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FINITE ELEMENT MODEL OF THE ORE DISINTEGRATION PROCESS

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ABSTRACT:
This paper is focused on the numerical analysis of the hard rock (ore) disintegration process. The computational modelling leads to the mechanical contact problem between the hard rock and the cutting bit. The bit (i.e. excavation tool with a flat frontal side and a conical edge) moves and sinks into the hard rock and subsequently disintegrates it. The whole problem of the hard rock disintegration process (i.e. stress-strain relationship, contact forces, reaction forces and fracture of the ore) is solved via FEM (MSC.MARC/MENTAT software). Some results (reaction forces in the cutting bit etc.) are also compared with experimental measurements.

KEYWORDS:
Hard rock (ore), cutting bit, disintegration process, Finite Element Method, experiments

1. INTRODUCTIVE NOTES

Science and technical development supplies new ways for the solution of the ore disintegration process, see Fig.1 and rederences [1], [7], [9] and [10]. Provision of sufficient quantities of raw materials and energy for the processing industry is the main limiting factor of further development. In this case, it is very important to understand the analysis of the ore disintegration process, which includes the analysis of the bit (i.e. excavation tool) used in mining operations. The main focus is dedicated to the modelling of the mechanical contact between the bit and the ore, see Fig.1 and references [4] and [10].

FIGURE 1. TYPICAL EXAMPLE OF MECHANICAL INTERACTION WITHIN THE BITS AND HARD ROCK (I.E. ORE DISINTEGRATION PROCESS)

2. FINITE ELEMENT MODEL OF THE ORE DISINTEGRATION PROCESS

There is also a possibility of Finite Element Method (FEM) applications. Hence, FEM (i.e. MSC.MARC/MENTAT 2005r3 software) was used in the solution of the ore disintegration process. Figure 2 shows the basic scheme of the solution via FEM. The FE mesh contains 37663 nodes and 71755 plane elements.

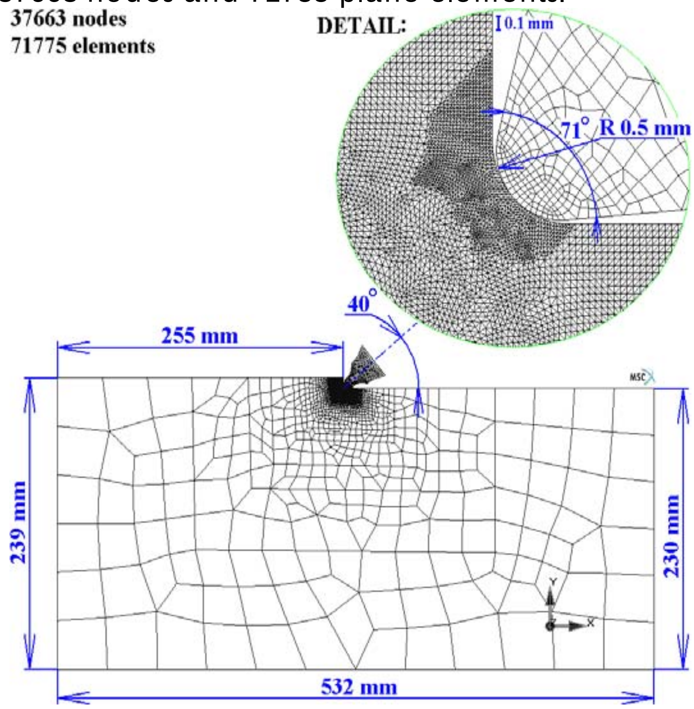

FIGURE 2. SCHEME AND GEOMETRY OF THE 2D FE MESH MODEL AND ITS DETAIL

The basic boundary conditions for plain strain formulation and loads are described in Fig.3, where u is the prescribed X-axis displacement and v is the prescribed Y-axis displacement. There is also a mechanical contact with Coulomb's friction between the bit and platinum ore, because the bit works through the ore and disintegrate it. From Fig.3, it is evident that the bit is moving into the ore by the prescribed time dependent function $u = f(t)$, see arrows in Fig.3. There is also prescribed zero displacement on three edges of the modelled area, see arrows in Fig.3.

