

9th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering

## A NEW MULTISCALE STEEL-CONCRETE BOND MODEL FOR STRUCTURAL DYNAMICS

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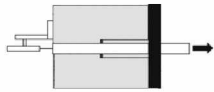
# Content



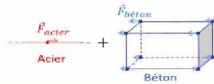
Interest of the subject for dynamic applications: Energy dissipation at the steel-concrete interface level.



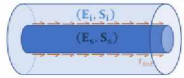
Physical description of the interface behavior.



Experimental characterization of the steel-concrete bond.



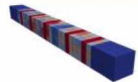
Numerical strategies proposed in the literature for the interface modeling.



Proposal of a new multiscale modeling strategy of the interface behavior: **principles**.

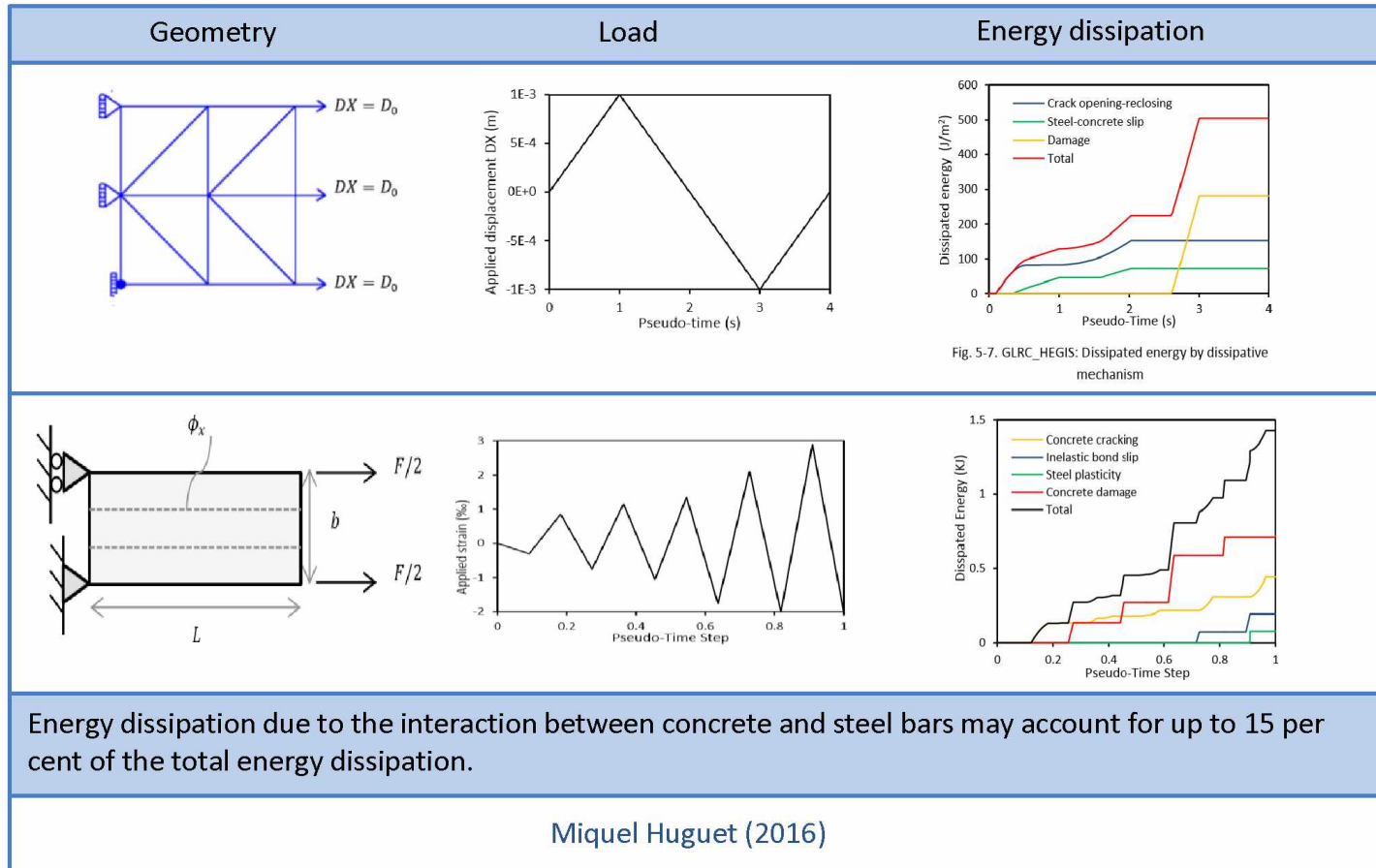


Proposal of a new multiscale modeling strategy of the interface behavior: **validation examples**.



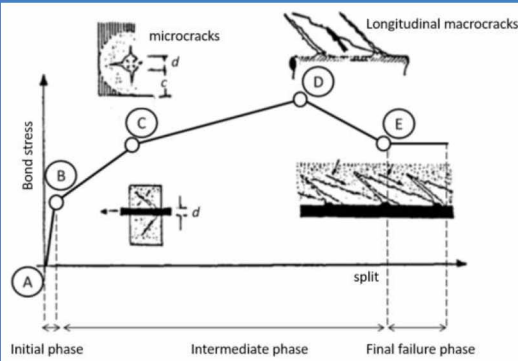
Proposal of a new multiscale modeling strategy of the interface behavior: **application examples**.

# Energy dissipation at the steel-concrete interface level

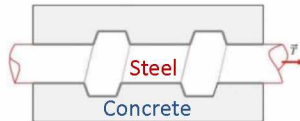


# Interface behavior

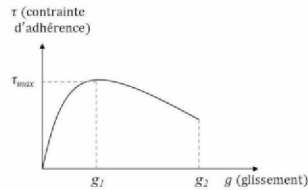
## Physical description



Frantzeskakis (1987)



Torre-Casanova (2012)



$$\tau = k_1 g - k_2 g^2 + k_3 g^3$$

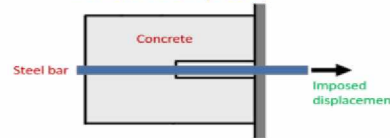
Nilson (1968)

## Experimental tests

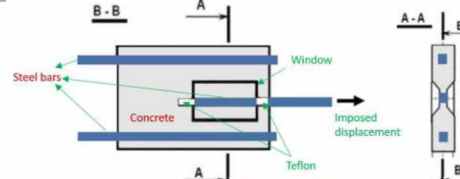
Ties Clément (1987)



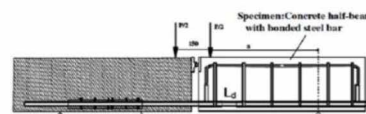
Pull-out Dahou et al.(2009)



