# Reduction of Finite Element Models for Structural Reliability Analysis and Predictive Maintenance Applications

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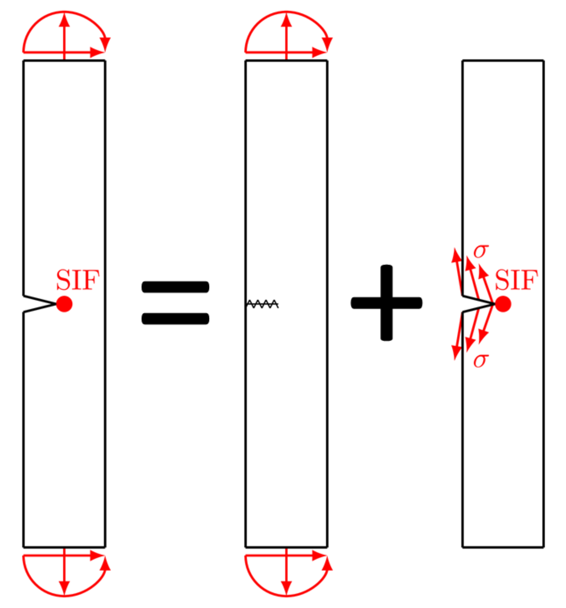
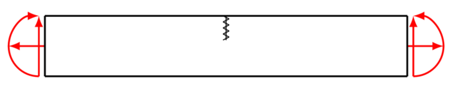
## Introduction

Advanced predictive maintenance procedures, increasingly used in the industry, often require damage tolerance analysis, which simulates the propagation of cracks in components and structures based on the laws of Fracture Mechanics. Linear Elastic Fracture Mechanics (LEFM) allows for the analysis of crack propagation by combining remote stress fields in the solid with Stress Intensity Factors (SIFs) obtained for specific crack configurations, subsequently applying crack propagation laws such as Paris' Law. This approach avoids more complex and computationally expensive procedures like the Extended Finite Element Method (XFEM). In this process, stress fields are calculated using the Finite Element Method (FEM) on an uncracked structure, while SIFs are determined analytically for each crack geometry and loading case. However, several challenges may arise during this process:

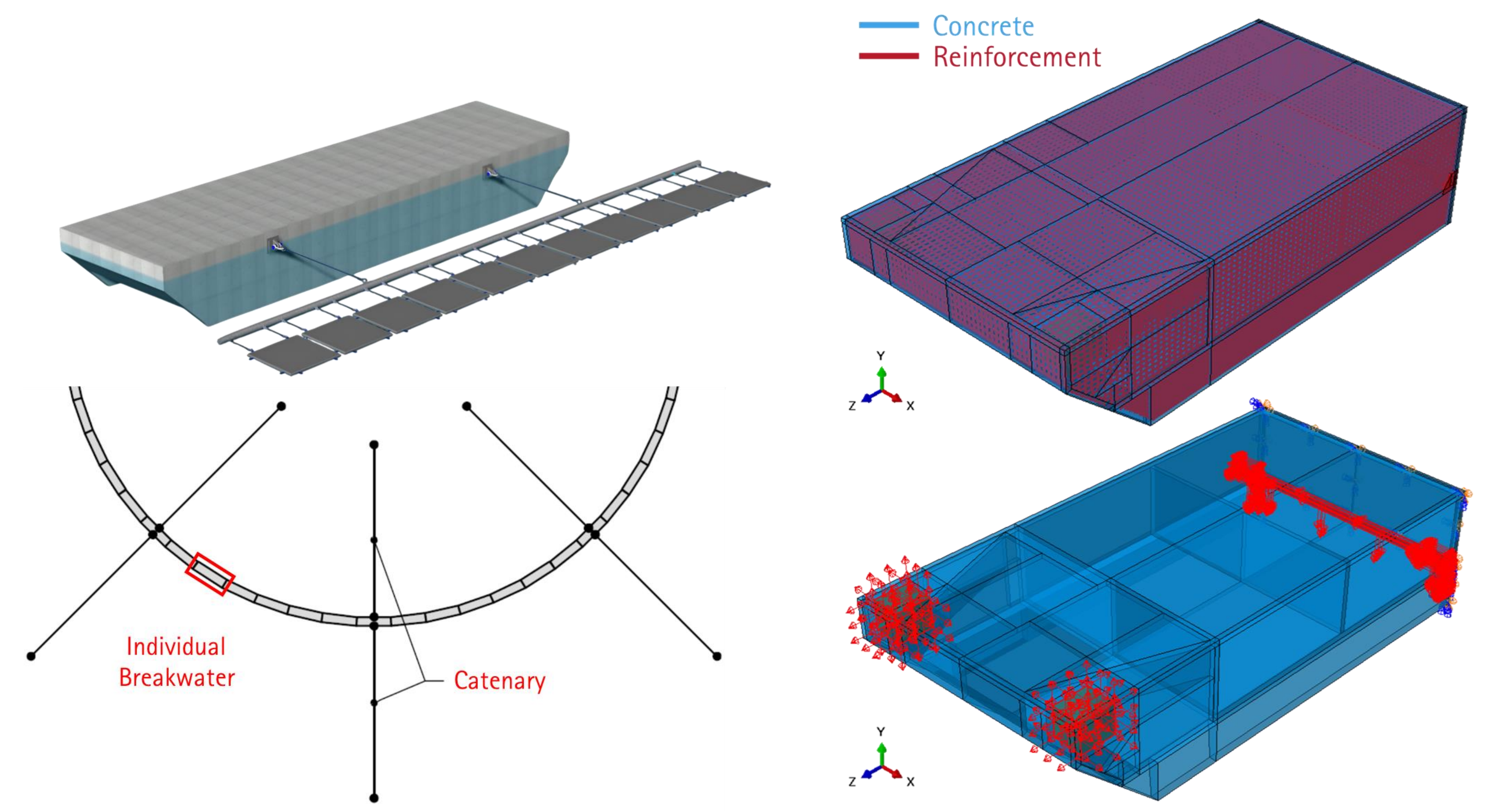
1. Large systems are costly and challenging for detailed finite element simulations; advanced techniques are necessary.
2. Some complex crack scenarios still require generation. Although they are used in analytical processes, FEM is needed to obtain them.




## Stress Field Calculation on the Uncracked Structure

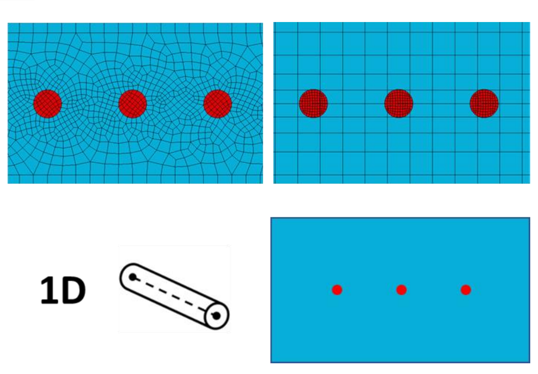


A floating breakwater, measuring 20 m x 5 m x 2.5 m, is being studied in the SUREWAVE project to protect a farm of floating photovoltaic panels (FPV).

