FAKULTA STROJNÍHO INŽENÝRSTVÍ
ústav automobilního a dopravního inženýrství

UKÁZKY CO-SIMULACÍ DEM SE STRUKTURÁLNÍ FEM A MBD PRO RŮZNÉ PRŮMYSLOVÉ APLIKACE

Konferenční prezentace

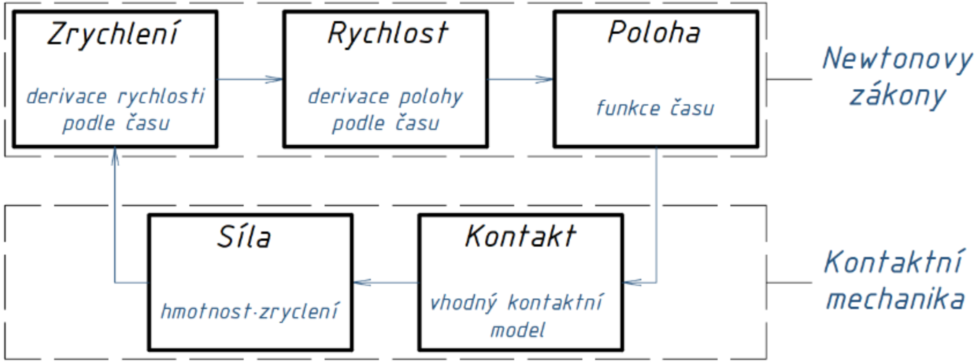
Autor: Ing. Jiří Frühbauer, Ing. Michal Kubiš, Ing. Ondřej Sedlařík

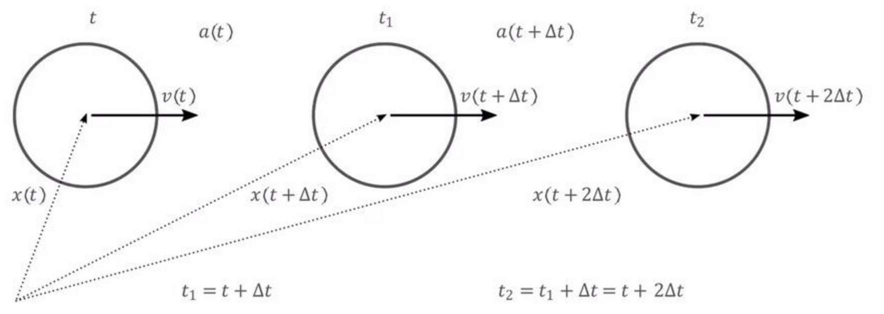
23.6.2026

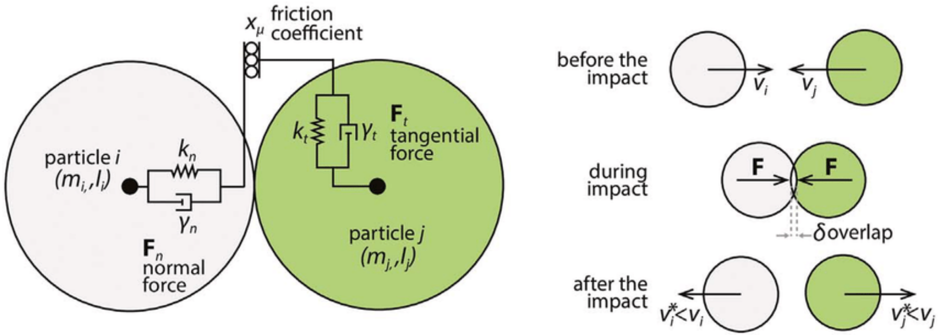
OBSAH

ÚVOD DO DEM SIMULACÍ

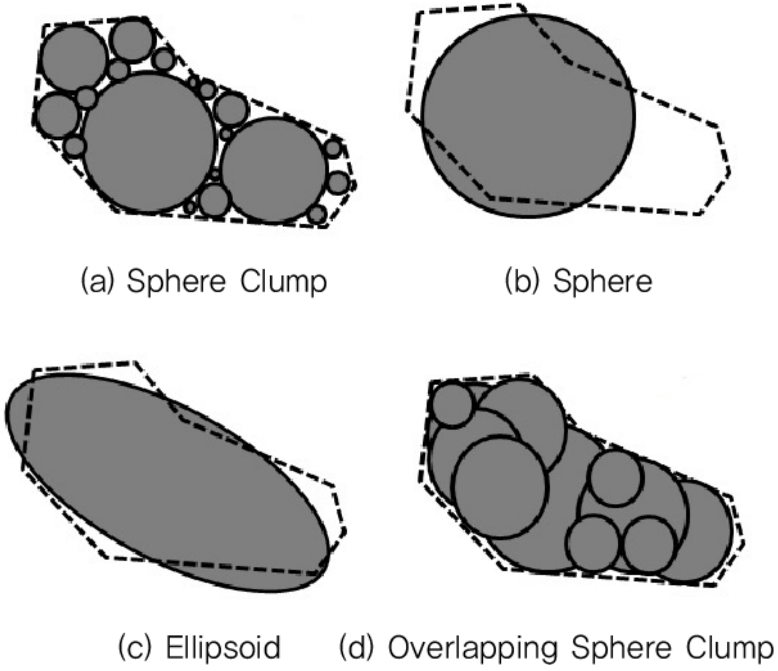
- DEM (Discrete Element Method)
- Vztah mezi Newtonovými pohybovými rovnicemi a kontaktní mechanikou

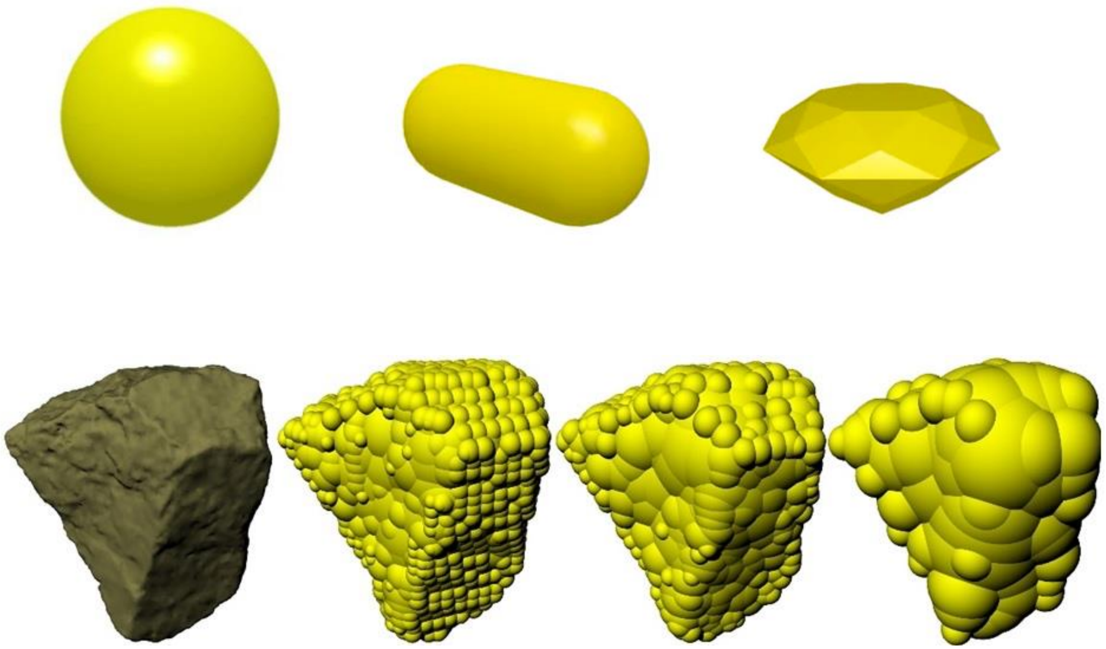






MODELOVÁNÍ SYPKÝCH MATERIÁLŮ PRO DEM ANALÝZY

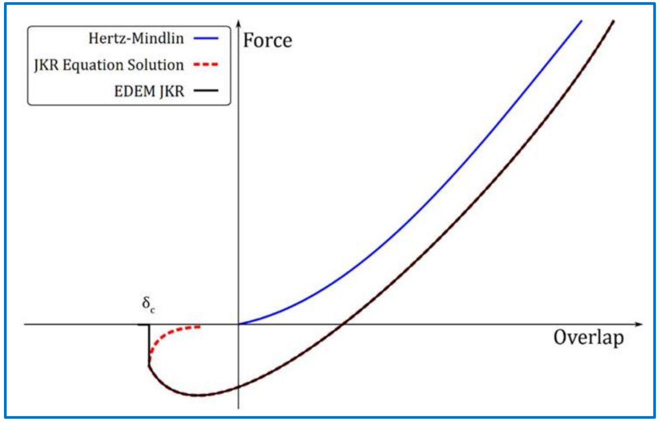


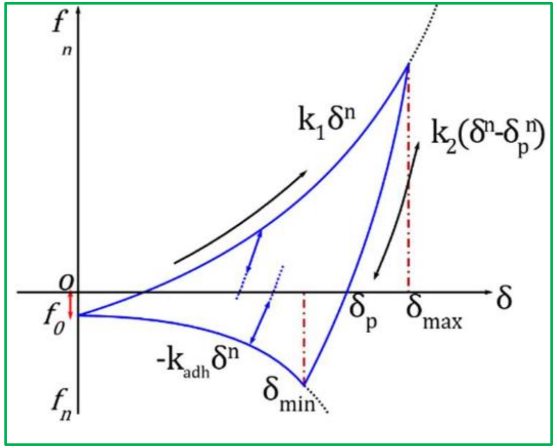


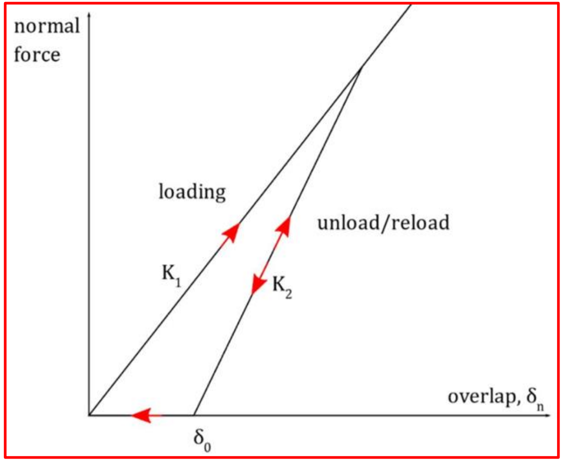
MODELOVÁNÍ SYPKÝCH MATERIÁLŮ PRO DEM ANALÝZY

- Přibližná volba kontaktního modelu:

