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NUMERICAL SIMULATION OF ELASTIC-PLASTIC CONTACT OF LAYERED BODIES

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ABSTRACT
This paper is concerned with the finite element simulation of layered solids in elastic-plastic contact. The simulation is performed on 2D plane strain model, by indentation of elastic cylinder into layered plane. We investigate the dependence between external load necessary to induce plastic deformation and surface layer thickness and hardness. For the given range of thickness and material parameters, on the basis of numerical results, appropriate mathematical model was developed. It is useful to gain insights into load bearing capacity of layered contact pair with respect to material properties.
Keywords: numerical simulation, finite element method, mathematical model, contact

1. INTRODUCTION

In order to improve contact properties, we frequently use layered surface with different material properties in each layer. For contact problems of this type, stress strain state could be determinated analytically only for elastic, small strain, friction free and simple geometry problems, (Kannel i Dow 1986, Jaffar i Savage, 1988). Nonlinear contact analysis based on FEM has become the main tool for determination of elastic-plastic contact stresses and deformations of layered solids in real-world problems. We investigate this procedure for the case of 2D plane strain model shown in Fig.1.

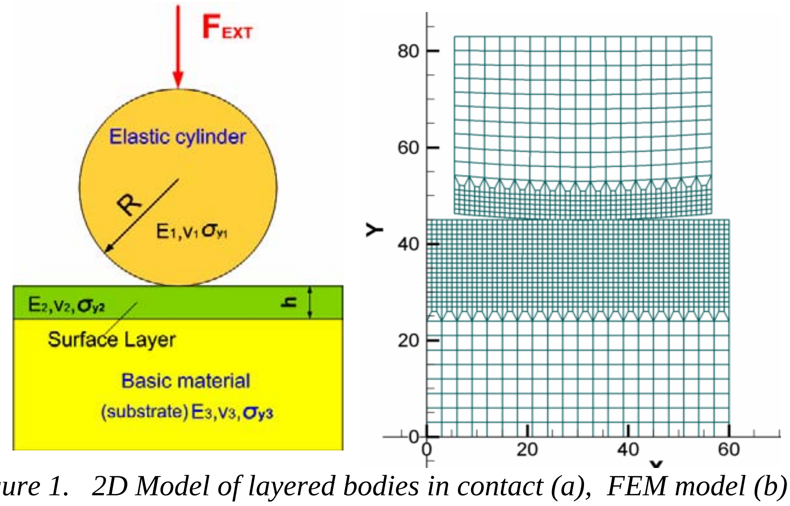

Figure 1. 2D Model of layered bodies in contact (a), FEM model (b)

The stress – strain analysis in contact zone will be conducted through series of numerical simulations, varying the key parameters: thickness of surface layer, yield stress of surface layer material (and yield stress of basic (substrate) material. By numerical simulation we get information about external load level necessary to induce plastic deformations in contact zone, depth of point where first yield occur and influence of surface layer thickness and material properties on these values. The common case in practice is contact of steel parts with surfaces improved by hardfacing. For such kind of problems, elastic properties (E,ν) of hardfacing material and basic material are very similar. So, in this series of simulations, we use the same elastic material parameters for the layer and substrate.

2. NUMERICAL SIMULATION

For the model at Fig.1(b) we developed the code for nonlinear elastic-plastic contact analysis. Contact algorithm is based on 2D node-to-segment approach with penalty method for contact constraint. Nonlinear material behavior is modeled by bilinear elastic-plastic, vMises (J_2) material model. Material properties are selected in the range in which they appear in practice (substrate material yield stress $\sigma_{yo}^{basic} = 450 - 900\ N/mm^2$, hard layer yield stress $\sigma_{yo}^{layer} = 550 - 1000\ N/mm^2$, hard layer thickness 3-12 mm). External load is applied in 25 increments in the range 0 – 1000 kN.

The vMises stress for the case of cylinder radius R=250 mm, cylinder thickness of b=100 mm and hardfacing layer thickness of 6 mm is shown in Fig.2.

