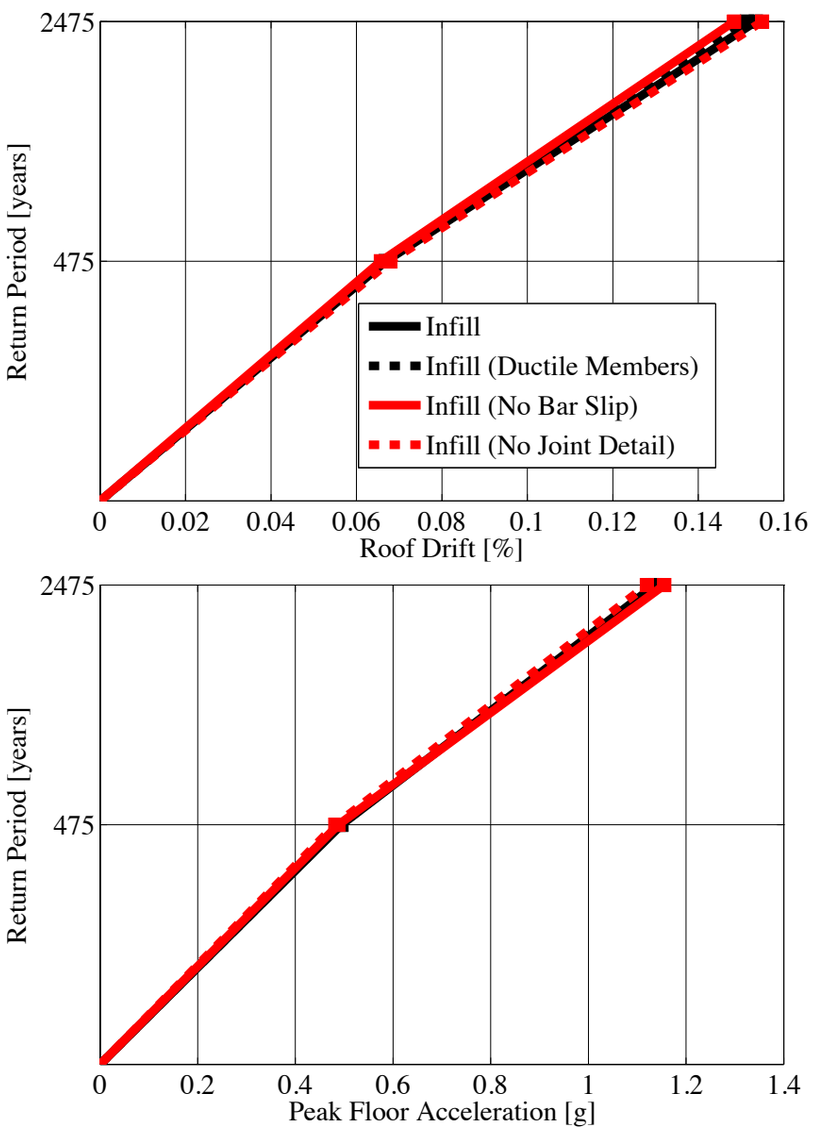


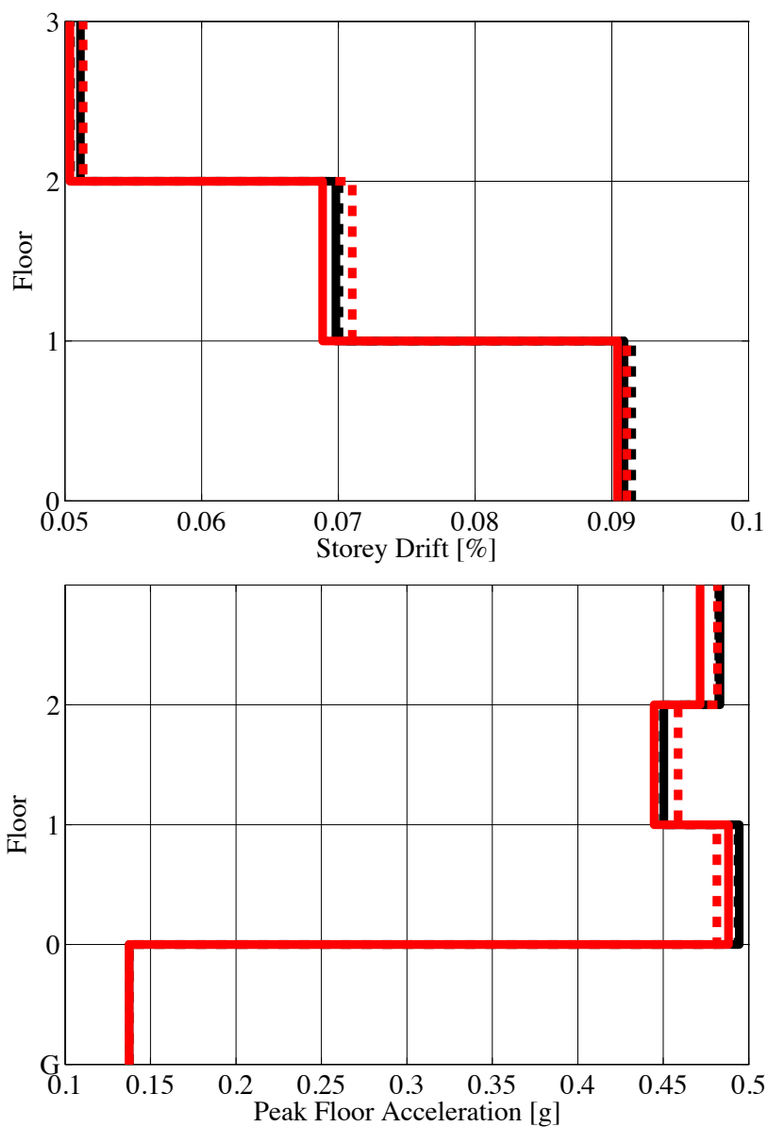
Pushover

- Low ductility results in difference between ductile members and full model being quite small.

