Determination of the constitutive laws of FRC by inverse analysis and its application on the design of FRC structures

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Webinar Civitest 2021

Universidade do Minho

1. Introduction
   - Motivation
   - Model Code 2010
   - Inverse analysis approaches
2. COFIT software
   - Main features
   - Theoretical aspects
     - Underlying algorithms
     - Simulation of the numerical response
   - COFIT workflow
     - Overview
     - Input datafile
     - Output results
   - Predictive performance
3. Practical case demonstration
   - Case description
   - COFIT application
   - Results
4. Conclusions

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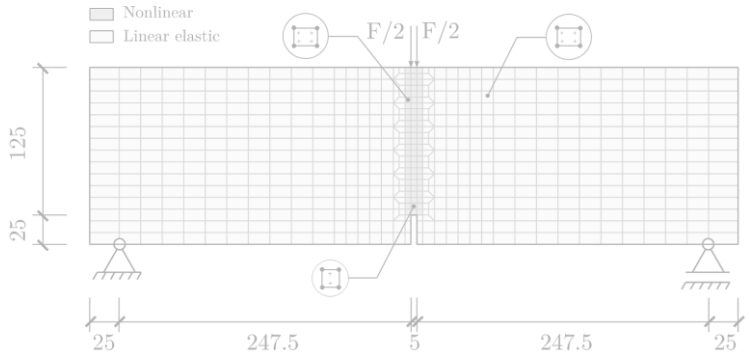
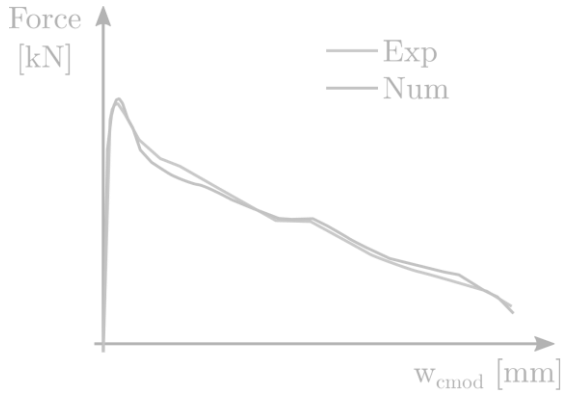
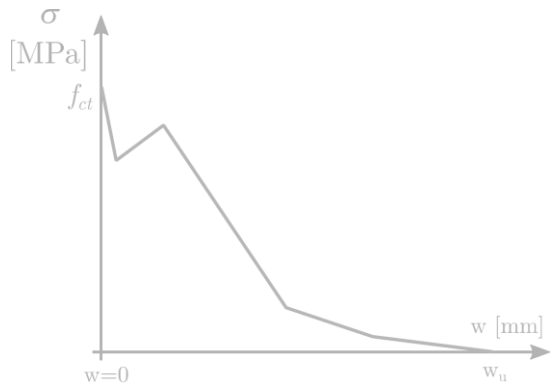
- Chacterise the tensile behaviour of FRC (σ-w relationwship)
- Determine the necessary fracture parameters to simulate, analyse and design FRC structures







Develop a practical, efficient and automatised tool capable of determining these properties in a optimised way

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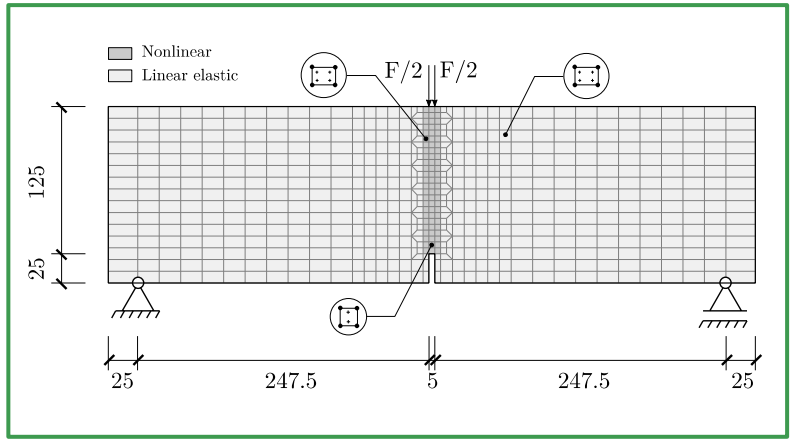
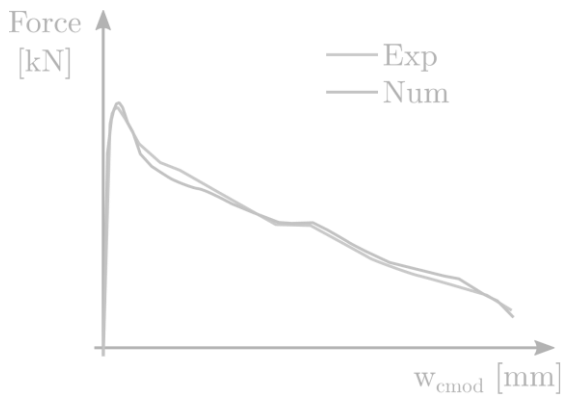
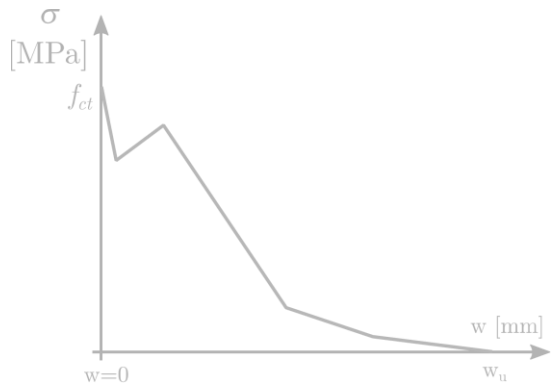
FEM model







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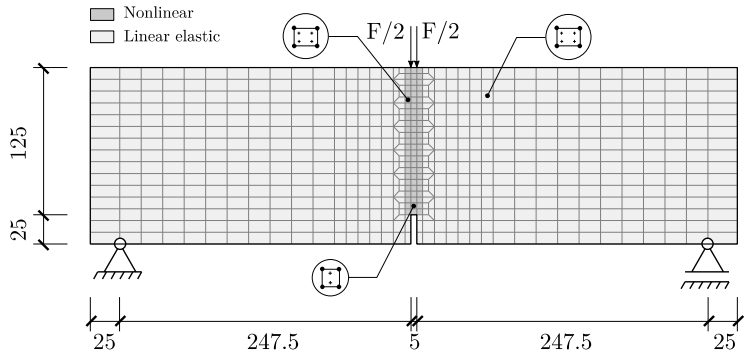
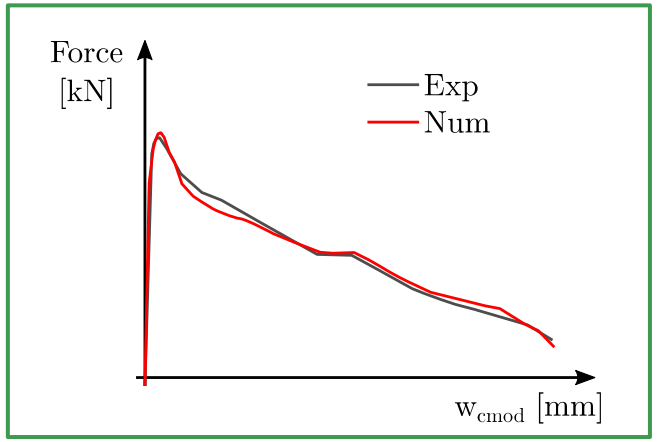
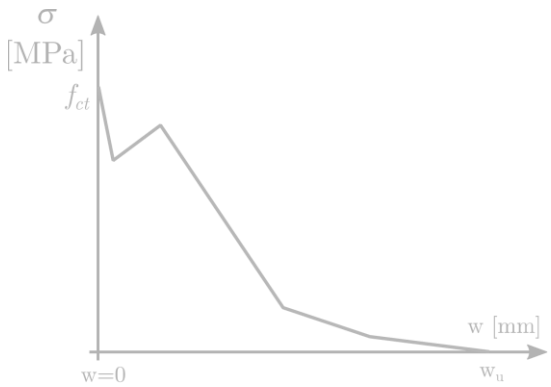


Check response





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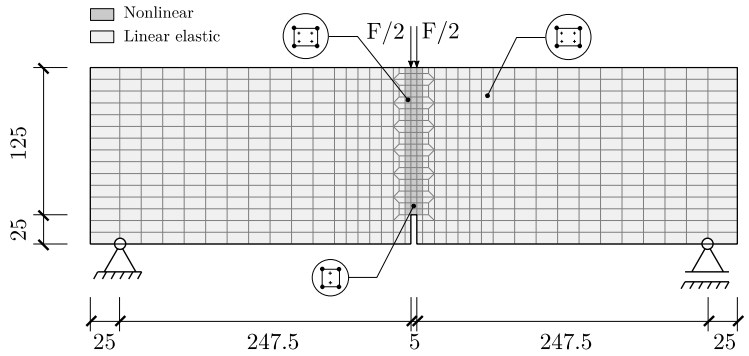
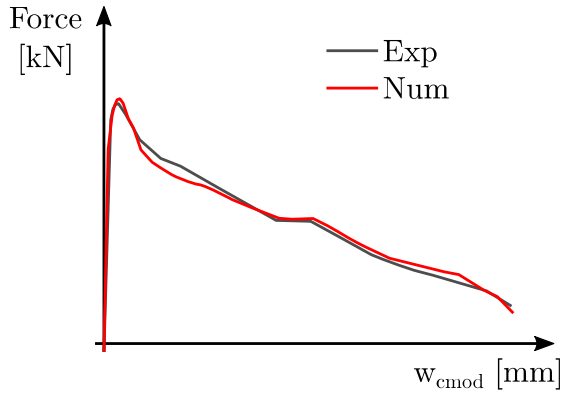
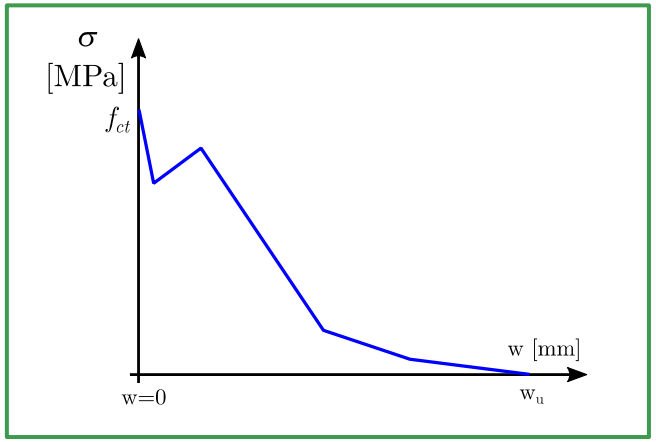




Modify parameters



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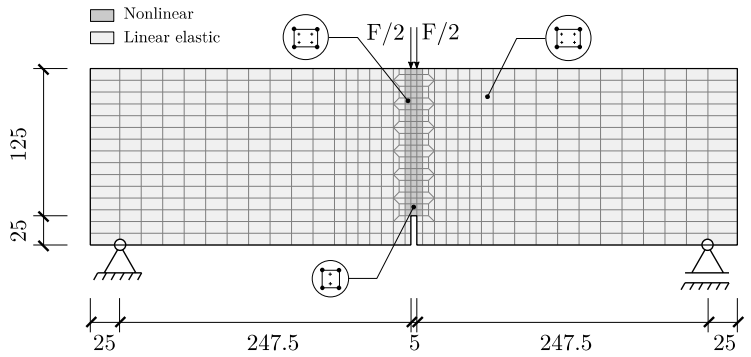

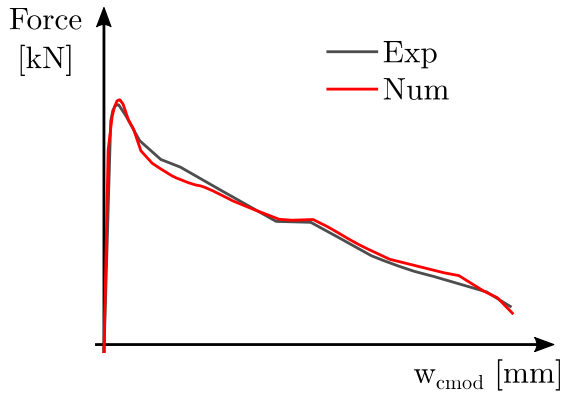

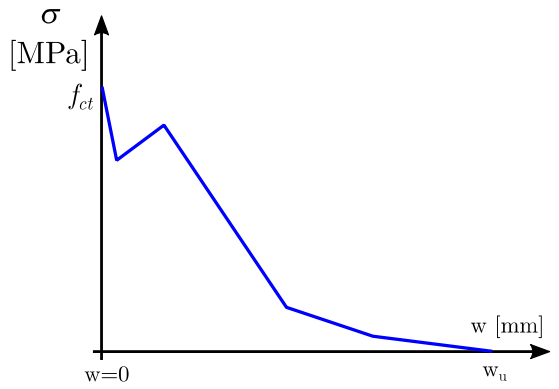

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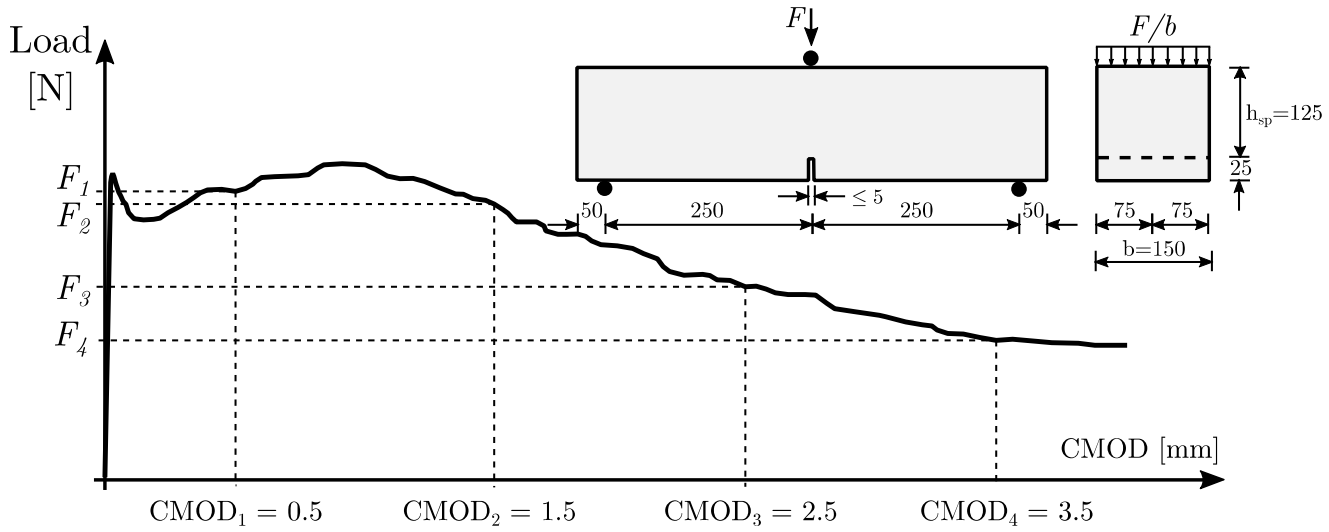
Model Code 2010

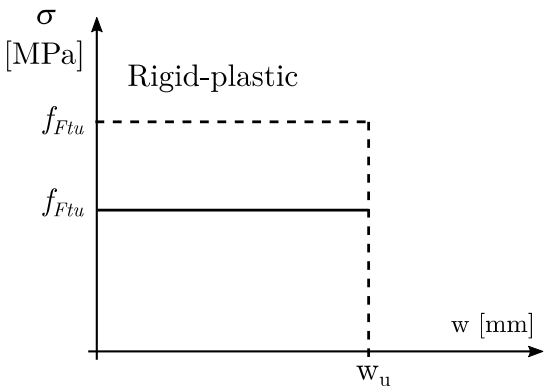
- According to MC2010 the tensile behaviour and fracture mode I parameters are determined from the residual flexural strength parameters, f_{Rj}, obtained by performing three-point notched beam bending tests (3PNBBT)

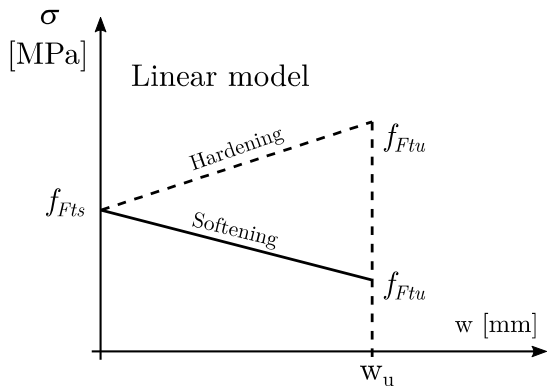


$$f_{Rj} = \frac{3 \cdot F_j \cdot l}{2 \cdot b \cdot h_{sp}^2}$$

Tensile constitutive Law

- Simplified approach proposed by MC2010



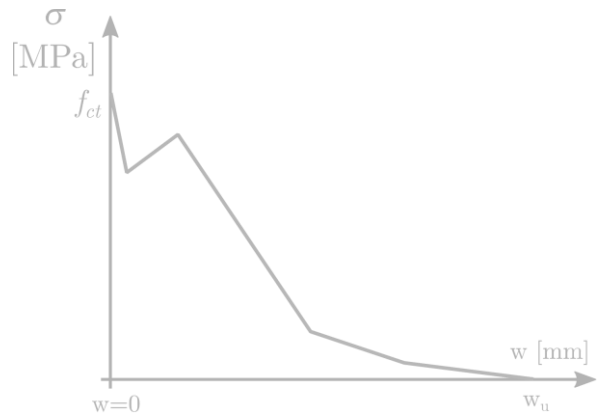


$$f_{Ftu} = \frac{f_{R3}}{3}$$

$$f_{Fts} = 0.45 f_{R1}$$

$$f_{Ftu} = f_{Fts} - \frac{w_u}{CMOD_3}(f_{Fts} - 0.5 f_{R3} + 0.2 f_{R1}) \geq 0$$

