FEM ANALYSIS OF A SUPERCONDUCTING CABLE

8/17/2011

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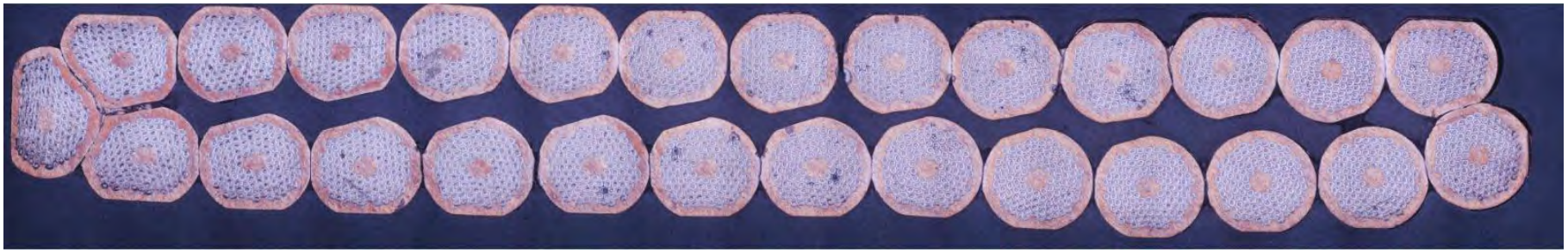
Outline:

- Introduction
- Detailed model
- Simplified model
- Model comparison
- N strands cable model
- Load cases
- Deformation as function of N
- Preliminary results
- Next steps

Introduction

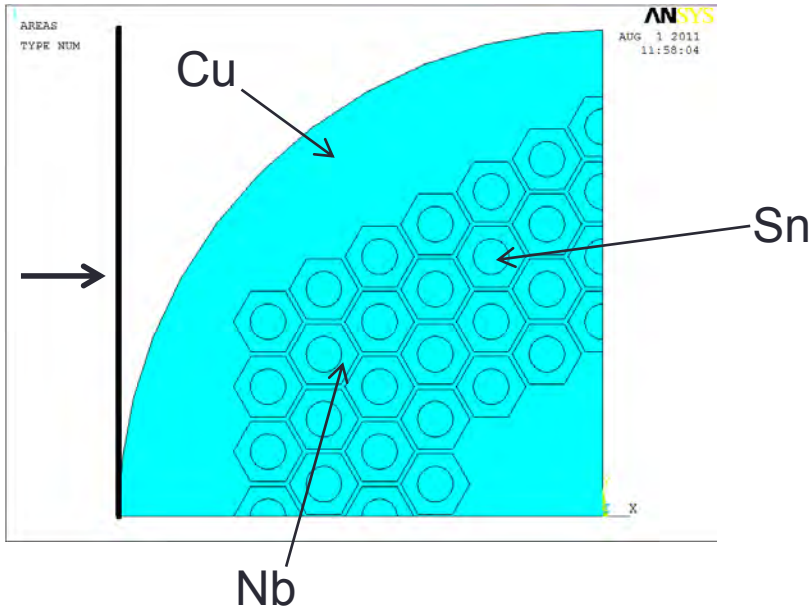


FEM analysis of a 27 strands cable to evaluate its mechanical behavior during the fabrication:

- find out which are the critical strands
- estimate how they will be damaged by the process

Detailed model

Material	Young Modulus, GPa	Poisson Modulus	Yield tensile strength, MPa
Cu	110	0.364	280
Sn	41.4	0.330	20
Nb	103	0.380	420

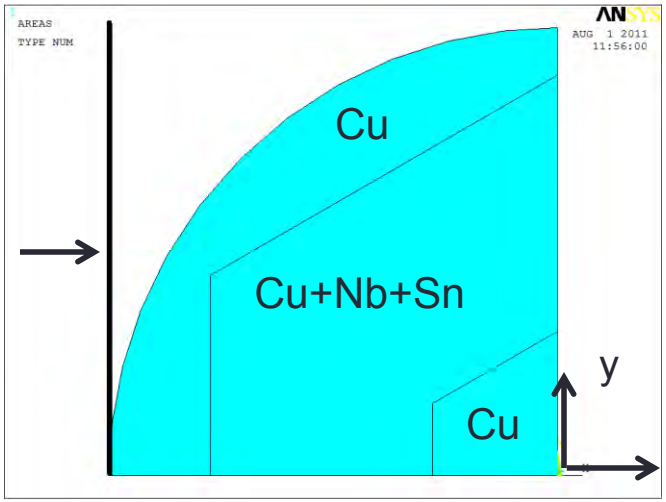


Giuseppe Gallo created a detailed model of a single strand which matches well experimental results [1]

Too heavy for entire cable simulation

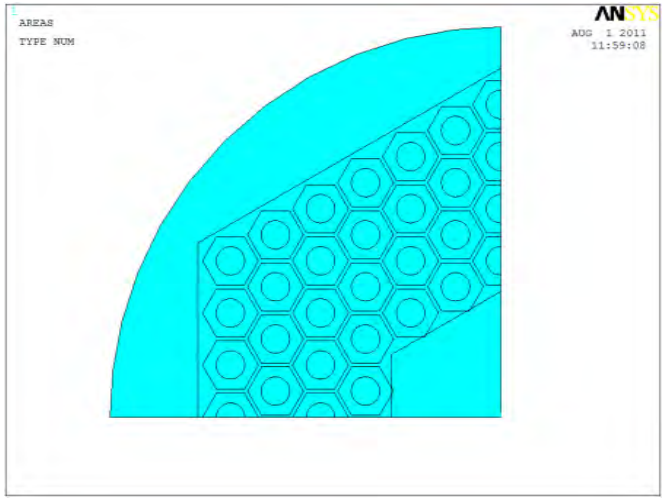
[1] "*A Model to Study Plastic Deformation in Nb_3Sn Wires*", E. Barzi, M. Bossert, and G. Gallo, IEEE Trans. Appl. Sup., **V. 21**, No. 3, p. 2588 (2011).