Materiál se plasticky deformuje
- ne → Materiál je kohezní
  - ne → Hertz-Mindlin
  - ano → Hertz-Mindlin JKR
- ano → Materiál je kohezní
  - ne → Hysteretic spring
  - ano → EEPA







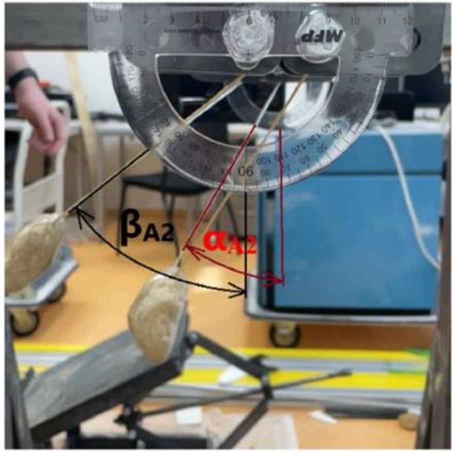
MODELOVÁNÍ SYPKÝCH MATERIÁLŮ PRO DEM ANALÝZY

Rozdělení velikosti částic

Sypný úhel

Sypná hmotnost

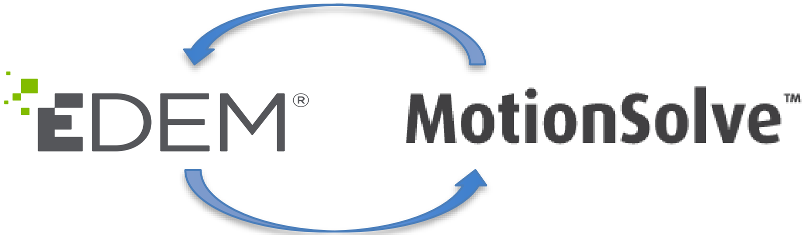
Koeficient restituce

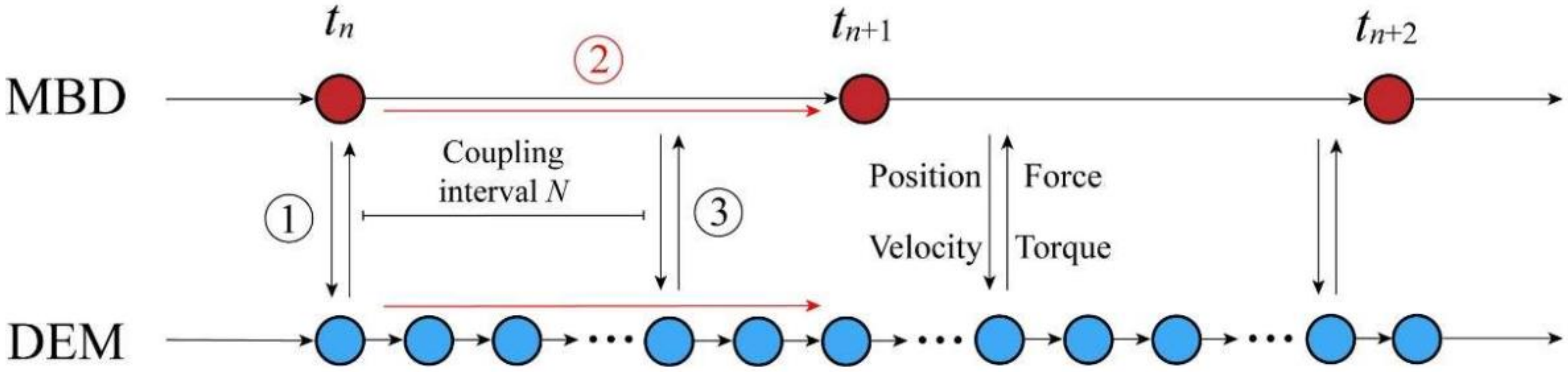


Koeficient statického tření

CO-SIMULACE DEM-MBD

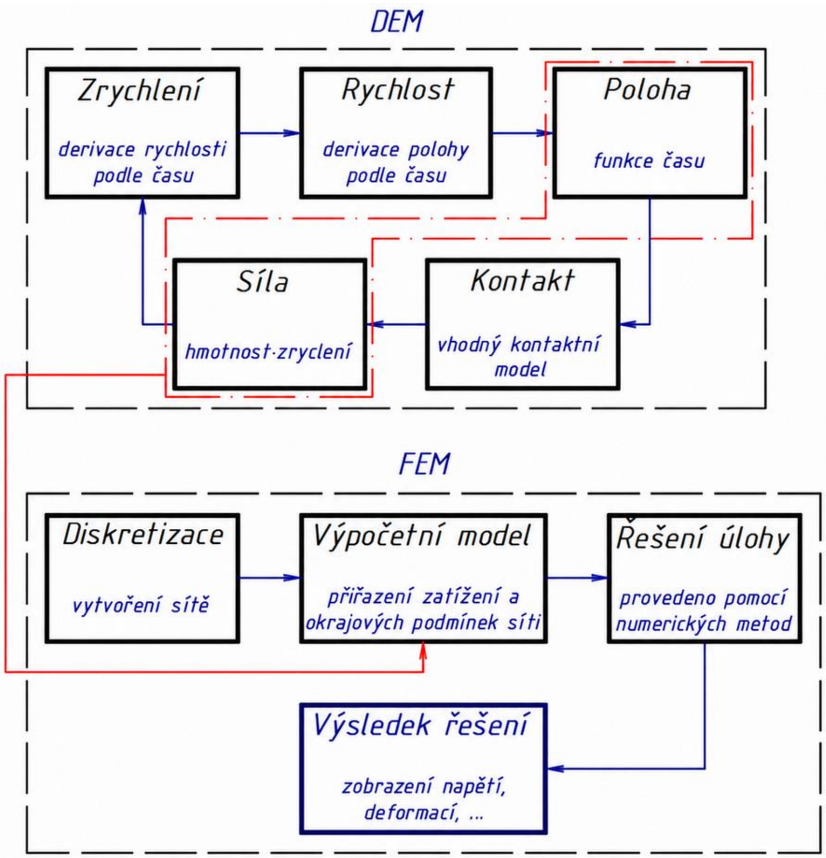
- Předávání informací z **MotionSolve** o pozicích/rychlostech geometrie a získávání zpětné silové/momentové vazby z **EDEM**
- Tvorba v prostředí **EDEM+MotionSolve**





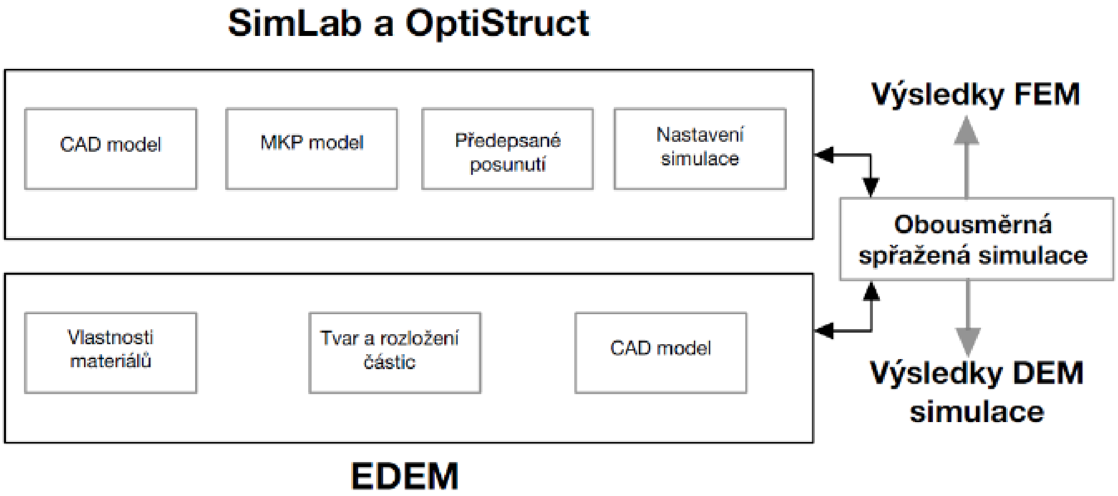
JEDNOSMĚRNÁ A OBOUSMĚRNÁ CO-SIMULACE DEM-FEM

- Předávání informací z **EDEM** o pozicích a velikostech sil působících na geometrii a export silového pole do **Optistruct** nebo **SimSolid**
- Tvorba v prostředí **EDEM+OptiStruct** a **EDEM+SimSolid**



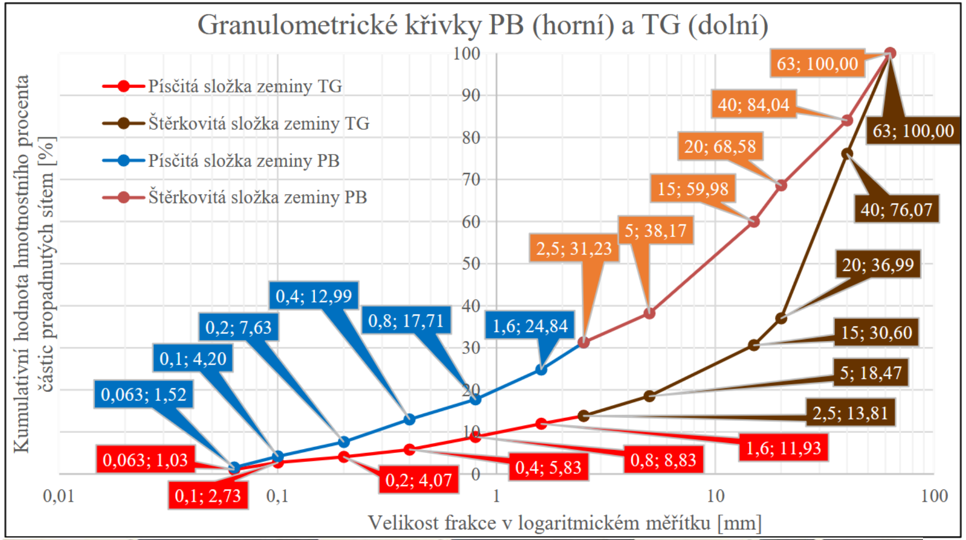
JEDNOSMĚRNÁ A OBOUSMĚRNÁ CO-SIMULACE DEM-FEM

- Předávání informací ze **SimLab** o pozicích uzlů geometrie a získávání zpětné silové/momentové vazby z **EDEM** a aktualizace posunutí uzlů sítě geometrie v **SimLab**
- Tvorba v prostředí **EDEM+SimLab** s explicitním řešičem **OptiStruct**

