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PROBABILISTIC APPROACHES APPLIED IN THE SOLUTION OF PROBLEMS IN MINING AND BIOMECHANICS

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Abstract: *This paper focuses on the probabilistic numerical solution of the problems in mining and biomechanics. Theory and applications of the Simulation-Based Reliability Assessment (SBRA) method are presented in the solution of a hard rock (ore) disintegration process (i.e. the bit moves into the ore and subsequently disintegrates it, the results are compared with experiments, new design of excavation tool is proposed) and in the solution of designing of the external fixators applied in traumatology and orthopaedics (these fixators can be applied for the treatment of open and unstable fractures or for lengthening human or animal bones etc.). Application of the SBRA method connected with FEM in these areas is a new and innovative trend.*

Keywords: ***SBRA method, hard rock (ore) disintegration, rock mechanics, traumatology, external fixators, biomechanics.***

1. Introduction

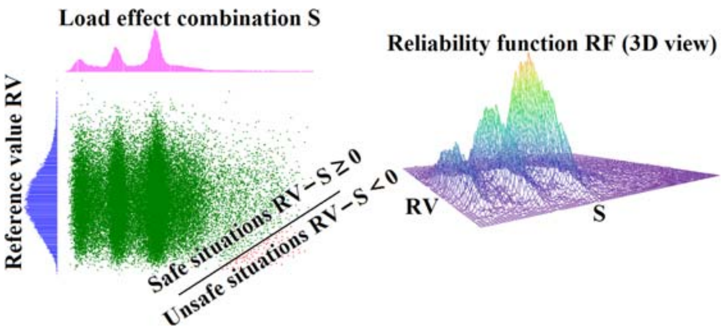

Fig. 1: Reliability function RF (SBRA method).

In structural reliability assessment, the concept of a limit state separating a multidimensional domain of random (stochastic) variables into “safe” and “unsafe” domains has been generally accepted, see references Frydrýšek1 (2009), Haldar & Mahadevan (2001), Marek & Brozzetti (2003) and Marek & Guštar (1995). Let us consider the Simulation-Based Reliability Assessment (SBRA) Method, a probabilistic direct Monte Carlo approach, in which all inputs are given by bounded histograms. Bounded histograms include the real variability of the inputs. Application of the SBRA method is a modern and innovative trend in mechanics. Using SBRA method, the probability of failure (i.e. the probability of undesirable situation) is obtained mainly by analyzing the reliability function $RF = RV - S$, see Fig. 1. Where RV is the reference (allowable) value and S is a variable representing the load effect combination. The probability of failure is the probability that S exceeds RV (i.e. $P(RF \le 0)$). The probability of failure is a relative value depending on the definition of RV and it usually does not reflect an absolute value of the risk of failure (for example, it usually does not correspond to a “total” collapse).

Hence, this paper focuses on the probabilistic numerical solution of the problems in mining and biomechanics. Application of the SBRA method connected with FEM in these areas is a new and innovative trend.

2. Solution of a hard rock disintegration process

The provision of sufficient quantities of raw materials for the metallurgy is the main limiting factor of further development. It is therefore very important to understand the ore disintegration process, including an analysis of the bit (i.e. excavation tool) used in mining operations. The main focus is on

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modelling of the mechanical contact between the bit and the platinum ore and its evaluation (i.e. practical application in the mining technology), see Fig. 2. However, material properties of the ore have a large stochastic variability. Hence, the stochastic approach (i.e. SBRA Method in combination with FEM is applied). MSC.Marc/Mentat software was used in modelling this problem.

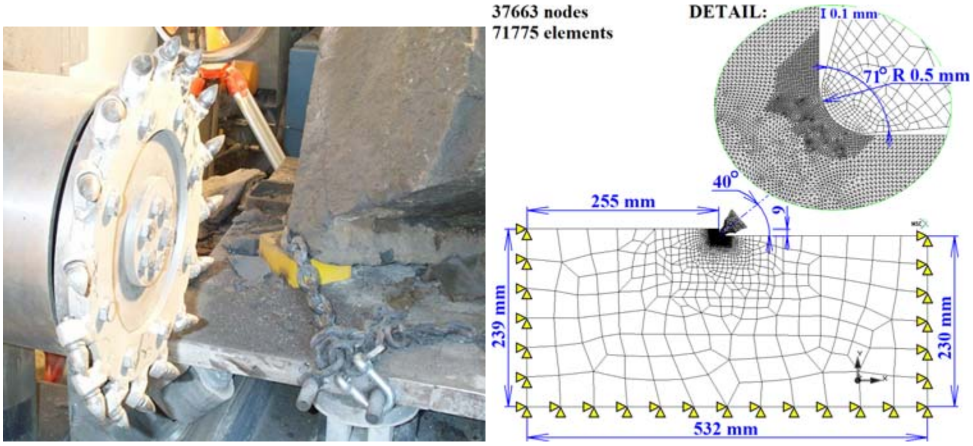

Fig. 2: Typical example of mechanical interaction between bits and hard rock (ore disintegration process) and its solution via FEM.