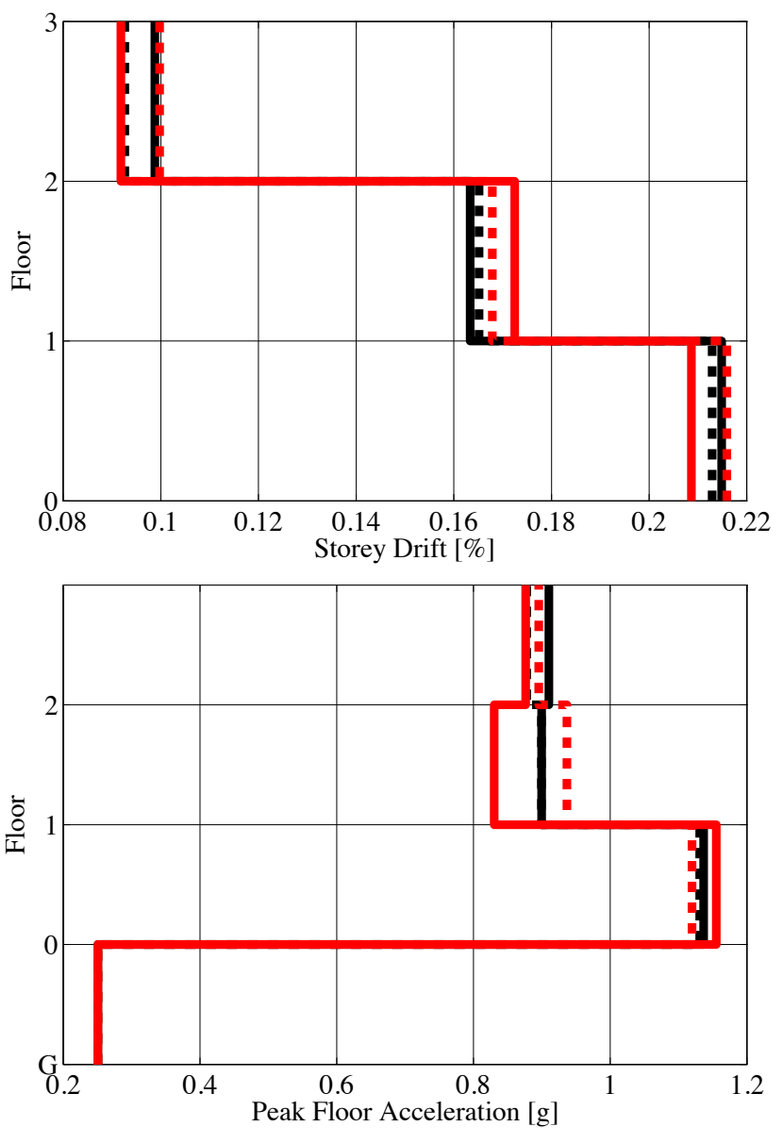
Infill Frame Model Results

475yrs



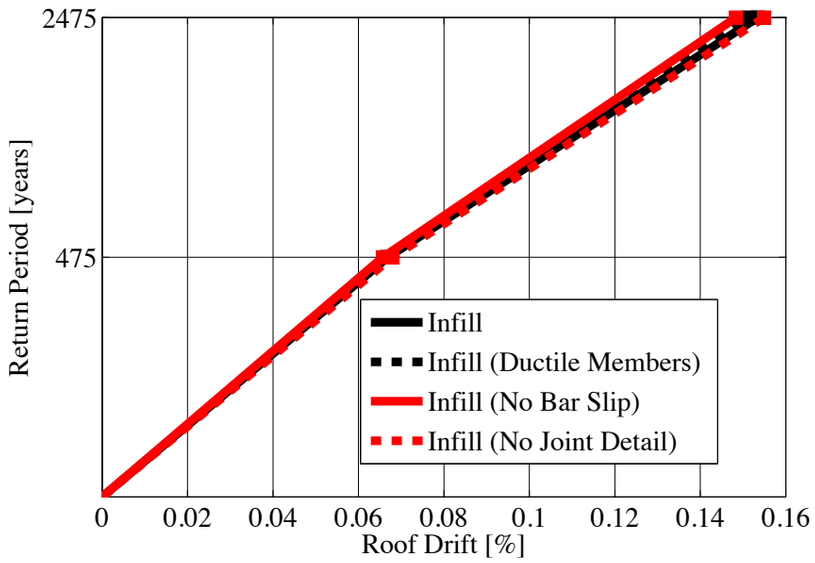


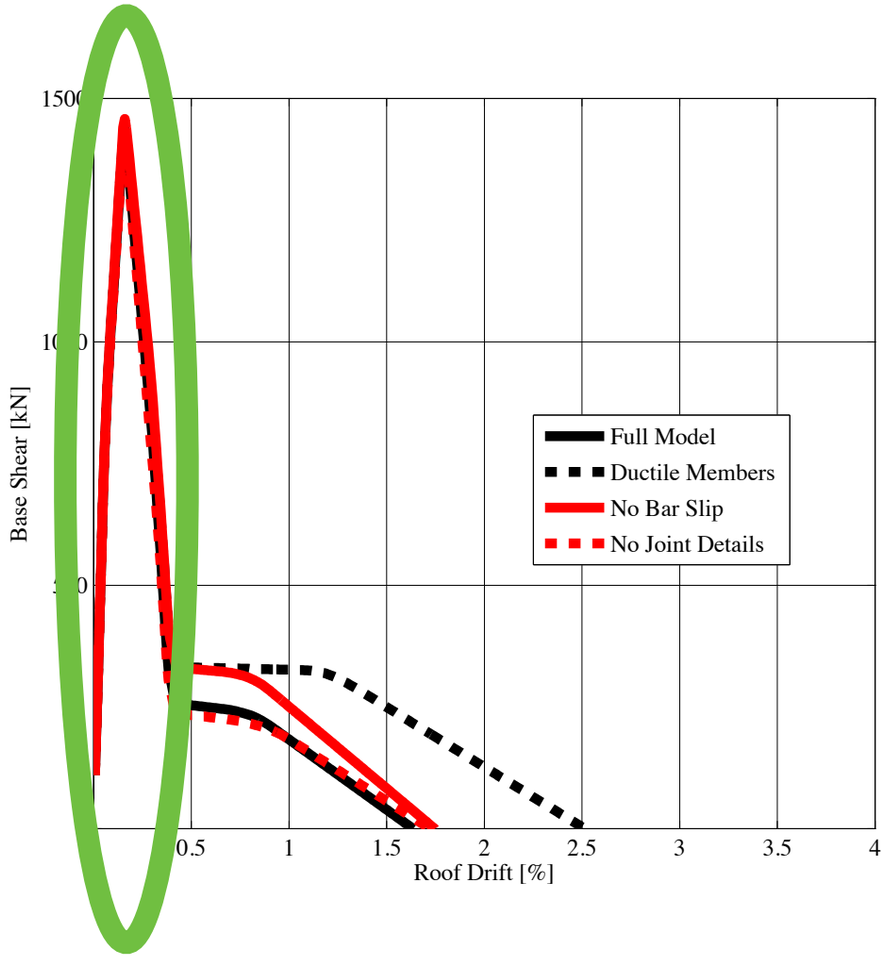
2475yrs



- Infilled frames show little difference between models.