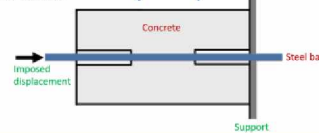
PIAF test Tran et al. (2009)



Beam tests Dancygier and Katz (2012)



Push-in test Tixier(2015)

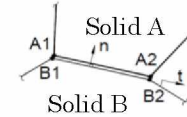


## Numerical modeling

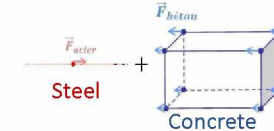
Springs Ngo et Scordelis (1967)



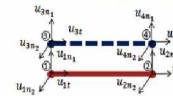
Joint elements Dominguez (2005)



Internal forces Torre-Casanova (2012)



1D steel – 3D point Mang (2015)



Homogenization Sellier et Millard (2019)



# Proposal of a new multiscale modeling strategy of the interface behavior: principles

## Motivations

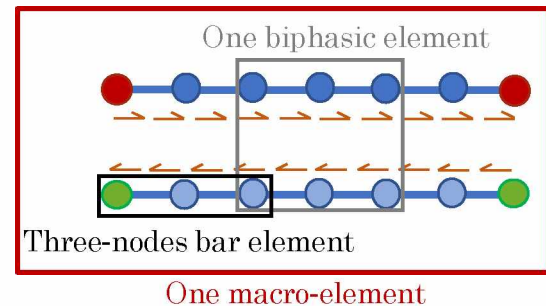
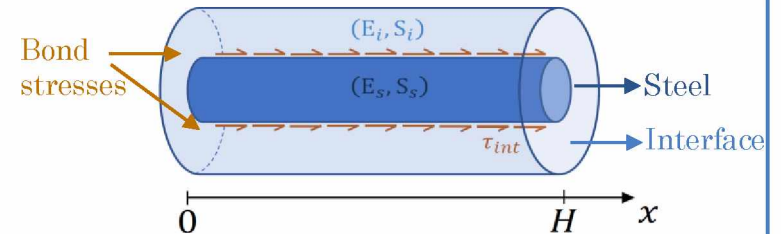
- The numerical modeling of the steel-concrete interface behavior is important for a good representation of the concrete cracking and a better estimate of material energy dissipation.
- A representative description of the interface behavior at the scale of an industrial building using existing models is still tedious and impractical.

## Principles

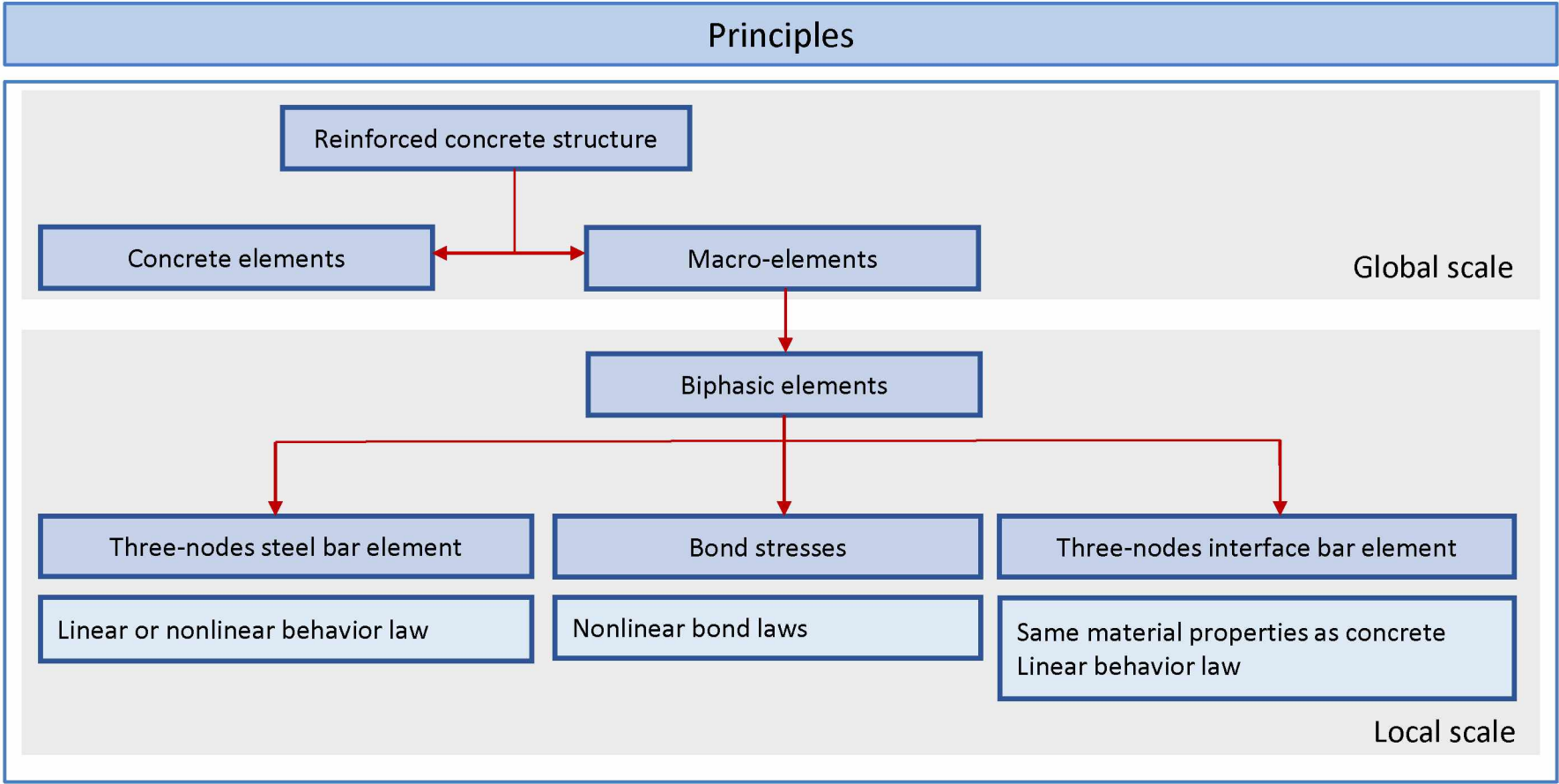
One macro-element = an assembly of several biphasic elements

One biphasic element = an assembly of :

- one three-nodes bar elements representing steel;
- one three-nodes bar elements representing the interface;
- bond stresses