The bit moves into the ore with the prescribed time dependent function and subsequently disintegrates it. When the bit moves into the ore (i.e. a mechanical contact occurs between the bit and the ore) the stresses (i.e. the equivalent von Mises stresses) in the ore increase. When the equivalent stress is greater than the tensile strength in some elements of the ore, then these elements break off. Hence, a part of the ore disintegrates. This is done by deactivating the elements, see Fig. 3.

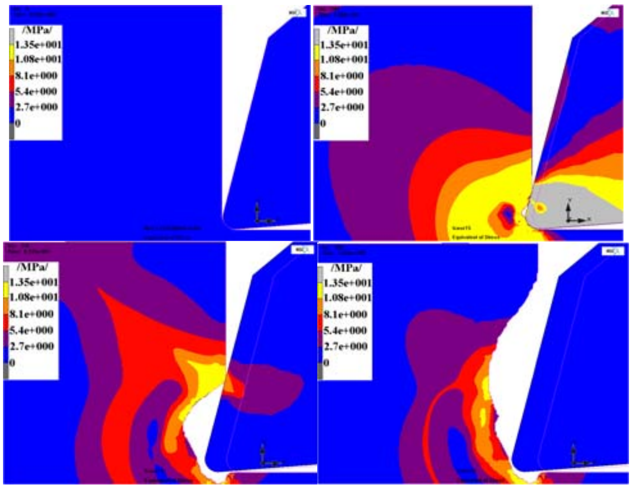

Fig. 3: Disintegration of the ore and movement of the bit (equivalent von Mises stresses distributions).

The ore material is elasto-plastic with isotropic hardening rule. The probabilistic inputs, i.e. elastic properties (Modulus of elasticity E and Poisson's ratio μ) and plastic properties (yield stress R_p and fracture stress R_m) are described by bounded histograms, see Fig. 4.

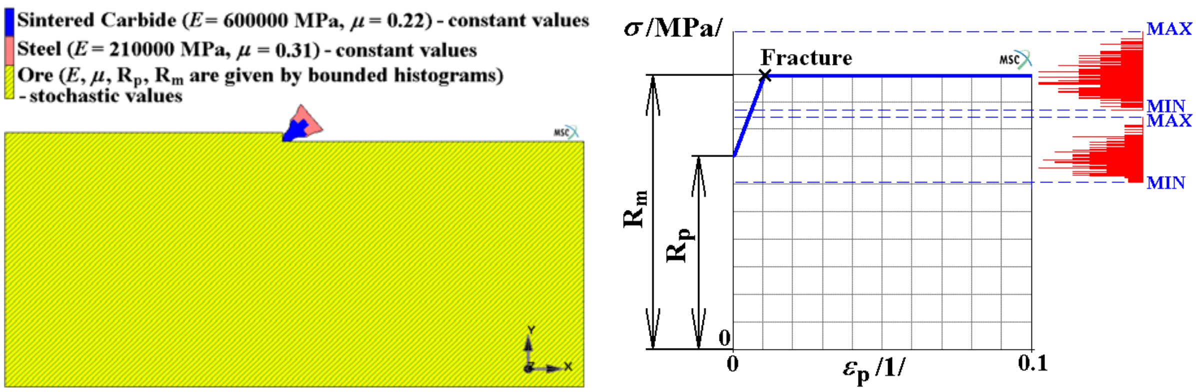

Fig. 4: Material properties (probabilistic inputs).

The results (acquired by SBRA method in combination with FEM) were subsequently statistically evaluated (Anthill, MSC.Marc/Mentat and Mathcad software were used). Because of the material non-linearities, the mechanical contacts with friction, the large number of elements, many iteration steps, and the choice of 500 Monte Carlo simulations, four parallel computers (with 26 CPU) were used to handle the large computational requirements for this problem.

From the results, the reaction forces can be calculated. These forces act in the bit, see Fig. 5 (distribution of the total reaction forces acquired from 500 Monte Carlo simulations - stochastic result, i.e. print of 500 curves). The calculated maximum forces (i.e. SBRA-FEM solutions, see Fig. 5a) can be compared with the experimental measurements (i.e. compared with a part of Fig. 5b). However, the experimental results also have large variability due to the anisotropic and stochastic properties of the material and due to the large variability of the reaction forces.

All the results presented here were applied for optimizing and redesigning of the cutting bit (excavation tool), see Fig. 6. For more information see references Frydrýšek (2009a), Frydrýšek (2009b) and Frydrýšek (2009c).