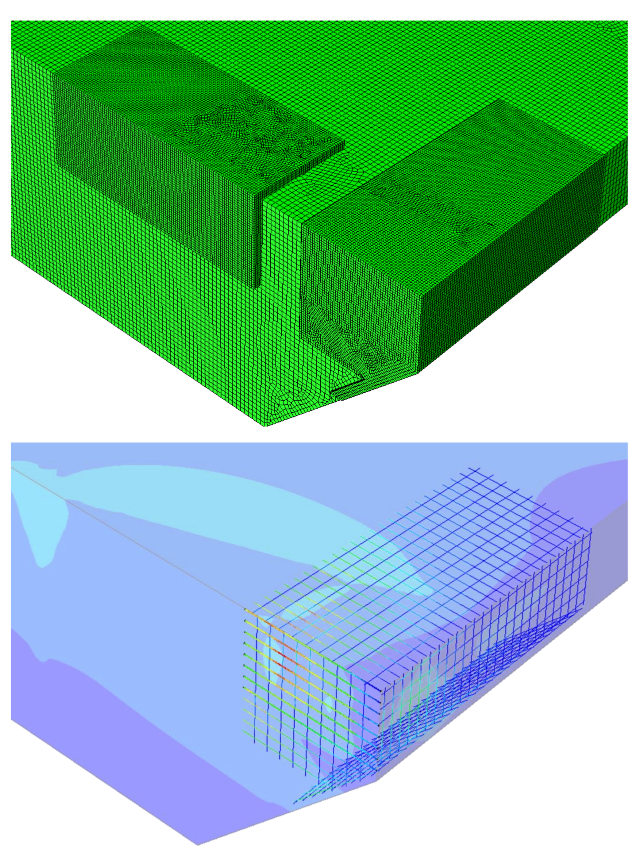



### Mesh Superposition Technique

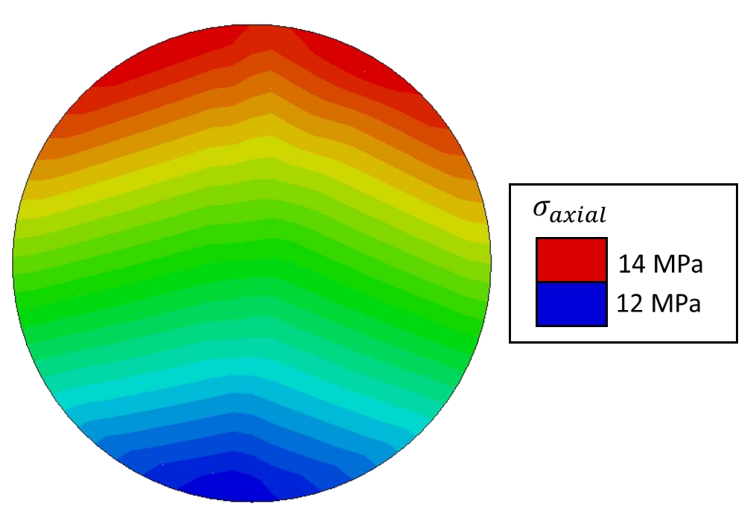
More than 2.000 rebars are used for reinforcement, complicating the meshing process. To simplify this without sacrificing accuracy, 1D truss elements are embedded within the global model using an advanced mesh superposition technique.



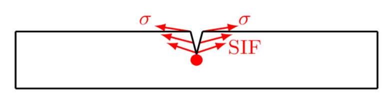

### Submodelling Technique



To quickly obtain detailed stress fields in the rebars, which are critical components due to corrosion and long-term fatigue, submodelling is used. In this approach, 1D rebars are replaced with 3D hexahedral elements in the critical regions.

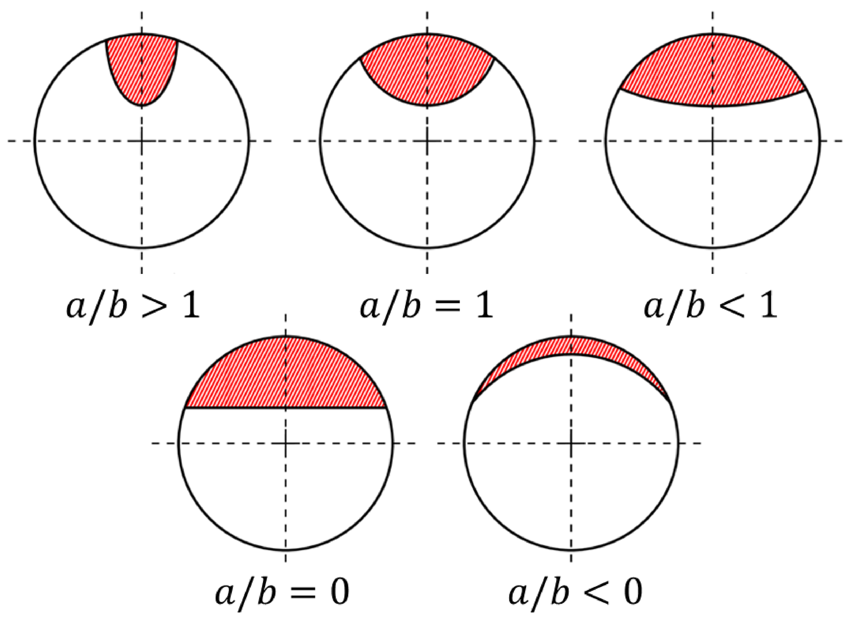



## Stress Intensity Factors (SIFs) Obtainment




Geometric correction factors ($Y$) relate crack geometry to SIFs. These solutions are fitted to analytical expressions that depend on the parameters of the crack geometry.

