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DEPARTMENT OF
MECHANICAL ENGINEERING

Sequential algorithms for the numerical analysis of delaminations: a new efficient and versatile approach

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2010 - 2016

Bachelor/Master degree in Aerospace Engineering
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Sequential algorithms for the numerical analysis of delaminations: a new efficient and versatile approach

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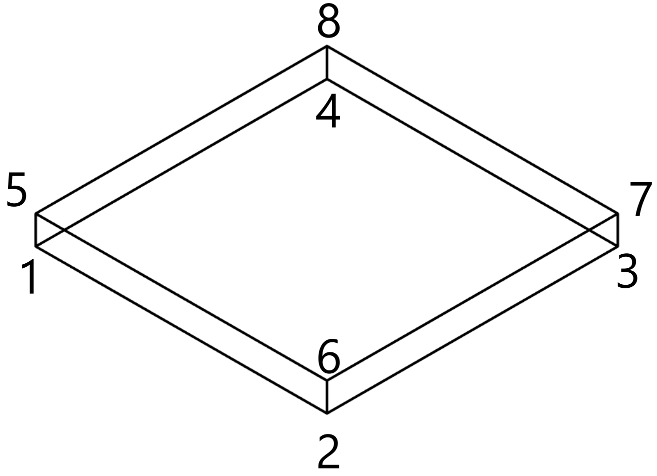
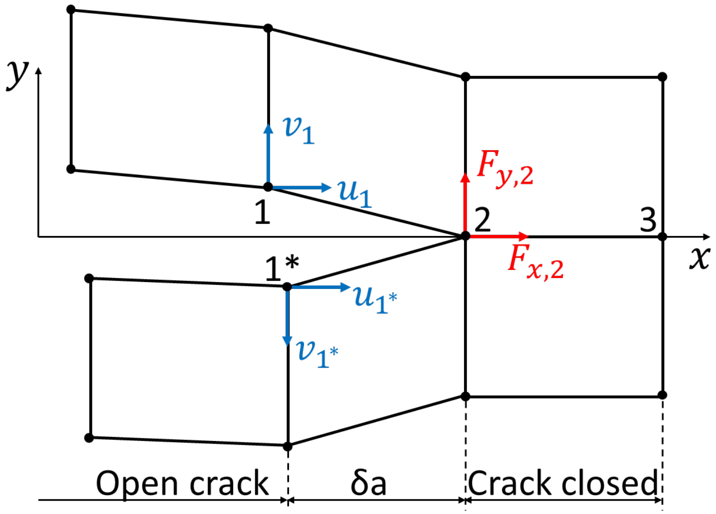
SIMULATIONS OF DELAMINATIONS UNDER FATIGUE

MODELLING DELAMINATION PROPAGATION UNDER FATIGUE

Cohesive elements



Virtual Crack Closure Technique

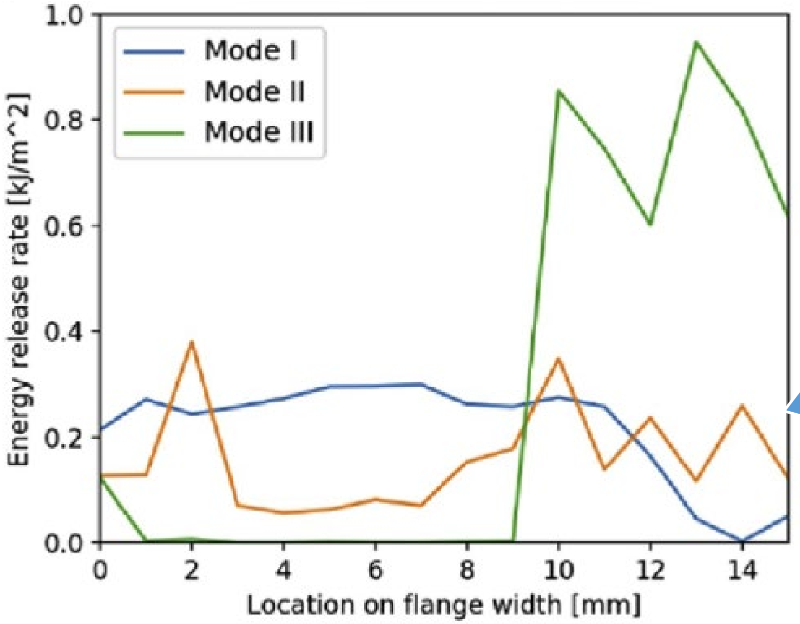


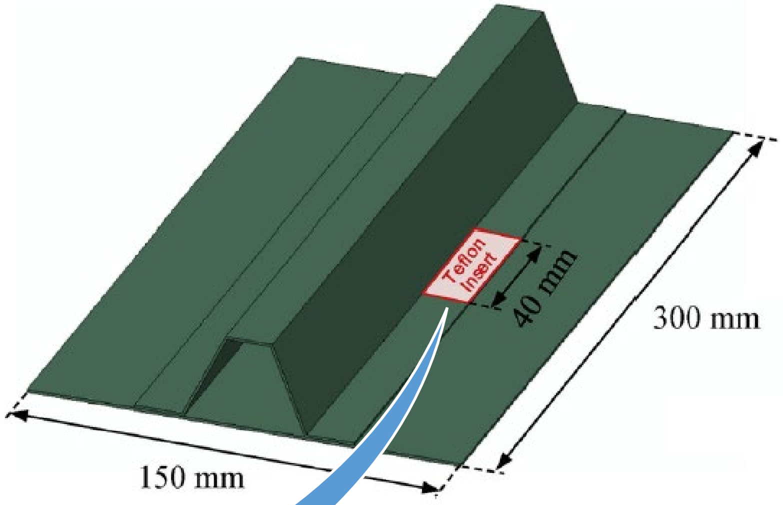
THE BENCHMARK: THE DIRECT CYCLIC (DC) ALGORITHM

- Highly inefficient: from 2 to 15 more computationally expensive than cohesive zone models [1]

- Input limited to a single set of Paris parameters [1,2]

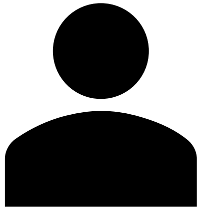
$$\frac{da}{dN} = C\mathcal{G}^m$$



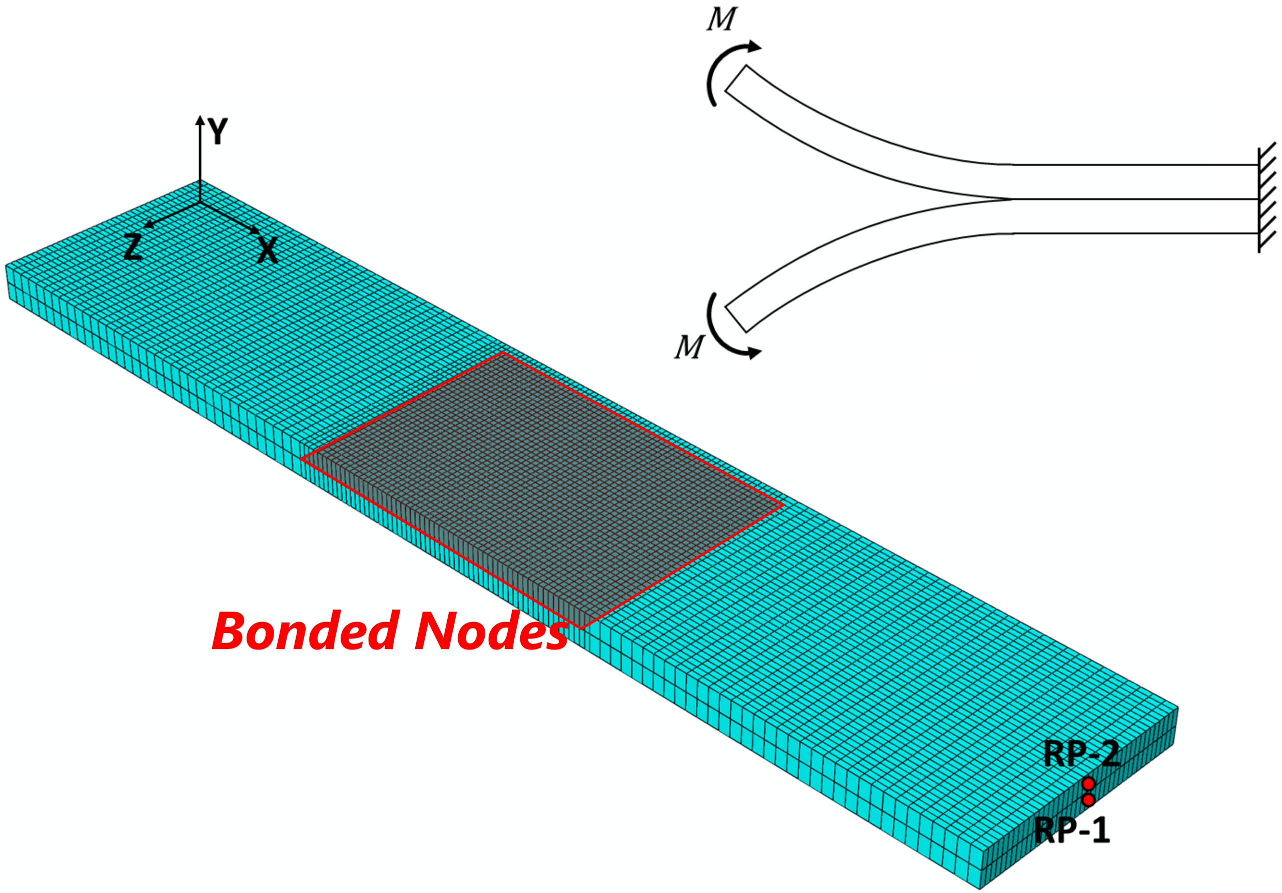


[1] Pirondi et al. (2014)
[2] Raimondo et al. (2020)

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

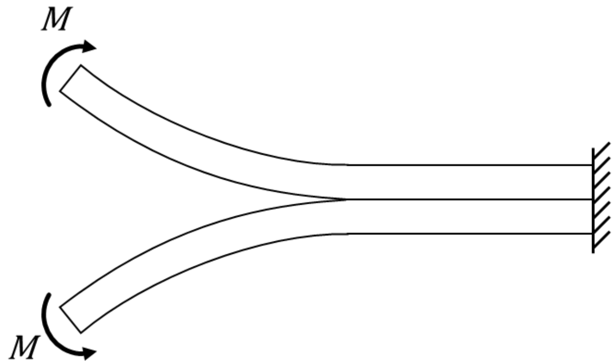


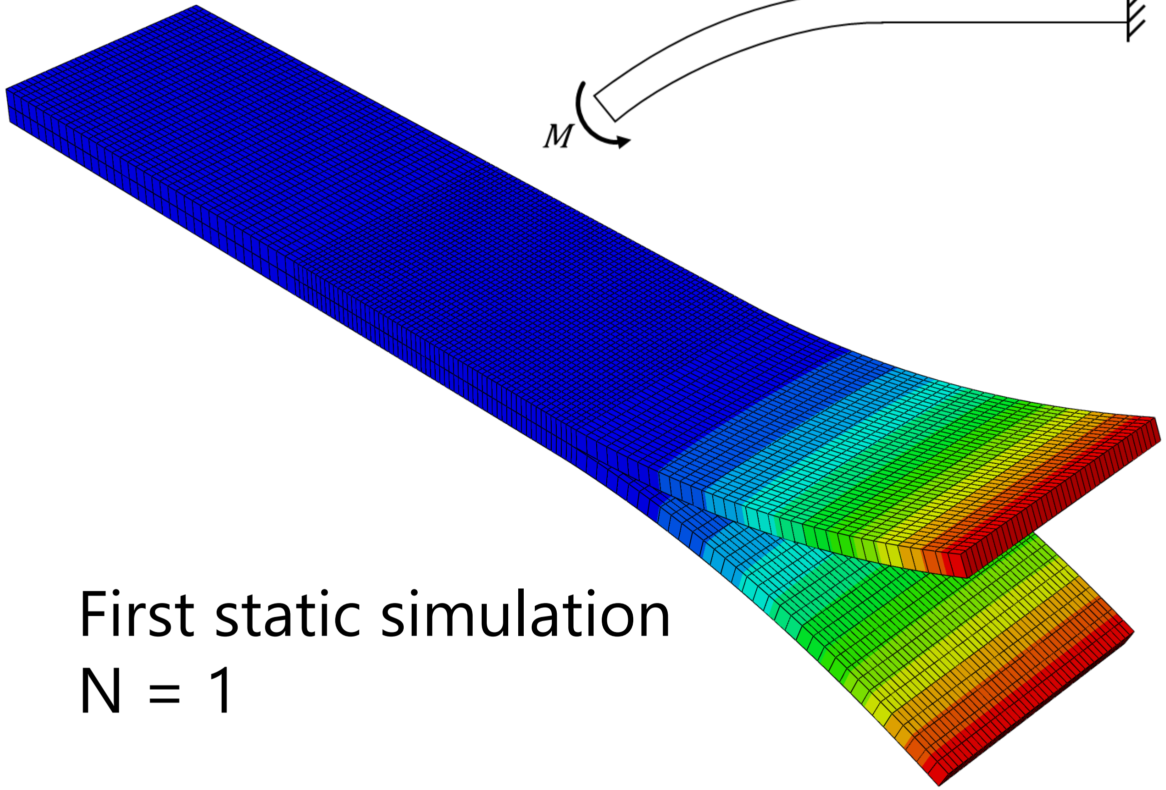
- **Pre-processing**



OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

- Pre-processing
- **Launch simulation**

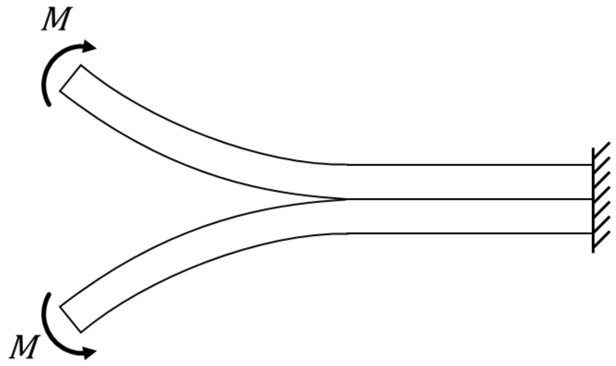




First static simulation
N = 1

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

- Pre-processing
- Launch simulation
- **SERR extraction**
- **Calculation of number of cycles to release one node**



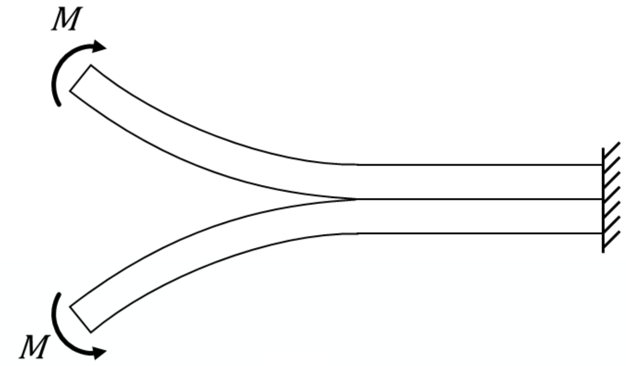
$$\frac{da}{dN} = f\left(\mathcal{G}_{\max}, \mathcal{G}_{\min}, \frac{\mathcal{G}_{II} + \mathcal{G}_{III}}{\mathcal{G}_{tot}}\right)$$

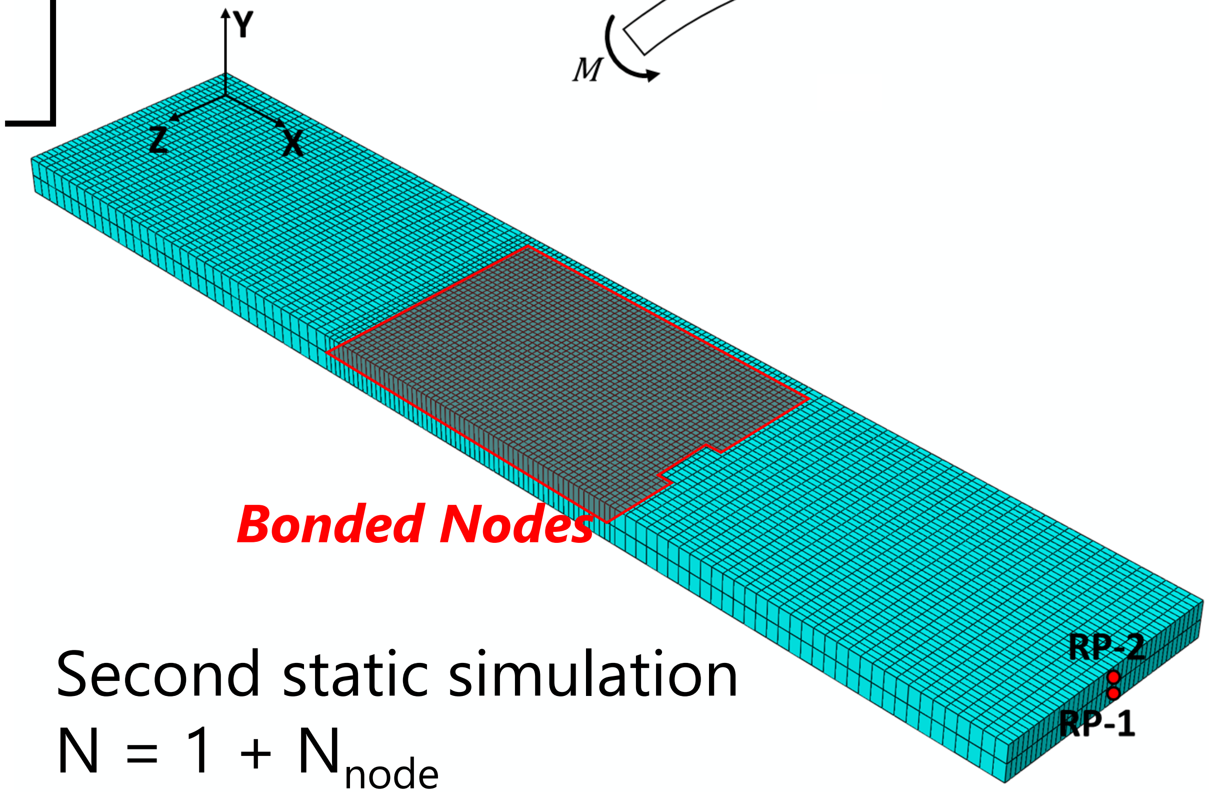
$$a = l_{el}$$

$$N_{node}$$

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

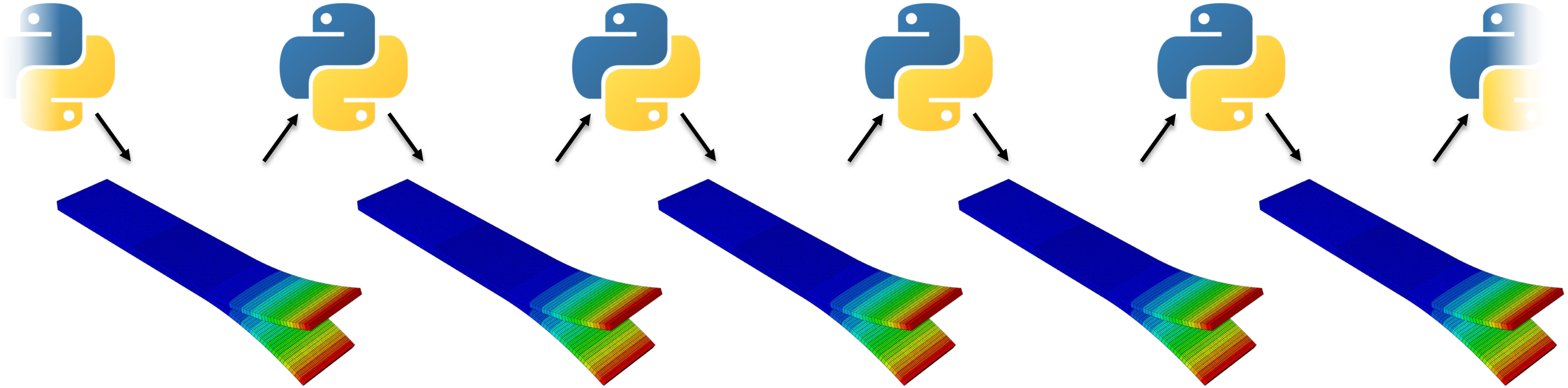
- Pre-processing
- Launch simulation
- SERR extraction
- Calculation of number of cycles to release one node





