Fatigue Simulation of a fibre-glass ship

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Invited Session: Lightweight Composite Materials in Shipbuilding

Göteborg, 13th May 2019

BRIEF DESCRIPTION & OBJECTIVES

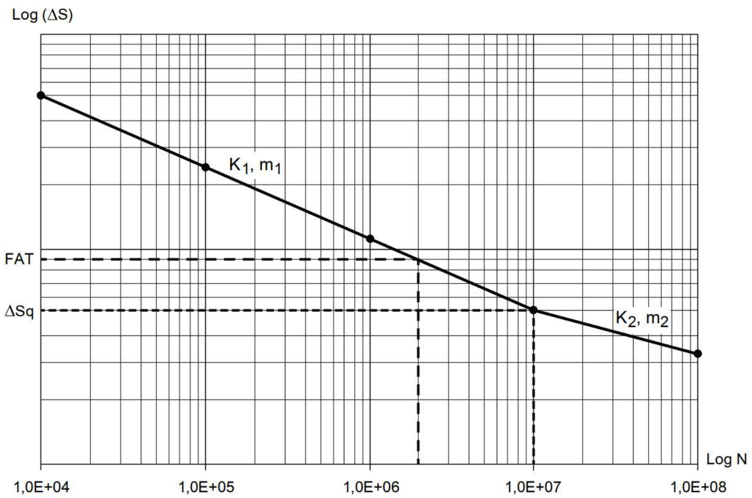
- **Formulation:**
  - **FATIGUE DAMAGE MODEL.**
- **Adaptation of fatigue formulation to composites.**
- **Validation of the methodology proposed.**
  - **Two different composite systems: SANDIA & KAWAI TESTS.**
- **RESULTS & CONCUSIONS**
  - **Failure modes and load-position graphs.**

- **OBJECTIVES**
  - **Apply the fatigue formulation developed to complex composite structure with multi-axial loads.**
  - **Analyze the fatigue performance of the structure, identifying which plies are more prompt to fail, as well as the failure mode.**
  - **Study the potential capabilities of the formulation and methods introduced.**

TASK: Fatigue performance of composites

INTRODUCTION. Fatigue phenomenon

ASTM E1823 standard: “*The process of permanent, progressive and localized structural change which occurs to a material point subjected to strains and stresses of variable amplitudes which produces cracks which lead to total failure after a certain number of cycles”.*



Importance of the fatigue in naval structures. Prove of it is the existence of specific rules on Class Societies

DNV-RP-C203

ShipRight FDA

NI 611 DT R00 E

FATIGUE FORMULATION

- Fatigue damage formulation initially developed for metallic materials.
- The constitutive law is modified by means of a reduction function, to account for the cyclic behaviour of the load: **phenomenological model (stiffness and strength degradation).**
- Forward advanced strategy → stabilization norm

$$\eta = \sum \frac{R^k - R^{k-1}}{R^k}$$

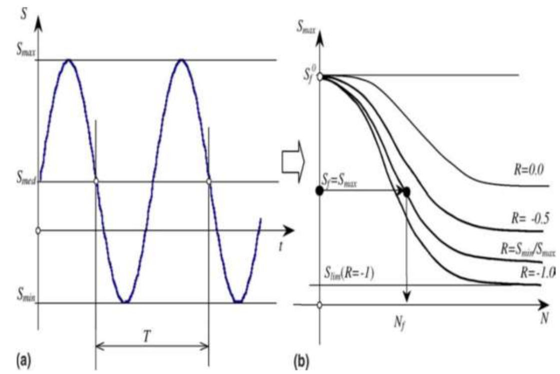
- The formulation can take into account different block loading sequence.
- Material parameters of f_{red} are obtained by means of experimental S/N of the materials.

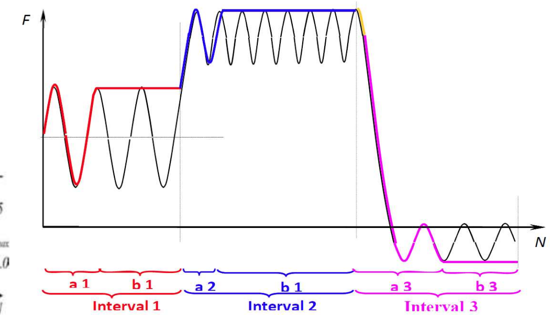
Non-fatigue constitutive equation: $f(\sigma) - K(\sigma_{th}) \leq 0$