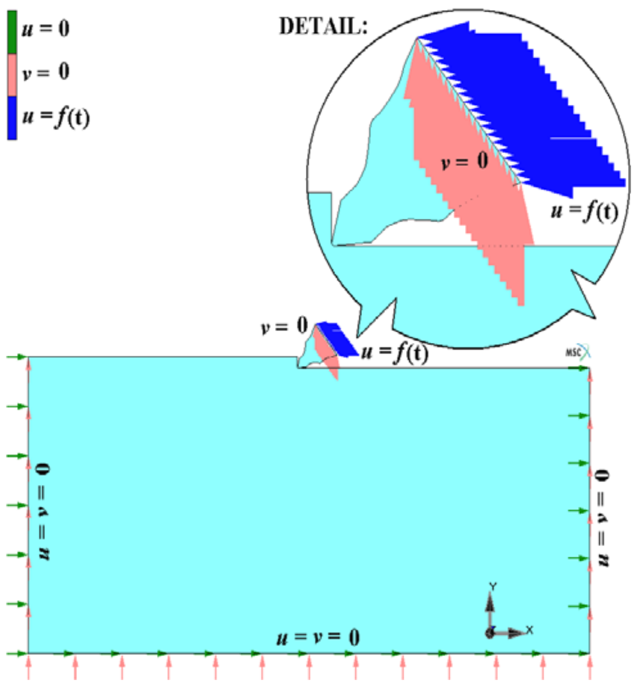

FIGURE 3. BOUNDARY CONDITIONS SCHEME OF THE 2D MODEL (PLANE STRAIN FORMULATION).

Material properties (i.e. isotropic and homogeneous materials) of the whole system are described in Fig.4, where E is Young's modulus of elasticity and μ is Poisson's ratio.

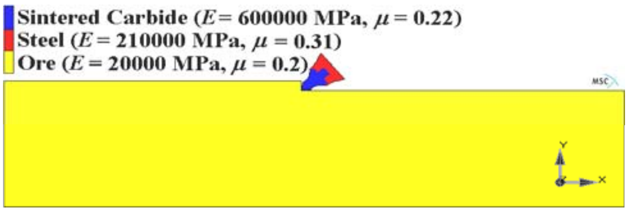

FIGURE 4. MATERIAL PROPERTIES.

Hence, the bit is made of sintered carbide (sharp edge) and steel. The ore material is elasto-plastic with yield limit $R_p = 12\,\mathrm{MPa}$ and fracture limit $R_m = 13.5\,\mathrm{MPa}$, see Fig.5.

When the bit is moving into the ore (i.e. a mechanical contact between the bit and the ore occurs) the stresses (i.e. equivalent von Mises stresses, see [4] and [5]): $\sigma_{HMH} = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 - \sigma_1\sigma_2 - \sigma_2\sigma_3 - \sigma_3\sigma_1}$ in the ore increases. When the situation $\sigma_{HMH} > R_m$ occurs (i.e. equivalent stress is greater than the fracture limit) in some elements of the ore, then these elements break off (i.e. these elements are dead). Hence, the disintegration of a part of the ore is done. In the MSC.MARC/MENTAT software, it is done by deactivating the elements which satisfy condition $\sigma_{HMH} > R_m$. This deactivation of the elements was done in every 5th step of the solution.

Because of the material non-linearities, the mechanical contacts with friction, the large number of elements and many iteration steps, four parallel computers (Linux OS, 4×CPU AMD Opteron 848 with 4 GB RAM memory, application of Domain Decomposition Method, see Fig.6) were used to solve the large computational needs of this problem.