Second static simulation
$N = 1 + N_{node}$

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)



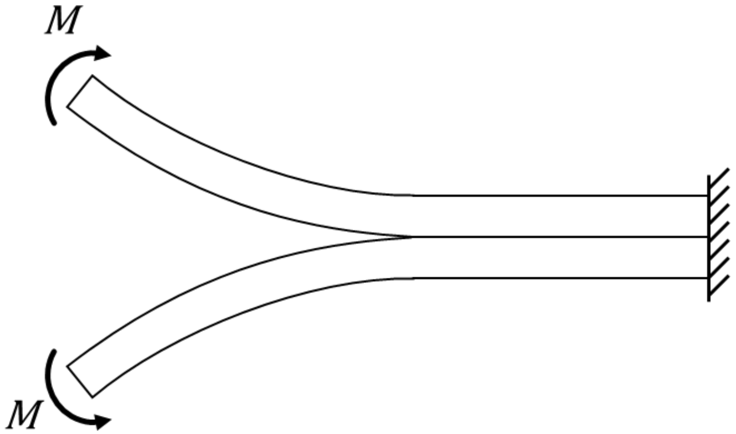
Fatigue load history is simulated via a series of static simulations

The algorithm uses the VCCT already implemented in Abaqus

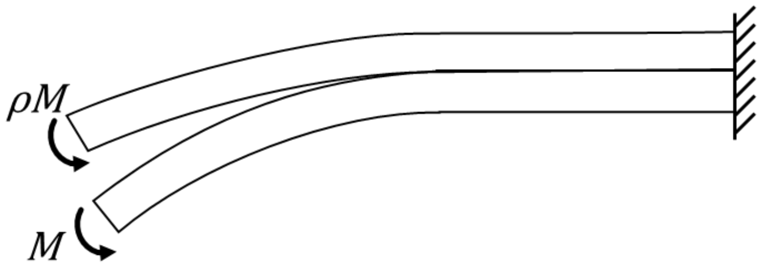
SSF VALIDATION

Experimental data from Asp et al. (2001)

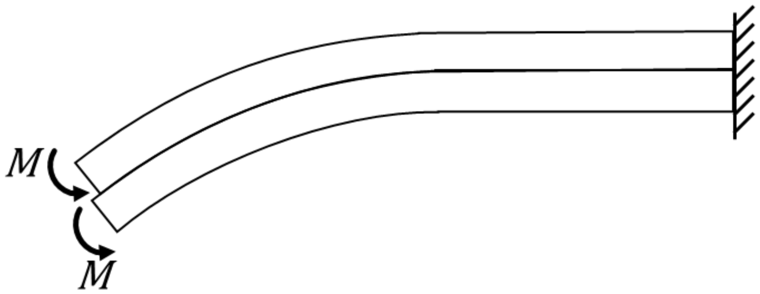
Mode I



Mixed mode
(50% mode-mixity)

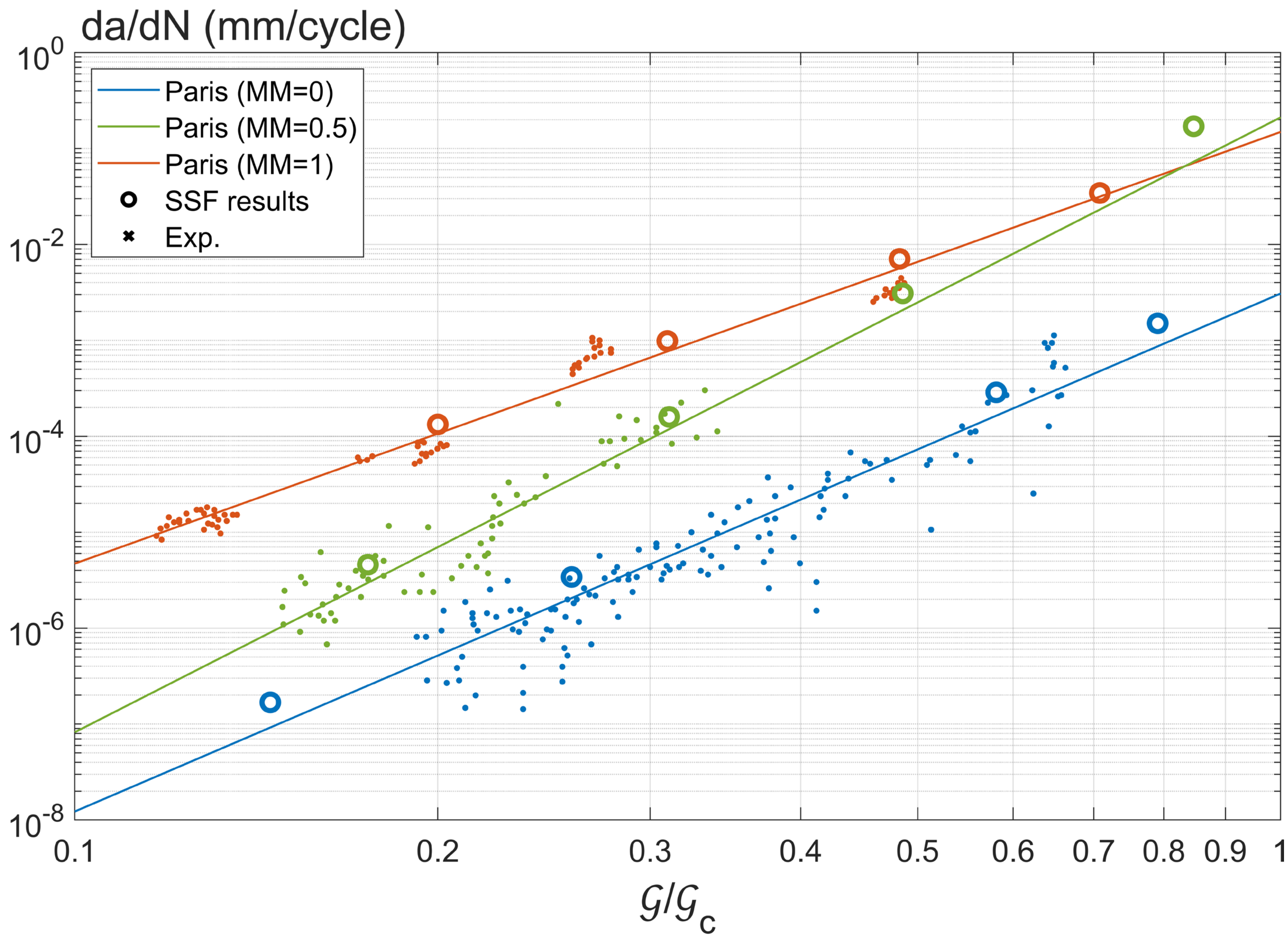


Mode II



Applied moment→ Constant propagation speed

SSF PERFORMANCE



SSF AND DC COMPARISON

Simulation	DC Time	SSF Time	Reduction factor
Finer mesh – mode I 0.5 mm propagation	39 h, 58 m, 54 s		
Coarse mesh – mode I 10 mm propagation			
Coarse mesh – mixed mode 10 mm propagation			
Coarse mesh – mode II 10 mm propagation			

SSF AND DC COMPARISON

Simulation	DC Time	SSF Time	Reduction factor
Finer mesh – mode I 0.5 mm propagation	39 h, 58 m, 54 s	2 m, 46 s	867
Coarse mesh – mode I 10 mm propagation	86 h, 42 m, 45 s	8 m, 29 s	613
Coarse mesh – mixed mode 10 mm propagation	76 h, 3 m, 15 s	9 m, 46 s	305
Coarse mesh – mode II 10 mm propagation	52 h, 43 m, 48 s	14 m, 56 s	212

BENCHMARK VALIDATION

Composite Structures 210 (2019) 932–941

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

A benchmark test for validating 3D simulation methods for delamination growth under quasi-static and fatigue loading

L. Carreras[a,*], J. Renart[a], A. Turon[a], J. Costa[a], B.L.V. Bak[b], E. Lin
F. Martin de la Escalera[c], Y. Essa[c]

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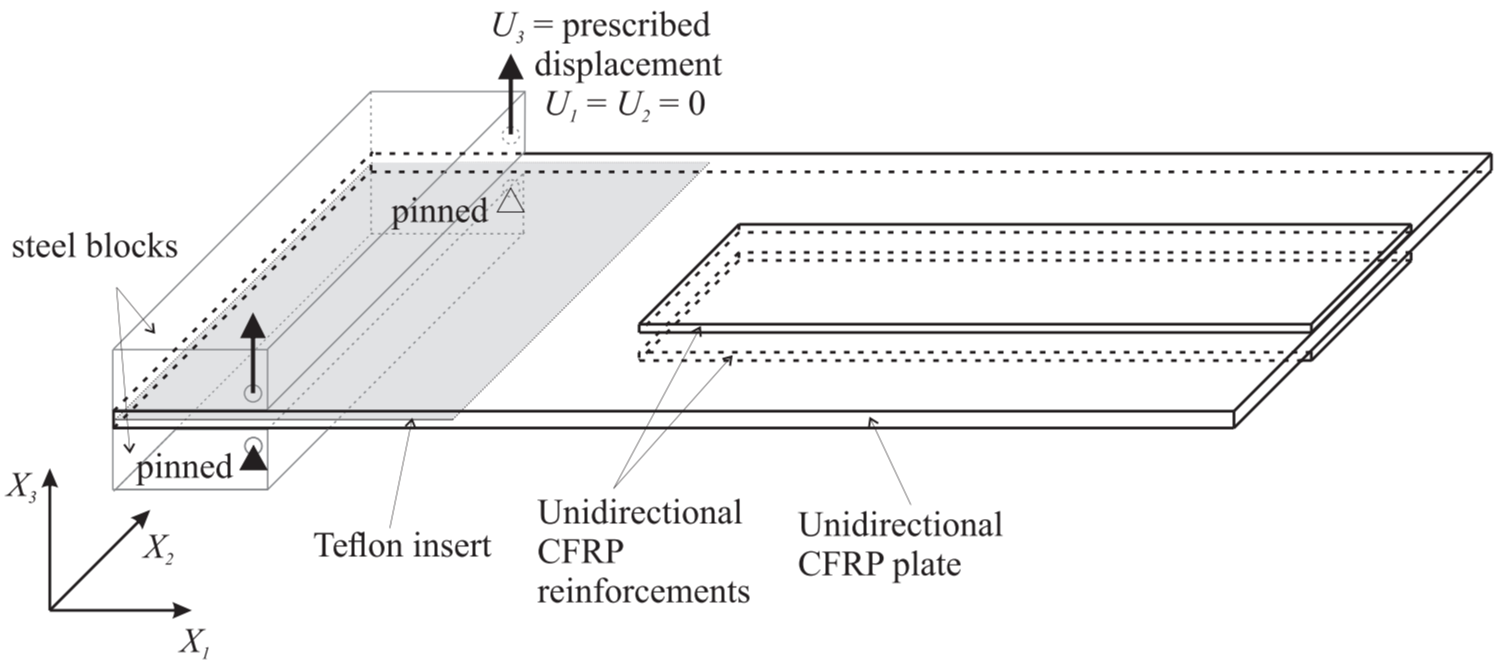
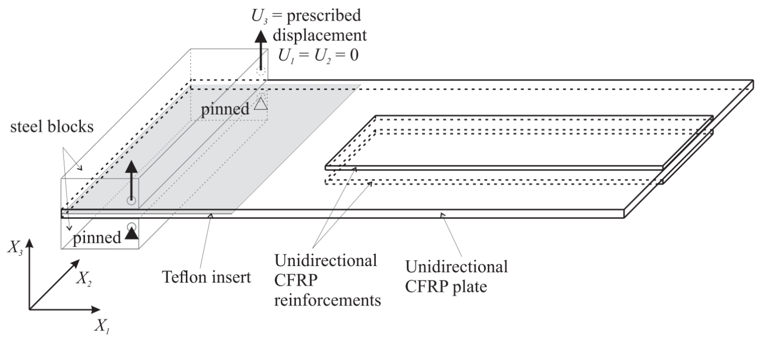
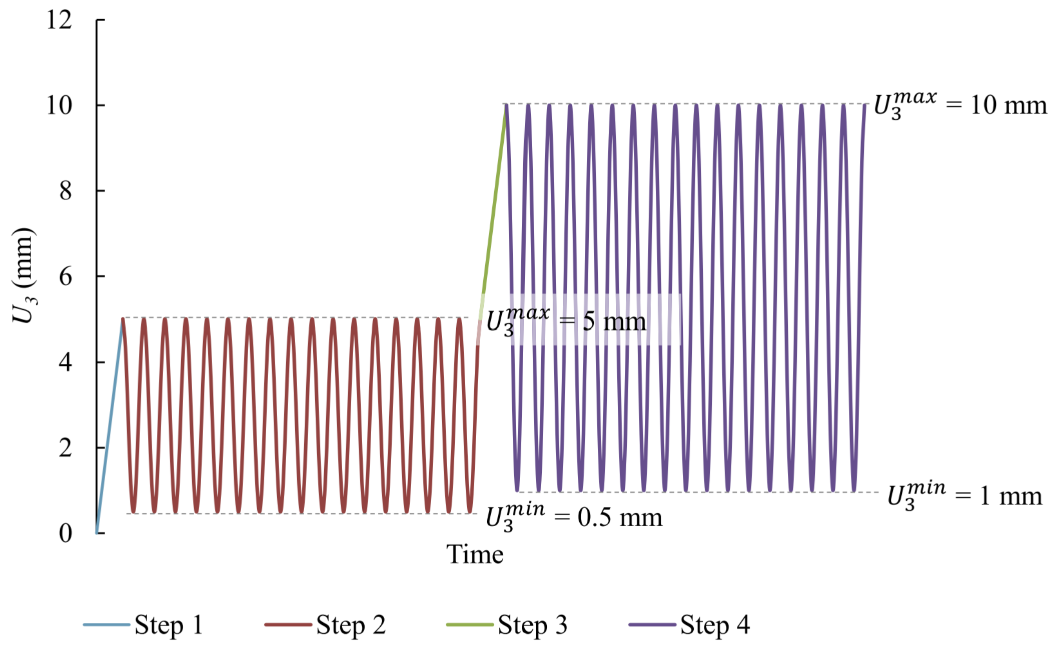
[c] AERNNOVA Engineering Division SA, Llano Castellano Avenue 13, E-28034 Madrid, Spain



Carreras et al. (2019)