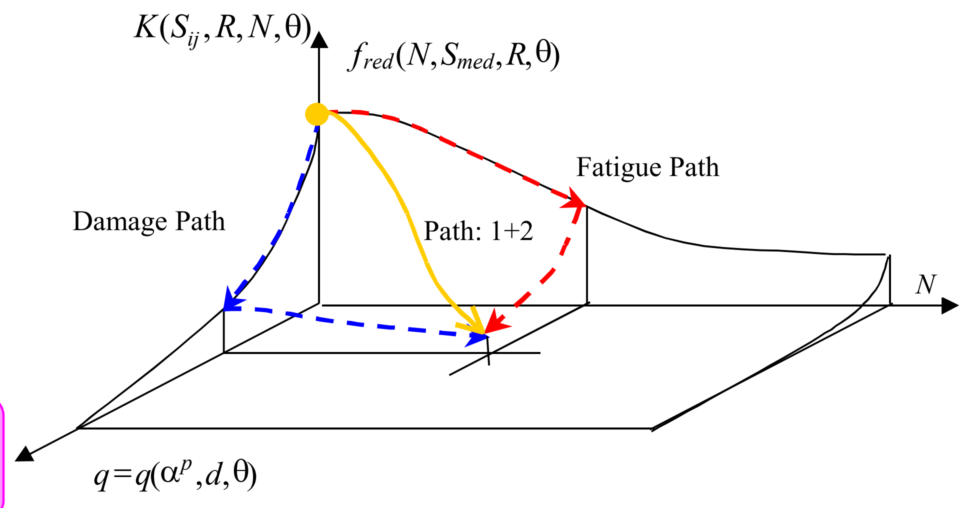
Fatigue application: $f(\sigma) - f_N(N, \sigma_m, R) \cdot K(\sigma_{th}) \leq 0$

Influence of N_c strength reduction (HCF)

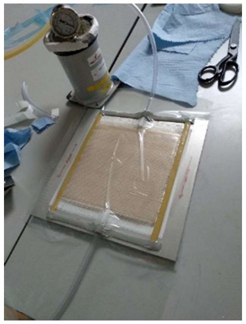
Influence of *Quasi-Static* strength reduction.







ADAPTATION OF FATIGUE FORMULATION TO COMPOSITES

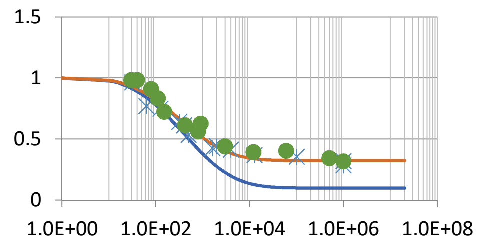


UD loaded at longitudinal direction has a fibre-dominated performance.

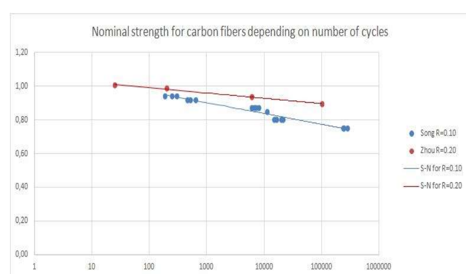
UD loaded at transverse direction has a matrix-dominated performance.

FATIGUE MODELS

UD 90 S/N normalized



UD 0 S/N normalized



Fatigue constitutive law for matrix

Fatigue constitutive law for fibers

SP MIXING THEORY

Fatigue models coupling

Composite laminate fatigue performance

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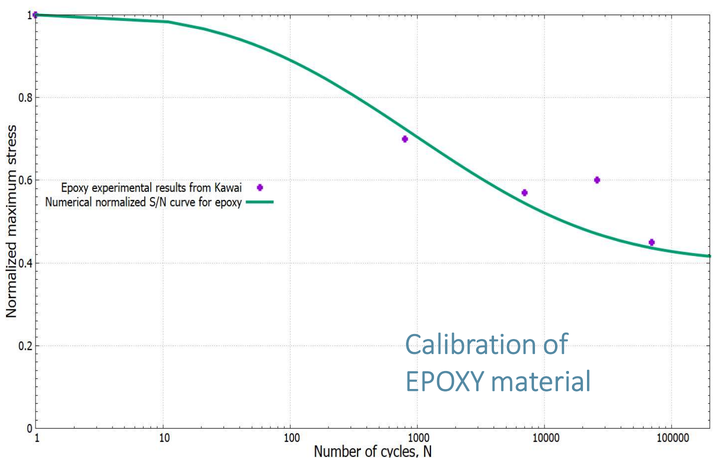
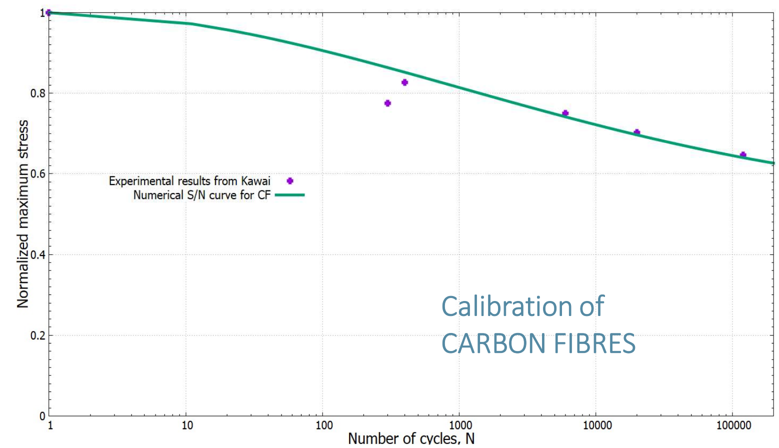
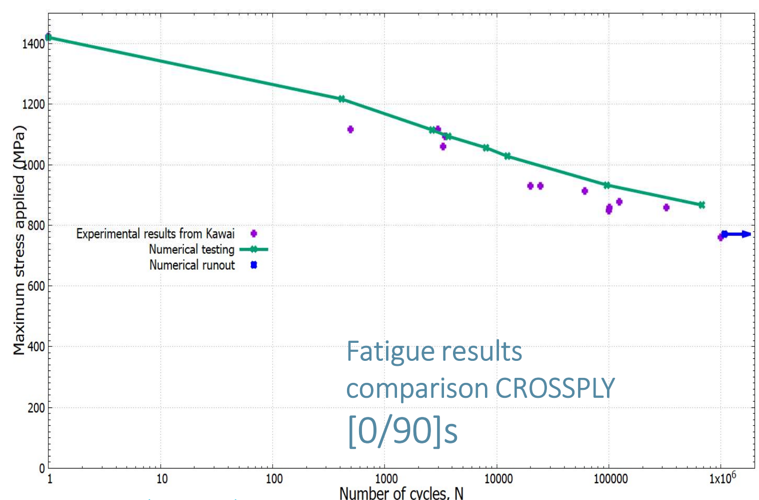
Carbon/Epoxy system. Kawai