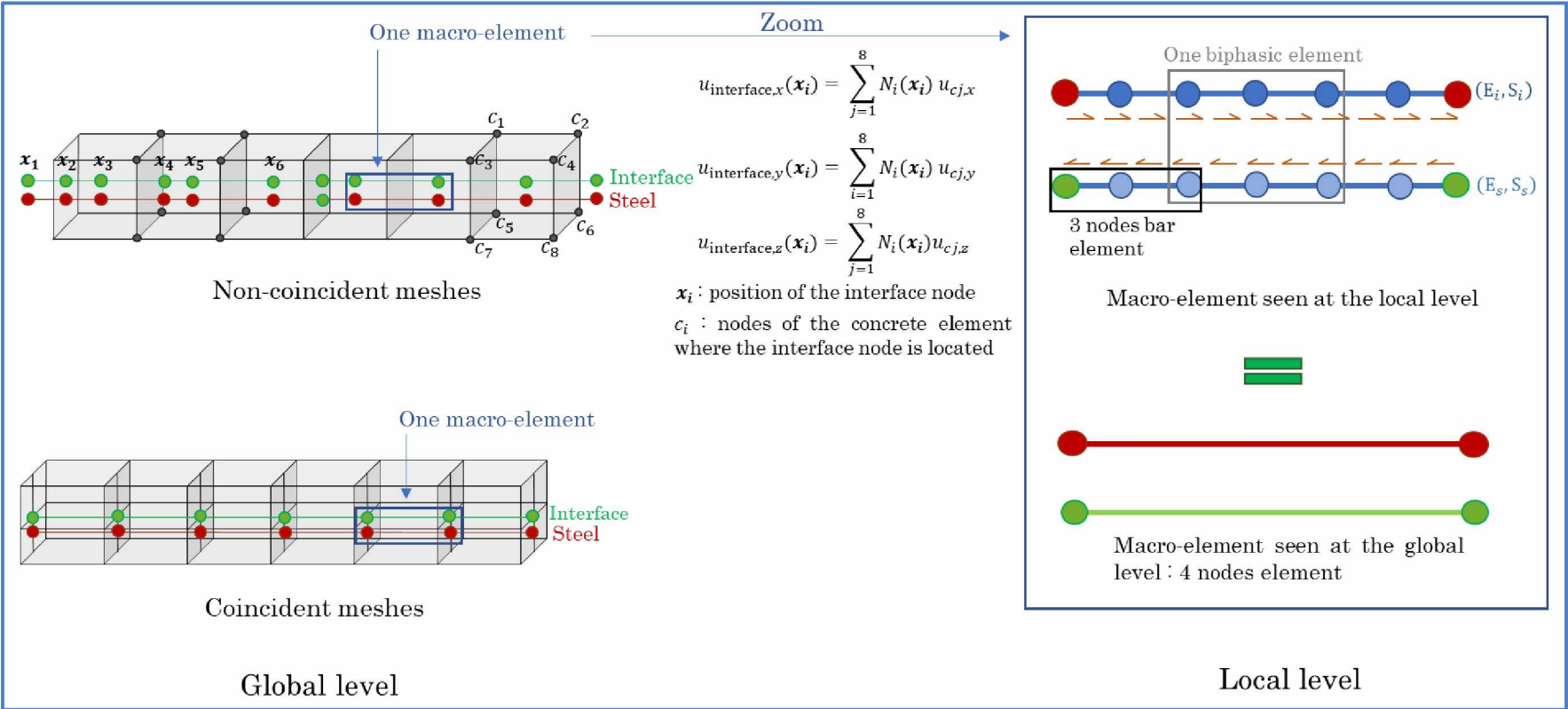


# Proposal of a new multiscale modeling strategy of the interface behavior: principles

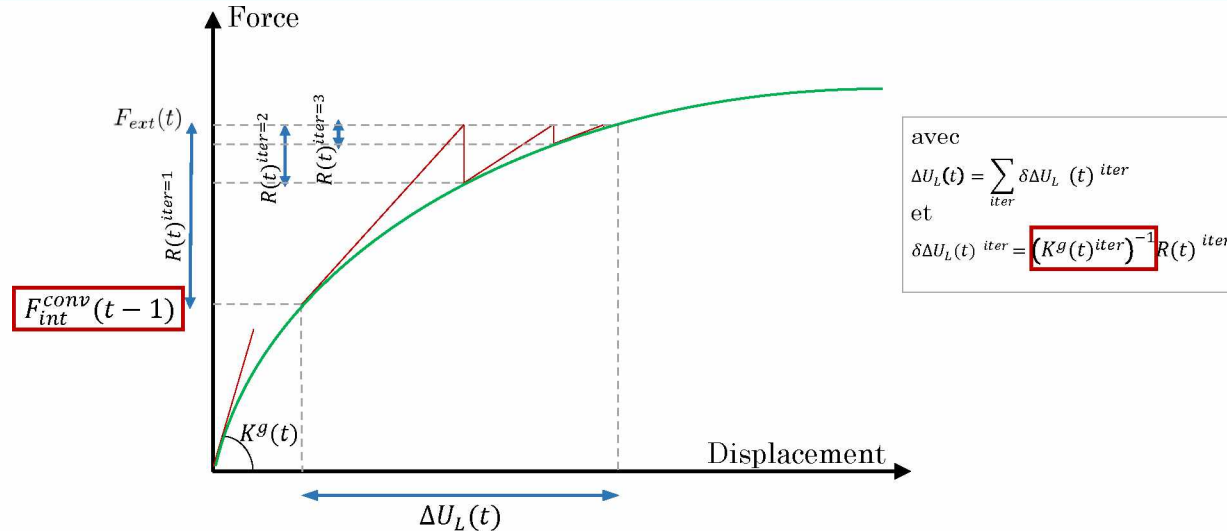


# Proposal of a new multiscale modeling strategy of the interface behavior: principles

## Principles



## Principles



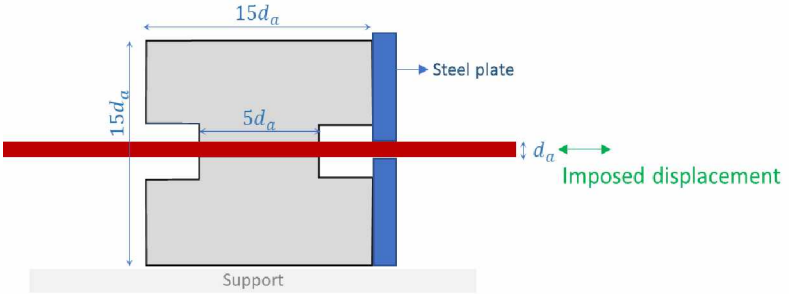
- For the calculation of  $F_{int}$  and  $k$ , a local algorithm is called in order to establish the equilibrium of the macro-element (internal force at internal nodes = 0).
- A static condensation technique is used in order to condense the stiffness matrix of the macro-element at its four external nodes.