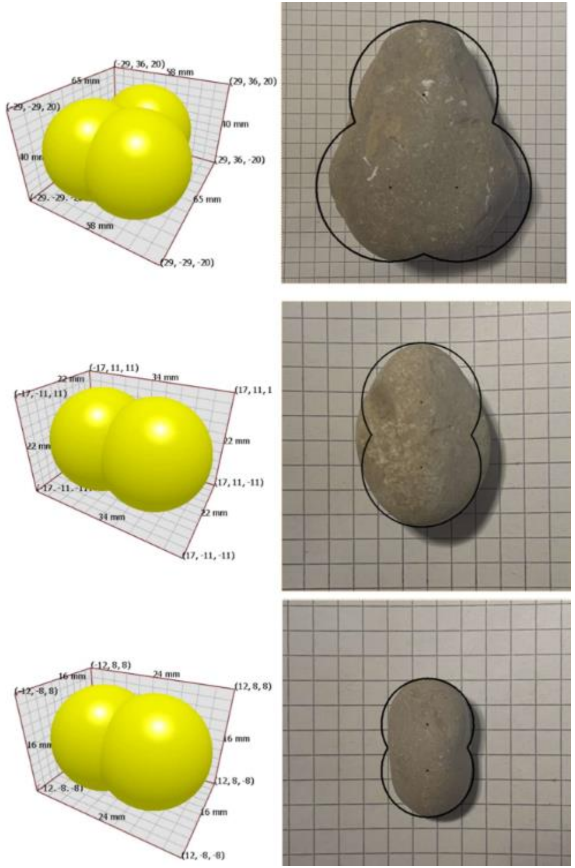


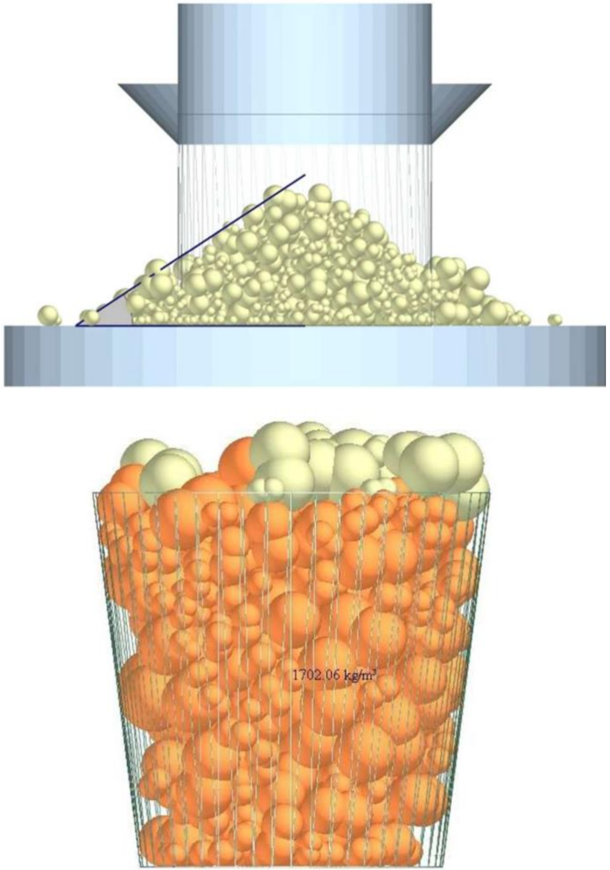
MĚŘENÍ MATERIÁLU PRO STAVEBNÍ STROJE

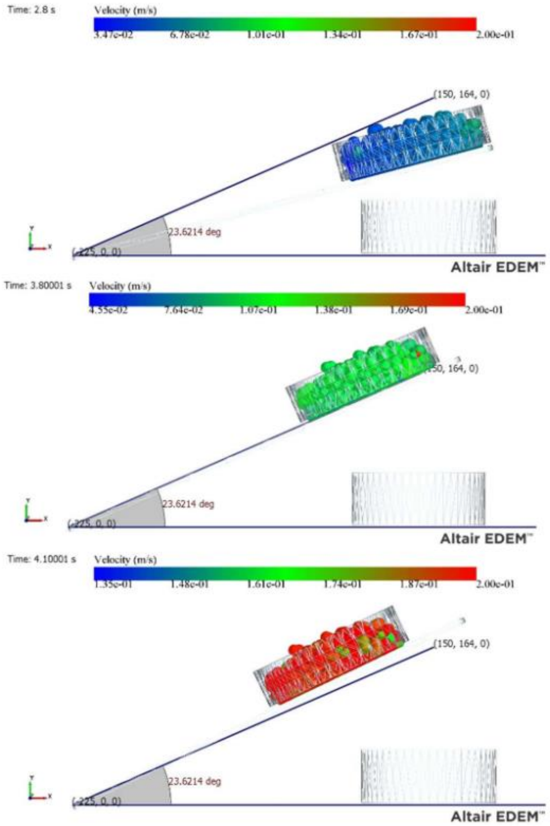
- Autor: Ing. Michal Kubiš, Bc. Patrik Míra, Ing. Vít Vašíř
- Použitý model: Hertz-Mindlin JKR



KALIBRACE MATERIÁLU PRO STAVEBNÍ STROJE



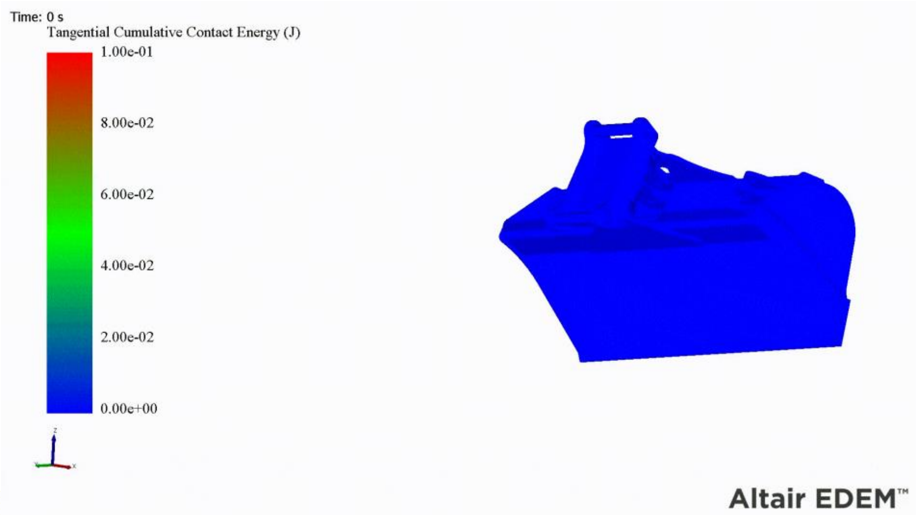


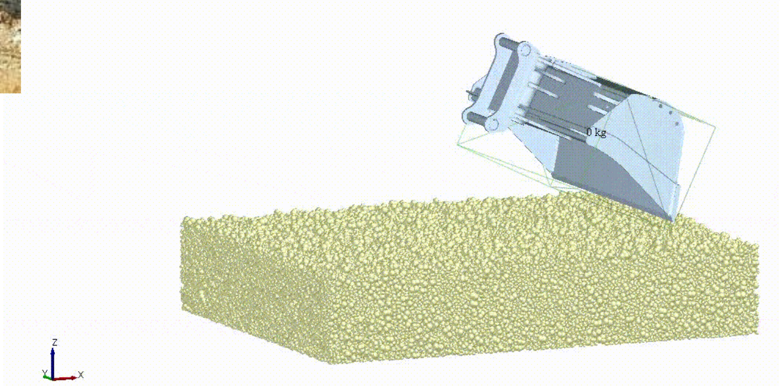


ANALÝZA LOPATY RYPADLA (2W DEM-FEM)