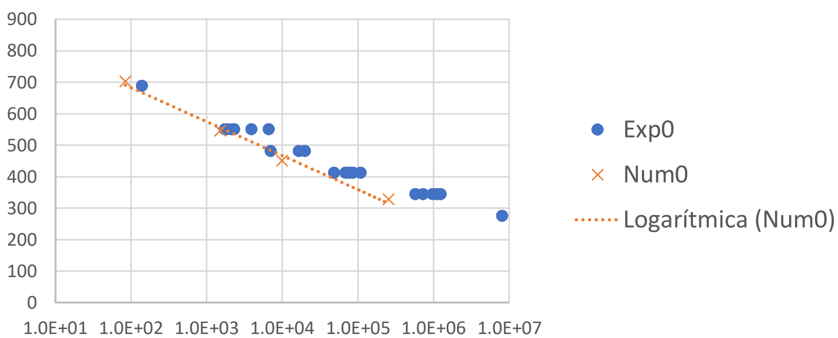




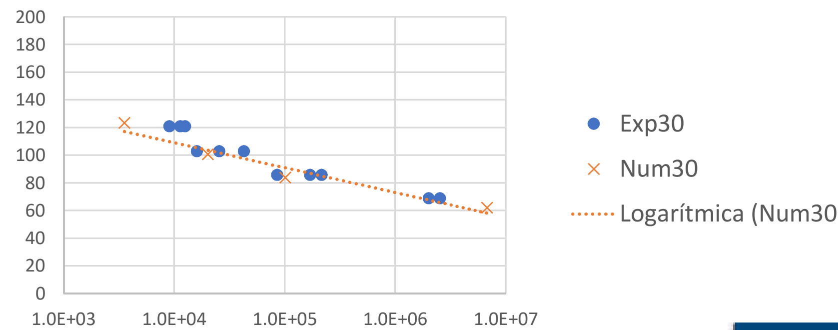
VALIDATION OF THE FORMULATION APPLIED TO COMPOSITES

Glass/Polyester system. Sandia

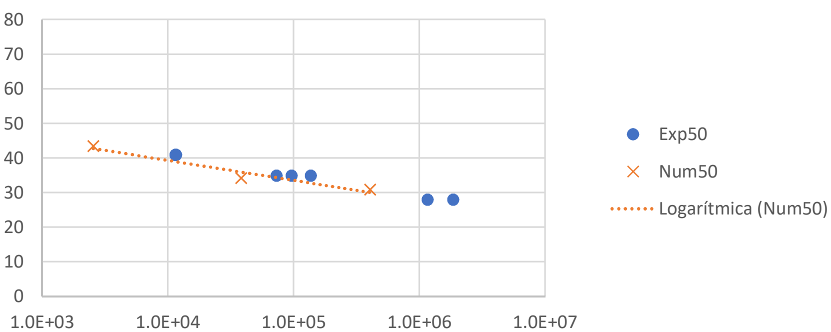
[0/0]



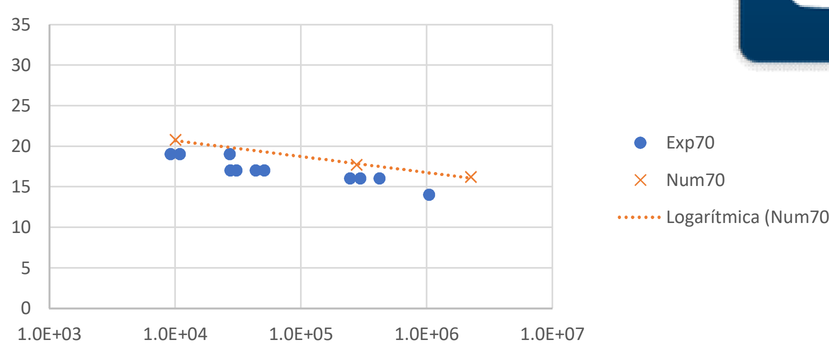
[+30-/-30]



[+50/-50]



[+70/-70]



FATIGUE SIMULATIO OF A SHIP-SUB-STRUCTURE.

