

UNCERTAINTY OF NUMERICAL MODELS OF RC STRUCTURES

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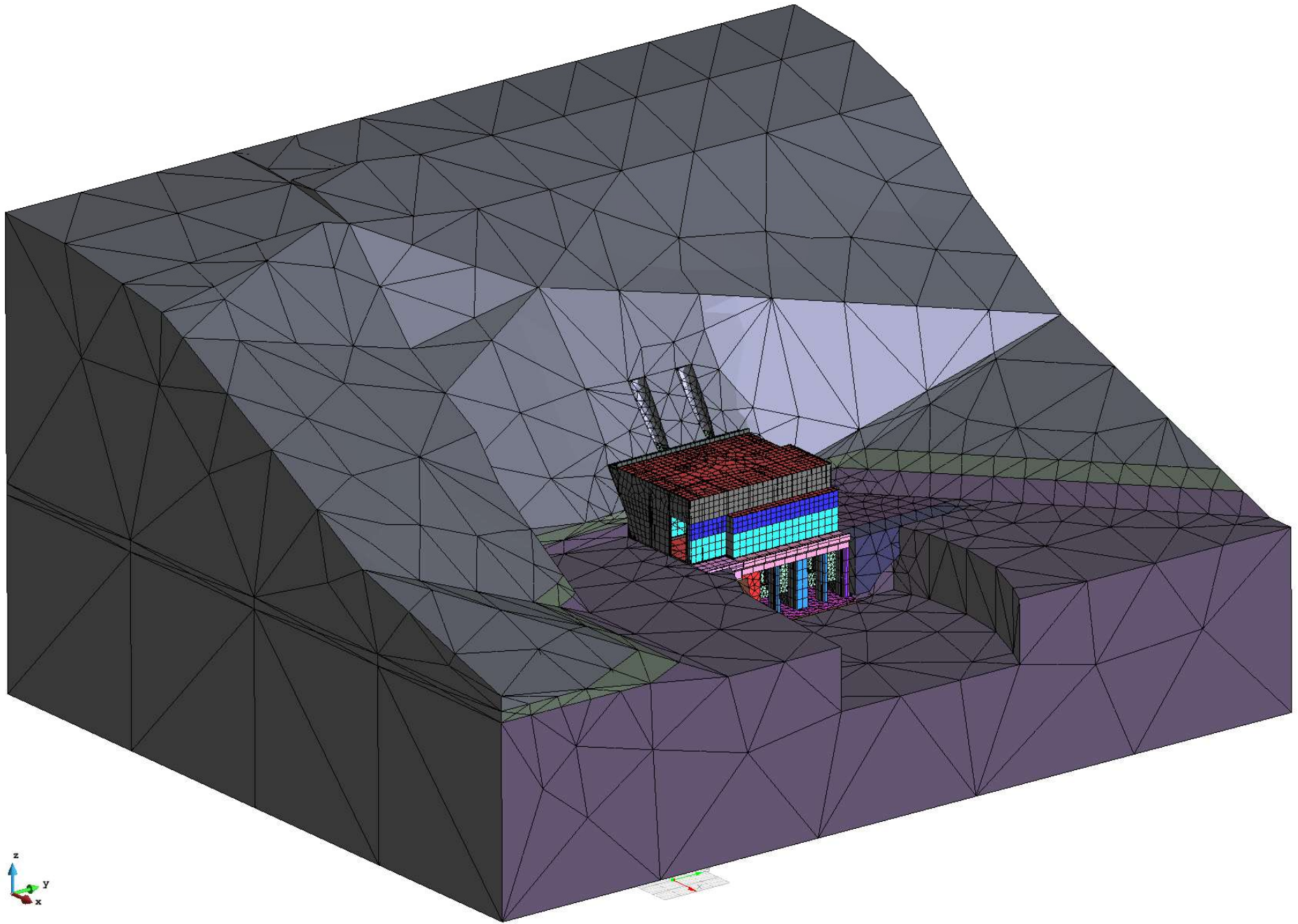
Model uncertainty