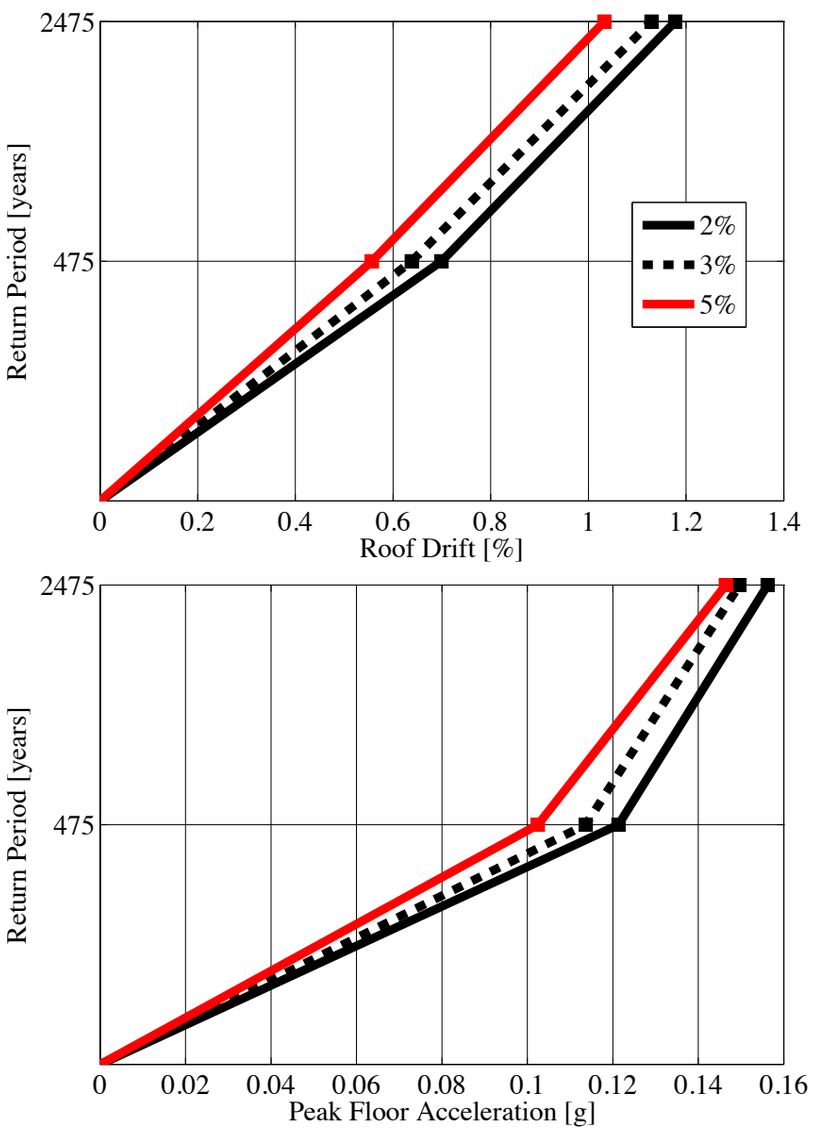
Infill Frame Model Results



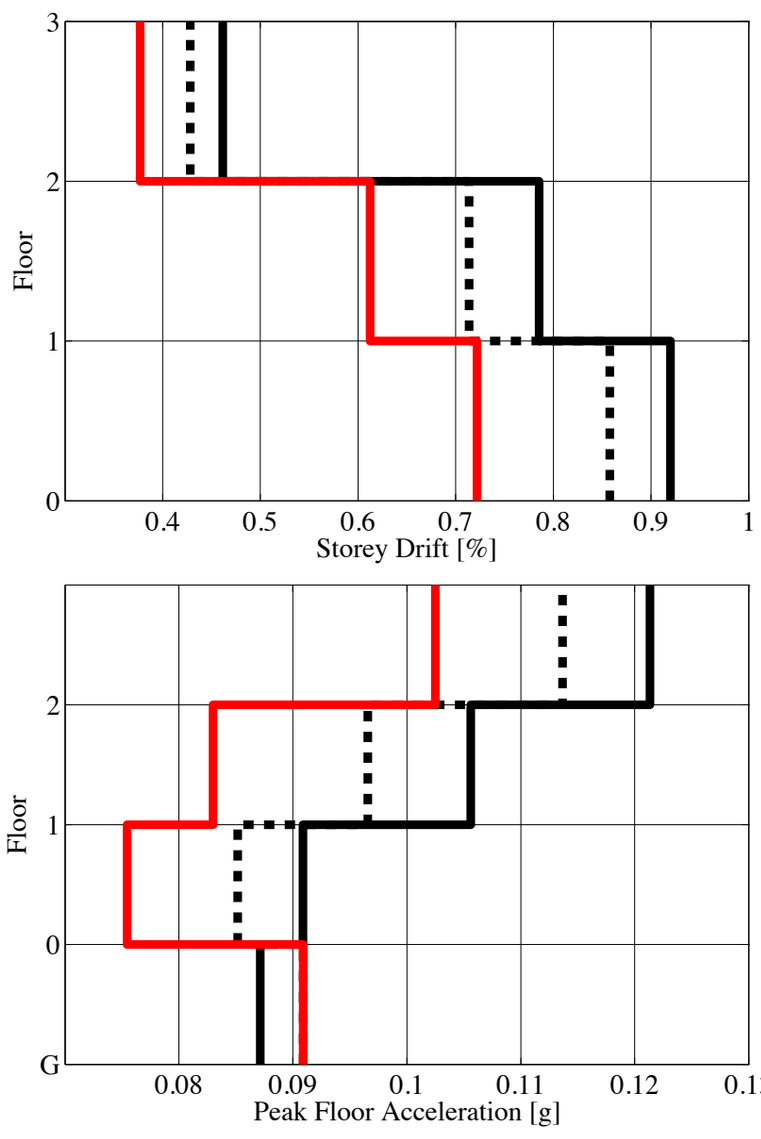


- Max roof drift at 2475 years is ~0.15%.
- Difference would be more pronounced in ductile range.
- Collapse capacity would differ also.
- Dolsek & Fajfar [2008] previously noted that unless infill exceeds peak then it tends to dominate the response.