Simplified model



Geometric

comparison



In the central hexagon, we used average properties weighted on the area percentage of each component. To align the simplified model results with the detailed model results, those percentages have been corrected:

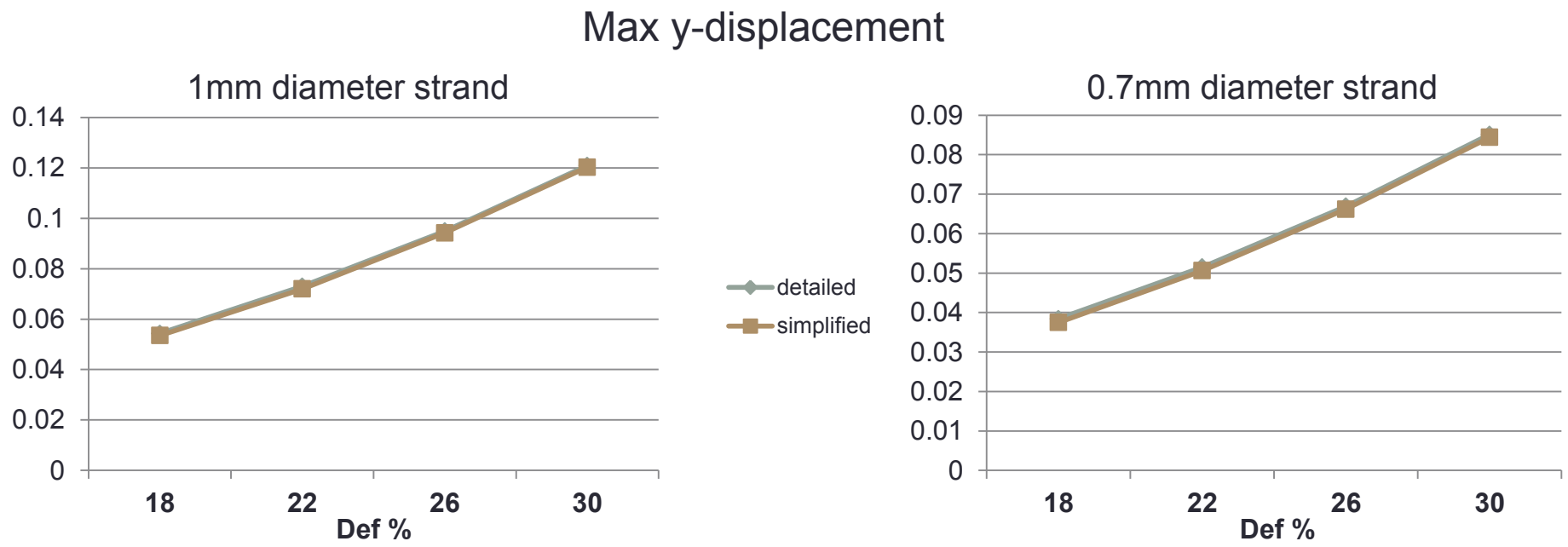
Material	Original %	Modified %	Correction
Cu	0.206	0.156	-0.05
Sn	0.250	0.430	0.18
Nb	0.544	0.414	-0.13

Average properties (with modified percentage)		
Young Modulus, GPa	Poisson Modulus	Yield tensile strength, MPa
77.6	0.356	193

Max y-component of displacement in detailed model: 0.1209 mm

Simplified model		Error
Original %	0.1183	2.2%
Modified %	0.1203	0.5%

Model comparison (1)

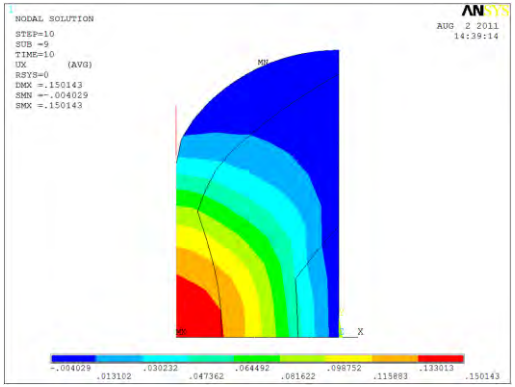


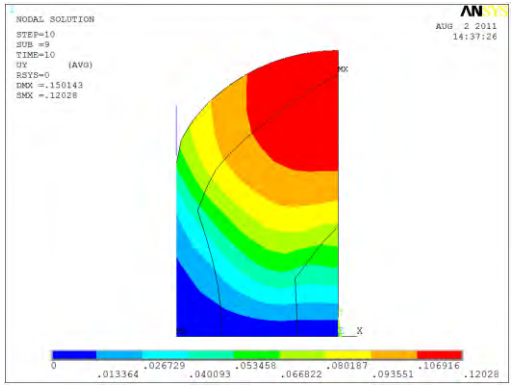
Model comparison (30% deformation) (2)

