POLITECNICO
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DEPARTMENT OF
MECHANICAL ENGINEERING

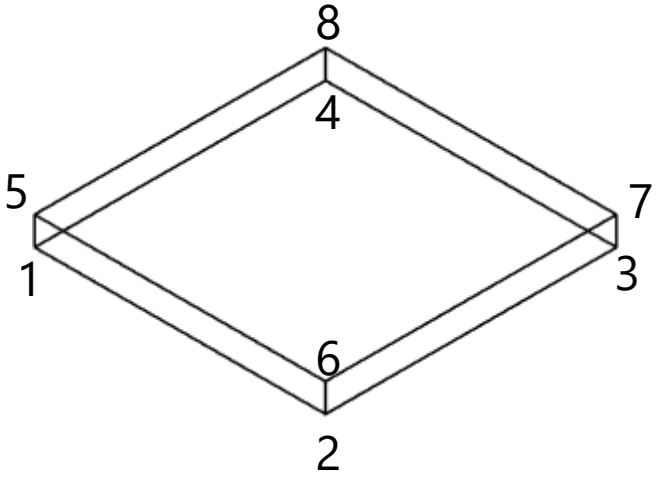
The Sequential Static Fatigue algorithm: a fast approach to predict composites delamination growth under fatigue loadings

L. M. Martulli, A. Bernasconi

lucamichele.martulli@polimi.it

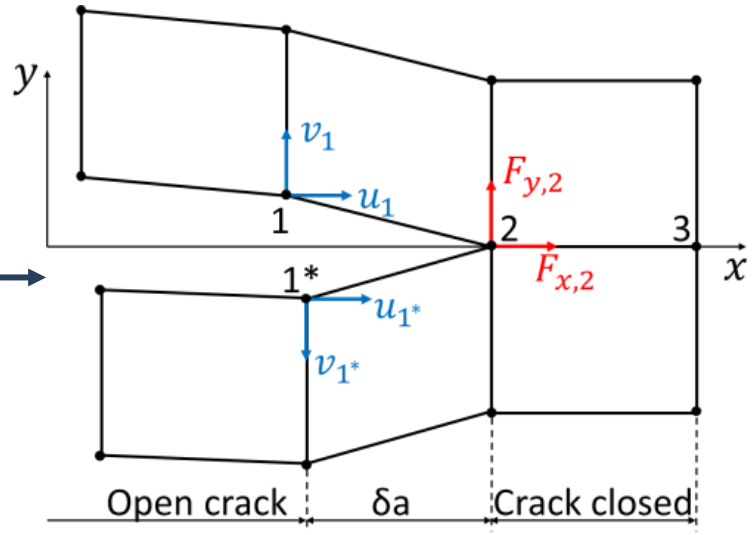
BACKGROUND

Cohesive elements



Modelling delamination propagation under fatigue

Virtual Crack Closure Technique



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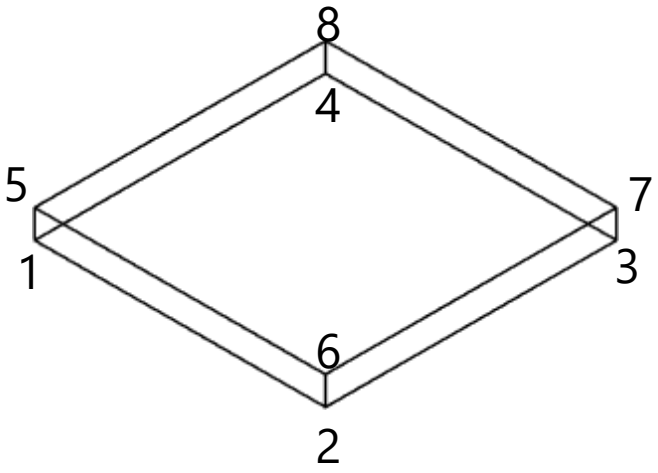

Modelling delamination propagation under fatigue

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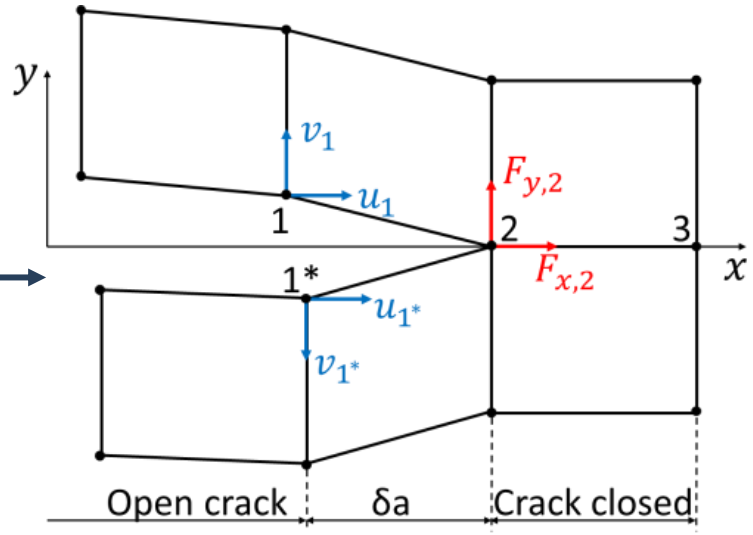


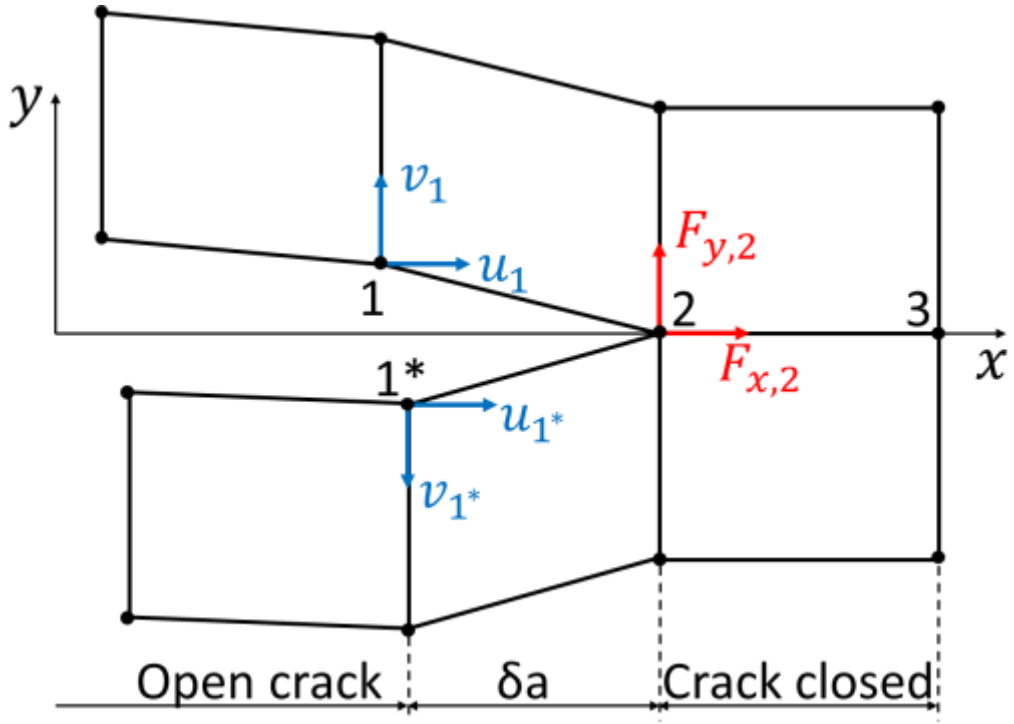
9:10 10:30 Session 9: **COHESIVE ZONE MODELLING**
Chairman:

Oral

R006 - The sequential static fatigue algorithm: a fast approach to predict composites delamination growth under fatigue loadings

Luca M. Martulli, Andrea Bernasconi
Politecnico di Milano

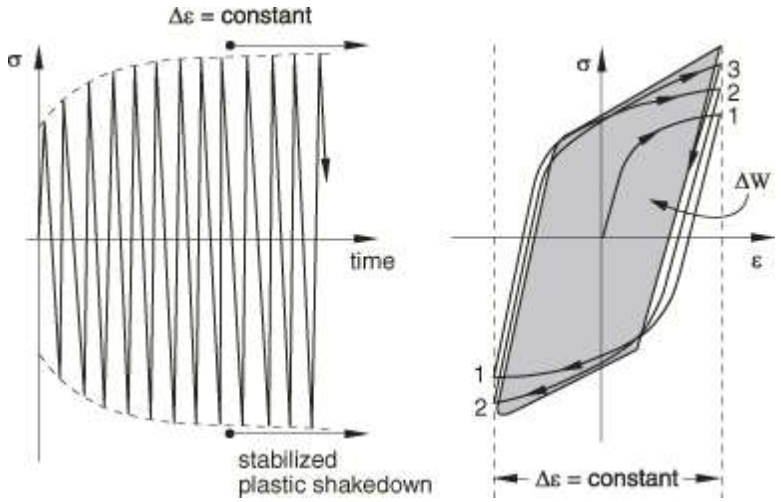
VIRTUAL CRACK CLOSURE TECHNIQUE (VCCT)

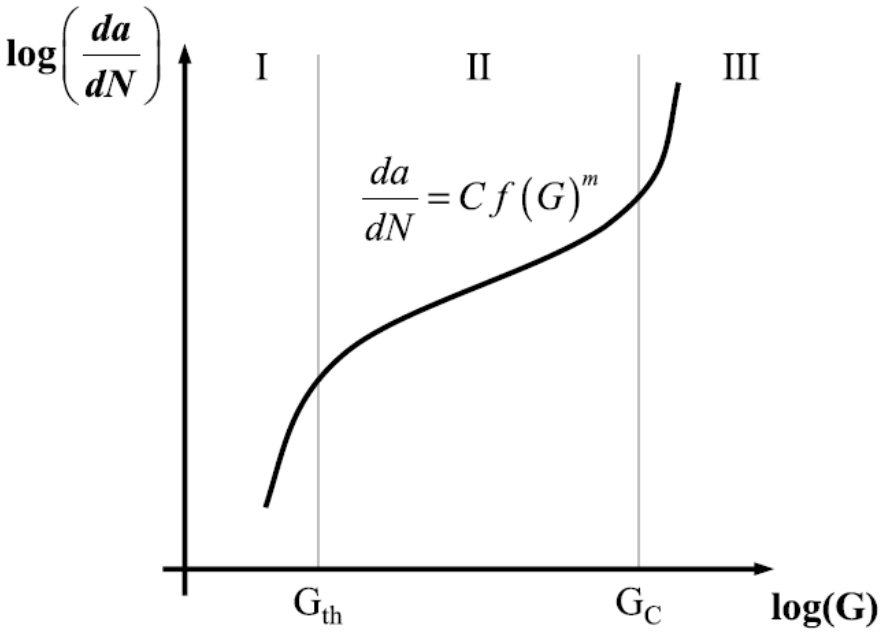


Strain Energy Release Rate computation technique

Widely used for quasi-static simulations

THE BENCHMARK: THE DIRECT CYCLIC (DC) ALGORITHM





Load history is approximated via a Fourier series

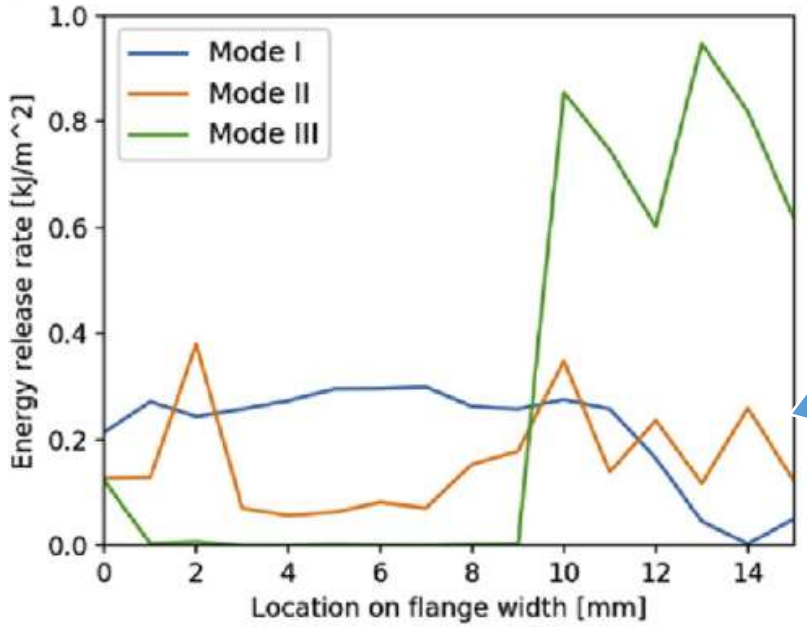
Suitable for low cycle fatigue (plasticity)