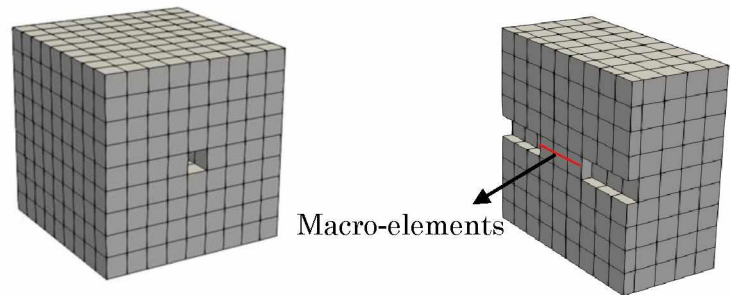
# Proposal of a new multiscale modeling strategy of the interface behavior: validation

## Pullout test of Torre-Casanova 2012

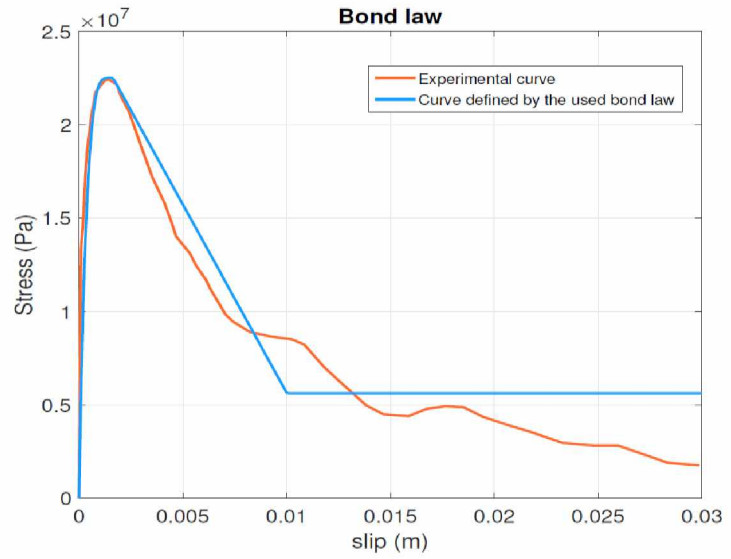
### Test description



### Mesh

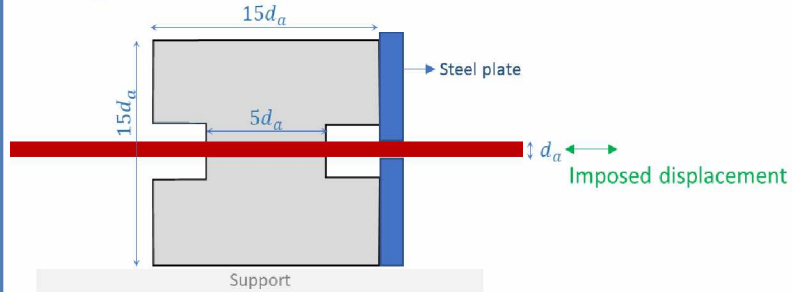


### Material parameters

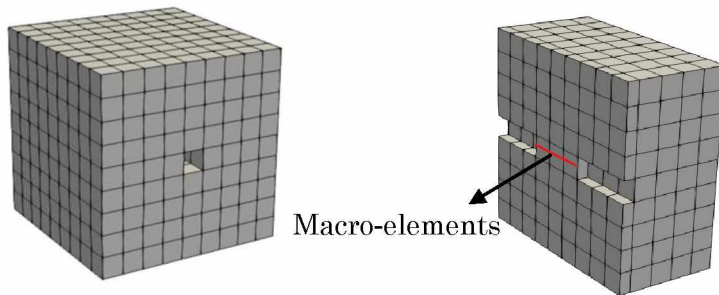


## Pullout test of Torre-Casanova 2012

### Test description



### Mesh



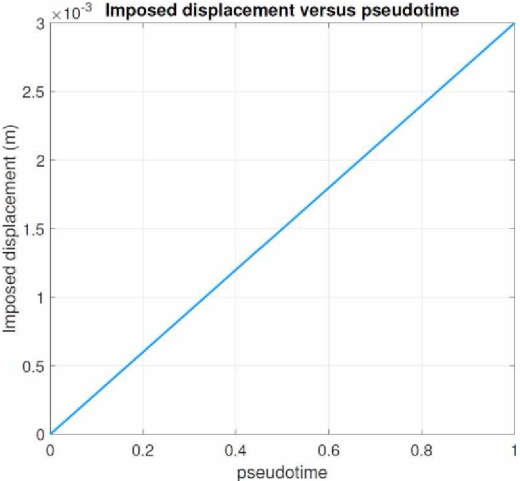
### Material parameters

Concrete parameters	Description	Value	Unit
$E_c$	Young's modulus	28	GPa
$\nu_c$	Poisson's ratio	0.22	-
$f_t$	Tensile strength	3.16	MPa
$\epsilon_{d0}$	Damage threshold	$1.1143 \times 10^{-4}$	-
$A_t$	Local Mazars' model input	Not used - the law is regularized	-
$B_t$	Mazars' model input	Regularized	-
$A_c$	Mazars' model input	1.1	-
$B_c$	Mazars' model input	700	-
$\beta$	Mazars' model input	1.06	-
$G_f$	Fracture energy	150	J/m <sup>3</sup>
Steel parameter	Description	Value	Unit
$E_a$	Young's modulus	200	GPa

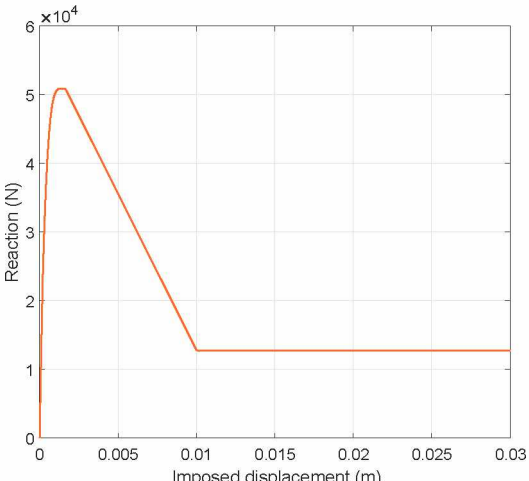
# Proposal of a new multiscale modeling strategy of the interface behavior: validation