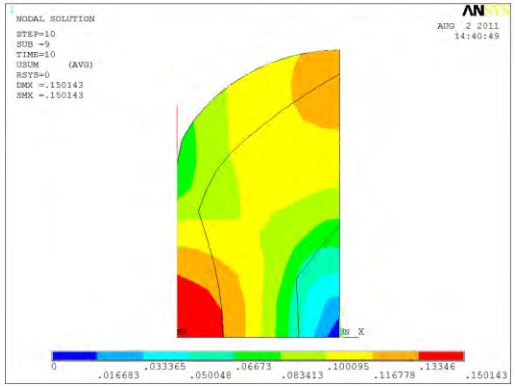
X-component of displacement

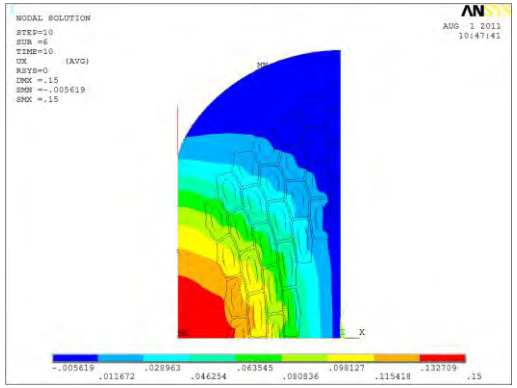
Y-component of displacement

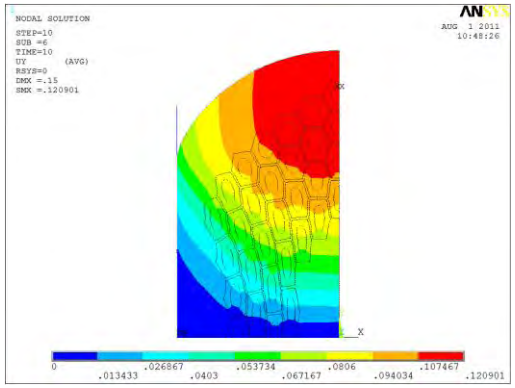
Displacement vector sum

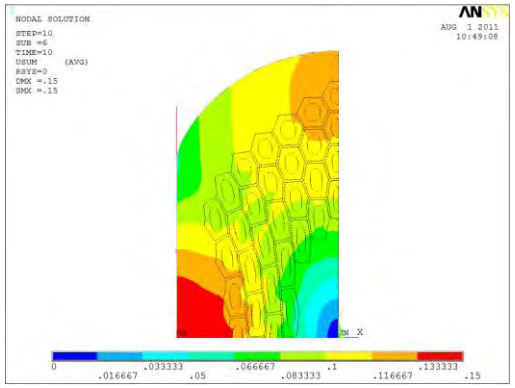






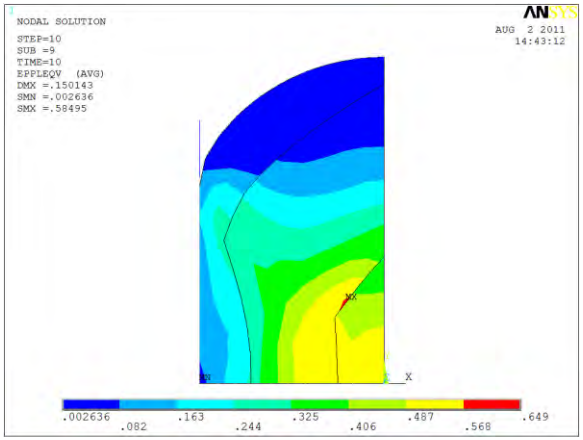




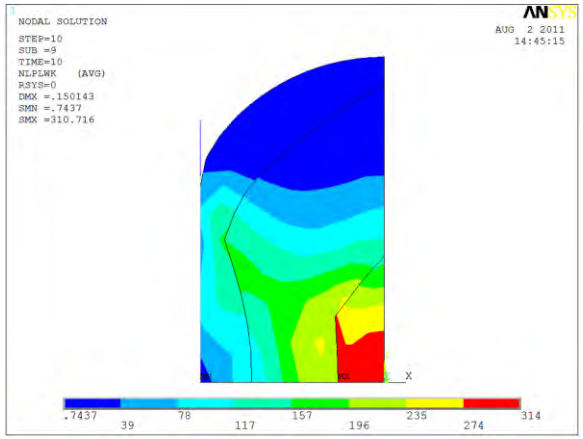


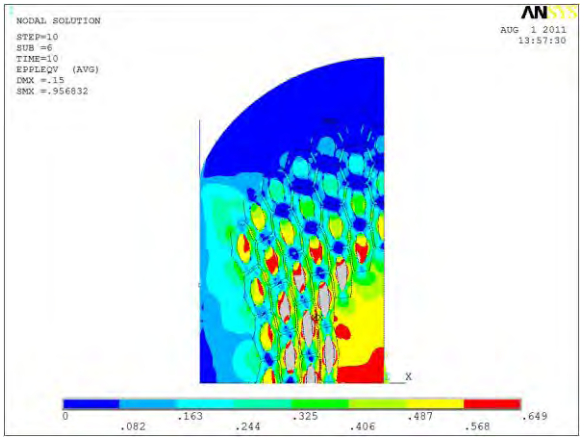
Model comparison (30% deformation) (3)

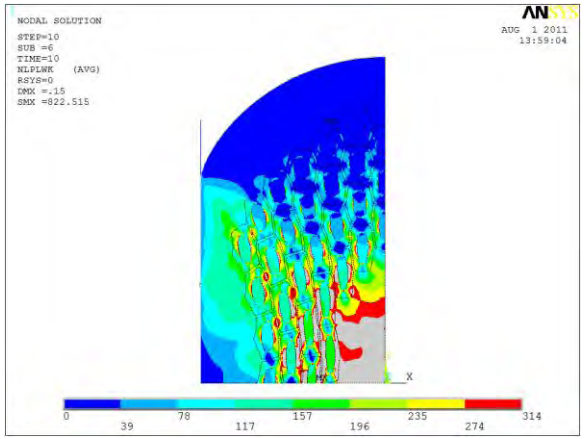
Von Mises plastic strain



Plastic work



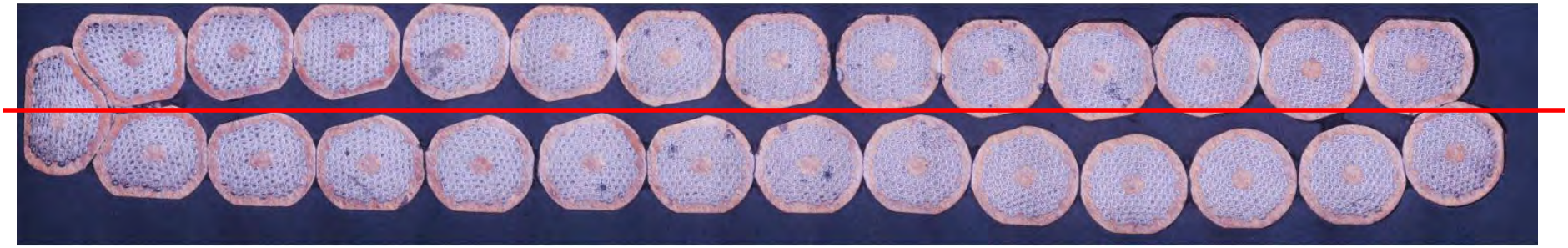




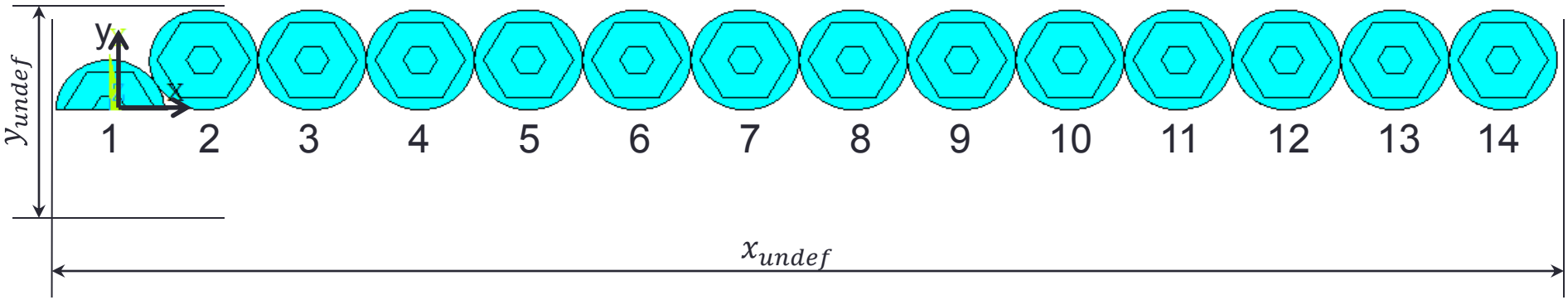
The simplified model does not represent local effects as the detailed model does