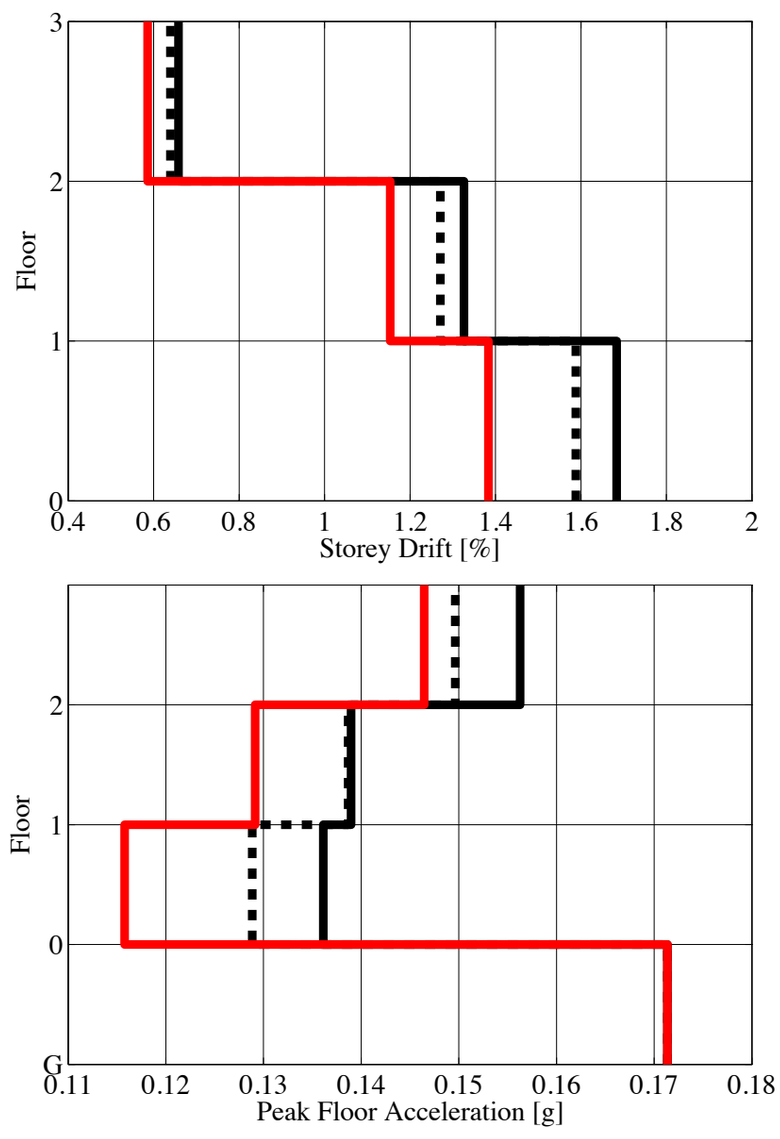
Elastic Damping Results



475yrs



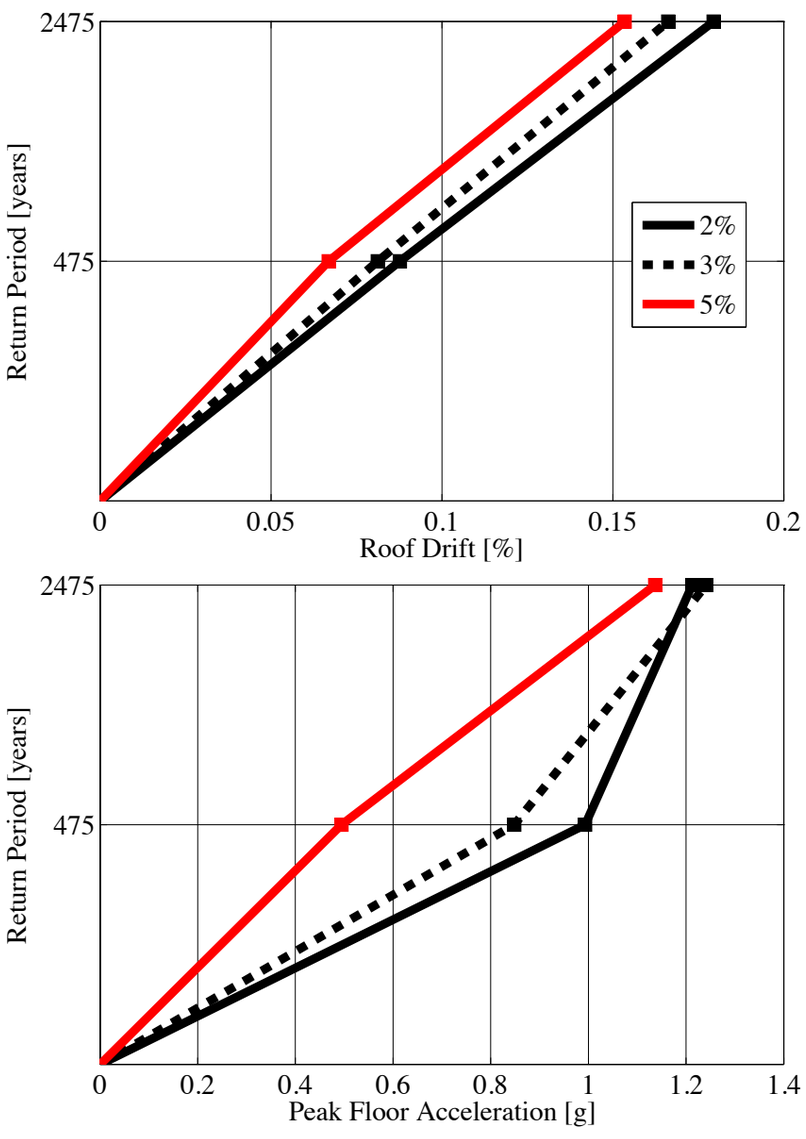
2475yrs

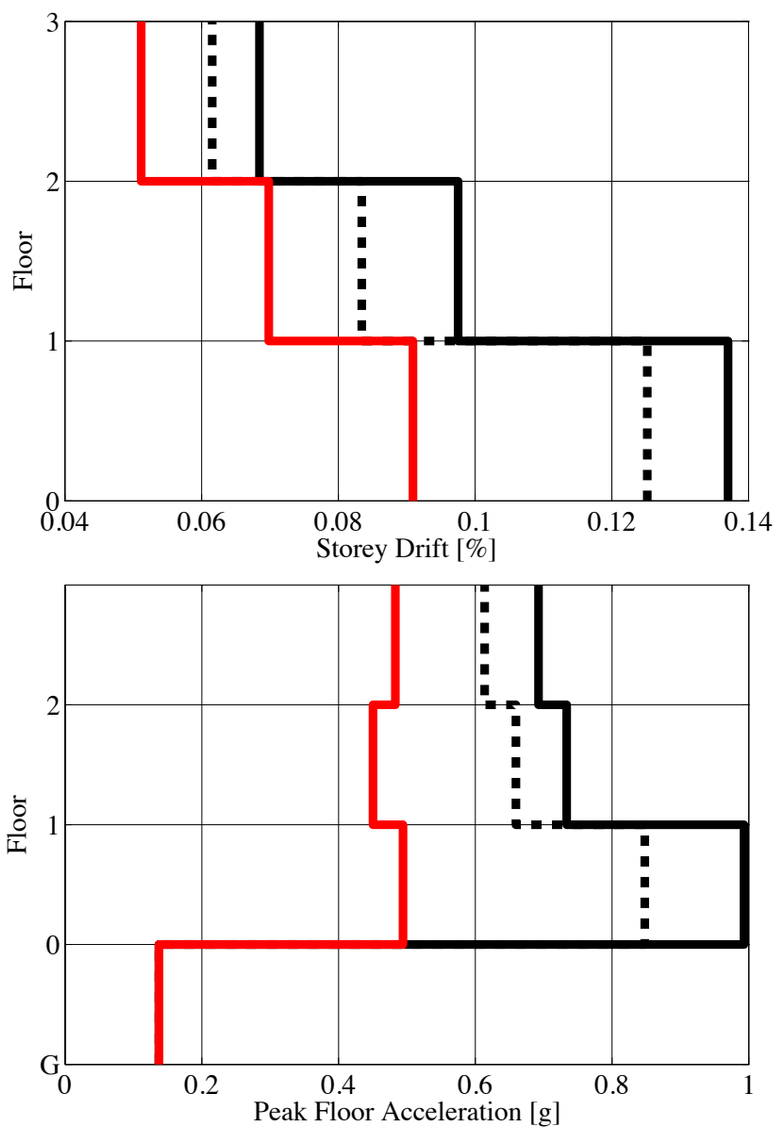


- Influence of elastic damping is quite large.

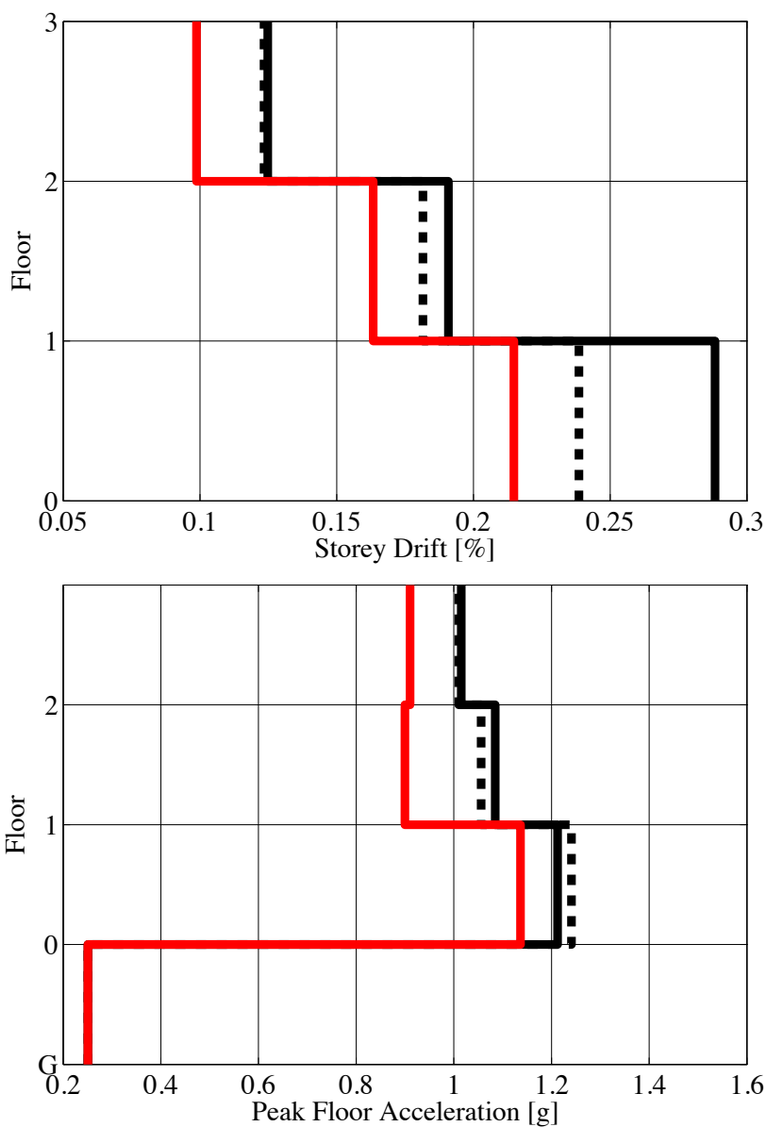
Infill Frame Model Results

475yrs





2475yrs



- Similarly for infill case, whose response is essentially elastic.

Observations

- Lack of joint consideration results in an increase in response.
- Omitting the effects of bar slip on flexibility and capacity results in a decrease in response.
- Little influence of using ductile members due to low ductility demand.
- Similarly for infill frame cases.
- Elastic damping has a noticeable influence on response.

Conclusions

- Relevance of modelling decisions in assessment discussed.
- Methods of accounting for joint and member behaviour associated with older Italian RC frames presented.
- Accounting for joint behaviour was seen to be quite influential, given the low ductility levels.
- Further collapse studies could provide a clearer insight.