## Pullout test of Torre-Casanova 2012

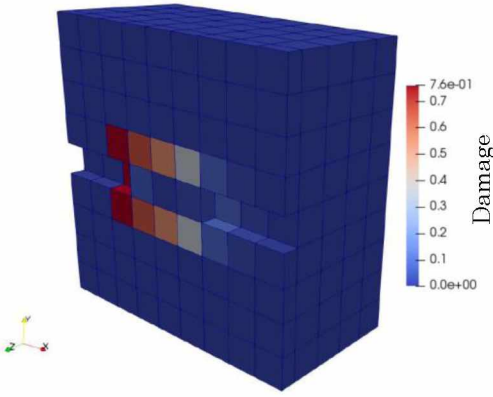
### Imposed displacement



### Reaction



### Damage

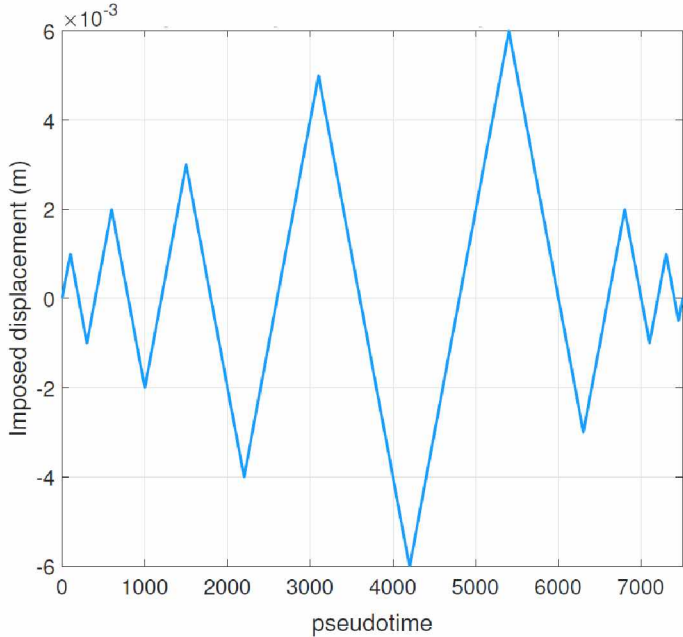


The resultant reaction curve verifies the pullout constitutive equation :  $\tau_s = \frac{F}{\phi\pi l}$

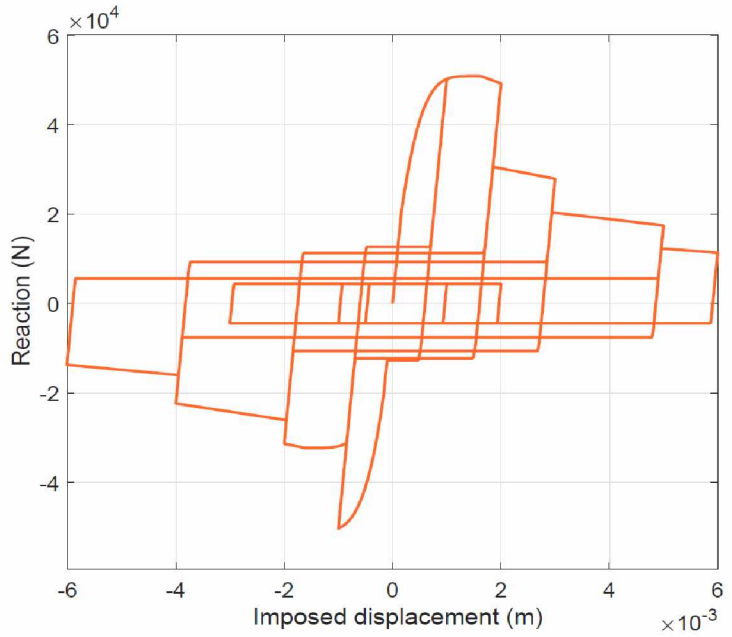
# Proposal of a new multiscale modeling strategy of the interface behavior: validation