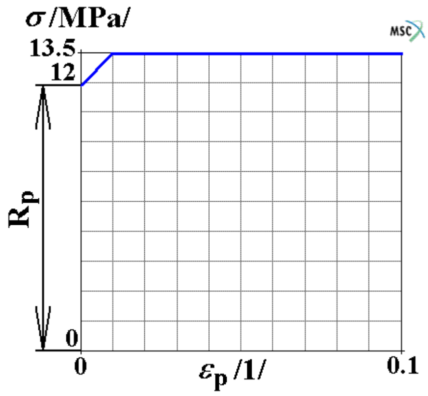

FIGURE 5. RELATIONSHIP BETWEEN STRESS AND PLASTIC STRAIN FOR PLATINUM ORE

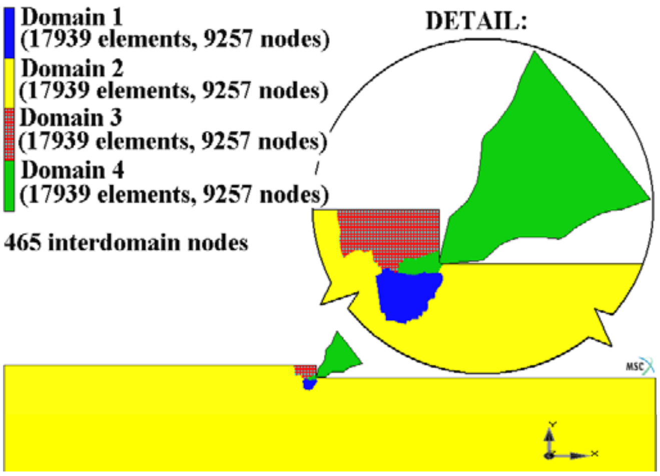

FIGURE 6. DOMAIN DECOMPOSITION METHOD APPLIED FOR APPLICATION OF 4×CPU.

3. RESULTS OF FEM

The whole solved time of the non-linear solution (i.e. 1.04 s) was divided into 370 steps of variable length. The Full Newton-Raphson method was used for solving the non-linear problem.

The following figures show equivalent stress (i.e. σ_{HMH} distributions) at some chosen time t of the solution. Hence: Fig.7 - t =0 s, i.e. start of the solution, Fig.8 - t = 3.37×10^{-2} s, Fig.9 - t = 2.388×10^{-1} s, Fig.10 - t = 3.714×10^{-1} s, Fig.11 - t = 5.796×10^{-1} s, Fig.12 - t = 8.335×10^{-1} s, Fig.13 - t = 8.511×10^{-1} s and Fig.14 - t = 1.026 s.

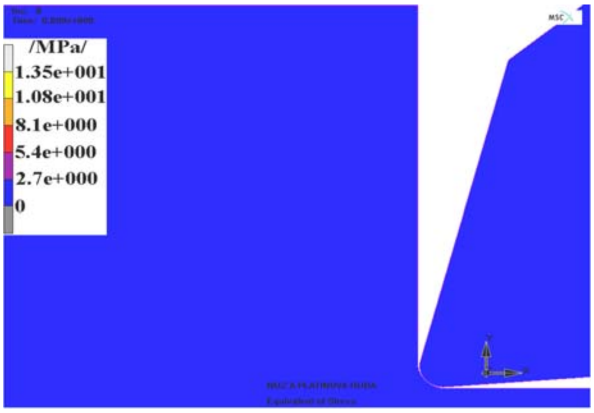

FIGURE 7. - t =0 s (Start of the Solution).

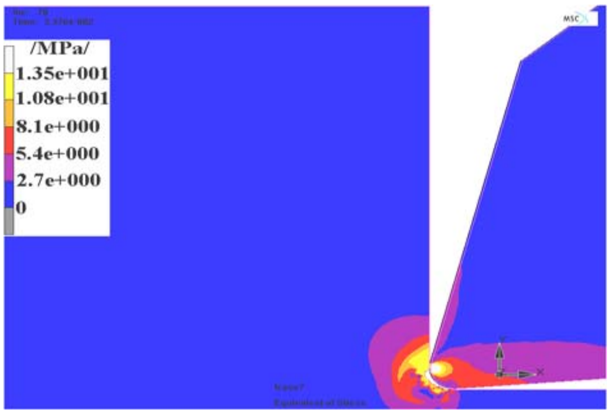

FIGURE 8. - t = 3.37×10^{-2} s.