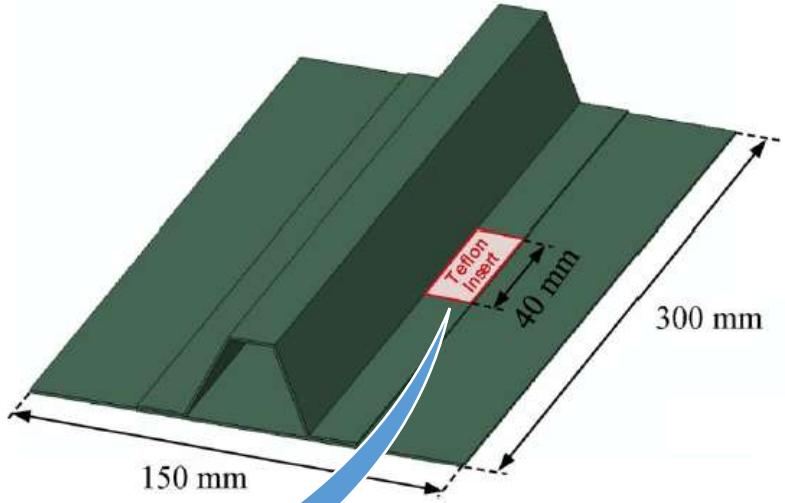
VCCT can be used with DC for crack propagation predictions

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]

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

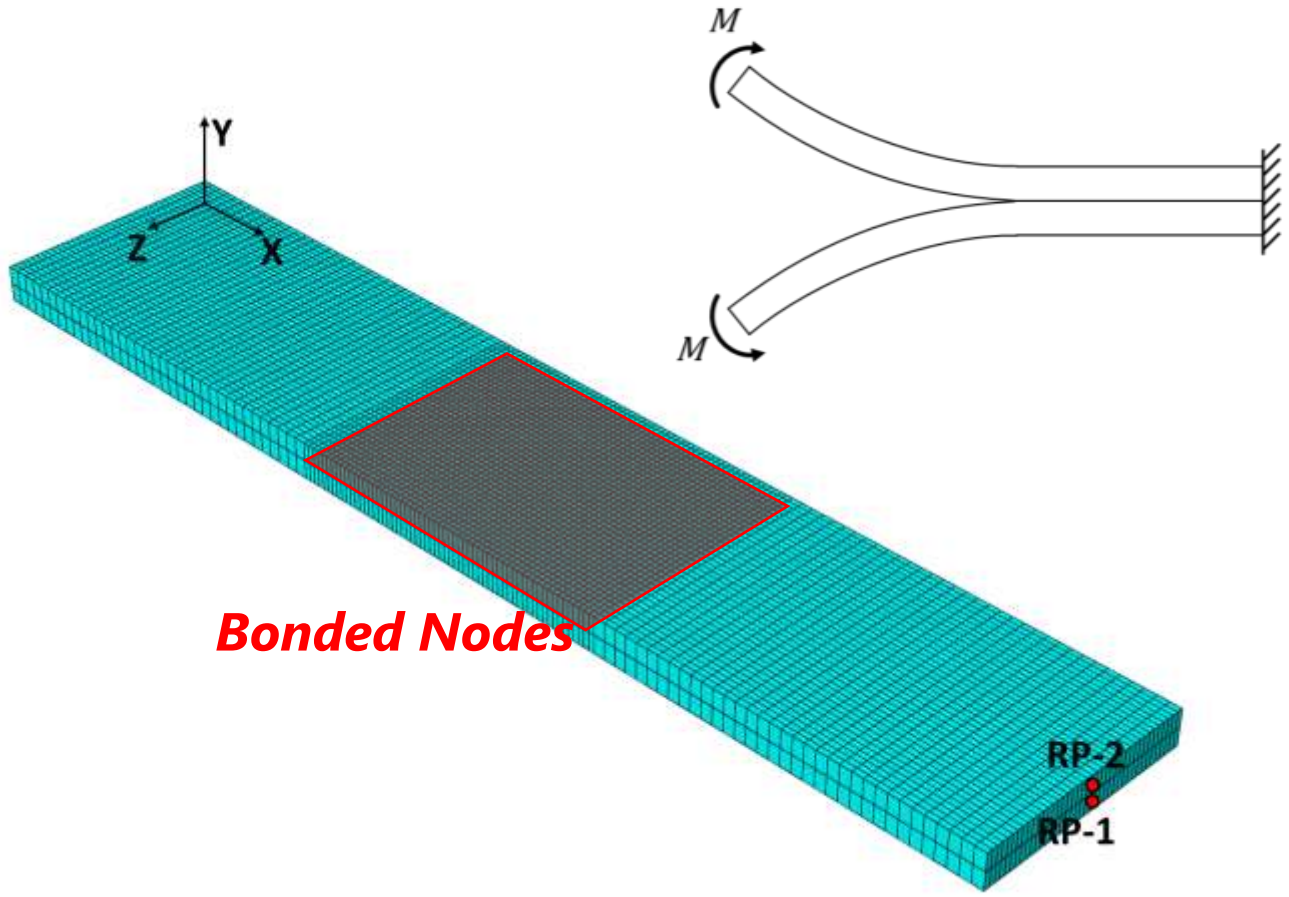




[1] Pirondi et al. (2014)
[2] Raimondo et al. (2020)

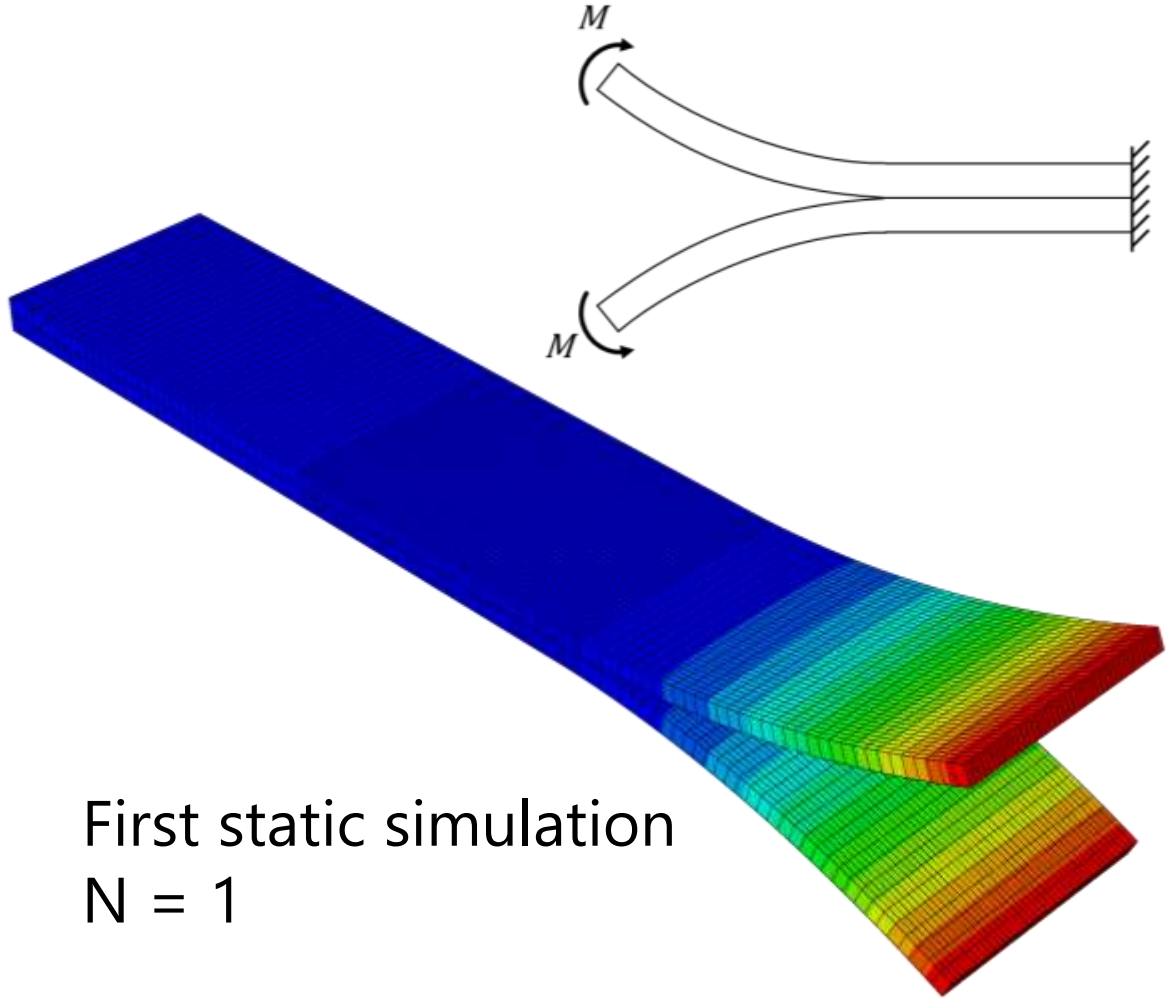
OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

- **Pre-processing**



OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

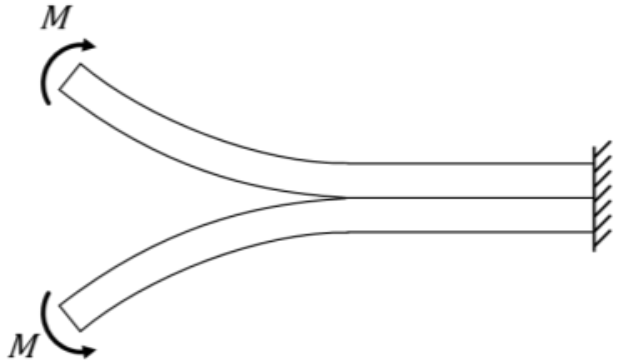
- Pre-processing
- **Launch simulation**