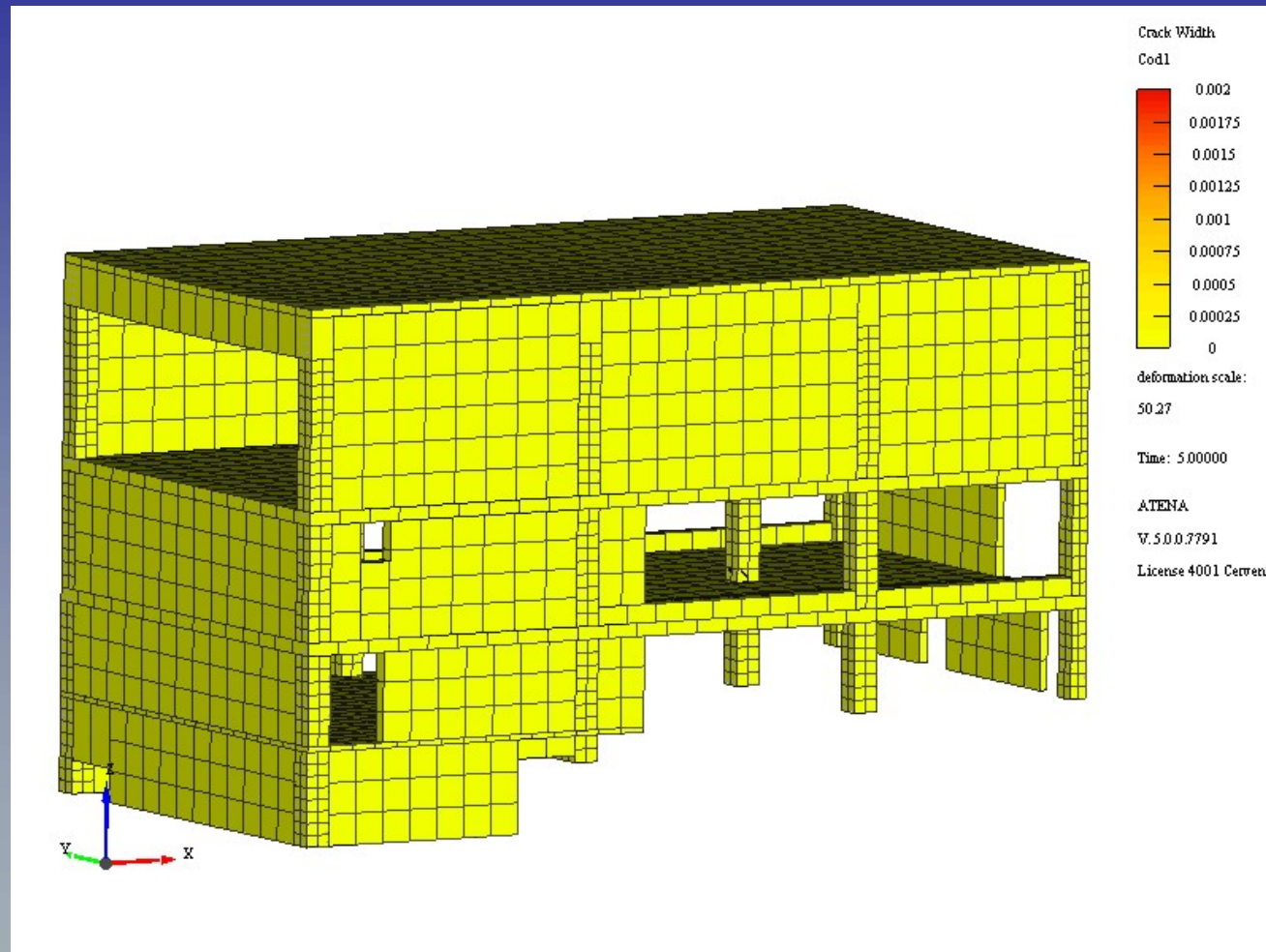
Experiments

Numerical simulations in ATENA

Safety factor for model uncertainty







FEM Nonlinear analysis of ULS → Global safety format

$$F_d < R_d$$

$$R_d = \frac{R_m}{\gamma_M \gamma_{Rd}}$$

Global safety factor for material uncertainty γ_M

Safety factor for model uncertainty γ_{Rd}

EN 1992 - 2

$$\gamma_{Rd} = 1.06$$

Model Code 2010

$$\gamma_{Rd} = 1.0 \div 1.1$$

Failure mode

Constitutive formulations



Model uncertainty as random variable

Method of assessment based on validation by experiments

$$\theta = \frac{R_{test}}{R_{simulation}}$$

Data base θ_i , i – no. of samples

Safety factor of model uncertainty

Large data set – log-normal PDF

$$\gamma_{Rd} = \frac{\exp(\alpha_R \beta \times V_\theta)}{\mu_\theta}$$

Limited data set – Student's PDF

$$\gamma_{Rd} = \frac{1}{\mu_\theta \exp(t_{p=0.112} (n-1) \times V_\theta)}$$



Case study ULS 33 cases

Punching shear tests 15

**Guandalini, S. And Muttoni, A., EPFL, Lausanne
Hallgren M., KTH Stockholm**

Shear strength of large beams 7

Collins M.P., Toronto

Bending strength of beams 11

Debernardi P.G., Torino



Range of parameters:

Modes of failure:

Brittle (concrete), ductile (steel)

With and without shear reinforcement

Concrete:

NSC, HSC

Size range:

0.1 to 4 m

scale 1:40



Numerical simulation by ATENA

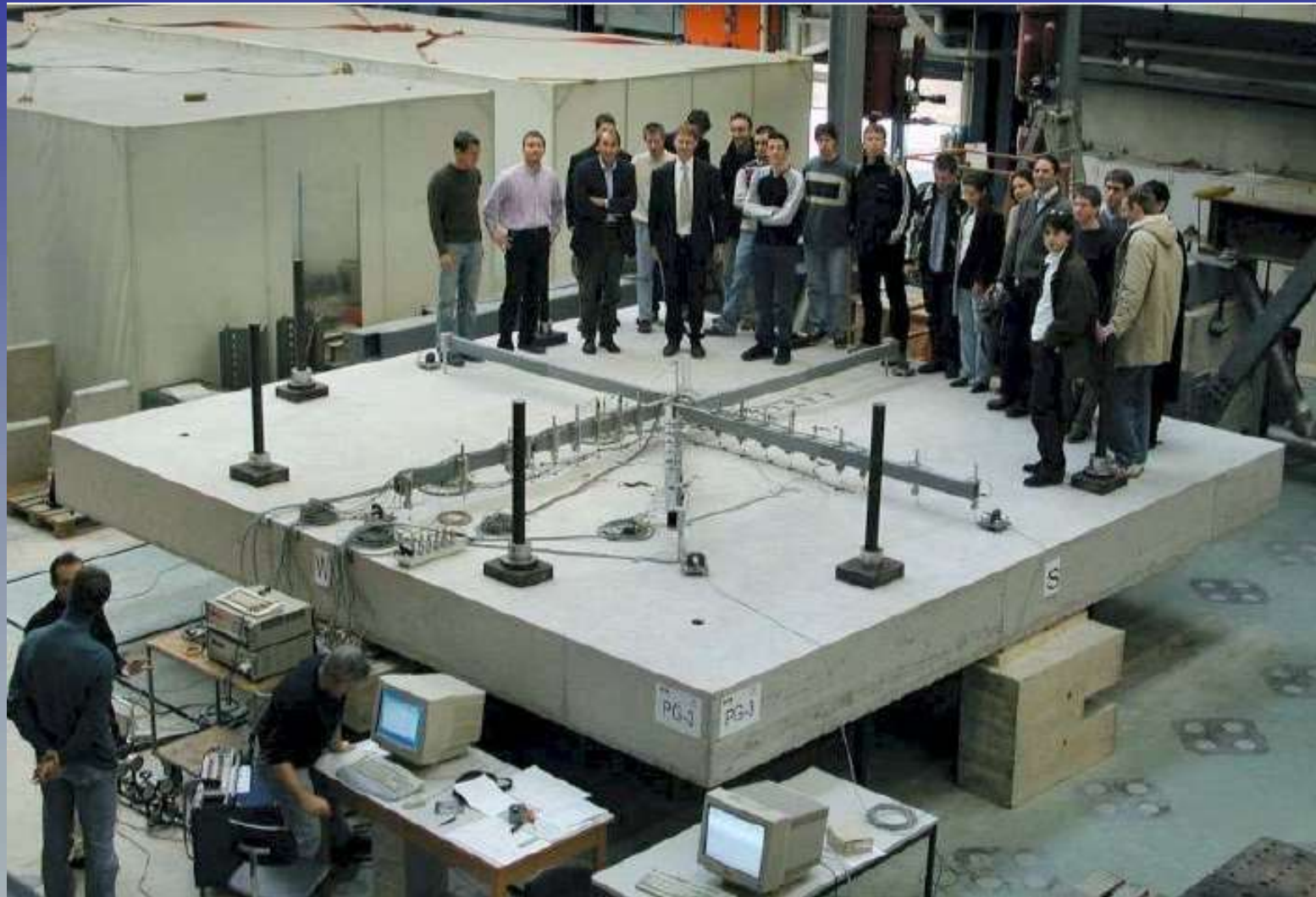
concrete: fracture-plastic constitutive law