## Pullout test of Torre-Casanova 2012

Imposed displacement

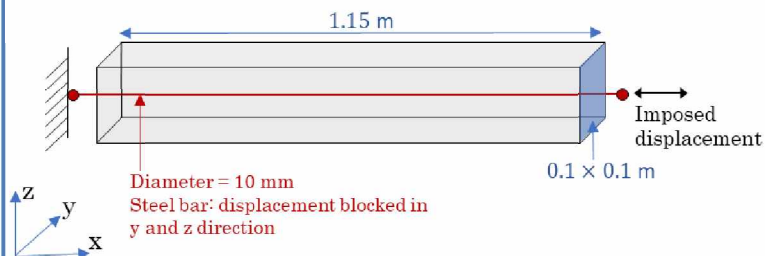


Reaction

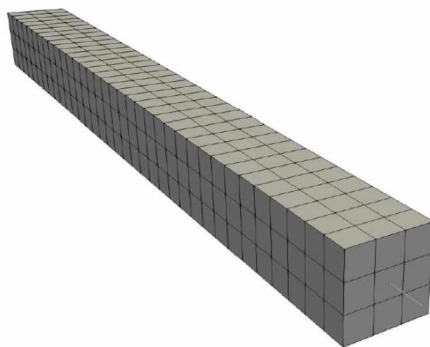


## Tie test of Farra 1995

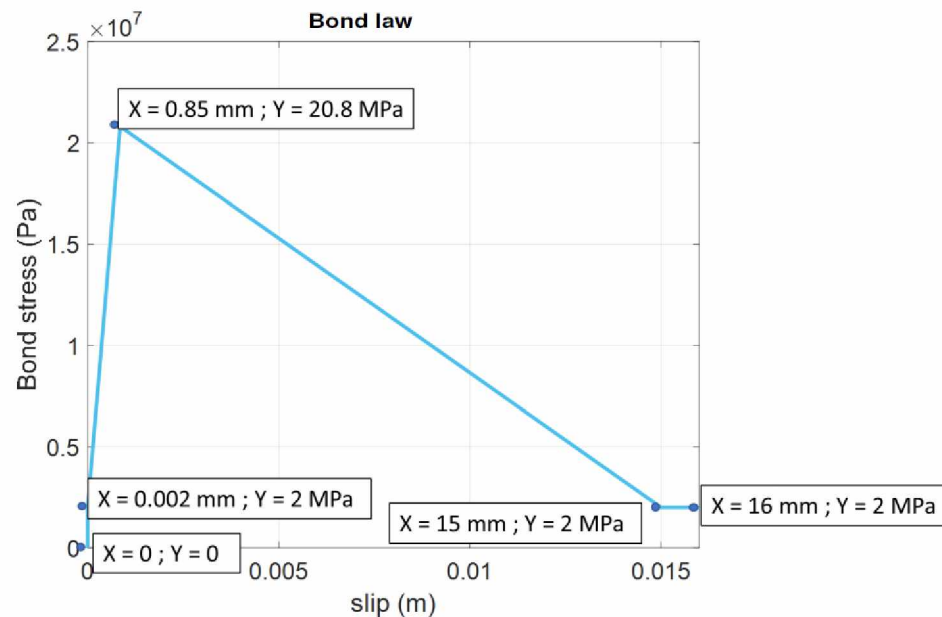
### Test description



### Mesh

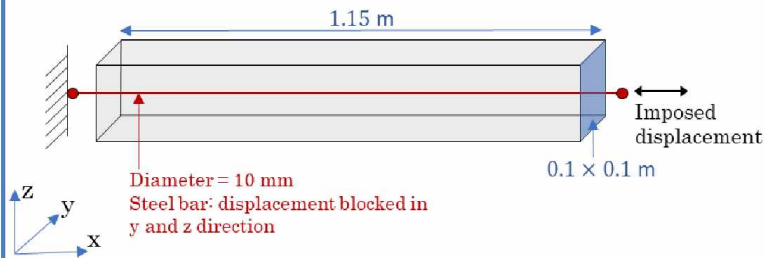


### Material parameters

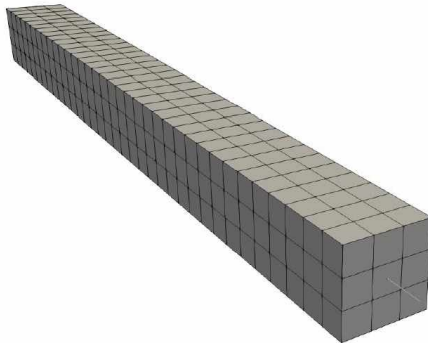


## Tie test of Farra 1995

### Test description



### Mesh



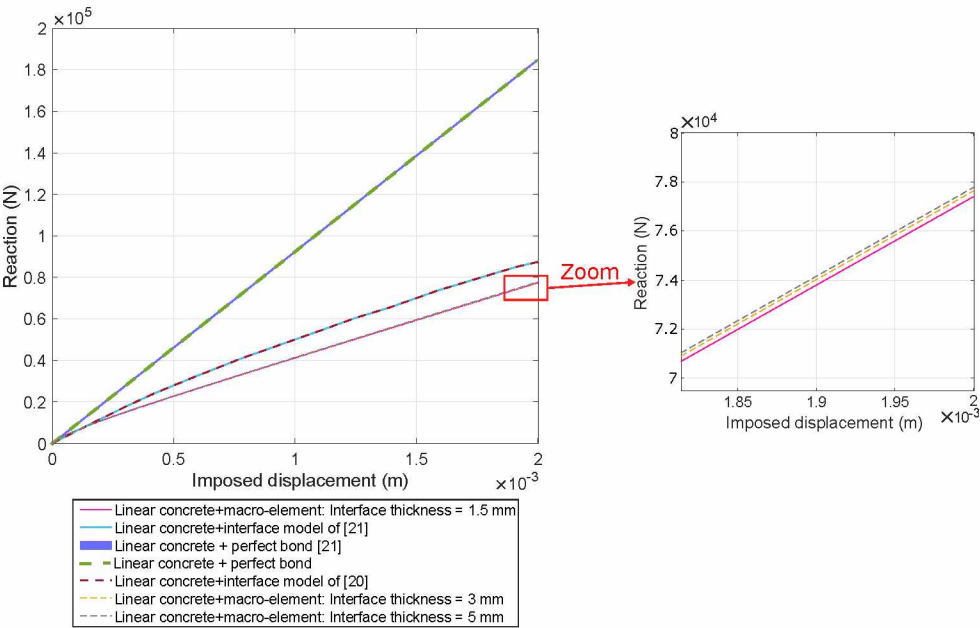
### Material parameters

Concrete parameters	Description	Value	Unit
$E_c$	Young's modulus	30.4	GPa
$\nu_c$	Poisson's ratio	0.22	-
$f_t$	Tensile strength	2.6	MPa
$\epsilon_{d0}$	Damage threshold	$8.5526 \times 10^{-5}$	-
$A_t$	Local Mazars' model input	Not used - the law is regularized	-
$B_t$	Mazars' model input	Regularized	-
$A_c$	Mazars' model input	1.2	-
$B_c$	Mazars' model input	700	-
$\beta$	Mazars' model input	1.06	-
$G_f$	Fracture energy	150	J/m <sup>3</sup>
Steel parameter	Description	Value	Unit
$E_a$	Young's modulus	200	GPa

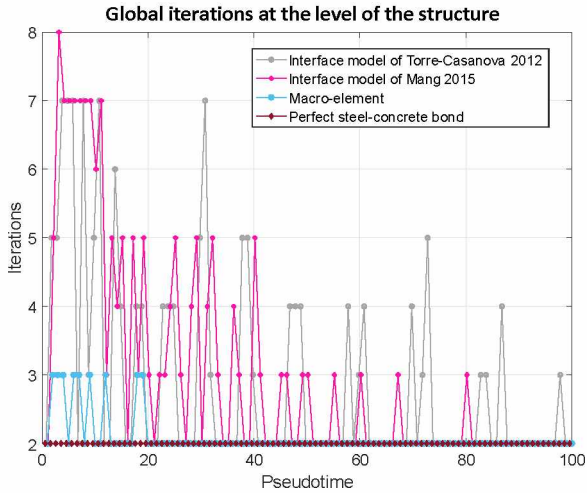
# Proposal of a new multiscale modeling strategy of the interface behavior: application