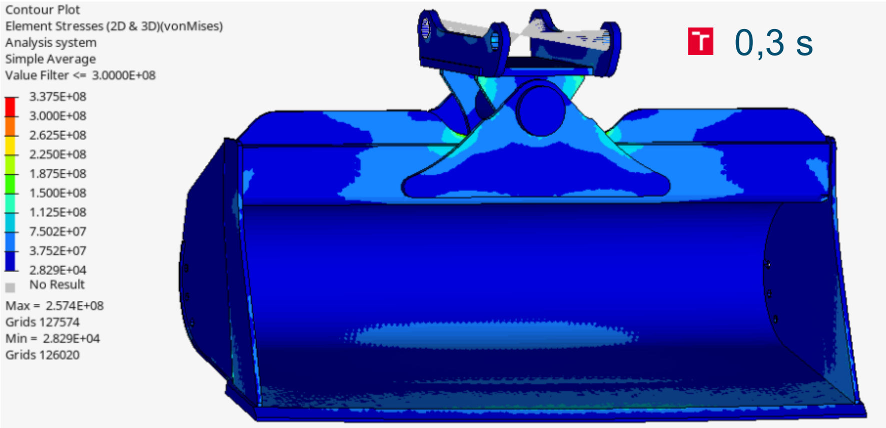
- Autor: Bc. Patrik Míra

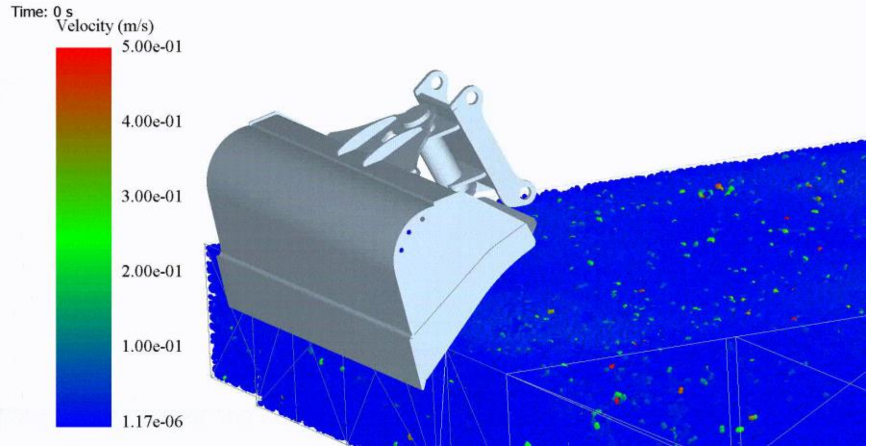
- Kolové rypadlo Wacker Neuson EW100

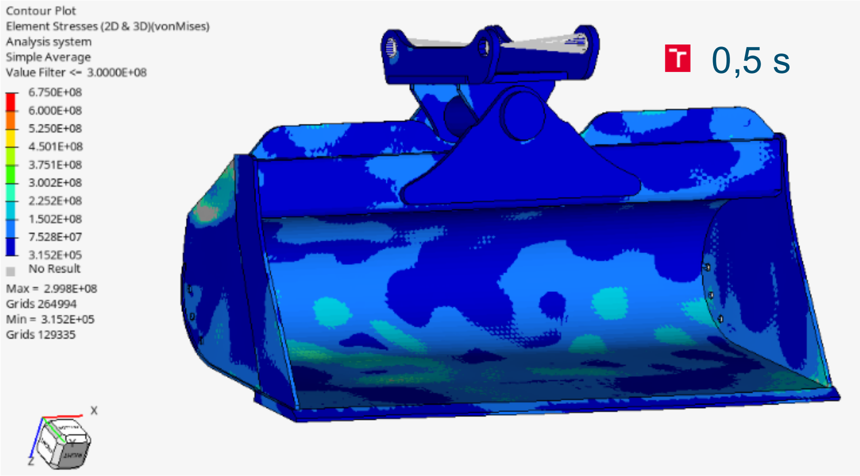


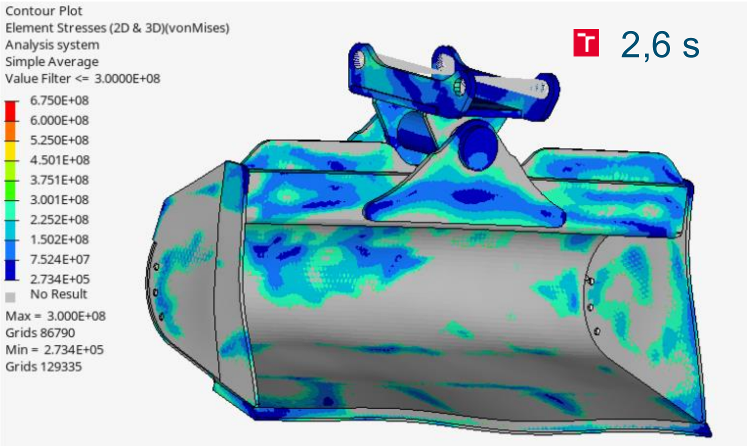


ANALÝZA LOPATY RYPADLA (2W DEM-FEM)



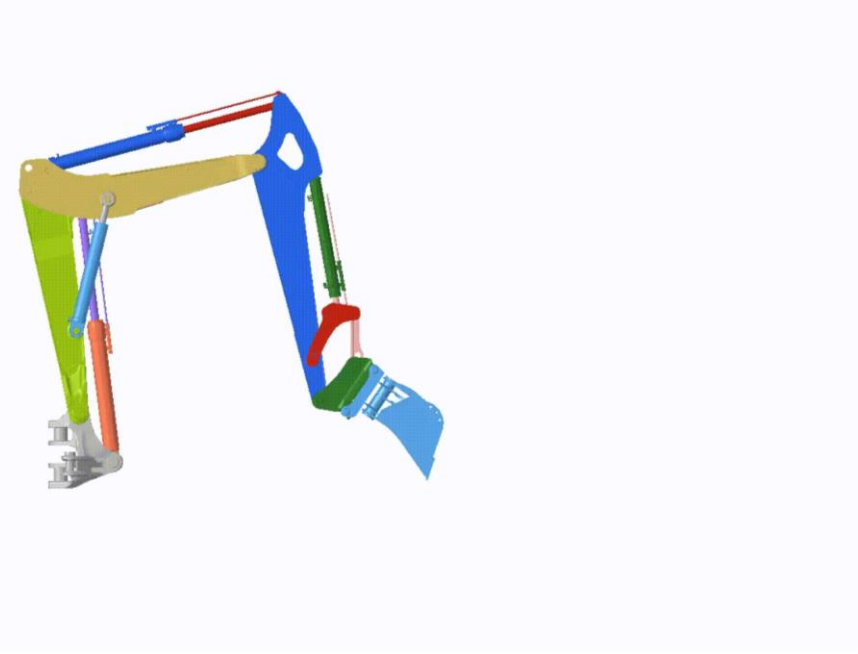




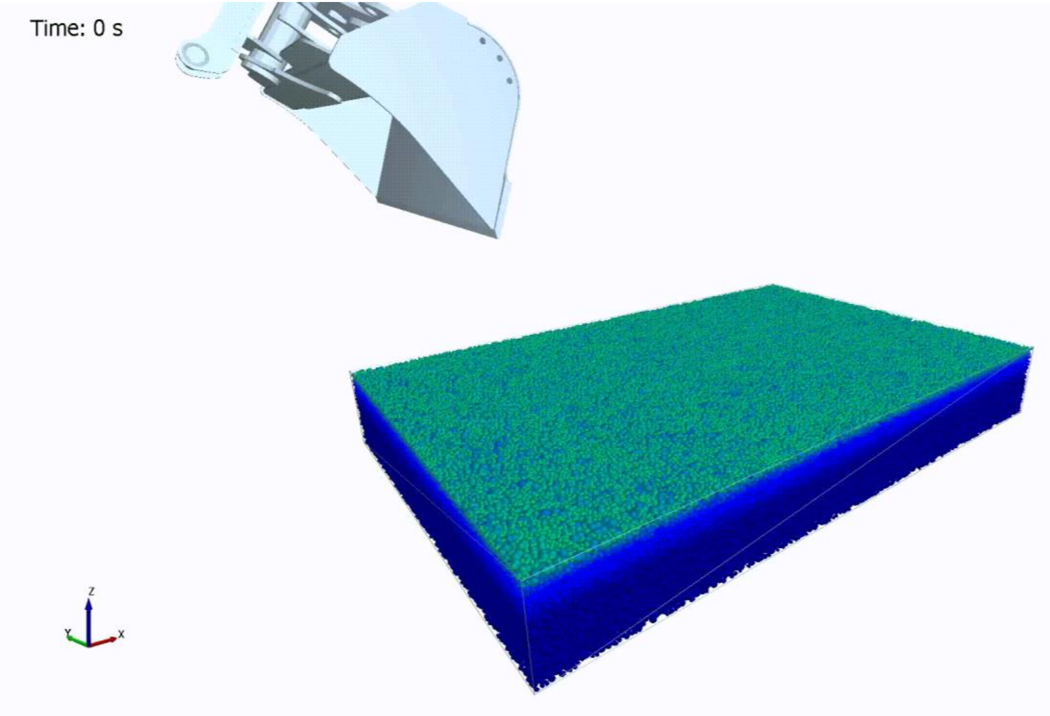


ANALÝZA PRACOVNÍHO CYKLU RYPADLA (DEM-MBD)