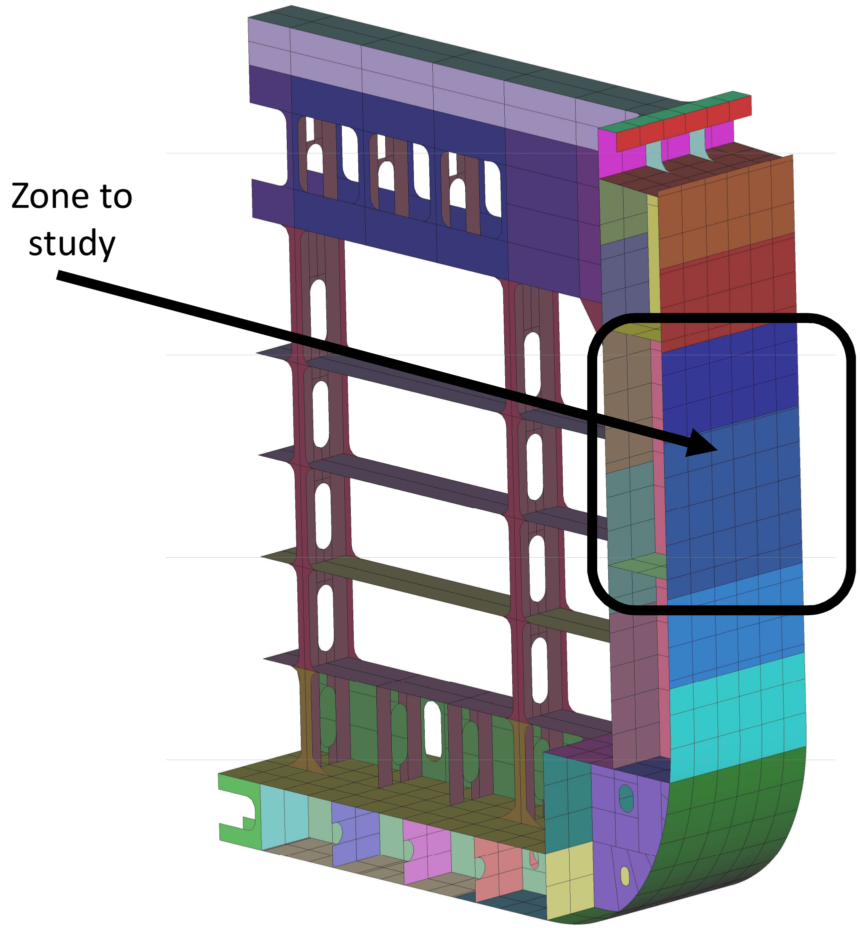
PREFACE

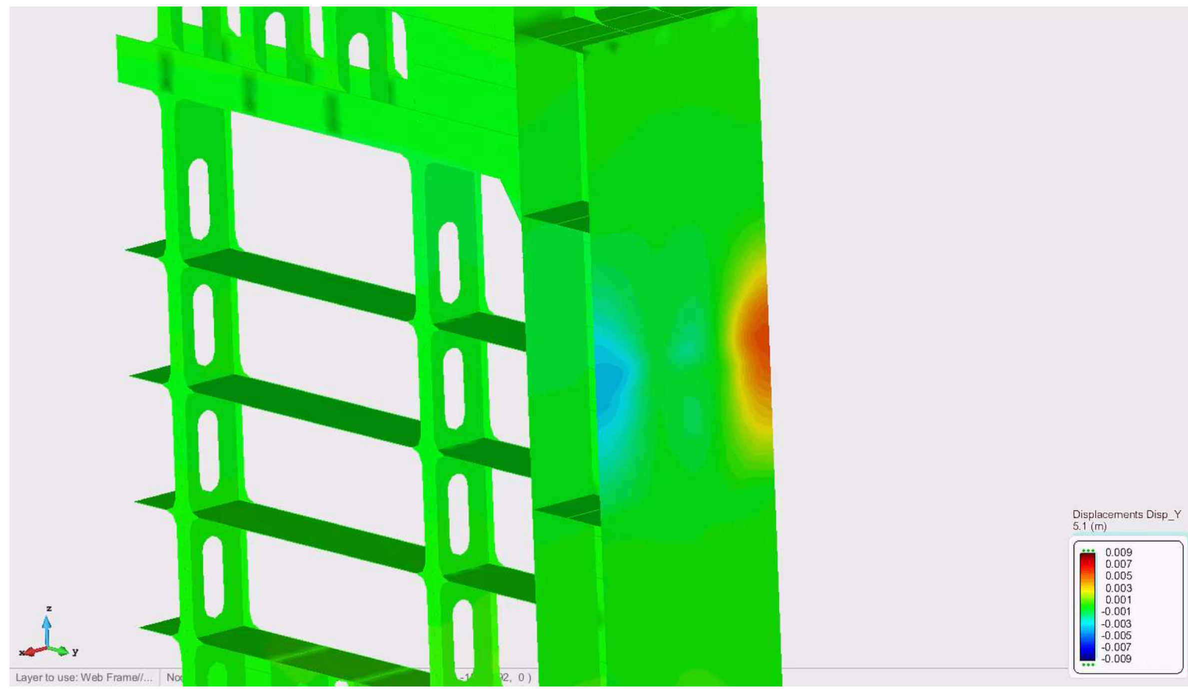
- Container ship has been used as one of the fibre-ships to design.

- From a Steel Ship to a Composite Ship. New architecture, new scantlings, new behavior.

- From an existing steel ship, the loads applied to the structure are obtained. These loads will be applied as boundary conditions to the composite vessel.

