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U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Advanced Methodology for Estimation of Economic Seismic Losses in RC Buildings

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Outline

- Motivation
- Objective
- Numerical Modelling
- Calibration Process
- Results
- Conclutions

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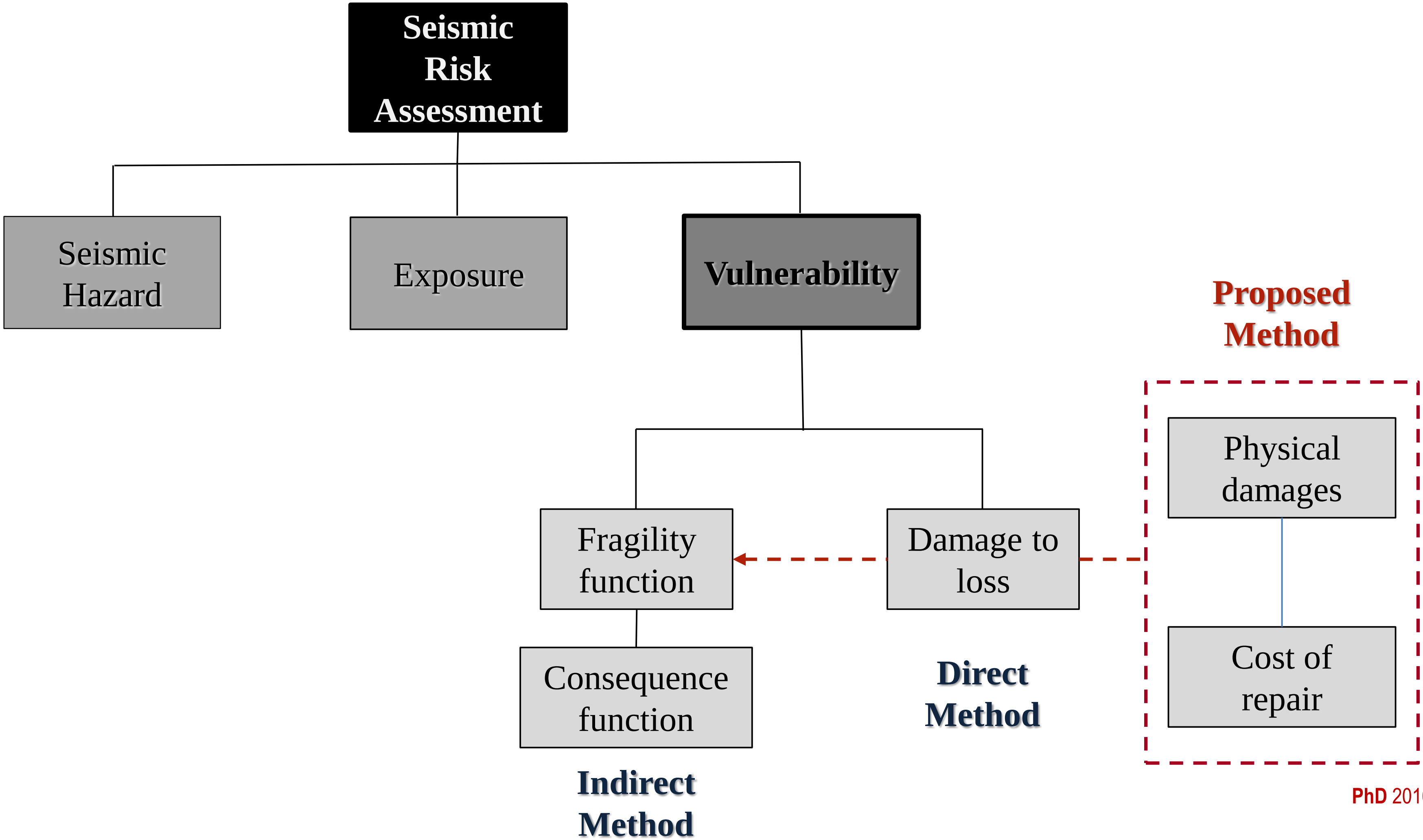
Motivation