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**

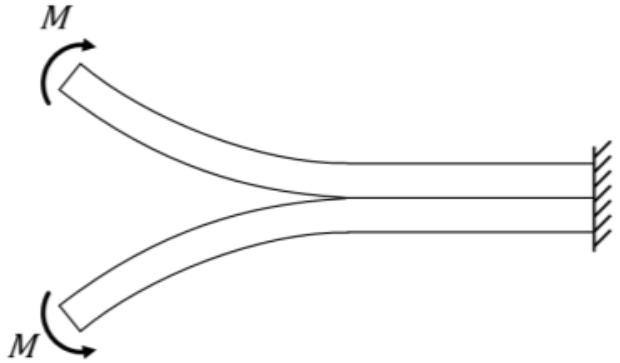


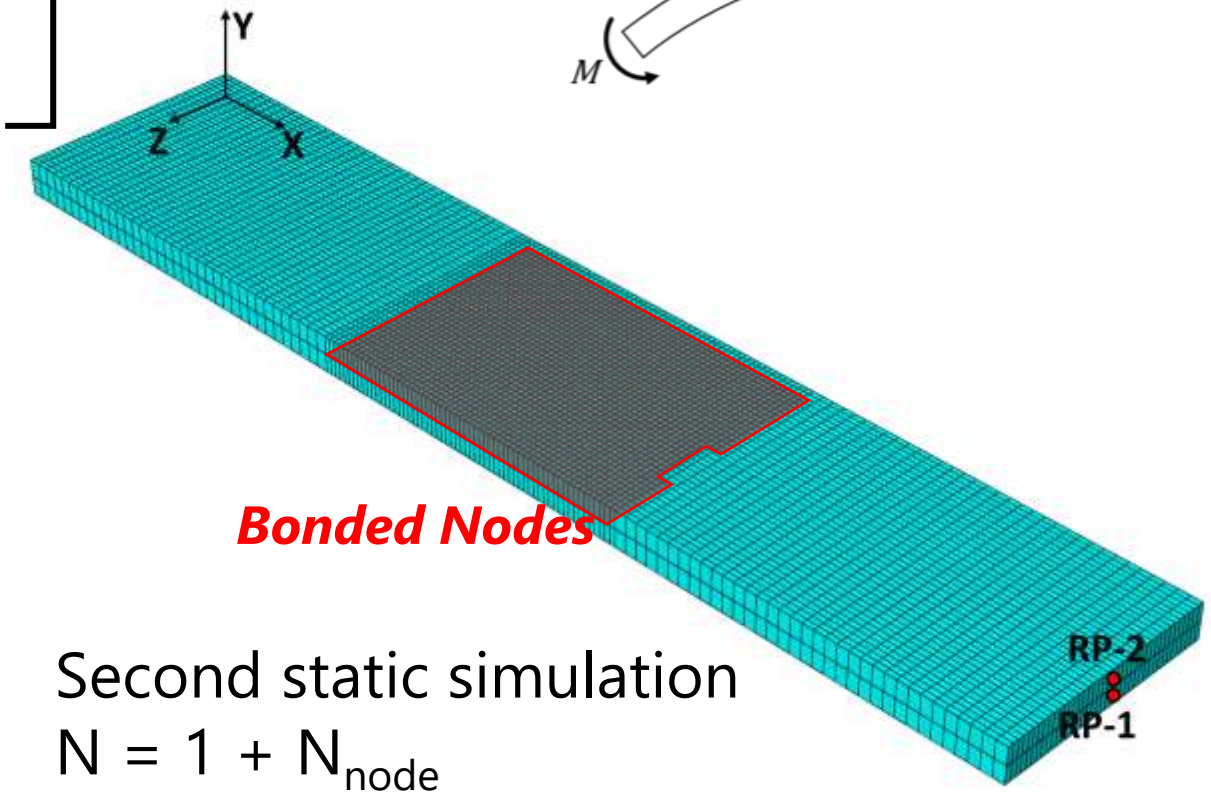
$$\frac{da}{dN} = f\left(\mathcal{G}_{\max}, \mathcal{G}_{\min}, \frac{\mathcal{G}_{II} + \mathcal{G}_{III}}{\mathcal{G}_{tot}}\right)$$

$$a = l_{el} \longrightarrow N_{node}$$

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)

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

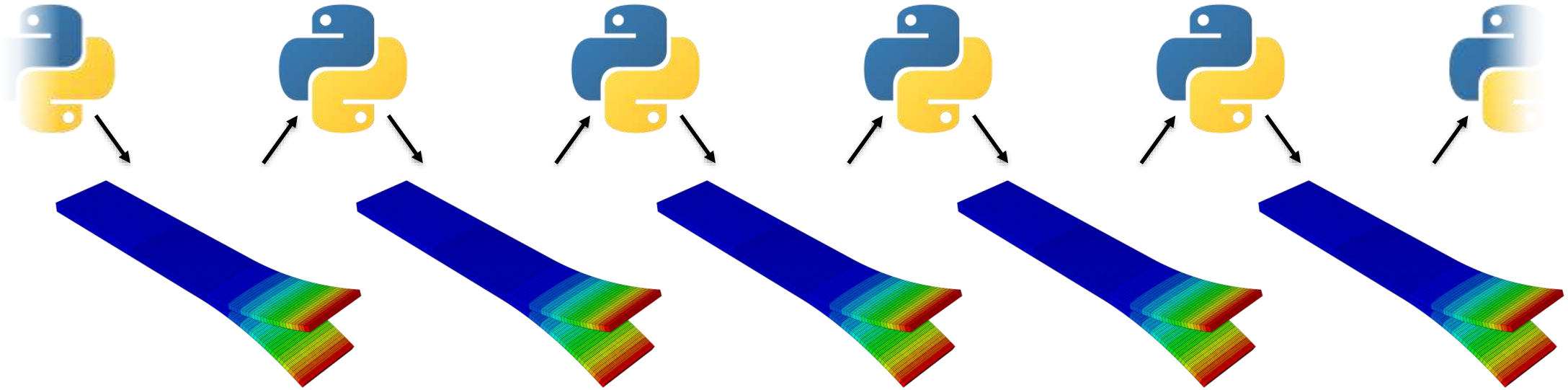




Second static simulation

$N = 1 + N_{node}$

OUR APPROACH: SEQUENTIAL-STATIC FATIGUE (SSF)



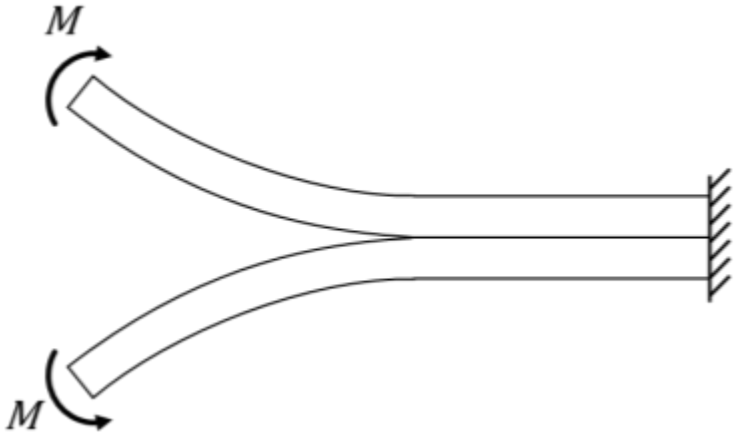
Fatigue load history is simulated via a series of static simulations

The algorithm uses the VCCT already implemented in Abaqus

SSF VALIDATION

Experimental data from Asp et al. (2001)

Mode I

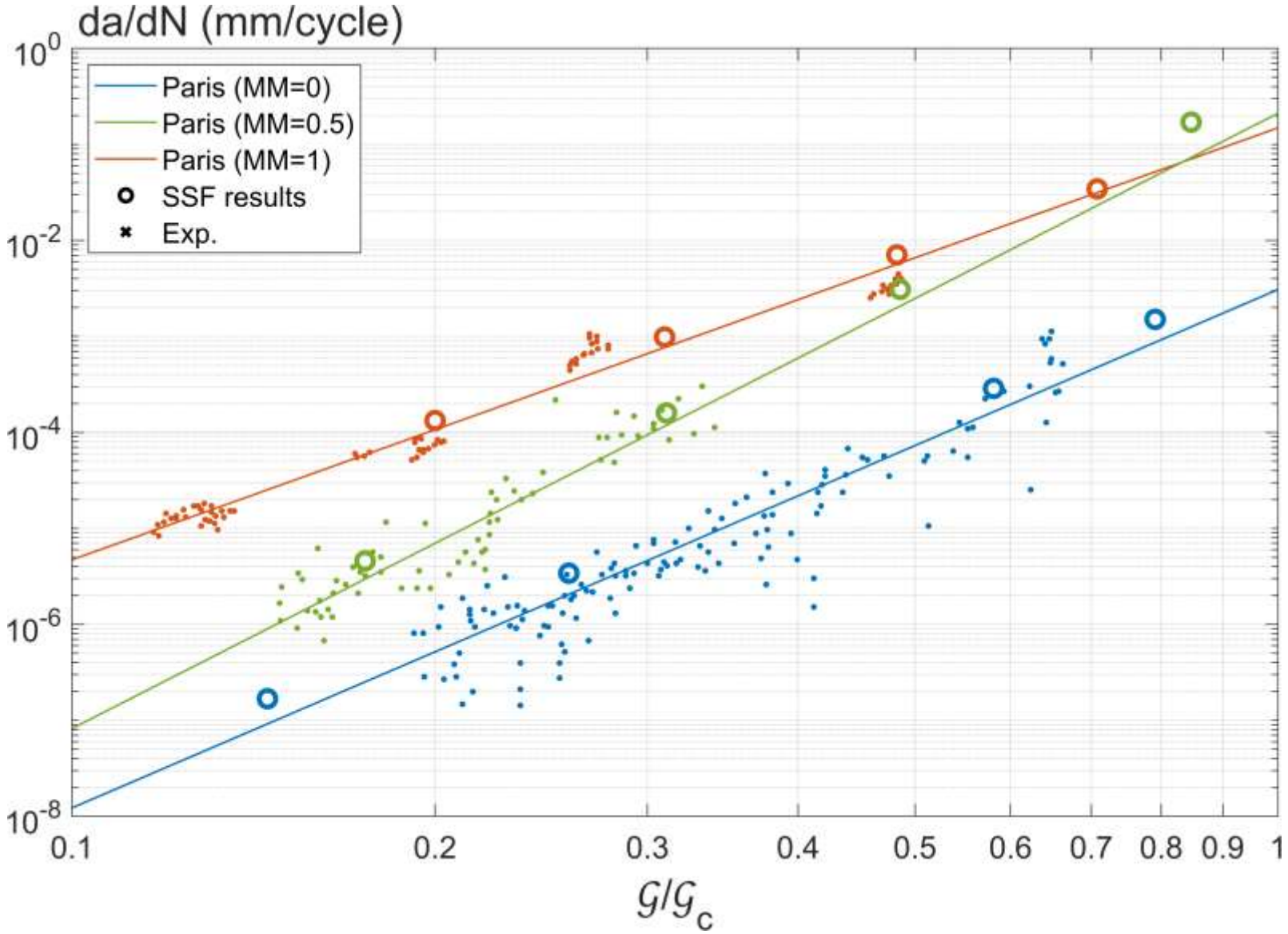


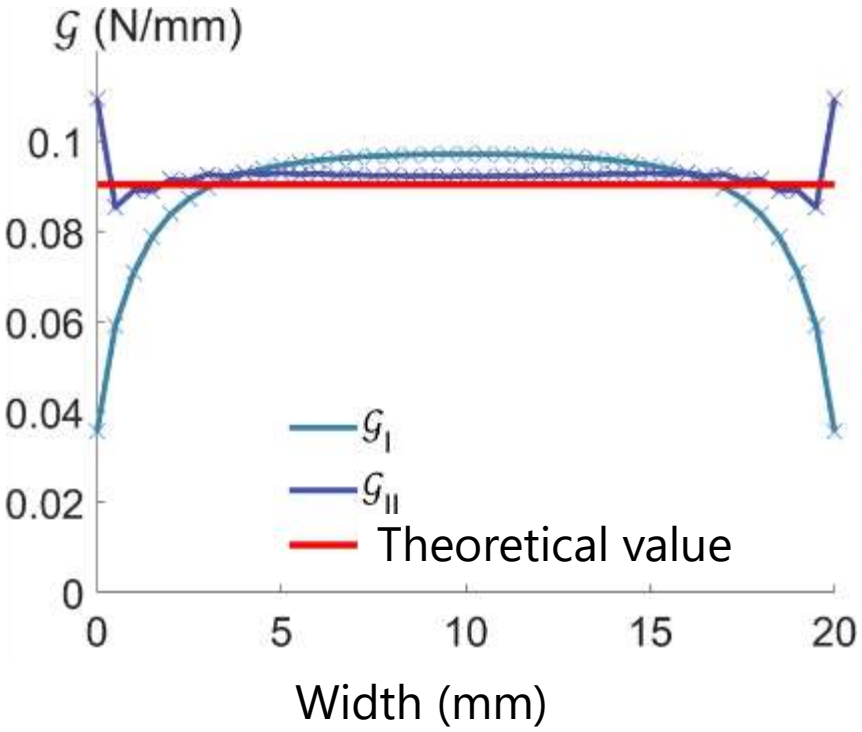
Mixed mode
(50% mode-mixity)

