# On efficient FEM calculations of plastic and viscoplastic deformations in 6-parameter nonlinear shell theory.

**Stanisław Burzyński*, Jacek Chróścielewski† and Wojciech Witkowski†**

* Gdańsk University of Technology
Narutowicza 11/12, 80-233, Gdańsk, Poland
e-mail: staburzy@pg.gda.pl, web page: www.pg.edu.pl
† Gdańsk University of Technology

## ABSTRACT

The main goal of paper is the derivation of elasto-plastic and elasto-viscoplastic constitutive laws in 6-parameter nonlinear shell theory [1]. It is important to notice, that 6$^{th}$ DOF (drilling rotation) enters this theory in the natural way. The kinematic model in used shell theory is formally equivalent to the Cosserat surface with three rigidly rotating directors.

The derivation rests on the assumption that there exists generalized plane stress of Cosserat continua at each the layer of shell. Assumption of the Reissner-Mindlin kinematics is introduced here. Stress and couple resultants are given as integrals of stress tensors components, which gives equations for materially nonlinear constitutive law for shell [2,3].

The resulting constitutive equations for stress resultant and couple resultants are expressed in terms of two micropolar constants: the micropolar modulus $G_c$ and the micropolar characteristic length $l$.

Both constitutive laws are based on $J_2$ plasticity theory generalized on Cosserat continua [4]. Small strains with additive decomposition in elastic and inelastic parts are assumed in the paper. Associative flow rule is taken into account.

Our investigations are summarised by analysing some numerical examples. Computer code is developed in Fortran programming language. Efficiency of numerical algorithms for plasticity are compared. Attention is paid to parallel computations, their implementation into computer code and the use of software for solving large sparse symmetric linear systems of equations. Shell theory applied in the work is dedicated in natural way to solving irregular, multibranched shells problems.

In numerical examples, we also evaluate influence of the additional micropolar constants on the behaviour of shell models in the geometrically nonlinear range of deformations.

Acknowledgement: Stanisław Burzyński is partially supported by grant DEC-2012/05/D/ST8/02298, National Science Centre of Poland.

## REFERENCES

[1] J. Chróścielewski, J. Makowski and H. Stumpf, Genuinely resultant shell finite elements accounting for geometric and material non-linearity, Int. J. Numer. Meth. Eng. **35**, 63–94, (1992).

[2] S. Burzyński, J. Chróścielewski and W. Witkowski, "Elastoplastic material law in 6-parameter nonlinear shell theory". In: W. Pietraszkiewicz and J. Górski (eds.) *Shell Structures: Theory and Applications, Vol 3.*, London: CRC Press, 377-380 (2014).

[3] S. Burzyński, J. Chróścielewski and W. Witkowski, "Elastoplastic law of Cosserat type in shell theory with drilling rotation", *Mathematics and Mechanics of Solids*, DOI: 10.1177/1081286514554351 (2014).

[4] R. de Borst, Simulation of strain localization: a reappraisal of the Cosserat continuum, *Engineering computations*, 8, 317–322 (1991).