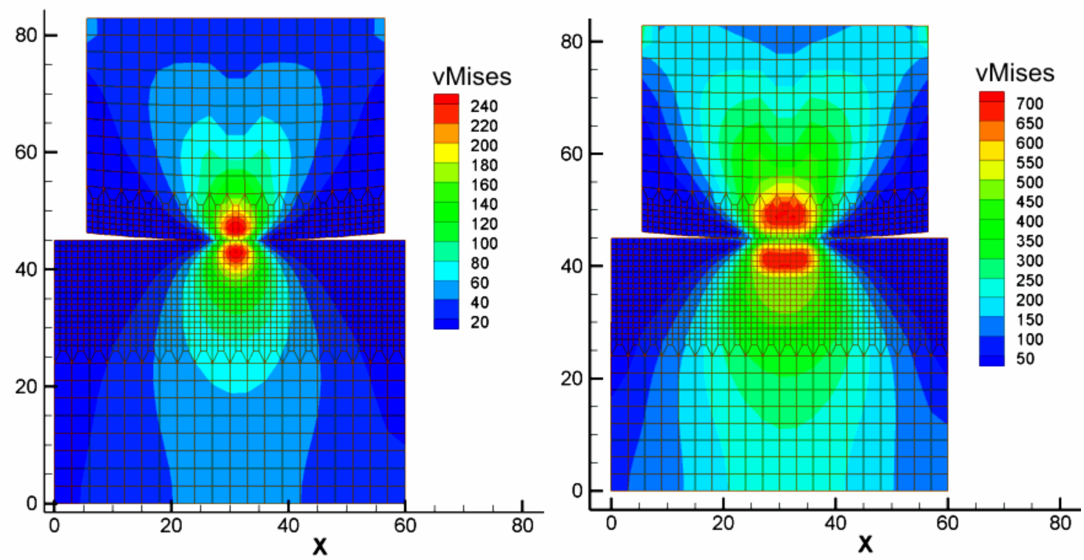

Figure 2. Distribution of von Mises stress, $\sigma_{yo}^{basic} = 450 N/mm^2$, hard layer $\sigma_{yo}^{layer} = 700 N/mm^2$, h=6 mm, external load F= 250 kN (a) and F= 1000 kN (b)

In addition to stress-strain state, we have determinated the load level at which plastic deformations occur, depth at which it began and the path of plastic zone spreading. Equivalent (effective, accumulated) plastic strain is the most appropriate variable to show initiation and spreading of plastic zone. In Fig.3 we show moment of plastic zone initiation (a) and size and shape of developed plastic zone at the final load step (b). Initiation of plastic flow began at 600 kN at 6 mm depth, at the boundary of hard layer and substrate.

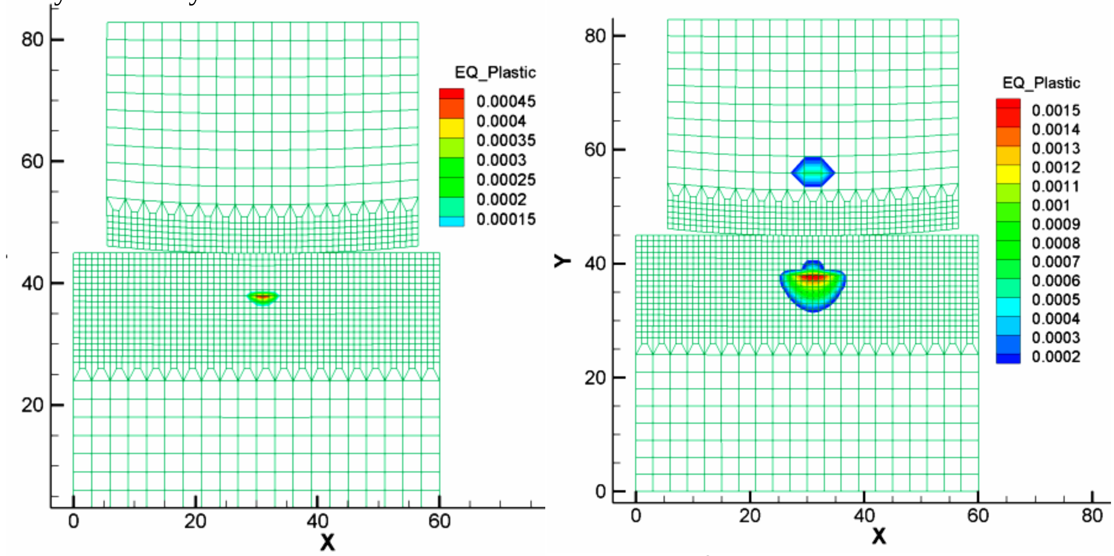

Figure 3. Initiation (a) and spreading of plastic zone (b)