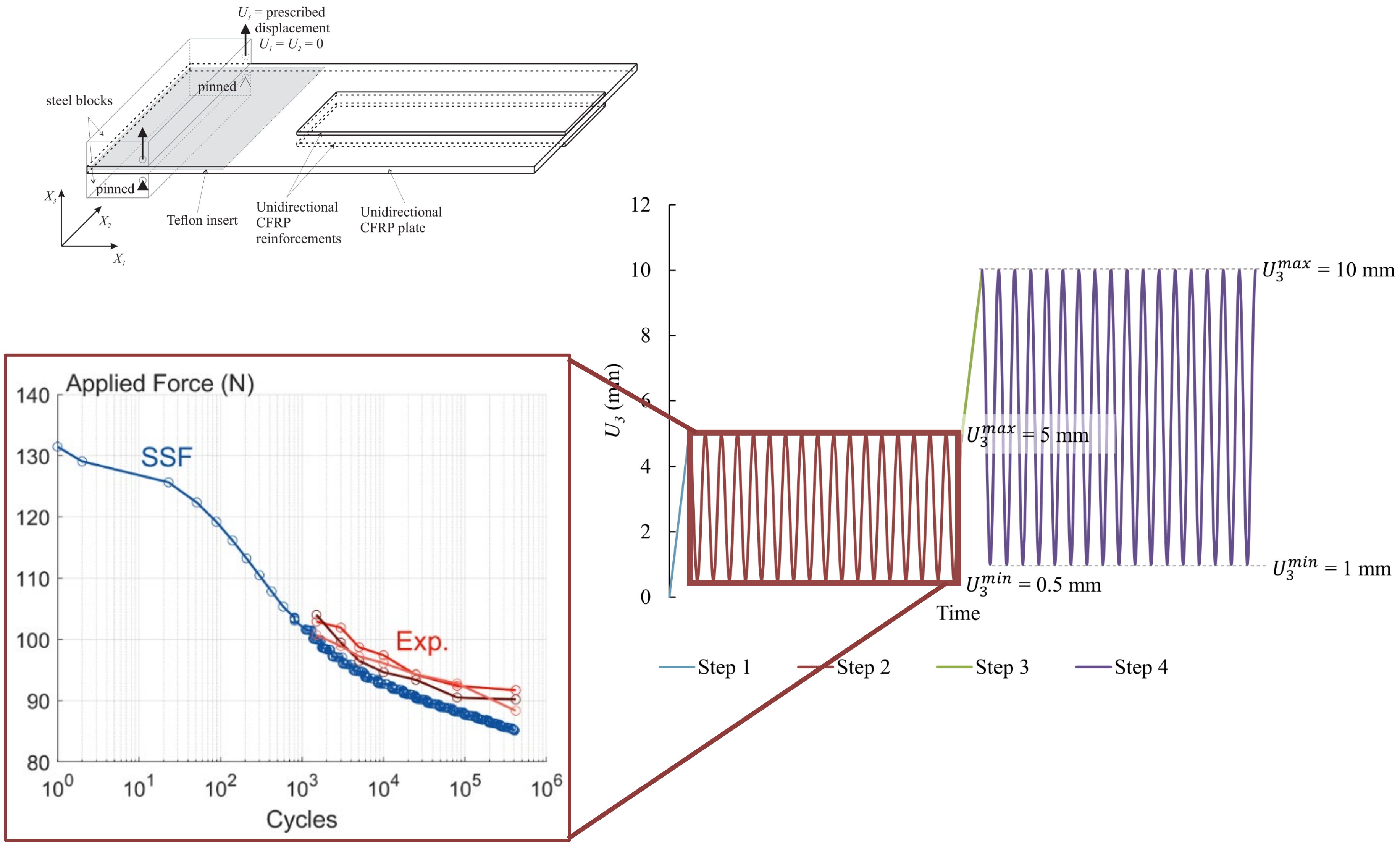
BENCHMARK VALIDATION





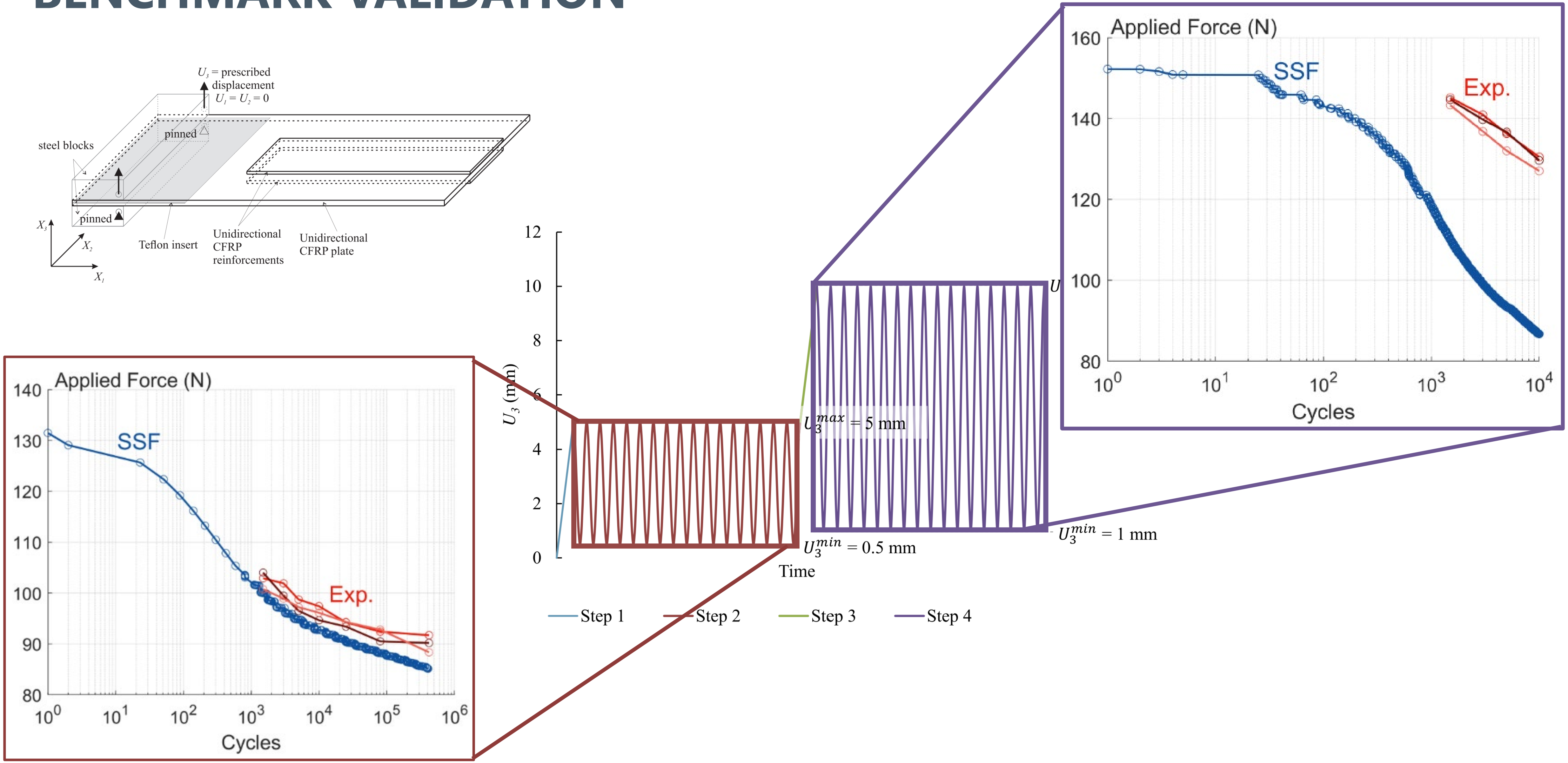
Carreras et al. (2019)

BENCHMARK VALIDATION



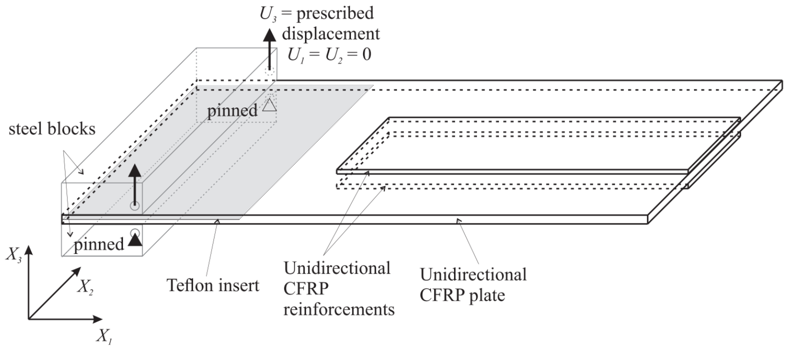
Carreras et al. (2019)

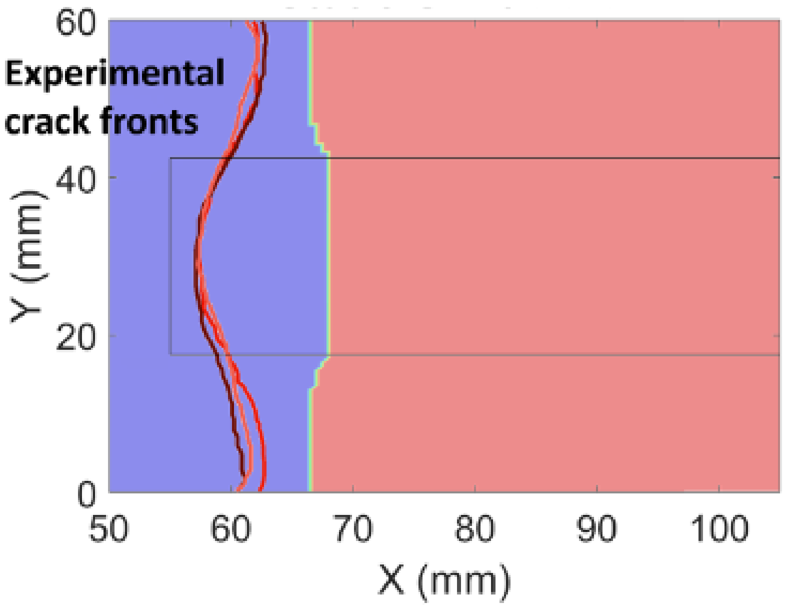
BENCHMARK VALIDATION

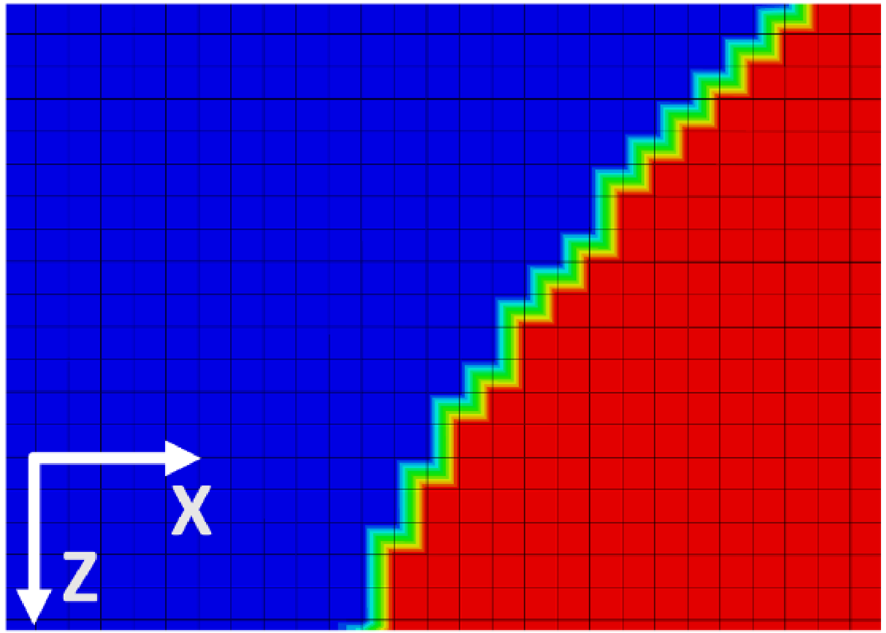


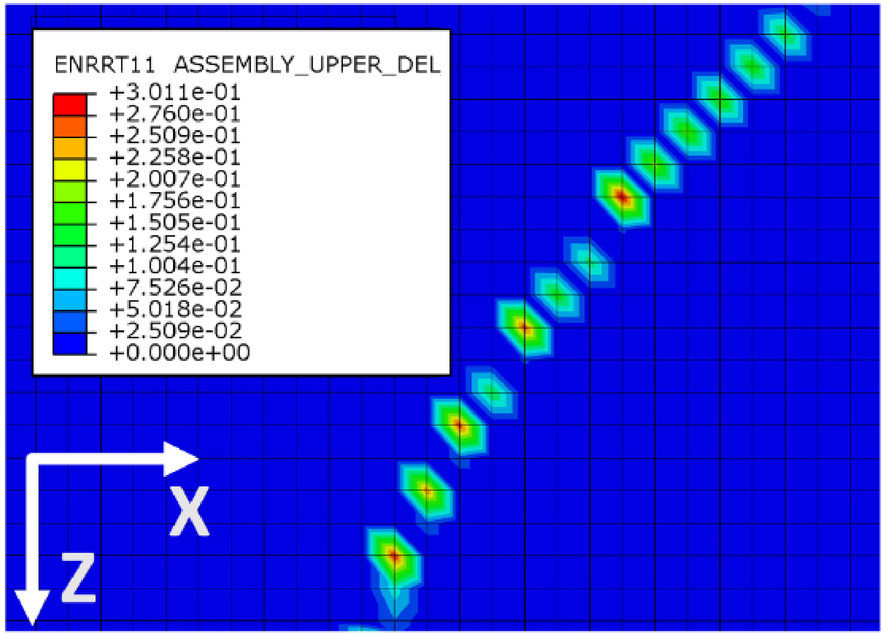
Carreras et al. (2019)

PROBLEMS





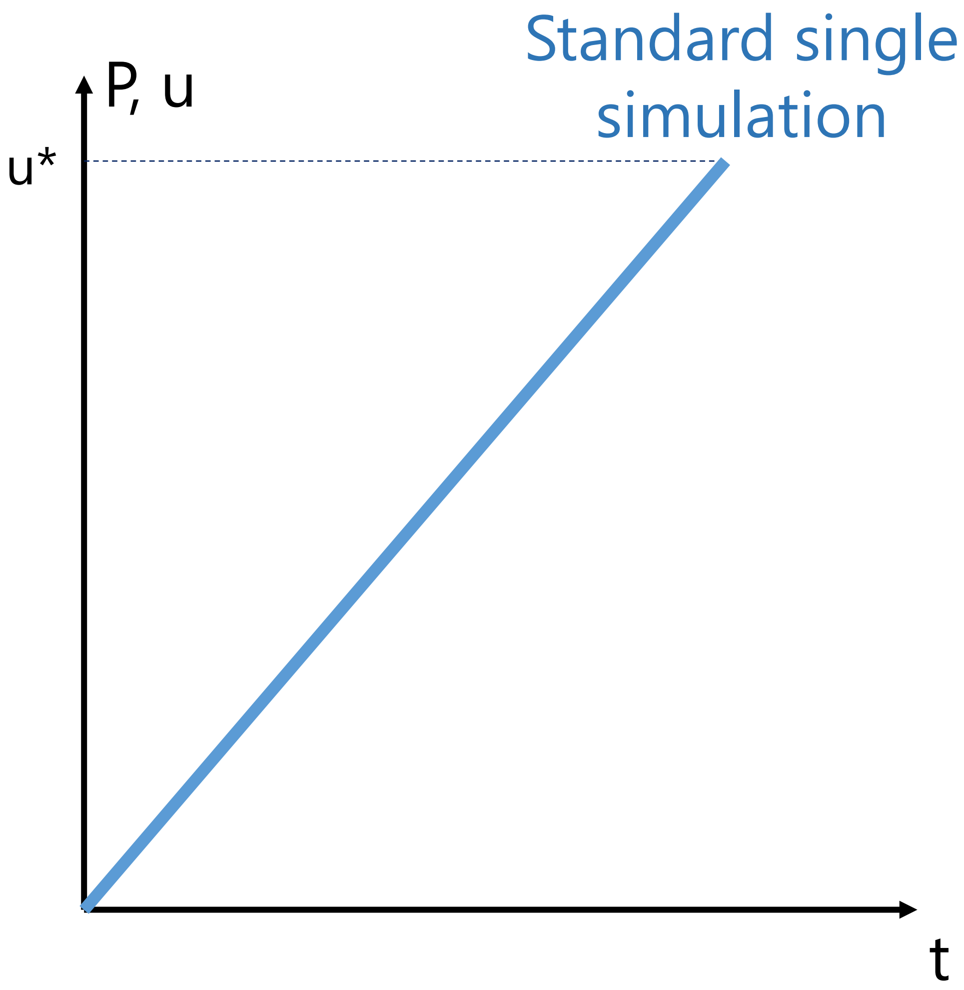




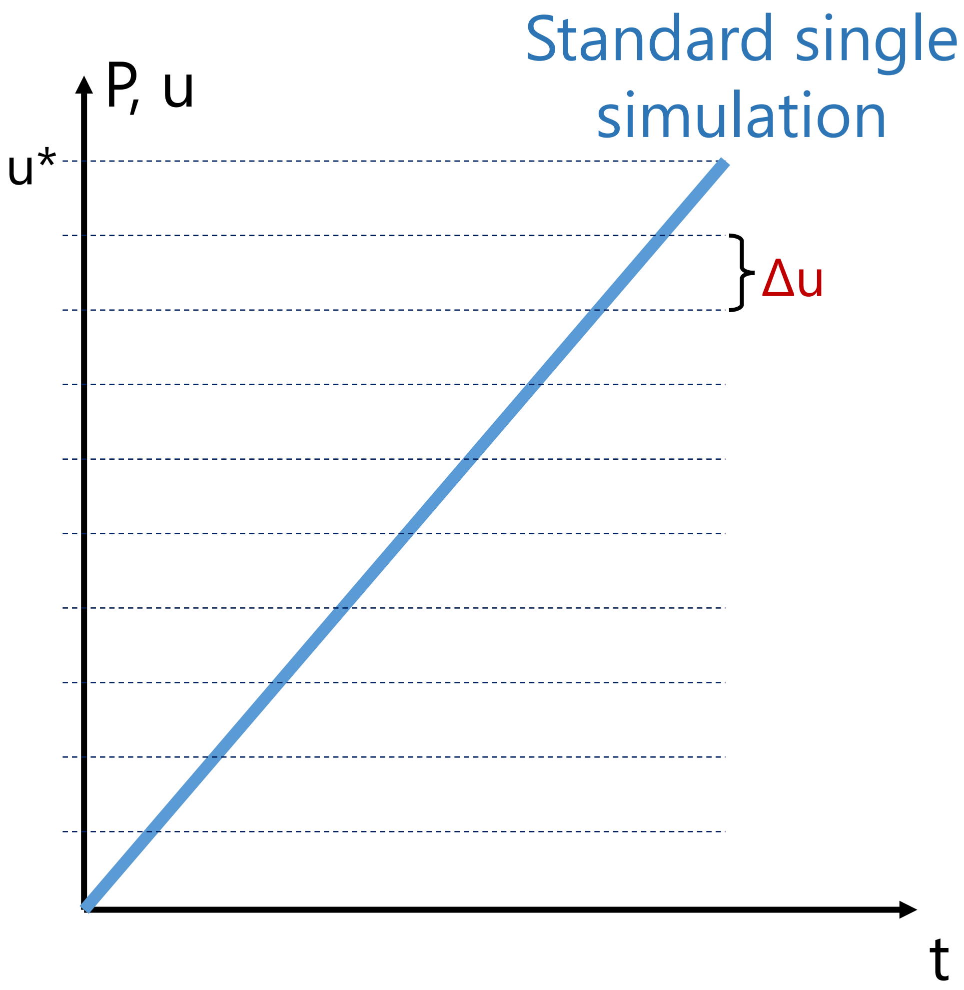
Carreras et al. (2019)