Some values are out of range

Cable model



Symmetric shape

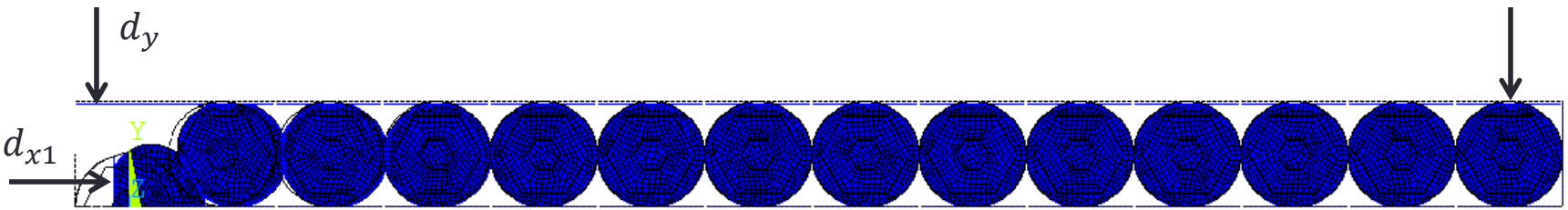


The simplified strand model has been used to build the whole cable model (to ensure a shorter calculus time)

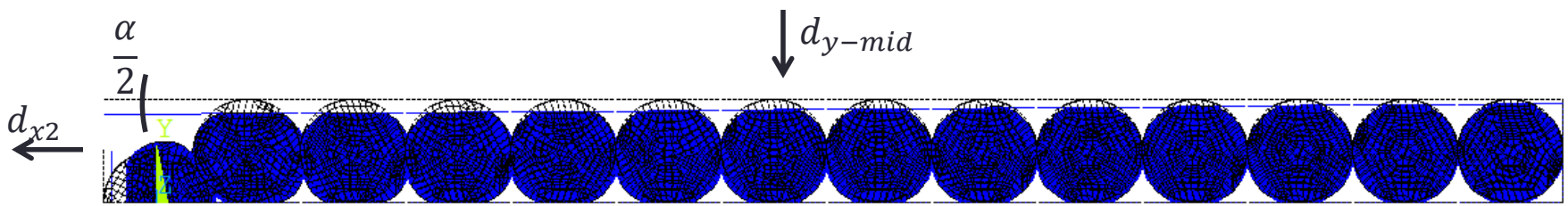
Load cases (1)

The cable is deformed by 4 rollers which give it the final shape, so we decided to set an imposed displacement value (calculated knowing the distance between corresponding rollers in the process). The deformation is given in 2 steps:

First step: rectangular deformation (all the strands have the same d_y)

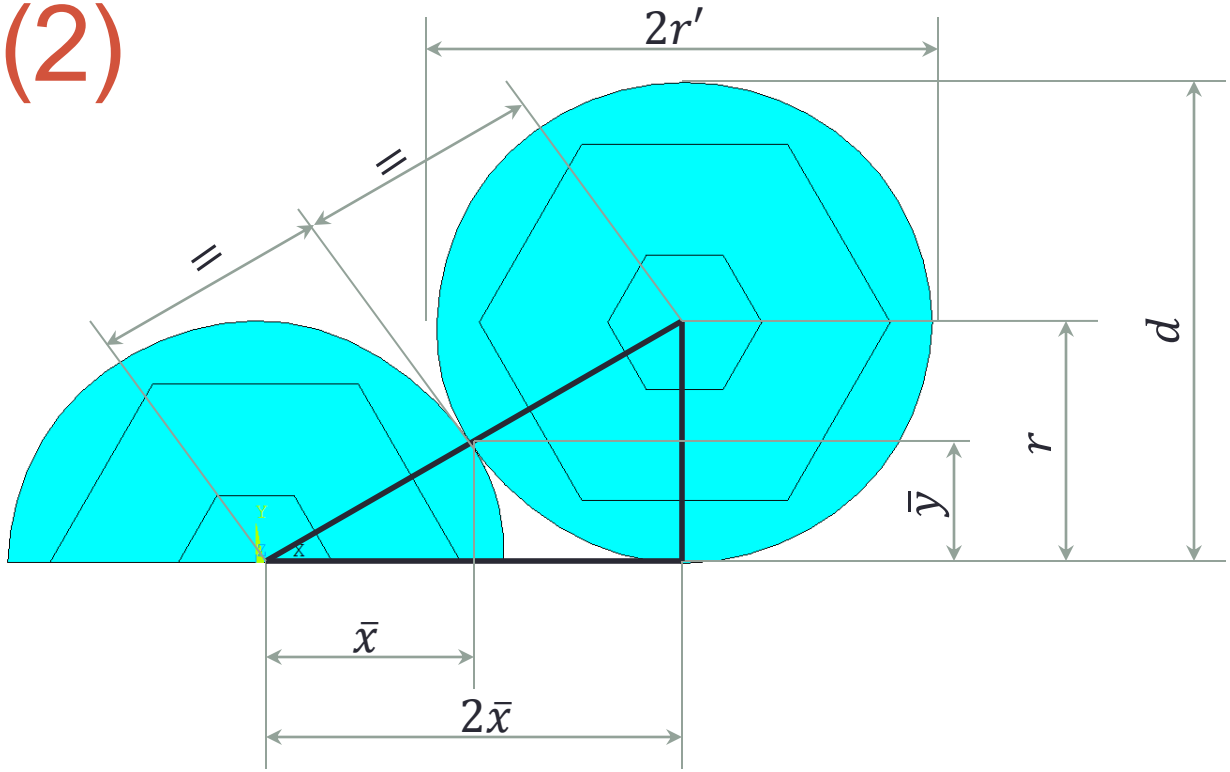


Second step: Keystoned turk-head (strands have different d_y)



d_{x1} (mm)	d_y (mm)	d_{x2} (mm)	d_{y-mid} (mm)	α (deg)
0.372	0.025	0.082	0.100	0.9

Load cases (2)



$$r' = \frac{r}{\cos(\alpha_{pitch})}$$

Ellipse equation:

$$\frac{x^2}{r'^2} + \frac{y^2}{r^2} = 1$$

$$\frac{r}{2\bar{x}} = \frac{\bar{y}}{\bar{x}} \longrightarrow \bar{y} = \frac{r}{2}$$

$$\bar{x} = r'\frac{\sqrt{3}}{2} \Longrightarrow \begin{aligned} x_{undef} &= 2\bar{x} + (N-1)r' \\ y_{undef} &= 2d \end{aligned}$$

Load cases (3)