Framework of Seismic Risk Assessment



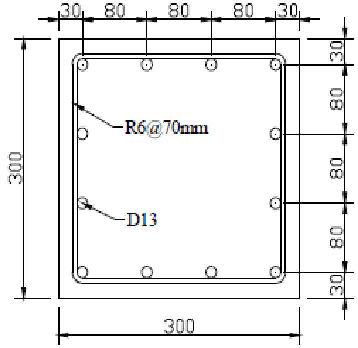
Objectives

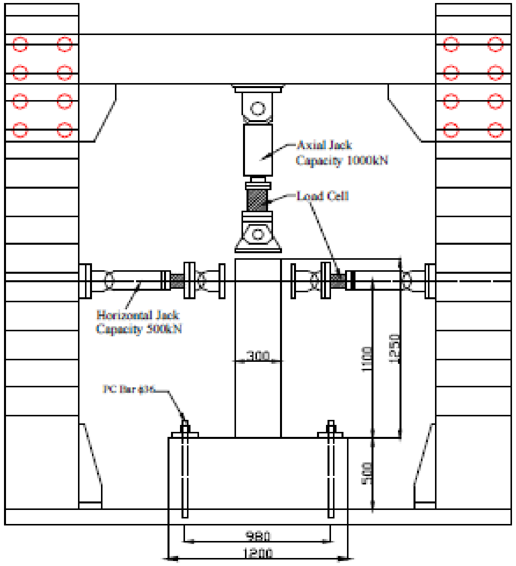
- Forming systematic calibration processes
- Defining a set of damage limit states
- Developing an analytical damage-to-loss methodology
- Providing objective seismic vulnerability assessment
- Establishing a database for building inventory

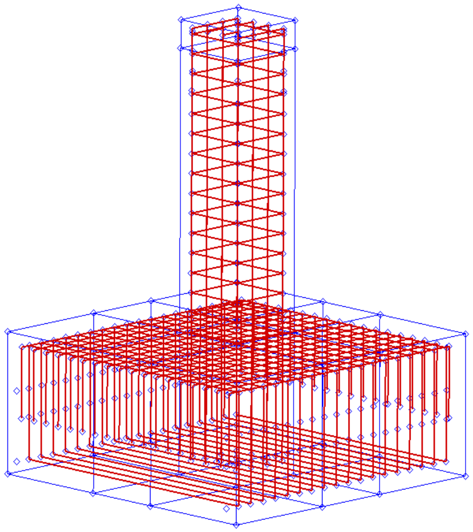
Numerical Modelling

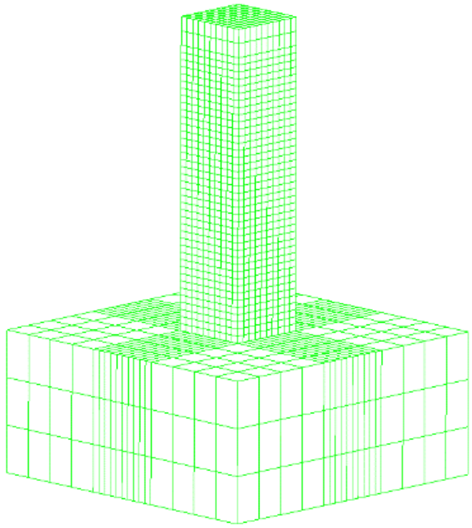
1st Experimental Test

- Performed by Shima (2005)* (V1, V2, V3 &V4)
- Mesh Sensitivity
- Pushover Analysis
- Compression Fracture Energy
- Geometric Nonlinearity
- Bond-Slip Action







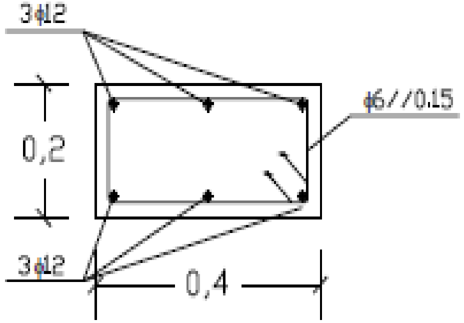


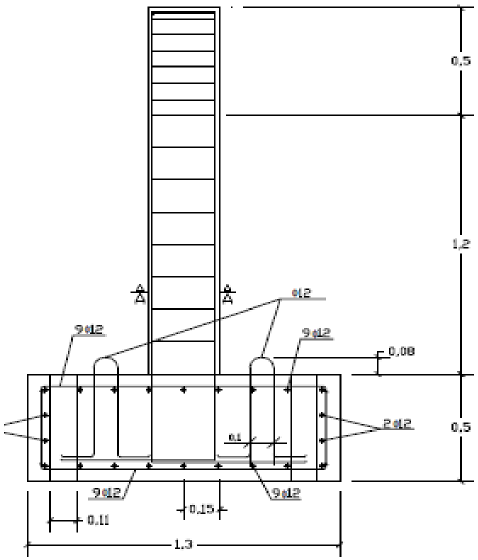
Denponpang, T. & Shima, H., 2005, "Effect of axial load on ductility of reinforced concrete columns", 30th conference on our world in concrete & structures, Singapore

