

# Extended Subloading Surface Model with Non-Linear Kinematic Hardening for Finite Strains: Application to Cyclic Loading and Verification of Validity

Takuya Iguchi\*, Yuki Yamakawa<sup>†</sup> and Koichi Hashiguchi<sup>††</sup>

\* Ph. D Students, Department of Civil and Environmental Engineering, Tohoku University  
6-6-06 Aramaki-aza-aoba, Aoba-ku, Sendai-shi, Miyagi 980-8579, Japan  
email: takuya.iguchi.s4@dc.tohoku.ac.jp

<sup>†</sup> Department of Civil and Environmental Engineering, Tohoku University  
6-6-06 Aramaki-aza-aoba, Aoba-ku, Sendai-shi, Miyagi 980-8579, Japan

<sup>††</sup> Technical Adviser, MSC Software Ltd. (Emeritus Professor of Kyushu University)  
1-23-7 Nishishinjuku, Shinjuku-ku, Tokyo 160-0023, Japan

## ABSTRACT

This paper presents a finite strain elastoplastic constitutive model incorporating the extended subloading surface[1] concept within the *unconventional plasticity* framework for cyclic loadings. This is a reformulated and extended version of the small strain model[2]. The constitutive formulation is underpinned by the multiplicative decomposition of the deformation gradient tensor, which is the well-established modern kinematical framework in geometrically nonlinear elastoplasticity. In addition to the conventional multiplicative decomposition into elastic and plastic parts, we further introduce two kinds of multiplicative decompositions of the plastic deformation gradient tensor. One decomposition is related to kinematic hardening, and the other an evolution of the elastic-core tensor, i.e. a key internal variable in the extended subloading surface model, which stands for a stress state where the material exhibits most elastic responses. In each decomposition, the plastic deformation gradient tensor is split into an energetic part and a dissipative part, and the former is related to the back-stress tensor for kinematic hardening or the elastic-core tensor defined on a pertinent intermediate configuration via a hyperelastic format. Therefore, the whole constitutive theory can be formulated in terms of deformation-like tensorial variables without resort to any objective or co-rotational rates of stress-like variables such as the back-stress, fulfilling the principle of material frame indifference. We then focus on the numerical stress update scheme for the proposed material model based on the fully implicit return-mapping. Basic properties of the proposed model, as well as the capability of the developed numerical scheme, are examined and verified through numerical examples.

## REFERENCES

- [1] K. Hashiguchi, Subloading surface model in unconventional plasticity, *International Journal of Solids and Structures*, Vol. 25, pp. 917–945 (1989).
- [2] T. Iguchi, Y. Yamakawa and K. Ikeda, A re-formulation of extended subloading surface model for cyclic plasticity within small strain framework: hyperelastic-based formulation and fully implicit return-mapping scheme, *Transactions of the JSME (in Japanese)*, Vol. 82, No. 841 (2016).