- More accurate stress-crack width relationships for numerical analysis



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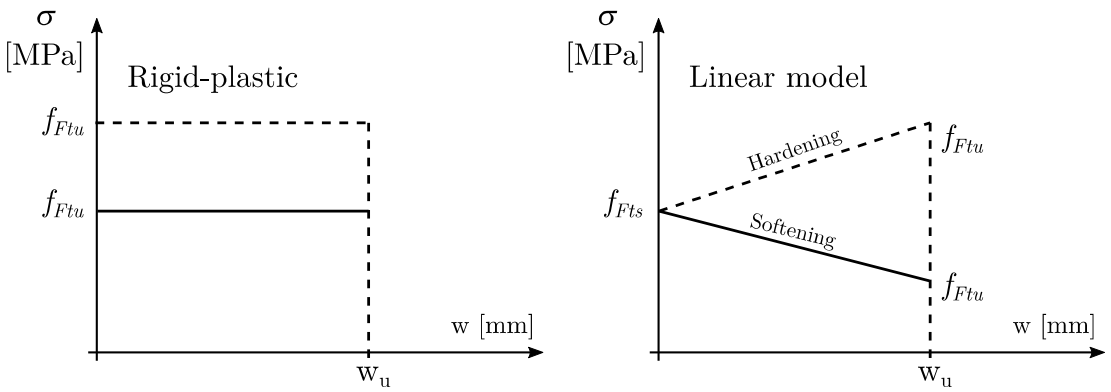

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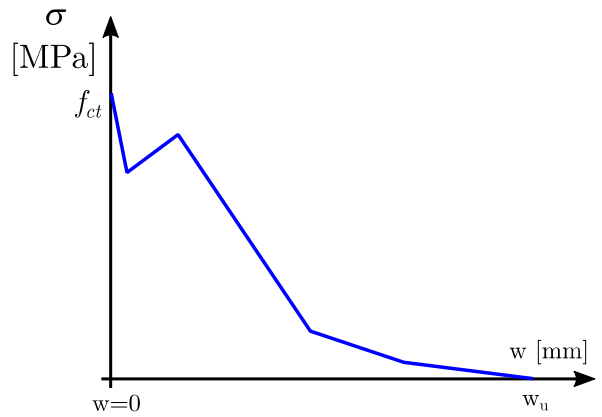
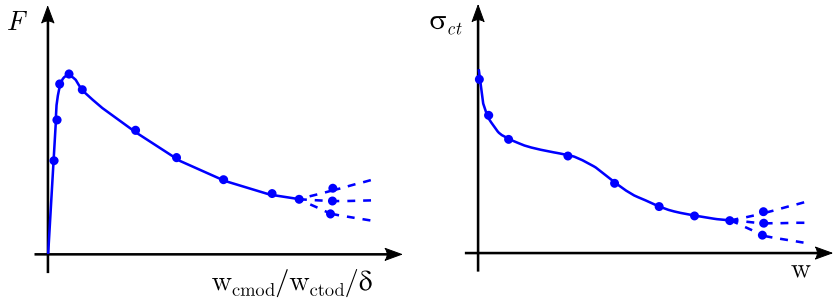


Inverse Analysis

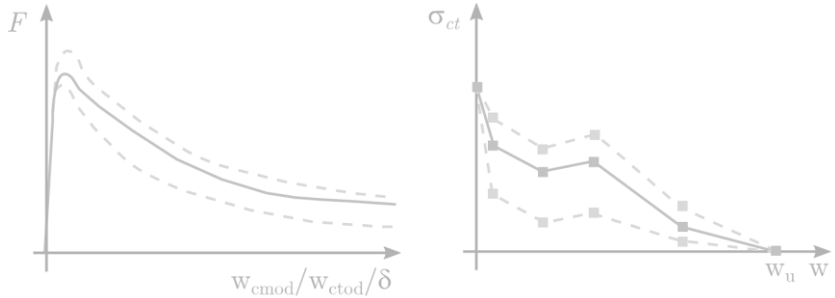
Inverse analysis (IA) approaches

Point-by-point approach



- ✓ Each point in the s-w diagram is determined from the previous one
- ✓ No initial assumption about the s-w relationship is needed
- Prone to accumulation of errors

Global approach



- ✓ σ-w diagram is defined a-priori and its governing points modified
- ✓ Different σ-w relationships can be used (exponential, multilinear)
- Might lead to spurious solutions if the optimization is not boundary constrained

Inverse analysis (IA) approaches

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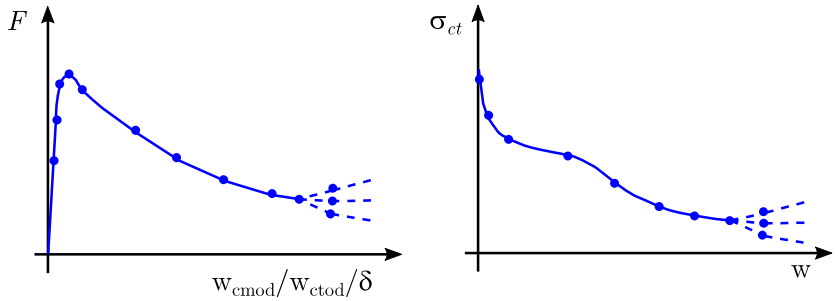

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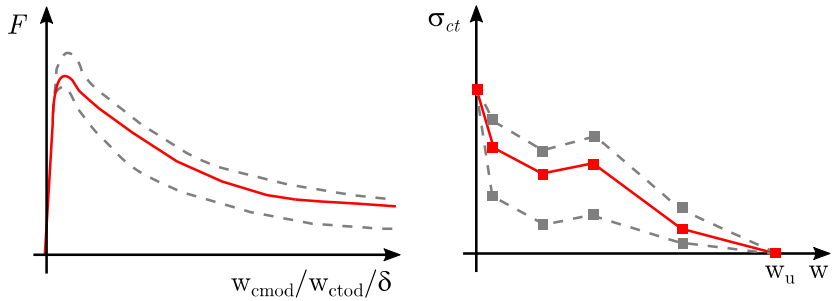

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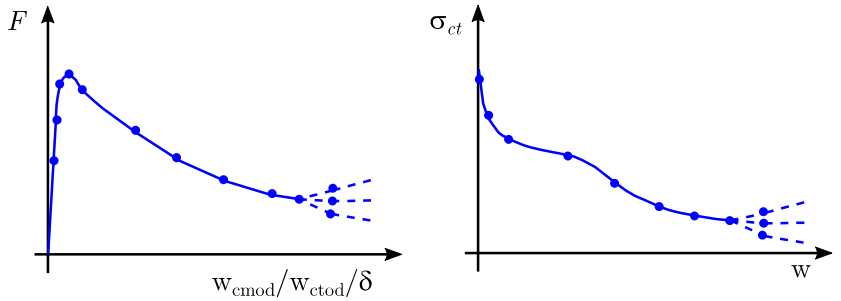

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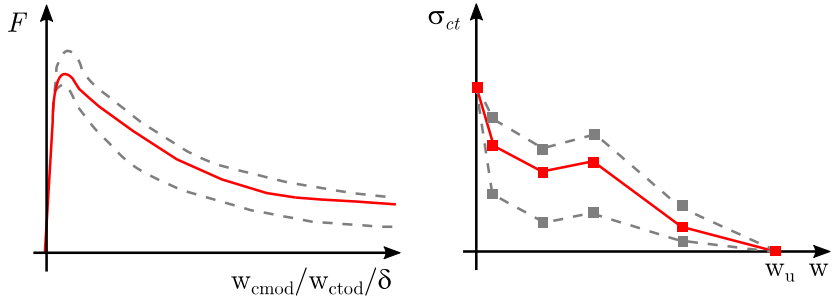

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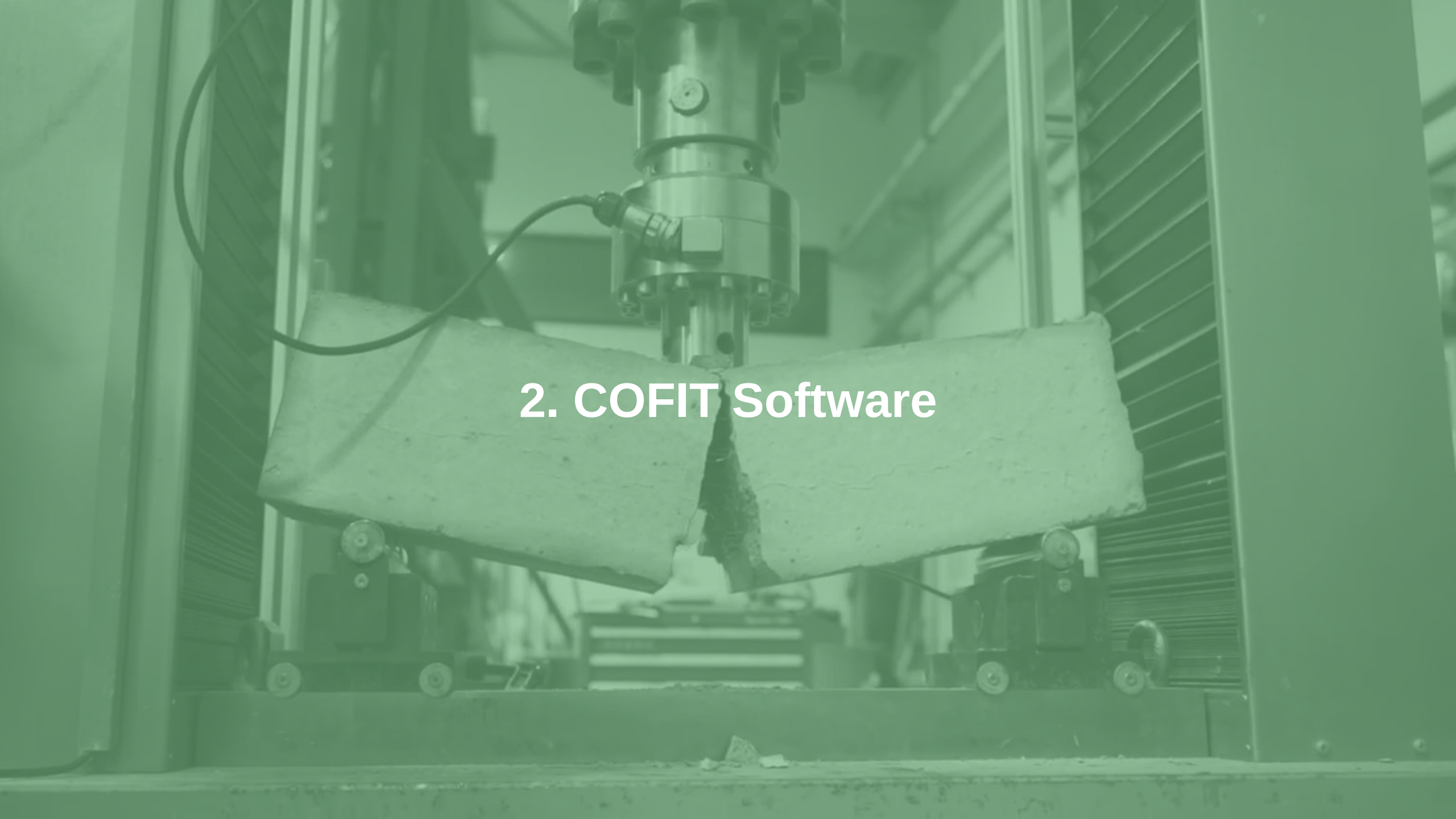

2. COFIT Software

Main features

2 problem types

Include/exclude *fct* and/or *Ec* from the IA procedure

Possible implementation of additional models due to **modular architecture**

fx Numerical response based on **analytical models** reducing computational time

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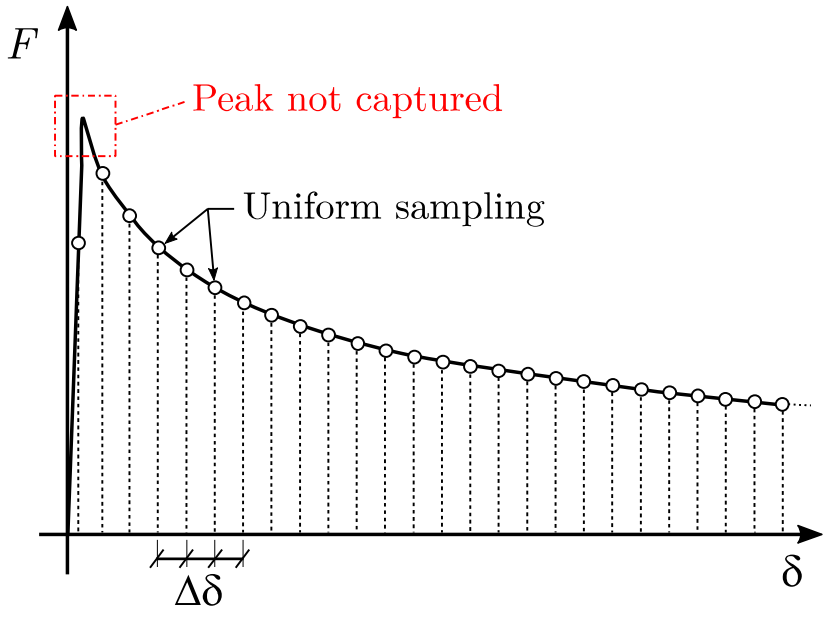
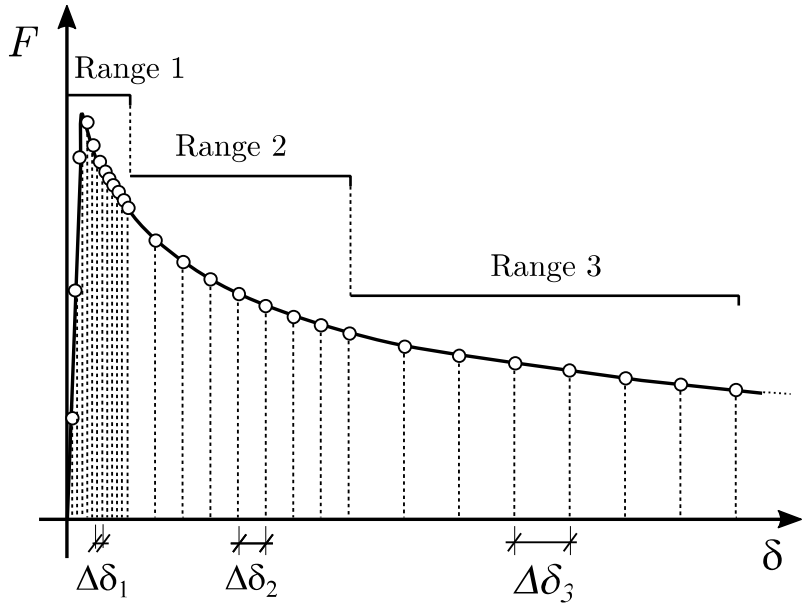
Main features

Custom discretisation of the experimental curve



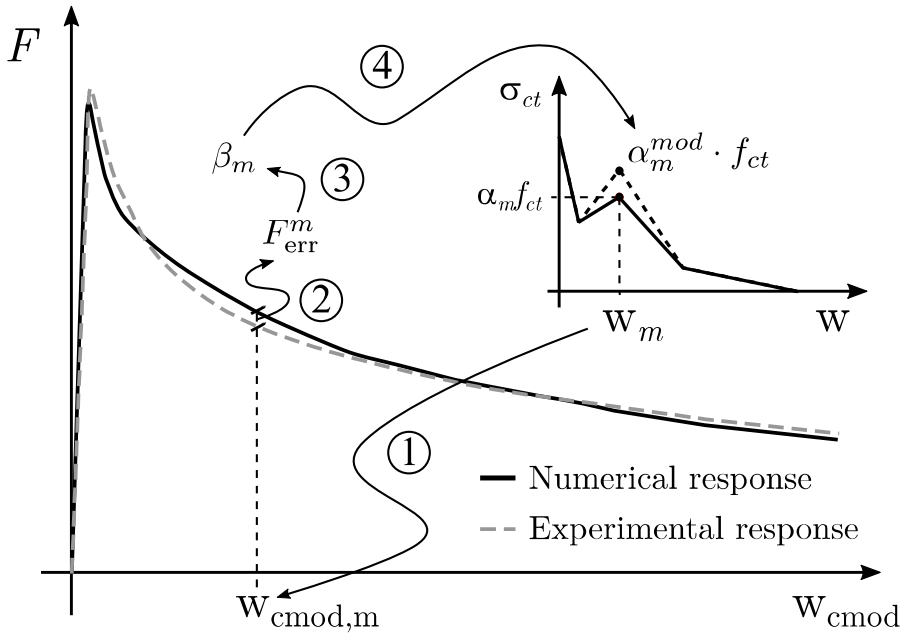
Uniform sampling approach



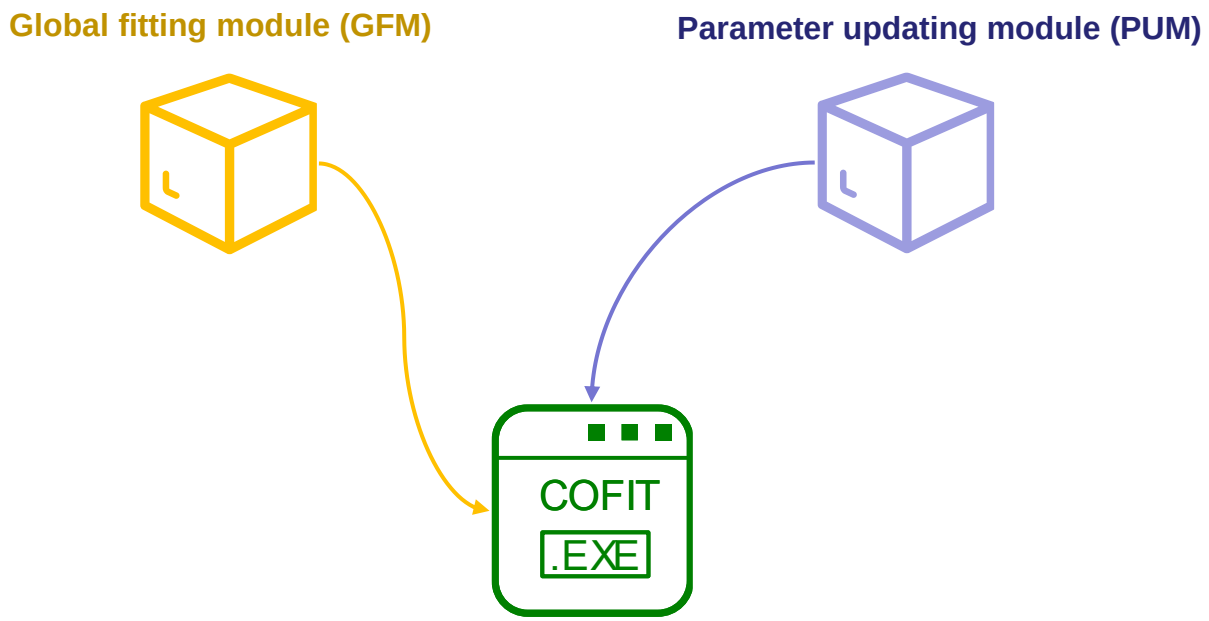
Custom method with specification of different sampling in different regions of the response