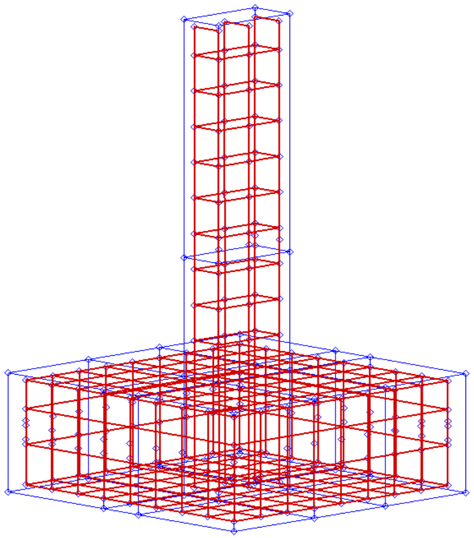
Numerical Modelling

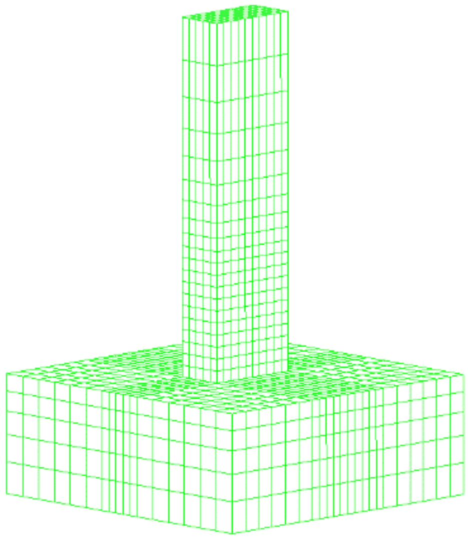
2nd Experimental Test

- Performed at FEUP, Rodrigues (2012)*
- Pushover Analysis
- Cyclic Analysis
- Geometric Nonlinearity
- Bond-Slip Action









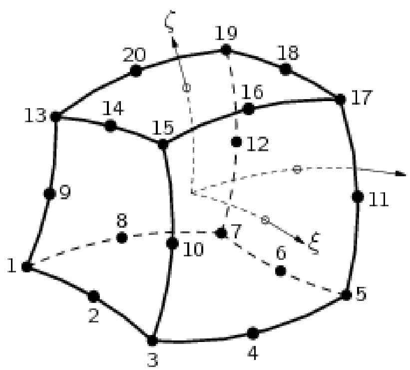
* *Rodrigues, H., 2012. "Biaxial seismic behavior of reinforced concrete columns", PhD Dissertation*

Constitutive Model for Concrete

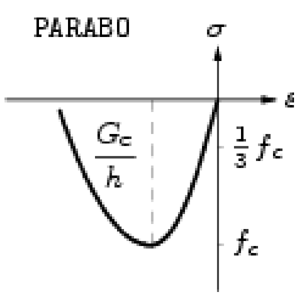
- Brick elemets with 27 Gauss points are selected (a)
- Rotating smeared crack model is adopted
- Nonlinear material properties are used (b&c)

Constitutive Model for Steel

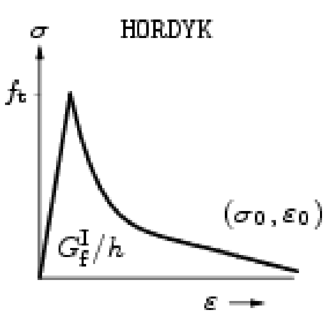
- Von Mises equivalent plastic strain parameters are used (d)
- Maekawa buckling model is adapted for the bars under compression



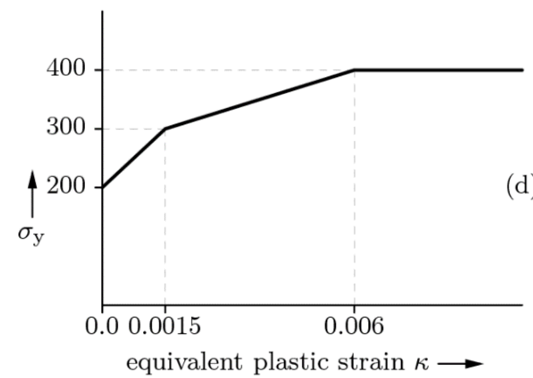
a



b



c



d

**Diana 9.6 User Manual*

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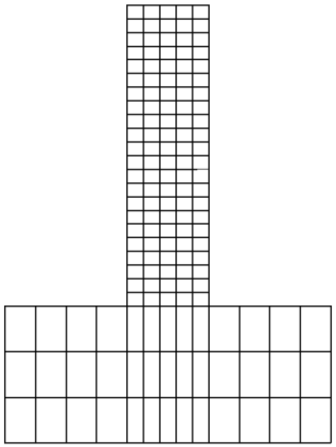
Calibration Process