steel: multilinear with hardening

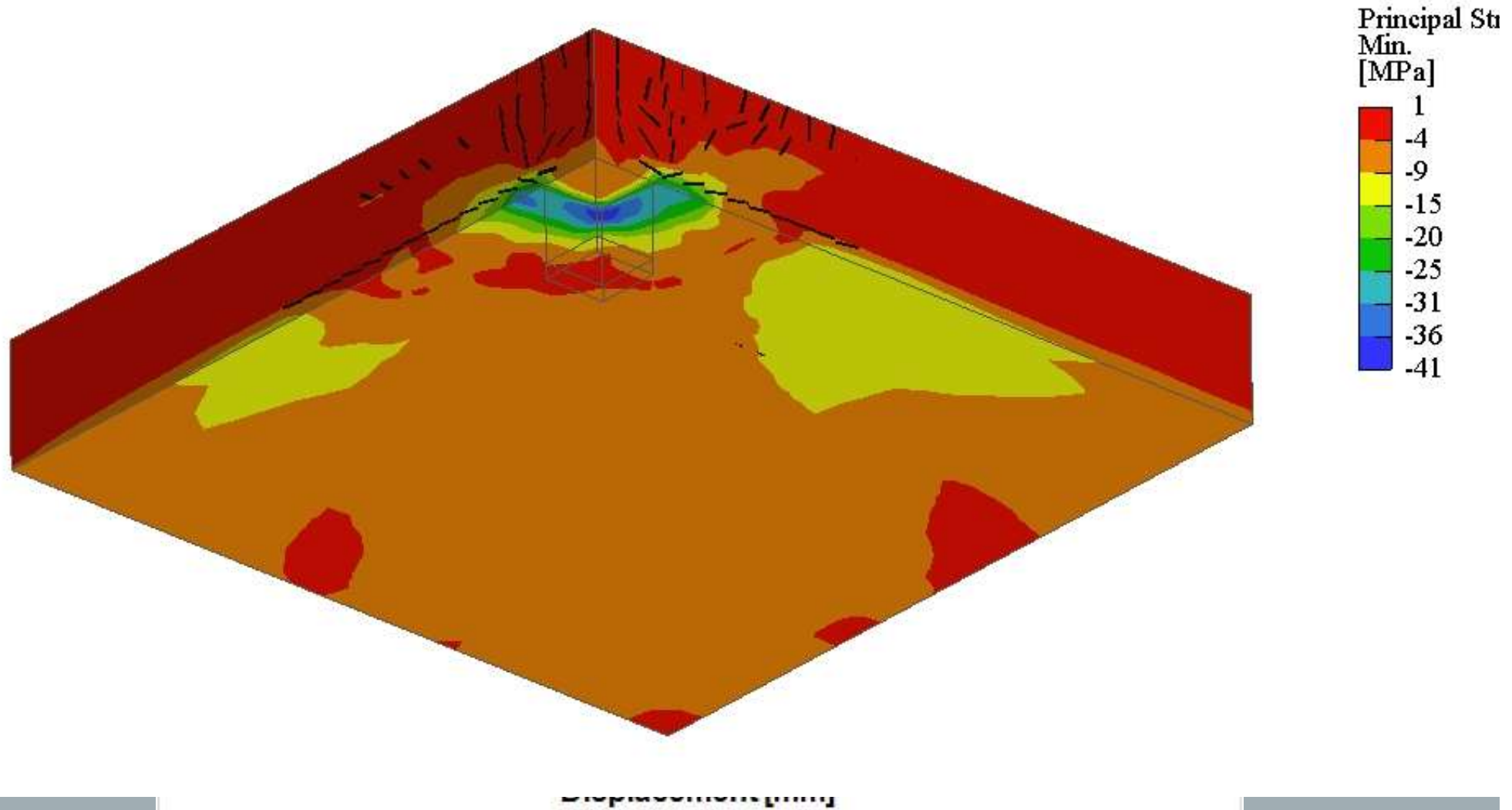
bond-slip interface



Punching shear tests by Guandalini, S. And Muttoni, A., EPFL, Lausanne



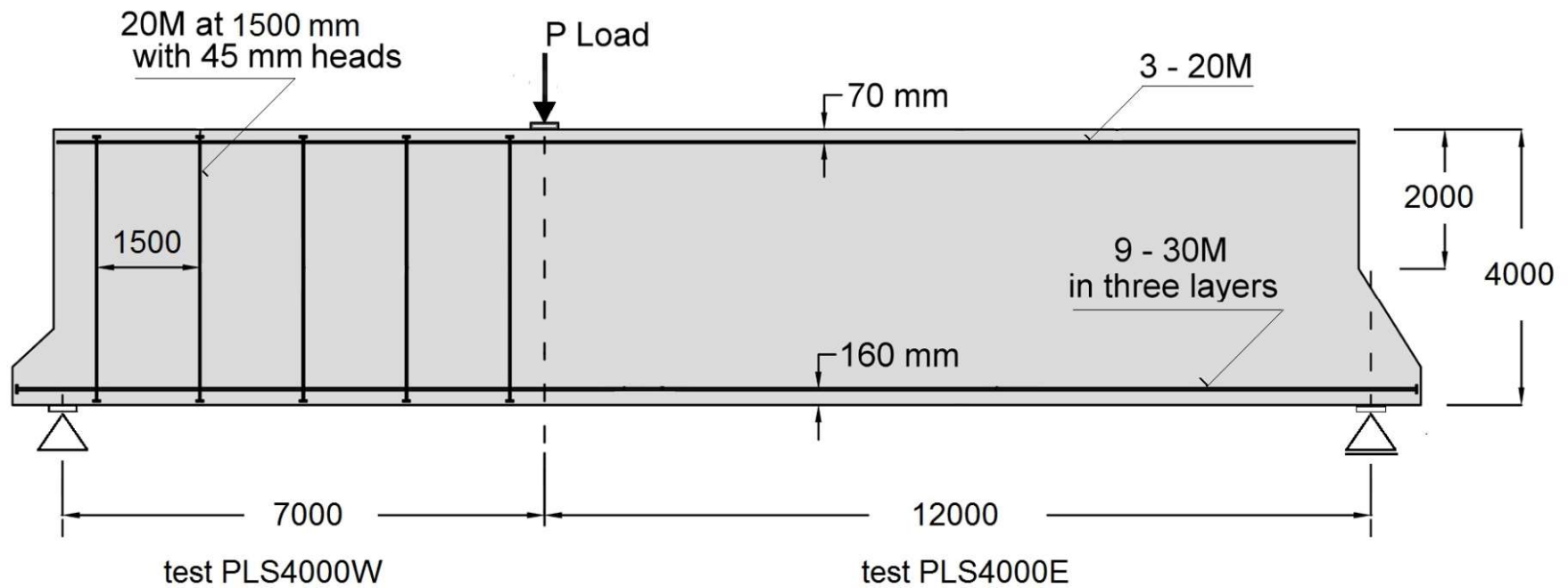
Punching shear



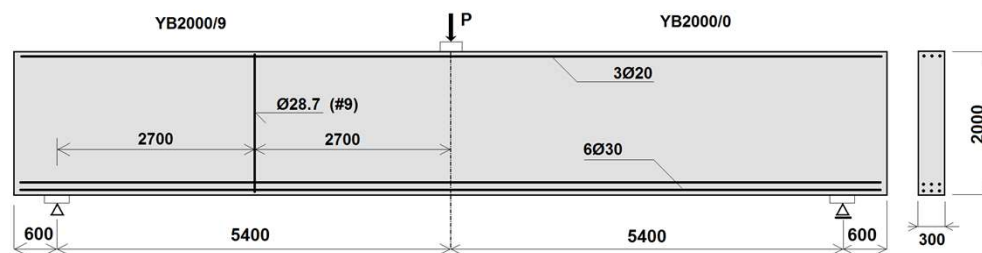
Prediction of shear strength test Toronto 2015