Main features

Automatic variable updating based on numerical-experimental error

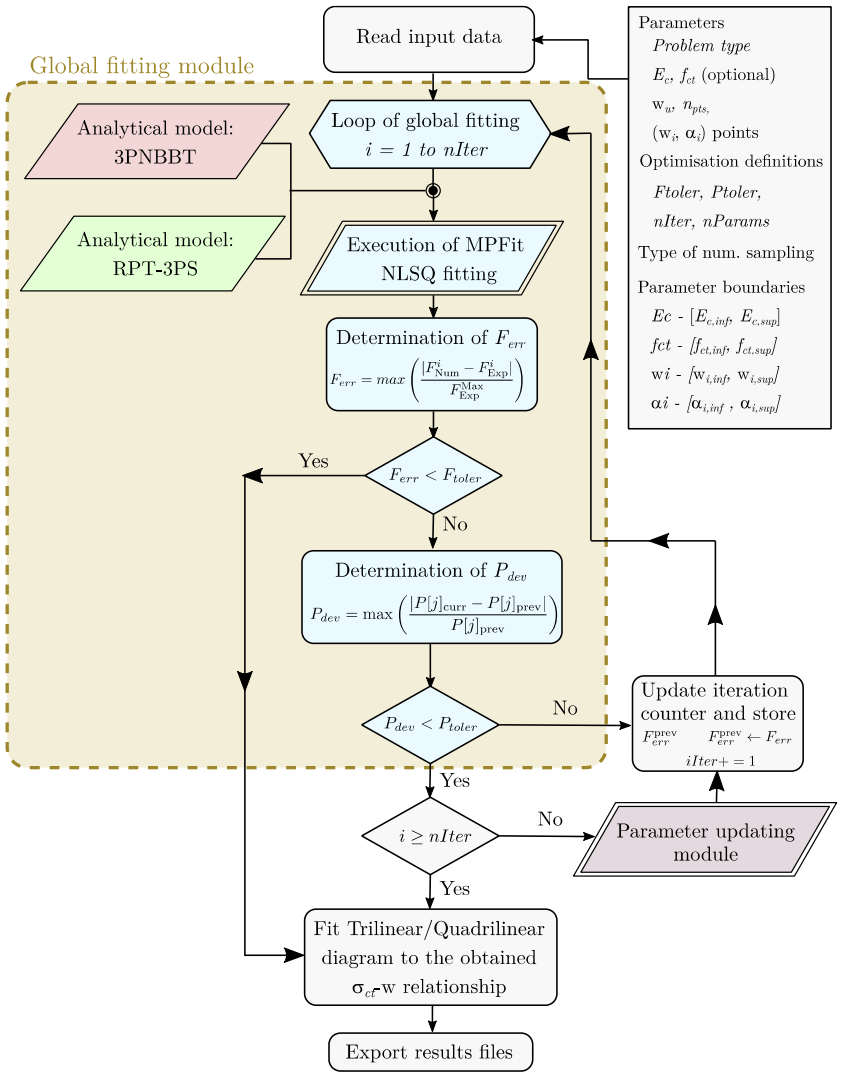


Theoretical aspects – underlying algorithms



Theoretical aspects – underlying algorithms

GFM



- Executes the main fitting procedure
- Nonlinear least square fitting (NLSQ) algorithm

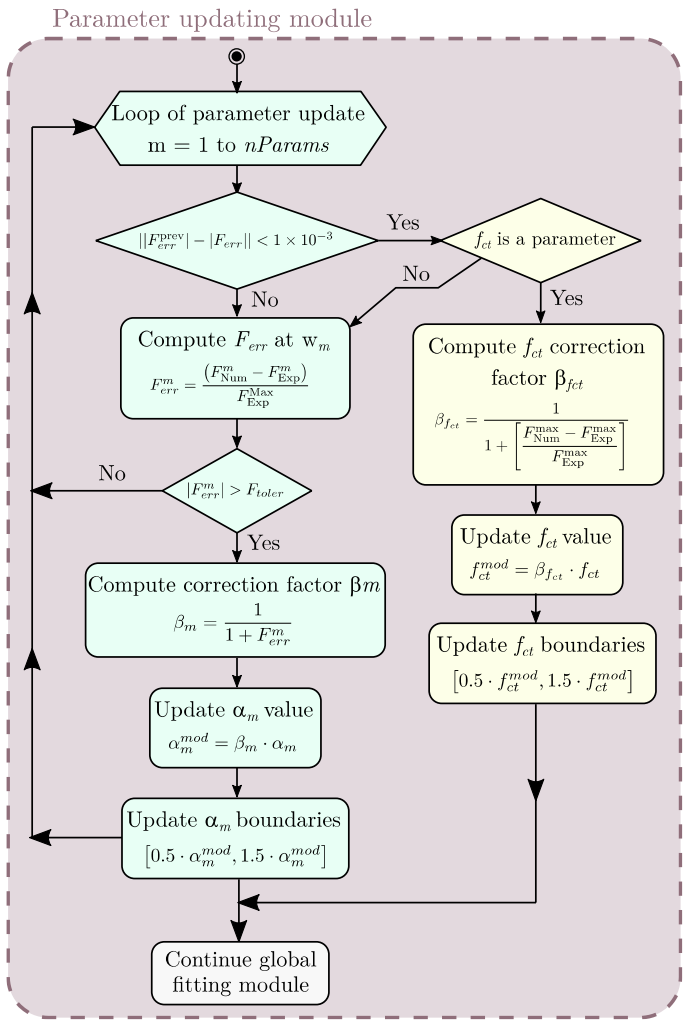
$$min \sum_{i=1}^{n} \left(F^i_{Exp} - F^i_{Num}\right)^2$$

- MPFit library implemented in C language
- Based on the MINPACK-1 fitting library
- Boundary constrained fitting

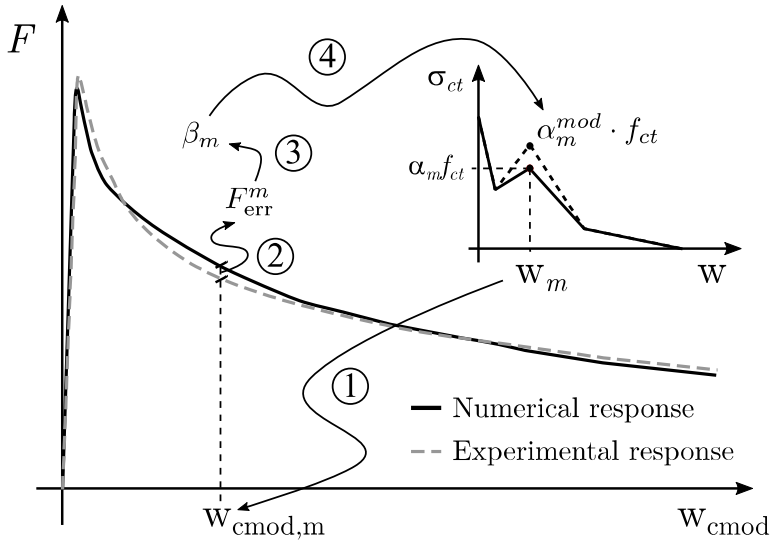
Matos LPM, Barros JAO, Ventura-Gouveia A, Calçada RAB. "A new inverse analysis approach for predicting the fracture mode I parameters of fibre reinforced concrete." http://dx.doi.org/10.1016/j.engfracmech.2021.10761

Theoretical aspects – underlying algorithms

PUM

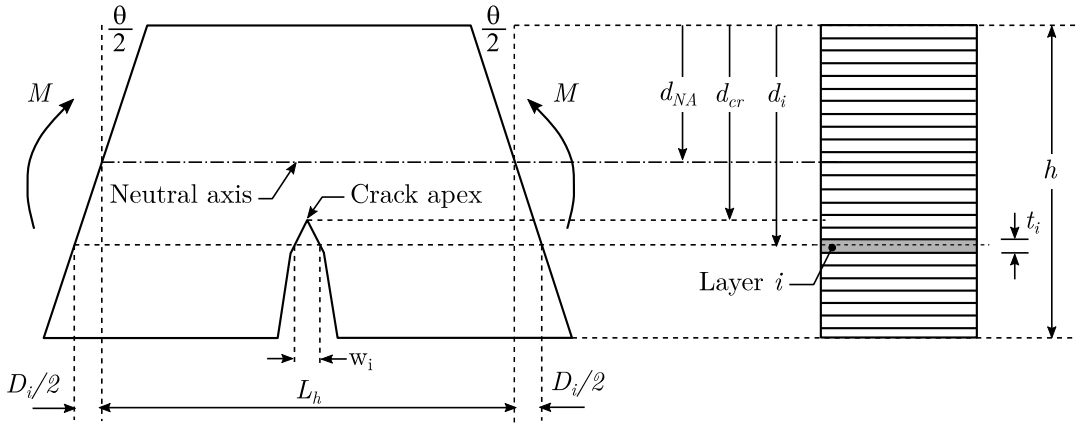


- Modifies the optimized variables and limits
- Update is based on the force deviation error between numerical and experimental curve
- Ensures that a global solution is found



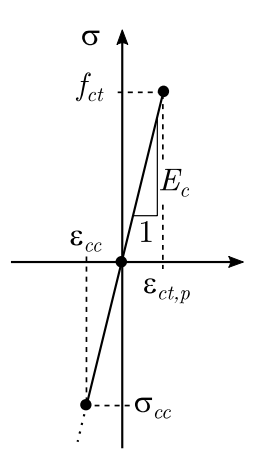
Theoretical aspects – simulation of the numerical response

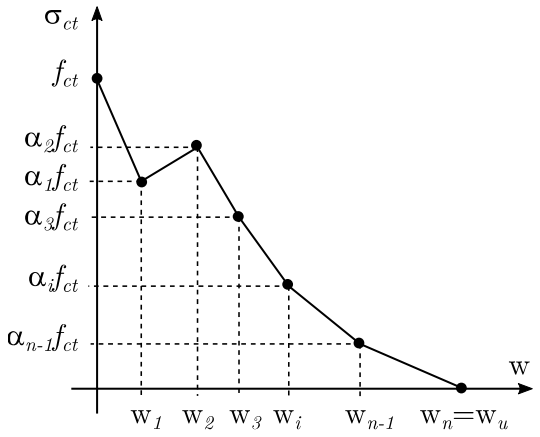
M – θ flexural model



- Imposed rotation
- Neutral axis (NA) position is sought based on force equilibrium
- Root finding algorithm is used to optimize this step

Linear behaviour



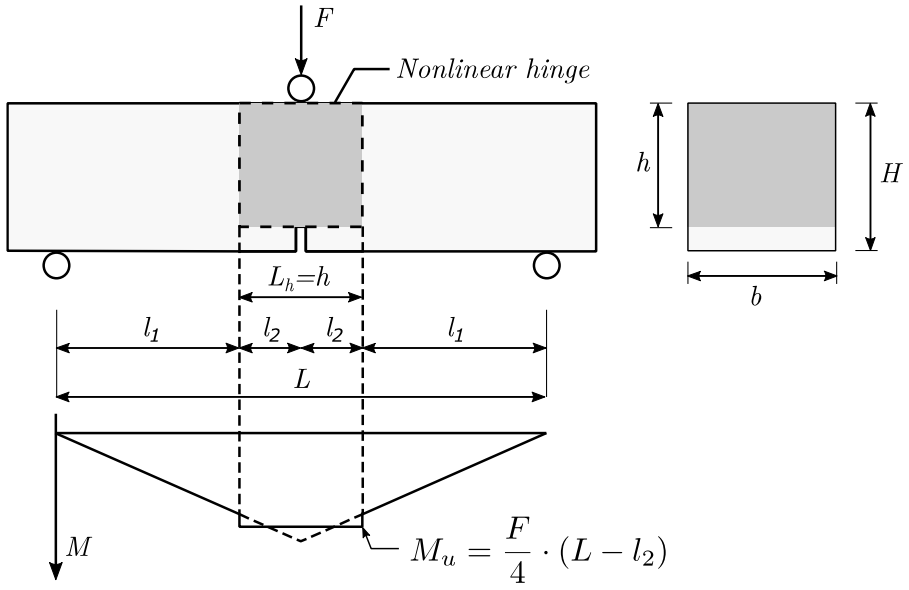


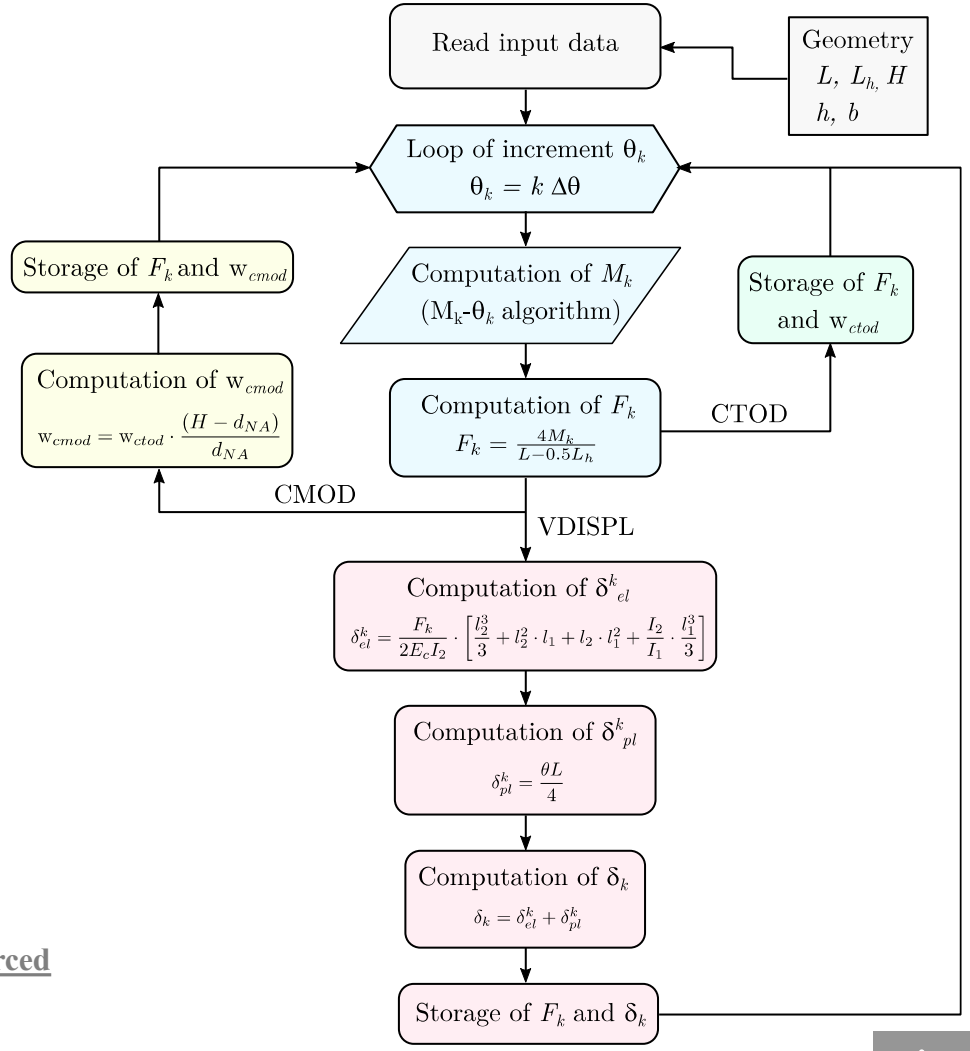
Multi-linear tensile relationship

Barros JAO, Figueiras JA. "Flexural behavior of SFRC: testing and modeling". J Mater Civ Eng 1999;11(4):331–9. http://dx.doi.org/10.1061/(ASCE)0899-1561(1999)11:4(331).