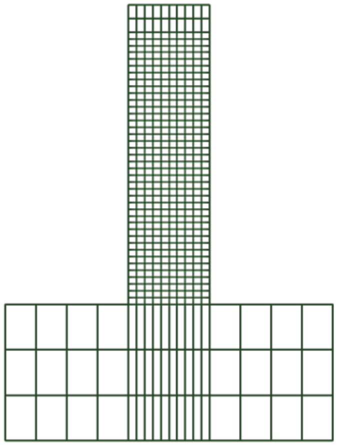
Calibration steps	**Investigated parameters and values**	
Mesh sensitivity	Fine mesh element size	3x3x2.5 cm^3
	Coarse mesh element size	6x6x5 cm^3
Compression fracture energy	$G_c = \frac{h \times f_c' \times \varepsilon_u}{2}$	50,60,70,80 kN/mm
Geometric nonlinearity	Including the P-Δ effect	
Bon-slip action	Confined-good bonding	The parameters are obtained from CEB-FIB 1993 and clear rib spacing is assumed 20 mm
	Confined-others	
	Unconfined-good bonding	
	Unconfined-others	

Results

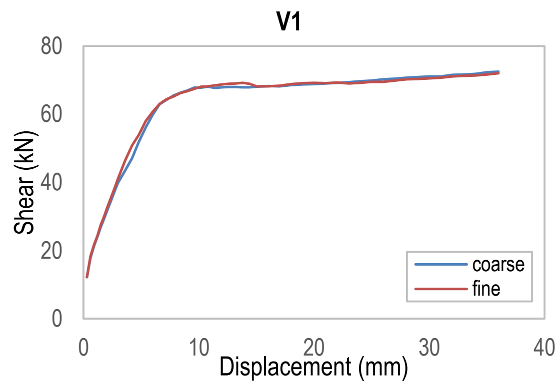
Mesh Sensitivity

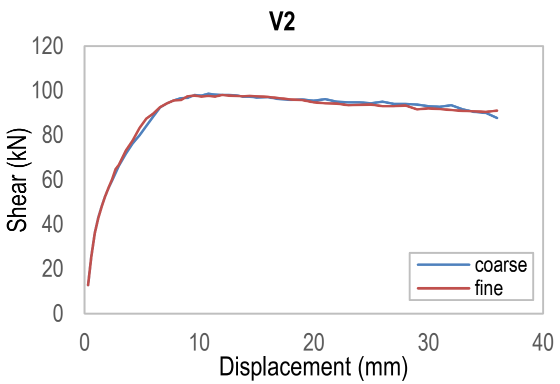


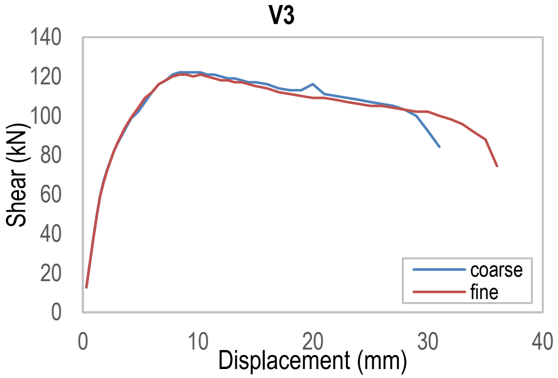
Coarse Meshed Model

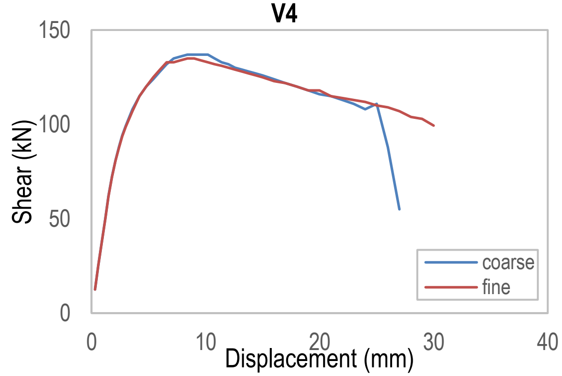


Fine Meshed Model









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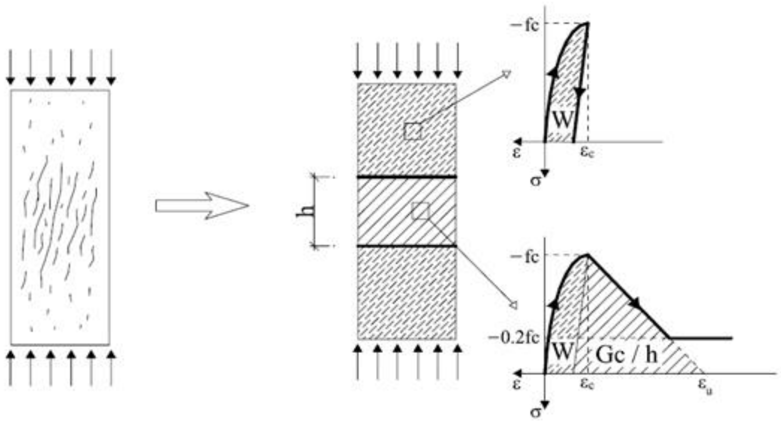
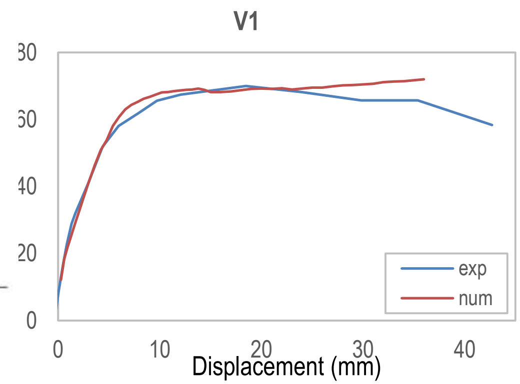
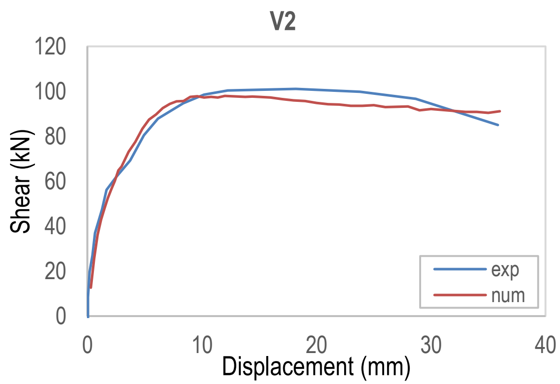
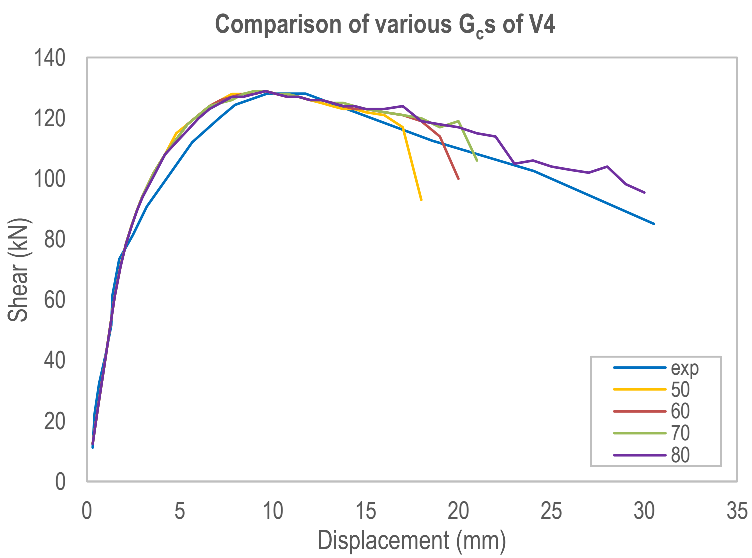
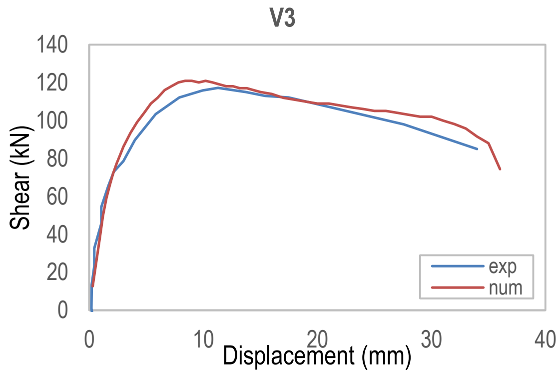
Compression Fracture Energy