## Tie test of Farra 1995 – linear concrete behavior

### Reactions



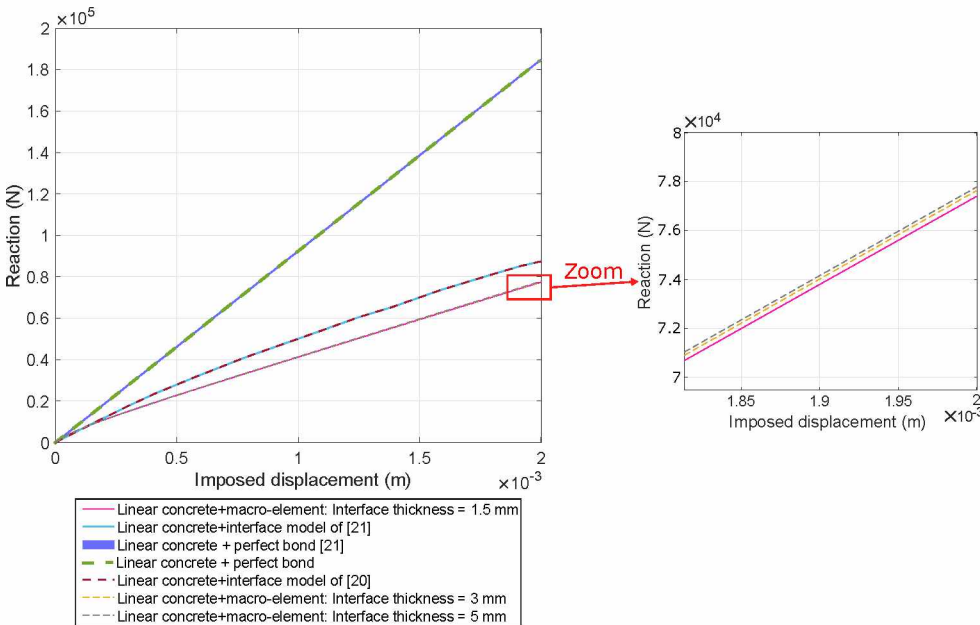
### Iterations



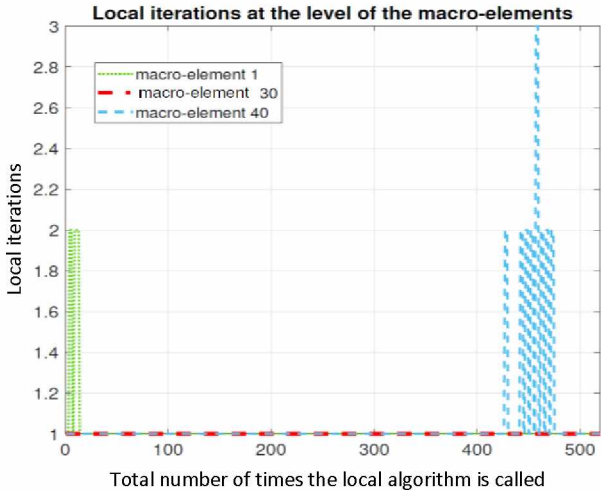
Model	Perfect bond	Torre-Casanova 2012	Mang 2015	Macro-element
Iterations	200	289	299	209

## Tie test of Farra 1995 – linear concrete behavior

### Reactions



### Iterations





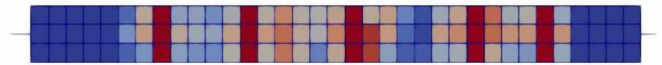
# Proposal of a new multiscale modeling strategy of the interface behavior: application

## Tie test of Farra 1995 – nonlinear concrete behavior

### Concrete damage



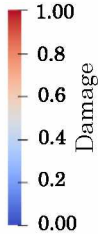
Experimental cracking pattern



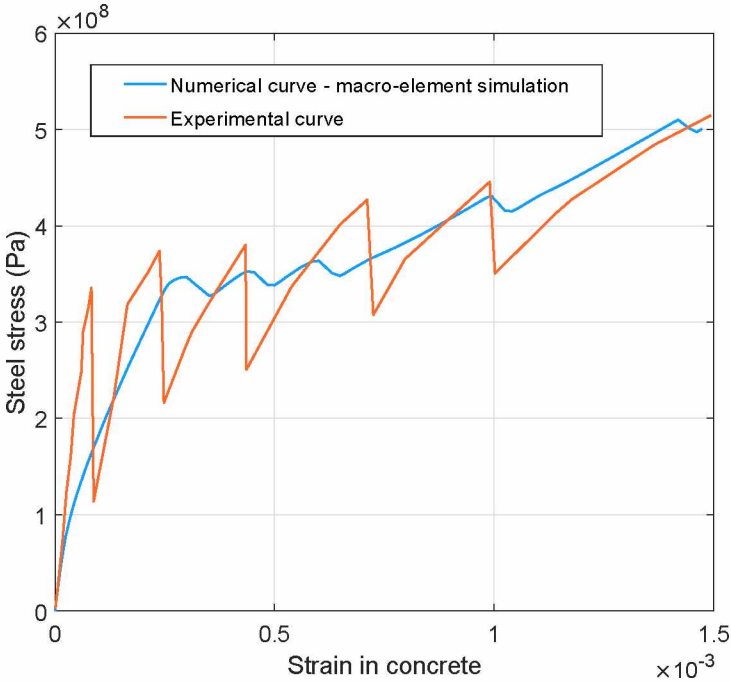
Macro-element



Perfect bond



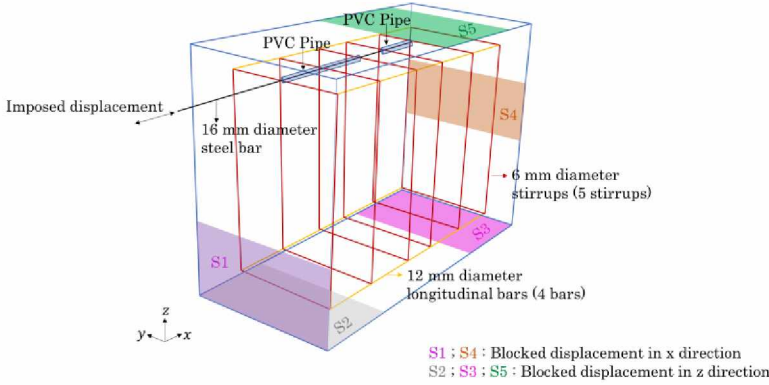
### Experimental – numerical curves



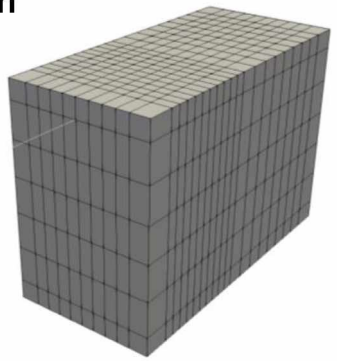
# Proposal of a new multiscale modeling strategy of the interface behavior: application