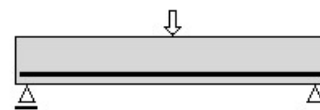
H=4m



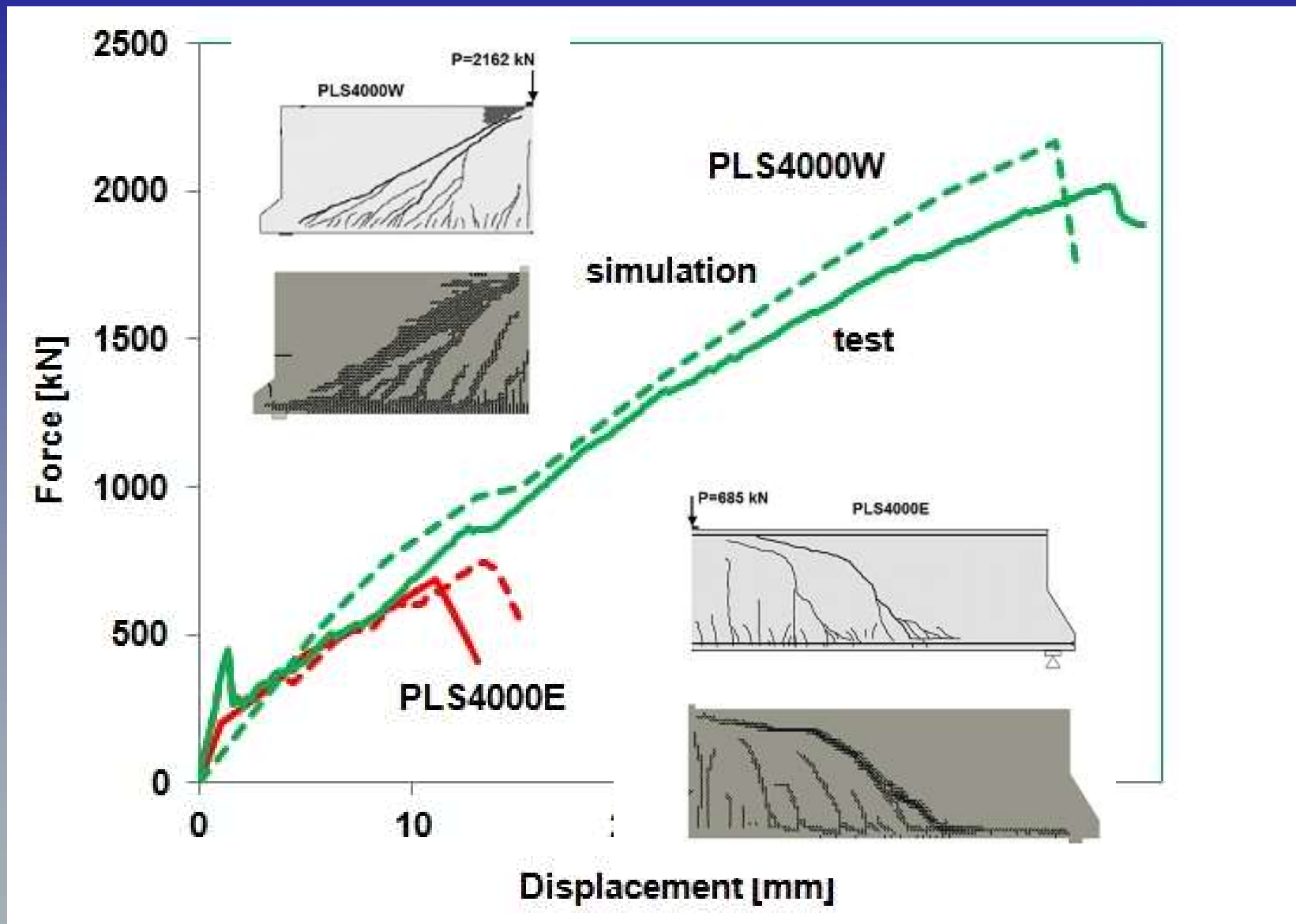
H=2m



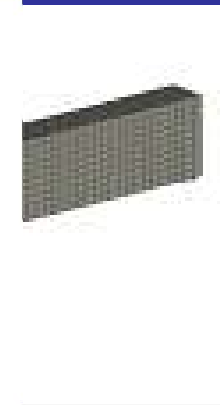
H=0.3m



Shear strength predictions



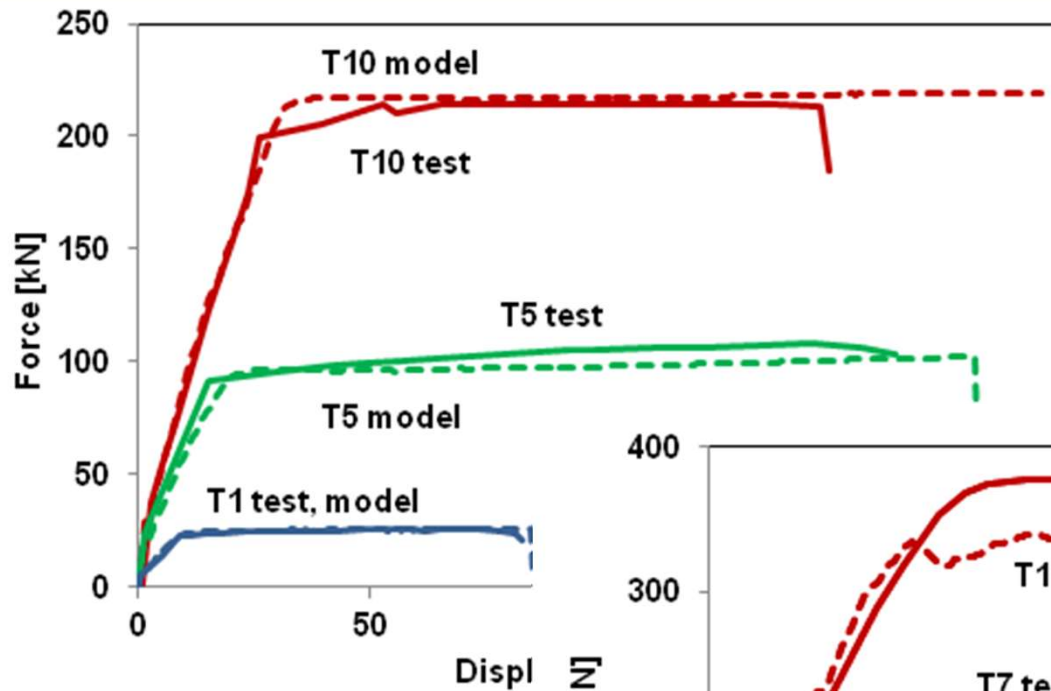
Bending strength of normal beams by Debernardi, Torino