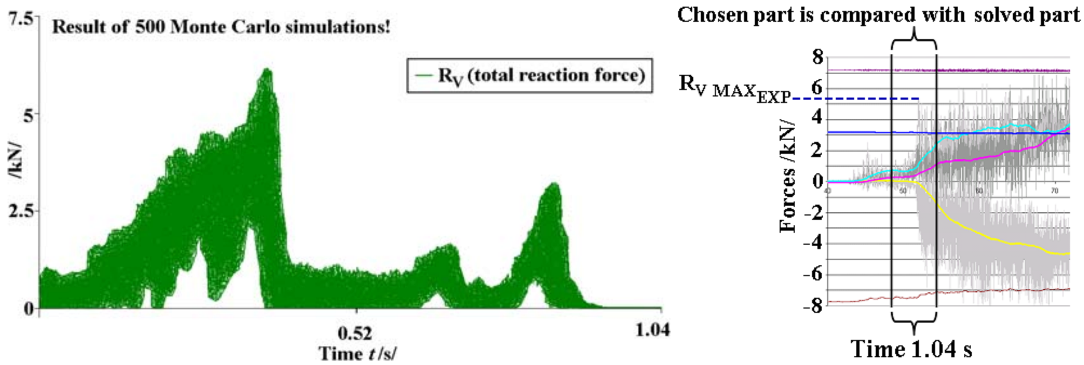

Fig. 5: Calculated reaction forces in the bit (probabilistic approach) and their measurements.

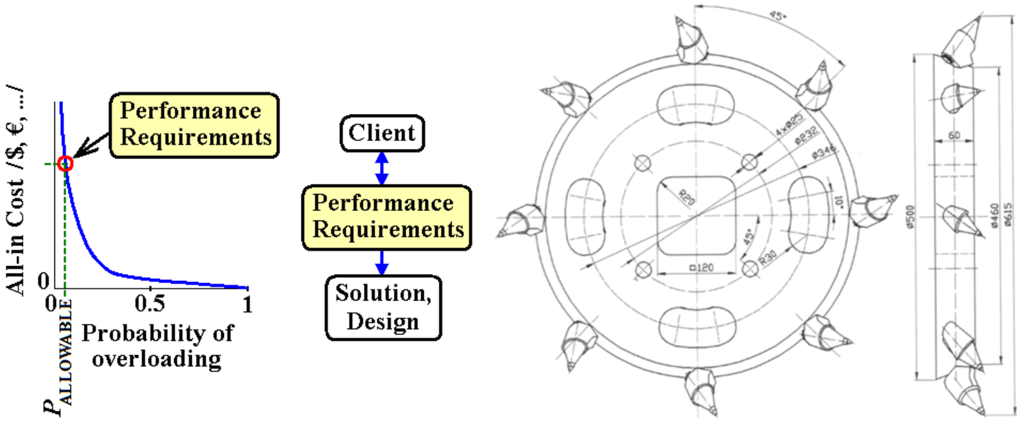

Fig. 6: Definition of the acceptable probability of overloading and final shape of excavation tool for platinum ore disintegration process.

3. Designing of external fixators applied for the treatment of open and unstable fractures

According to the current studies and research, performed at VŠB – Technical University of Ostrava and Traumatology Centre of the University Hospital of Ostrava (Ostrava, Czech Republic), for example see references Frydrýšek & Pleva (2010), Madeja & Pleva (2009), Pleva (1999) and Rozum (2008), the current design of external fixators must be modified, see Fig. 7. Fixators can be applied in traumatology, surgery and orthopaedics. Such as treatment of open and unstable (complicated) fractures, limb lengthening, deformity correction, consequences of poliomyelitis, foot deformities, hip reconstructions, for treatment of humans and animals etc. However, there are real needs to make a modern design of fixators which satisfy new trends and demands in medicine, see Frydrýšek & Pleva (2010). These demands, which are mutually

Fig. 7: Design of external fixators a) based on metals - current design, heavier, expensive, etc. b) based on reinforced polymers - new design, lighter, cheap, more friendly etc.).

connected, should be solved by:

1. Applications of new smart materials (The outer parts of fixators must be x-ray invisible - which leads to shortening the operating time and reducing the radiation exposure of patients and surgeons. Antibacterial protection - application of nanotechnologies on the surface of the outer parts of the fixators to prevent or reduce possible infection. Weight optimalization).
2. New design (according to shape, ecological perspective, patient's comfort, reducing the time of the operation, reducing the overall cost, "friendly-looking design").
3. Measuring of the real loadings (strain gauges etc.).

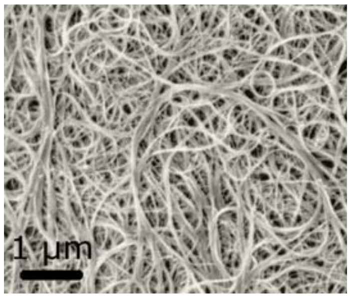

Fig. 8: CNT bundles.

4. Numerical modelling and experiments (i.e. SBRA application, FEM etc., to avoid the overloading).

It is possible to satisfy all these demands by a new composite materials using proper polymers reinforced by the carbon nanotubes (CNT), because some current solutions based on light metals (aluminium, titanium etc.) are heavy and visible in x-ray diagnostic, see Fig. 7 and 8. New proposed design cannot be more specified here. The reason for this are the business secrets.

4. Conclusions

Application of the SBRA Method in the area of rock mechanics (hard rock disintegration process - design of excavation tool) and biomechanics (design of external fixators in traumatology) were reported. Application of the SBRA method is a modern and innovative trend in engineering.

Acknowledgement

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