Mode II

Applied moment→ Constant propagation speed

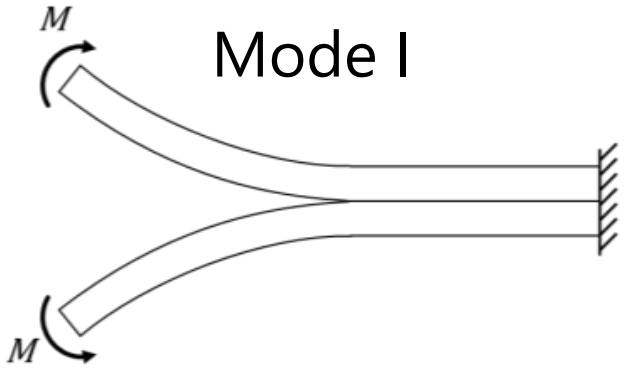
SSF PERFORMANCE





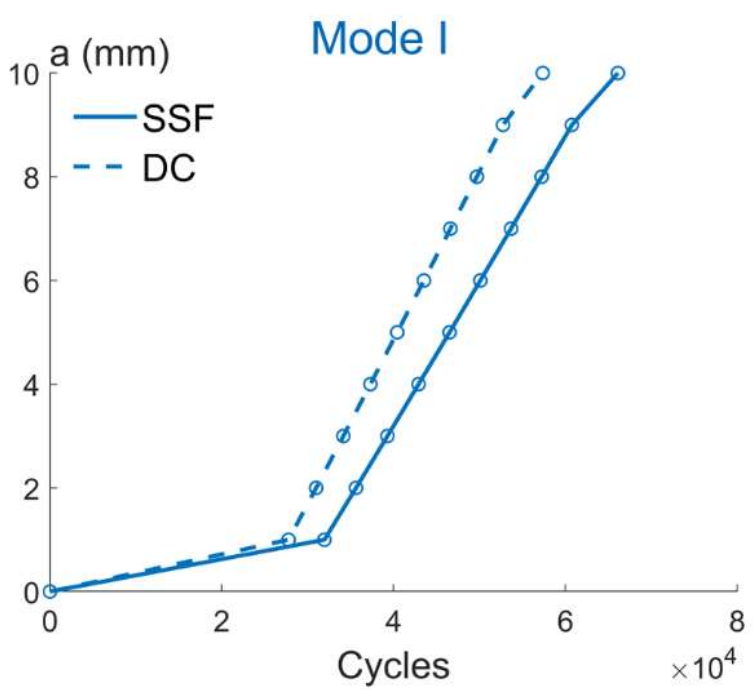
SSF AND DC COMPARISON

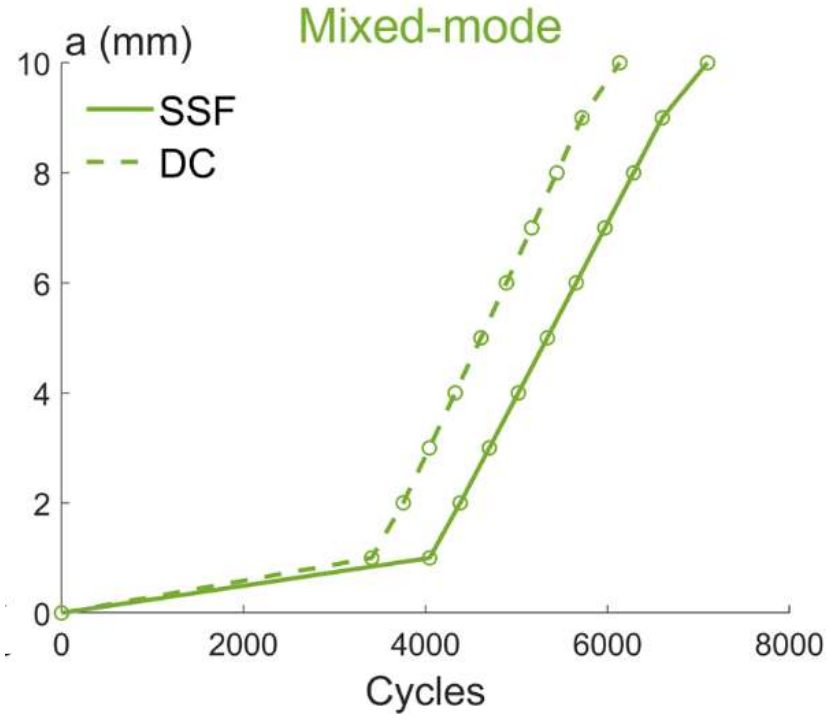
Mode I

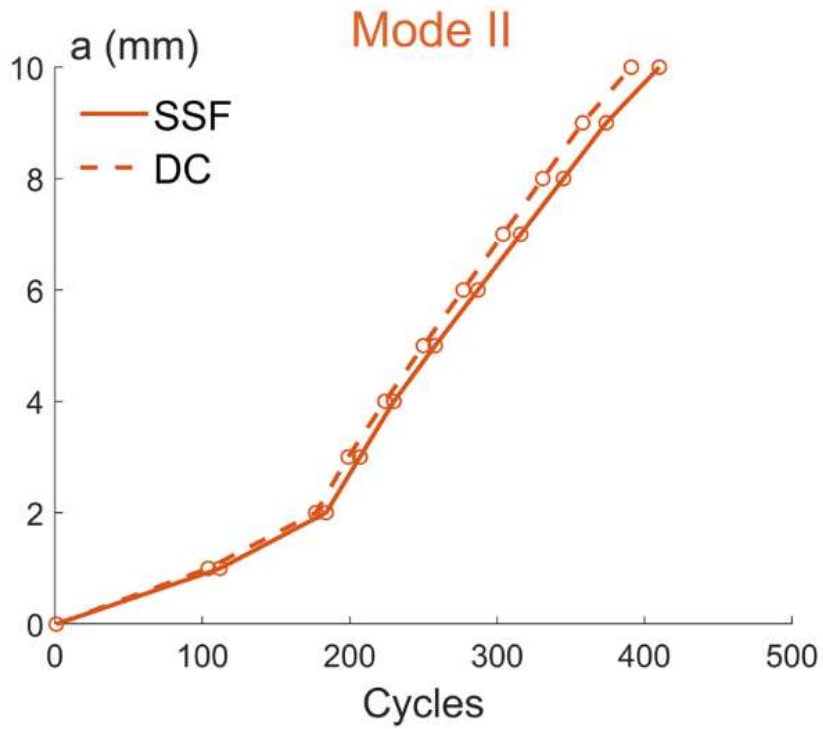


Mixed mode
(50% mode-mixity)

Mode II







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**		

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	86 h, 42 m, 45 s		
Coarse mesh – mixed mode 10 mm propagation	76 h, 3 m, 15 s		
Coarse mesh – mode II 10 mm propagation	52 h, 43 m, 48 s		

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

PROBLEMS

Composite Structures 210 (2019) 932–941

Contents lists available at ScienceDirect

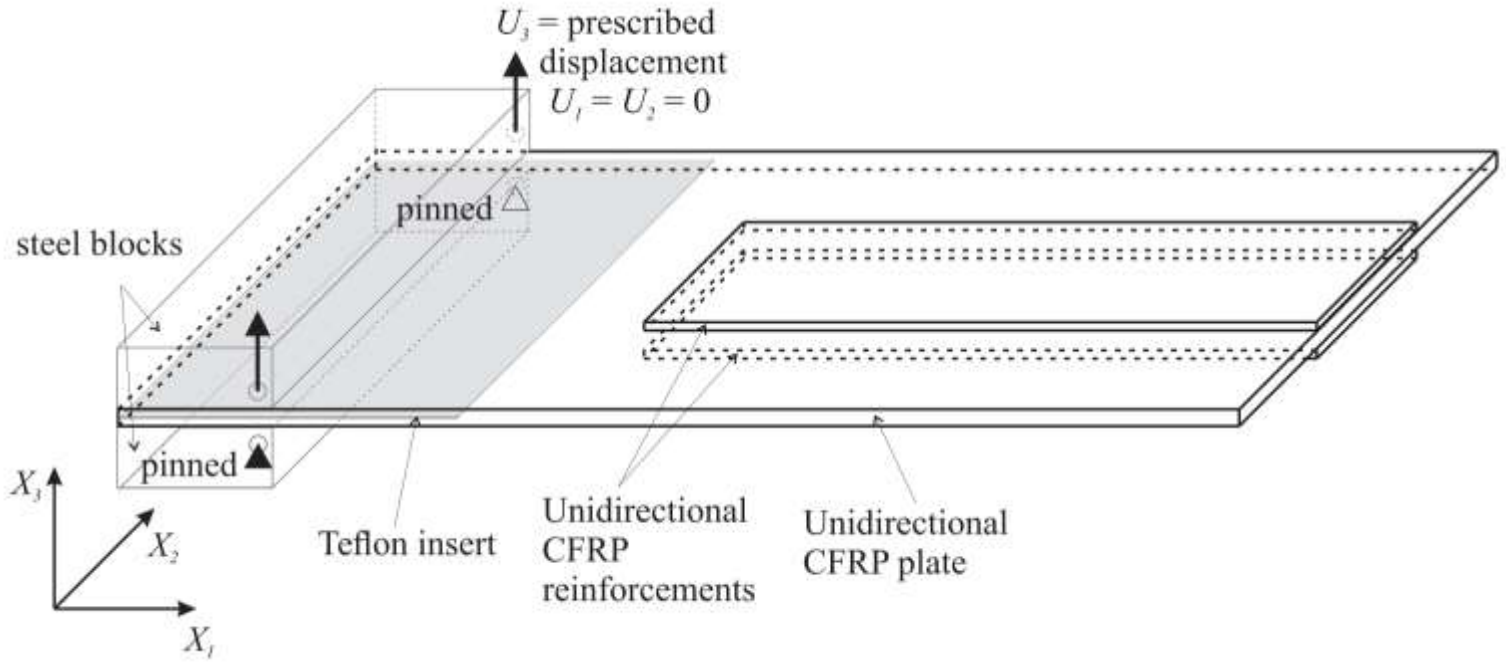
Composite Structures

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

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

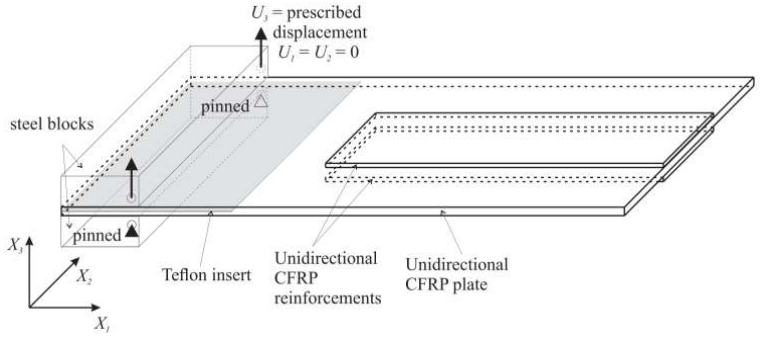
L. Carreras[a,*], J. Renart[a], A. Turon[a], J. Costa[a], B.L.V. Bak[b], E. Lin
F. Martin de la Escalera[c], Y. Essa[c]