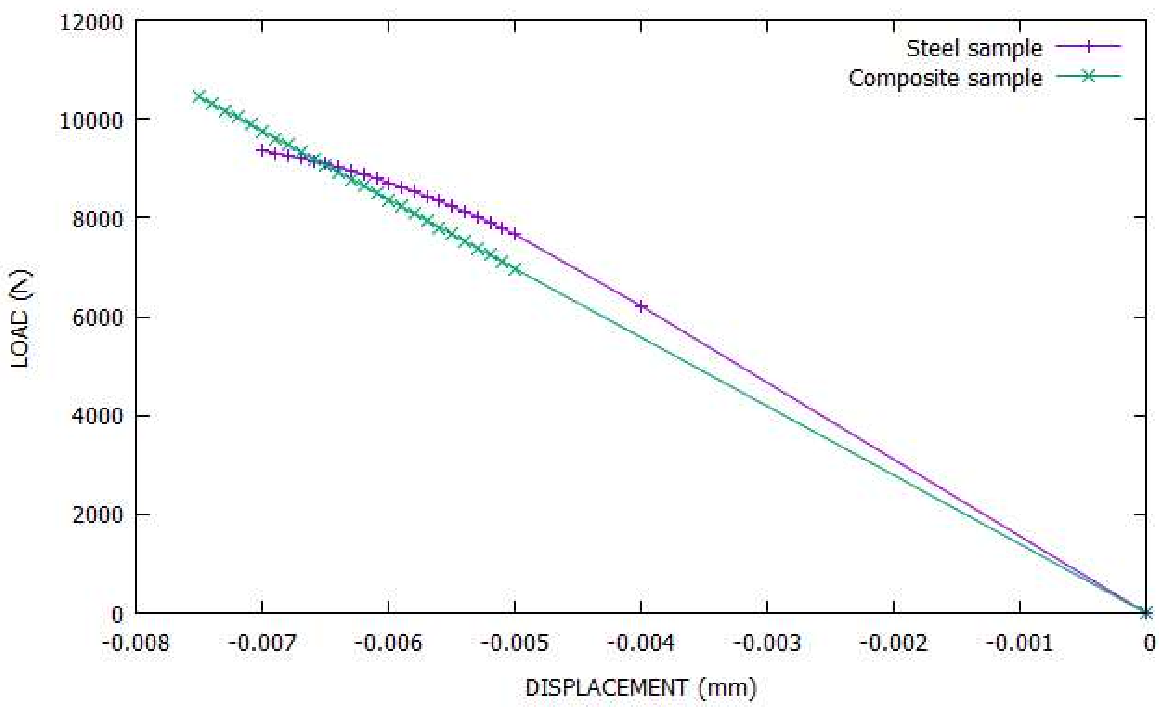
FATIGUE SIMULATIO OF A SHIP-SUB-STRUCTURE. From Steel to Composite

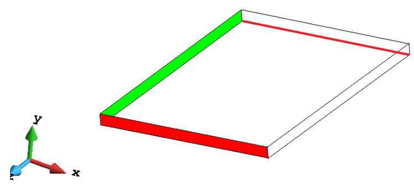




FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Equivalent material

Material	Length (mm)	Width (mm)	Thickness (mm)	Nº elements	Nº nodes	E (GPa)	I (mm4)	E*I
Steel	315	245	15	25600	21609	16	68.906	14.124.500
Composite	315	245	35	12800	9261	205	875.365	14.005.840