Symmetry ⟹ $$d_y = \frac{y_{undef} - rollers_{y-distance}}{2}$$

$$d_x = \frac{x_{undef} - rollers_{x-distance}}{?}$$

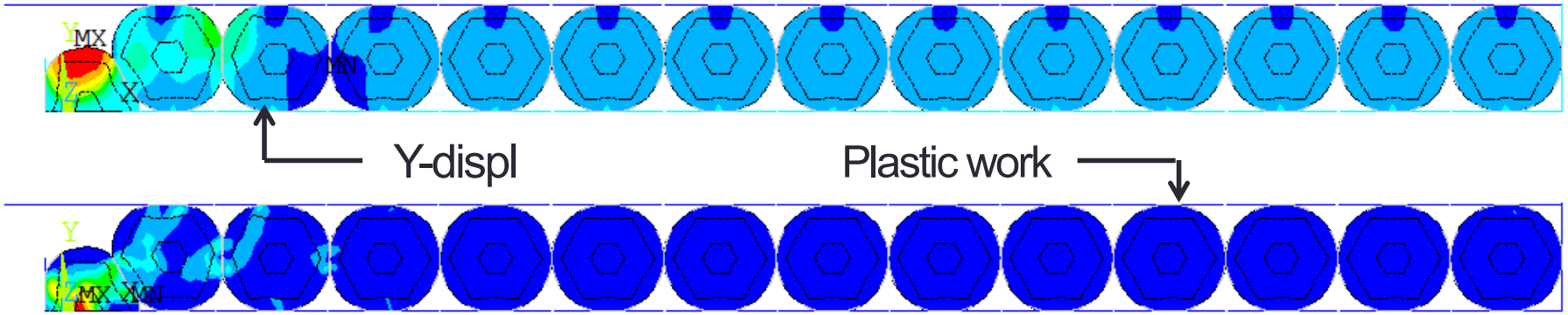
In order to cover more load cases, we decided to study two possible load repartitions:

A) Whole displacement applied on left edge of cable

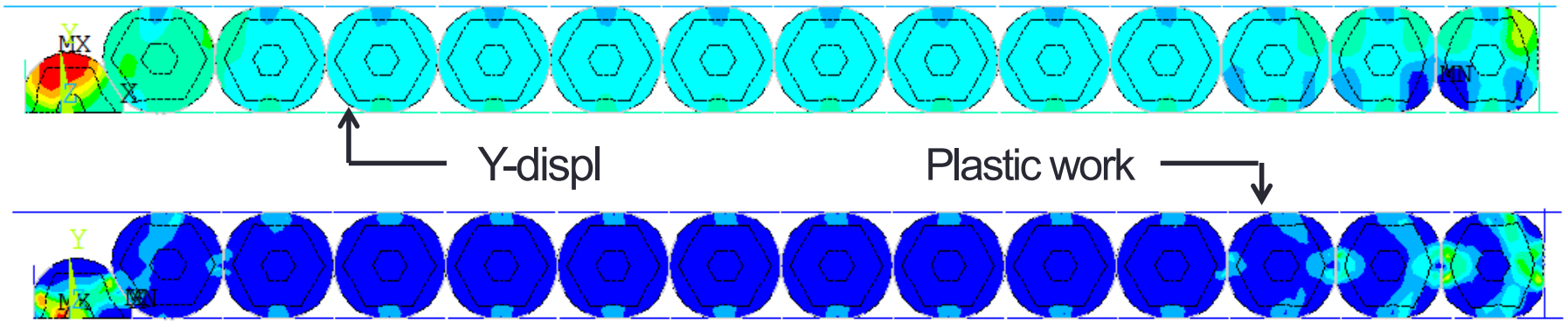
B) Displacement equally distributed between left and right edges of cable

Load cases (3)

A) Whole displacement applied on left edge of cable



B) Displacement equally distributed between left and right edges of cable



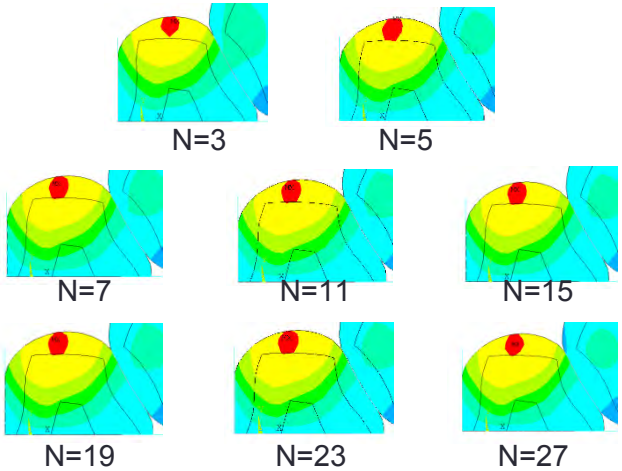
Deformation as function of N (1)

For each N analyzed, we chose to apply 3 values of $rollers_{x-distance}$ (w_c):

1) $w_c = x_{undef} - \Delta x$ (with same Δx for all N)

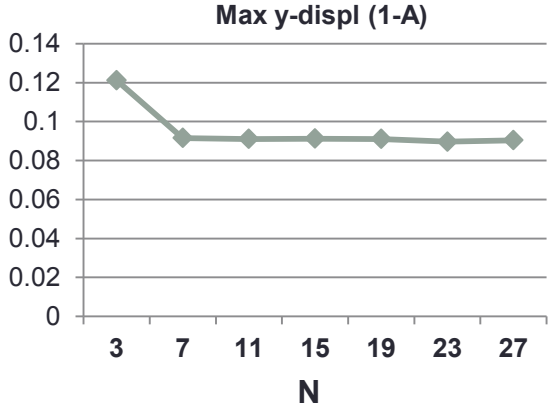
2) $\frac{x_{undef} - w_c}{x_{undef}} = a$ (with same a for all N)

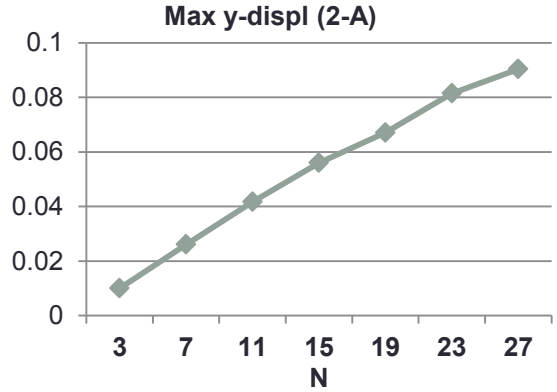
3) $w_c = \frac{N}{2} \frac{d_{strand}}{\cos(\alpha_{pitch})}$