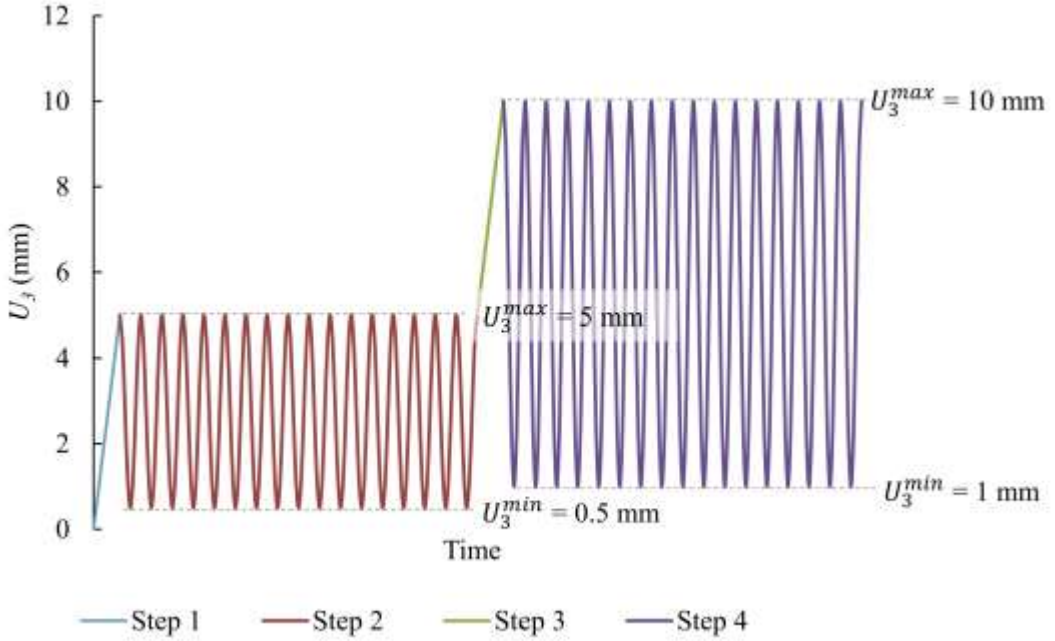
[a] AMADE, Polytechnic School, University of Girona, Universitat de Girona 4, E-17003 Girona, Spain
[b] Dept. of Materials and Production, Aalborg University, Fibigerstraede 16, DK-9220 Aalborg East, Denmark
[c] AERNNOVA Engineering Division SA, Llano Castellano Avenue 13, E-28034 Madrid, Spain



Carreras et al. (2019)

PROBLEMS





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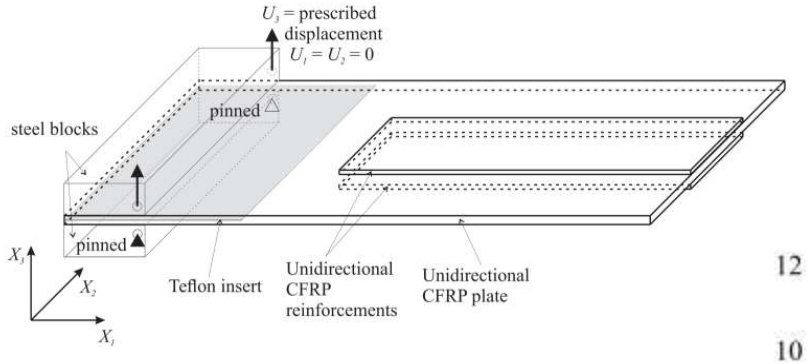

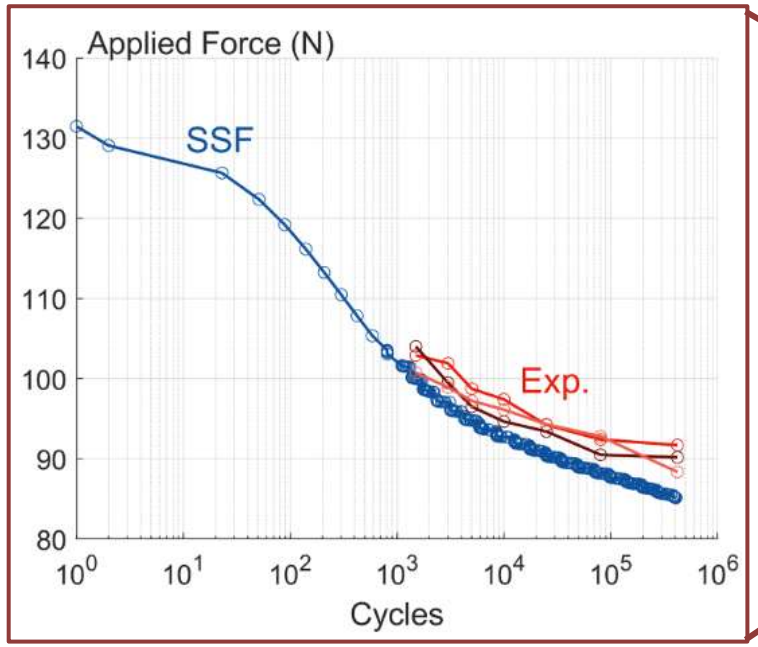

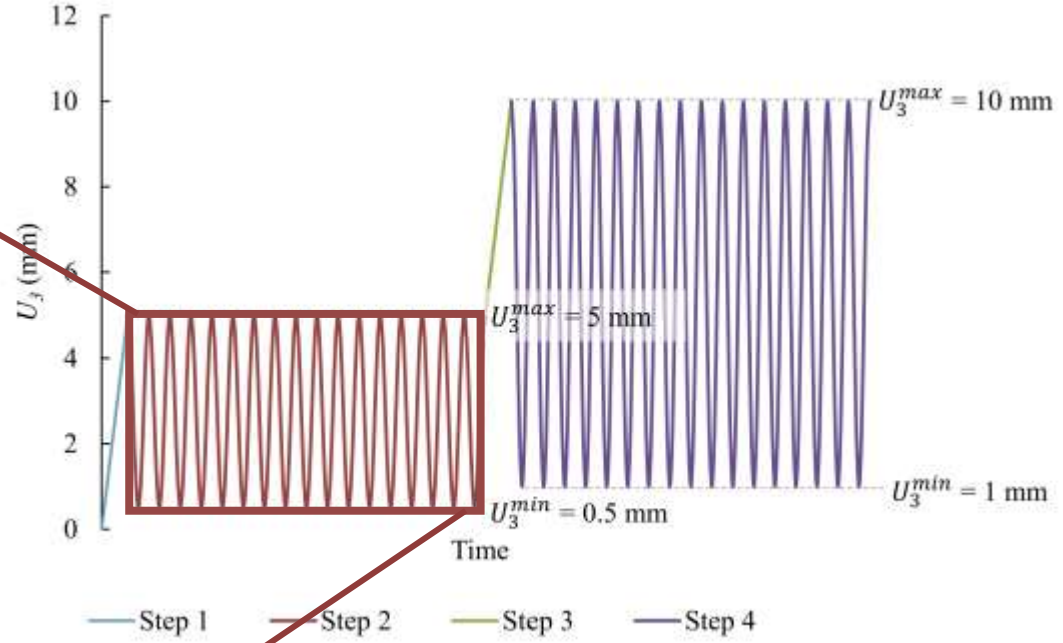

Carreras et al. (2019)

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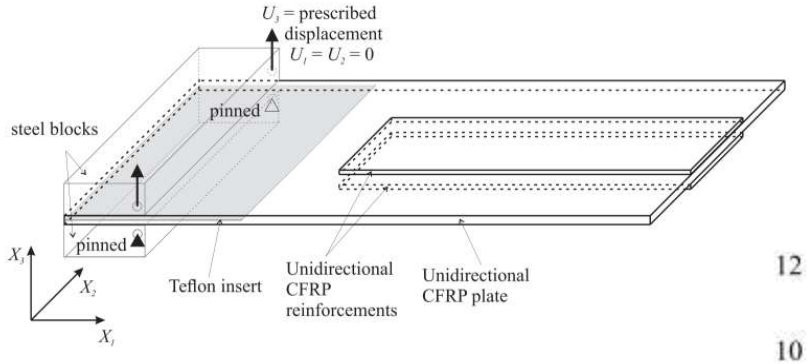