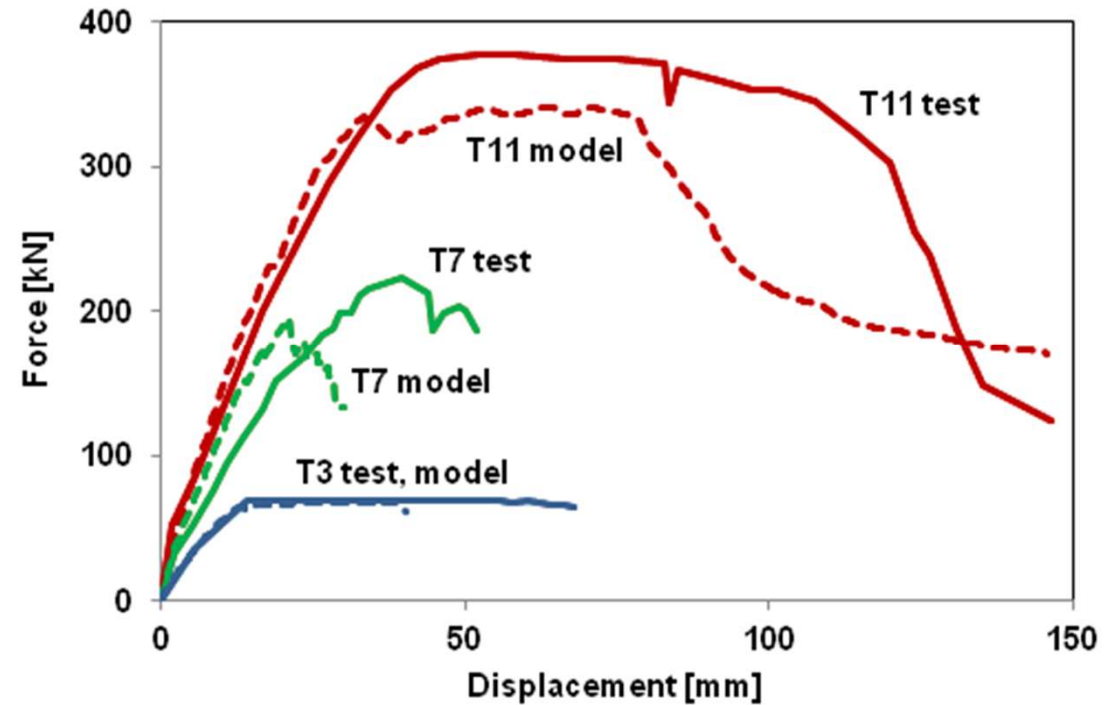
$h = 200, 400, 600\text{mm}$

$\rho = 0.6-2\%$

steel failure



concrete failure



Safety factors in ULS due to model uncertainty NLFEA

Failure mode	μ_{θ}	V_{θ}	γ_{Rd}
Punching	0.971	0.076	1.16
Shear	0.984	0.067	1.13
Bending	1.072	0.052	1.01
All failure modes	0.979	0.081	1.16



CONCLUSIONS ULS

Model uncertainty is reflecting the knowledge comprised in numerical model.

Validation by experiments is required.

Safety factor for model uncertainty for ULS of all RC structural types and sizes

$$\gamma_{Rd} = 1.16$$

It is valid for ATENA models only



Uncertainties of crack models in SLS

$$\theta_w = w_{\text{experiment}} / w_{\text{model}}$$

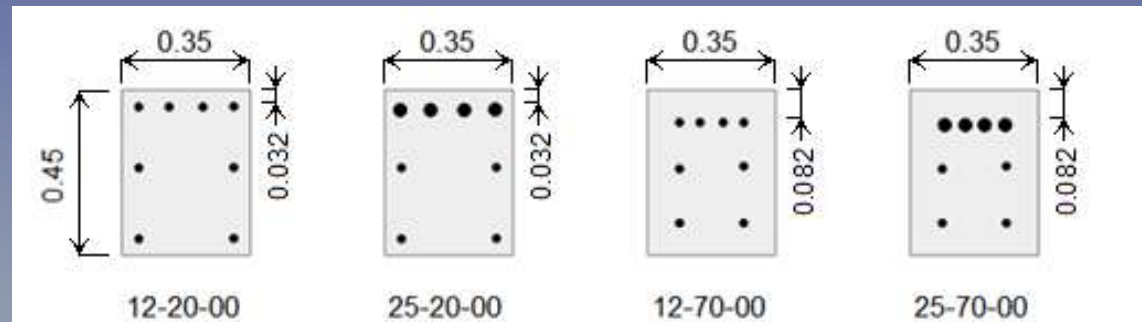
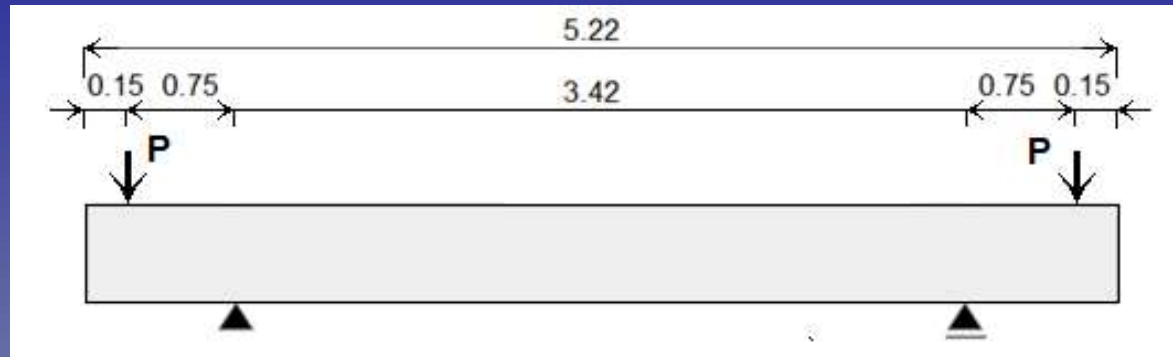
Model uncertainty θ_w is a random variable