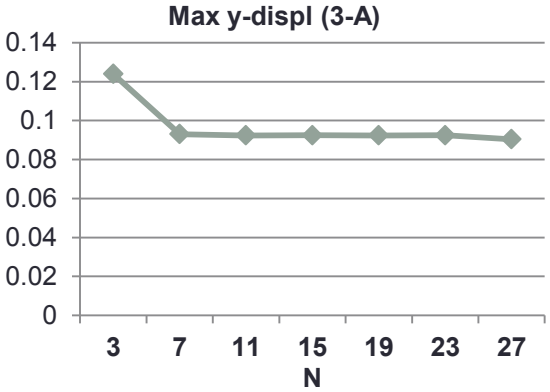


Max Y-displacement location

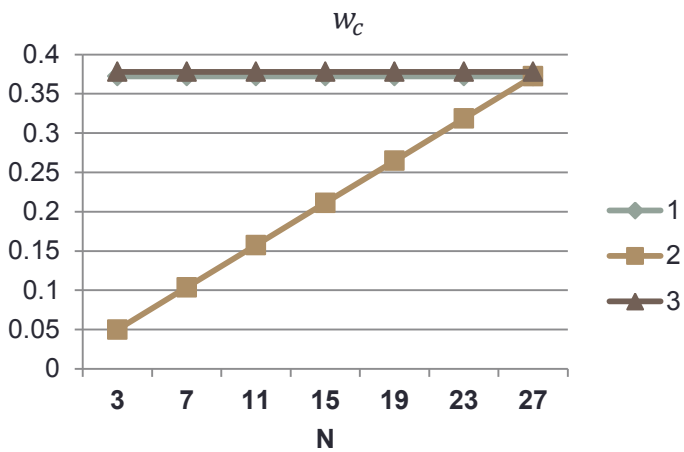
Whole displacement on left edge (A)



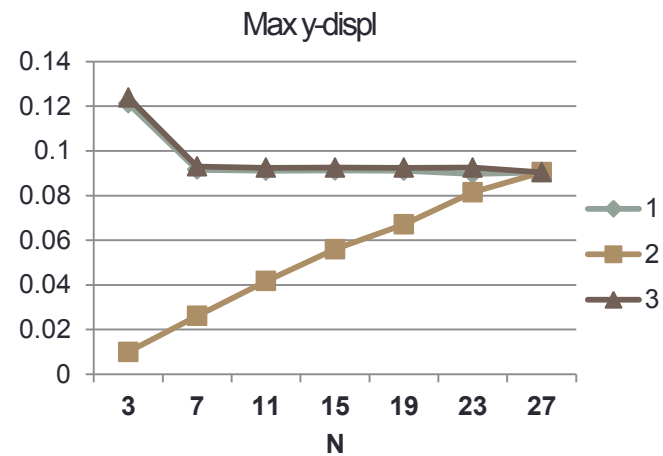




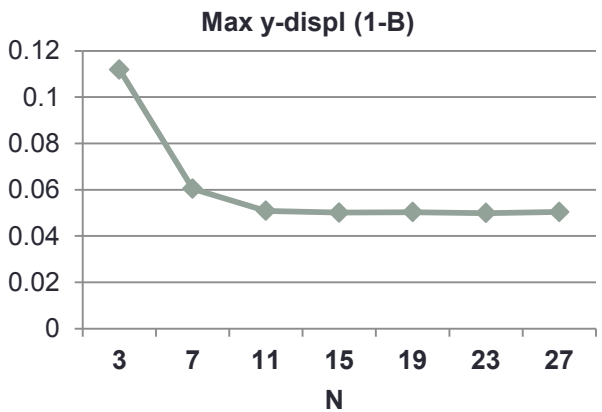
Deformation as function of N (2)

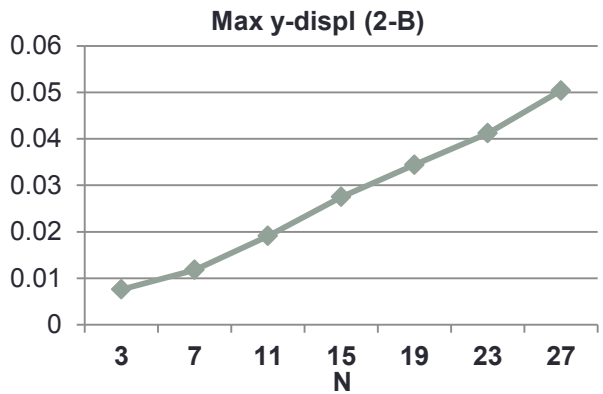


We noticed that load cases (1) and (3) where almost the same, so we decided to use only case (1) and (2) in next analysis



Displacement distributed between left and right edges (B)





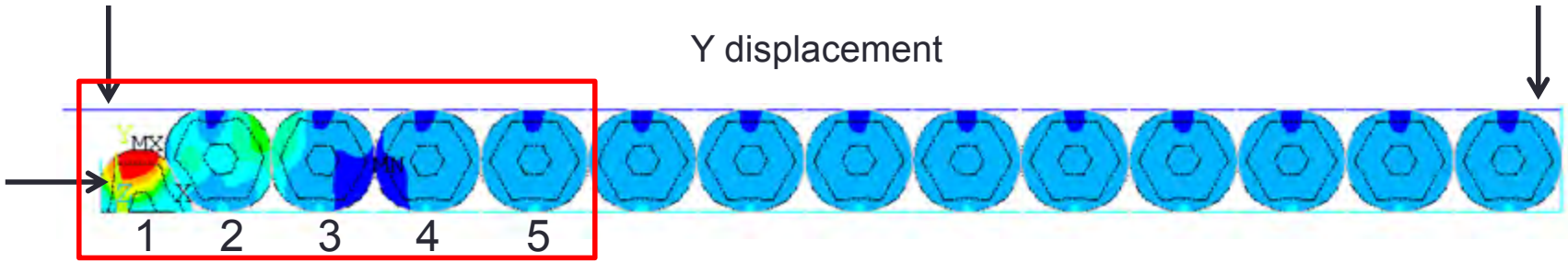
N effects:

- Loads repartition changes max y-displ values, but not the trend
- Increasing N has a linear effect on max y-displ (if w_c increases linearly too)
- Increasing N has no effect on max y-displ (if Δx is the same for all N)

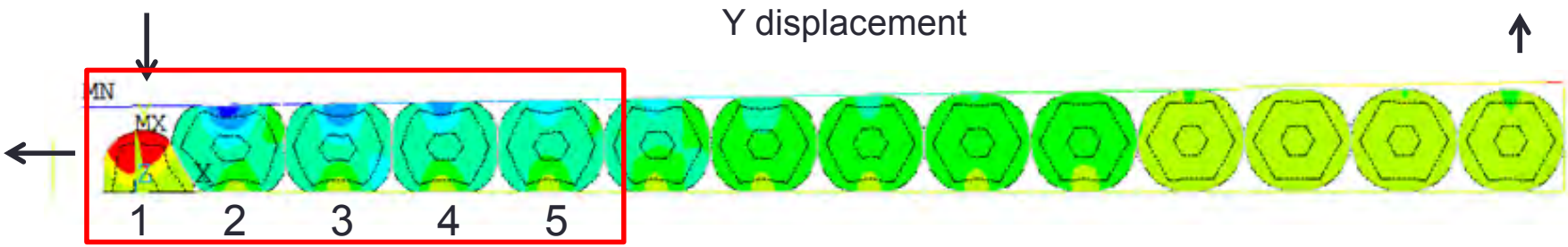
Preliminary results (1)