SIMULATIONS OF DELAMINATIONS UNDER STATIC LOADINGS

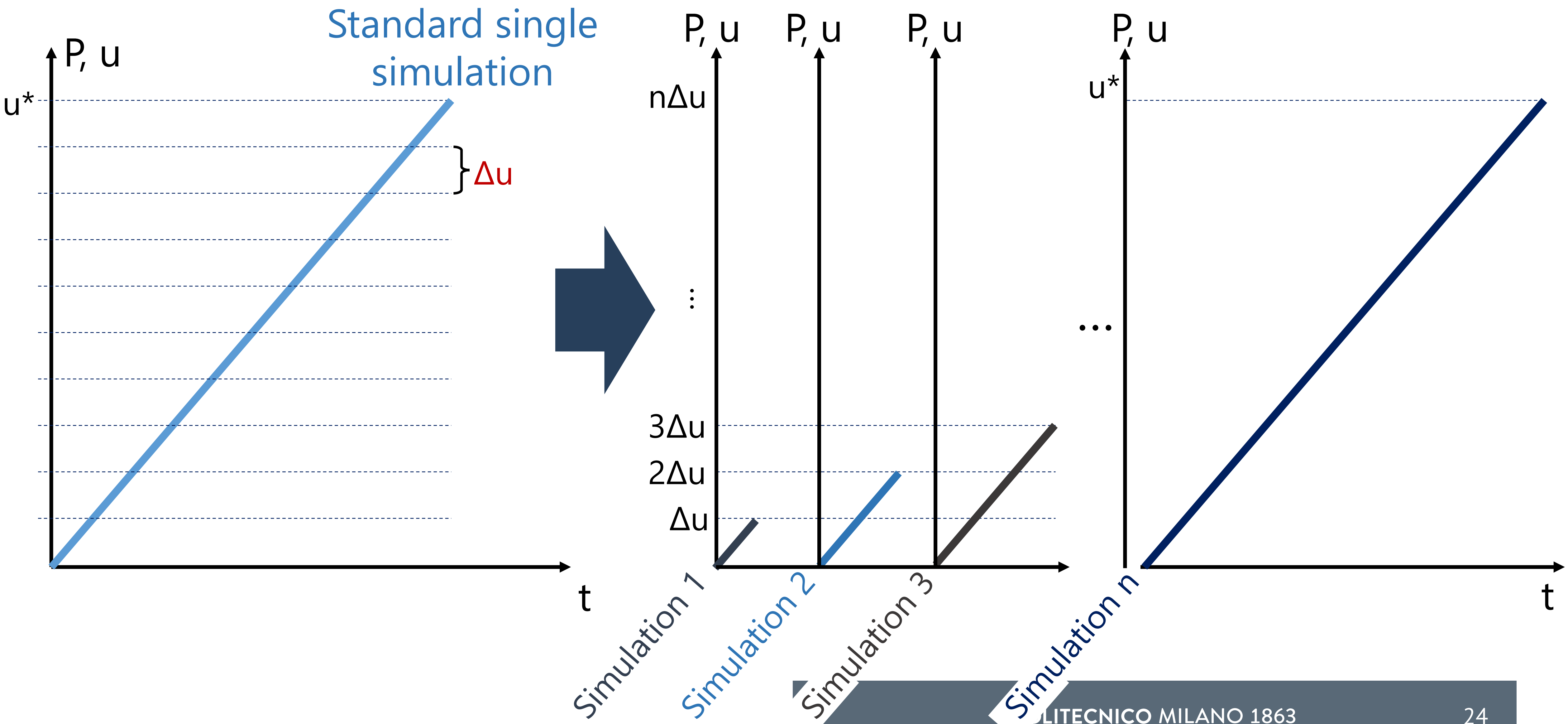
STATIC SEQUENTIAL ALGORITHM



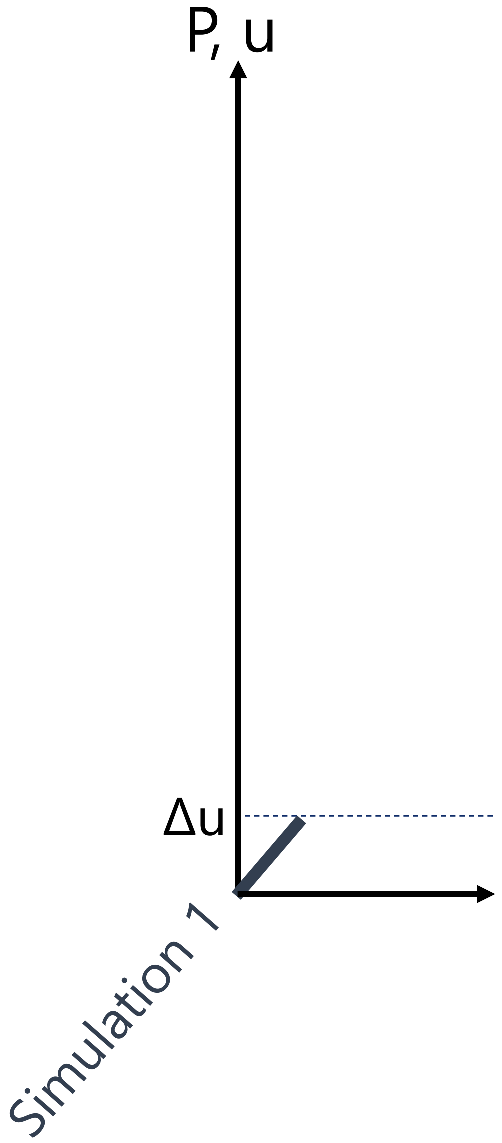
STATIC SEQUENTIAL ALGORITHM

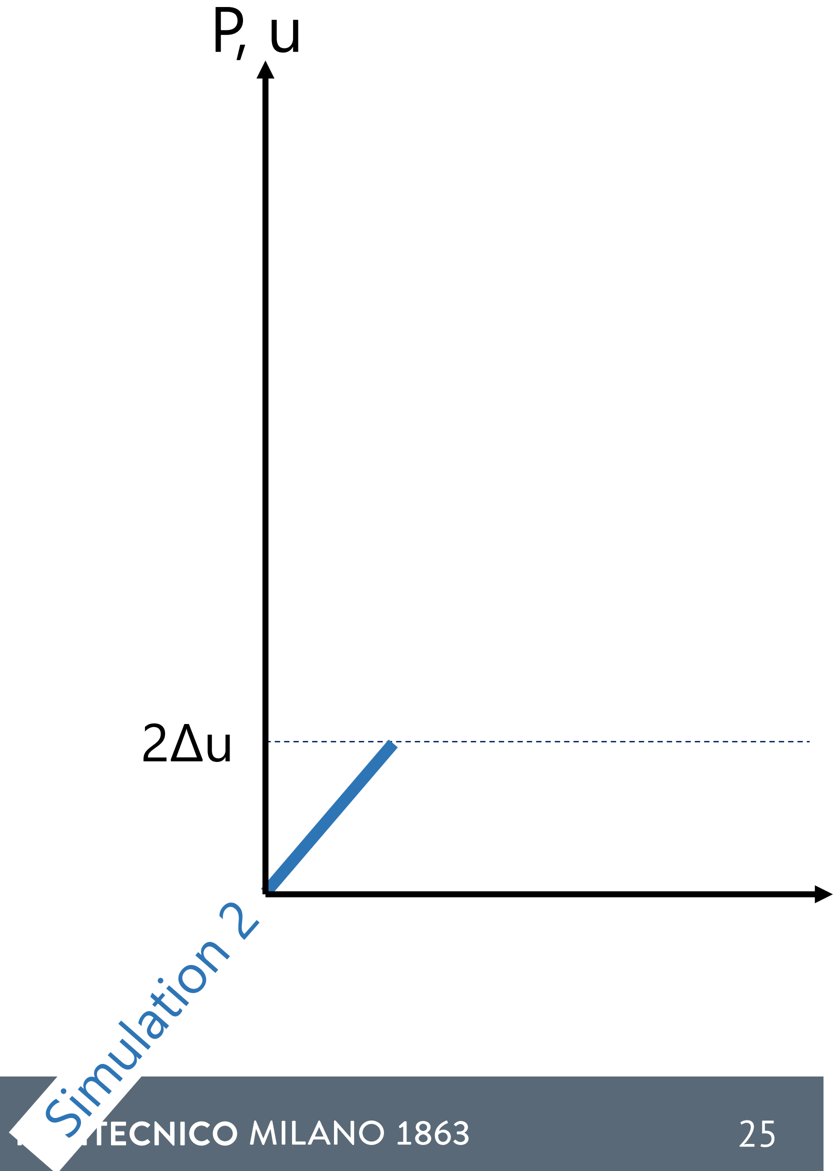


STATIC SEQUENTIAL ALGORITHM

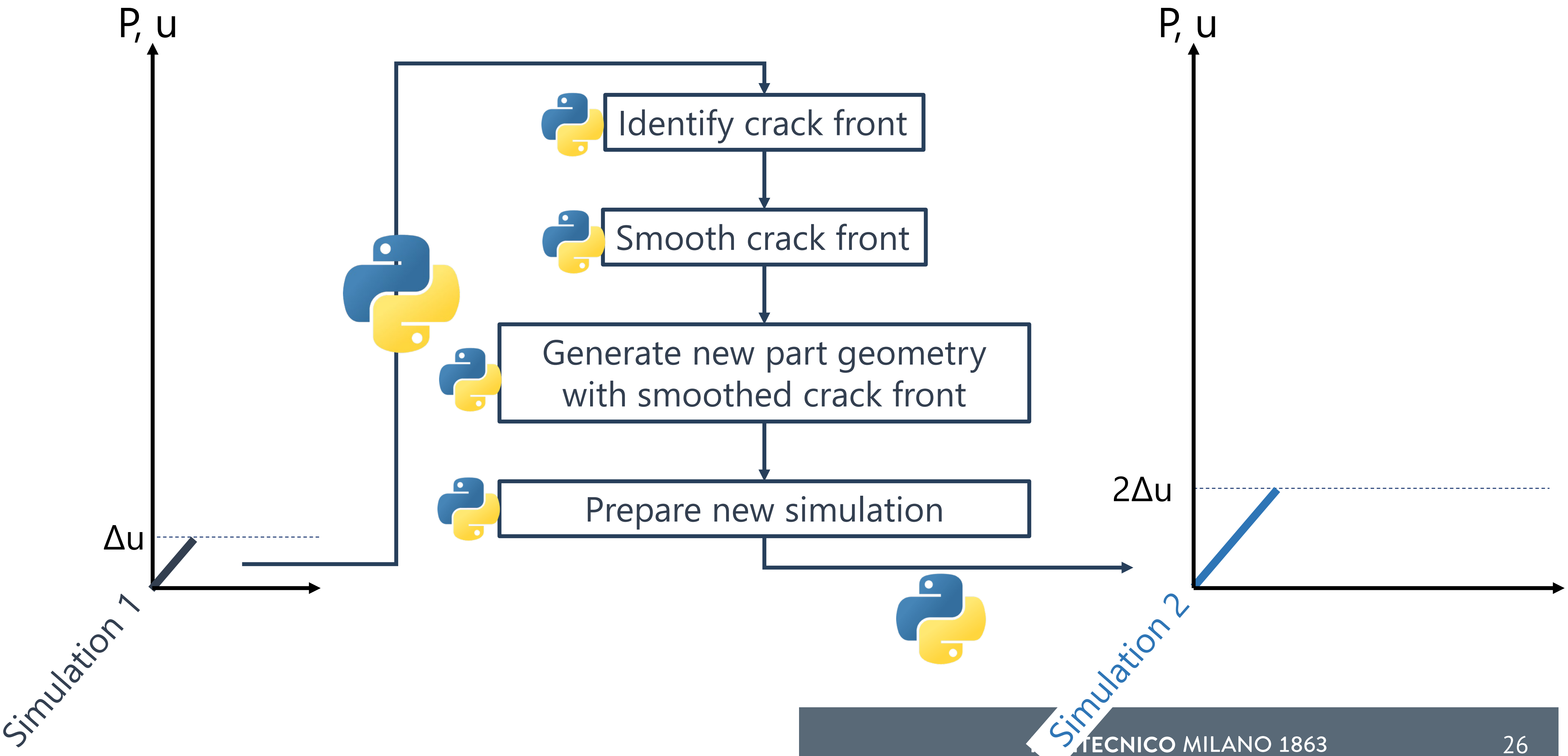


STATIC SEQUENTIAL ALGORITHM

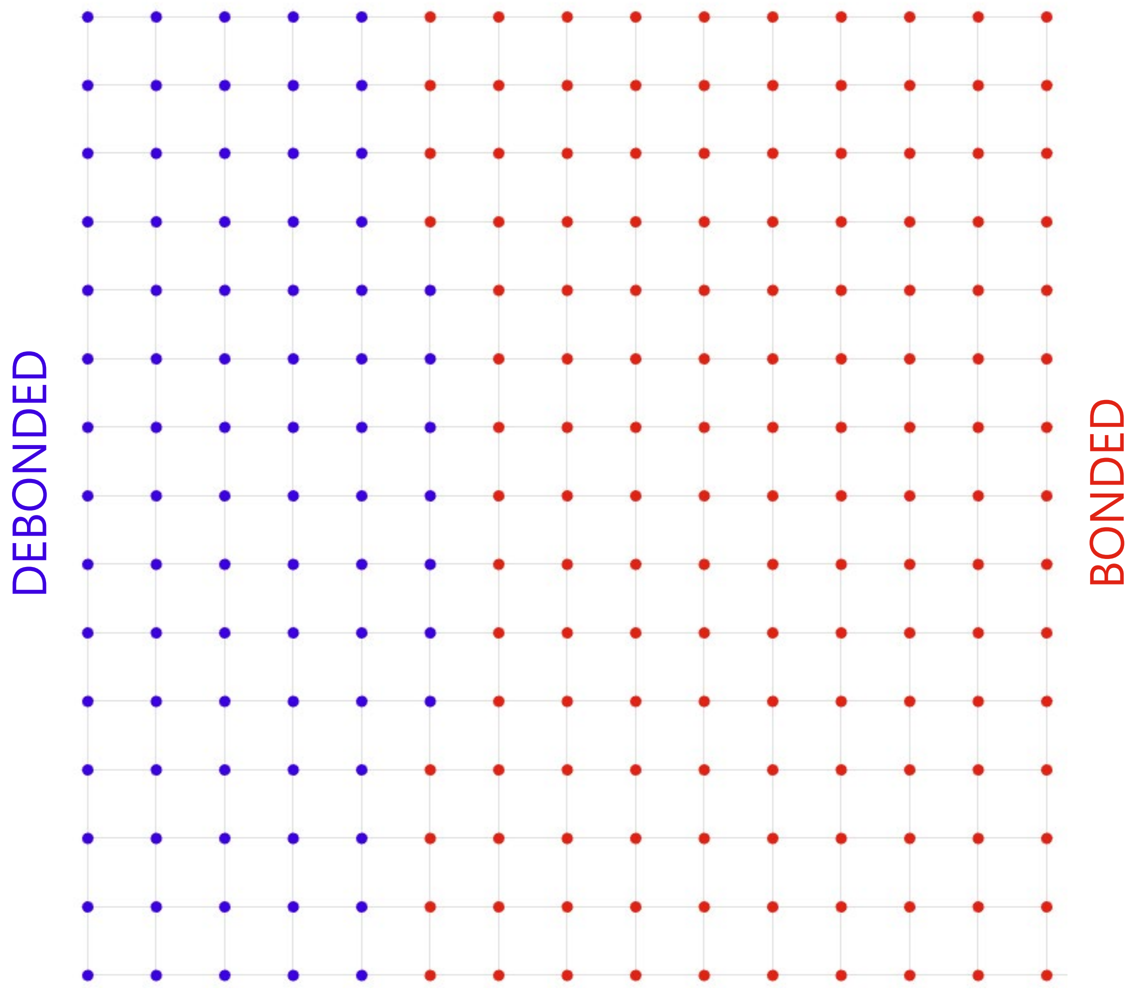




STATIC SEQUENTIAL ALGORITHM

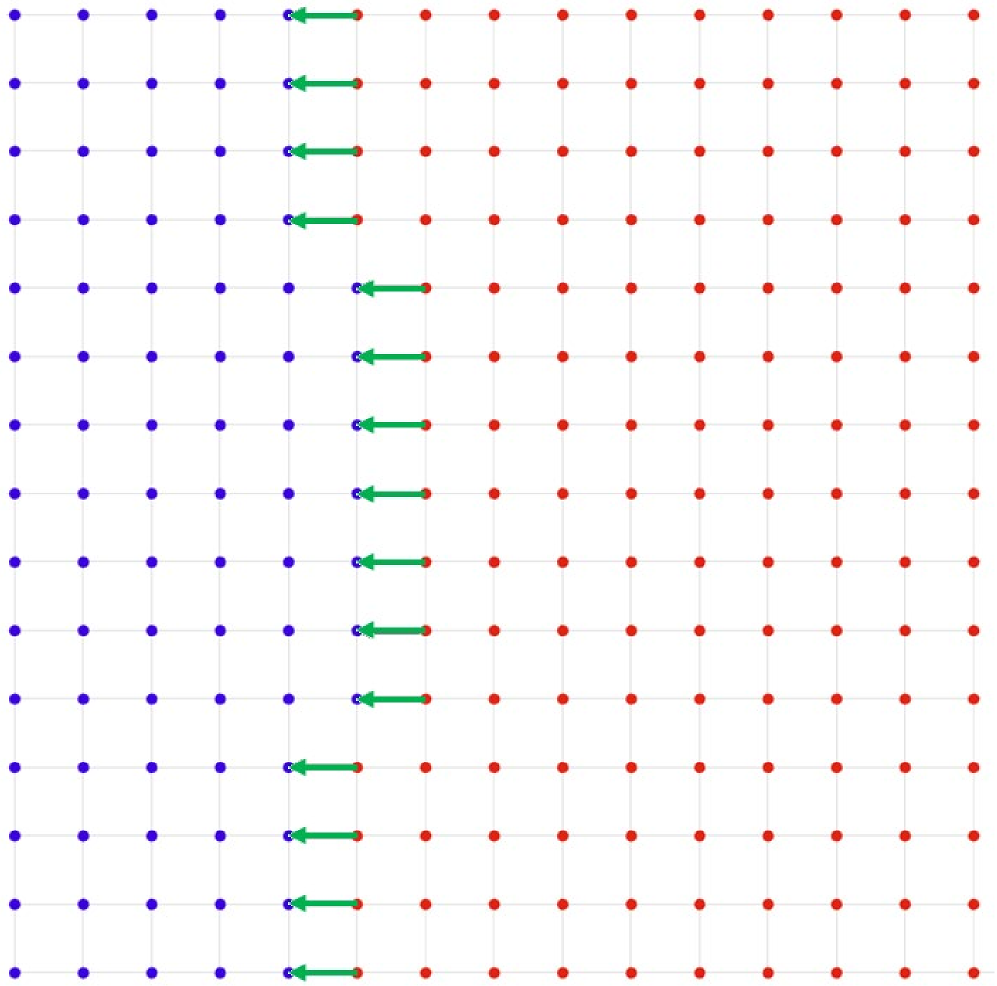


FRONT IDENTIFICATION



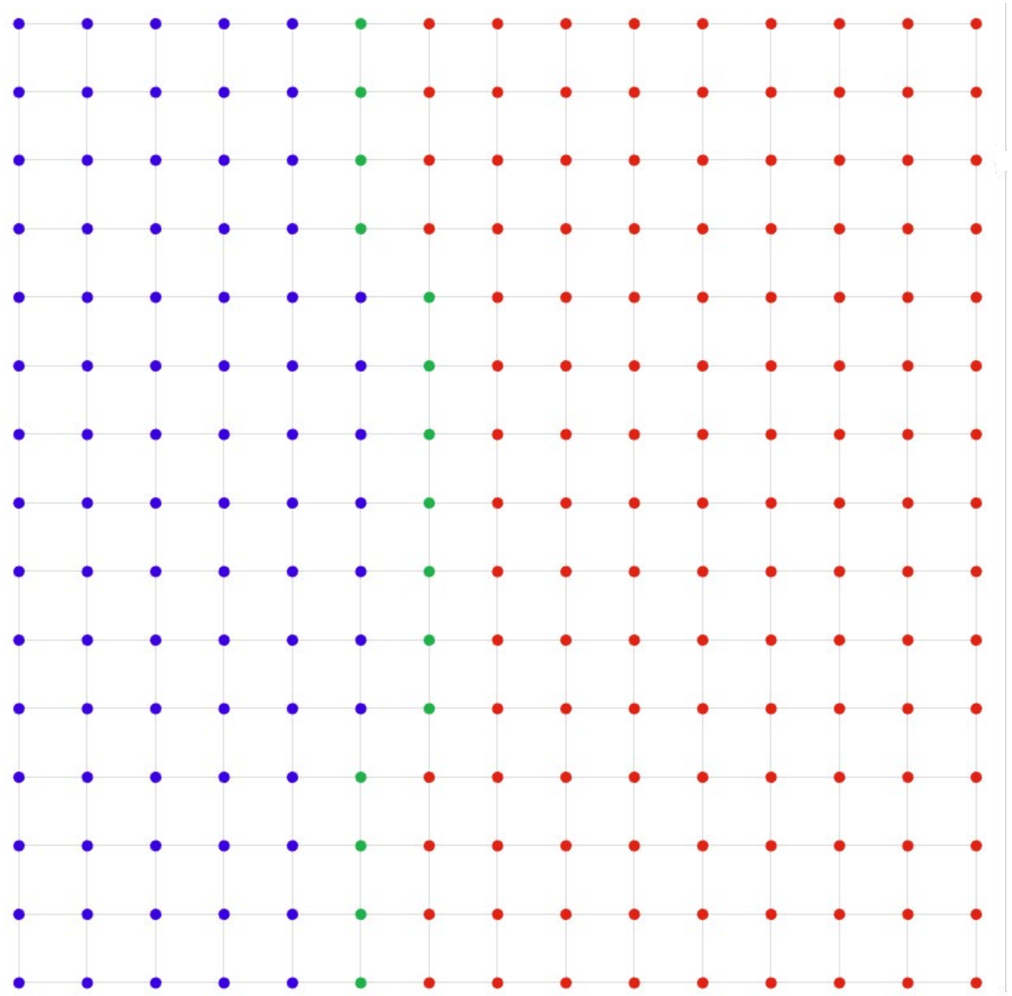
The Abaqus model does not define the delamination front.
It uses bonded (red) and de-bonded (blue) nodes.