Theoretical aspects – simulation of the numerical response

- **3PNBBT**

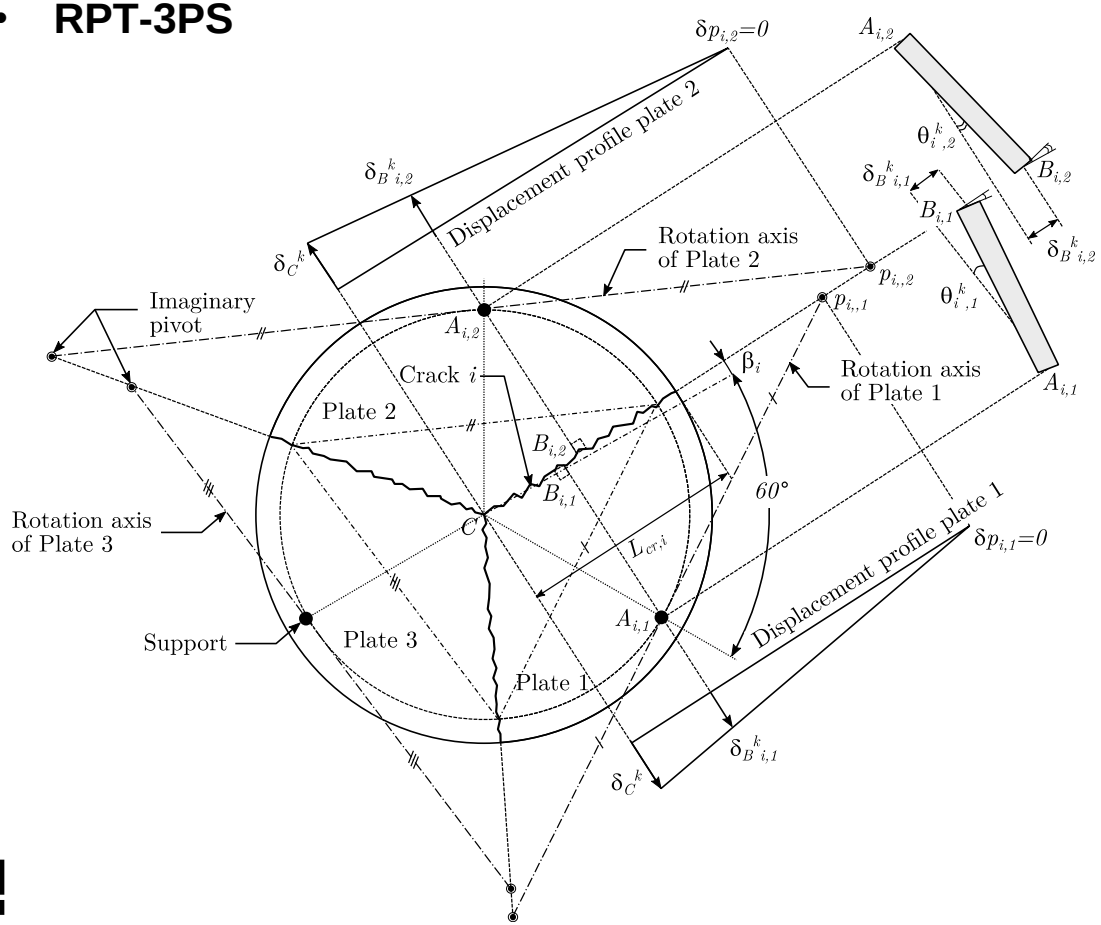


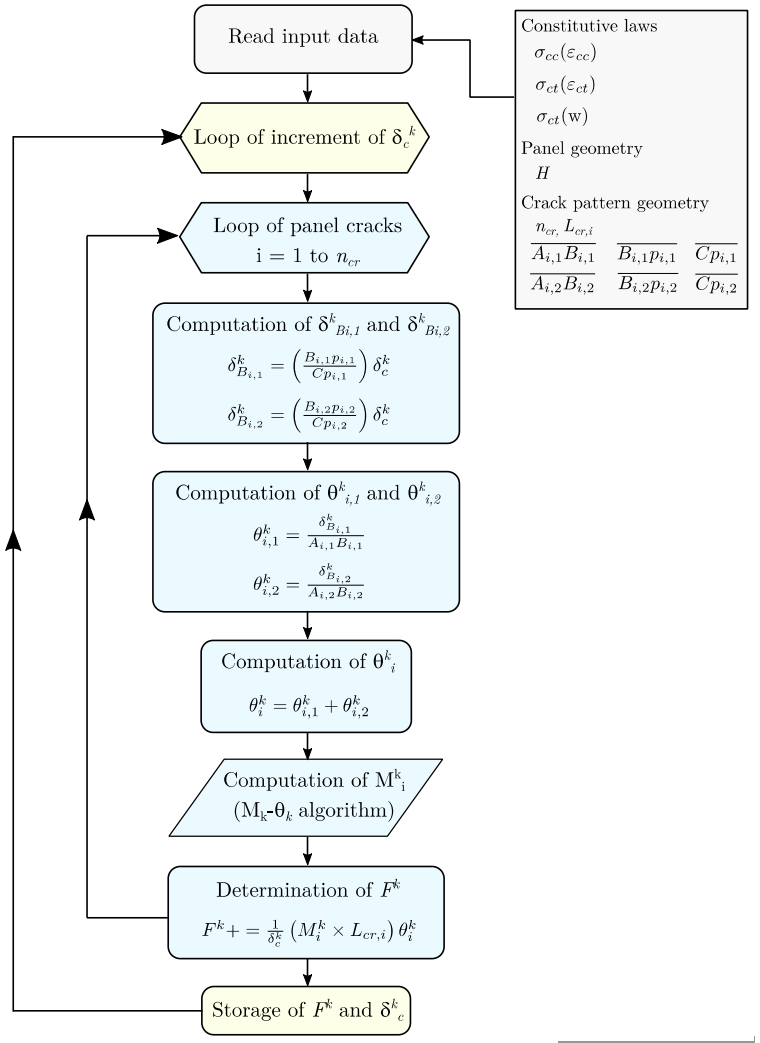


Salehian H. "Evaluation of the Performance of Steel Fibre Reinforced Self-Compacting Concrete in Elevated Slab Systems; from the Material to the Structure". PhD thesis, University of Minho.

Theoretical aspects – simulation of the numerical response

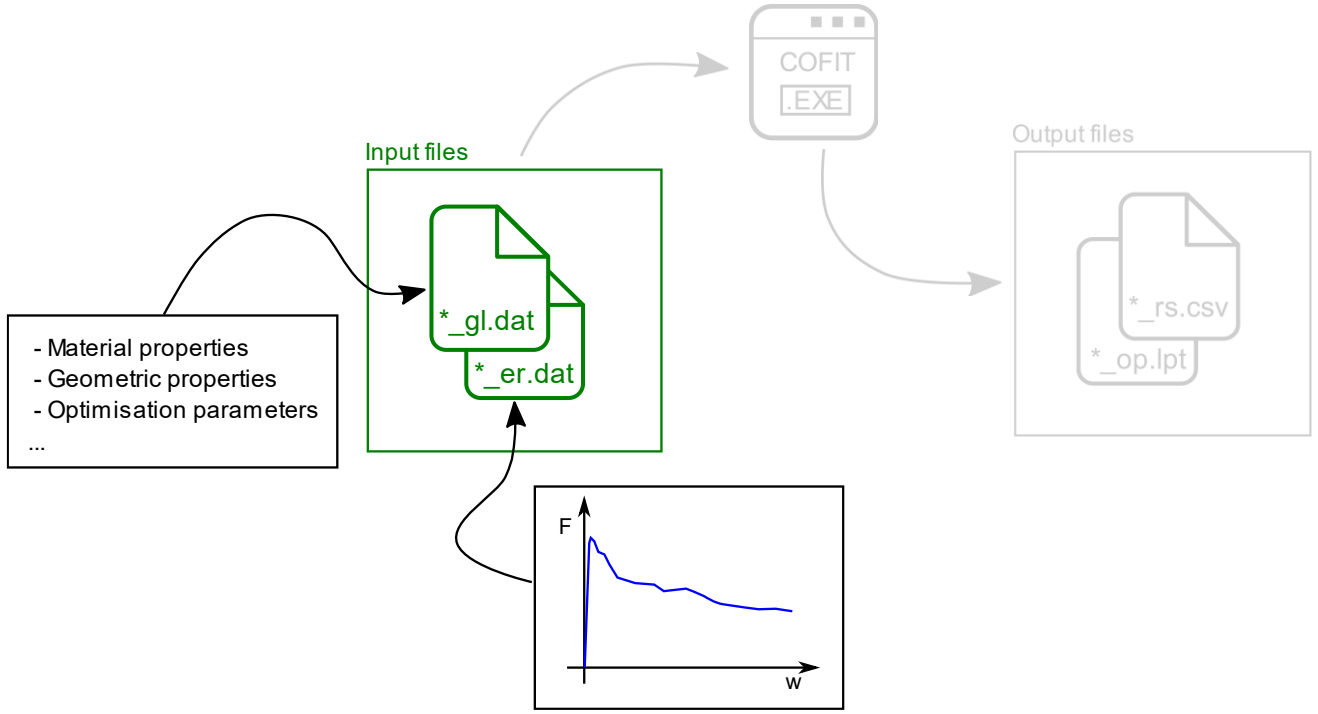
- **RPT-3PS**





Salehian H, Barros JA, Taheri M. "Evaluation of the influence of post-cracking response of steel fibre reinforced concrete (SFRC) on load carrying capacity of SFRC panels". Constr Build Mater 2014;73:289–304. http://dx.doi.org/10.1016/j.conbuildmat.2014.09.043

COFIT workflow – overview



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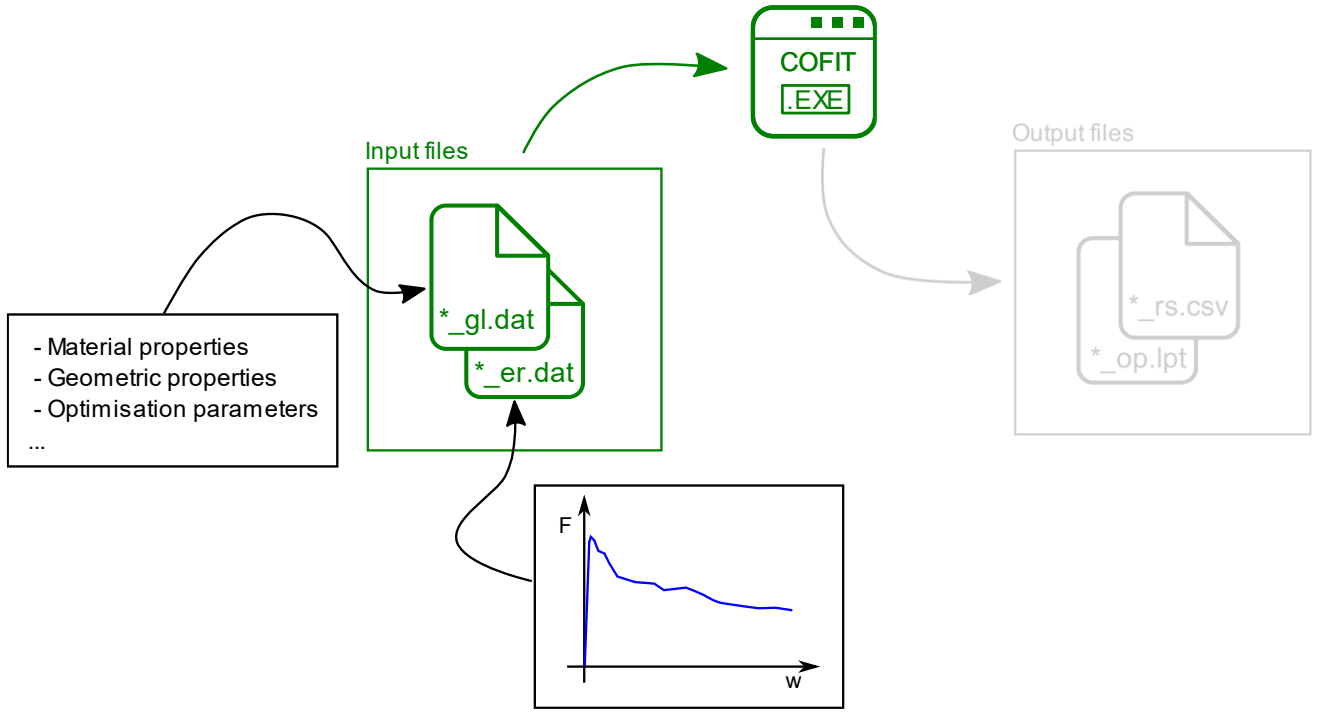

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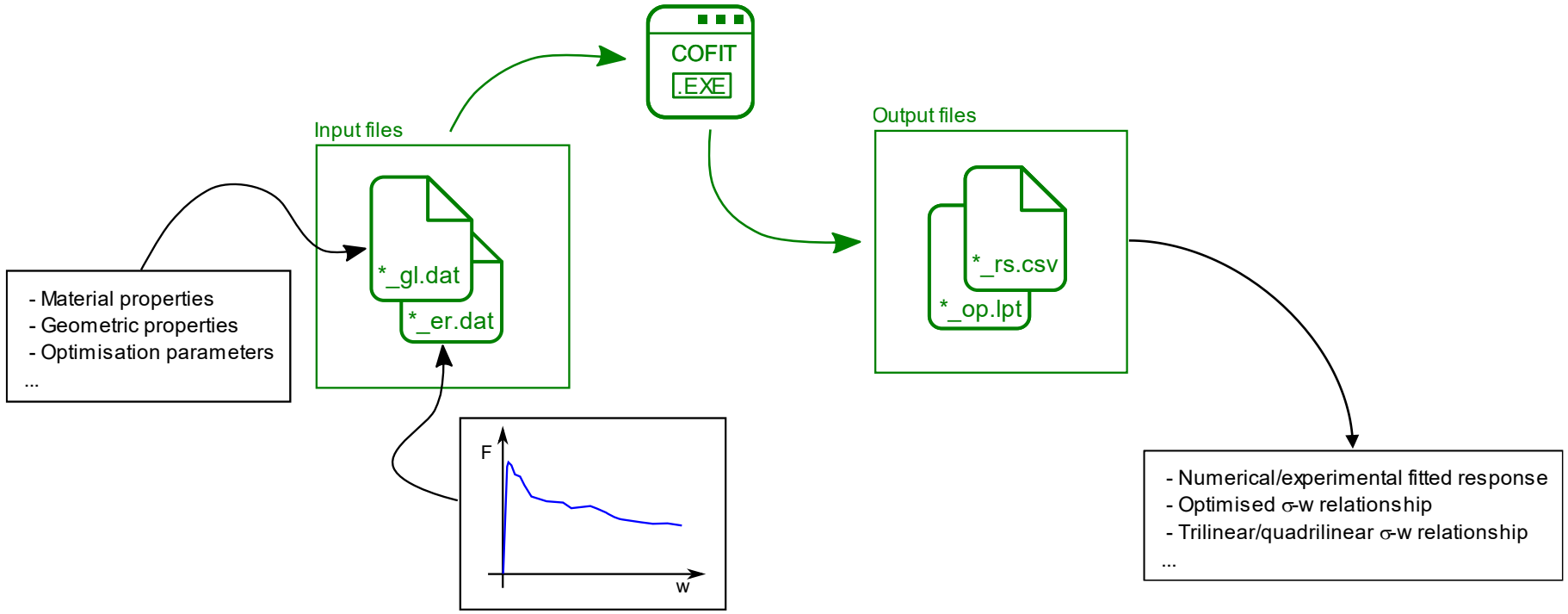
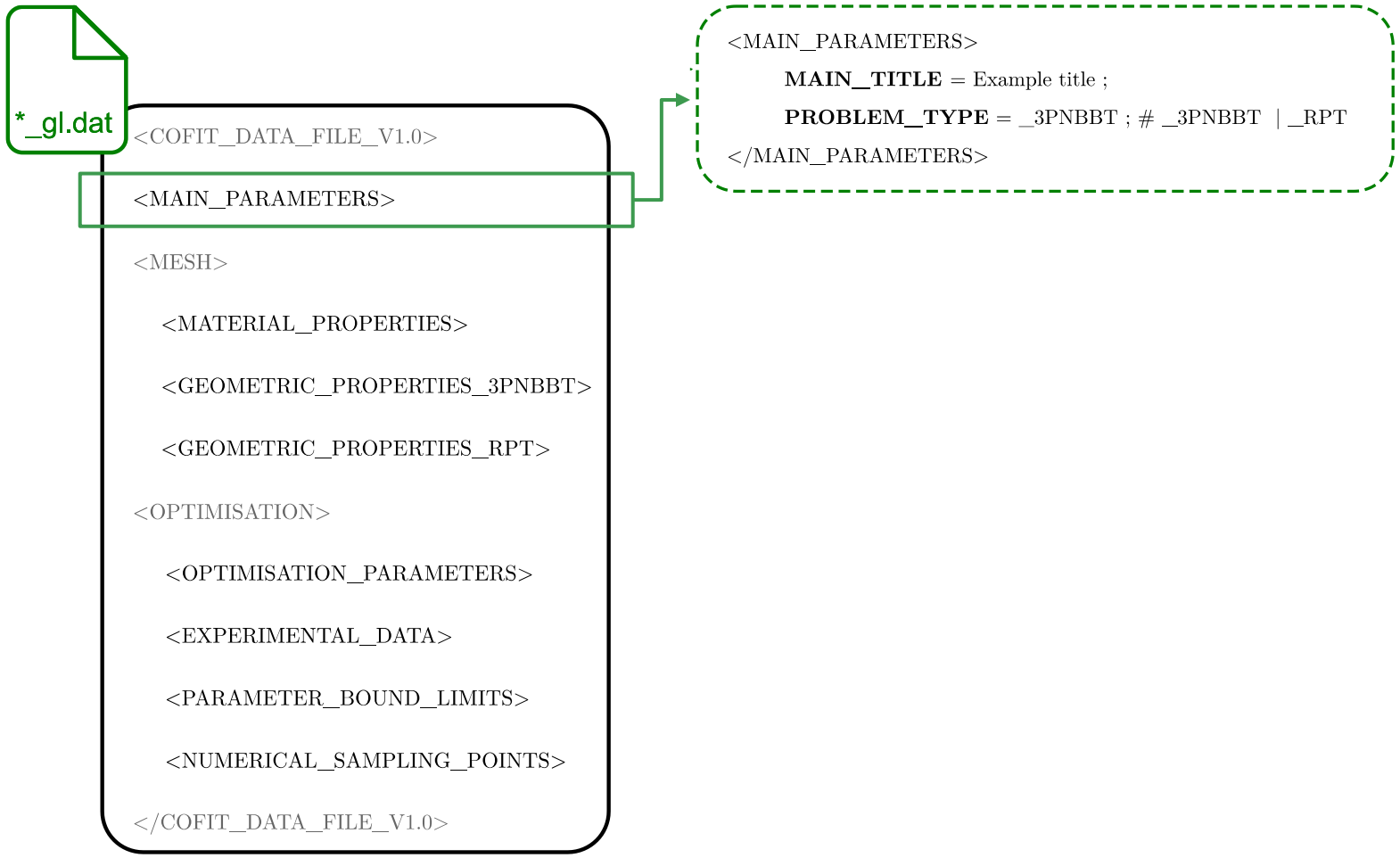


COFIT workflow – input datafile


```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

COFIT workflow – input datafile

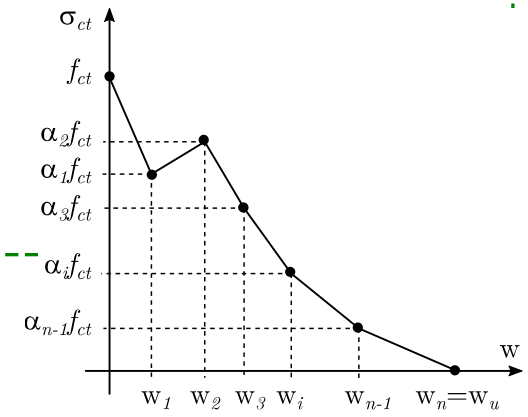


COFIT workflow – input datafile

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
  <MATERIAL_PROPERTIES>
  <GEOMETRIC_PROPERTIES_3PNBBT>
  <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
  <OPTIMISATION_PARAMETERS>
  <EXPERIMENTAL_DATA>
  <PARAMETER_BOUND_LIMITS>
  <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<MATERIAL_PROPERTIES>
  ## Properties of the concrete material model
  ## Content of each column:
  # A -> Young's modulus [MPa]
  # B -> Tensile strength [MPa]
  # C -> Maximum crack width [mm]
  # D -> N. of set of values (wi - ai) of the stress-crack width relationship
  # E -> Values (wi - ai) defining the stress-crack width relationship:
  #       (wi) - crack width at the i-th post-peak point [mm]
  #       (ai) - ratio between the stress and the tensile strengh at the i-th post-peak point
  #        A        B      C     D
           Ec       fct    wu    nPts

  #       E
          w1   α1
          w2   α2
          w3   α3
          w4   α4
          w5   α5 ;
</MATERIAL_PROPERTIES>
```

