

# MODELLING OF FIBER-REINFORCED CONCRETE AND APPLICATION CASE

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**Abstract.** *This report summarizes the first results of 2D and 3D finite element method numerical modelling analysis of fiber-reinforced concrete behaviour and a tunnel case study application. A porosity strength-dependant material model was assumed and preliminary calibrated to fit the mechanical performance of fiber-reinforced concrete stress and crack opening displacement measured results.*

## 1 INTRODUCTION

This extended abstract summarizes the methodology and first results of the 2D and 3D finite element (FE) modelling analysis of fiber-reinforced concrete behaviour. Fiber-reinforced concrete (both metallic and/or polymeric) is a worldwide extended construction technique for many precast concrete applications. For example, a proper fiber dosage may be capable to bear and avoid the concrete shrinkage cracks in particular cases, without needing additional steel-rebar installation. A preliminary case study is presented and methodology proposed to analyse the fiber-reinforced shotcrete application in tunnelling. A first attempt tunnel 3D modelling is presented as a case study in this report.

A porosity strength-dependant material model has been used to perform fiber-reinforced concrete behaviour and damage propagation<sup>[1]</sup>. To calibrate the numerical model, measurements following the EN-14651 test<sup>[2]</sup> were obtained with four different polyethylene fiber dosages. This European Standard specifies a method of measuring the flexural tensile strength of fibered concrete specimen and allows the determination of the limit of proportionality (LoP; which relates to the vertical load applied) and the crack mouth opening displacement (CMOD; which relates to the open gap evolution of the prescribed notch).

## 2 NUMERICAL MODEL

Figure 1a presents a test sample following the EN 14651, and Figure 1b presents the 2D plane strain FE model mesh generated (897 quadrilateral elements generating 961 nodes). As stated, a constitutive model which relates the porosity evolution to the tensile strength was considered to fit the fiber-reinforced concrete behaviour<sup>[1]</sup>. This material model allows the performance of tensile strength loss after a certain value of material porosity is reached. Elastic-plastic behaviour with Drucker-Prager failure criterion was assumed, implemented with the porosity strength-dependant model in the EN-14651 case studies.

Table 1 presents the concrete material properties assumed to perform the EN-14651 tests. Main material properties of the further tunnelling case study are also given.

**Table 1:** Material properties: EN-14651 test and tunnel case study (main materials):

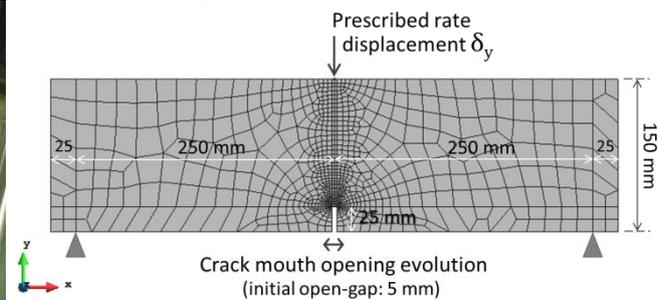
Parameters:	Main materials:					Units:
	Concrete (EN-14651)	Soil (Tunnel)	Shotcrete layers (Tunnel)	Truss beams (Tunnel)	Invert (Tunnel)	
Unit weight, $\gamma$	23.5	20.5	23.5	27.5	23.5	kN/m <sup>3</sup>
Initial porosity, $\phi_0$	0.145 <sup>(a)</sup>	0.250	0.145 <sup>(a)</sup>	0.001	0.145	-
Elastic modulus, E	30000	1000	25000 & 35000 <sup>(b)</sup>	210000	35000	MPa
Poisson's ratio, $\nu$	0.15	0.30	0.15	0.30	0.15	-
Friction angle, $\phi$	30 & 38 <sup>(c)</sup>	-	30	-	-	deg.
Dilatancy angle, $\psi$	30 & 38 <sup>(c)</sup>	-	30	-	-	deg.
Cohesion, c	200	-	200	-	-	kPa
Reference porosity, $\phi_{00}$ <sup>(d)</sup>	0.150	-	0.150	-	-	-
Porosity function, n <sup>(e)</sup>	50	-	50	-	-	-