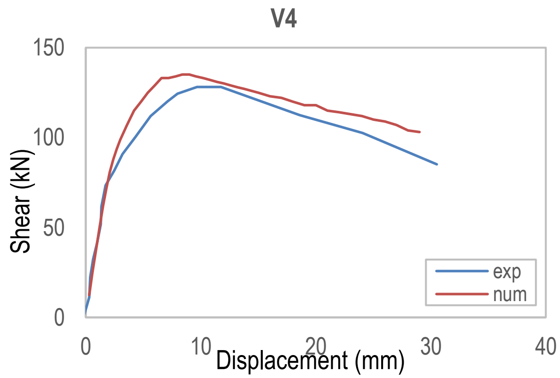




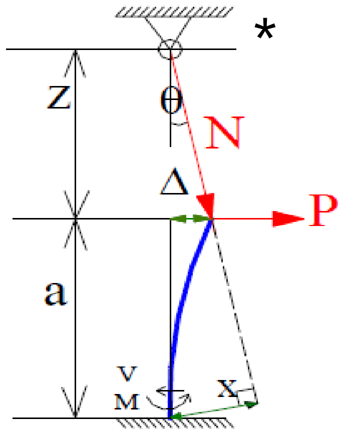








Geometric Nonlinearity

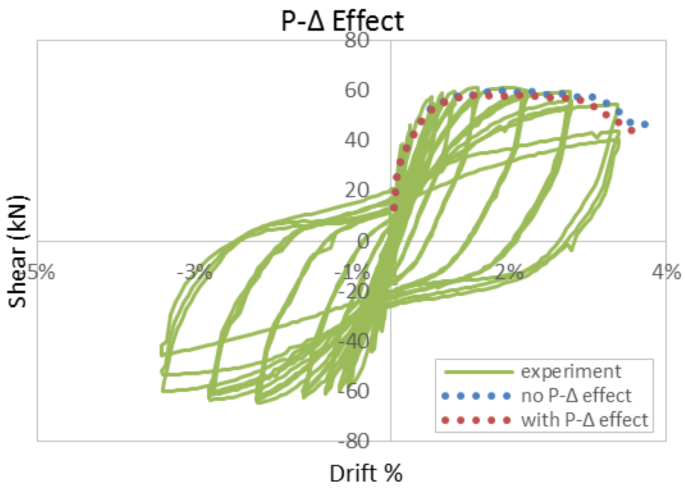


$$V = P + N \times \frac{x}{a}$$

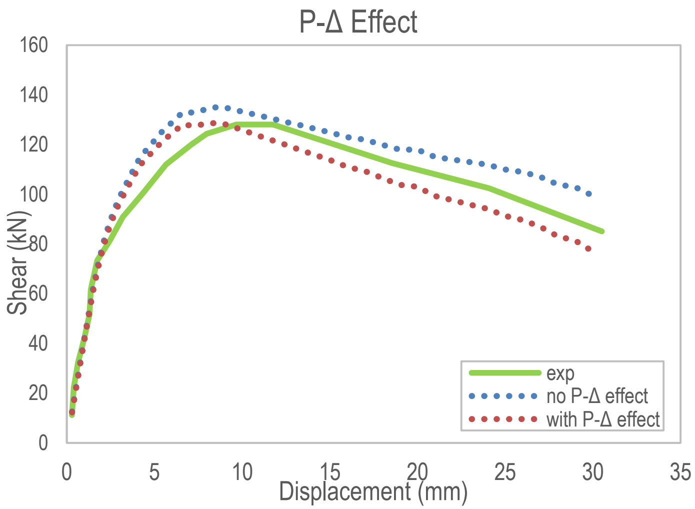
$$x = (z + a) \times \sin\theta$$

$$\theta = \tan^{-1}\left(\frac{\Delta}{Z}\right)$$

Example of Rodrigues



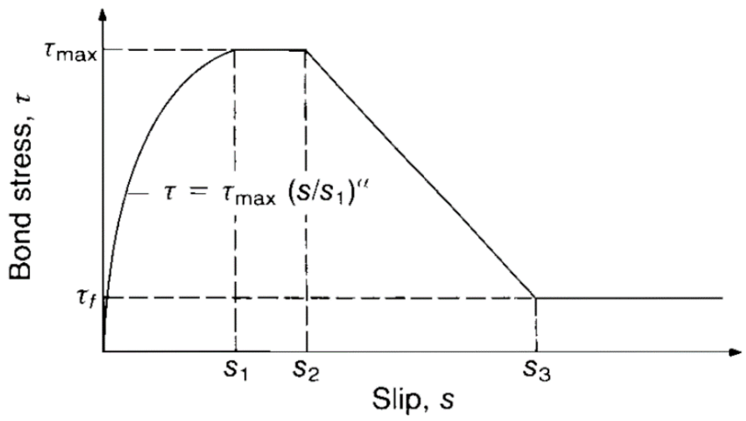
Example of Shima, V4



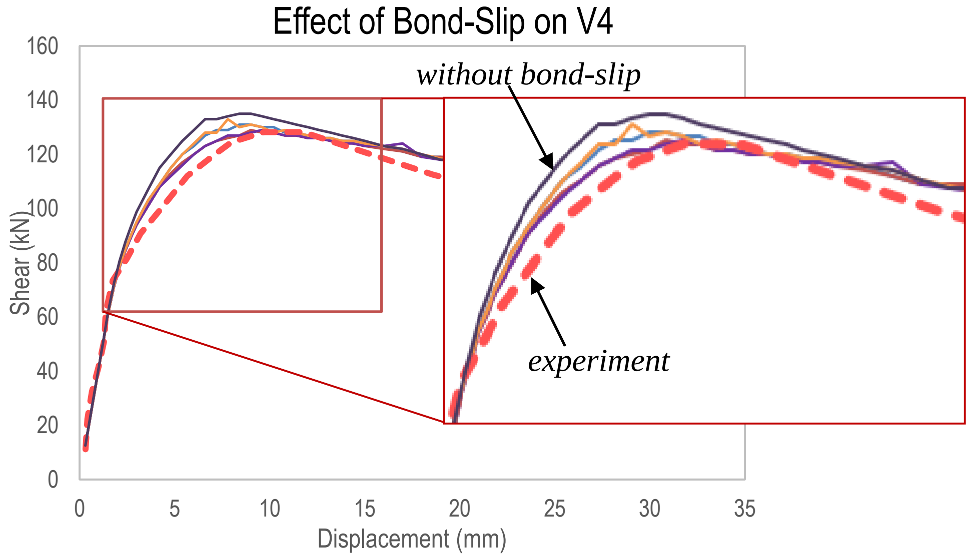
* *Denponpang, T. & Shima, H., 2005, "Effect of axial load on ductility of reinforced concrete columns", 30th conference on our world in concrete & structures, Singapore*

Bond-Slip Action

	Unconfined		Confined	
	good bond	others	good bond	Others