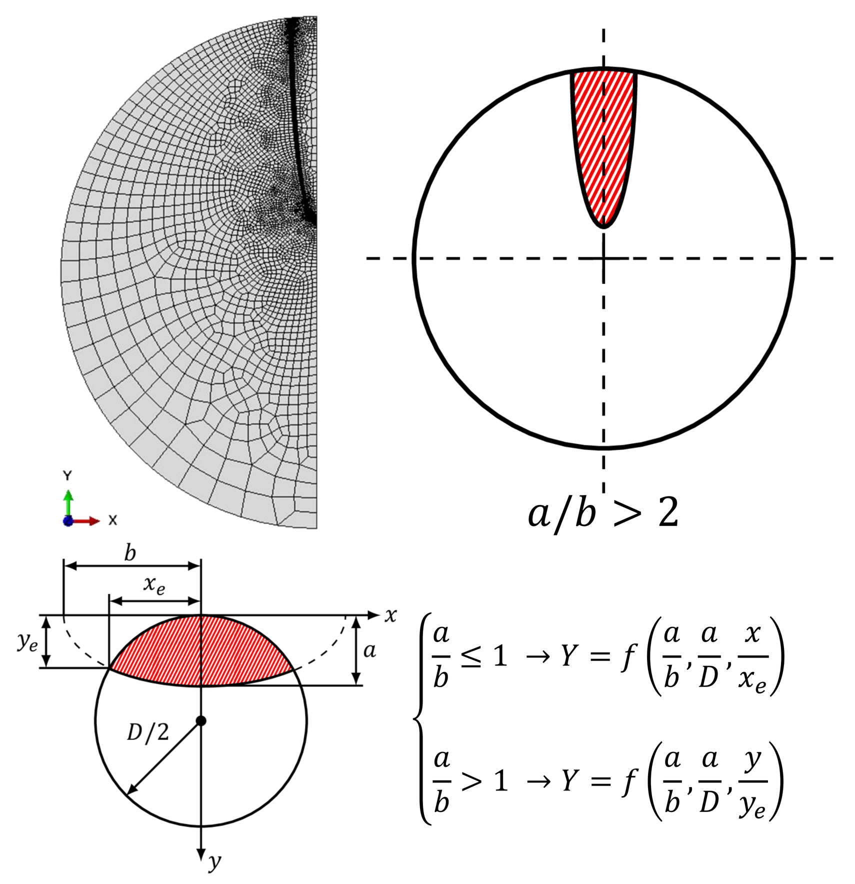
### Existing SIF Solutions




$$Y = \sum_{i=0}^{2}\sum_{j=0}^{7}\sum_{k=0}^{2} M_{ijk}\left(\frac{a}{b}\right)^i\left(\frac{a}{D}\right)^j\left(\frac{x}{h}\right)^k$$

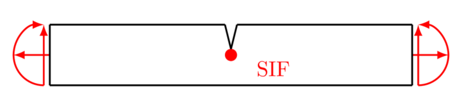
$$Y = \sum_{q=0}^{9}\sum_{r=0}^{4}\sum_{s=0}^{2}\sum_{\substack{t=0\\t\neq 1}}^{3} C_{i,qrst}\left(\frac{a}{b}\right)^q\left(\frac{a}{D}\right)^r\left(\frac{x}{h}\right)^s\gamma^t$$