Notes: <sup>(a)</sup> Assuming a solid particles density of  $\gamma_s=27.5$  kN/m<sup>3</sup>, a concrete unit weight of  $\gamma_c=23.5$  kN/m<sup>3</sup> returns an initial porosity of  $\phi=0.145$  ( $\phi=(\gamma_s-\gamma_c)/\gamma_s$ ). <sup>(b)</sup> Different shotcrete layers were assumed: the first one to be installed just after the soil excavation and in contact with the soil, and the second one (stiffer) after installing the truss, in contact with the first concrete layer. <sup>(c)</sup> Two different cases are shown in this study in order to perform sensitivity analysis due to strength changes. <sup>(d)</sup> The reference porosity relates to the porosity value from where the tensile strength (cohesion) is zero. <sup>(e)</sup> The porosity function refers to the shape of the decreasing strength from the initial porosity to the reference porosity, i.e., n=1 (straight linearly decreasing); n=10 (smooth curve shape); n=100 (sharp curve decreasing). (For a deep explanation about the model see Reference <sup>[1]</sup>)

a) EN-14651 test performance:



b) 2D FE model geometry:

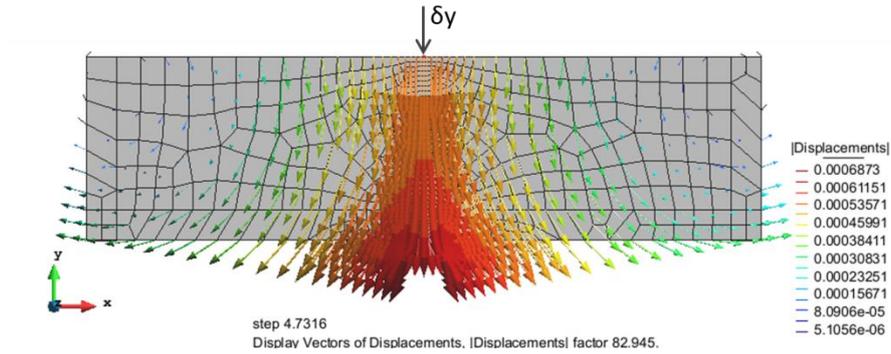


**Figure 1:** EN-14651 test (a) and 2D finite element model mesh detail (b).

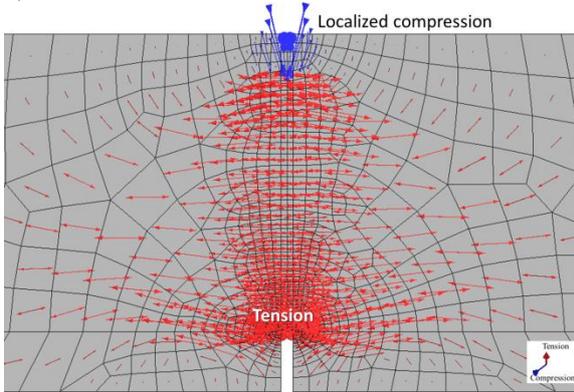
### 3 RESULTS

Figure 2 presents the EN-14651 modelled test displacement results, the inner stress development, and the plastic shear contour fields obtained. As shown, a clear zone location of the higher tension values was obtained at the notch's inner tip, where the deviatoric (shear) plastic strains arose. The material porosity changes achieved are shown in Figure 3a consequently related to the cohesion strength loss (Figure 3b). A zone without cohesion strength was obtained relating to crack propagation processes and damage emergence.