FRONT IDENTIFICATION



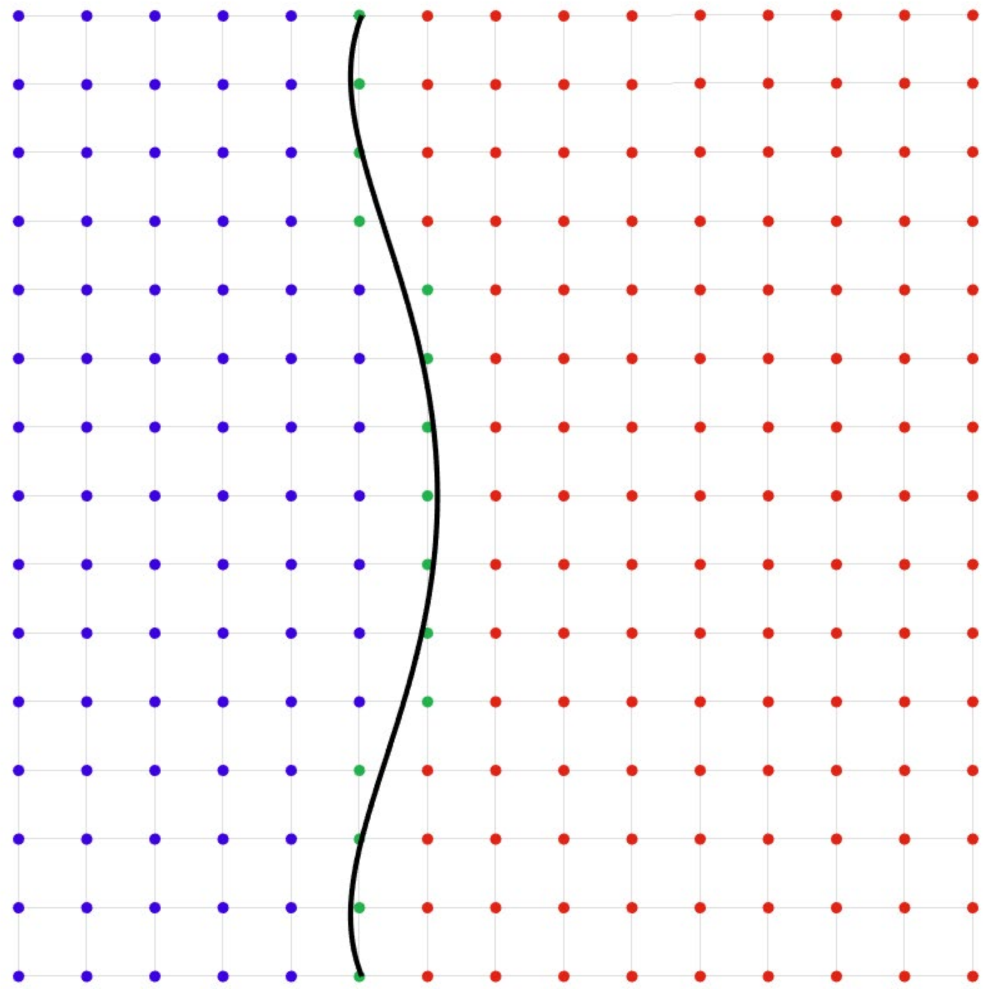
The front is identified using the distance between bonded and de-bonded nodes.

FRONT IDENTIFICATION



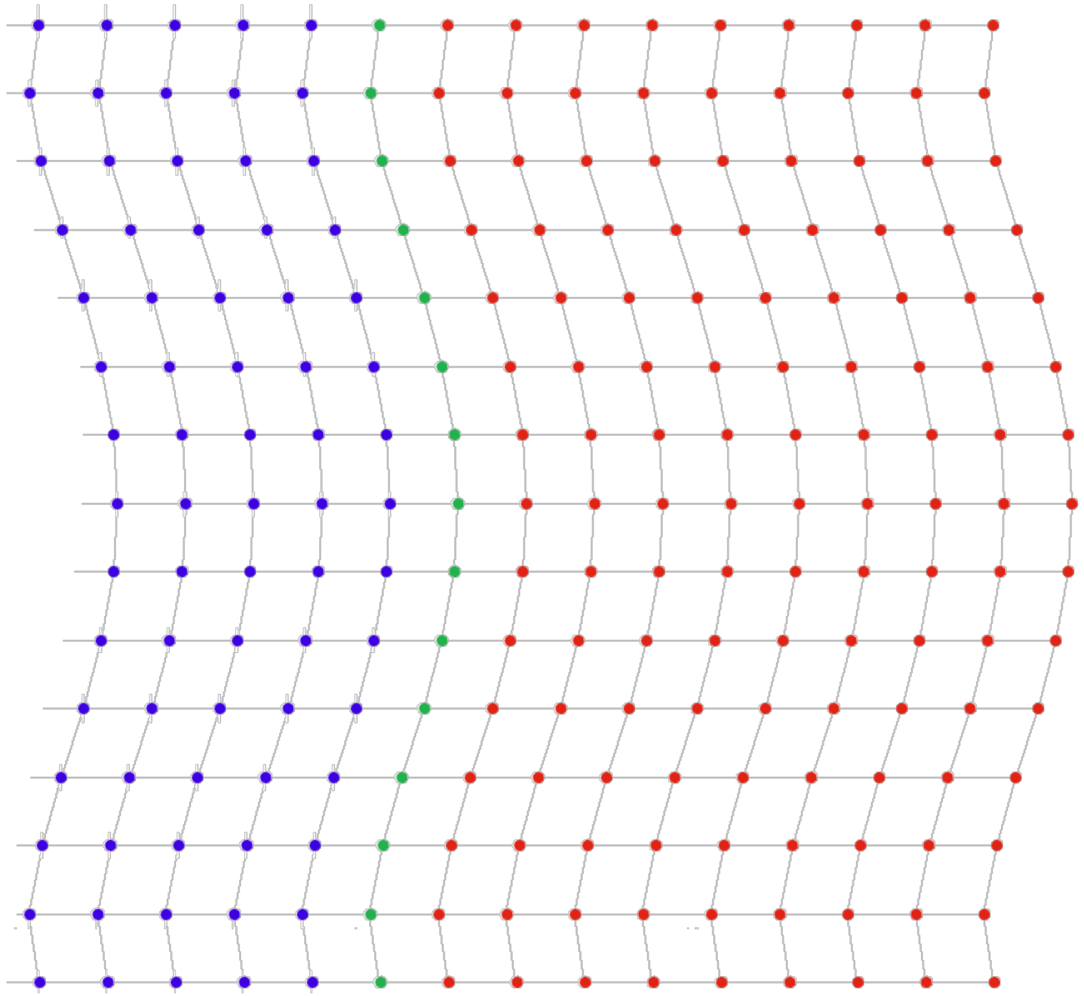
If the distance is under a threshold proportional to the element size, the bonded node is considered a front node.

FRONT IDENTIFICATION



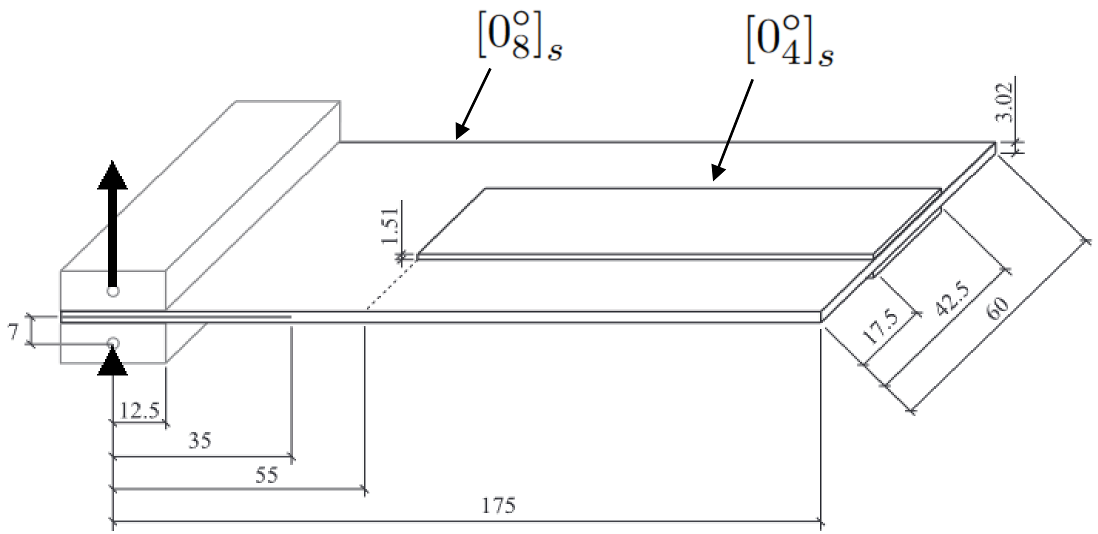
The front nodes are approximated with a polynomial function.

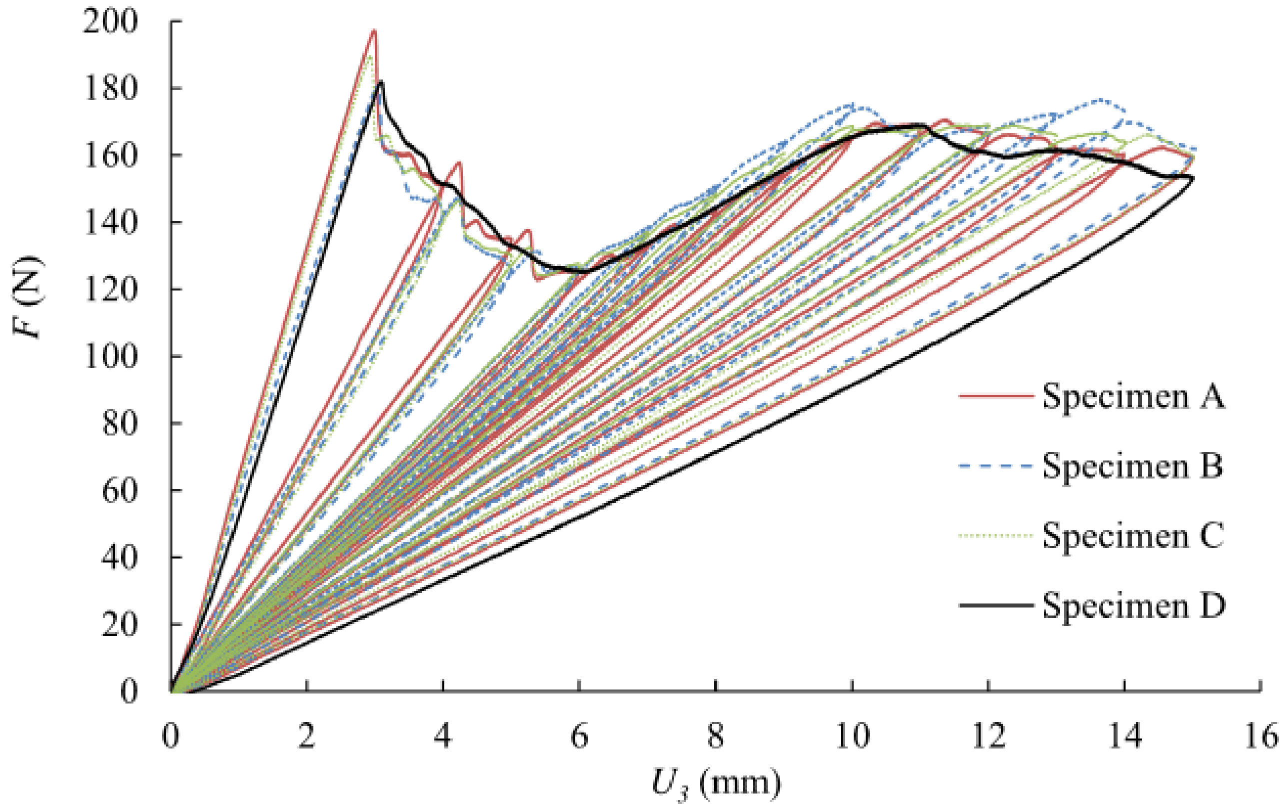
FRONT IDENTIFICATION



The original model is copied, partitioned along the front and remeshed.