Thank you

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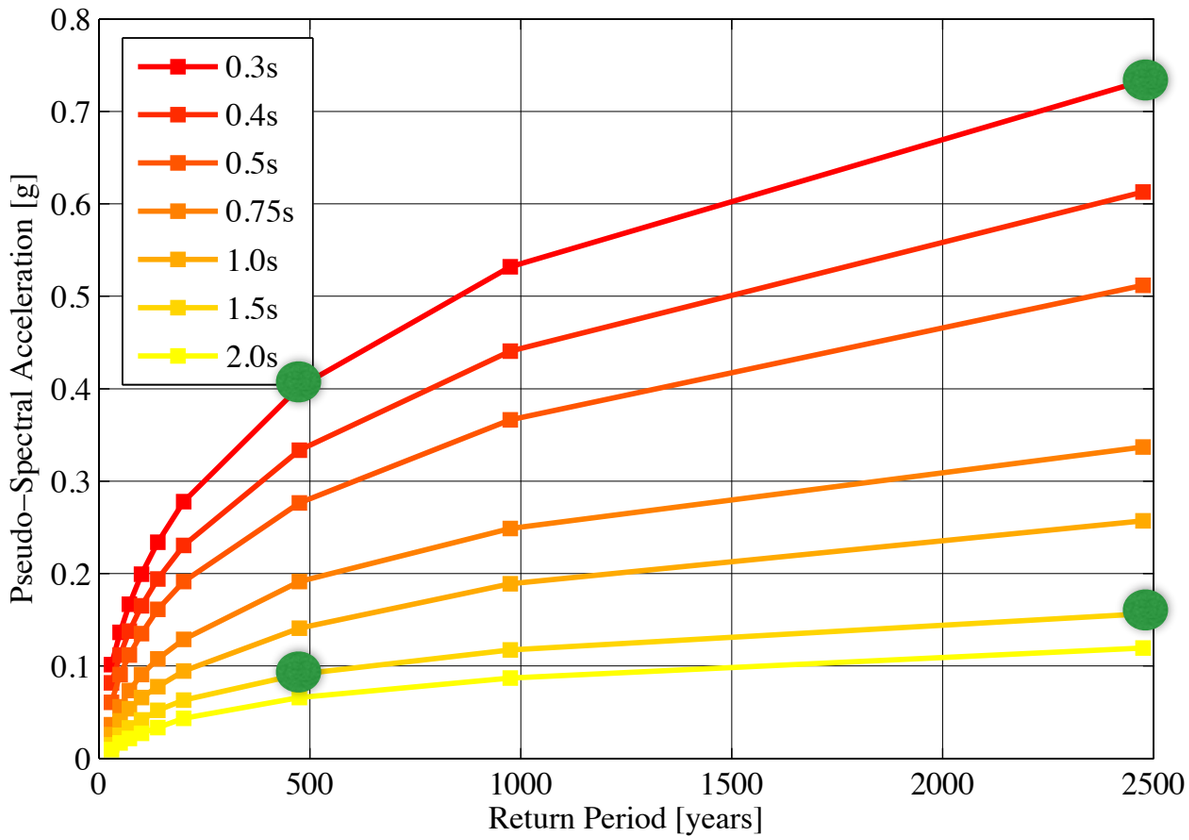
Pavia

Seismic Hazard & Ground Motions

- Ground motion sets at T*=0.3s and 1.5s are selected.
- These are selected at a T_R of 475yrs and 2475yrs for the numerical analysis.