s1	0.6	0.6	1.0	1.0
s2	0.6	0.6	3.0	3.0
s3	1	2.5	clear rib spacing	
α	0.4	0.4	0.4	0.4
τ_{max}	2.0√fck	1.0√fck	2.5√fck	1.25√fck
τ_f	0.15 τ_{max}	0.15 τ_{max}	0.40 τ_{max}	0.40 τ_{max}



("CEB-FIB model code for concrete structures," Thomos Telford, Lausanne, 1993)



$$\tau = \tau_{max}\left(\frac{s}{s_1}\right)^{a}, for \quad 0 \le s \le s_1$$

$$\tau = \tau_{max}, for \quad s_1 < s \le s_2$$

$$\tau = \tau_{max} - (\tau_{max} - \tau_f) \times \left(\frac{s - s_2}{s_3 - s_2}\right), for \quad s_2 < s \le s_3$$

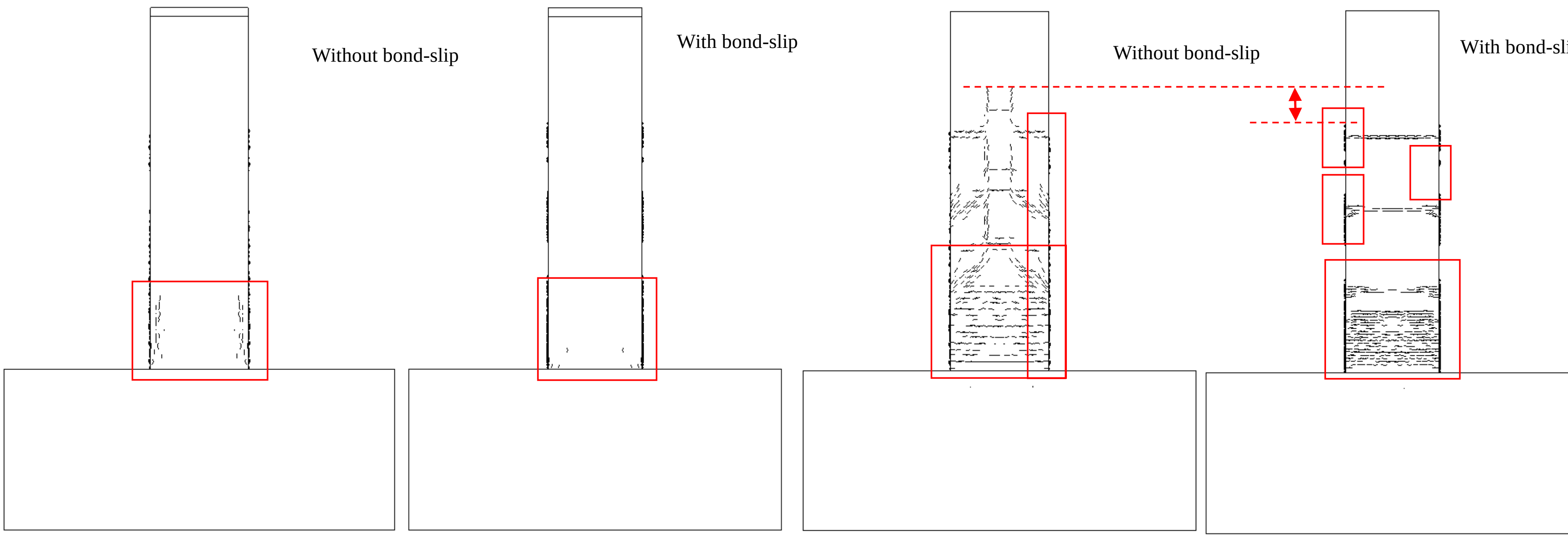
$$\tau = \tau_f, for \quad s_3 < s$$

("CEB, "RC elements under cyclic loading," Thomas Telford, London , 1996)