- Autor: Ing. Michal Kubiš

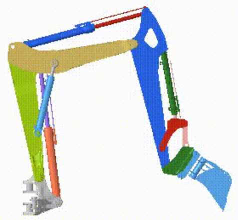


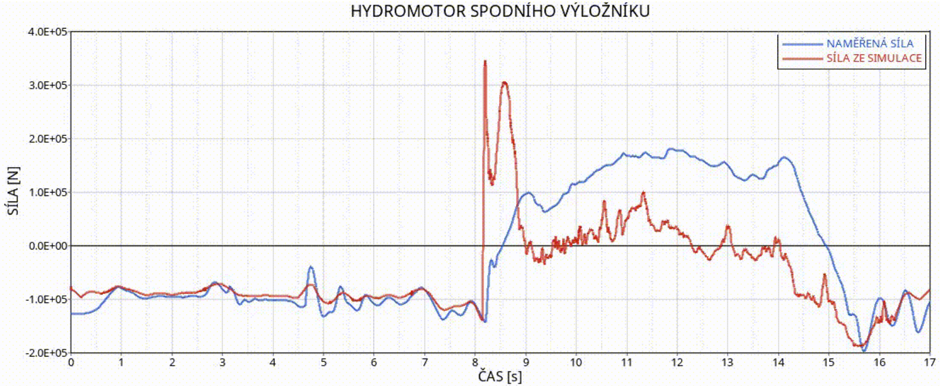
- MBD část

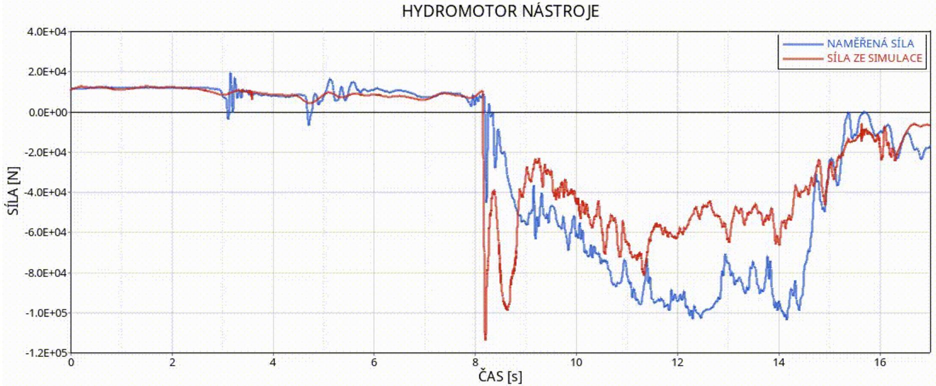


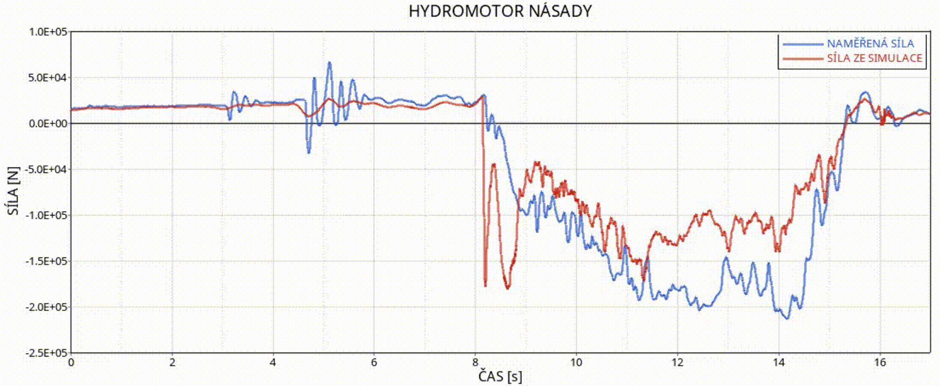
- DEM část

ANALÝZA PRACOVNÍHO CYKLU RYPADLA (DEM-MBD)



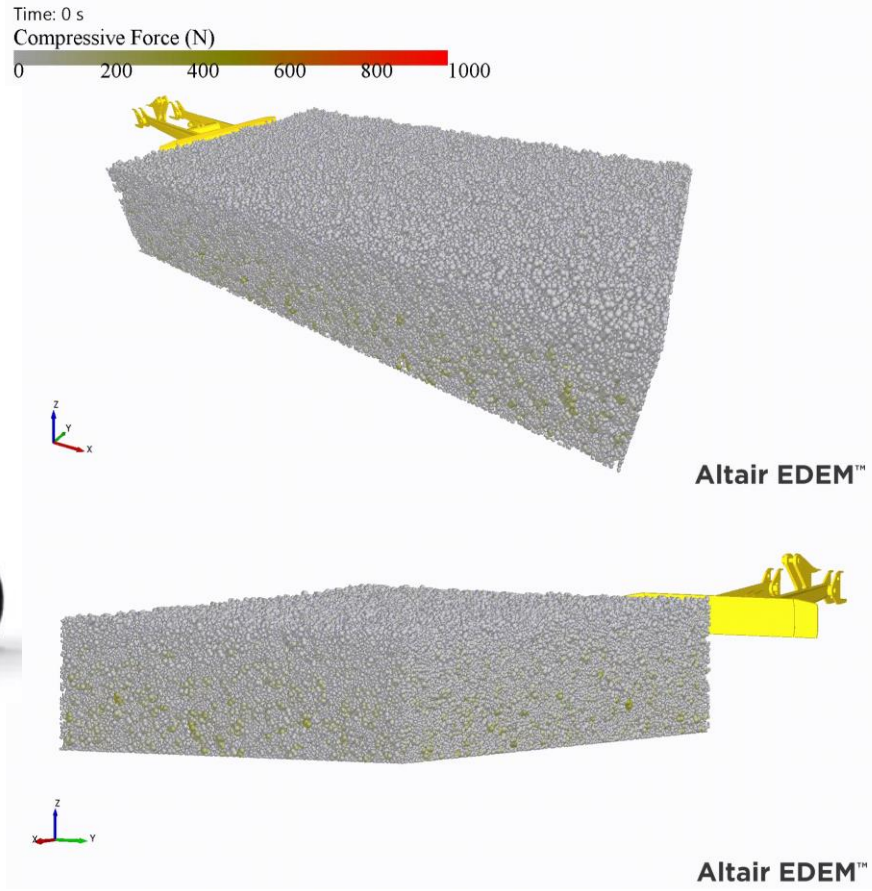






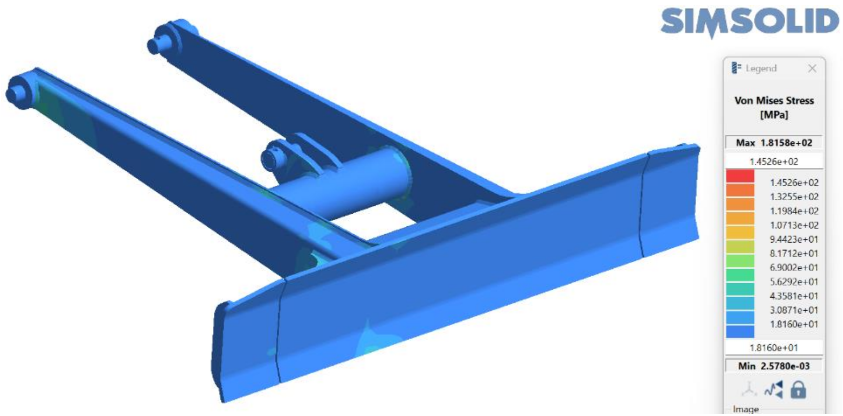
ANALÝZA DOZEROVÉ LOPATY RYPADLA (1W DEM-FEM)

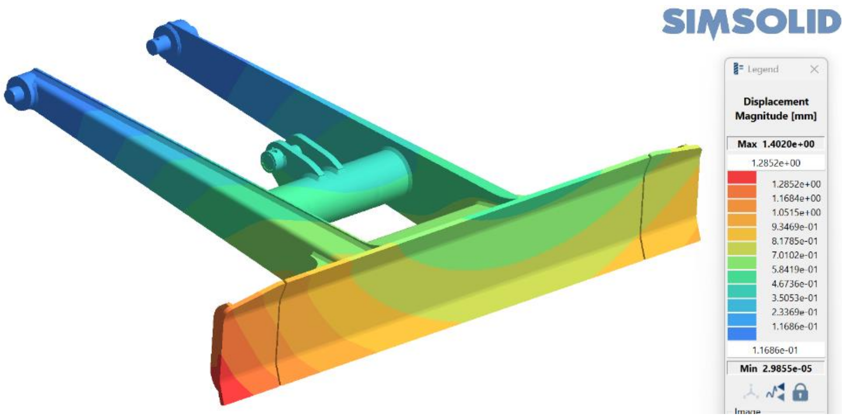
- Autor: Bc. Jindřich Pilař



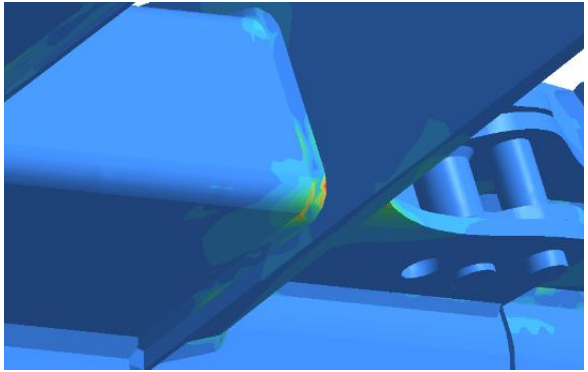
- Pásové rypadlo Wacker Neuson EZ26

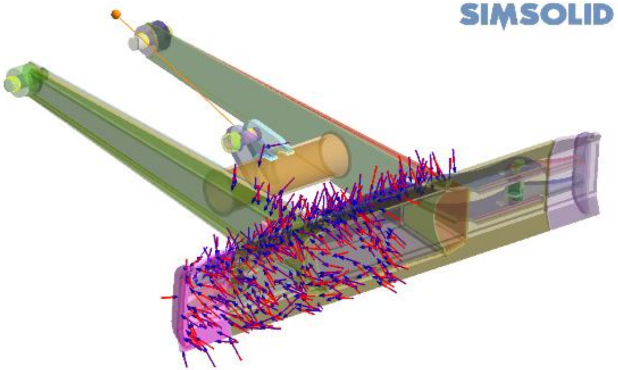
ANALÝZA DOZEROVÉ LOPATY RYPADLA (1W DEM-FEM)