A first analysis of the whole cable has been performed. It covers the whole process applying imposed displacements in two steps:

1) Rectangular deformation



2) Keystoned turk-head

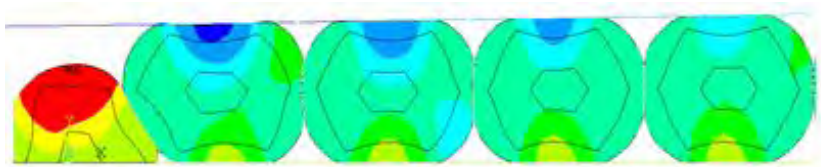


X displacement applied ONLY on left edge (A)

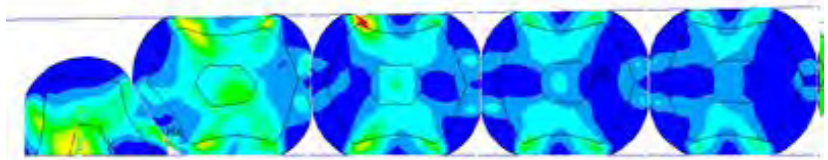
Preliminary results (2)

Critical strands: 1 - 5

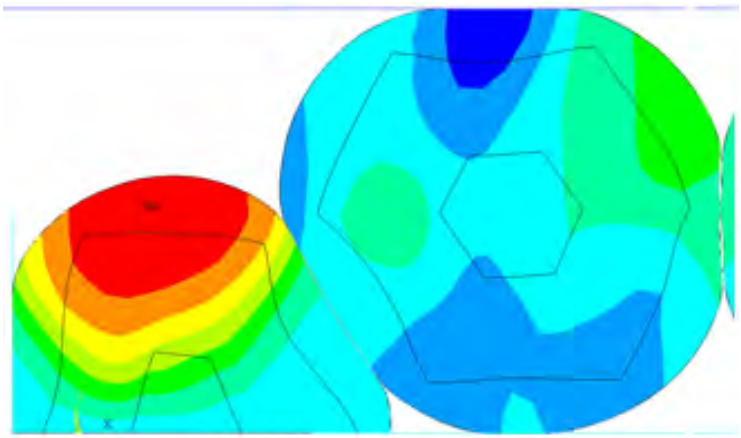
Y displacement

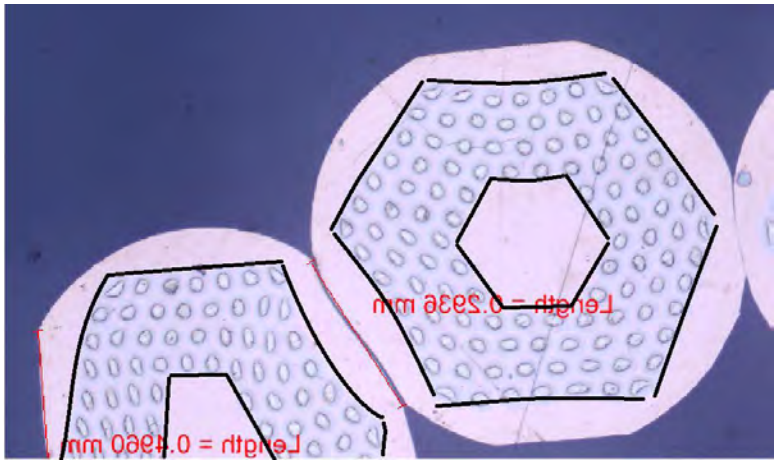


Plastic work



Experimental results





FEM analysis reflects properly the deformed shape observed with the microscope

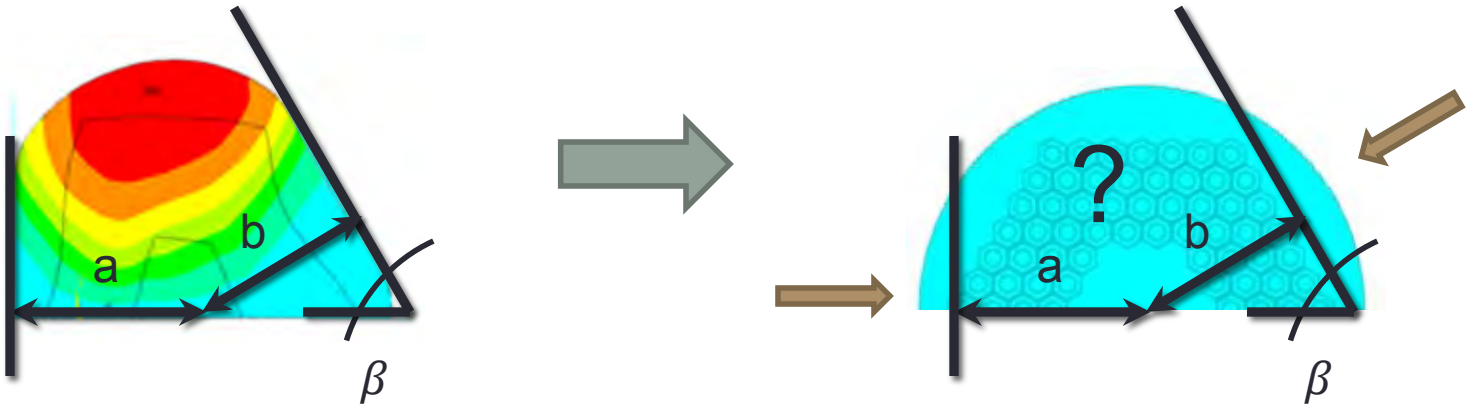
Next steps (1)

1) Improve whole cable analysis with a refined mesh, studying displacement repartition too