EXPERIMENTAL VALIDATION CASE

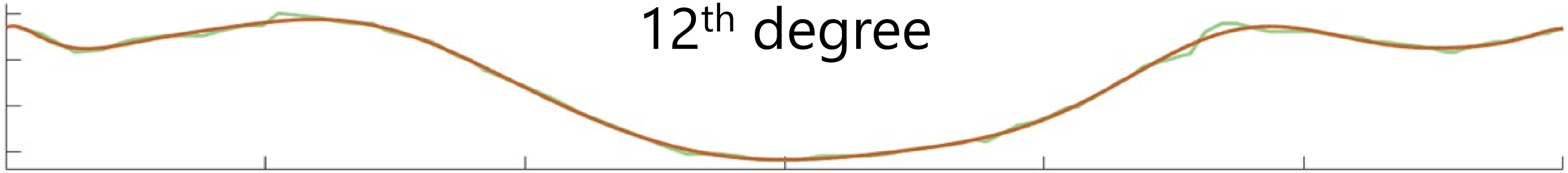




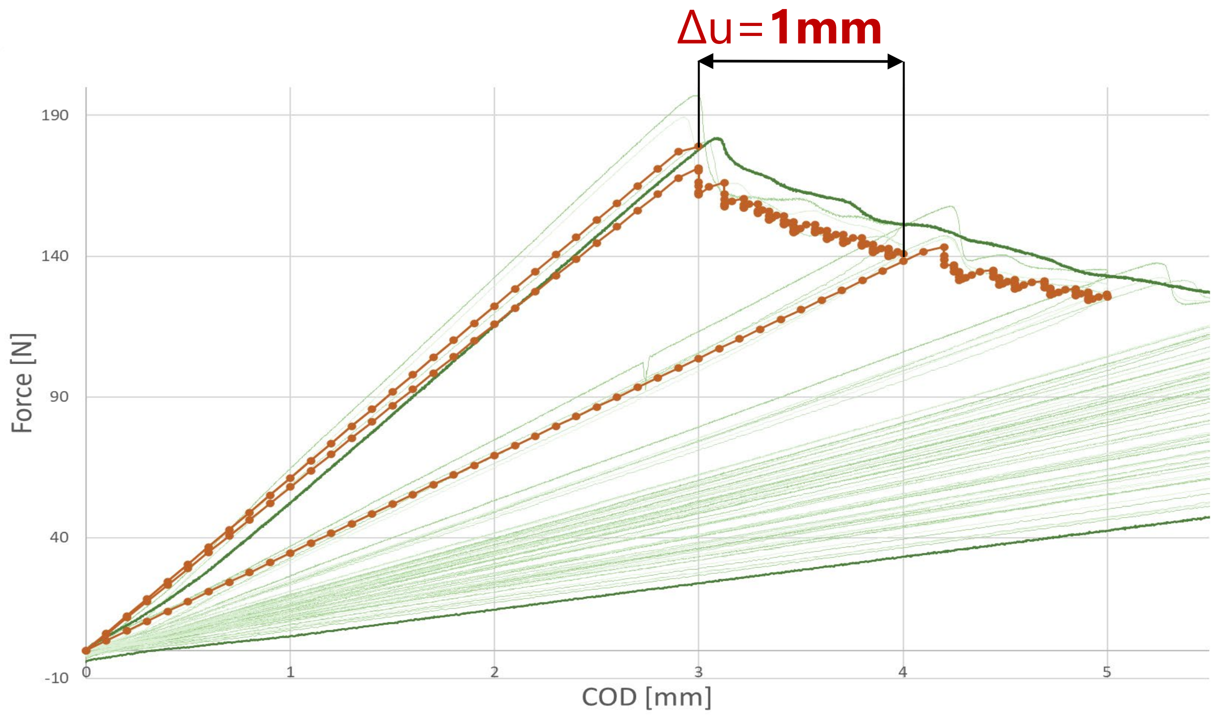
Carreras et al. (2019)

ALGORITHM PARAMETERS

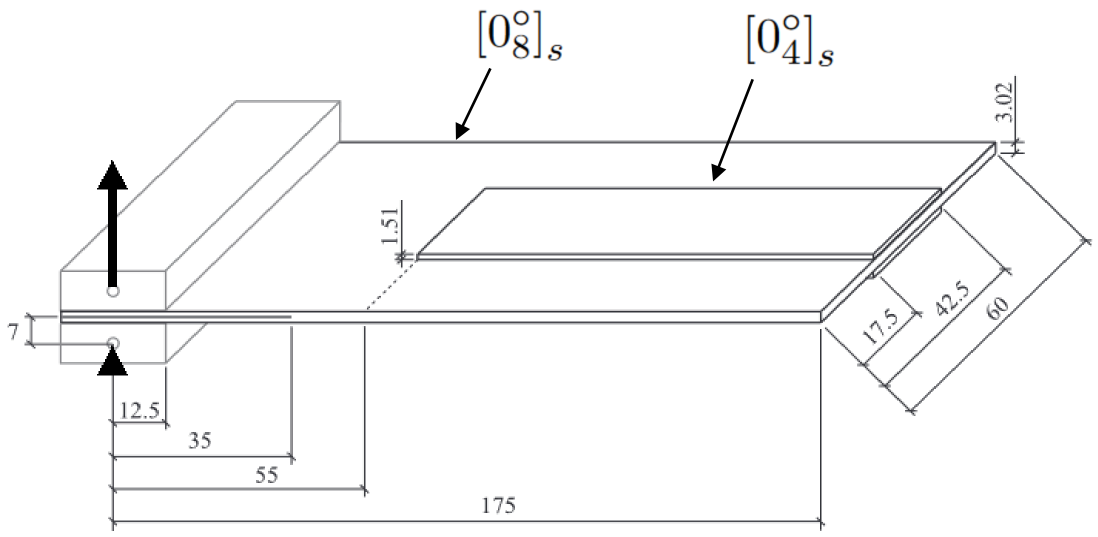
Polynomial smoothing of crack fronts

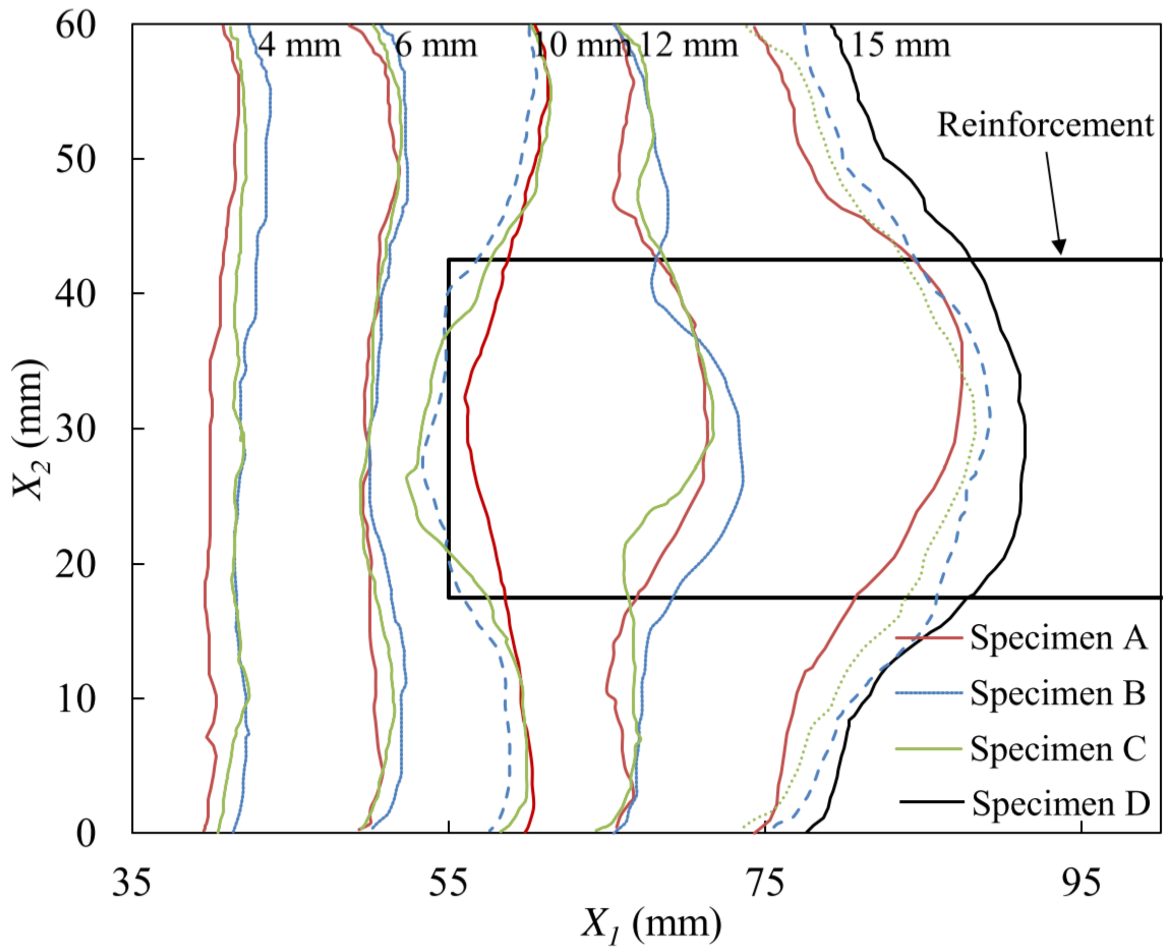


Displacement intervals between simulations



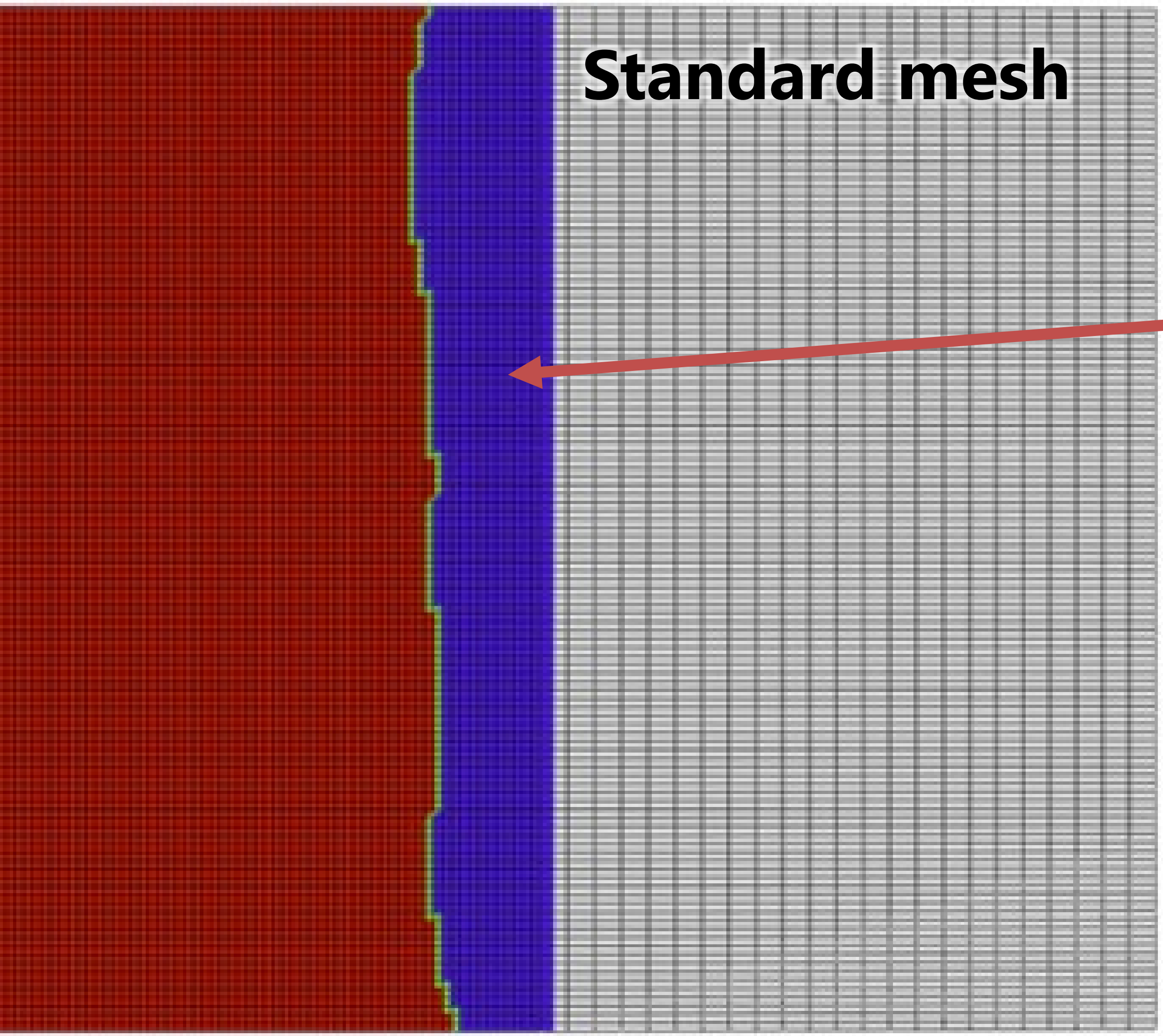
FIRST VALIDATION: NO PROPAGATION

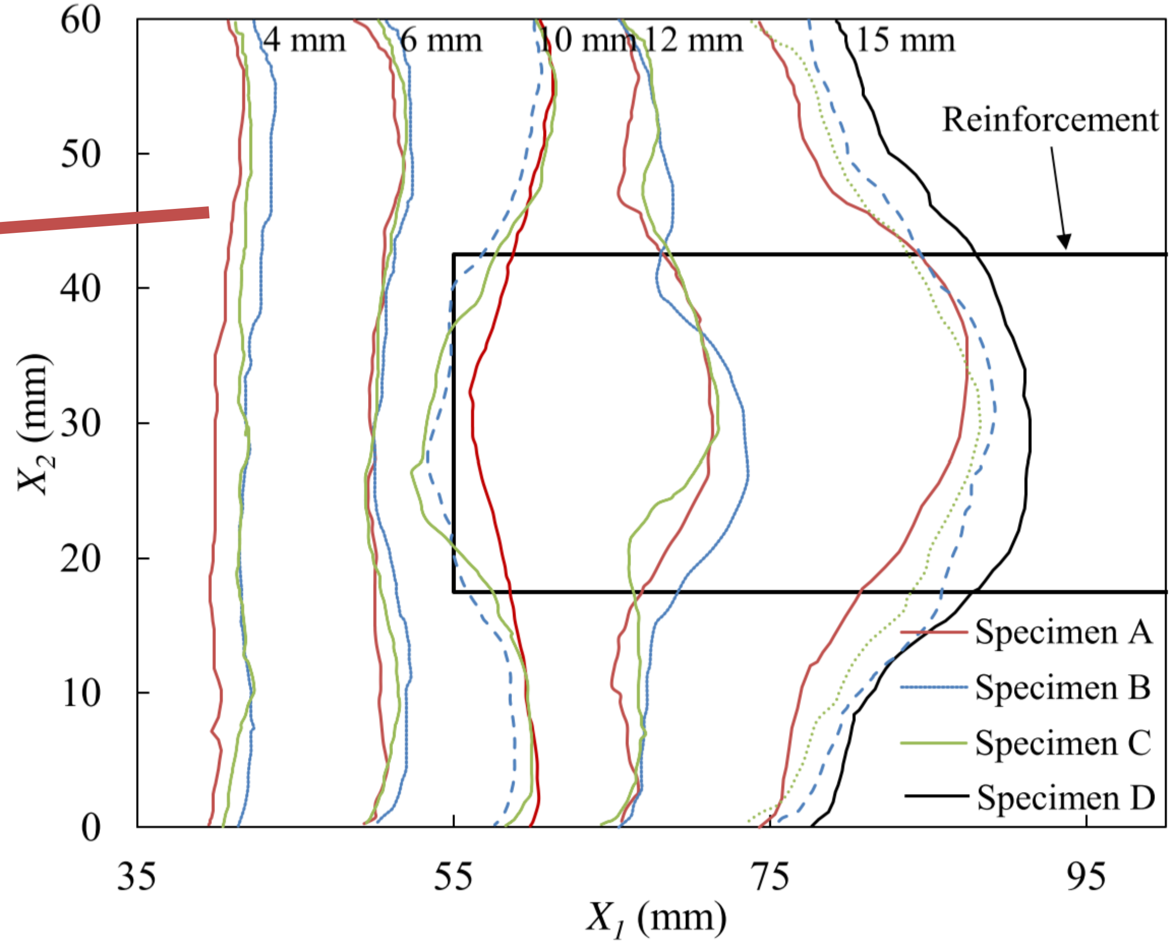




Carreras et al. (2019)