3. MATHEMATICAL MODEL

It could be very useful in practice to have a possibility for the preliminary determination of contact pair load capacity without numerical simulation. For that purpose, we develop mathematical model based on the data obtained by numerical simulation (meta-model). The model should include three parameters: thickness of surface layer (h), yield stress of surface layer material (σ_{yo}^{layer}) and yield stress of basic (substrate) material (σ_{yo}^{basic}). In mathematical sense, it is necessary to establish relation between external load level that causes plastic deformation (F_{max}), layer thickness and material properties. The relation could be in the form: $F_{\max} = f(\sigma_{yo}^{basic}, \sigma_{yo}^{layer}, h_{layer})$. Series of numerical simulations consist of 4·4·4 = 64 individual simulation. The obtained database is used for multidimensional polynomial approximation based on last square fit. The quadratic polynomial model with three variables requires a lot of parameters C_i to be computed (10). From the practical point of view, it is not suitable so we choose to develop model based on 2 variables, considering the value of yield stress of basic material as constant for the given model. In that case, the model is defined as:

$$F_{MAX} = f(\sigma_{Y0}^{SL}, h_{SL}) = C_0 + C_1 \cdot \sigma_{Y0}^{SL} + C_2 \cdot h_{SL} + C_3 \cdot (\sigma_{Y0}^{SL})^2 + C_4 \cdot (h_{SL})^2 + C_5 \cdot \sigma_{Y0}^{SL} \cdot h_{SL} \qquad (1)$$

In order to obtain coefficients $C_0 - C_5$ in the last square sense, the system of linear equation (2) have to be solved:

$$\frac{\partial F_{MAX}}{\partial C_i} = \sum 2 \begin{pmatrix} F_i^{MAX} - C_0 + C_1 \cdot (\sigma_{Y0}^{SL})_i + C_2 \cdot (h_{SL})_i + \\ + C_3 \cdot (\sigma_{Y0}^{SL})_i^2 + C_4 \cdot (h_{SL})_i^2 + C_5 \cdot (\sigma_{Y0}^{SL})_i \cdot (h_{SL})_i \, \dfrac{\partial i}{\partial C_i} \end{pmatrix} = 0\,; \quad i = 0,1,2,\ldots 5 \qquad (2)$$

The solution of (2), for the given basic material $\sigma_{yo}^{basic} = 450\ N/mm^2$, $\sigma_{yo}^{basic} = 600\ N/mm^2$ will give the coefficients: *C_0 = -92.203;,C_1= 0.4377;C_2= -7.71299, C_3= -0.3 10^{-4},C_4= -1.389 10^{-2},C_5 = 1.4844 10^{-2}*
Quadratic polynomial approximation (fitting) is based at 16 points evaluation and it is shown in Fig.4.

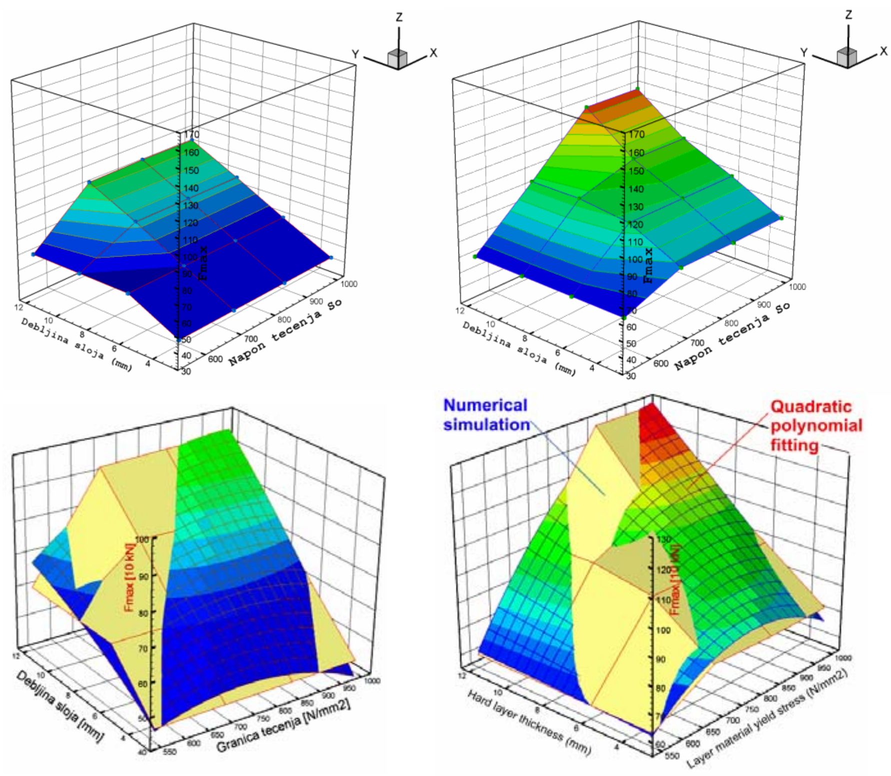

Figure 4. Quadratic polynomial approximation $\sigma_{yo}^{basic} = 450 N/mm^2$ **(a);** $\sigma_{yo}^{basic} = 600 N/mm^2$ **(b)**

