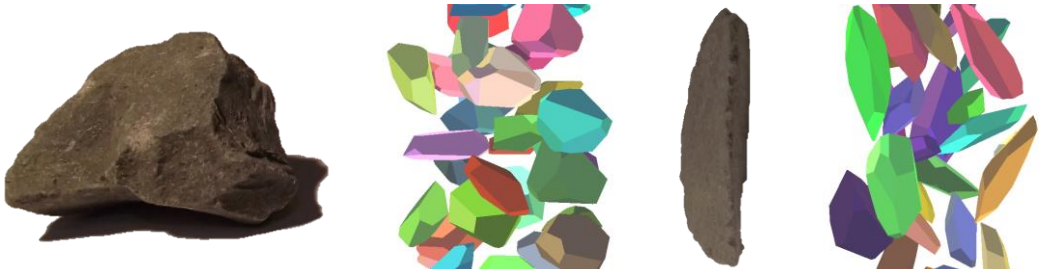
Discrete element modelling of crushed rocks to simulate railway ballast and machine-rock interaction

Researcher: Ákos Orosz (PhD student, Dept. of Machine and Product Design, BME)
Supervisors: Katalin Bagi (full prof., Dept. of Structural Mechanics, BME)
Kornél Tamás (assistant prof., Dept. of Machine and Product Design, BME)
György Kerényi (associate prof., Dept. of Machine and Product Design, BME)

Crushed rock aggregates are often found in architectural structures. One of their most common application is forming a railway ballast. The grains of the aggregate are subjected to dynamic loads from train traffic, which results in sliding and other changes in their mutual positions. Crushing and abrasive wear of the individual grains can happen as well. The individual motion of the particles makes discrete (distinct) element method (DEM) excellent for modelling them, which models the materials using particles (elements) with independent translational and rotational degrees of freedom and arising forces (interactions) between them.
There are several types of machines which interact with crushed rocks (e.g. mining and railway maintenance machines). Complex load distribution develops while the tools of these appliances come into interaction with the processed material. These loads are often simplified in calculations (e.g. analytic, finite element (FEM) simulations) and replaced with point or uniformly distributed loads. Concerning the desired precision, the simplification still can be a good solution as according to Saint-Venant's principle, the difference between two different, but statically equivalent loads becomes very small at sufficiently large distances from load. However, near the region, where loads act, the results using the simplifications are not precise, therefore finding the optimal tool design is difficult.
As DEM allows to simulate and track the trajectory of each particle and their loads, it is capable to compute the exact load distribution on the tool. By importing the loads from the DEM simulation into the FEM calculation thus performing a coupled simulation, the stress, strain and surface pressure field of the tool are calculated more accurately. In possession of the detailed stress state, the optimization of the tool can be performed, and a better construction may be created.

DEM modelling of crushed rock aggregate

Creating the proper DEM model of a material is a complex task: firstly, the suitable particle shape, constitutive models have to be chosen, then the parameters are calibrated iteratively by comparing the simulations with measurement data.
In our study the sharp crushed rocks are represented by 3D scanned and simplified, as well as randomly generated convex polyhedra (*Figure 1*), which creates the possibility to model and study the effect of the grain shape on the mechanical behaviour of the aggregate.



a) b) c) d)

Figure 1. Photos (a, c) and representations (b, d) of equant (a, b) and flat (c, d) grains [2]

For static calibration, uniaxial compression and large-scale shear box tests are conducted. The measurements are modelled (*Figure 2*) and compared with the corresponding experimental data to properly set the model parameters.

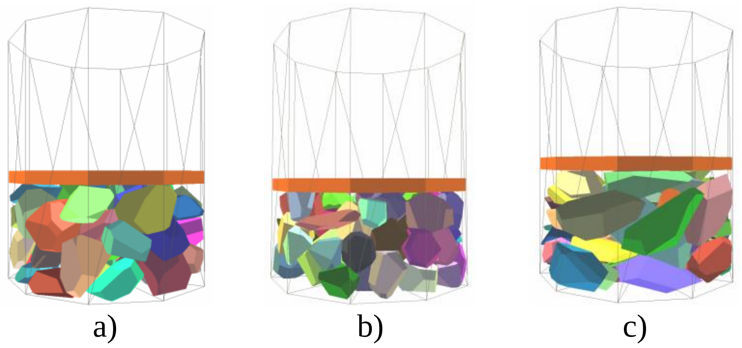


Figure 2. Different types of aggregates (a, equant, b, mixed, c, flat) at the start of the uniaxial press simulations [5]

Coupled FEM-DEM simulations

Finite element method is an excellent way to model materials as continuum, but often fails to simulate particles individually. Coupling DEM and FEM by modelling grains with DEM and the tool of the machines via FEM combines the benefits of each method.
A one-way connection was developed between an open source DEM (Yade) and a commonly applied FEM software (ANSYS). *Figure 3* shows the penetration of a crushed rock single particle due to uniaxial compression. The established method will be applied in technological simulations in the further stages of the research.