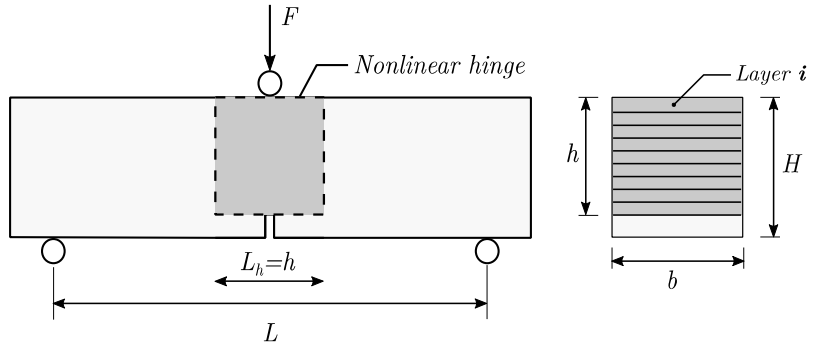


COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<GEOMETRIC_PROPERTIES_3PNBBT>
## Geometric properties of the cross-section
## Content of each column:
#  A -> Width of the cross-section [mm]
#  B -> Height of the cross-section [mm]
#  C -> Effective height of the cross-section
#       (i.e. height at the notched section in the 3PNBBT) [mm]
#  D -> Length of the non-linear hinge [mm]
#  E -> Span length [mm]
#  F -> Number of layers discretizing the cross-section
#  A    B    C    D    E    F
   b    H    h    Lh   L    nLayers ;
</GEOMETRIC_PROPERTIES_3PNBBT>
```



COFIT workflow – output results

*_gl.dat

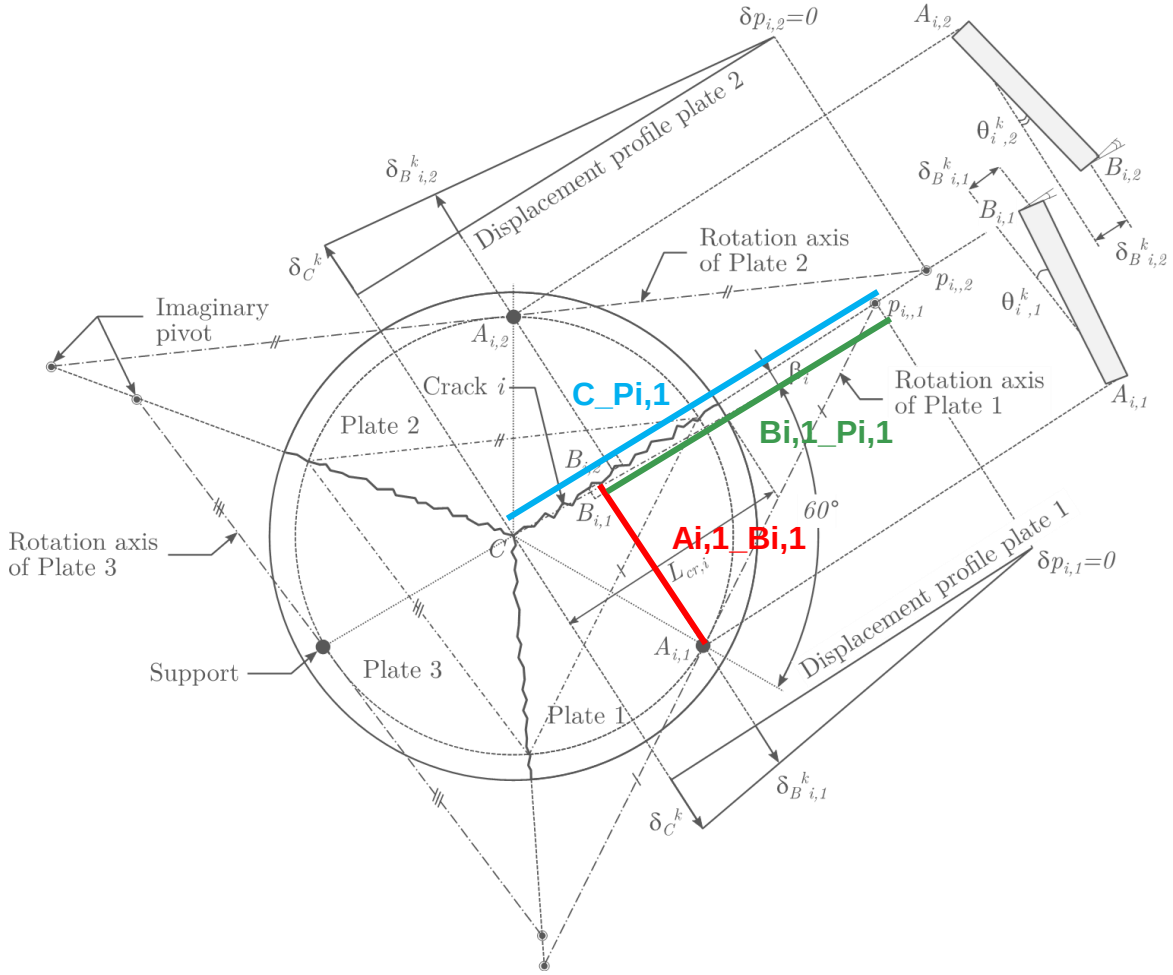
```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<GEOMETRIC_PROPERTIES_RPT>
  ## Geometric properties of cross-section and crack geometry
  ## Content of each column:
  #  A -> Height of the cross-section [mm]
  #  B -> Length of the non-linear hinge [mm]
  #  C -> Number of layers discretizing the cross-section
  #  D -> Number of cracks
  #  E -> Crack geometry parameters:
  #
  #    Input example:
        Lcr,i    Ai,1_Bi,1    Bi,1_Pi,1    C_Pi,1    Ai,2_Bi,2    Bi,2_Pi,2    C_Pi,2
  #
  #    Note: the parameter input must follow the above sequence
  #
  #  A   B   C            D
     H   Lh   nLayers      nCracks

  #  E
     Lcr,i    Ai,1_Bi,1    Bi,1_Pi,1    C_Pi,1    Ai,2_Bi,2    Bi,2_Pi,2    C_Pi,2 ;
</GEOMETRIC_PROPERTIES_RPT>
```

COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
  <MATERIAL_PROPERTIES>
  <GEOMETRIC_PROPERTIES_3PNBBT>
  <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
  <OPTIMISATION_PARAMETERS>
  <EXPERIMENTAL_DATA>
  <PARAMETER_BOUND_LIMITS>
  <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```



COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<OPTIMISATION_PARAMETERS>
    FORCE_DEVIATION_TOLER = Ftoler ;
    PARAMETER_DEVIATION_TOLER = Ptoler ;
    MAXIMUM_NUMBER_OF_ITERATIONS = nIter ;
    NUMBER_OF_PARAMETERS_TO_BE_OPTIMISED = nParams ;
    TYPE_OF_TENSILE_DIAGRAM = _TRILINEAR | _QUADRILINEAR ;
</OPTIMISATION_PARAMETERS>
```

COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<EXPERIMENTAL_DATA>
  ## Type and name of the file containing the experimental data
  ## Content of each column:
  #  A -> Type of recorded displacement presented in the experimental results data file
  #       - Available keywords: _CMOD, _CTOD or _VDISPL (in round panel test, only _VDISPL is available)
  #  B -> Name of the file containing the experimental results (example: FileName_er.dat)
  # A                                        B
    _CMOD | _CTOD | _VDISPL        C:\users\Desktop\jobname
</EXPERIMENTAL_DATA>
```

COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

```
<PARAMETER_BOUND_LIMITS>
  ## Bound limits of each parameter used in the optimisation analysis
  ## Content of each column:
  #  A -> Bound limits for the Young's modulus (range of values or keyword: _NONE) [MPa]
  #  B -> Bound limits for the tensile strength (range of values or keyword: _NONE ) [MPa]
  #  C -> N. of set of values (wi - ai) to be optimized
  #  D -> Bound limits for the values (wi - ai) defining the stress-crack width relationship
  # A                B                    C
     [Emin-Emax]  [fctmin-fctmax]    nSetPts

  # D
     [w1min-w1max]  [a1min-a1max]
     [w2min-w2max]  [a2min-a2max]
     [w3min-w3max]  [a3min-a3max] ;
</PARAMETER_BOUND_LIMITS>
```

COFIT workflow – output results

*_gl.dat

```
<COFIT_DATA_FILE_V1.0>
<MAIN_PARAMETERS>
<MESH>
   <MATERIAL_PROPERTIES>
   <GEOMETRIC_PROPERTIES_3PNBBT>
   <GEOMETRIC_PROPERTIES_RPT>
<OPTIMISATION>
   <OPTIMISATION_PARAMETERS>
   <EXPERIMENTAL_DATA>
   <PARAMETER_BOUND_LIMITS>
   <NUMERICAL_SAMPLING_POINTS>
</COFIT_DATA_FILE_V1.0>
```

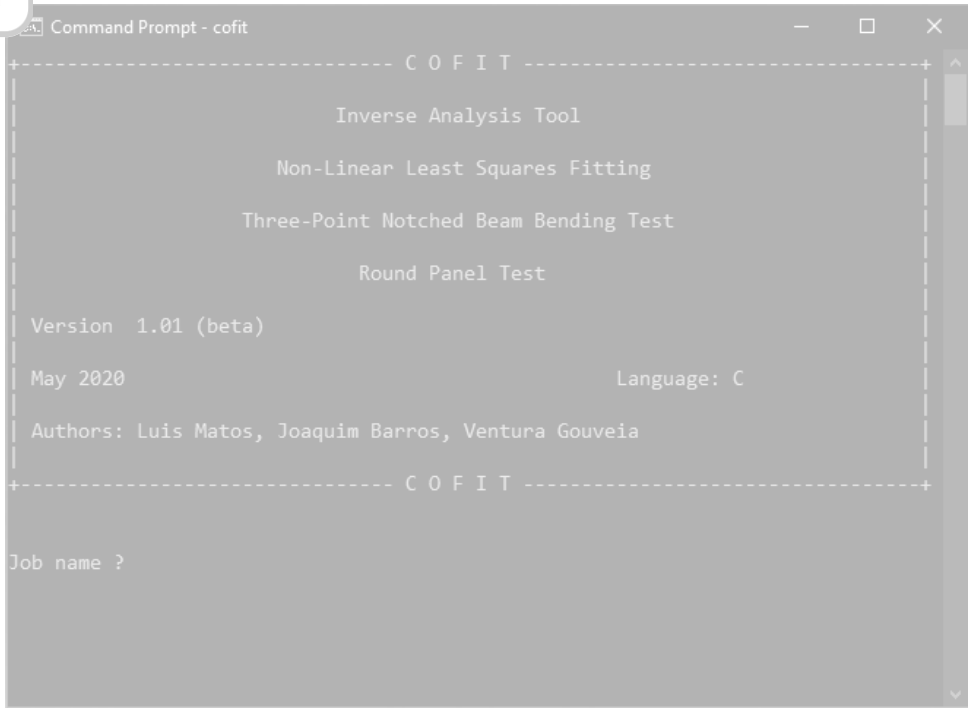
```
<NUMERICAL_SAMPLING_POINTS>
  ## Number of sampling points of the numerical curve
  ## Content of each column:
  #  A -> Type of procedure to obtain the numerical curve displacement values (keyword or constante value)
  #       - Available keywords: _CUSTOM
  #
  #       - Constant value:
  #          If a constant value is provided, the numerical curve will be calculated uniformly based on
  #          the maximum experimental displacement and the indicated number of sampling points
  #
  #       - Keyword:
  #          If the keyword '_CUSTOM' is provided, the user must indicate the number of sampling points
  #          used to calculate the numerical curve in each displacement range as well as the limits of the range.
  #
  #  B -> Number of ranges
  #  C -> Number of sampling points and limits of the displacement ranges (e.g.: 100   [0.01 - 1.0])
  #   A                    B
       _CUSTOM      nRanges
  #   C
      nPts    [0.001-1.0]
      nPts     [1.0-3.0] ;

</NUMERICAL_SAMPLING_POINTS>
```

COFIT workflow – output results

*_er.dat

```
<EXPERIMENTAL_RESULTS_DATA_FILE_V1.0>
<EXPERIMENTAL_RESULTS>
 ## Experimental results data
 COUNT = nExpPts ;

 ## Content of each column:
 #  A -> Counter
 #  B -> Displacement value
 #  C -> Force value
 # A   B       C
   1   0       0.075169452 ;
   2   0.001   5.732005488 ;
   3   0.002   6.1304812 ;
   4   0.003   6.415200534 ;
   5   0.004   5.317278498 ;
   6   0.005   8.819546876 ;
   7   0.006   7.235947932 ;
   8   0.007   7.120988918 ;
   9   0.008   5.518166165 ;
     ...                   ;
</EXPERIMENTAL_RESULTS>

</EXPERIMENTAL_RESULTS_DATA_FILE_V1.0>
```

COFIT .EXE

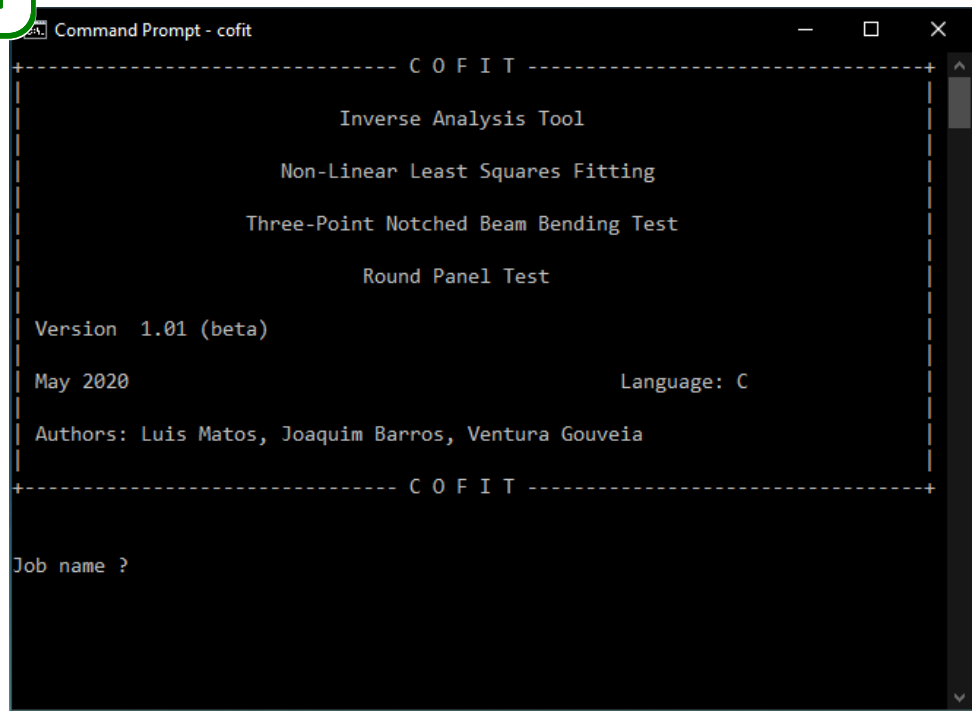


COFIT workflow – output results

*_er.dat

```
<EXPERIMENTAL_RESULTS_DATA_FILE_V1.0>
<EXPERIMENTAL_RESULTS>
 ## Experimental results data
 COUNT = nExpPts ;

 ## Content of each column:
 #  A -> Counter
 #  B -> Displacement value
 #  C -> Force value
 # A   B       C
   1   0       0.075169452 ;
   2   0.001   5.732005488 ;
   3   0.002   6.1304812 ;
   4   0.003   6.415200534 ;
   5   0.004   5.317278498 ;
   6   0.005   8.819546876 ;
   7   0.006   7.235947932 ;
   8   0.007   7.120988918 ;
   9   0.008   5.518166165 ;
       ...                 ;
</EXPERIMENTAL_RESULTS>

</EXPERIMENTAL_RESULTS_DATA_FILE_V1.0>
```

COFIT .EXE

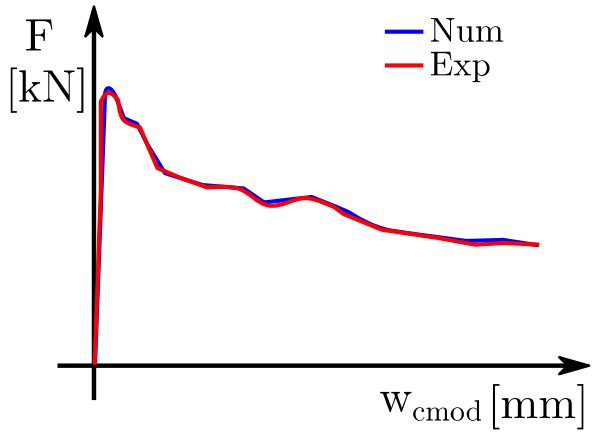


COFIT workflow – output results

*_rs.csv

```
"+------------------------- C O F I T -------------------------+"
"|                                                             |"
"|                      Inverse Analysis Tool                  |"
"|                                                             |"
"|                   Non-Linear Least Squares Fitting          |"
"|                                                             |"
"|                Three-Point Notched Beam Bending Test        |"
"|                                                             |"
"| Version    1.01 (beta)                                      |"
"| May 2020                                Language: C         |"
"|                                                             |"
"| Authors: Luís Matos, Joaquim Barros, Ventura Gouveia        |"
"|                                                             |"
"+------------------------- C O F I T -------------------------+"

"Date: Sun Apr 11 20:45:30 2021"

"Job Name: prism"

"Title: fib_prism_ia"