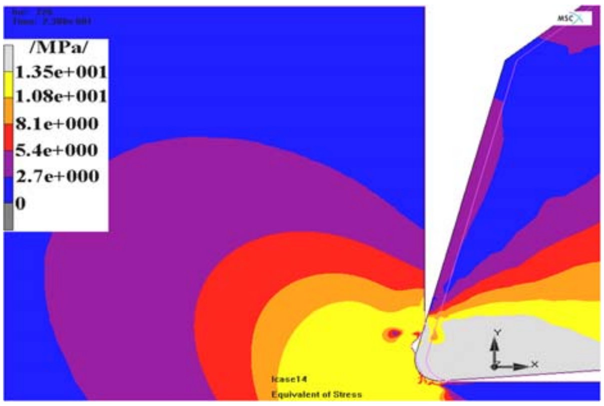

FIGURE 9. - t = 2.388×10^{-1} s.

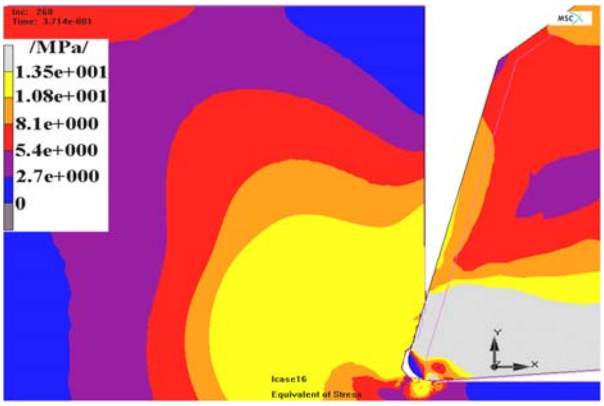

FIGURE 10. - t = 3.714×10^{-1} s.

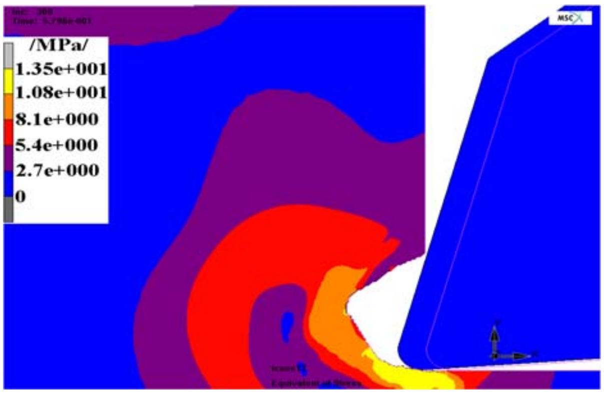

FIGURE 11. - t = 5.796×10^{-1} s.

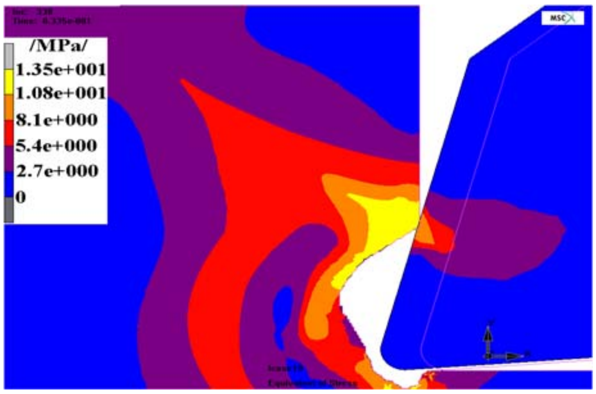

FIGURE 12. - t = 8.335×10^{-1} s.