μ_θ - mean uncertainty, model validation

V_θ - coefficient of variation, measure of uncertainty



Experiments by Alejandro Perez Caldentey



variable:

reinforcement \varnothing 12 and \varnothing 25mm
cover 20 and 70mm

$f_c = 27$ Mpa

$f_{yk} = 500$ MPa

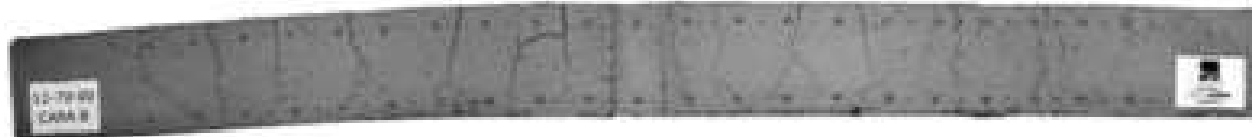


Experimental crack patterns

12-20-00



12-70-00



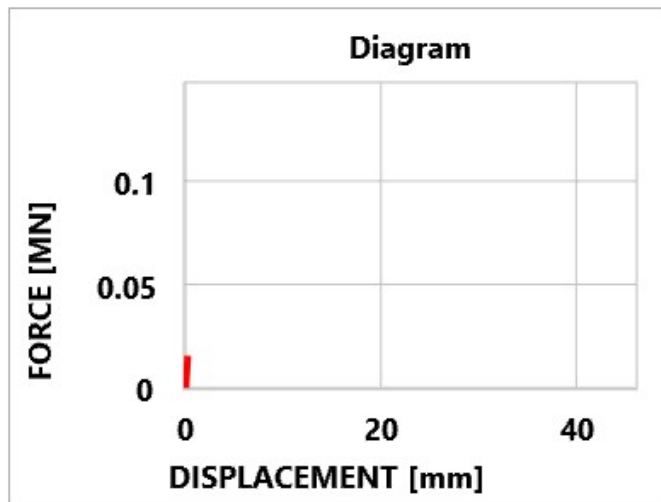
25-20-00



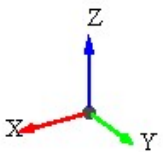
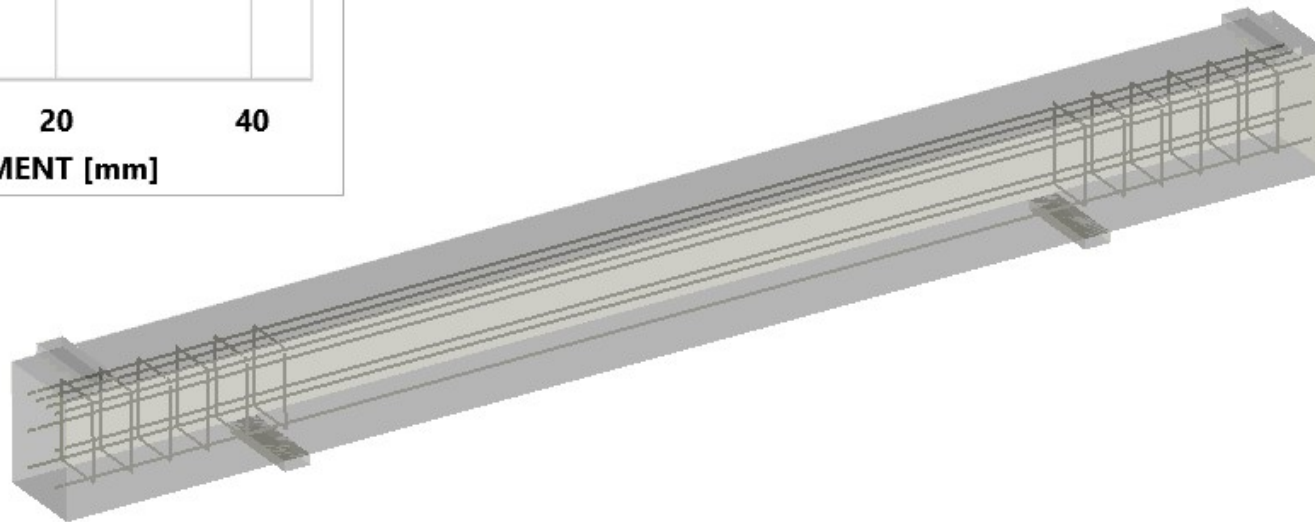
25-70-00