COFIT v1.01 results
Time elapsed: 63.80 s

"Content of each column:"
"  A  -> Counter"
"  B  -> Displacement type: _CMOD [mm] "
"  C  -> Numerical Force     [kN] "
"  D  -> Experimental Force [kN] "
"  E  -> Numerical Force obtained with the Trilinear/Quadrilinear relationship [kN] "
"  F  -> Crack width of the optimised Stress-Wcr relationship [mm]"
"  G  -> Stress of the optimised Stress-Wcr relationship [MPa] "
"  H  -> Crack width of the trilinear/quadrilinear diagram [mm]"
"  I  -> Stress of the trilinear/quadrilinear diagram [MPa] "
```

- Numerical/experimental fitting result

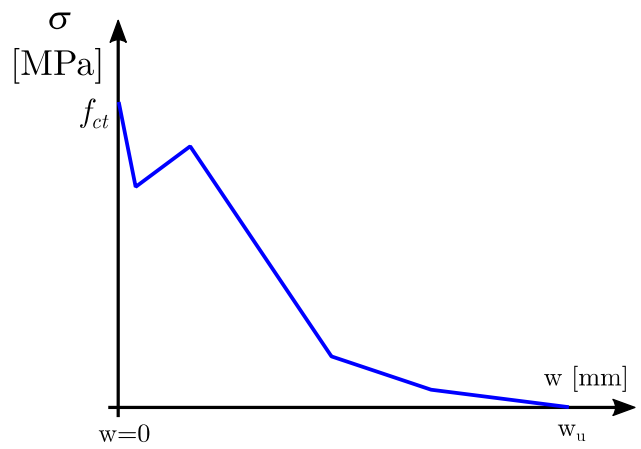


COFIT workflow – output results

*_rs.csv

```
"+------------------------- C O F I T -------------------------+"
"|                                                             |"
"|                      Inverse Analysis Tool                  |"
"|                                                             |"
"|                   Non-Linear Least Squares Fitting          |"
"|                                                             |"
"|                 Three-Point Notched Beam Bending Test       |"
"|                                                             |"
"| Version    1.01 (beta)                                      |"
"| May 2020                                Language: C         |"
"|                                                             |"
"| Authors: Luís Matos, Joaquim Barros, Ventura Gouveia        |"
"|                                                             |"
"+------------------------- C O F I T -------------------------+"

"Date: Sun Apr 11 20:45:30 2021"

"Job Name: prism"

"Title: fib_prism_ia"

COFIT v1.01 results
Time elapsed: 63.80 s

"Content of each column:"
"  A  -> Counter"
"  B  -> Displacement type: _CMOD [mm] "
"  C  -> Numerical Force     [kN] "
"  D  -> Experimental Force [kN] "
"  E  -> Numerical Force obtained with the Trilinear/Quadrilinear relationship [kN] "
"  F  -> Crack width of the optimised Stress-Wcr relationship [mm]"
"  G  -> Stress of the optimised Stress-Wcr relationship [MPa] "
"  H  -> Crack width of the trilinear/quadrilinear diagram [mm]"
"  I  -> Stress of the trilinear/quadrilinear diagram [MPa] "
```

- Optimised σ-w relationship



COFIT workflow – output results

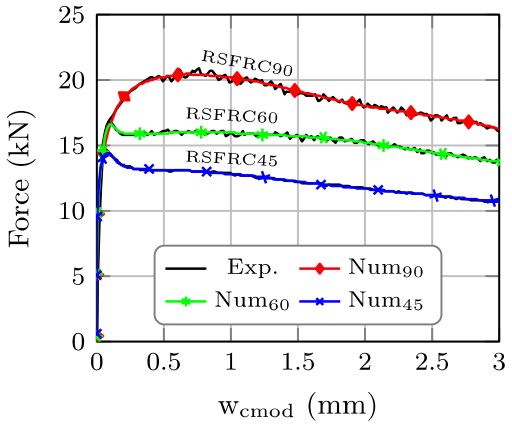
*_rs.lpt

```
+---------------------- C O F I T ----------------------+
|                                                       |
|                    Inverse Analysis Tool              |
|                                                       |
|                 Non-Linear Least Squares Fitting      |
|                                                       |
|               Three-Point Notched Beam Bending Test   |
|                                                       |
| Version      1.01 (beta)                              |
| May 2020                                Language: C   |
|                                                       |
| Authors: Luís Matos, Joaquim Barros, Ventura Gouveia  |
|                                                       |
+---------------------- C O F I T ----------------------+'

Date: Sun Apr 11 20:45:30 2021

Job Name: prism

Title: fib_prism_ia

>>> Optimised parameters that best fit the experimental data
-------------------------------------------------

Optimised parameters

## Content of each column:
#  A -> Young's modulus [MPa]
#  B -> Tensile strength [MPa]
#  C -> Wi value
#  D -> ai value
#    A                B
   40000.000        2.500
#    C                D
     0.0925           0.5706
     0.5506           0.6676
     1.5000           0.3719
     2.0757           0.2146
     2.5039           0.2472

-------------------------------------------------
>>> End of optimised parameters that best fit the experimental data
```

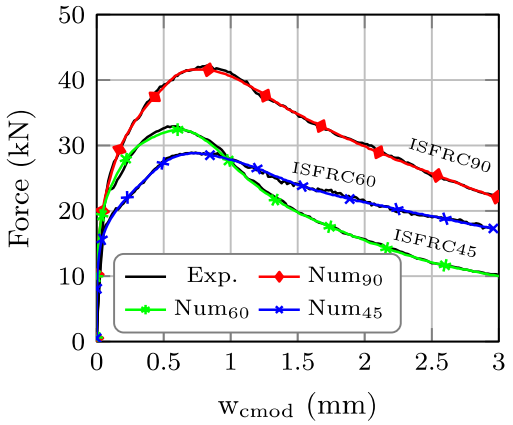
```
>>> Optimised stress-crack width diagram
-------------------------------------------------

Stress-crack width relationship obtained with the optimised parameters

## Content of each column:
#  A -> Crack width [mm]
#  B -> Stress [MPa]
#  C -> Fracture energy [N/mm]
#    A                B
       0.000            2.500
       0.093            1.426
       0.551            1.669
       1.500            0.930
       2.076            0.537
       2.504            0.618
       8.250            0.000
#    C
    4.569

-------------------------------------------------
>>> End of optimised stress-crack width diagram


>>> _QUADRILINEAR diagram that best fits the optimised stress-crack width relationship
-------------------------------------------------

Tensile-softening diagram

## Contents of each column
#  A -> Crack width [mm]
#  B -> Stress [MPa]
#  C -> Fracture energy [N/mm]
#    A                B
       0.000            2.500
       0.272            1.617
       0.939            1.380
       2.486            0.294
       8.250            0.000
#    C
    3.702

-------------------------------------------------
>>> End of _QUADRILINEAR diagram that best fits the optimised stress-crack width relationship