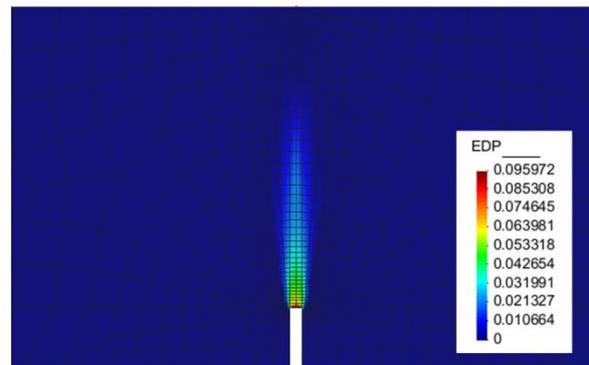
a) Vector displacements:



b) Main stress vectors detail:

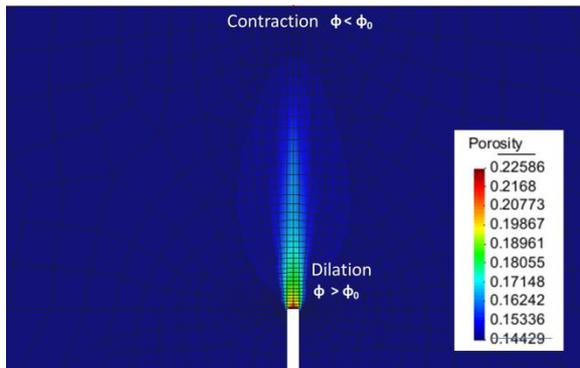


c) Plastic shear contour field:

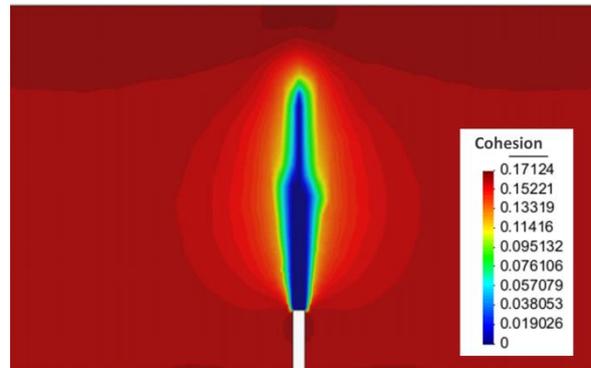


**Figure 2:** EN-14651 model results: displacement vectors (a), stress (b), and plastic shear shadings (c).

a) Porosity changes (damaged zone location):

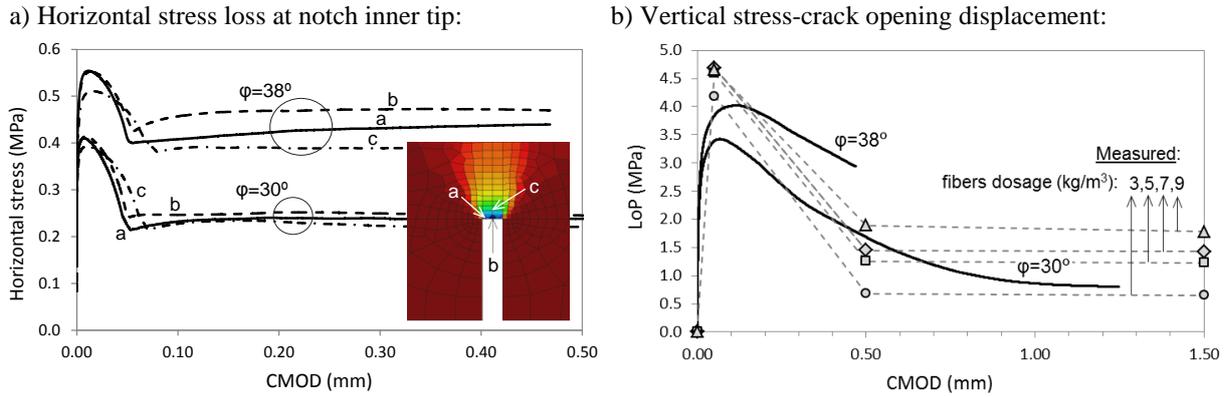


b) Tensile strength - cohesion loss:



**Figure 3:** Porosity changes (a) and tensile strength loss (b).

In Figure 4a, plots from the horizontal stress changes at the notch's inner tip are given for two different concrete friction angle model assumptions ( $\phi=30^\circ$  and  $38^\circ$ ). Clear strength loss was obtained for both cases, with an expected higher peak horizontal stress values for the strengthened case. Figure 4b presents the comparison between the two modelled cases and four measured test cases with different polyethylene fibre dosage. The strength loss was clearly obtained, and a reasonable agreement between the calculated (2D model) and measured EN-14651 test response was achieved.



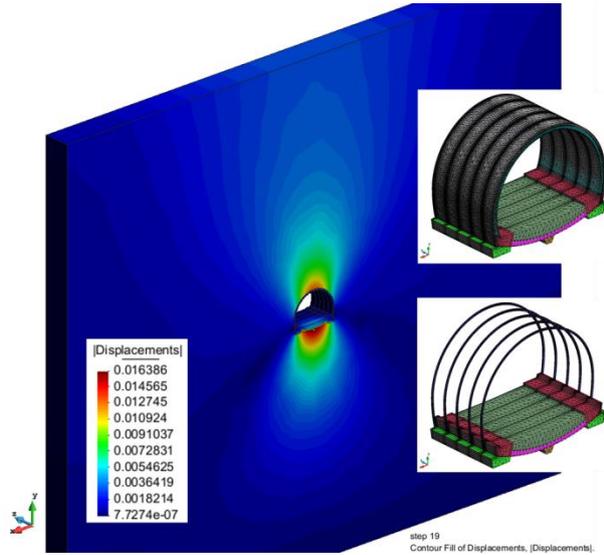
**Figure 4:** Horizontal stress loss (a) and Stress-displacement numerical-measured results comparison (b).

A preliminary tunnel application case was modelled and results at the end of construction (EoC) presented in Figure 5. The 3D numerical model was made with 541674 tetrahedral elements generating 94984 nodes. The modelled tunnel has about 12 m-diameter and 8 m-length, and assumed to be placed at about 70 m-depth. The model was calculated with a staged-construction considering step-by-step soil 1.6 m-thick-slice excavation and structural components installation through the tunnel axis. A first 0.2 m-thick shotcrete layer was considered to be installed after 1.6 m soil-slice excavation. 0.1 m-thick steel truss beams were then installed directly on the 1<sup>st</sup> shotcrete layer, performing a 1.5 m spacing distribution through the tunnel axis. After the underlying drain, invert construction and lateral concrete guide wall, a second shotcrete layer was finally projected surrounding the inner face of the tunnel. As previously specified (see Table 1), elastic-plastic model with Drucker-Prager failure criterion and porosity strength-dependant model was assumed for the shotcrete material zones, whereas the other components were assumed linear elastic (soil/ground, truss beams, invert, underlying drain, etc.). Further models with refined porosity strength-dependant and staged-construction are under the scope of the ongoing tasks.