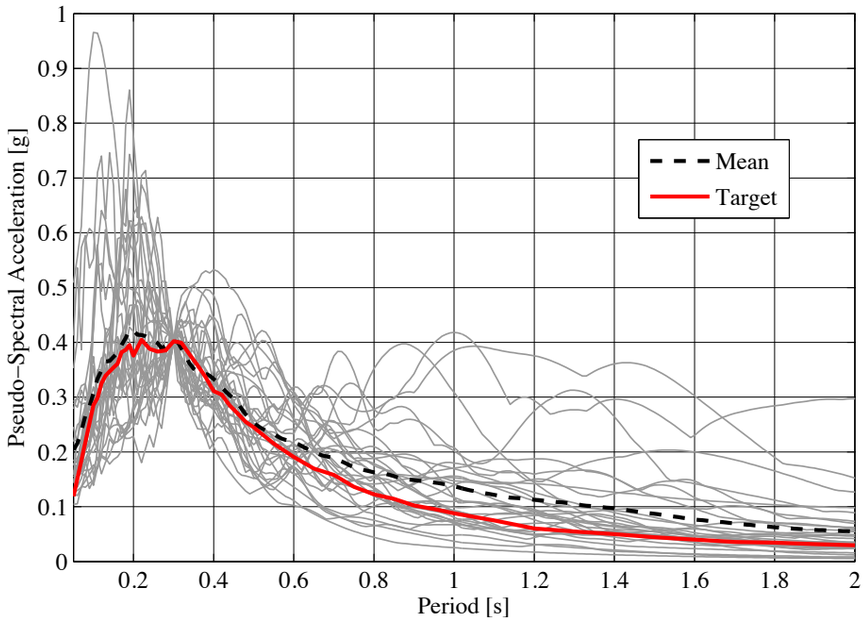


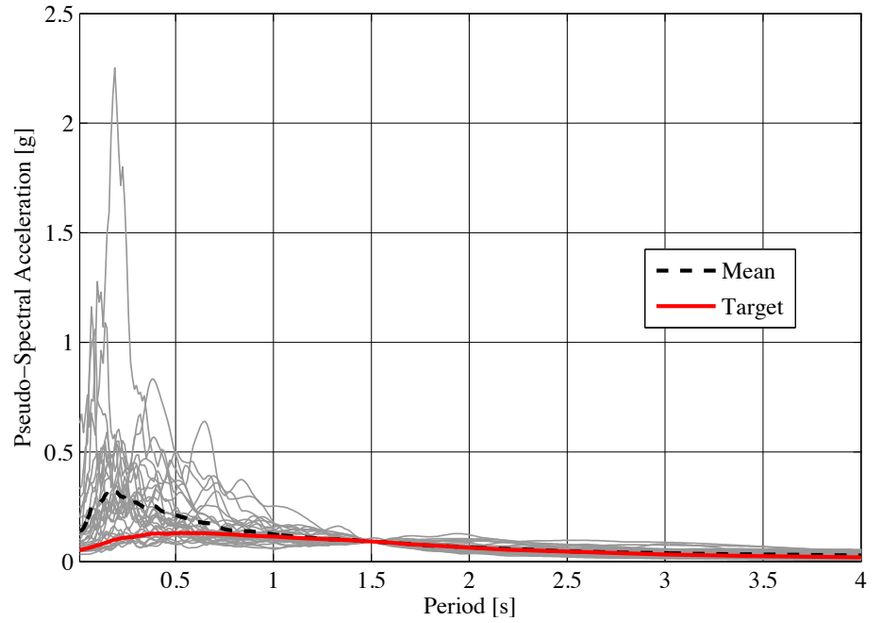
Periods of case study structures

Mode	Bare Frame				Infill Frame			
	Full	Ductile Members	No Bar Slip	No Joint	Full	Ductile Members	No Bar Slip	No Joint
1	1.49	1.36	1.34	1.66	0.23	0.23	0.23	0.23