Effects of Bond-Slip on Crack Pattern

Compressive side

Tensile side



V1-no axial load

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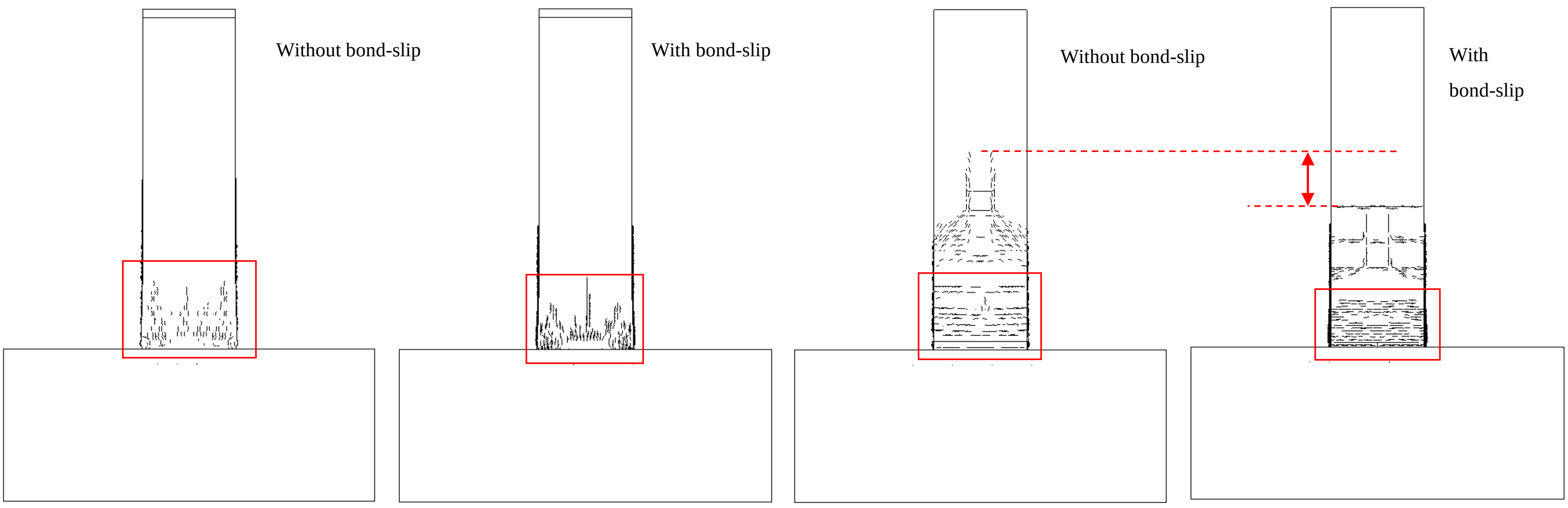
Effects of Bond-Slip on Crack Pattern

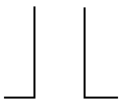
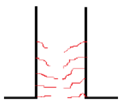
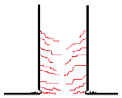
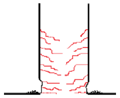
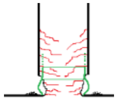
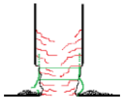
Compressive side

Tensile side



V4- 90% axial load level of Nb

Physical Damages

Damage States	Visible damage (for columns)	
Slight		Hairline cracks w<0.1 mm
		Cracks 0.1 mm<w<0.8 mm
Moderate		Crushing of concrete in the joints + Light Spalling of concrete
		Spalling of concrete
Severe		Buckling of bars
		Fracture of bars
Collapse		Element completely out of its original position

Conclusions

- There is a good agreement between experimental and numerical analyses in terms of global and local demands,
- The FE models could be considered insensitive to mesh size. Fine meshing is however used due to stability considerations,
- Compression fracture energy affects the ductility along backbone curve,
- Geometric nonlinearity plays a role on strength capacity and its influence increases with the lateral displacement,
- Bond-slip effect greatly influences the crack pattern even though its influence cannot be observed in global sense significantly.