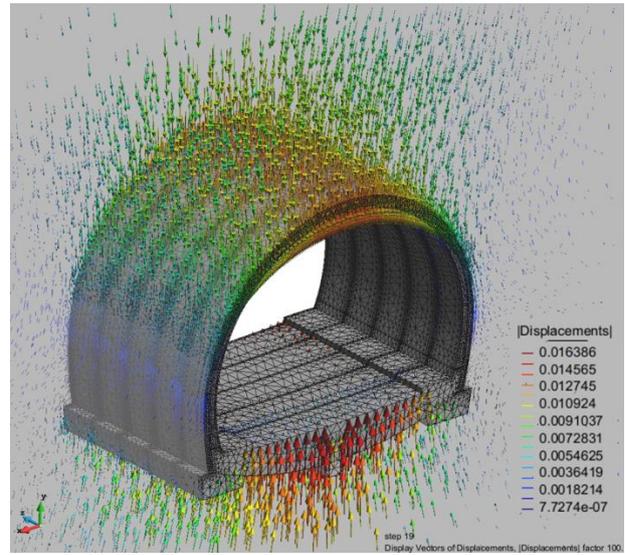
#### 4 CONCLUSIONS

- A 2D numerical finite element modelling was generated to analyse the stress-crack opening displacement results of fiber-reinforced concrete samples.
- A constitutive elastic-plastic material model including a porosity strength-dependant fits the measured test data (EN-14651) in a reasonable manner, and seems promising to further analysis of fiber-reinforced concrete applications.
- A 3D model of a tunnel is presented considering material plasticity and porosity strength-dependant of two shotcrete layer materials. The assumed staged-construction model methodology resulted capable to achieve satisfactory results with the porosity strength-dependant mode implementation and allowing other real-case assumptions (geometry, structural data, different boundary conditions, etc.).

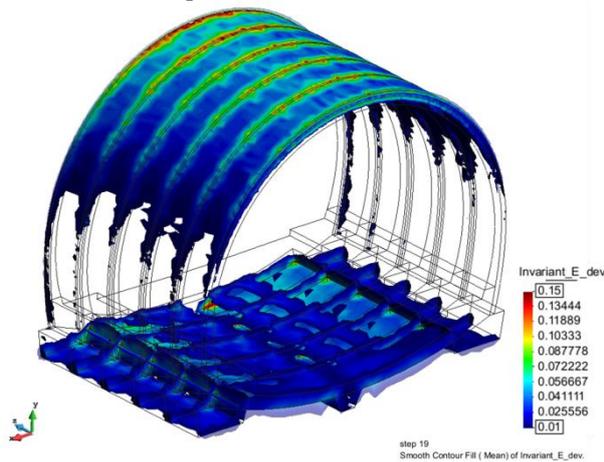
a) Global displacements and tunnel details:



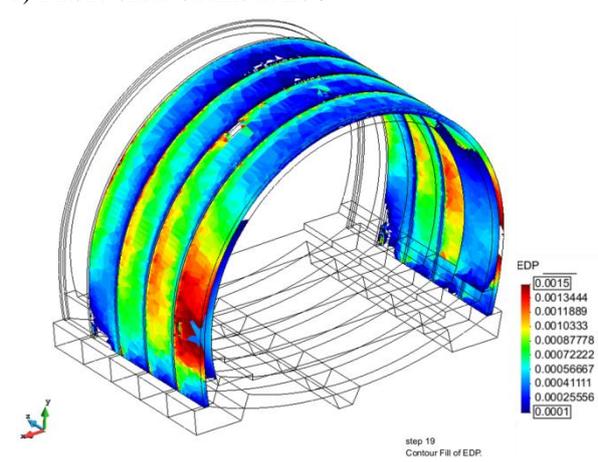
b) Vector displacements at EoC:



c) Total (elastic+plastic) shear strains at EoC:



d) Plastic shear strains at EoC:



**Figure 5:** Tunnel 3D model results.

## REFERENCES

- [1] Trabelsi H., Jamei M., Zenzri H., and Olivella S.; 2012. Crack patterns in clayey soils: Experiments and modeling. International Journal for Numerical and Analytical Methods in Geomechanics. Volume 36, Issue 11, Pages: 1410-1433.
- [2] EN 14651; 2005. Test method for metallic fibered concrete - Measuring the flexural tensile strength (limit of proportionality (LOP), residual). European Standard (EN), European Committee for Standardization (CEN/TC 229). Brussels, Belgium. June 2005.