- σ_{red} 181,6 MPa při rychlosti 6 km/h
- δ_{max} 1,8 mm při rychlosti 6 km/h

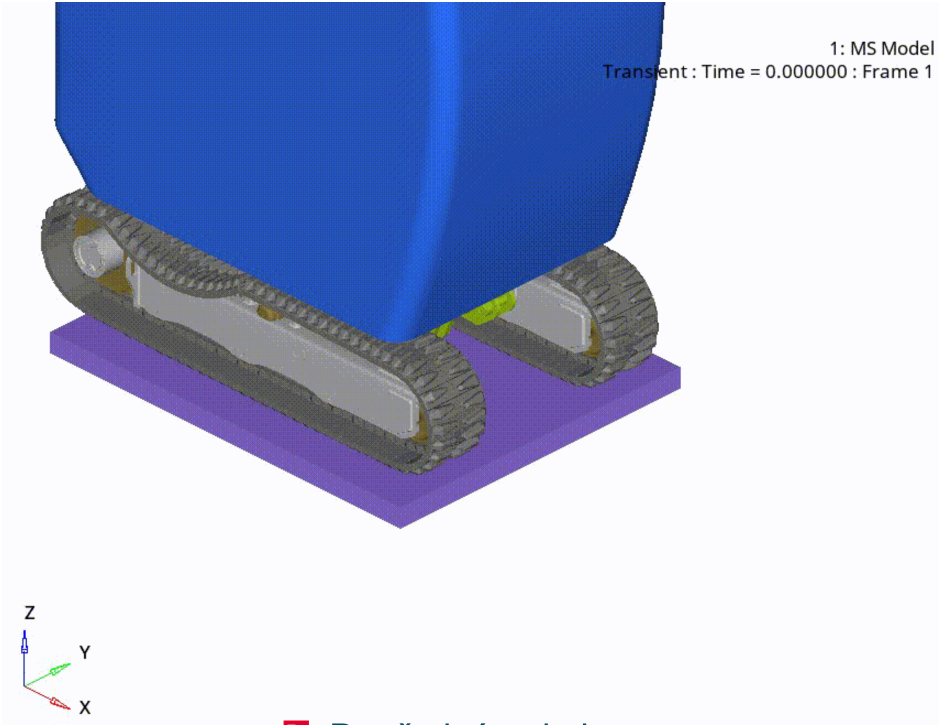




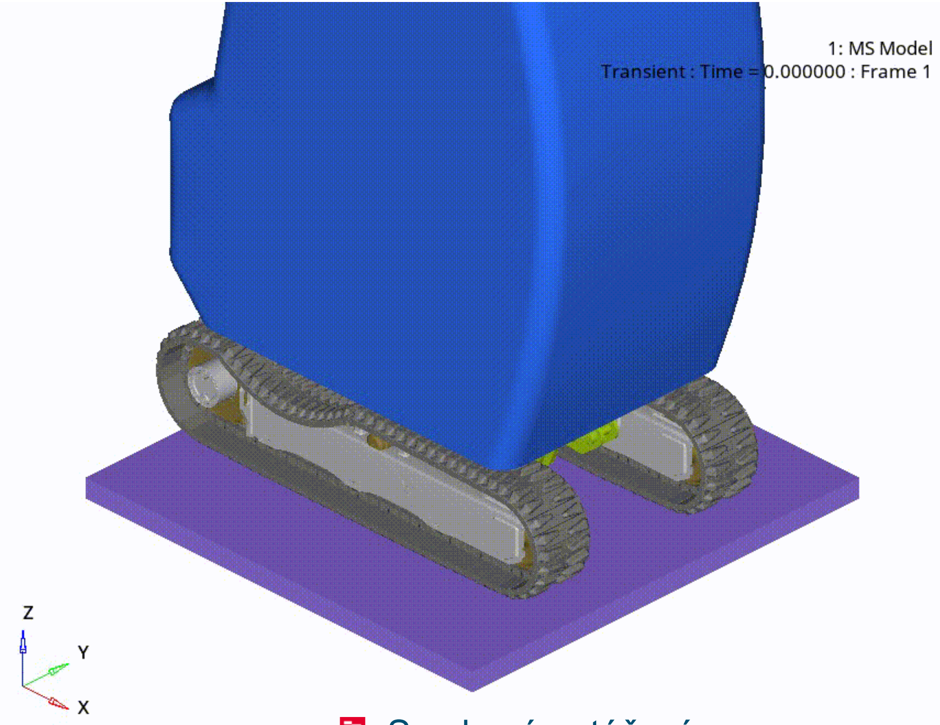
- Silové pole v čase 1,35 s

ANALÝZA PÁSOVÉHO PODVOZKU RYPADLA (DEM-MBD)

- Autor: Ing. Vít Vašíř



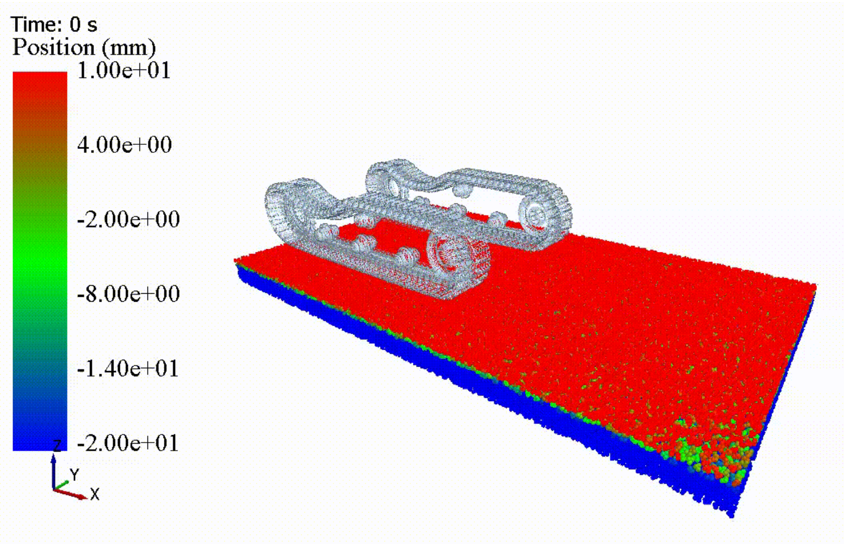
- Dopředný pohyb

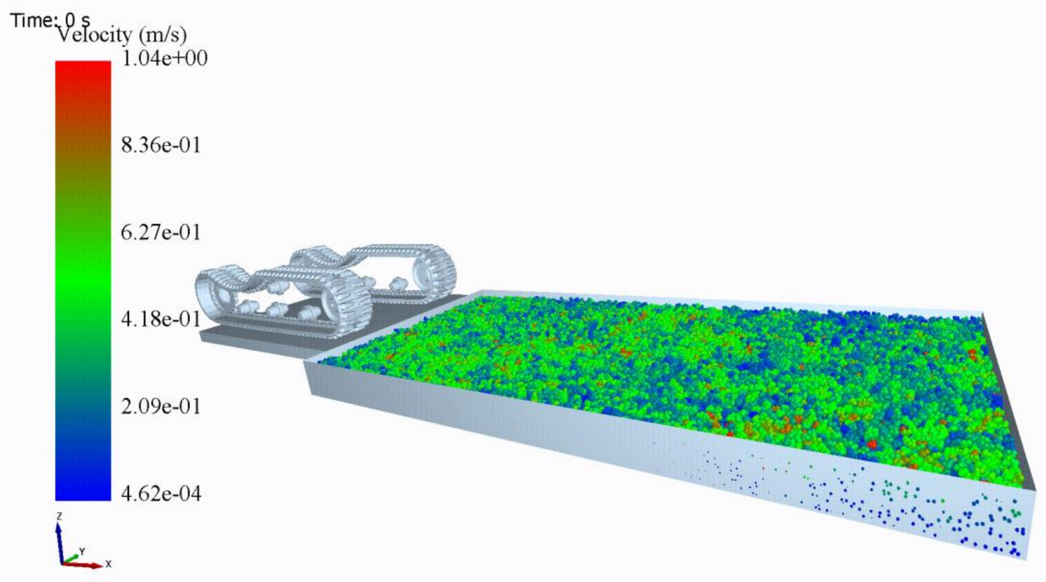


- Smykové zatáčení

ANALÝZA PÁSOVÉHO PODVOZKU RYPADLA (DEM-MBD)

- Autor: Ing. Vít Vašíř

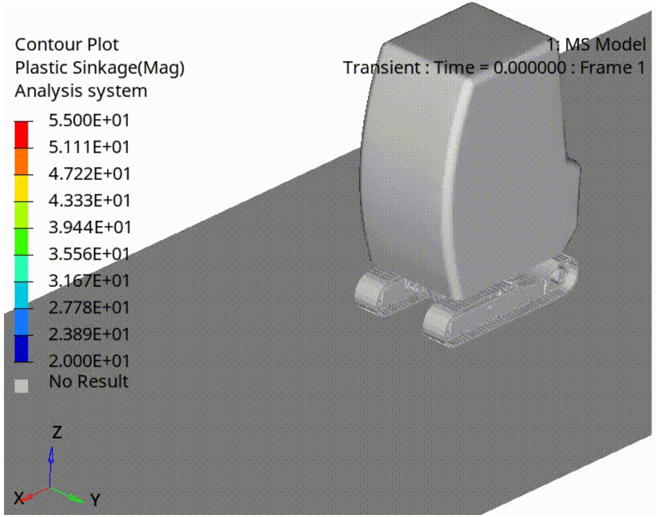


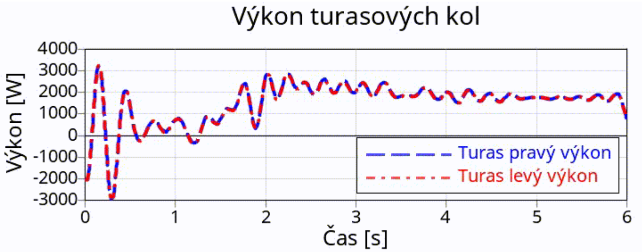


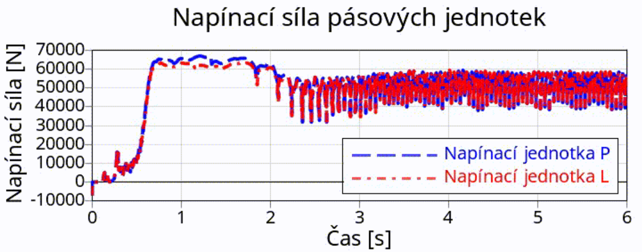
- Interakce sednutím
- Interakce najetím

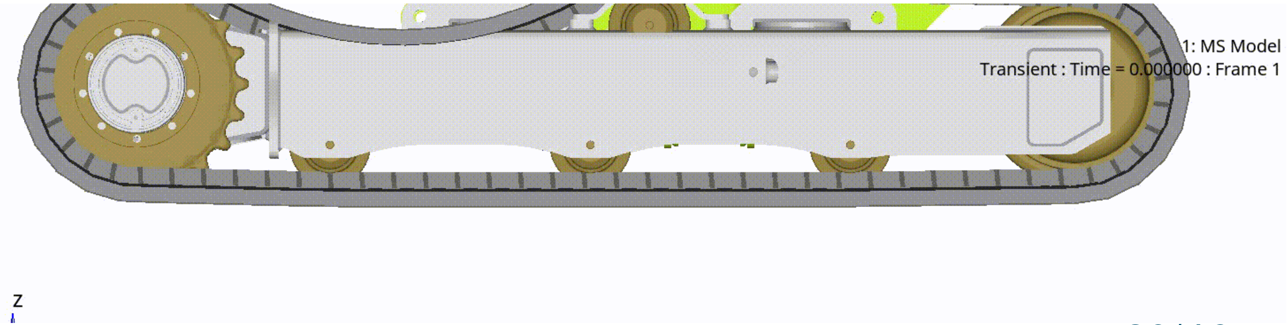
ANALÝZA PÁSOVÉHO PODVOZKU RYPADLA (DEM-MBD)