2) Compare FEM data with experimental values of strands displacement

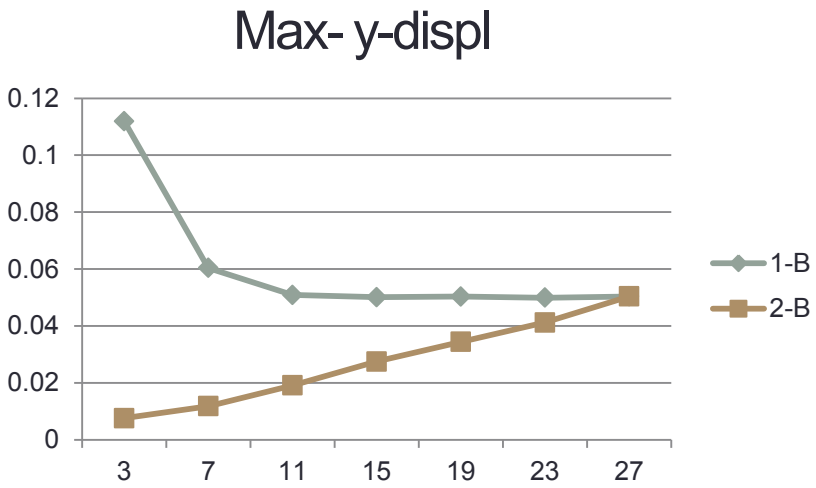
3) FEM model of 0.7mm diameter strand has been already created (the comparison between detailed and simplified model has been performed); we are working on the whole cable model

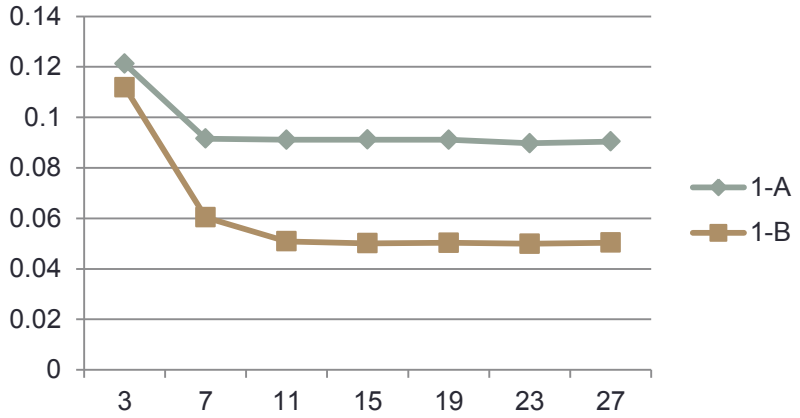
4) Simplified model is good just for deformation analysis. Starting from these analyses' results, we want to obtain information about strands surface displacement, so that we can apply those displacement to the detailed model of the single strand to find out what happens during the technology process

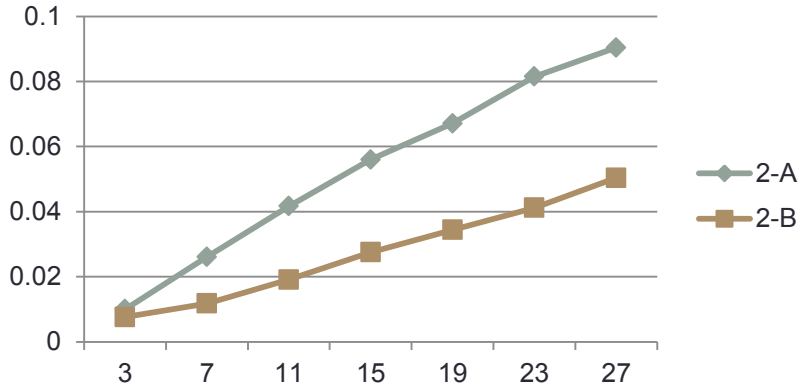


Backup slides

Deformation as function of N (3)







N effects:

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- Increasing N has a linear effect on max y-displ (if x_{imp} increases linearly too)

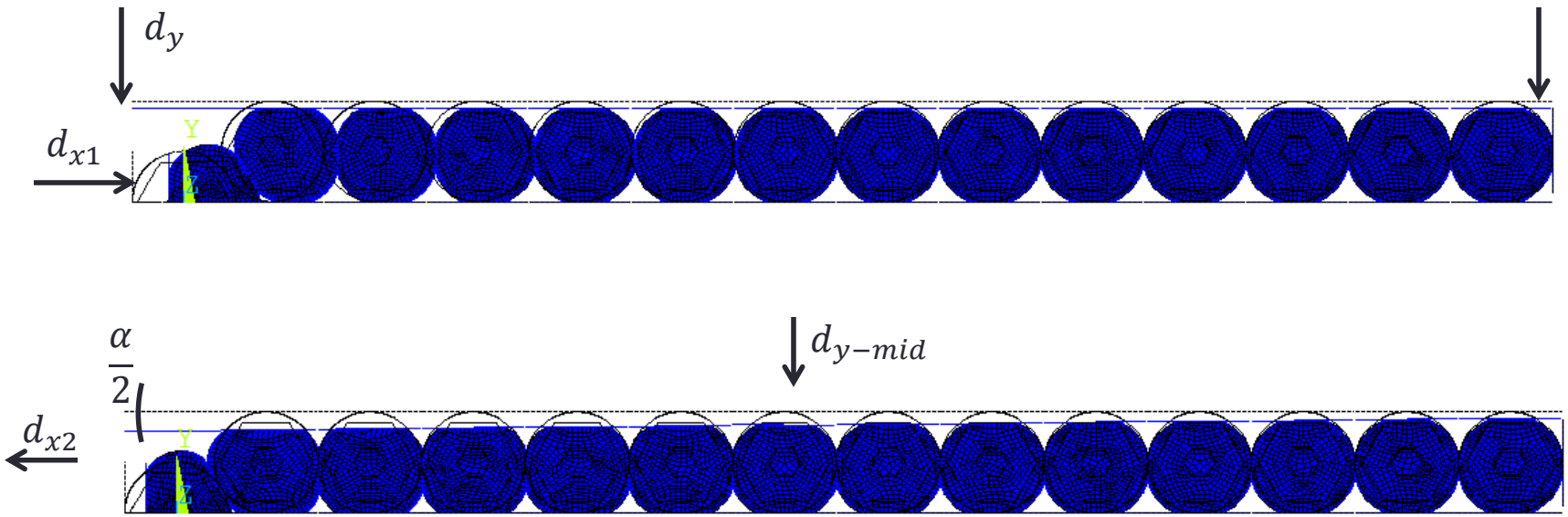
- Increasing N has no effect on max y-displ (if Δx is the same for all N)

Results comparison for maximum y-component of displacement (mm) (1mm diameter strand)

Def %	Detailed	Simplified	Error
18	0.0543	0.0535	1.47
22	0.0730	0.0720	1.37
26	0.0949	0.0942	0.74
30	0.1209	0.1203	0.49

Results comparison for maximum y-component of displacement (mm) (0.7mm diameter strand)

Def %	Detailed	Simplified	Error
18	0.0384	0.0375	2.34
22	0.0515	0.0506	1.75
26	0.0669	0.0662	1.05
30	0.0851	0.0844	0.82


d_y
d_{x1}
Y
$\frac{\alpha}{2}$
d_{y-mid}
d_{x2}
Y