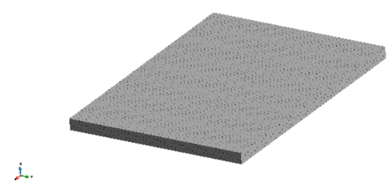


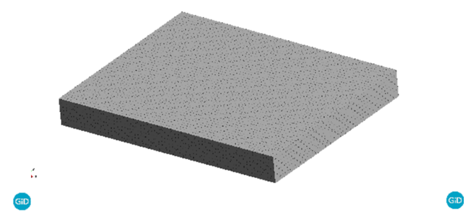


Quasi-isotropic laminate: [0/90/-45/+45]s

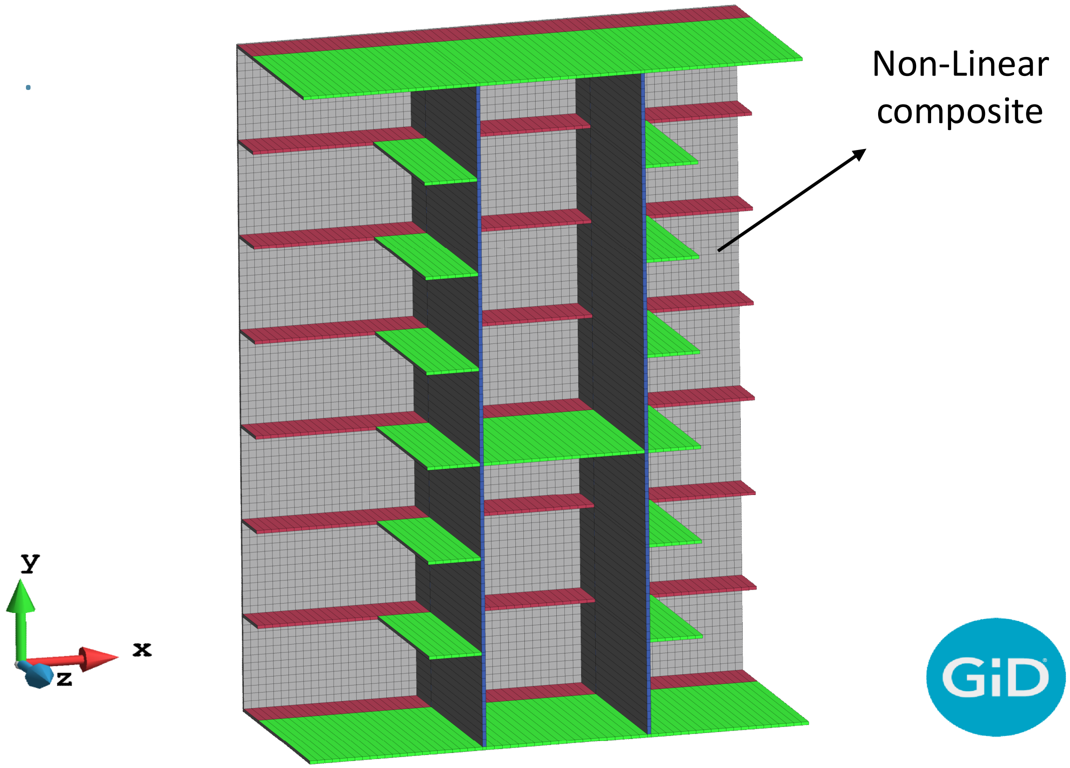
-Structured mesh
-Linear hexahedral elements
-Size = 5mm

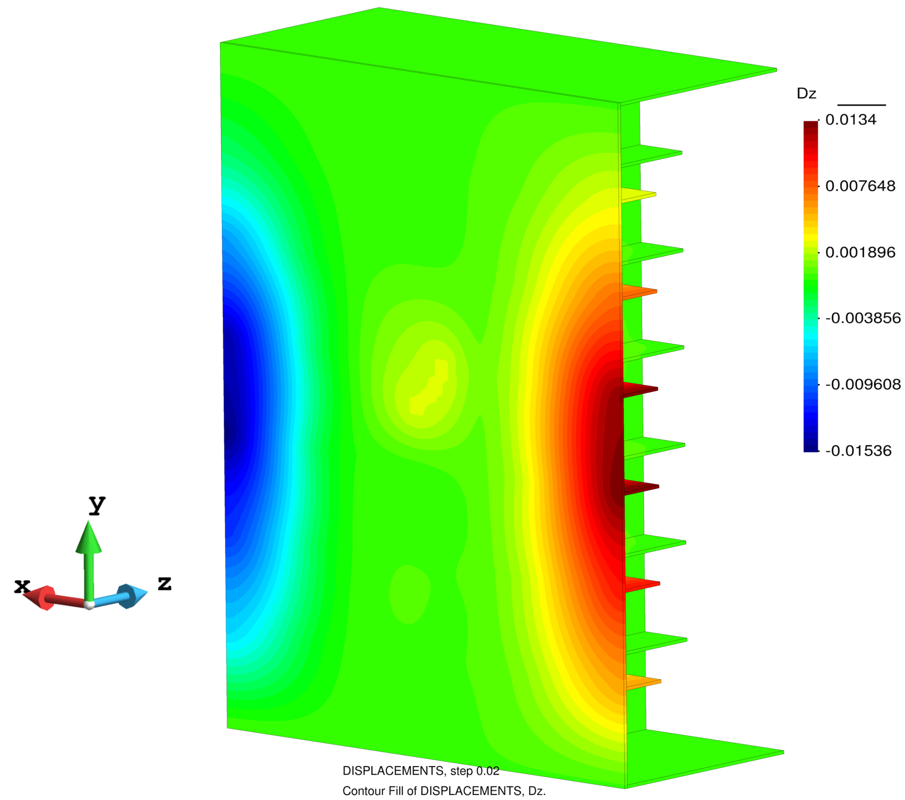
D
X





FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE.





Nº elements	Nº nodes	Element type	Element size
25600	21609	Linear hexahedral	35 mm

FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE

FIBRESHIP

Scenarios – First attempts

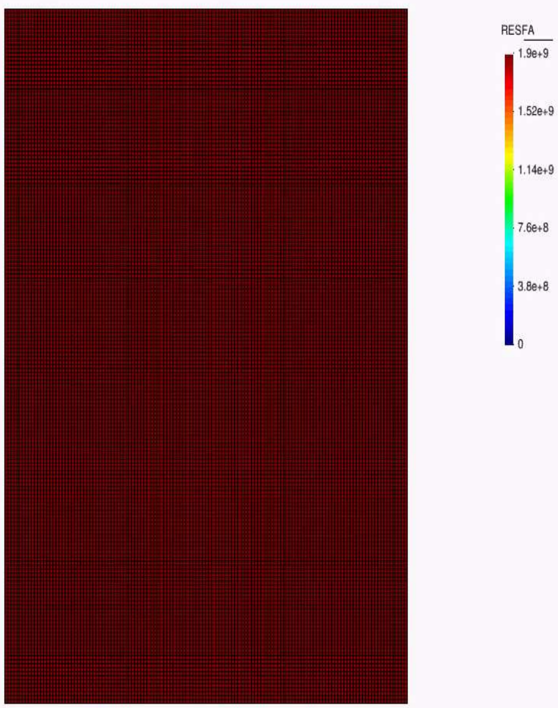
SCENARIO 1	SCENARIO 2	SCENARIO 3
-Stress ratio R=-1.0 -Jumps = 25.000 cycles -Maximum load level = 1.0	-Stress ratio R=-1.0 -Jumps = 75.000 cycles -Maximum load level = 1.5	-Stress ratio R=0.10 -Jumps = 50.000 cycles -Maximum load level = 1.6

Identify which cases are lead to fatigue failure and which process is it.