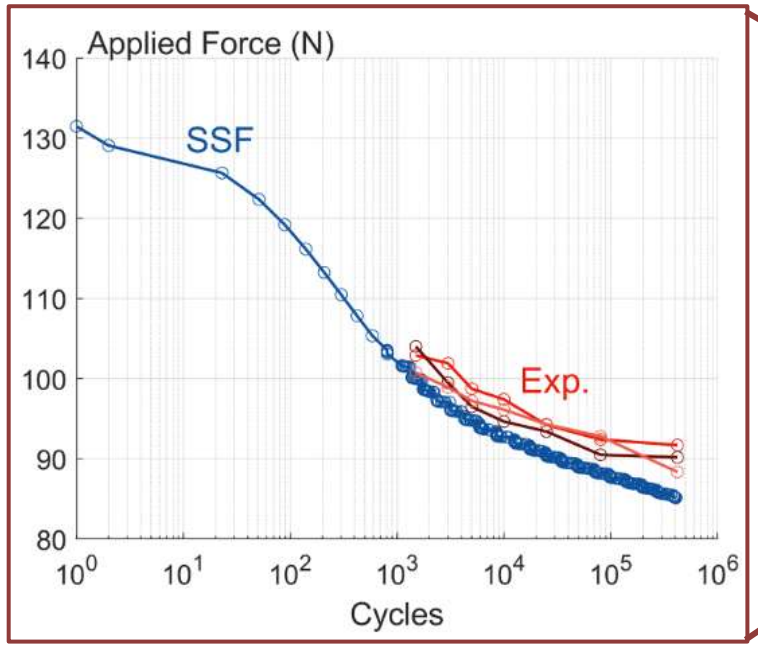

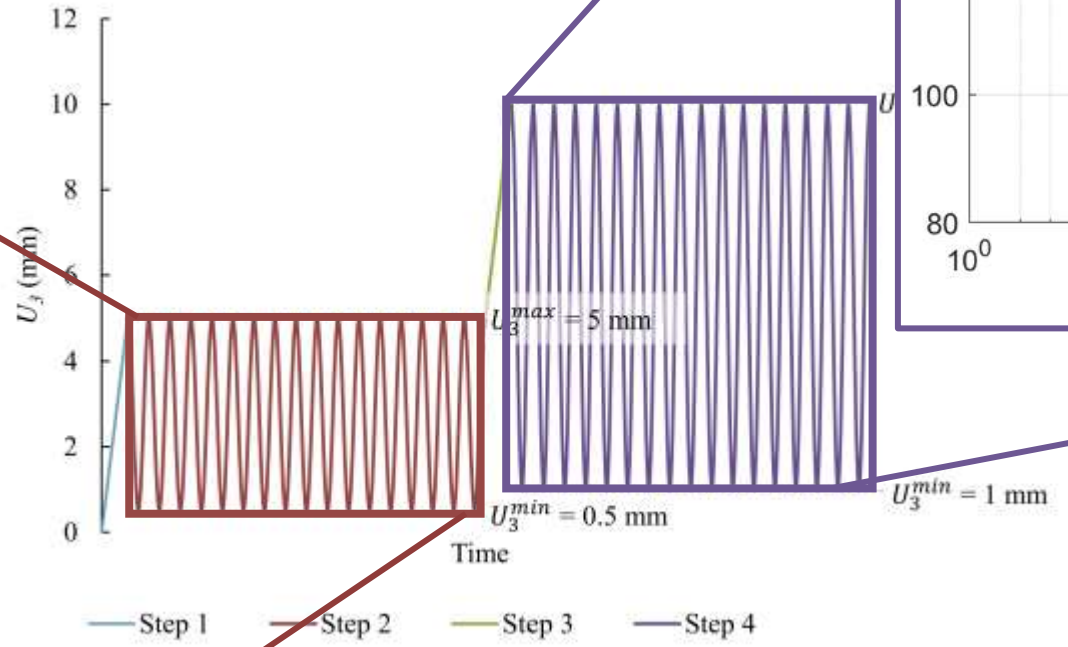

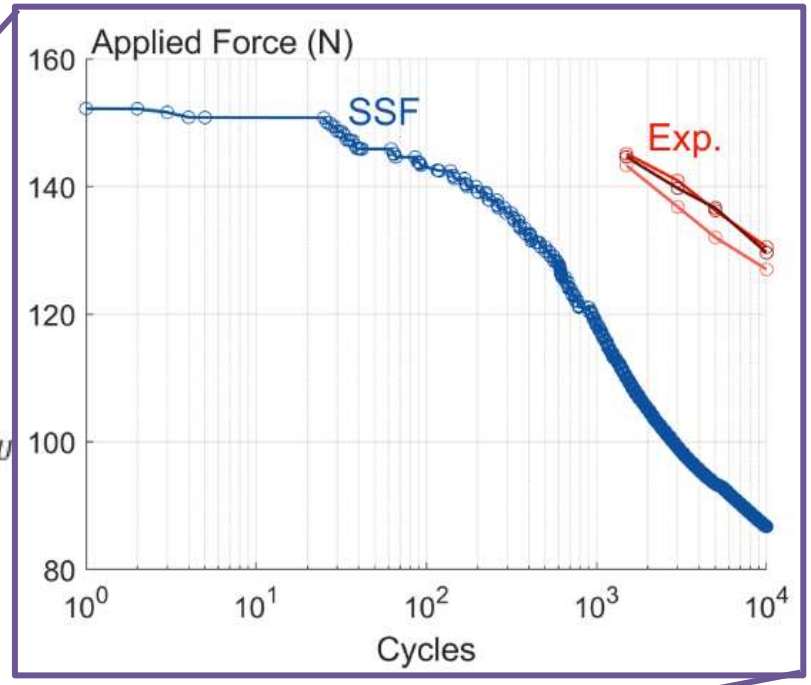

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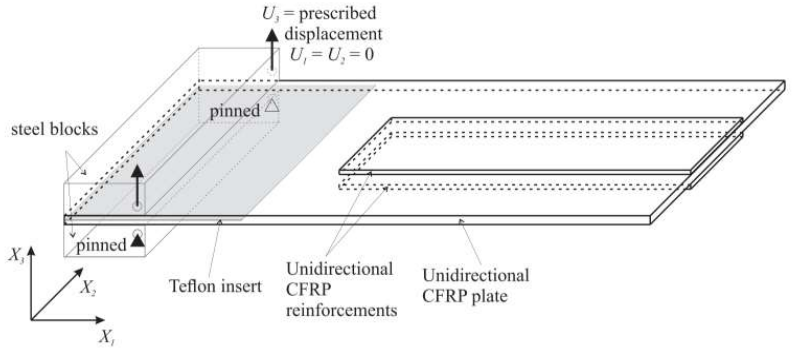
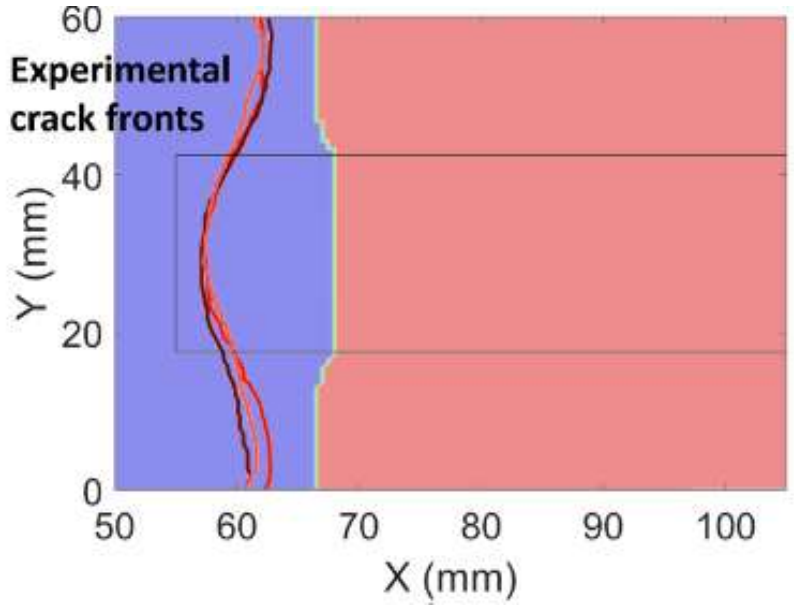
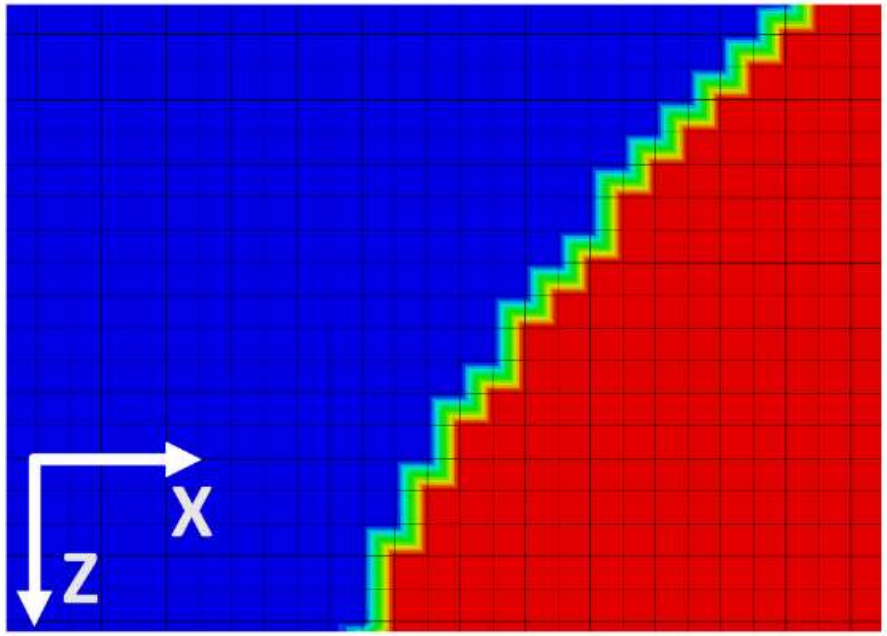
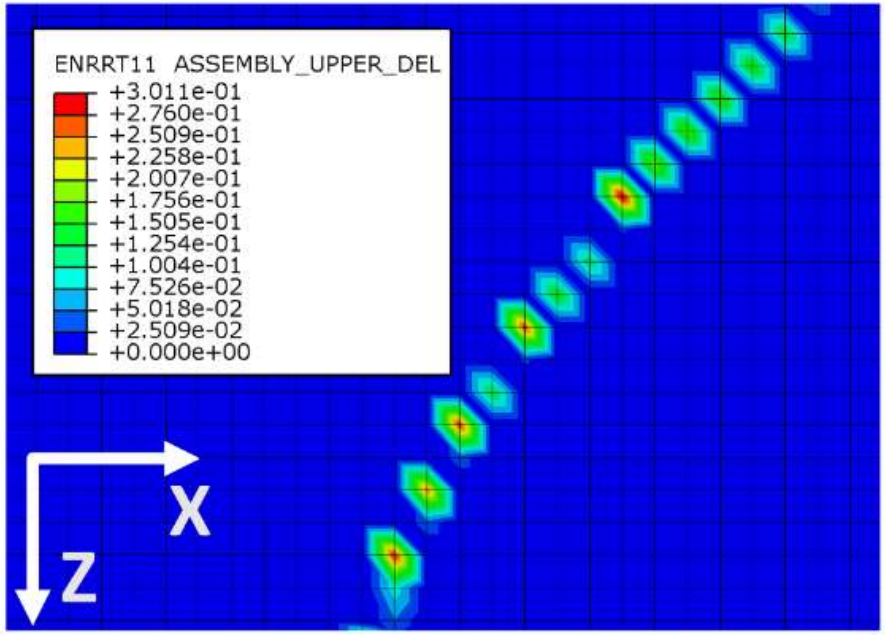


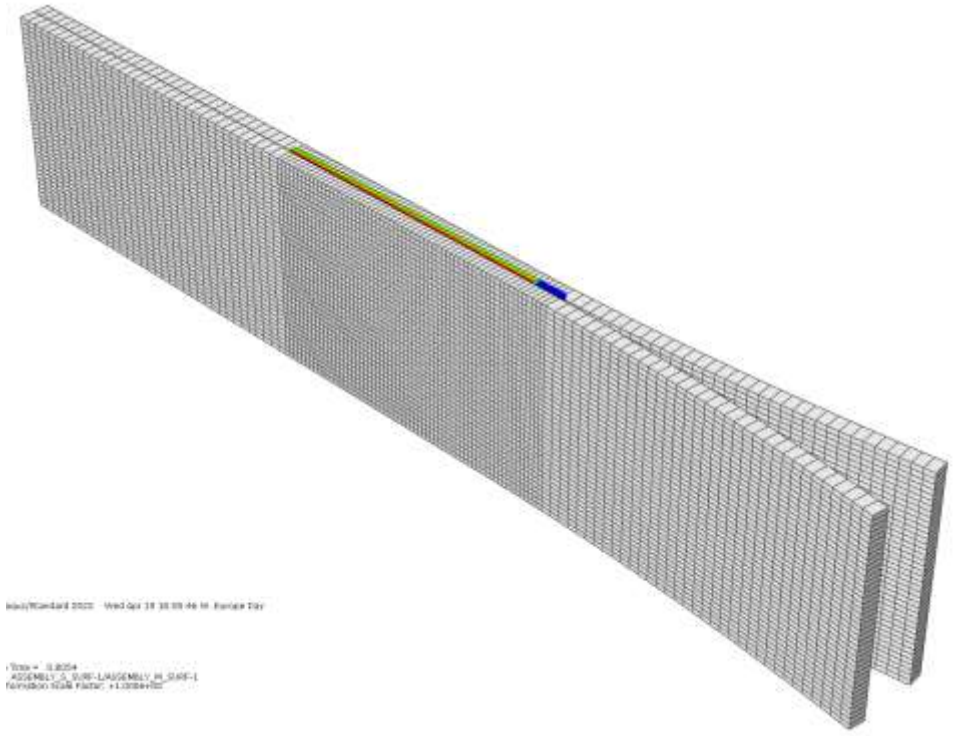






Carreras et al. (2019)

SOLUTION UNDER DEVELOPMENT



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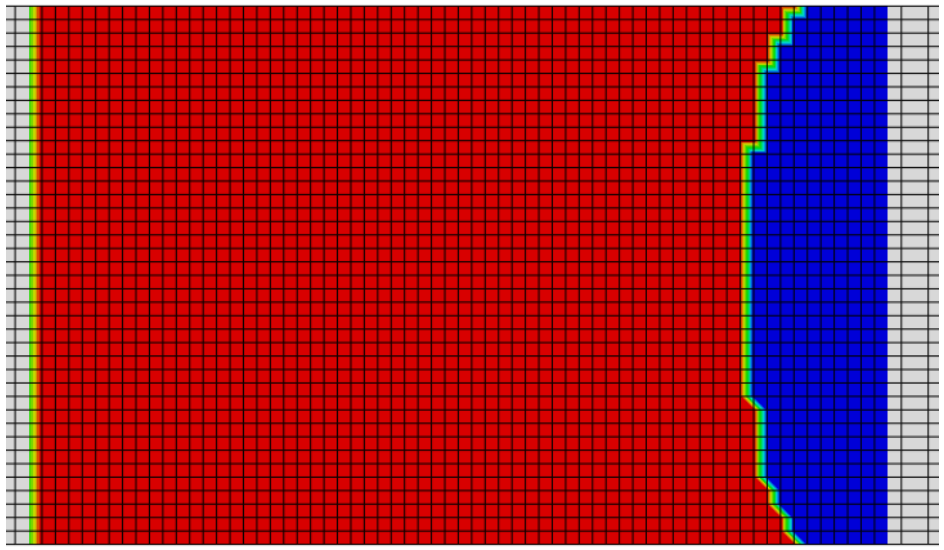