Time elapsed: 63.80 s
```

Performance assessment

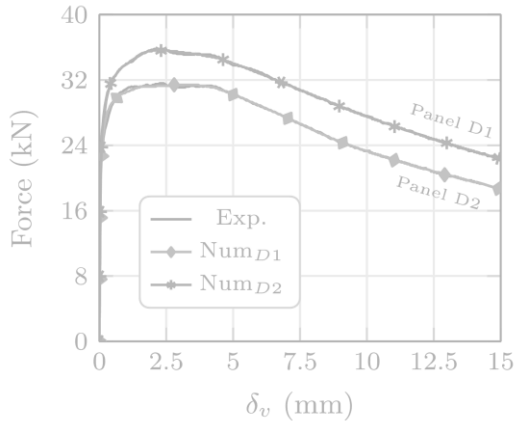
116.42 s 76.35 s 112.60 s



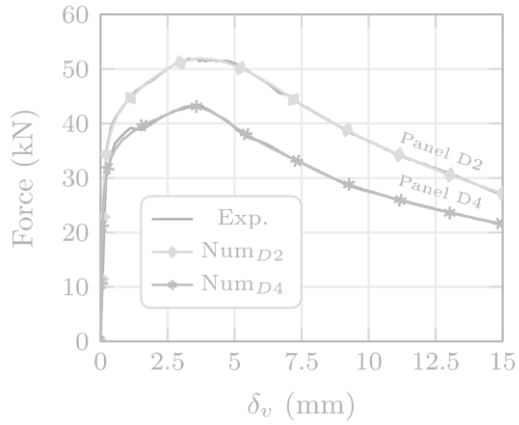
76.74 s 73.94 s 63.92 s

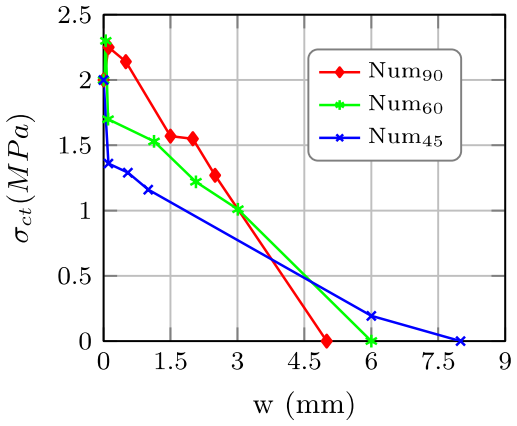


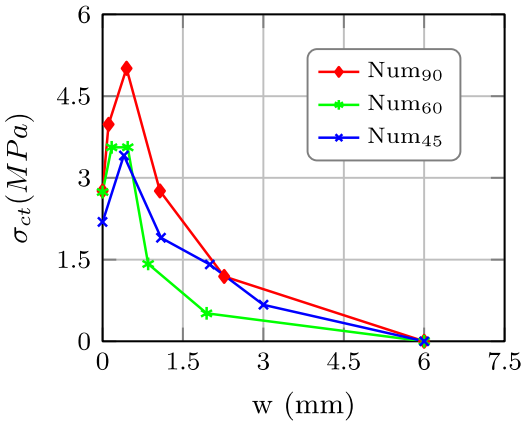
186.17 s 379.22 s

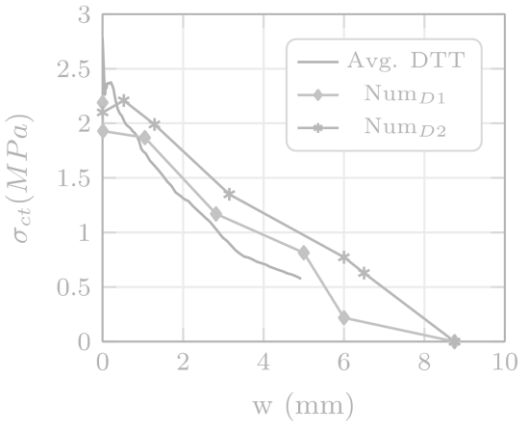


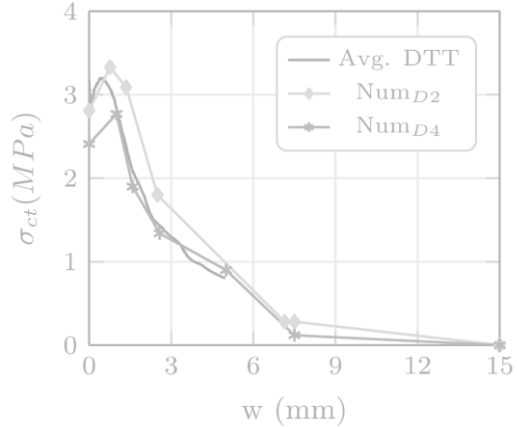
232.19 s 379.61 s



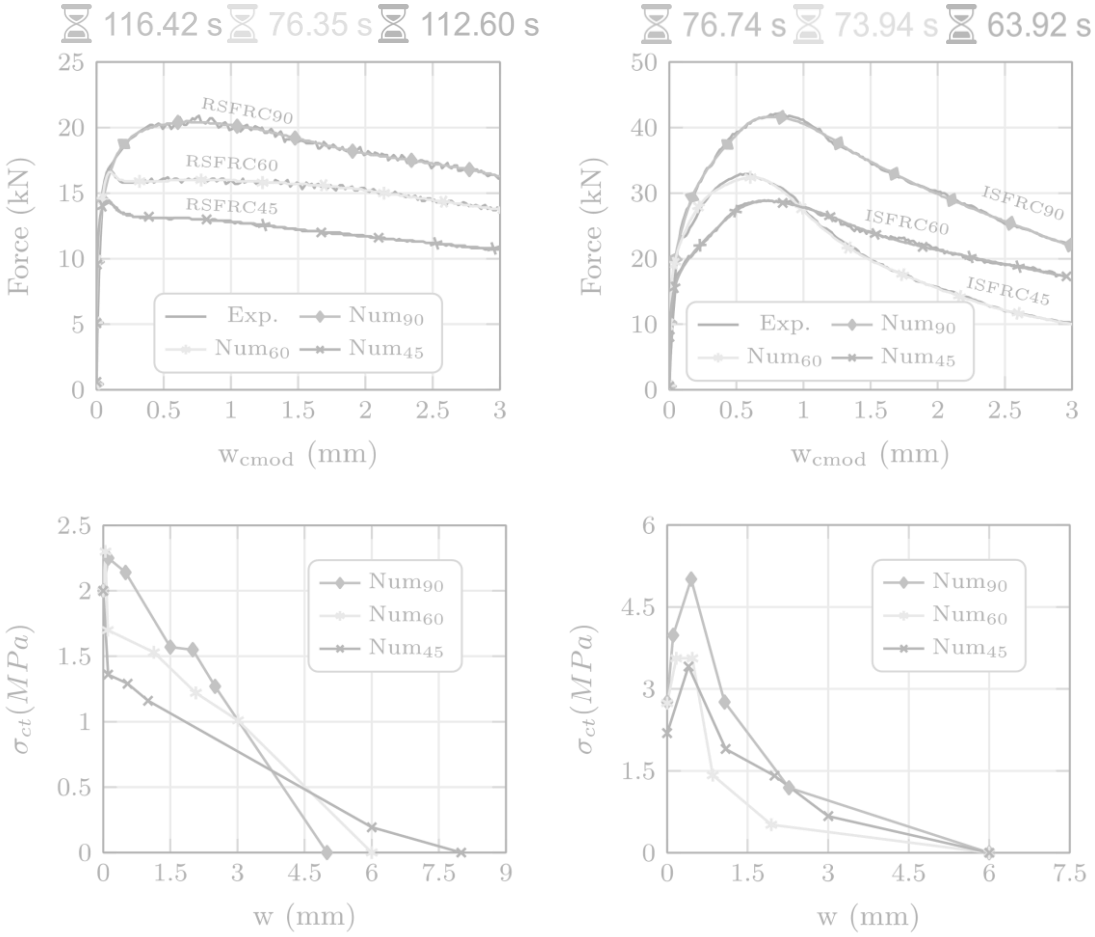




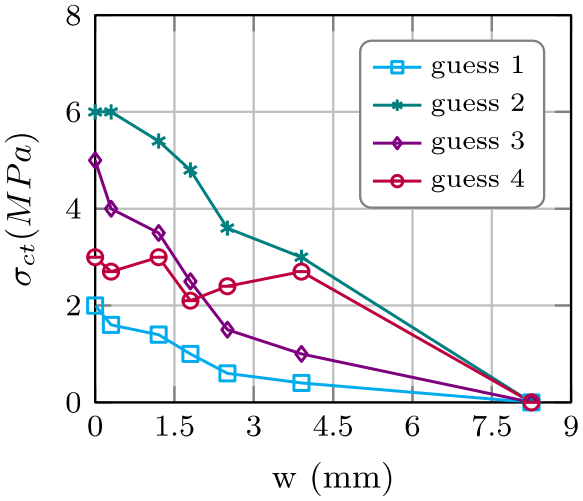


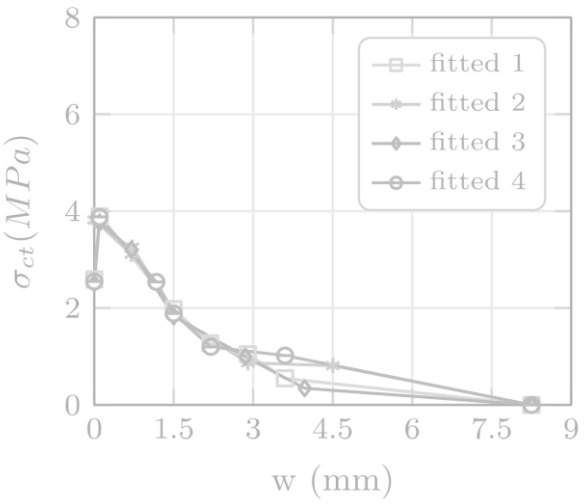


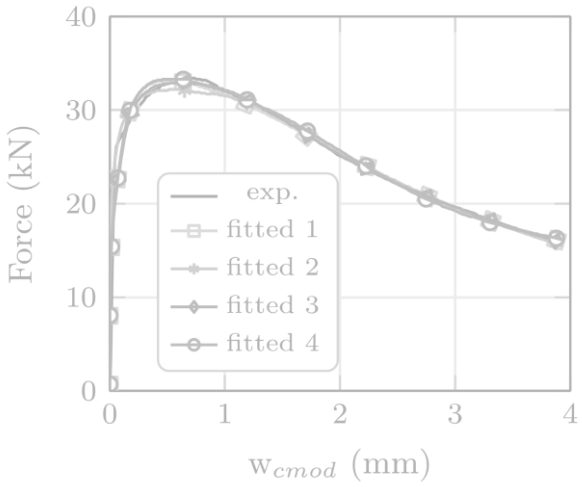
Performance assessment



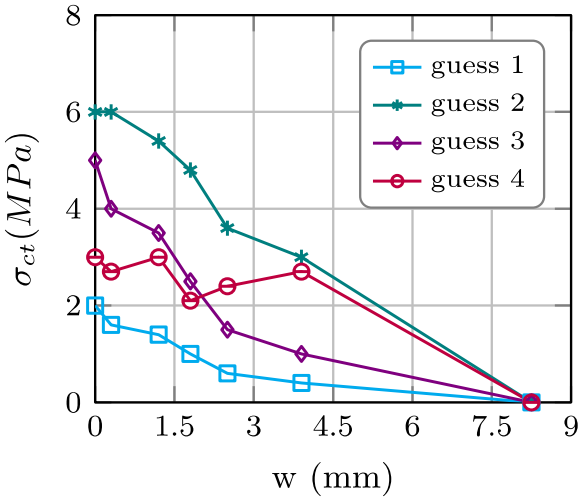
Impact of the initial guess

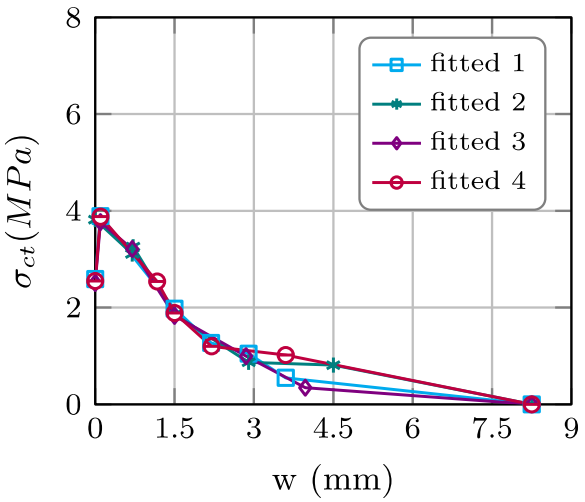


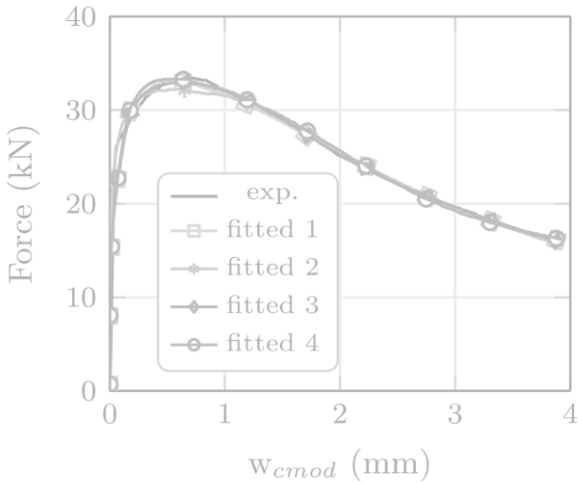




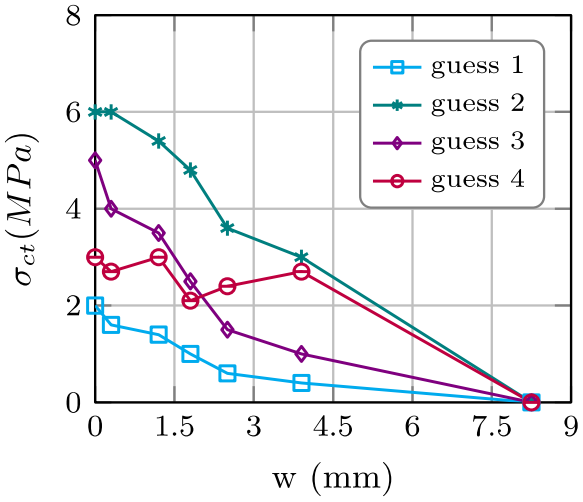
Impact of the initial guess

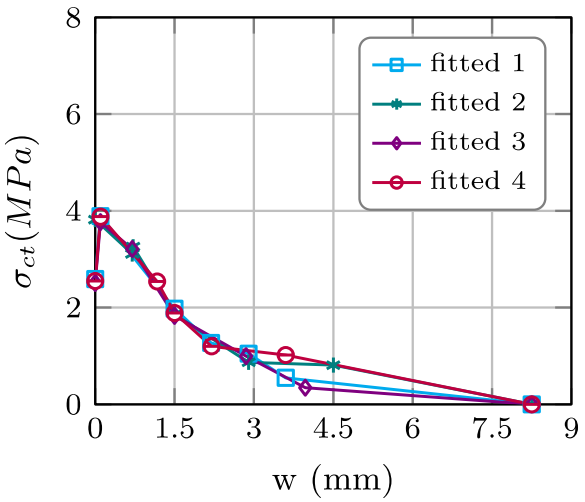


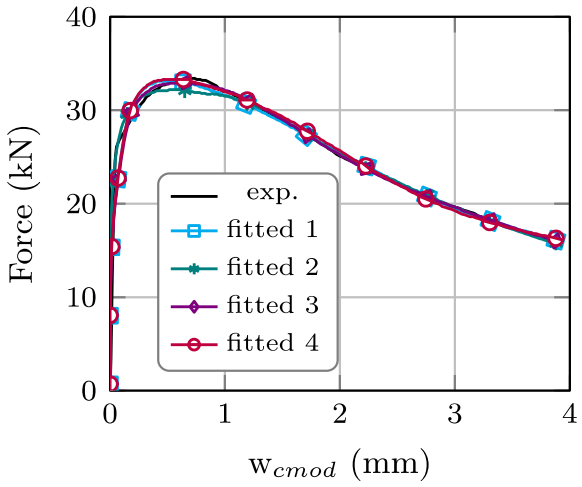




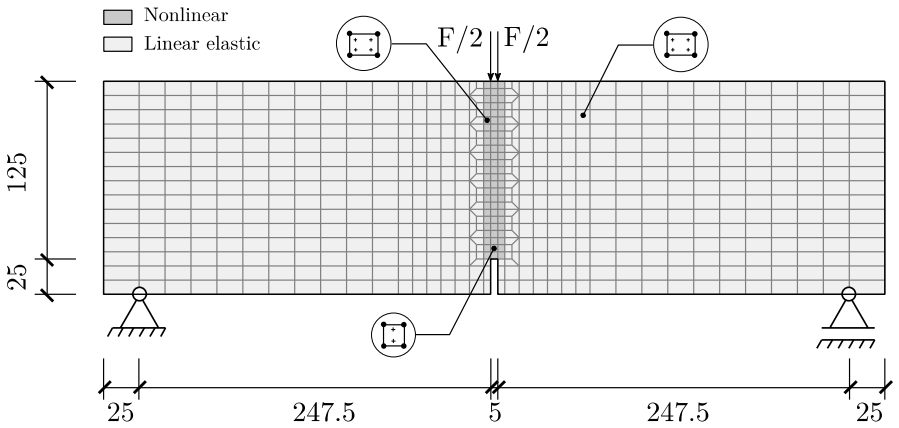
Impact of the initial guess

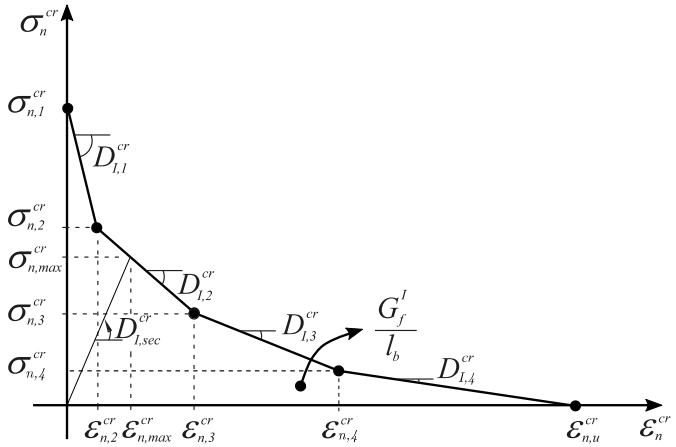


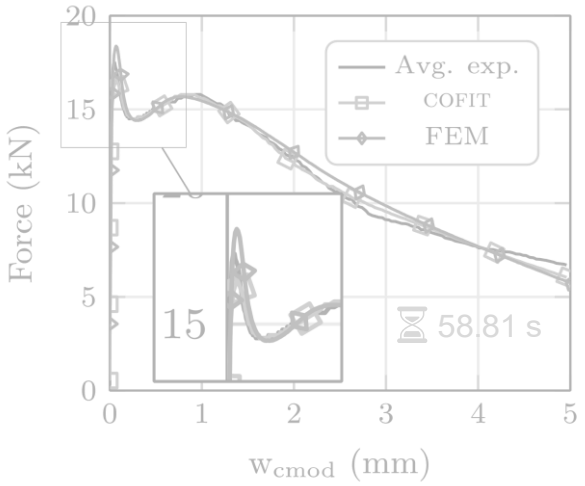


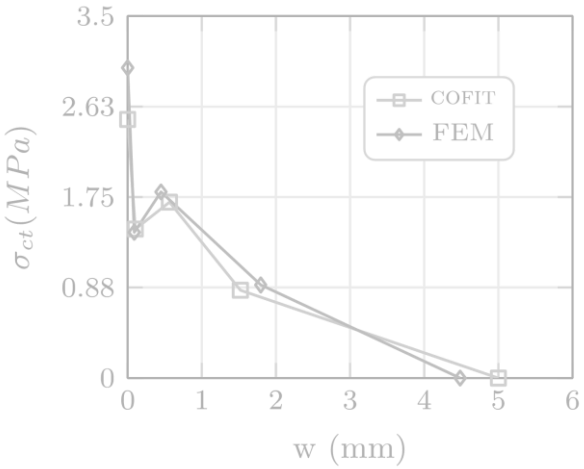


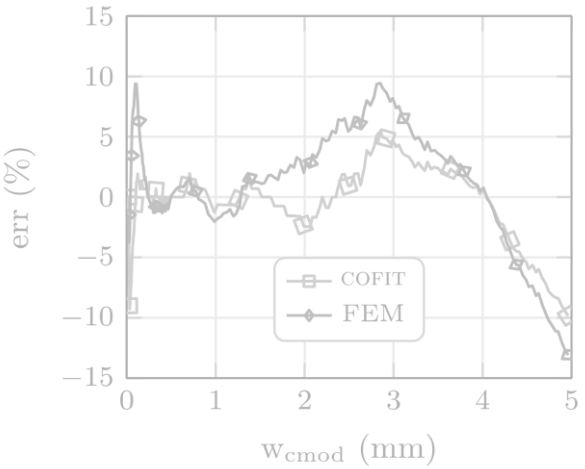
FEM vs COFIT



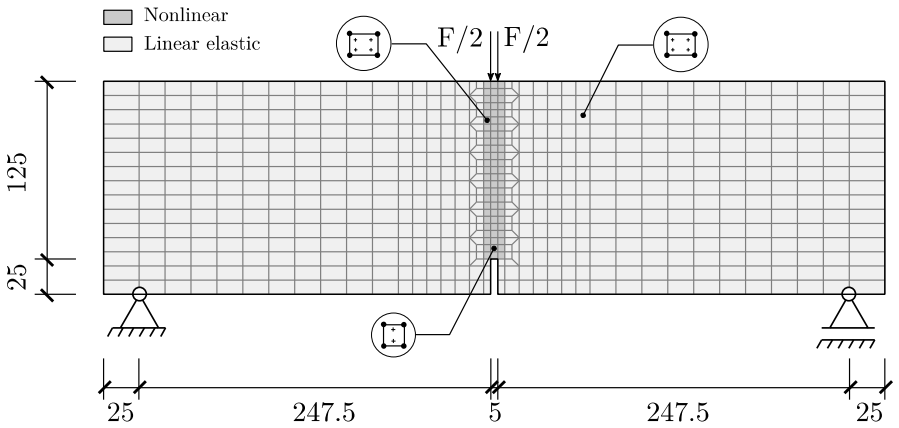


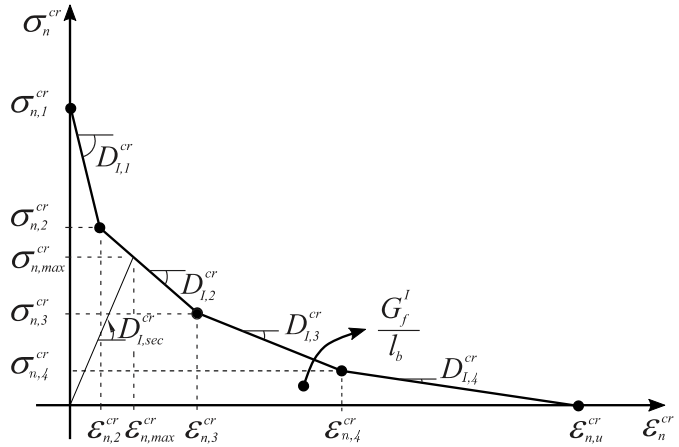


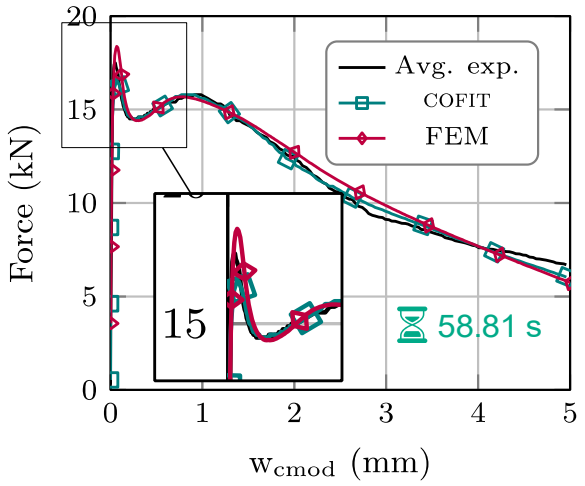


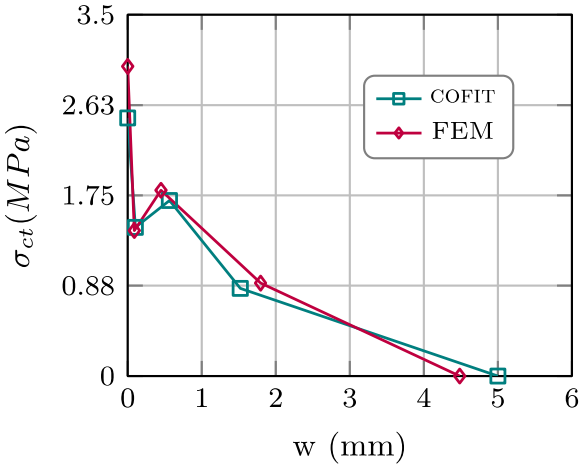


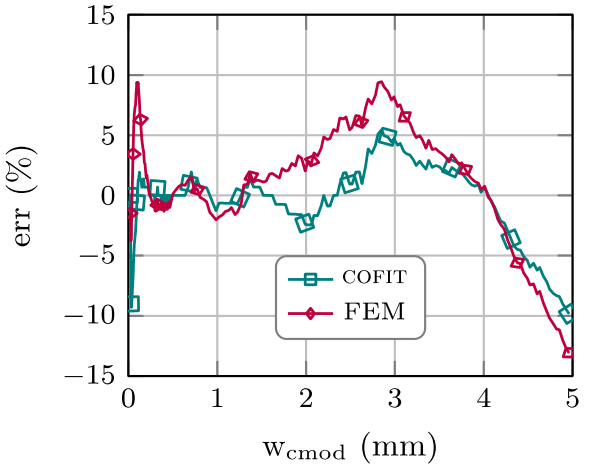
FEM vs COFIT





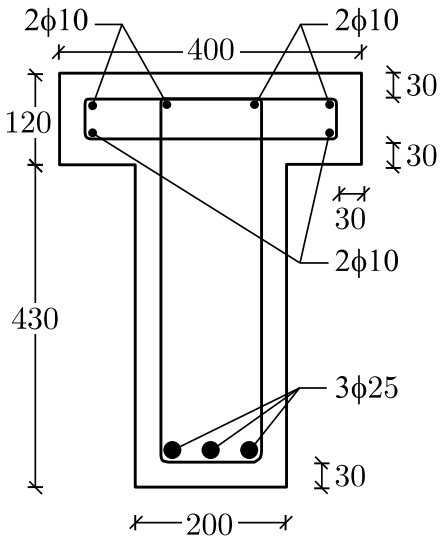


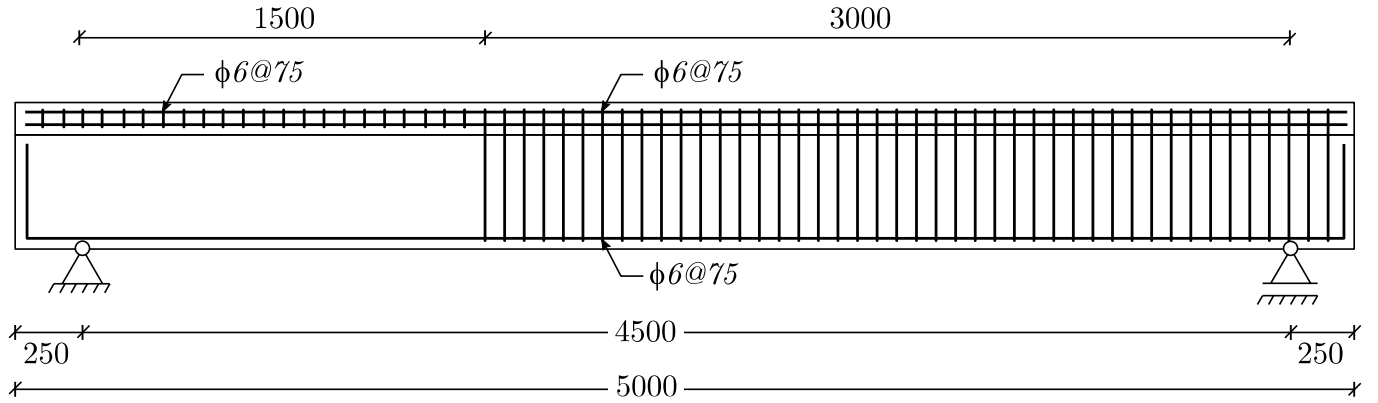


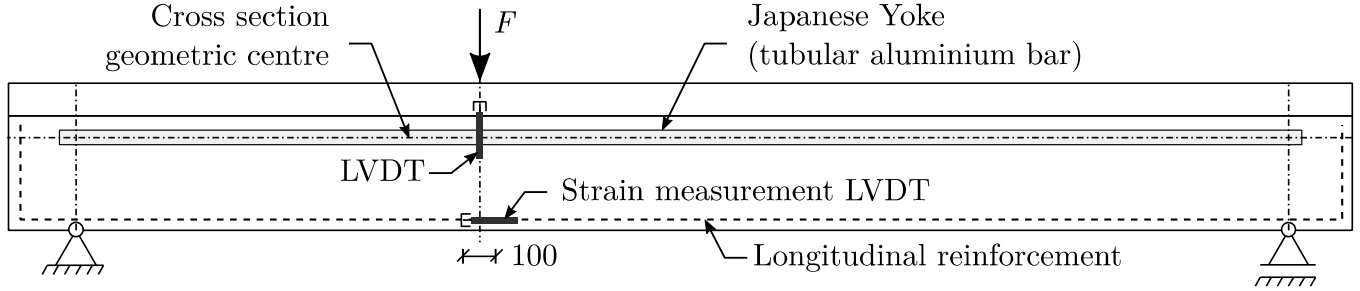


3. Practical case demonstration

Case description



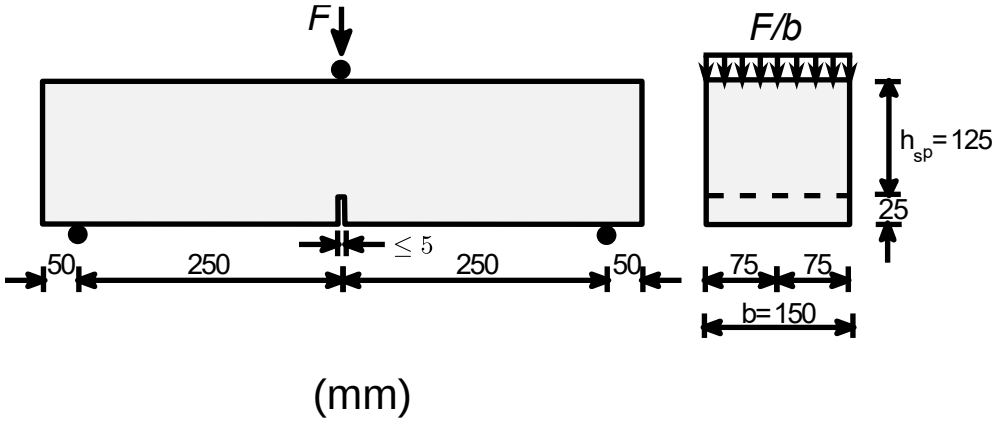




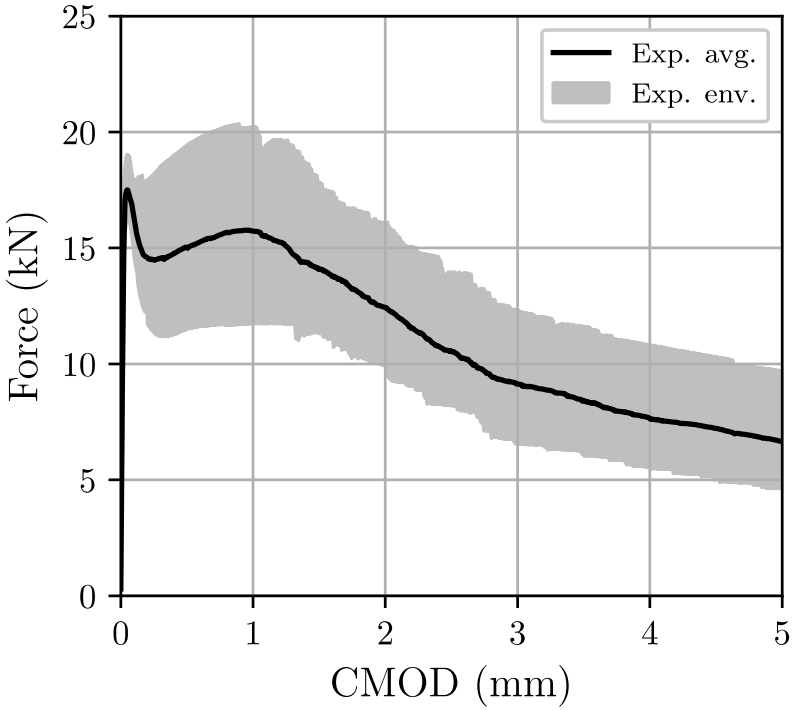