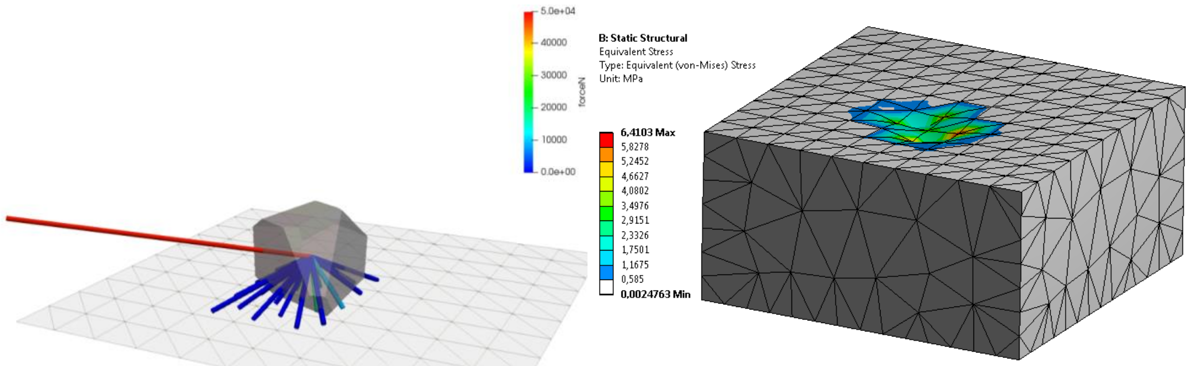


Figure 3. Simulation study of the interaction between steel and a rock grain during press [1]

Notable international publications

[1] A. Orosz, K. Tamas, J. P. Radics, and P. T. Zwierczyk, “Coupling Finite And Discrete Element Methods Using An Open Source And A Commercial Software”, in *ECMS 2018 Proceedings edited by Lars Nolle, Alexandra Burger, Christoph Tholen, Jens Werner, Jens Wellhausen*, 2018, pp. 399–404.

[2] Á. Orosz, K. Tamás, and J. P. Rádics, “The feasibility of modelling rocks in engineering applications with the use of discrete element method”, *Hungarian Agricultural Engineering*, no. 32, pp. 51–55, 2017.

[3] A. Orosz, J. P. Radics, and K. Tamas, “Calibration of railway ballast DEM model”, in *Proceedings 31st European Conference on Modelling and Simulation*, Budapest, Hungary, 2017, pp. 523–528.

[4] M. Gálos, Á. Orosz, J. P. Rádics, and K. Tamás, “Modelling the behaviour of concrete additives via discrete element numerical simulation”, in *Innovative Materials and Technologies for Concrete Structures: Proceedings of the fib Congress*, Tokaj, Hungary, 2017, pp. 607–614.

Publications in Hungarian language

[5] Gálos M. and Orosz Á., “Ágyazati kőanyagok viselkedésének vizsgálata ismételt terhelés hatására”, *Sínek Világa*, vol. 61, no. 1, pp. 10–15, 2019.

[6] Orosz Á., Zwierczyk P. T., Rádics J. P., and Tamas K., “A véges és a diszkrét elemes szimulációk kapcsolásának jelentősége a géptervezésben”, *OGÉT 2018: 26th International Conference on Mechanical Engineering*, Târgu Mureș, Romania, 2018, pp. 333-336.

[7] Gálos M., Orosz Á., Rádics J. P., and Tamas K., “Diszkrét elemes számítógépes módszer a vasúti zúzottkő ágyazat viselkedésének modellezésére,” *Sínek Világa*, vol. 59, no. 5, pp. 22–28, 2017.

[8] Orosz Á., Rádics J. P., and Tamás K., “Zúzottkő diszkrét elemes modelljének létrehozása vasúti pályakarbantartó gépek fejlesztéséhez”, in *OGÉT 2017: 25th International Conference on Mechanical Engineering*, Cluj-Napoca, 2017, pp. 291–294.