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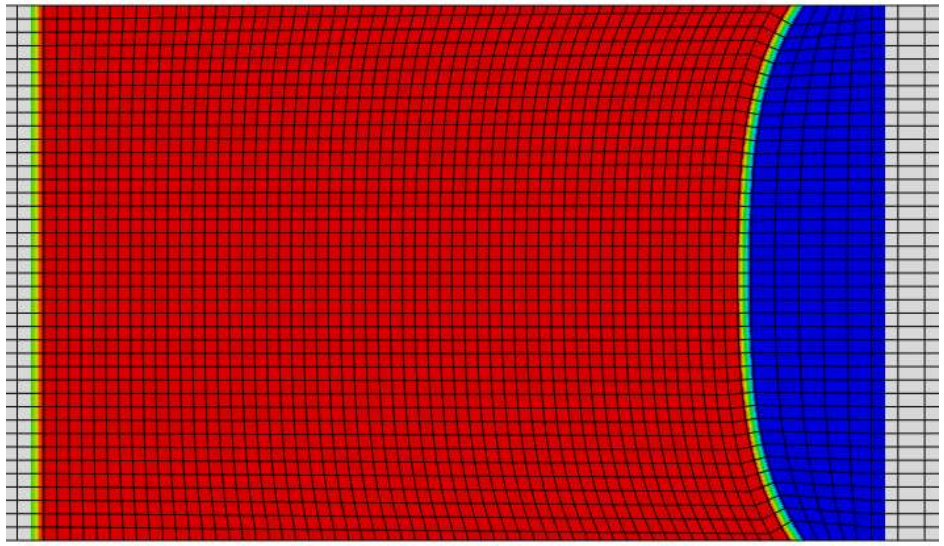
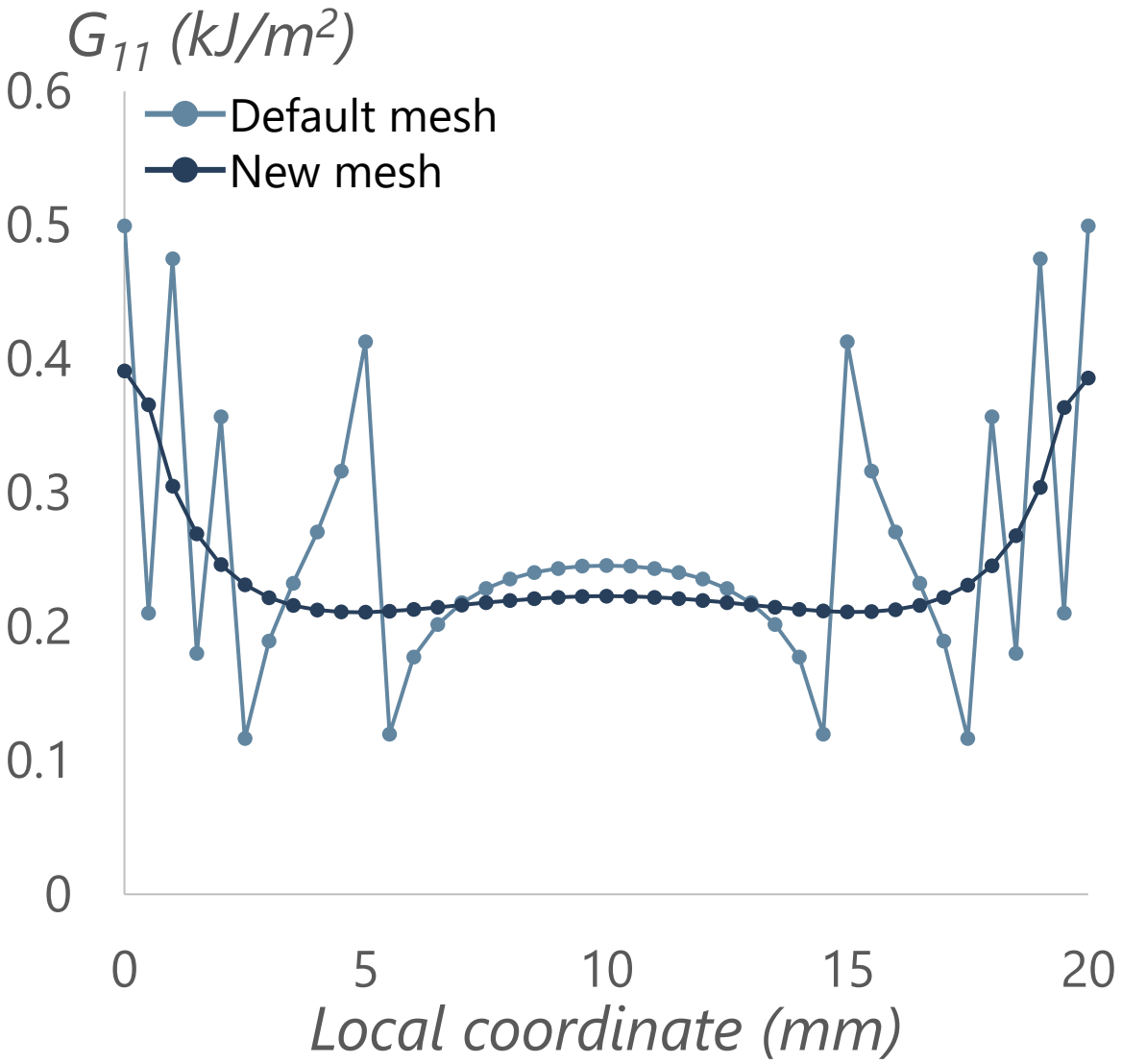


MSc thesis of Leonardo Guido Salvi

SOLUTION UNDER DEVELOPMENT



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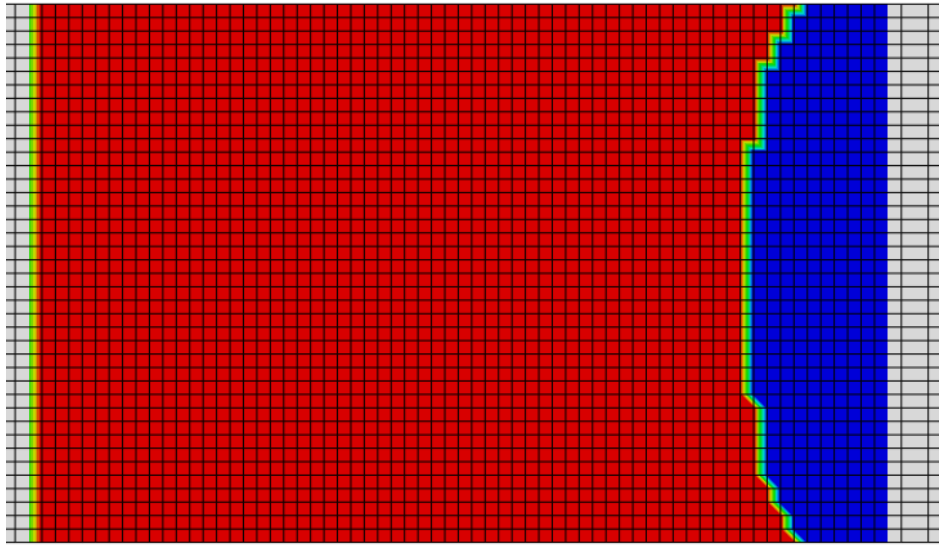

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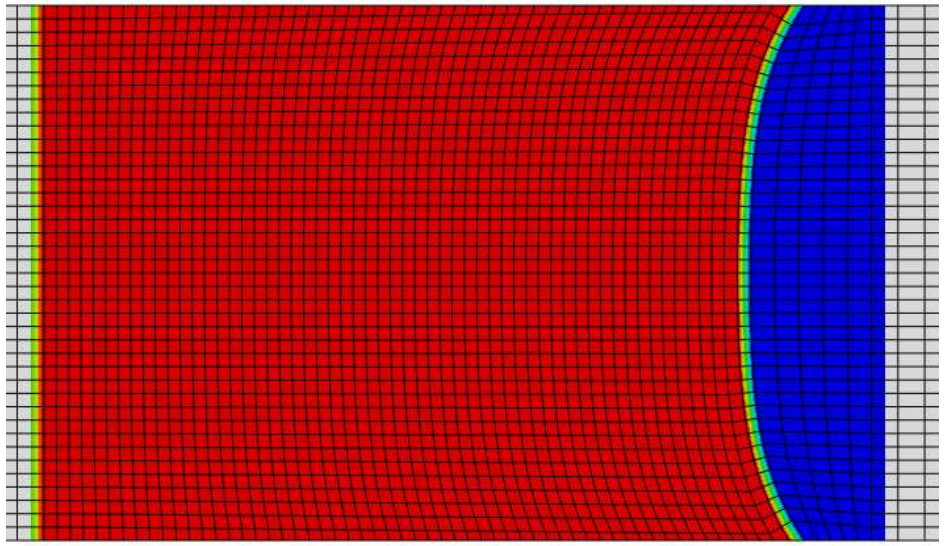
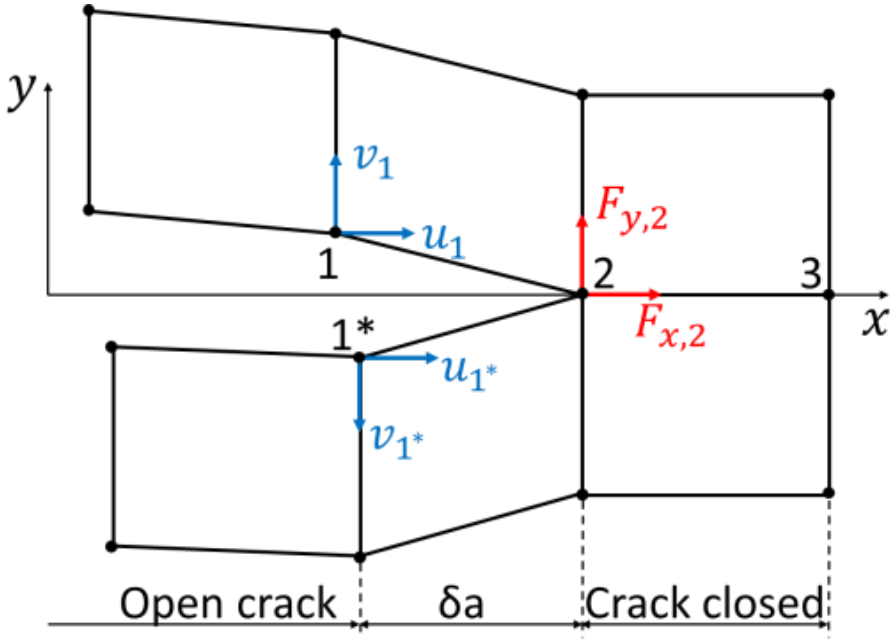


MSc thesis of Leonardo Guido Salvi

CONCLUSIONS

Sequential-Static Fatigue algorithm:

- Based on the quasi-static VCCT already implemented in Abaqus

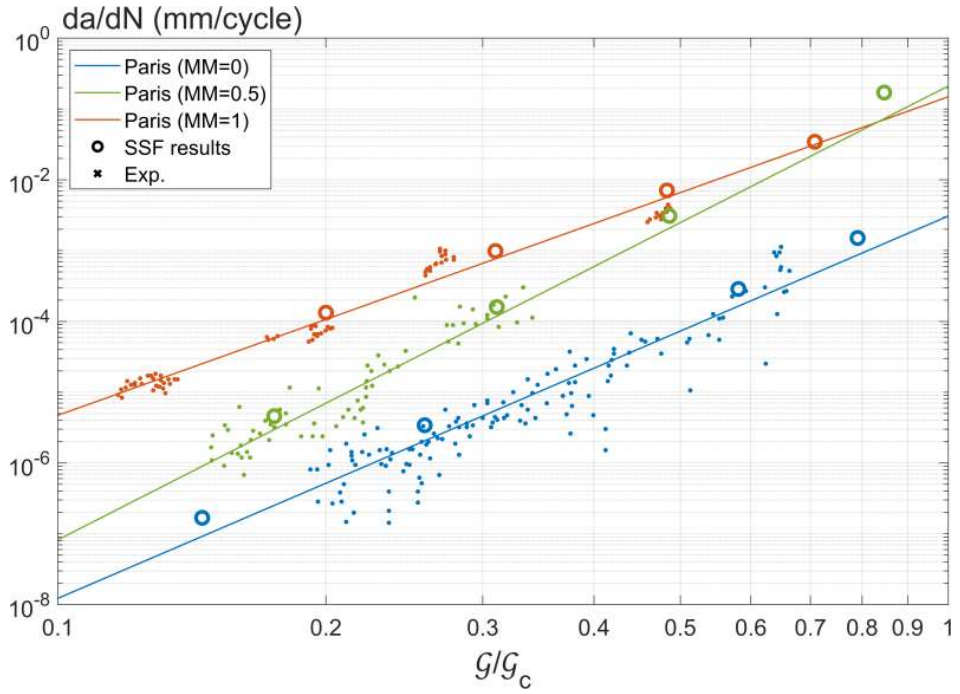


CONCLUSIONS

Sequential-Static Fatigue algorithm:

- Based on the quasi-static VCCT already implemented in Abaqus

- Excellent correlation with experimental data



CONCLUSIONS

Sequential-Static Fatigue algorithm:

- Based on the quasi-static VCCT already implemented in Abaqus
- Excellent correlation with experimental data
- Significantly less computationally expensive than the benchmark

	Reduction factor
	867
	613
	305
	212

PUBLICATION

International Journal of Fatigue 170 (2023) 107493

Contents lists available at ScienceDirect

International Journal of Fatigue

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

An efficient and versatile use of the VCCT for composites delamination growth under fatigue loadings in 3D numerical analysis: the Sequential Static Fatigue algorithm

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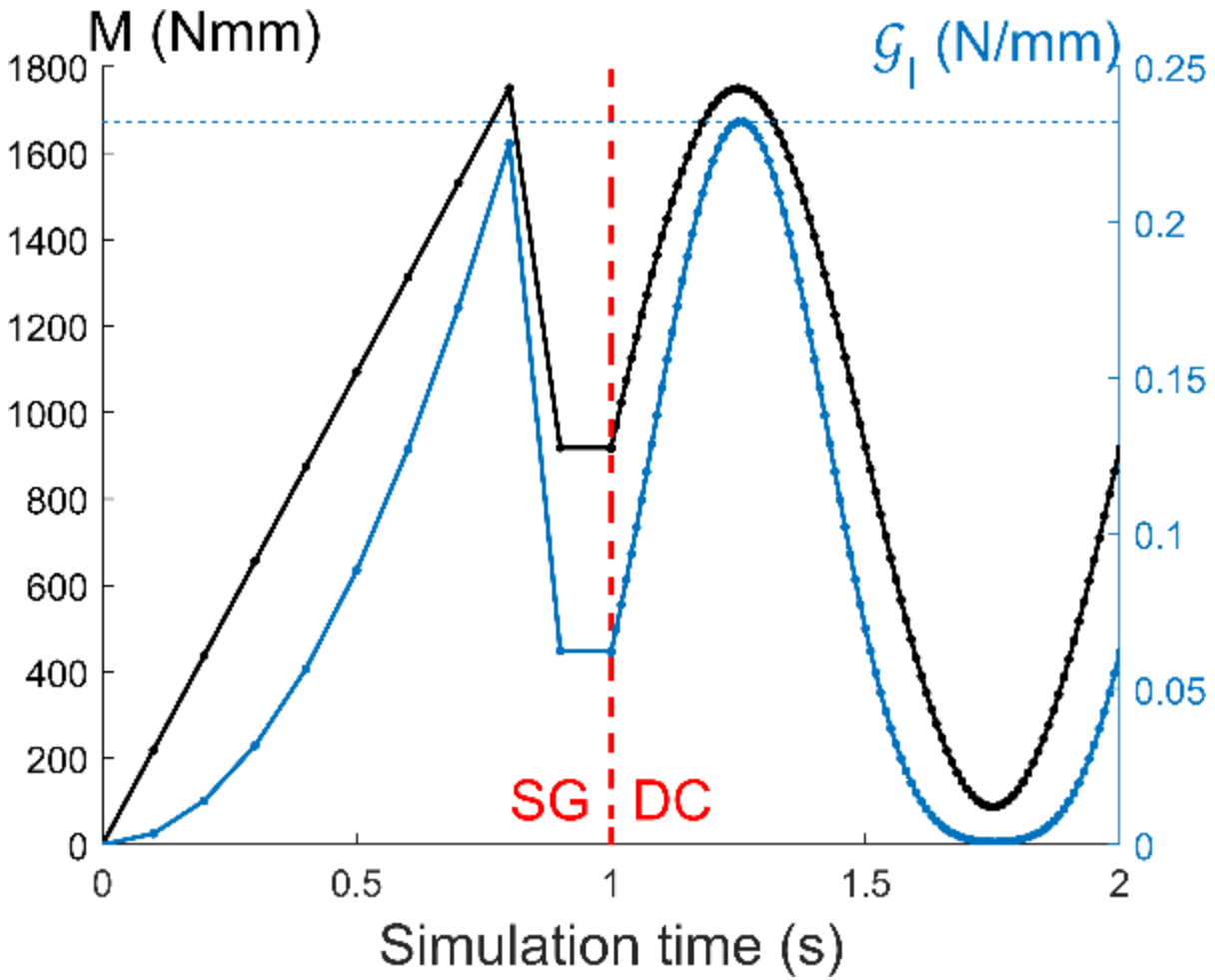
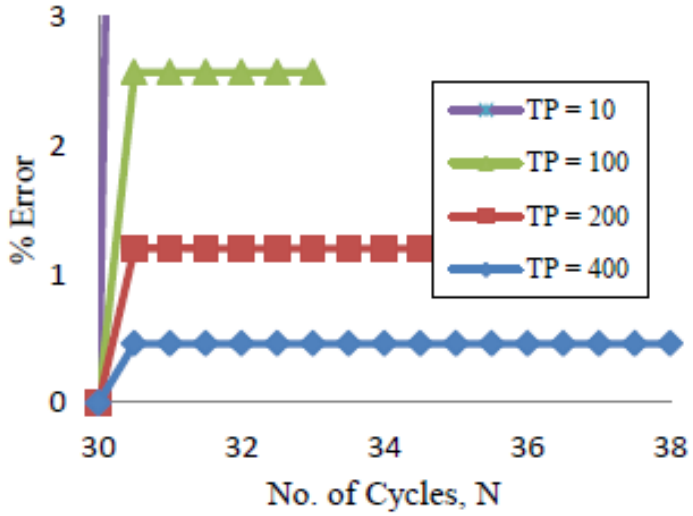
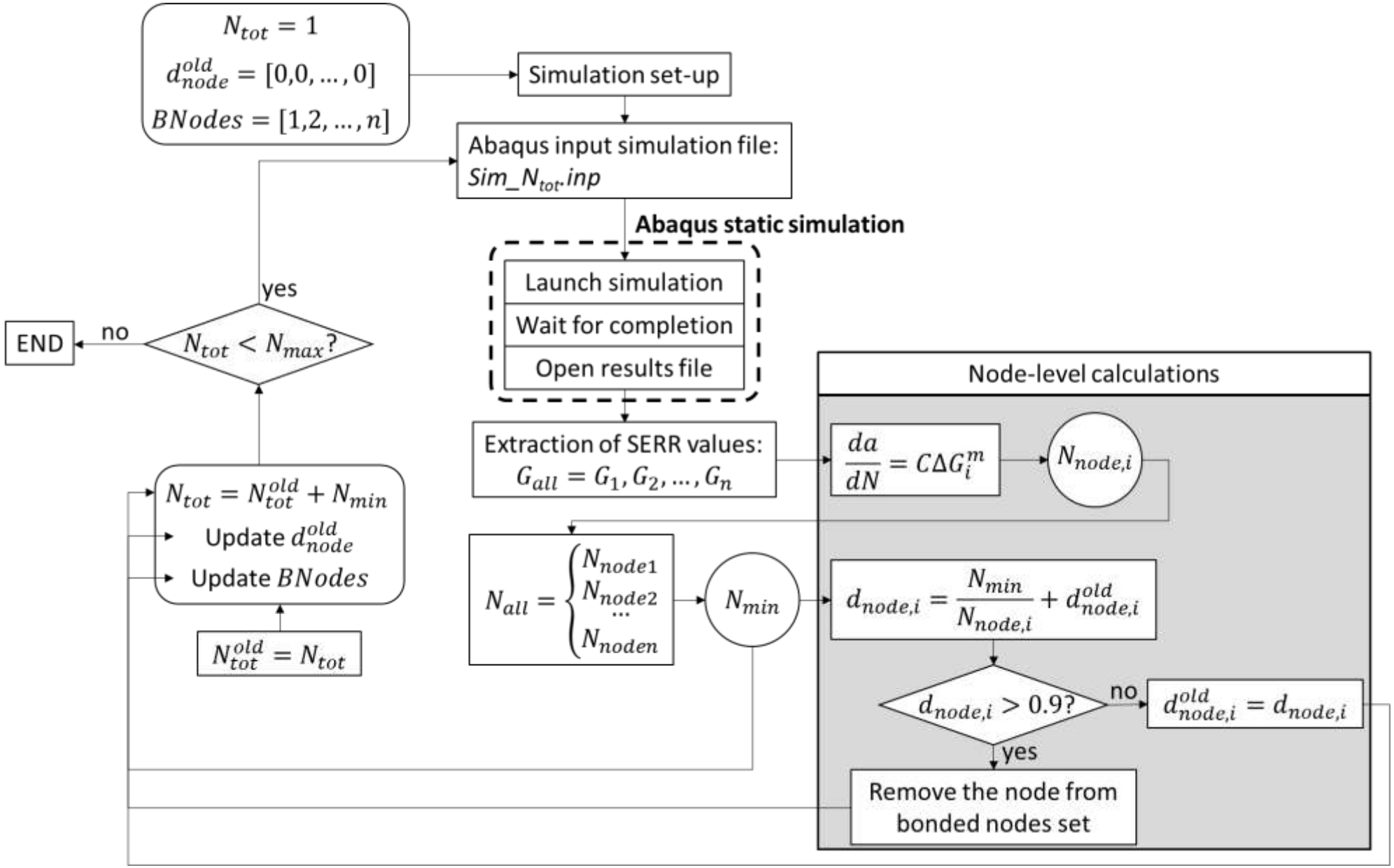




Jamil A., PhD Thesis (2014)


$N_{tot} = 1$
$d_{node}^{old} = [0,0,\dots,0]$
$BNodes = [1,2,\dots,n]$
Simulation set-up
Abaqus input simulation file:
$Sim\_N_{tot}.inp$
Abaqus static simulation
Launch simulation
Wait for completion
Open results file
Extraction of SERR values:
$G_{all} = G_1, G_2, \dots, G_n$
Node-level calculations
$\frac{da}{dN} = C\Delta G_i^m$
$N_{node,i}$
$N_{all} = \begin{cases} N_{node1} \\ N_{node2} \\ \dots \\ N_{noden} \end{cases}$
N_{min}
$d_{node,i} = \frac{N_{min}}{N_{node,i}} + d_{node,i}^{old}$
$d_{node,i} > 0.9?$
no
$d_{node,i}^{old} = d_{node,i}$
yes
Remove the node from bonded nodes set
$N_{tot} < N_{max}?$
no
END
yes
$N_{tot} = N_{tot}^{old} + N_{min}$
Update d_{node}^{old}
Update $BNodes$
$N_{tot}^{old} = N_{tot}$