4. CONCLUSIONS

The following conclusions can be drawn from the results of the numerical simulation:

- Contact concept based on node-to-segment contact algorithm and penalty function method for contact constraint regularization is stabile and robust concept for 2D elastic-plastic contact problems of layered solids.
- On the basis of developed model, it is possible to simulate and investigate different kind of contact problems and to reveal optimal surface layer/material properties.
- In the elastic range (equivalent stress is below yield stress) , there is no difference between layered body and homogeneous material because we take the same elastic properties for the surface layer and basic material.
- Increasing the load, the depth at witch yielding begin is also increasing. Plastic flow begins when equivalent stress reaches yield stress. The plastic zone is spreading mainly in radial and down directions. If load level is high enough, plastic zone would reach free surface (uncontained flow, large deformation).
- Deformations at the contact surface are small despite spreading of plastic zone. It is (plastic zone) surrounded with elastically deformed material and plastic and elastic part of the strain are of the same order of magnitude.
- Initiation of plastic flow in the depth of material has a little influence at magnitude of contact pressure and the form of its distribution. Only at high level of plastic deformation effect of contact pressure redistribution could be observed.
- Increasing the yield strength of surface layer does not guarantee plastic deformation protection. Thickness of hardfacing layer should be enough in order that yield occur in the hard layer, at higher load level (Fig.4 a,b). If hard layer in not thick enough, the plastic flow will occur in basic material below layer boundary. It could be the cause of surface layer breakdown.
- Mathematical model (1) is well suited for practical, preliminary determination of load bearing capacity for the given geometry and the given range of thickness/material properties. The extrapolation of data out of numerical simulation scope should be done with special attention.

5. REFERENCES:

[1] Arnell, R.D. and Djabella, H. Two-dimensional finite element analysis of elastic stresses in double layer systems under combined surface normal and tangential loads, Thin Solid Films, 226, 65-73,1993

[2] Chen W.T. (1971), Computation of stresses and displacements in a layered elastic medium, Int. J. Eng.Sci., 9, 775-800. Chen W.T. and Engel, P.A. (1972), Impact and contact stress analysis in multi-layered media, Int. J. Solids Structures., 8, 1257-1281.

[3] Cosic S., Maneski T. "Contact Analysis of Crawler Pads", TMT 2006, Barcelona, Spain 2006.

[4] Johnson, K.L., Contact Mechanics, Cambridge University Press, 1985

[5] J.C. Simo, T.J.R. Hughes, Computational Inelasticity, Springer-Verlag, New York 1998

[6] I. Hrgovic, "Analiza kontaktnih naprezanja i deformacija na metalnim prevlakama" Magistarski rad, Sveuciliste u Rijeci, Tehnicki fakultet, Rijeka 2000 god.

[7] Laursen TA, Simo JC. On the formulation and numerical treatment of finite deformation frictional contact problems, Computational Methods in Nonlinear Mechanics, 1991; 716–736.

[8] Pfister, Eberhard: , Frictional contact of flexible and rigid bodies, Springer-Verlag 2002

[9] Wriggers P. Computational Contact Mechanics, John Wiley and Sons, Ltd 2002.

[10] Elsharkaway, A.A. and Hamrock, B.J. (1993), Numerical solution for dry sliding line contact of multilayered elastic bodies, ASME J. Tribology, 115, 237-245.

[11] Gupta P.K. and Walowit, J.A. (1974) Contact stresses between an elastic cylinder and a layered elastic solid, ASME J. Lub. Tech., 96, 259-257.

[12] Komvopoulos, K. (1988), Finite element analysis of a layered elastic solid in normal contact with a rigid surface, Trans. ASME J. Trib., 110, 477-485.

[13] Komvopoulos, K. (1989), Elastic-plastic finite element analysis of indented layered media, Trans ASME J. Trib., 111, 430.

[14] Tian, H. and Saka, N. (1991), Finite element analysis of an elastic-plastic two-layer half-space; normal contact, Wear, 148, 47-68.