- Využití pluginu **SoftSoil**
- Zjednodušený model chování zemin
- Několikanásobně rychlejší oproti MBD+DEM nebo kontaktu s pevným tělesem





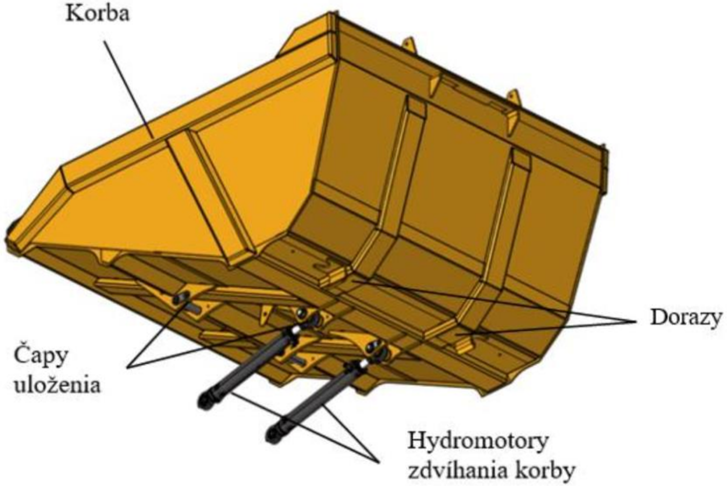


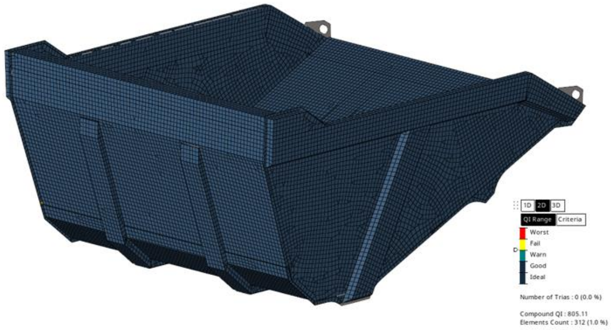


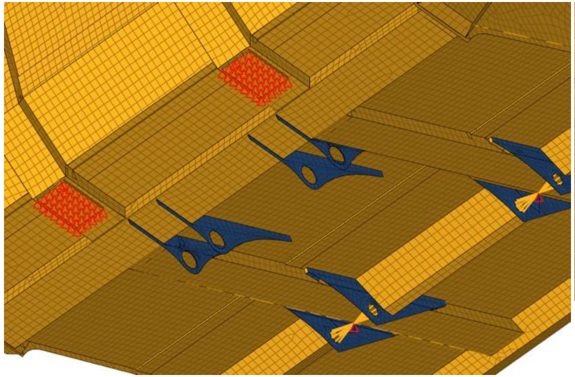
ANALÝZA KORBY DUMPERU (1W DEM-FEM)

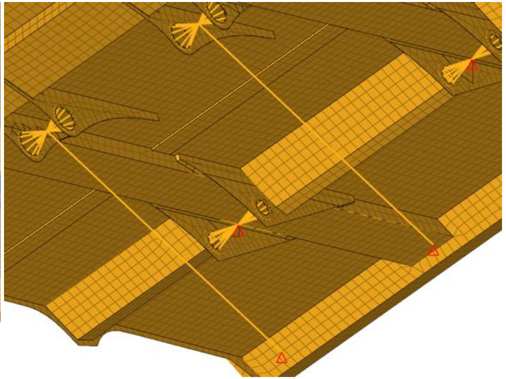
- Autor: Ing. Andrej Lukačovič

- Dumper Wacker Neuson DV125



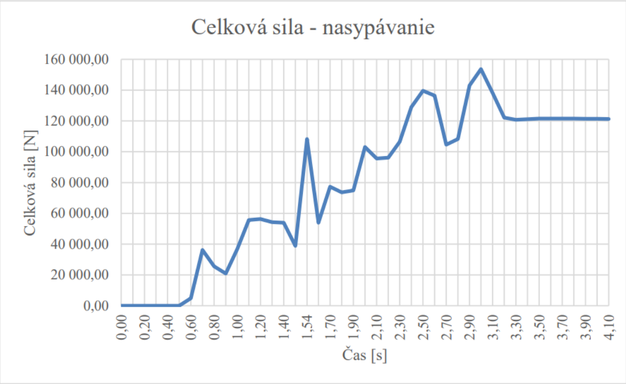


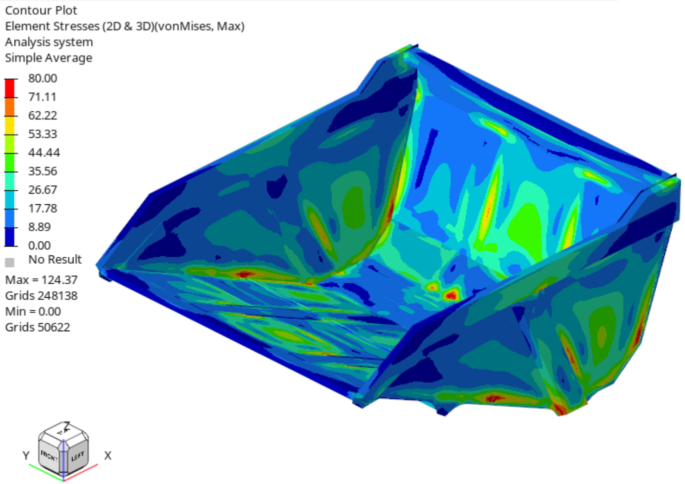


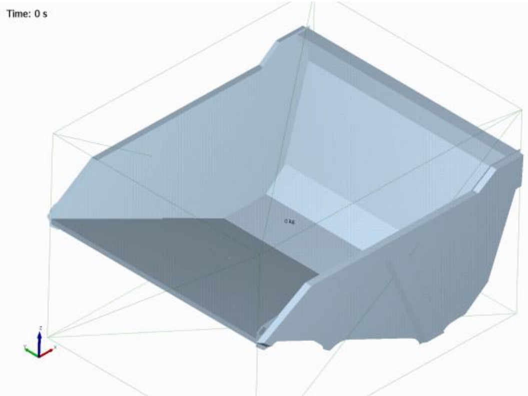


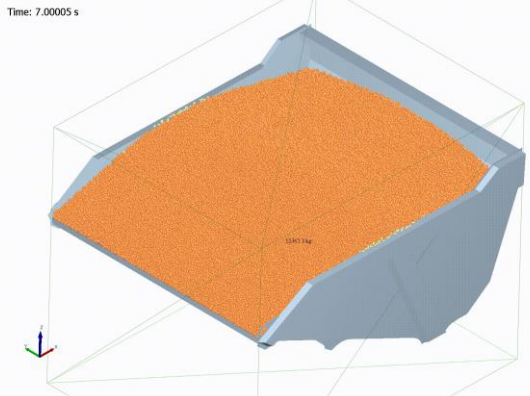
ANALÝZA KORBY DUMPERU (1W DEM-FEM)

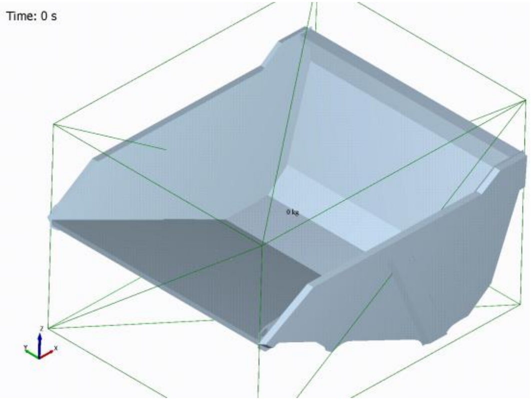
- Analýza nasypání korby:
  - 1. poloha = **10,03 tun**
  - 2. poloha = **12,36 tun**
  - 3. poloha = **11,34 tun**
- Pevnostní analýza:
  - Deformace: 3,56 mm
  - Maximální napětí: 72 MPa



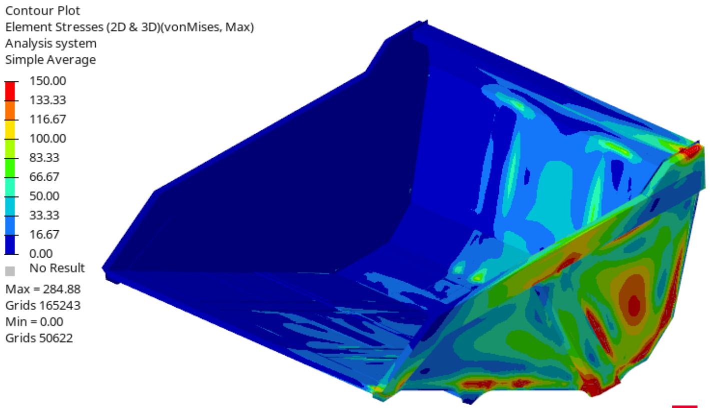


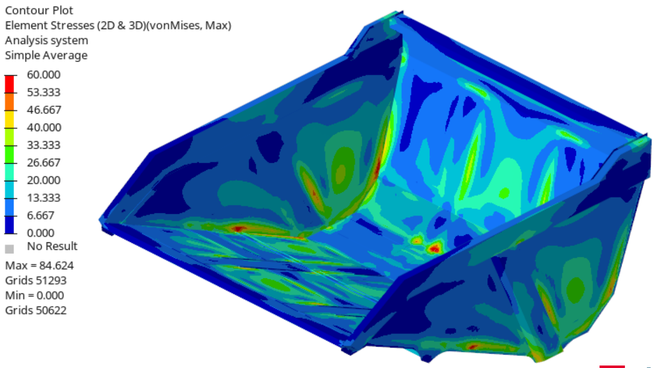




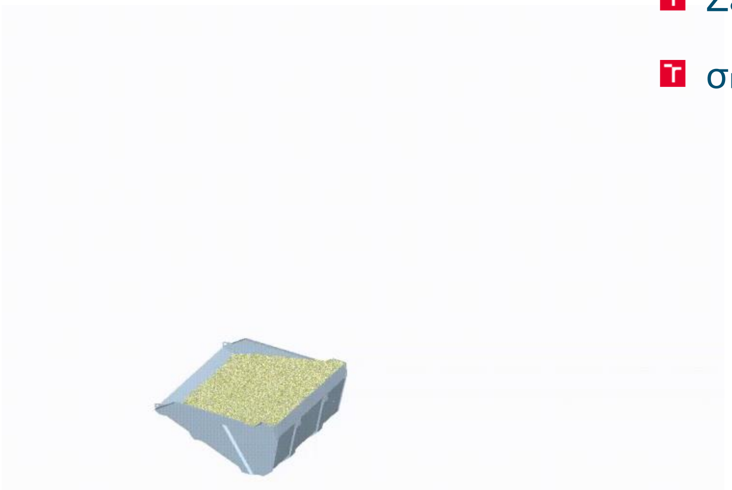


ANALÝZA KORBY DUMPERU (1W DEM-FEM)