Barros, J.A.O. *et al.*, "Blind competition on the numerical simulation of steel fibre reinforced concrete beams failing in shear", *fib* Structural Concrete Journal, 2021. http://dx.doi.org/10.1002/suco.202000345

COFIT application

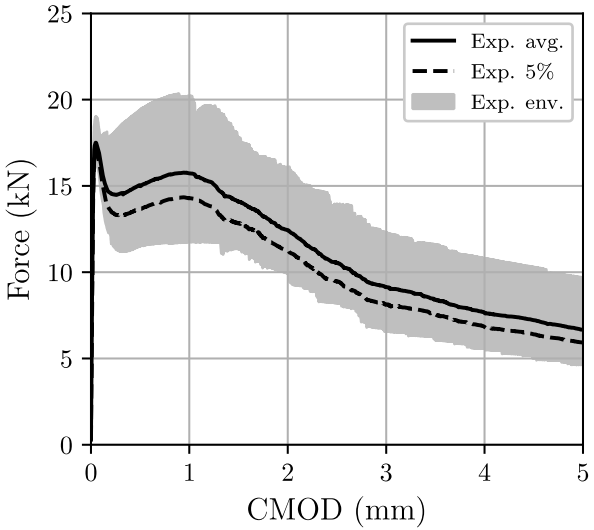
- 3PNBBT experimental results
- 10 specimens

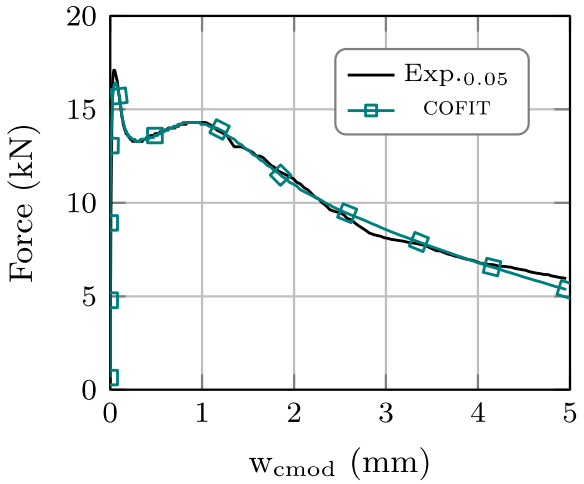


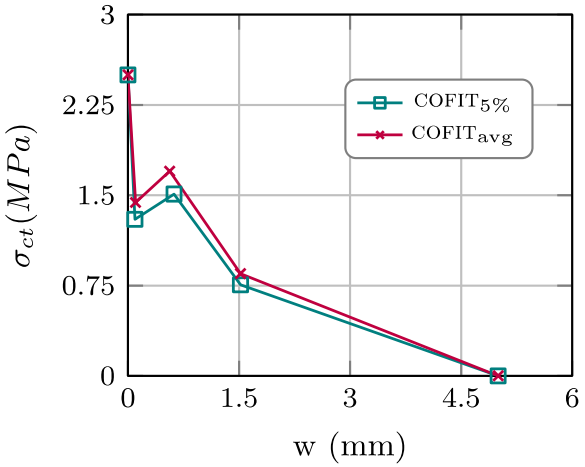
(mm)



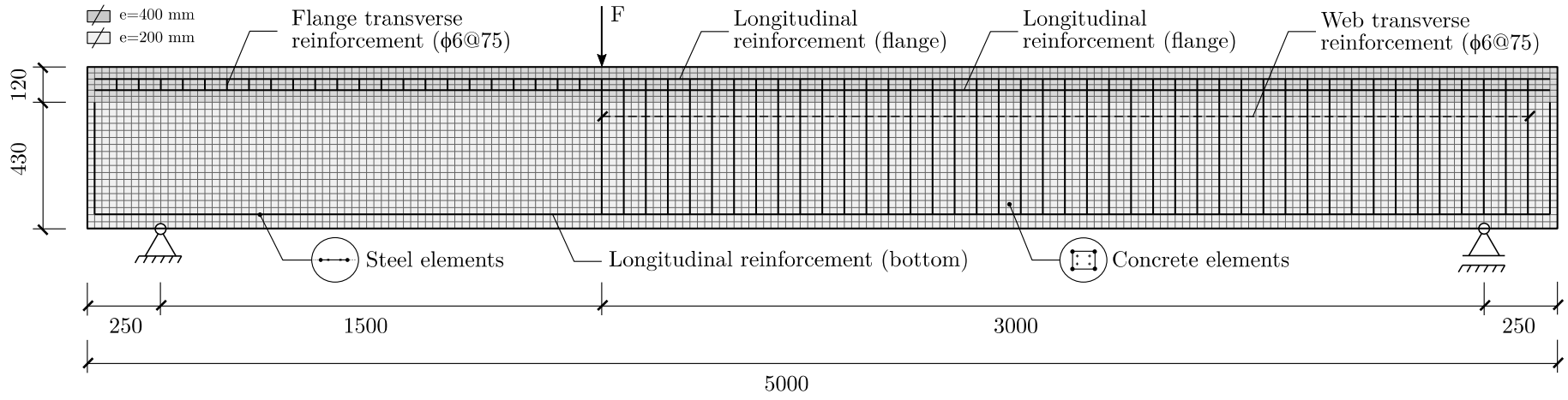
COFIT application - results

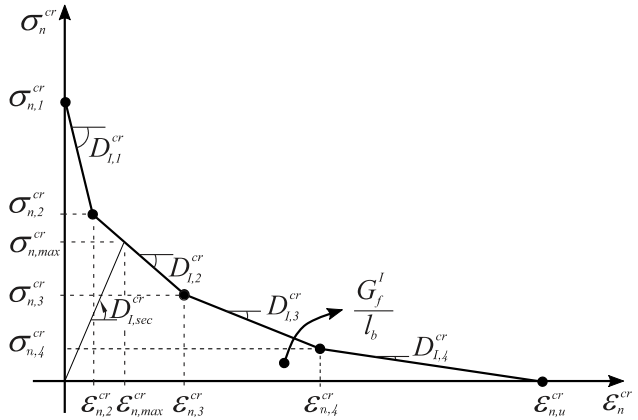


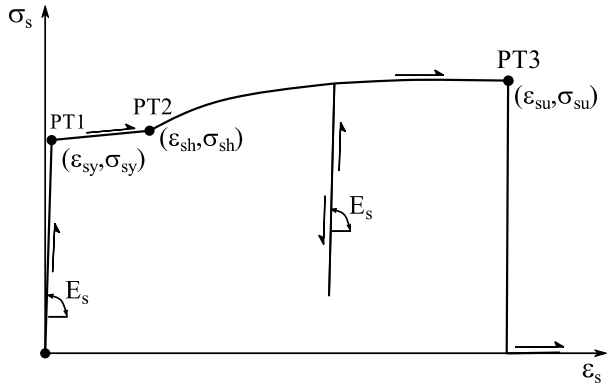


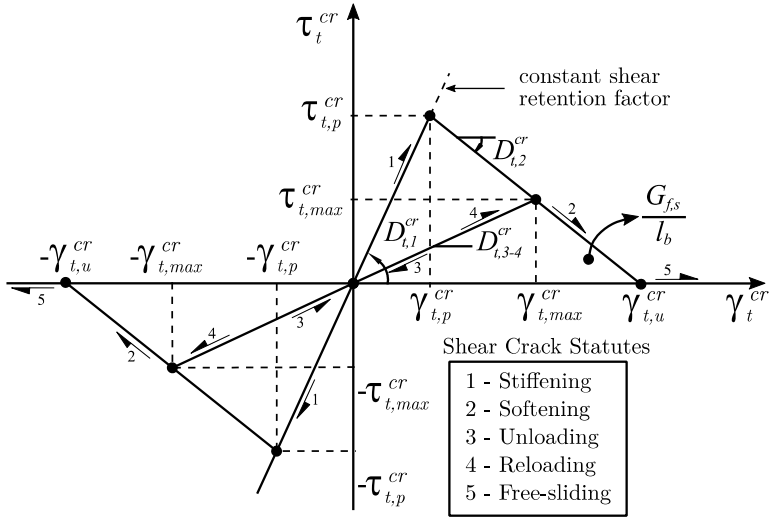


FE model









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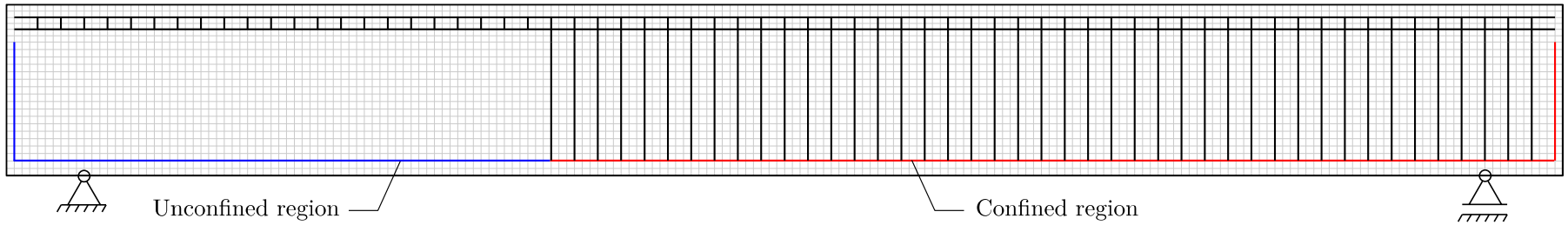
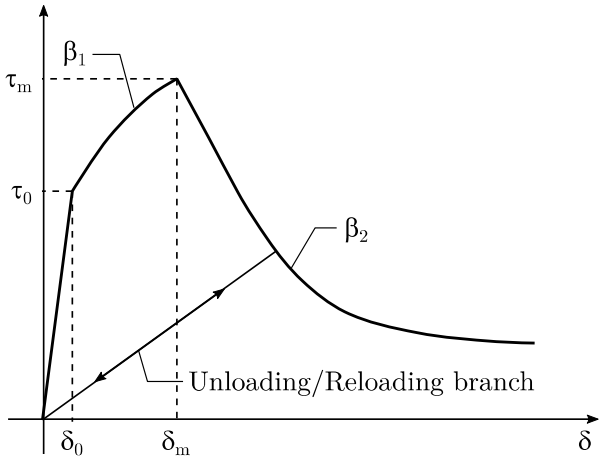
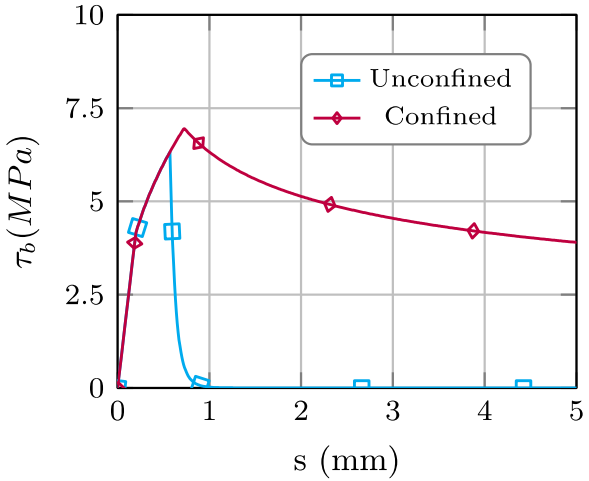
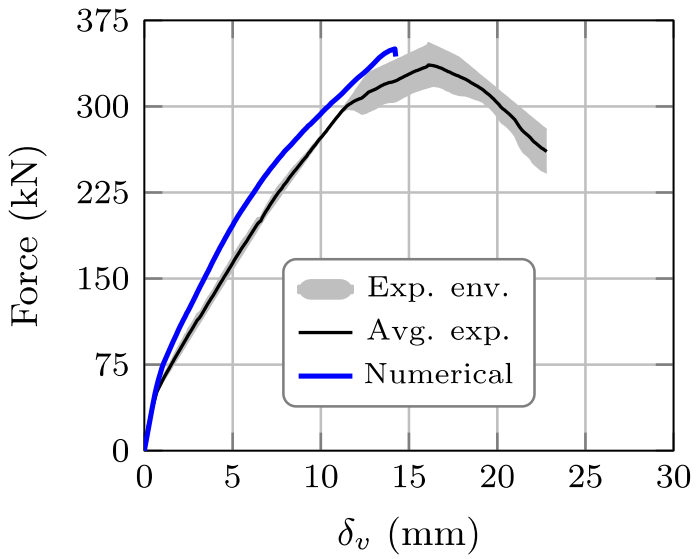
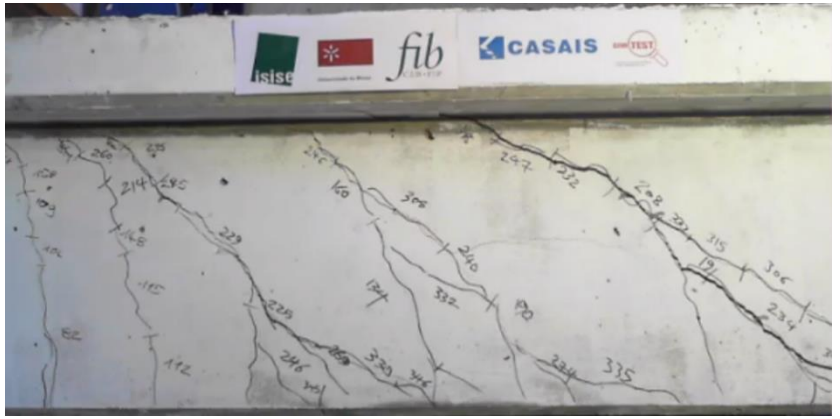


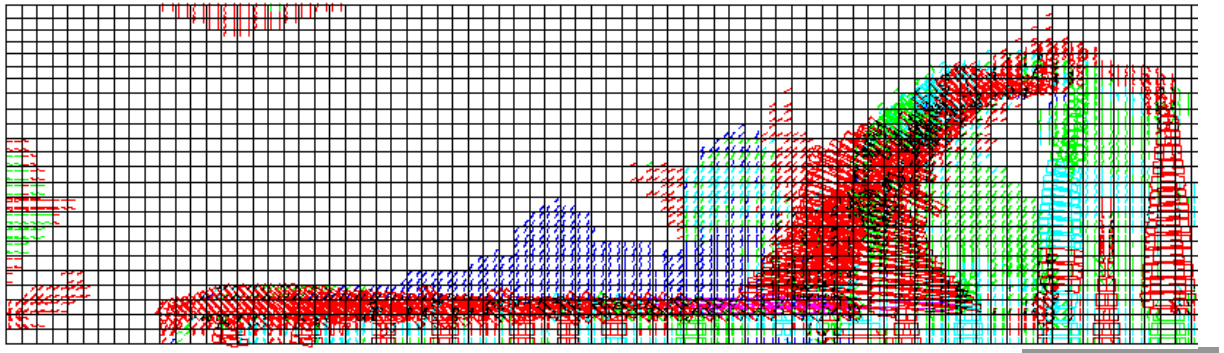




Results







4. Conclusions

4. Conclusions

- **COFIT** is a **practical**, **efficient** and **robust** inverse analysis tool
- Results from **3PNBBT** and **RPT-3PS** can be used
- COFIT shows a **very good performance**, and the values obtained for the multi-linear softening diagrams were consistent with the material characteristics;
- Runtimes:
  - **3PNBBT** – **1** to **2** minutes;
  - **RPT-3PS** – **4** to **6** minutes;
- Results are **not affected** by the **initial values provided by the user**, demonstrating the robustness of the automatic variable updating procedure;
- **COFIT** proved to be **more accurate and faster** than **FEM**-based approaches.

Acknowledgements

- FCT support through the grant PD/BD/135174/2017
- FCT support through the project POCI-01-0145-FEDER-027990 (PTDC/ECI-CON/27990/2017)


Thank you for your attention!