2	0.52	0.47	0.46	0.58	0.08	0.08	0.08	0.08
3	0.32	0.29	0.28	0.38	0.05	0.05	0.05	0.06

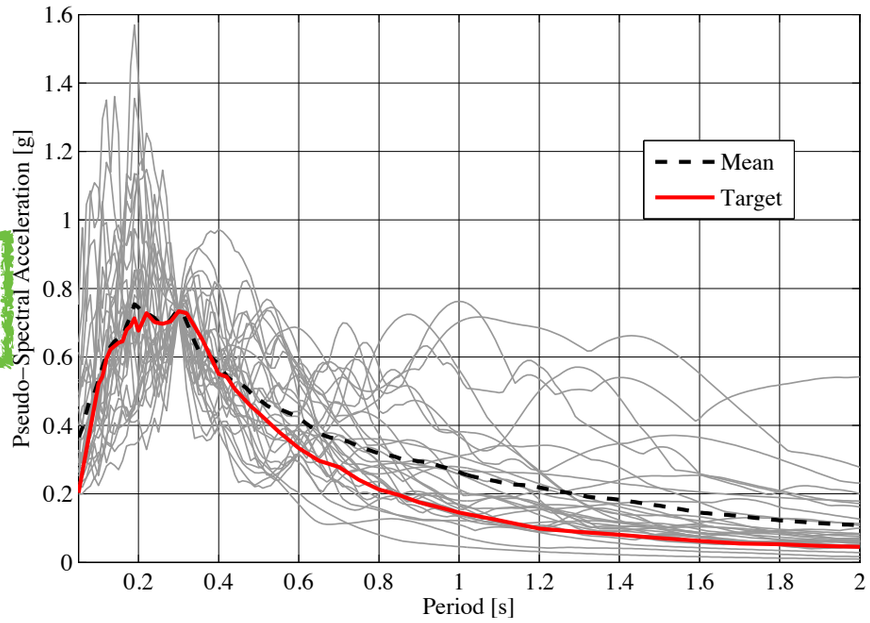
Seismic Hazard & Ground Motions

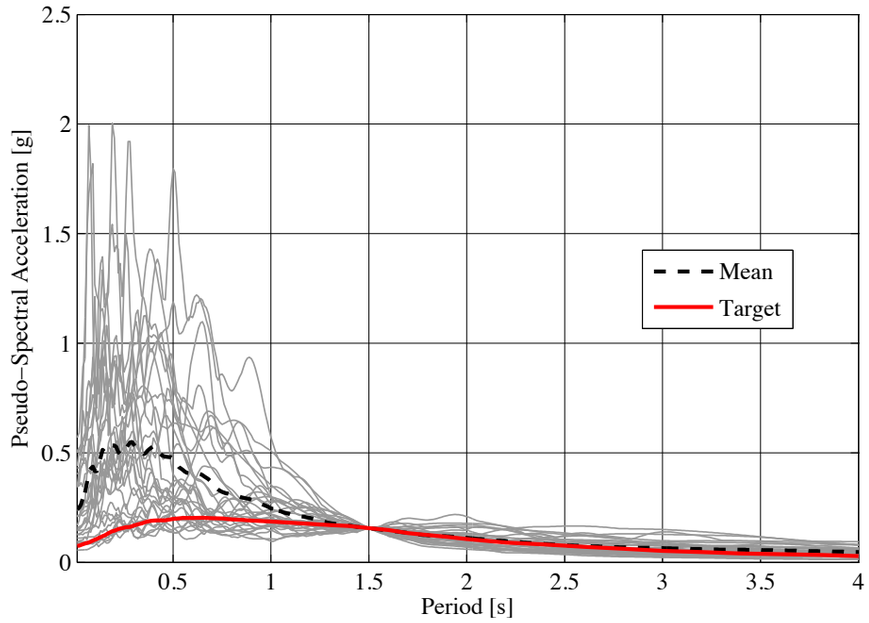
T_R=475yrs





T_R=2475yrs





T*=0.3s

T*=1.5s