## Beam end test of J. Rex et al. 2019

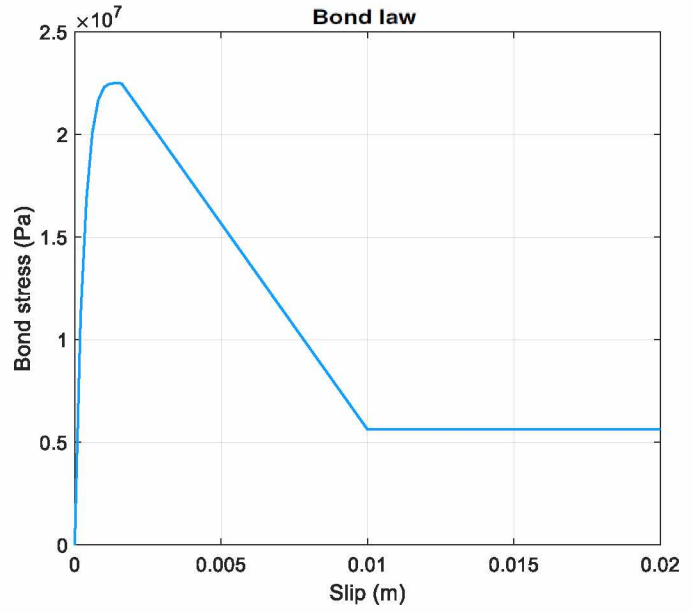
### Test description



### Mesh

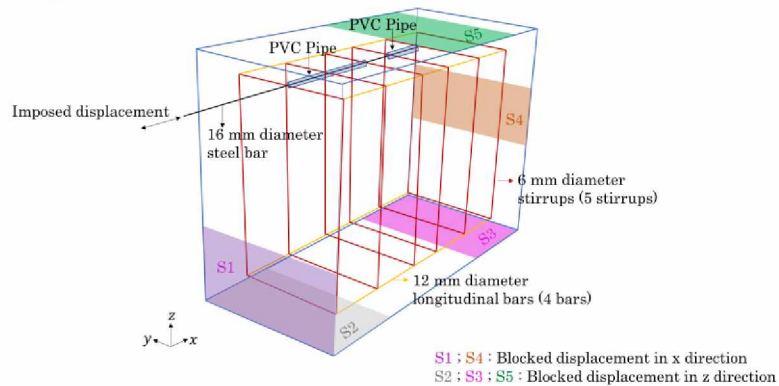


### Material parameters

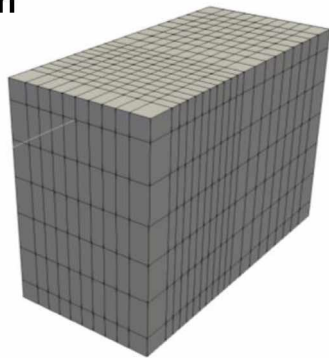


## Beam end test of J. Rex et al. 2019

### Test description



### Mesh



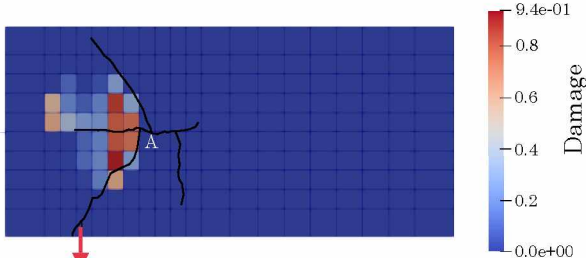
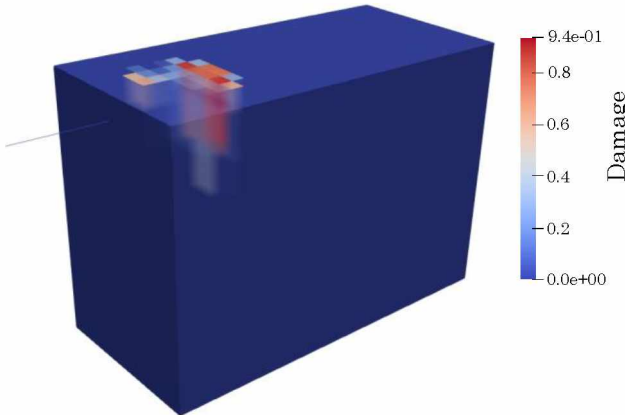
### Material parameters

Concrete parameters	Description	Value	Unit
$E_c$	Young's modulus	28	GPa
$\nu_c$	Poisson's ratio	0.2	-
$f_t$	Tensile strength	2.565	MPa
$\varepsilon_{d0}$	Damage threshold	$9.1607 \times 10^{-5}$	-
$A_f$	Local Mazars' model input	Not used - the law is regularized	-
$B_f$	Mazars' model input	Regularized	-
$A_c$	Mazars' model input	1.3	-
$B_c$	Mazars' model input	650	-
$\beta$	Mazars' model input	1.06	-
$G_f$	Fracture energy	150	J/m <sup>3</sup>
Steel parameter	Description	Value	Unit
$E_a$	Young's modulus	200	GPa

# Proposal of a new multiscale modeling strategy of the interface behavior: application

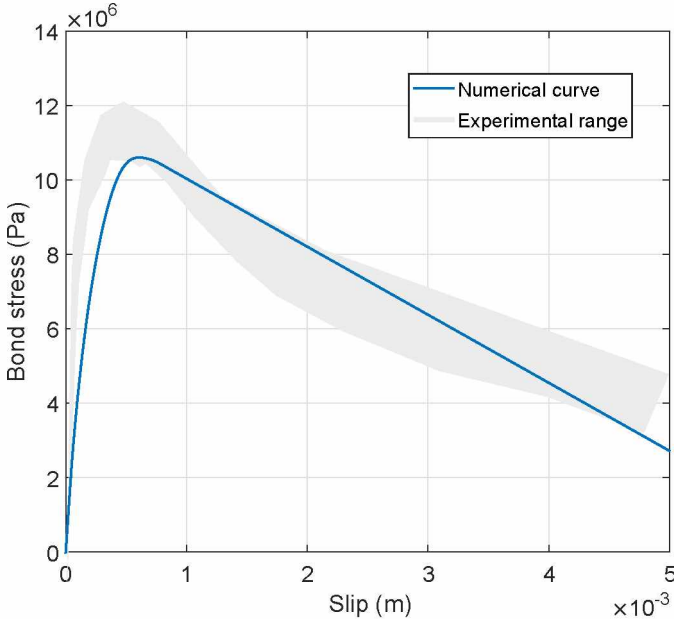
## Beam end test of J. Rex et al. 2019

### Concrete damage



Experimental cracking pattern

### Experimental – numerical curves



## Conclusions

- The main advantage of the proposed approach to model the steel-concrete interface is that it consists of modeling the steel and the steel-concrete interface within a single finite element, which makes it more practical to introduce the consideration of the interface behavior into a finite element calculation.
- Bond stresses are introduced locally within the macro-element. The studied examples show the robustness of the model and its ability to reproduce the experimental behavior of the interface.

## Perspectives

- Application for large-scaled structures subjected to both static and dynamic loads.

**Thank you !**

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