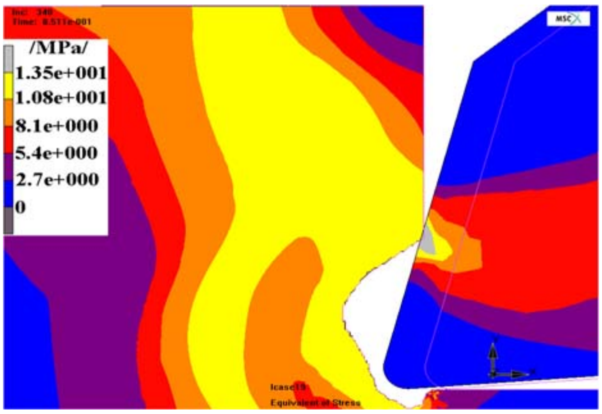

FIGURE 13. - t = 8.511×10^{-1} s.

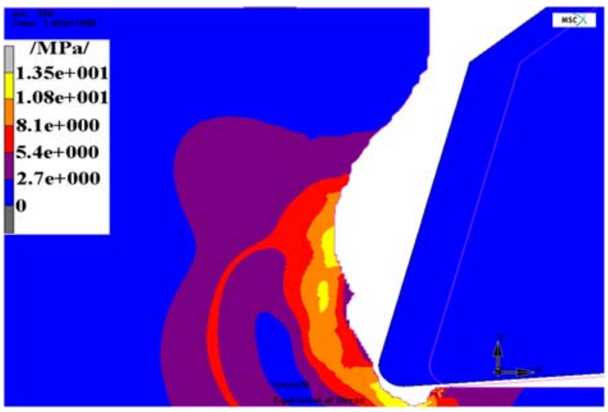

FIGURE 14. - t = 1.026 s.

In Figures 7 to 14, the moving of the bit is evident and also the subsequent disintegration of the ore caused by the cutting bit.

From the results of FEM the reaction forces R_X, R_Y and total reaction force $R = \sqrt{R_X^2 + R_Y^2}$ which act in the bit, can be calculated, see Fig.15 and 16. The maximum reaction force (acquired by FEM) is $R_{MAX_{FEM}} = 4598$ N.

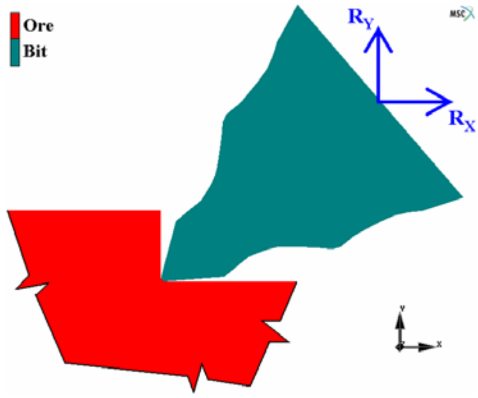

FIGURE 15. REACTION FORCES IN THE BIT

4. COMPARSION OF FEM RESULTS WITH EXPERIMENTAL MEASUREMENTS

The calculated forces (i.e. FEM solution, see Fig.16) can be compared with the experimental measurements (i.e. compared with the part of Fig.17), see also [2], [3] and [9].

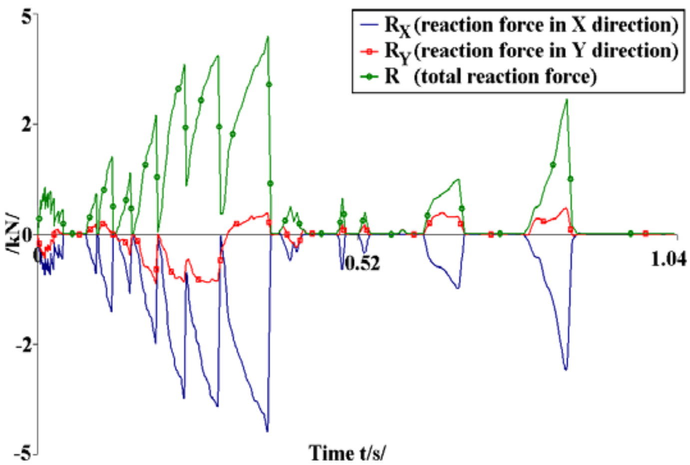

FIGURE 16. REACTION FORCES IN THE BIT (FEM RESULTS)

From the evaluation of experiments it is evident that the maximum force is $R_{MAX_{EXP}} = 5280$ N.