### Generation of New SIF Solutions



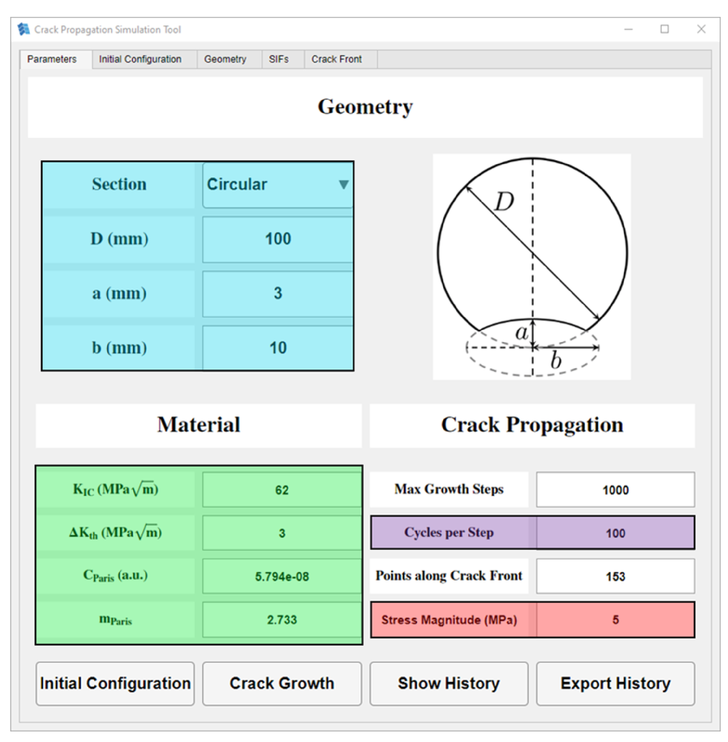

$$\begin{cases} \frac{a}{b} \leq 1 \rightarrow Y = f\left(\frac{a}{b},\frac{a}{D},\frac{x}{x_e}\right) \\ \frac{a}{b} > 1 \rightarrow Y = f\left(\frac{a}{b},\frac{a}{D},\frac{y}{y_e}\right) \end{cases}$$

## Crack Propagation Algorithm




Once the stress in the crack zone is determined and the SIFs for an initial crack are calculated, the evolution of the crack and its remaining life (dependent on the material's fatigue properties) can be assessed using a crack propagation algorithm.

$$\frac{da}{dN} = \boxed{C}(\Delta K)^{\boxed{m}} \quad \text{where} \quad \Delta K = \boxed{Y}\boxed{\Delta\sigma}\sqrt{\pi \boxed{a}}$$

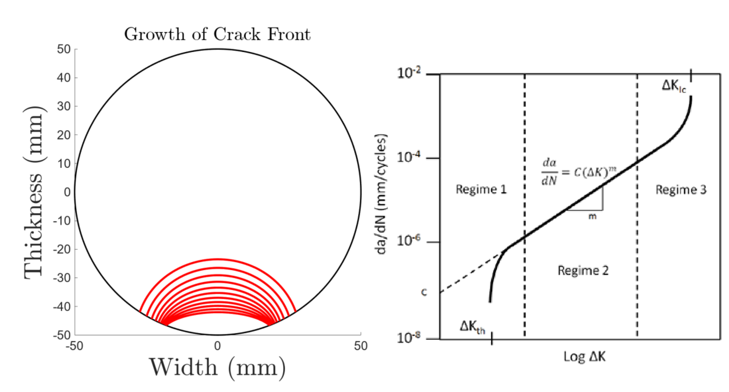



**Input**

| |
|---|
| Initial crack geometry for SIF calculation. |
| Fatigue properties of material. |
| Magnitude of applied load. |
| For every $N$ fatigue cycles. |

**Output**

Growth of crack front.




## Key References

[1] O. Vorobiov et al., *Mesh superposition applied to meso-FE modelling of fibre-reinforced composites: Cross-comparison of implementations,* International Journal for Numerical Methods in Engineering (2017), 111, pp. 1003-1024.

[2] A. J. C. B. Saint-Venant, *Mémoire sur la Torsion des Prismes*, Mémoire Divers Savants (1855), 14, pp. 233-560.

[3] P. Paris and F. Erdogan, *A Critical Analysis of Crack Propagation Laws,* Journal of Basic Engineering (1963), 85, pp. 528-533.

[4] J. Toribio et al., *A critical review of stress intensity factor solutions for surface cracks in round bars subjected to tension loading,* Engineering Failure Analysis (2009), 16, pp. 794–809.

## Contributions

## Acknowledgements

SUREWAVE