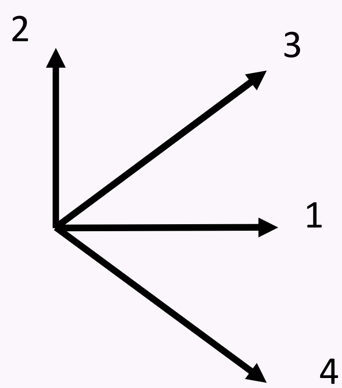
WORST: SCENARIO 2

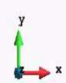
Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

Strength reduction Glass 2



step 1
Contour Fill of Int.Var.//Composite1//Layer03//EGlass//RESFA.





Strength reduction Glass 1

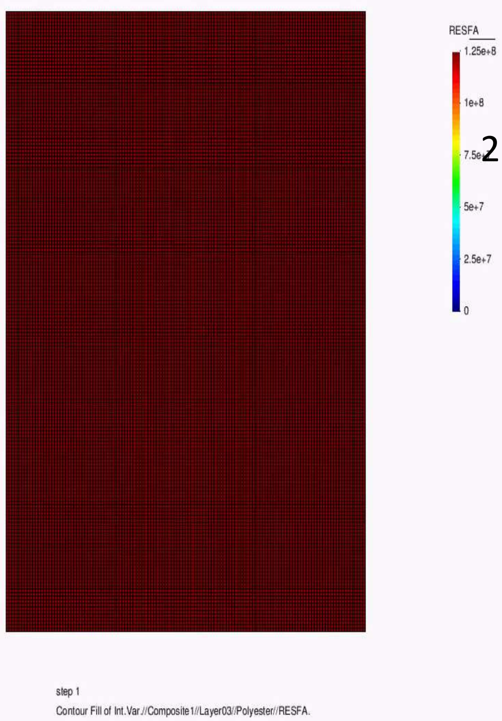
step 1
Contour Fill of Int.Var.//Composite1//Layer01//EGlass//RESFA.

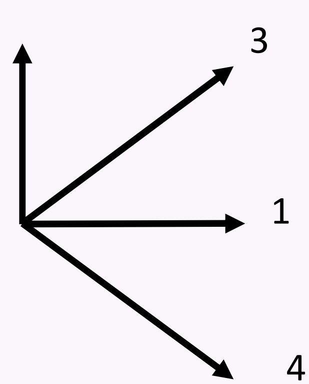
FATIGUE SIMULATION OF A SHIP SUB-STRUCTURE. Results