Hence, the relative error is:

$$\Delta_{R_{MAX}} = 100 \times \frac{R_{MAX_{EXP}} - R_{MAX_{FEM}}}{R_{MAX_{EXP}}} = 100 \times \frac{5280 - 4598}{5280} = 12.9\ \% . \qquad (1)$$

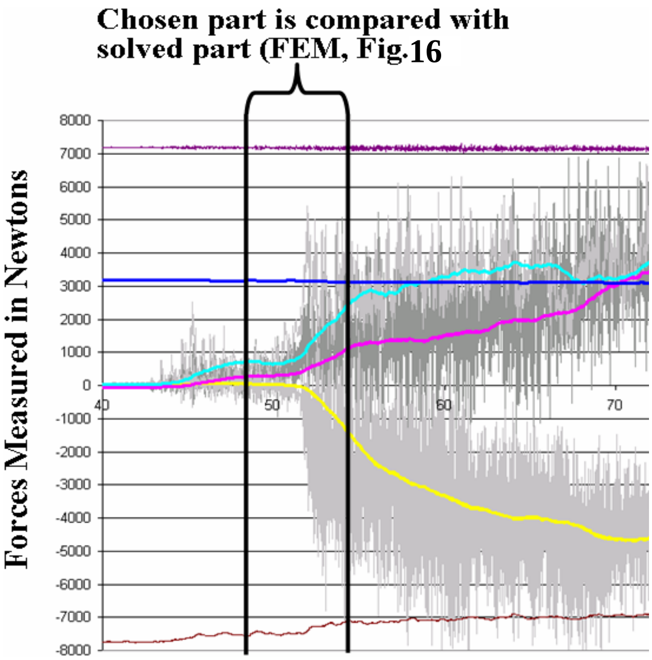

FIGURE 17. EXPERIMENTAL MEASUREMENTS AND ITS COMPARISON WITH THE FEM SOLUTION

The error of 12.9% is caused by the chosen 2D FE model (i.e. plane strain formulation) which is sometime a pure (but simple) approximation of real 3D situation. However, the experiments also have a large variability of inputs caused by anisotropic and stochastic properties of the material and by the large variability of reaction forces, for example see Fig.17.

5. THE CONCLUSIONS

This contribution shows FEM as tool for the solution of the hard rock (ore) disintegration process. All basic aspects (i.e. 2D boundary conditions, material nonlinearities, mechanical contacts and friction between the cutting bit and the ore, methodolgy of deactivation of FE elements during the ore disintegration process, application of paralel computers) was briefly explained. Using of deactivating of FE elements during the ore disintegration process (as a way of crack expansion) is a new and modern way of solution of this problems.

The error of the FEM result (i.e. comparing with experiments, see eq. (1)) is acceptable. Hence, FEM can be useful tool for the solution of the ore disintegration process.

All presented results were applied for optimalisation and new design of the bit.

In the future will be applied 3D FE models (instead of 2D plane strain formulation), which can be more accurate.

Because the real material of the ore (i.e. yield limit, fracture limit, Young's modulus, Poisson's ratio etc.) has large variability, the stochastic theory and theory of probability can be applied. Hence, in the future the whole presented problem can be solved via the SBRA Method (Simulation Based Reliability Assessment Method), see [6] and [8]. The SBRA Method, which is based on Monte Carlo simulations, can include all stochastic inputs and then all results are also of stochastic quantity. However, for application of SBRA method for the solution of this large problrm of mechanics must be used superfast parallel computers.

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