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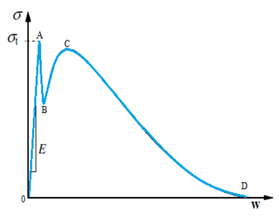
A Minimization Procedure for the Determination of SFRC Tensile Behaviour

1. Problem Definition

Objective

Characterize the tensile behaviour of Steel Fibre Reinforced Concrete (SFRC)



Main Purpose

Include SFRC tensile behaviour into analyses where the behaviour and the load capacity of structures are evaluated (e.g. punching of flat slabs).

Steel Fibre Reinforced Concrete (SFRC)

"Plain concrete with addition of discrete steel fibres"

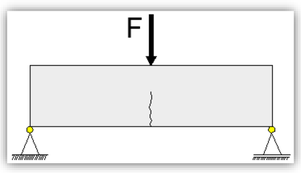
Main advantage of SFRC

Crack Control

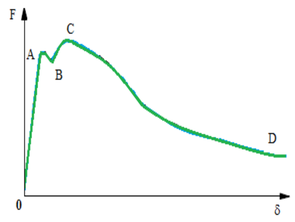
2. Adopted Methodology

Inverse Analysis based in **Bending Tests** on notched beams and round panels.

Bending Tests

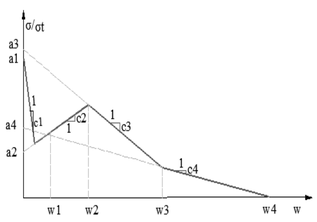


Experimental Load-Displacement Curve

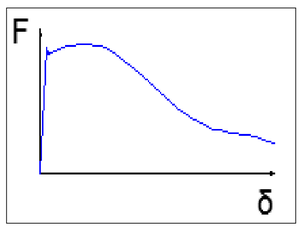


Easy to perform experimentally

Assume σ-w Relationship Parameters



Theoretical Load-Displacement Curve



Apply inverse analysis to compute σ-w parameters that **minimize the error, ε , between the Load-Displacement curves**

3. *Mathematical Problem Definition*:

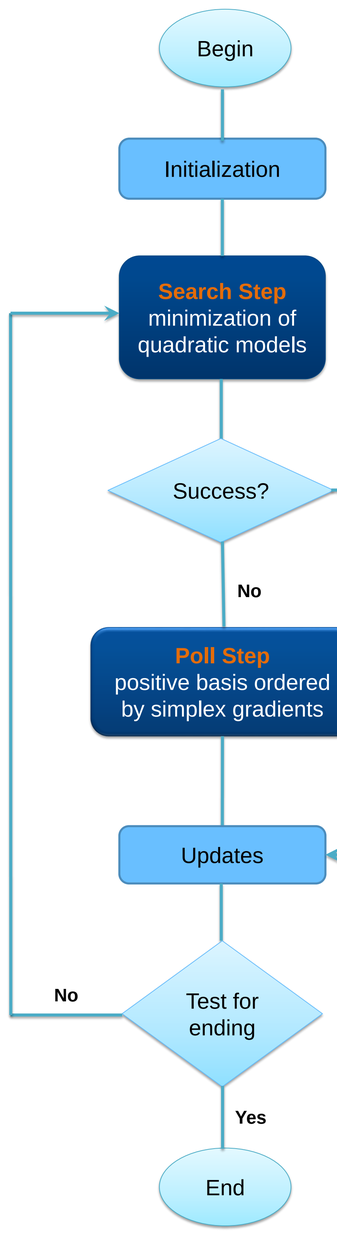
$$min\ \varepsilon\ (\sigma_t, w_1, w_2, w_3, c_1, c_2, c_3) = \int_0^{\delta_{max}} \left[P_{exp}(\delta) - P_{theo}(\delta)\right]^2 d\delta$$

s.t.