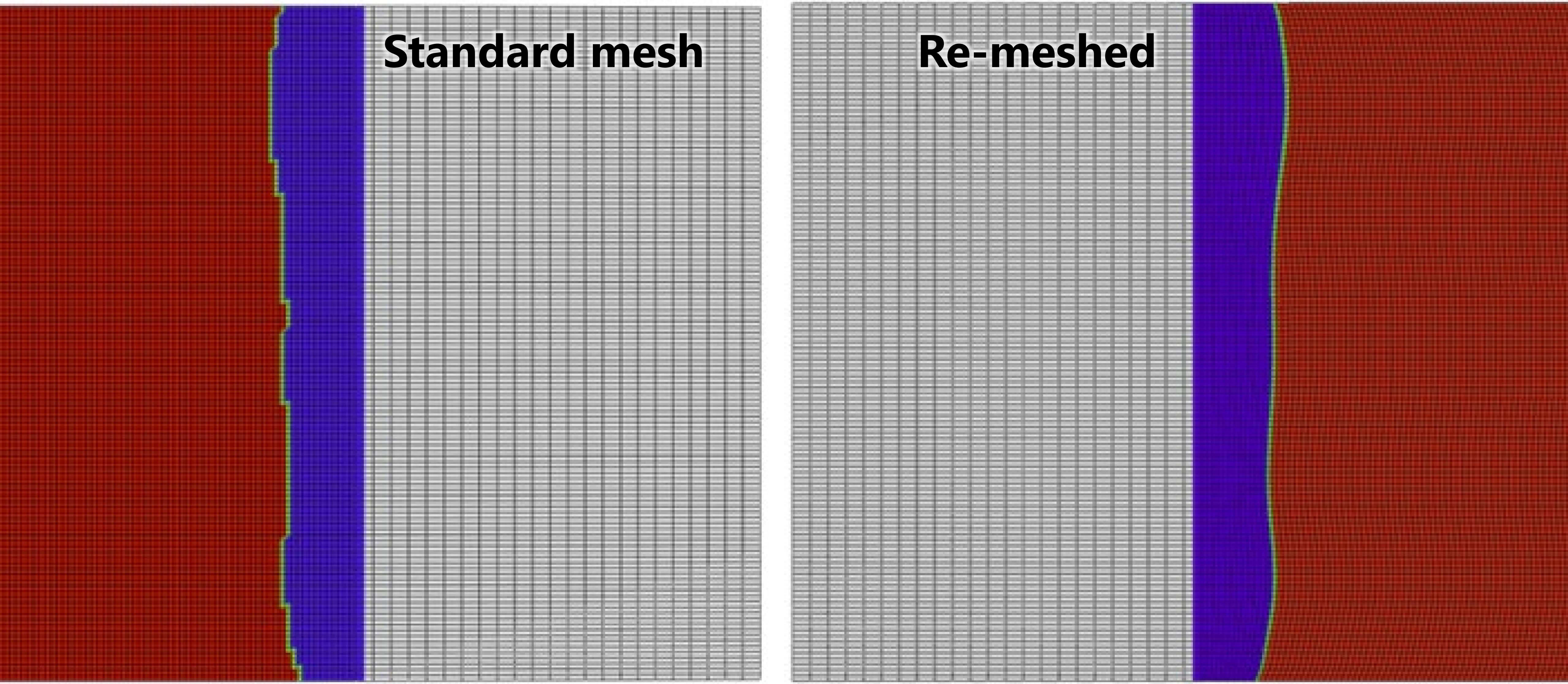
FIRST VALIDATION: NO PROPAGATION



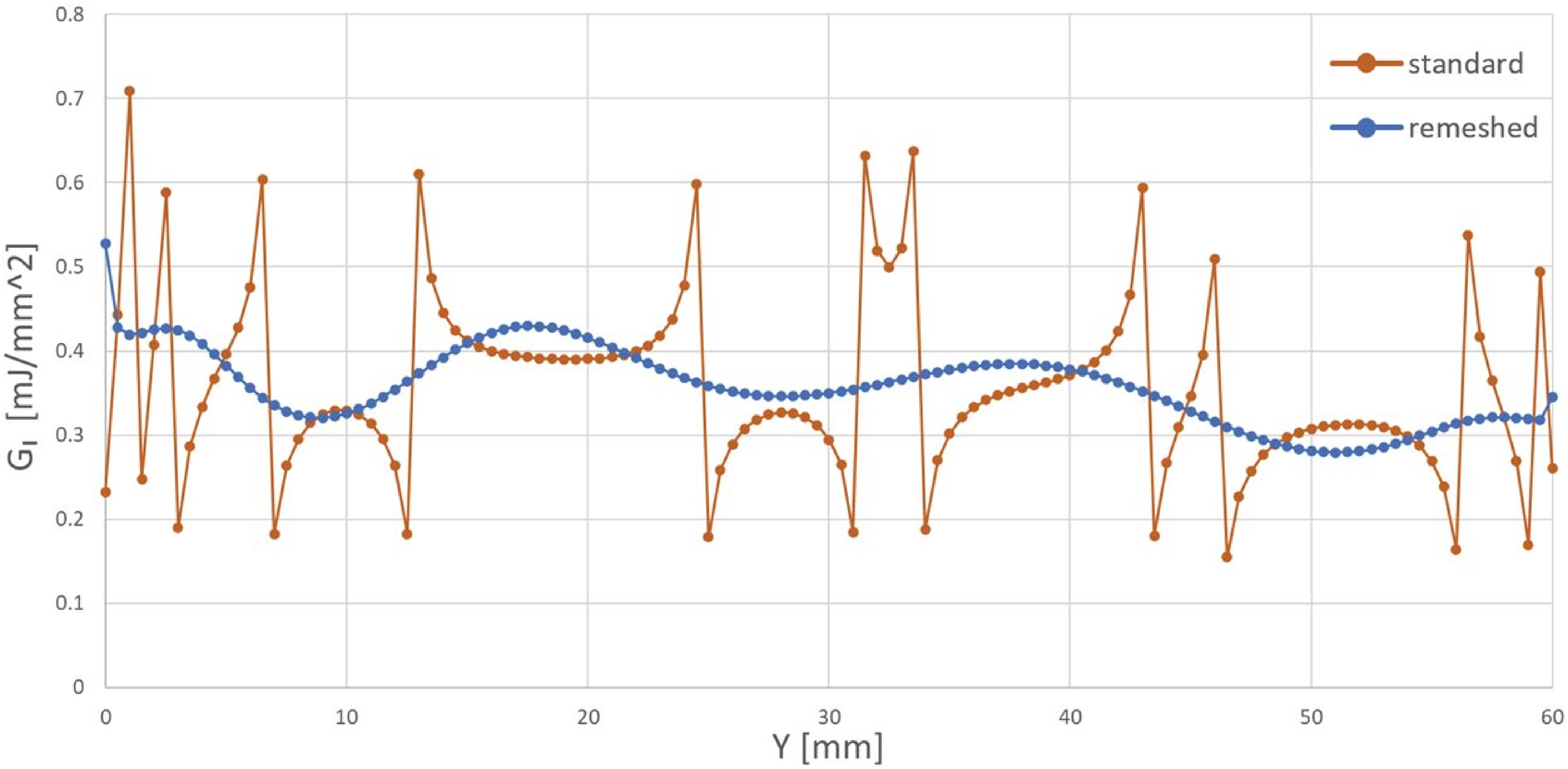


Carreras et al. (2019)

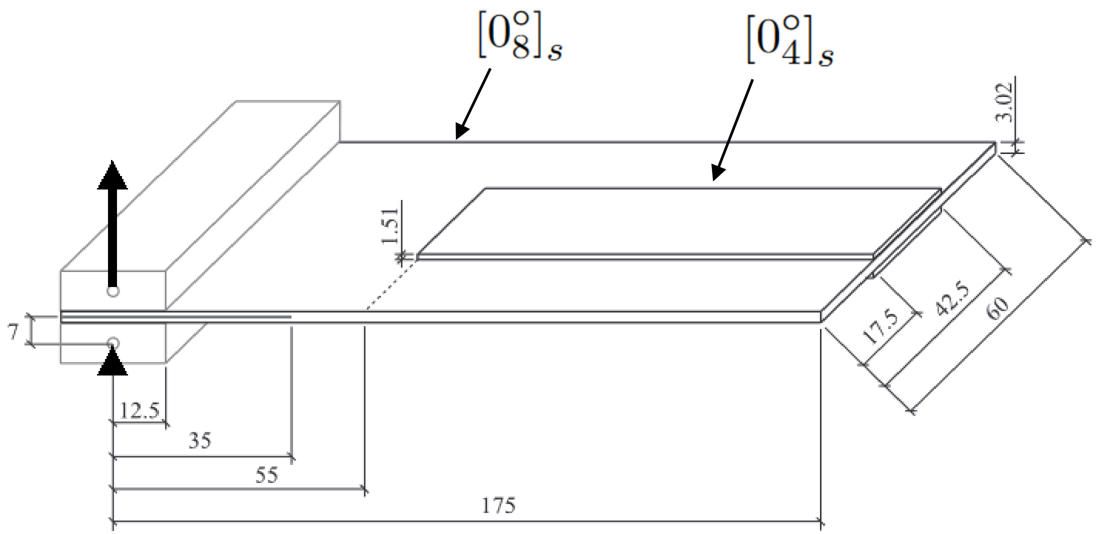
FIRST VALIDATION: NO PROPAGATION

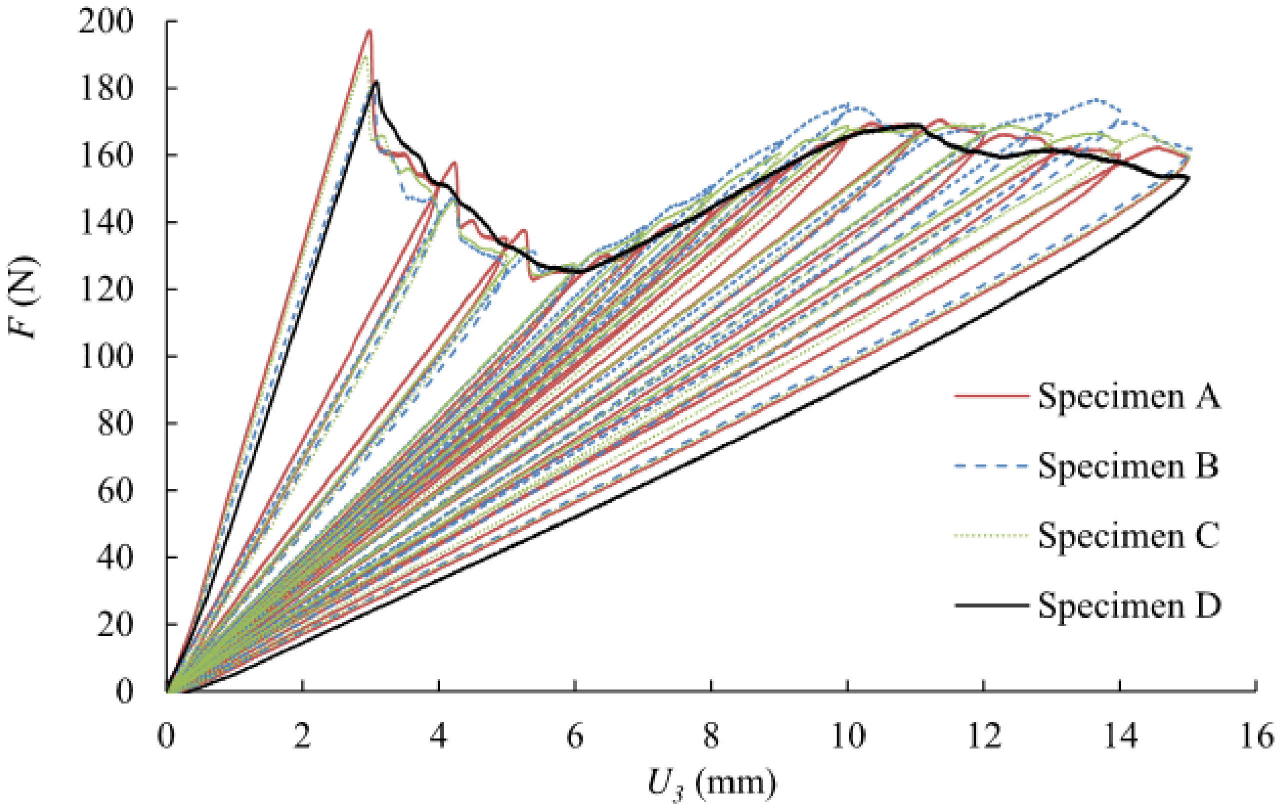


SIMULATION WITHOUT PROPAGATION



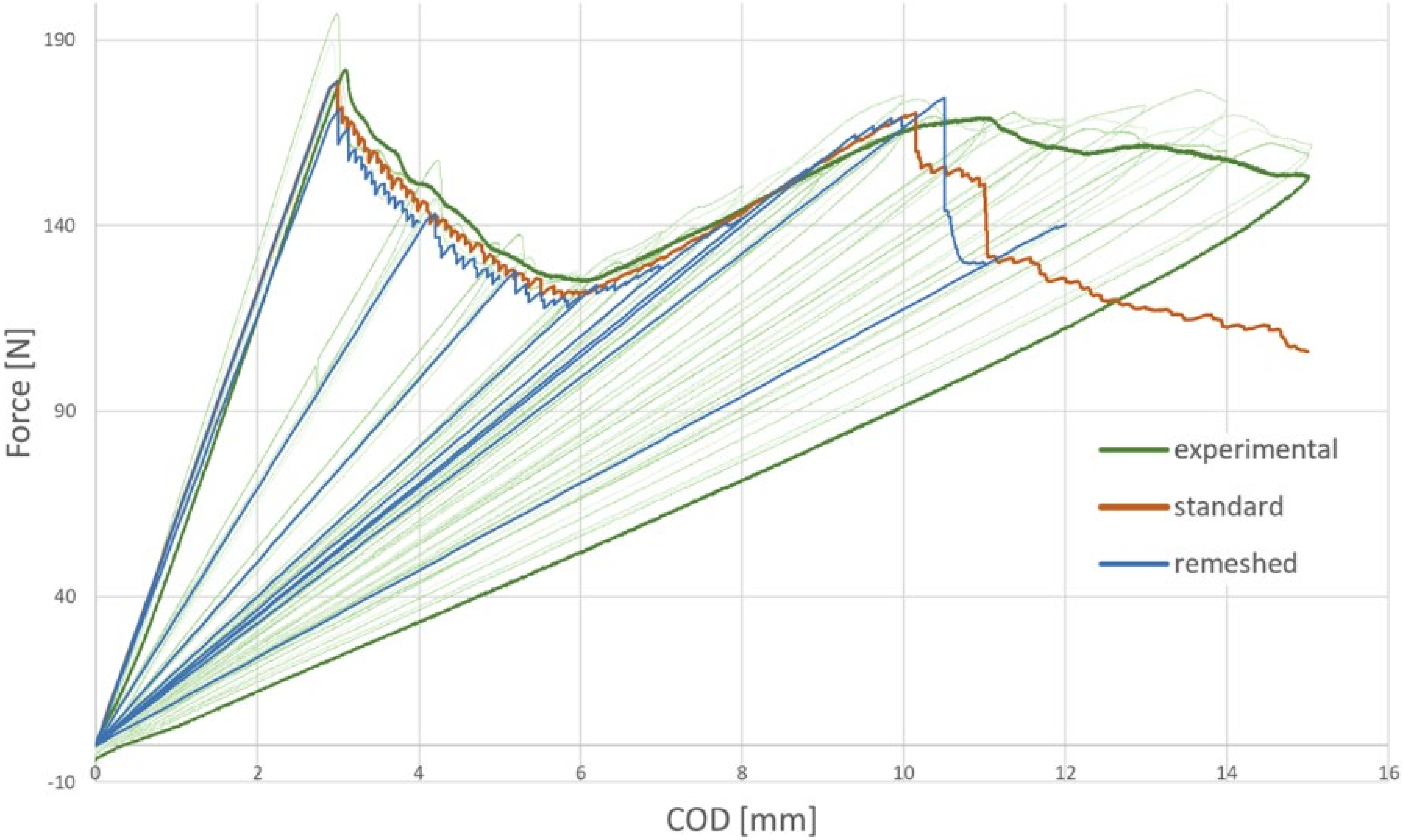
SECOND VALIDATION: FULL SIMULATION



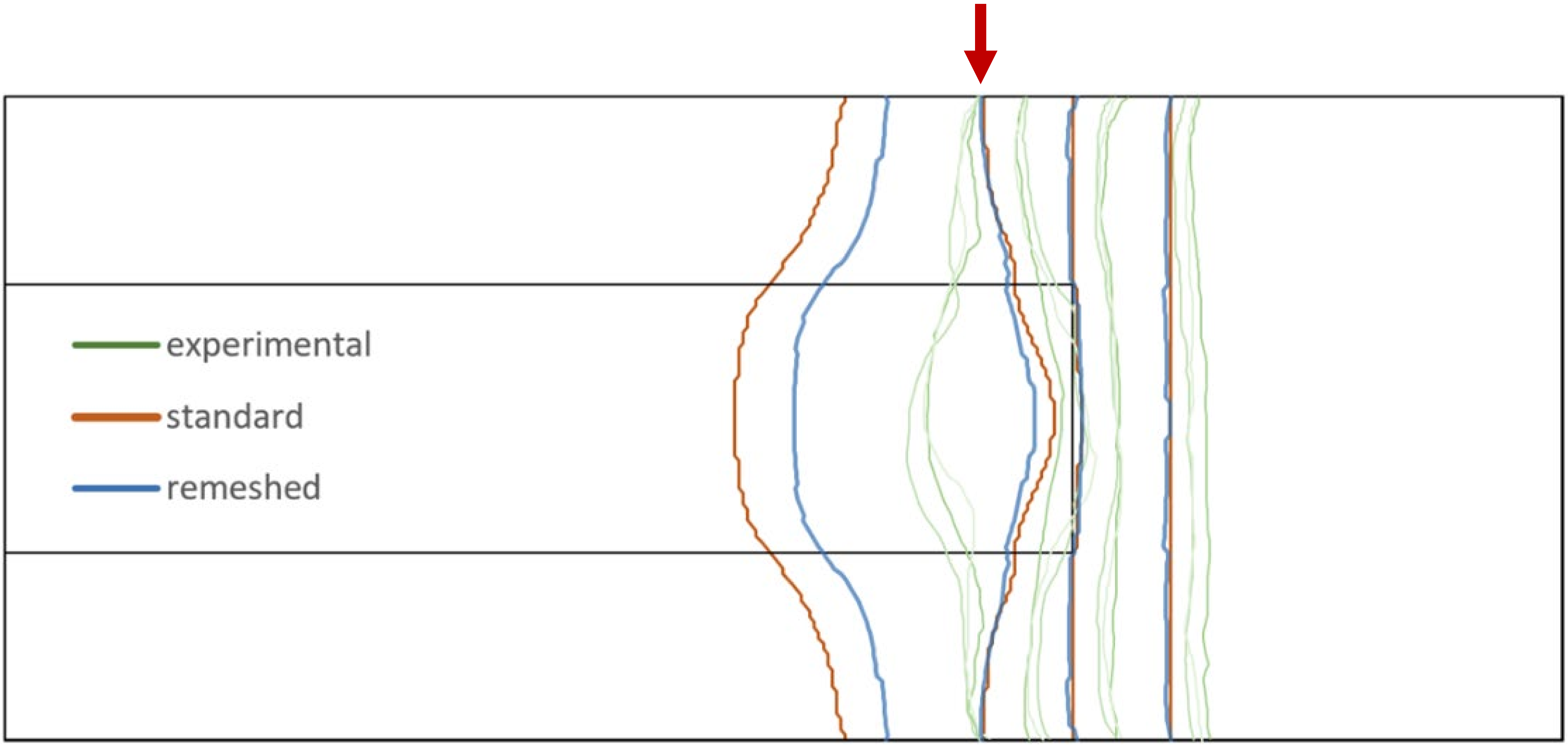


Carreras et al. (2019)