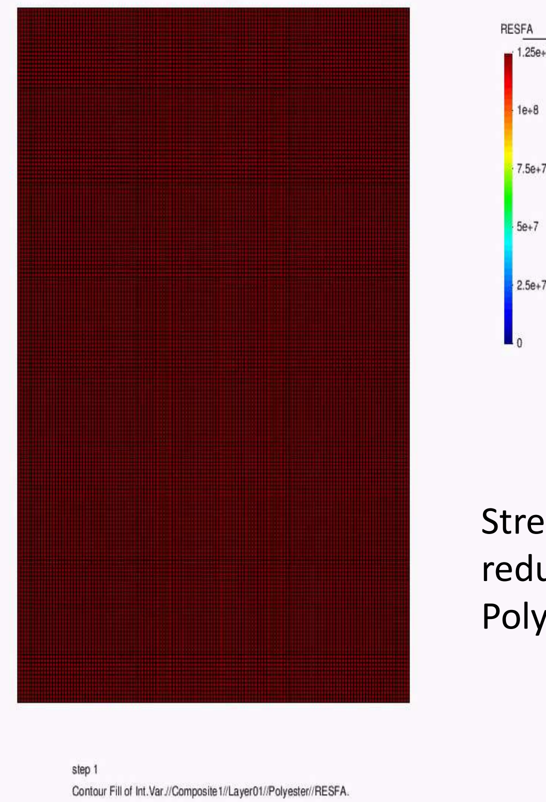
WORST: SCENARIO 2

Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

Strength reduction Polyester 2







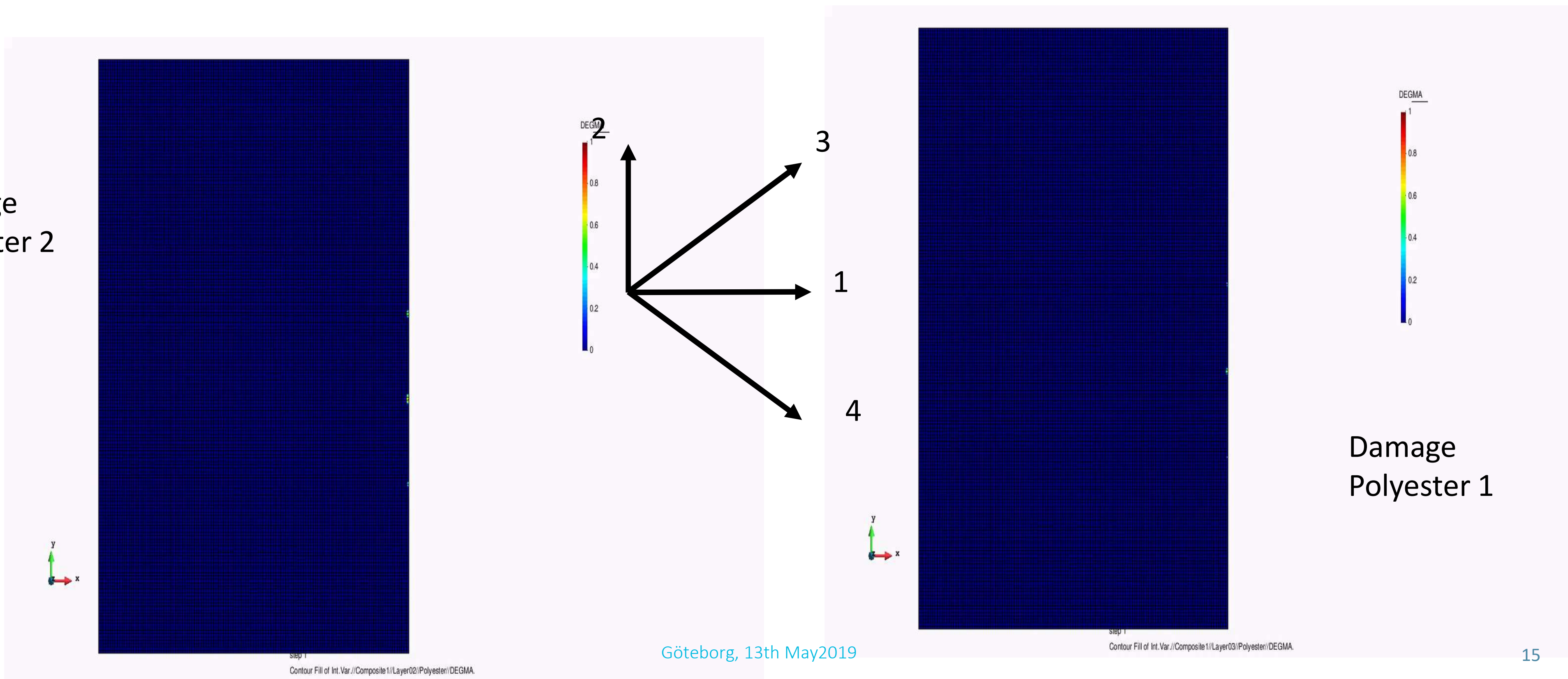
Strength reduction Polyester 1

FIBRESHIP

WORST: SCENARIO 2

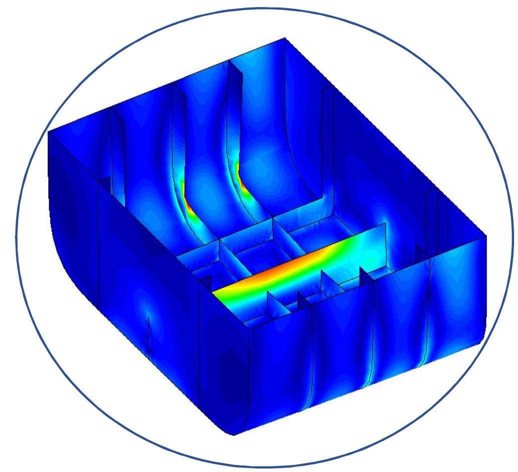
Cycle jumps: 1, 25.000, 150.000, 225.000 cycles.

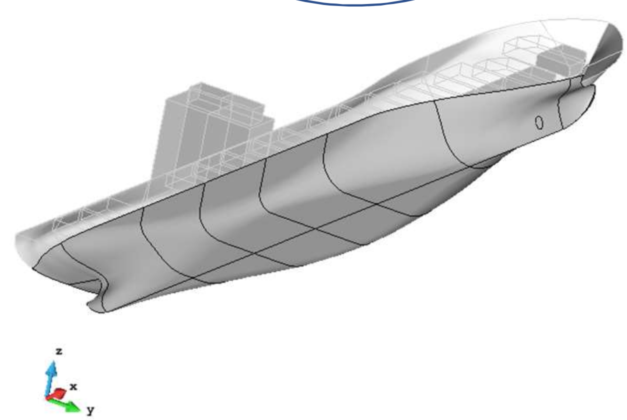
Damage
Polyester 2



CONCLUSIONS, RELEVANT ASPECTS AND FURTHER WORK

- A methodology has been conducted to adapt the existing fatigue formulation to composites.
- The methodology has been tested with success in two different composite systems and different configurations.
- The formulation is able to follow the fatigue degradation of constituent materials, obtaining the fatigue life of the structure.
- Fiber are not prompt to suffer fatigue → High stiffness requirements means higher scantlings → Lower stresses.
- 50% of loose of matrx strength! → Delamination and matrix cracking.
- Adapt the current formulation and methodology to 2D elements → Computationally expensive.
- One step beyond → Fatigue study of structural details.





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THANK YOU

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