- $\sigma_{min} \leq \sigma_t \leq \sigma_{max}$
- $w_{min}^i \leq w_i \leq w_{max}^i \quad , \quad i = 1,2,3$
- $w_i \leq w_{i+1} \quad , \quad i = 1,2$
- $w_3 \leq w_{max} \quad , \quad w_{max} \in \mathbb{R}$

Derivatives are not available for use

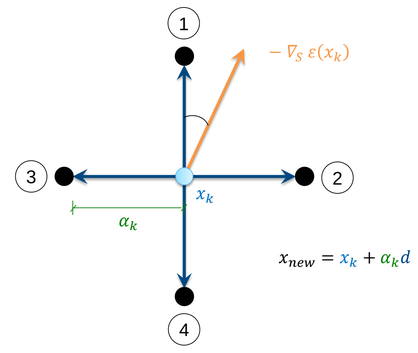
4. Optimization Procedure



Generalized Pattern Search method enhanced with quadratic interpolation or minimum Frobenius norm models and the use of simplex gradients (**code SID-PSM**).

$$\min m_k\ (x) = f(x_k) + g_k^T(x - x_k) + (x - x_k)^T H_k (x - x_k)$$

- minimum Frobenius norm models
- quadratic interpolation
- regression models



$$x_{new} = x_k + \alpha_k d$$

$$\alpha_k < 10^{-12} \ or \ maximum\ iterations = 20 \times 10^3$$

References

Custódio, A.L. and Vicente, L.N.: Using sampling and simplex derivatives in pattern search methods, *SIAM Journal on Optimization*, Vol. 18, pp. 537 – 555, 2007

Custódio, A.L., Rocha, H. and Vicente, L.N.: Incorporating minimum Frobenius norm models in direct search, *Computational Optimization and Applications*, Vol. 46, pp. 265 – 278, 2010

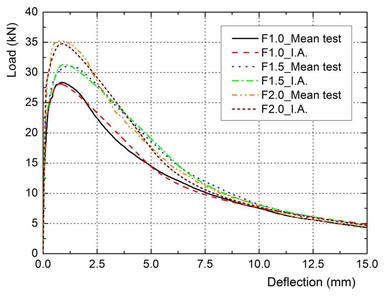
Gouveia, N., Faria, D. and Ramos, A.M.P.: Punçoamento em lajes de betão com fibras de aço, *Revista Internacional TECH ITT by Construlink*, Vol. 11, 2013, ISSN 1645-5576 (in Portuguese)

Gouveia, N., Fernandes, N., Faria, D., Ramos, A. and Lúcio, V.: SFRC flat slabs punching behaviour – experimental research, *Composites: Part B*, Vol. 63, pp. 161-171, 2014. DOI:10.1016/j.compositesb.2014.04.005

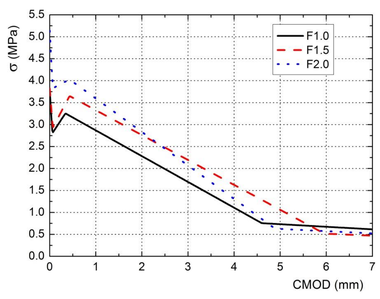
5. Results

Notched Beams

F-δ



σ-w

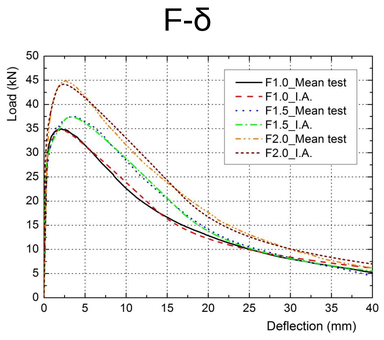


Minimum error values

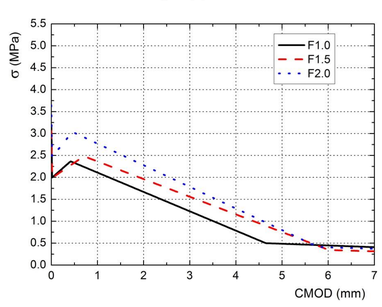
	F1.0	F1.5	F2.0
ε (%)	3.8	2.3	4.0

Round Panels

F-δ



σ-w



Minimum error values

	F1.0	F1.5	F2.0
ε (%)	3.6	1.8	3.5

Numerical behaviour adequately approaches the experimental results

The tensile behavior of SFRC can be obtained with a inverse analysis methodology and a optimization process

The SFRC tensile behaviour can be include in other analyses (e.g. punching of flat slabs)

Notes:
- Mean test corresponds to the experimental results
- I.A. corresponds to the inverse analysis results
- The number after F corresponds to the fibre volume contents.

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