BOTH TECHNIQUES UNDERESTIMATE THE DELAMINATION RESISTANCE

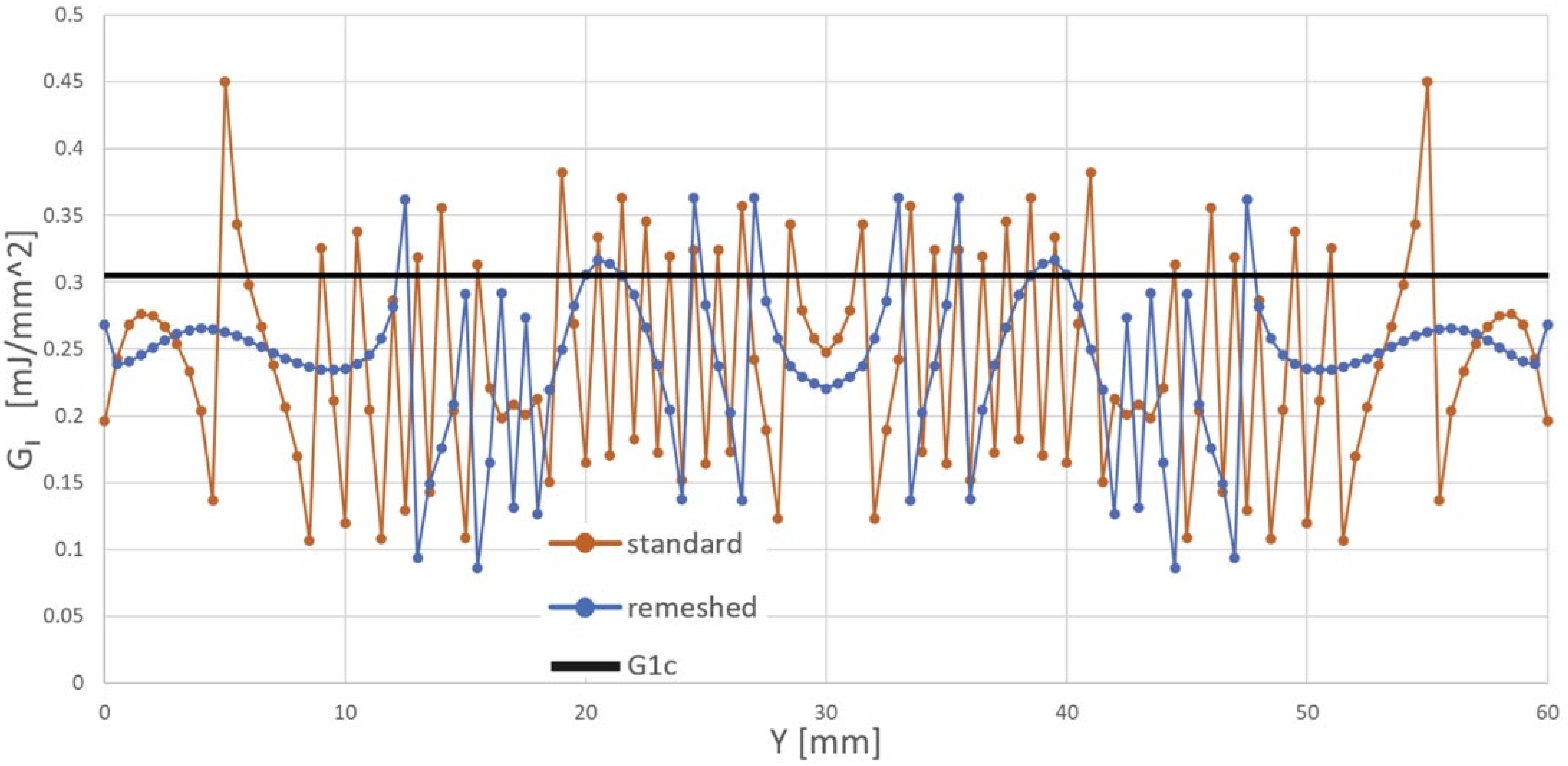


BOTH TECHNIQUES UNDERESTIMATE THE DELAMINATION RESISTANCE

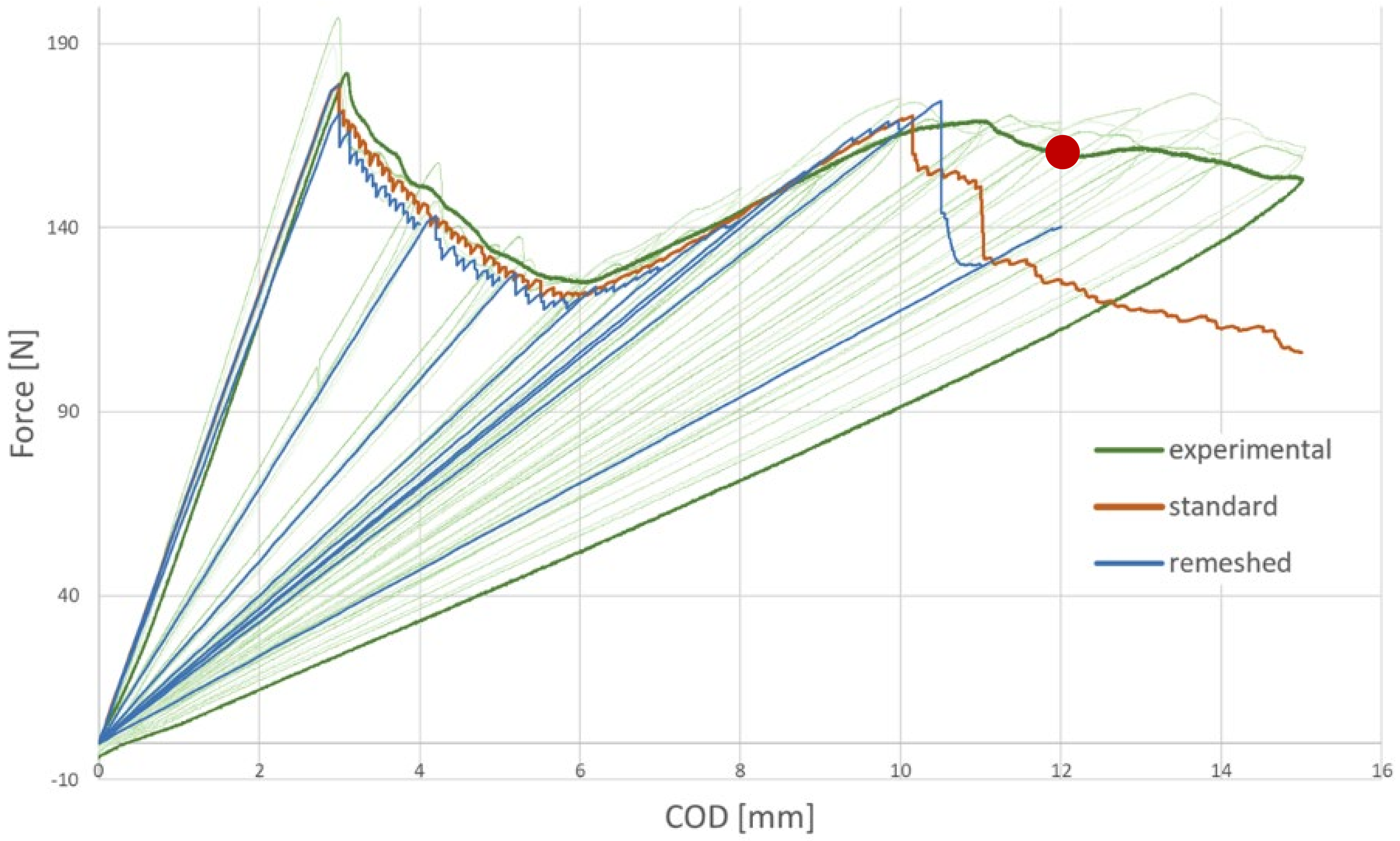


THE NEW MESH CANNOT COPE WITH SERR CONCENTRATIONS

@ 10 mm propagation

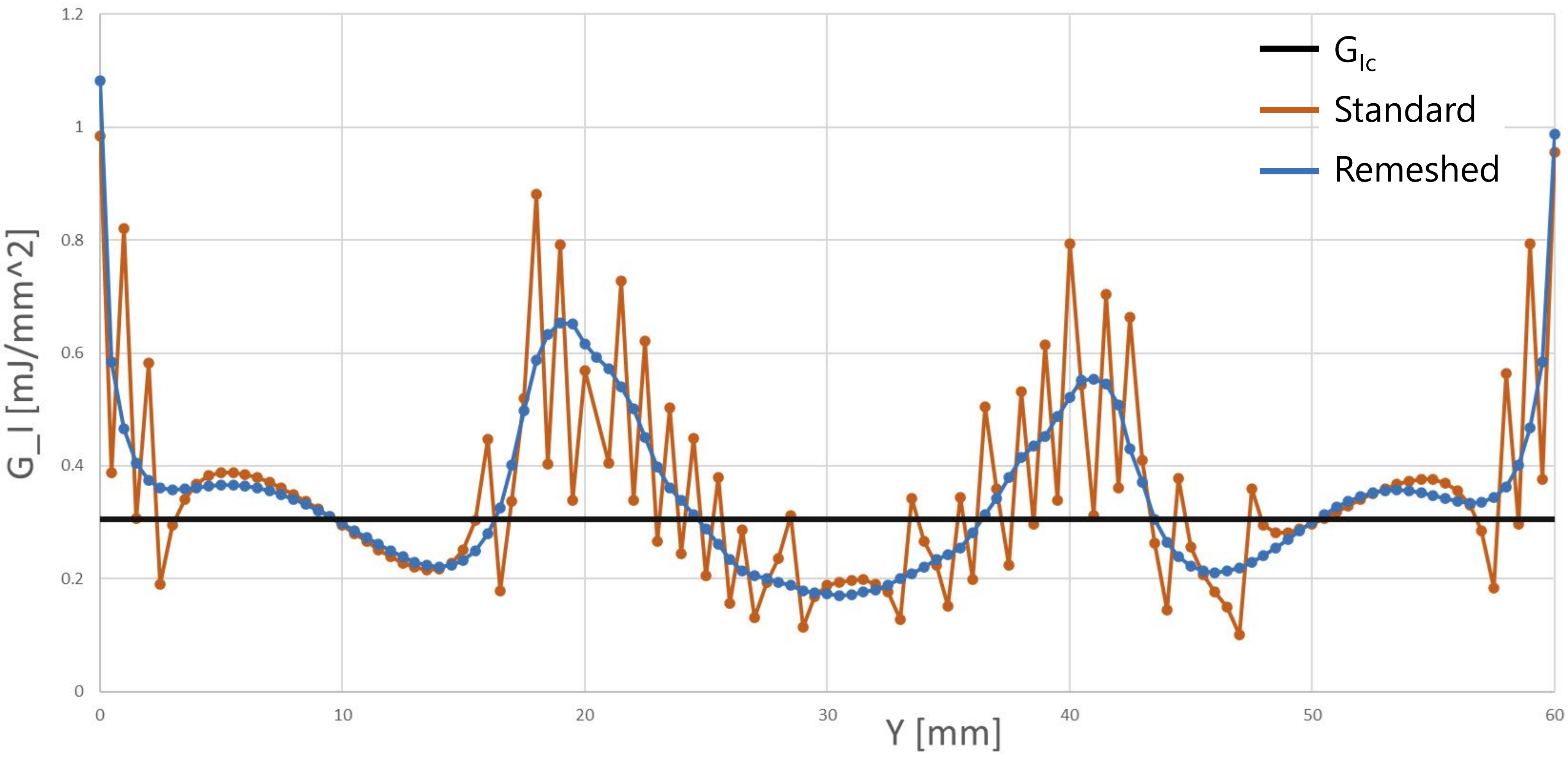


SIMULATION OF 12 MM DELAMINATION FRONT



SIMULATION OF 12 MM DELAMINATION FRONT

SIMULATION OF 12 MM DELAMINATION FRONT

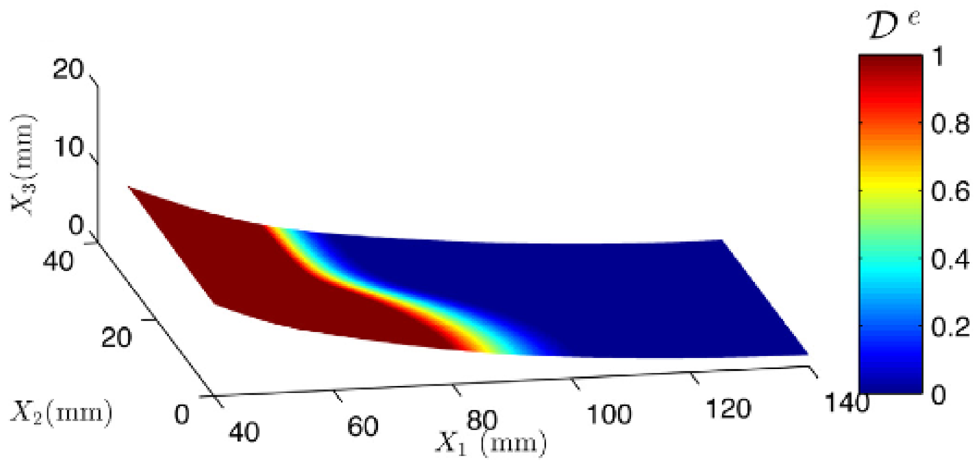


The experimental crack should not be possible **according to VCCT**

THE EXPERIMENTAL CRACK SHOULD NOT BE POSSIBLE ACCORDING TO VCCT

Possible explanations:

- VCCT is a node-wise technique that does not include a fracture process zone



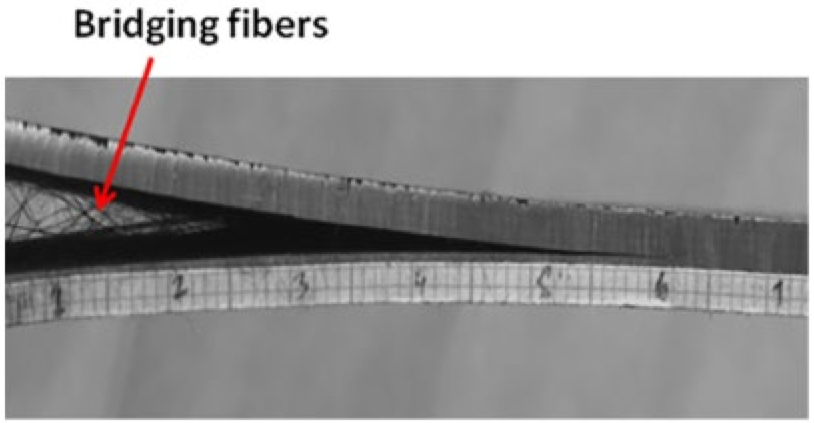
Carreras et al. (2019)

THE EXPERIMENTAL CRACK SHOULD NOT BE POSSIBLE ACCORDING TO VCCT

Possible explanations:

- VCCT is a node-wise technique that does not include a fracture process zone

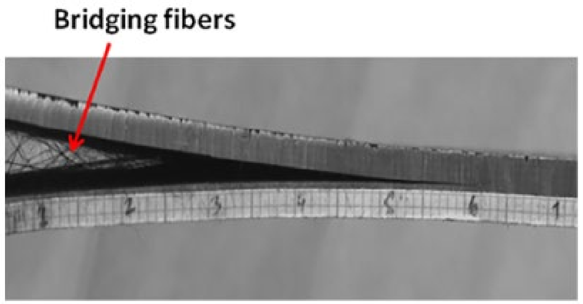
- Fibre bridging increases local fracture toughness

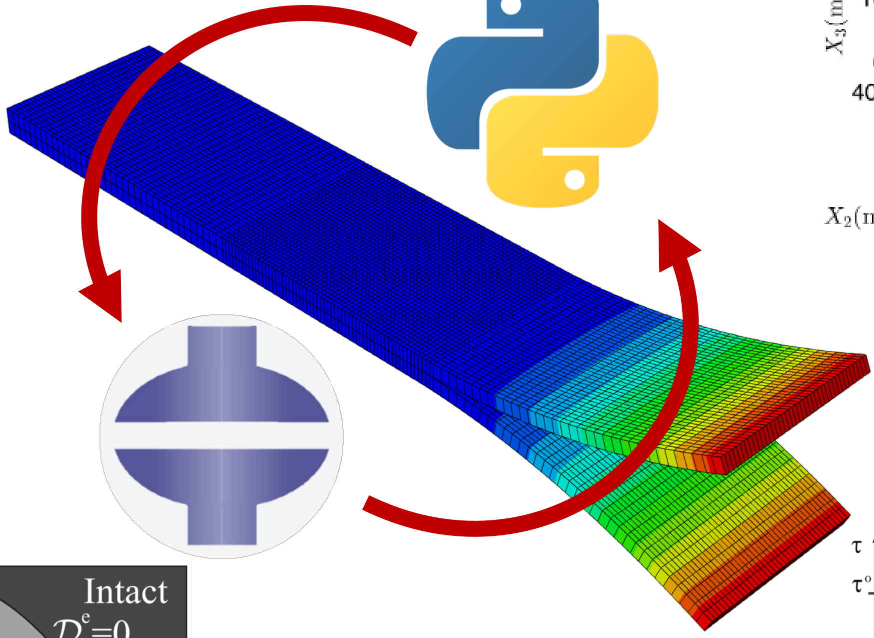


Khan (2019)

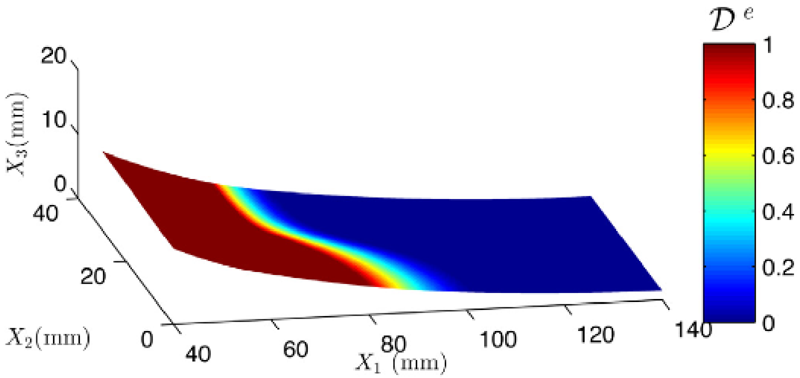
CONCLUSIONS: WHY AM I HERE?

Evolving fracture toughness
to model fibre bridging

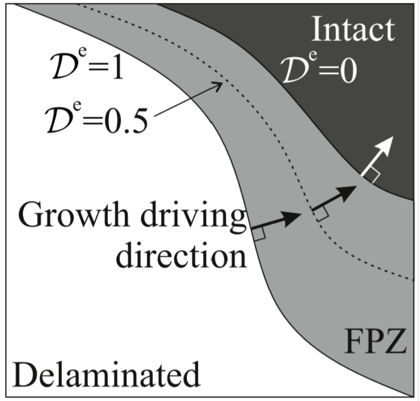




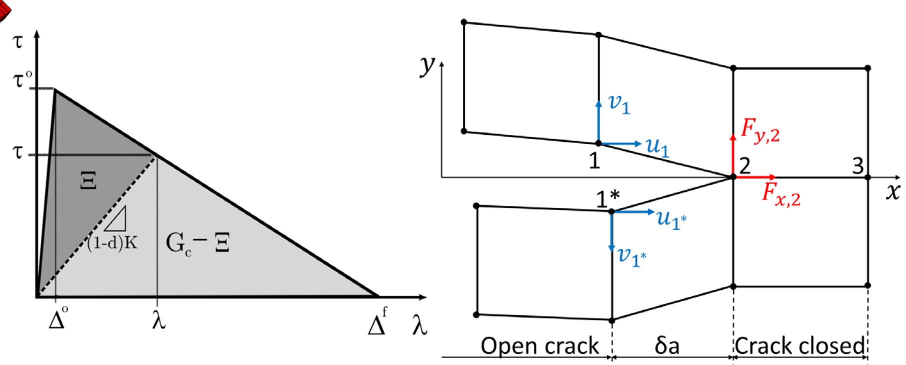
Fracture process zone in VCCT



Evaluate modes decomposition
with remeshed VCCT



Hybrid CZM-VCCT



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