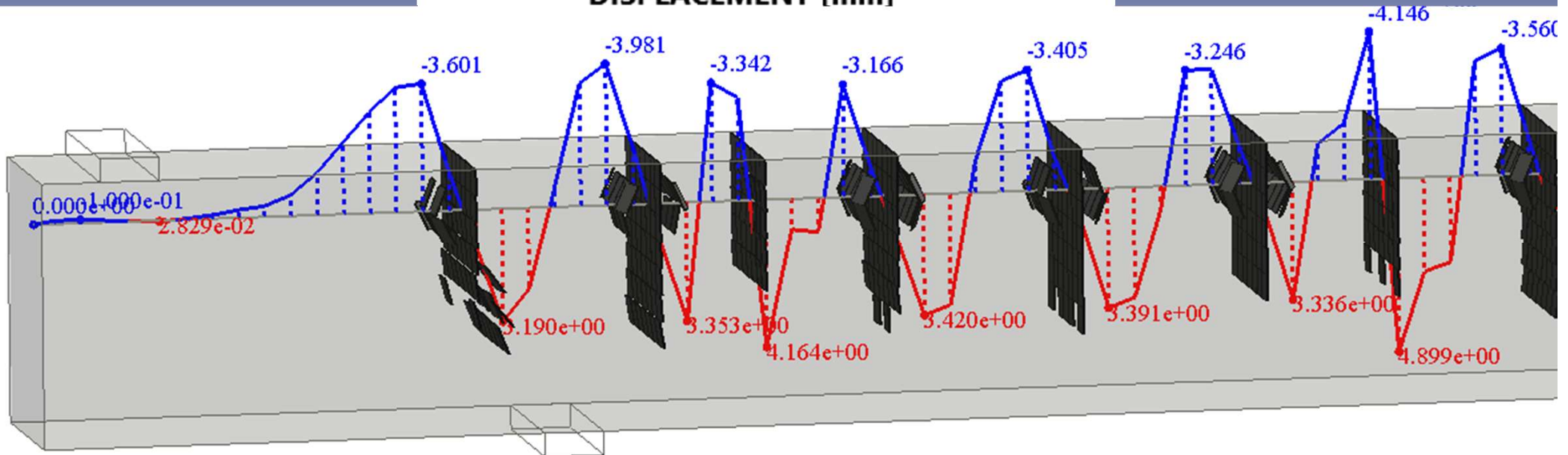
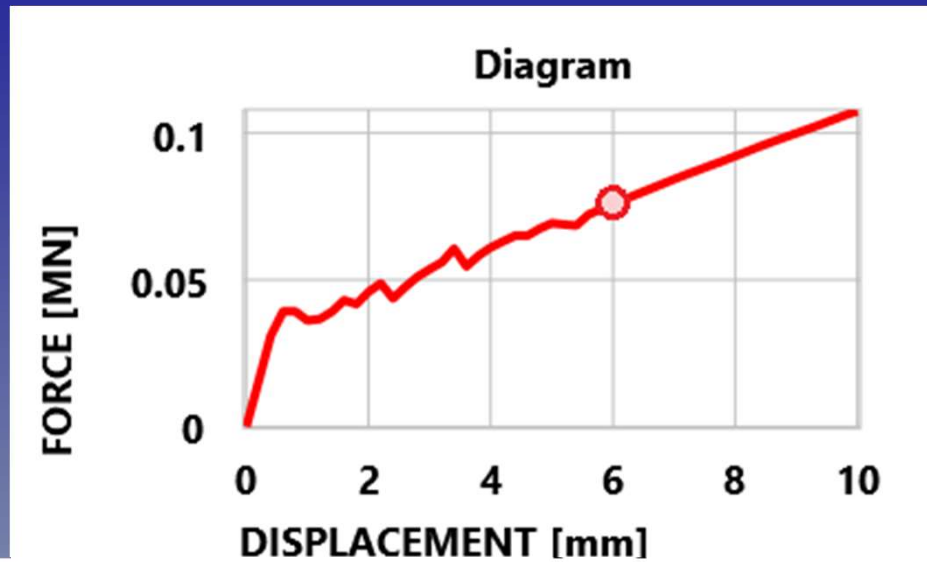
Crack development



Deformation scale:
5.
Time: 1.00000
ATENA
x64 V. 6.0.0.14638 mod



Bond stress



Model uncertainty of crack width

					Model uncertainty	
					<i>mean</i>	V_{θ}
12-20-00	P [kN]	69.6	89.2	161.6		
	w_{mean} [mm]	0.231	0.305	1.233		
	w_{max} [mm]	0.245	0.328	1.560		
	$\theta_{w,mean}$	0.711	0.797	0.513	0.67	0.22
	$\theta_{w,max}$	1.510	1.250	0.621	1.13	0.41
12-70-00	P [kN]	51.1	60.7	100		
	w_{mean} [mm]	0.297	0.353	0.691		
	w_{max} [mm]	0.297	0.374	0.780		
	$\theta_{w,mean}$	0.828	1.079	0.947	0.95	0.13
	$\theta_{w,max}$	1.111	1.275	1.474	1.29	0.14
25-20-00	P [kN]	102.1	183.3	403		
	w_{mean} [mm]	0.062	0.126	0.280		
	w_{max} [mm]	0.068	0.150	0.420		
	$\theta_{w,mean}$	1.971	1.178	1.259	1.47	0.30
	$\theta_{w,max}$	2.916	1.913	1.638	2.16	0.31
25-70-00	P [kN]	56.7	101.7	298.8		
	w_{mean} [mm]	0.082	0.192	0.621		
	w_{max} [mm]	0.089	0.217	0.877		
	$\theta_{w,mean}$	1.360	1.229	1.193	1.26	0.07
	$\theta_{w,max}$	1.787	1.544	1.324	1.55	0.15
All specimens all load levels	$\theta_{w,mean}$	1.218	1.071	0.978	1.09	0.35
	$\theta_{w,max}$	1.831	1.496	1.264	1.53	0.36



Thank You for your attention!