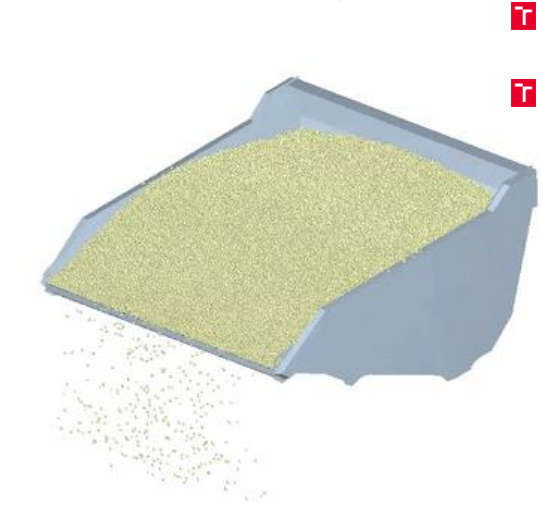




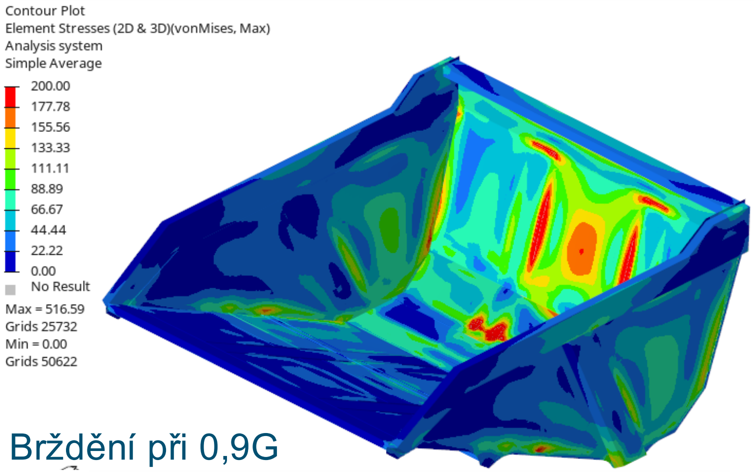
- Zatáčení při 1G
- σ_{red} 142 MPa

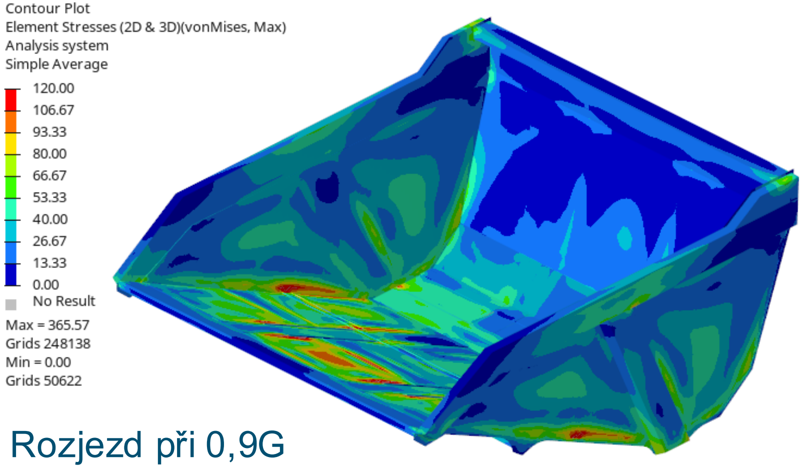


- Vysypávání
- σ_{red} 52 MPa



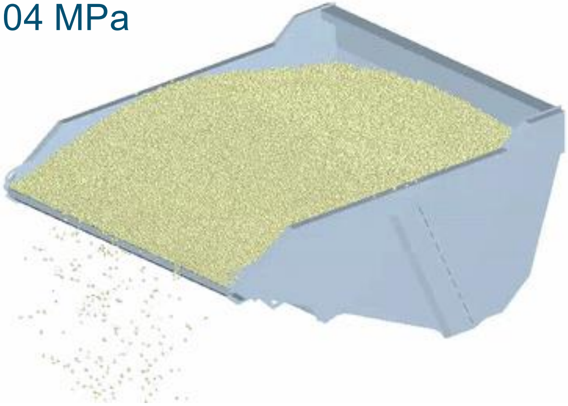
ANALÝZA KORBY DUMPERU (1W DEM-FEM)

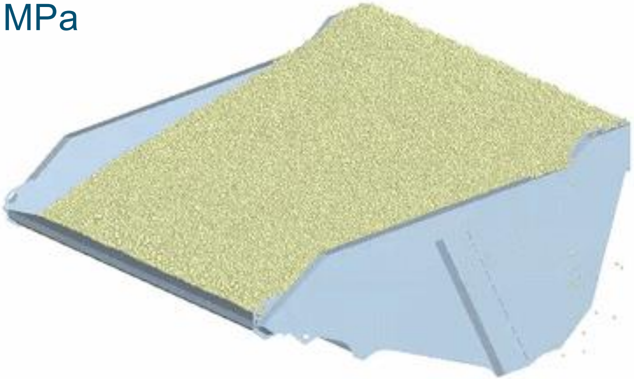




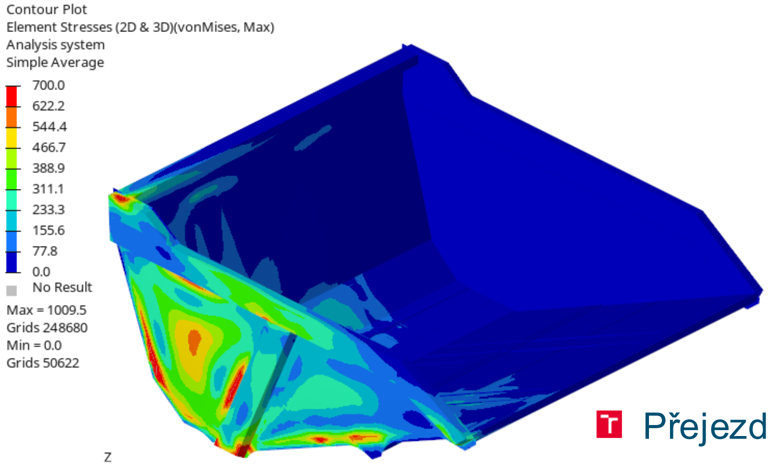
- Brždění při 0,9G
- σred 204 MPa

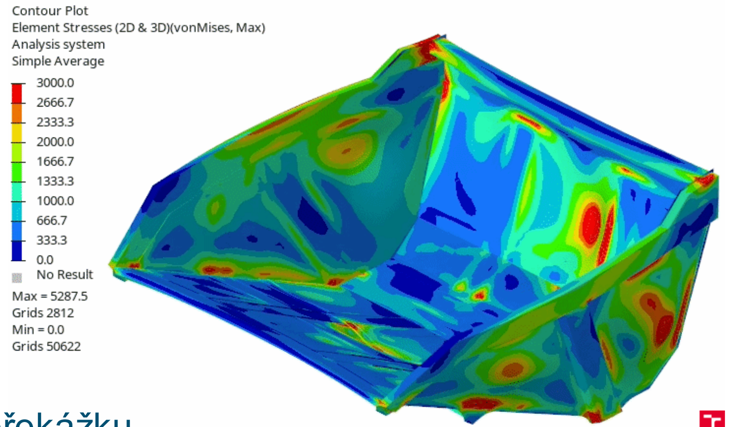
- Rozjezd při 0,9G
- σred 105 MPa



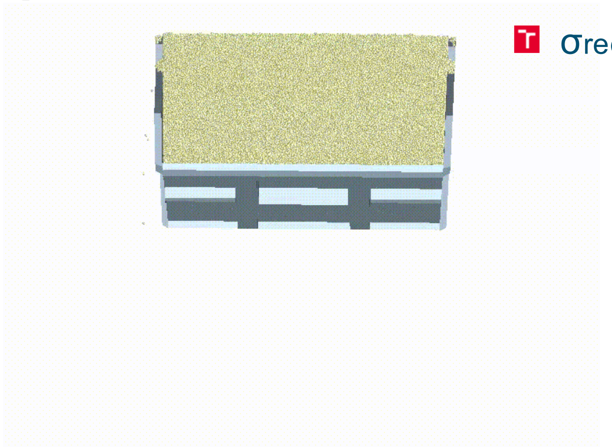


ANALÝZA KORBY DUMPERU (1W DEM-FEM)

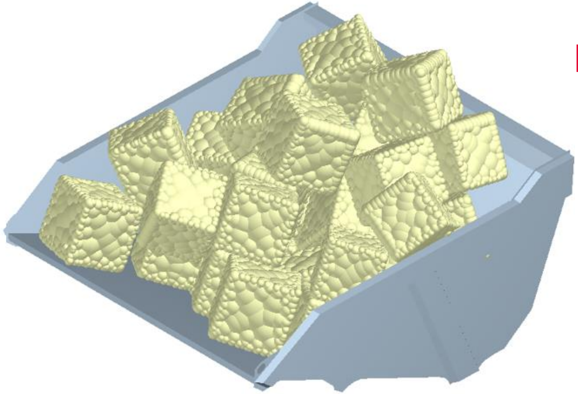




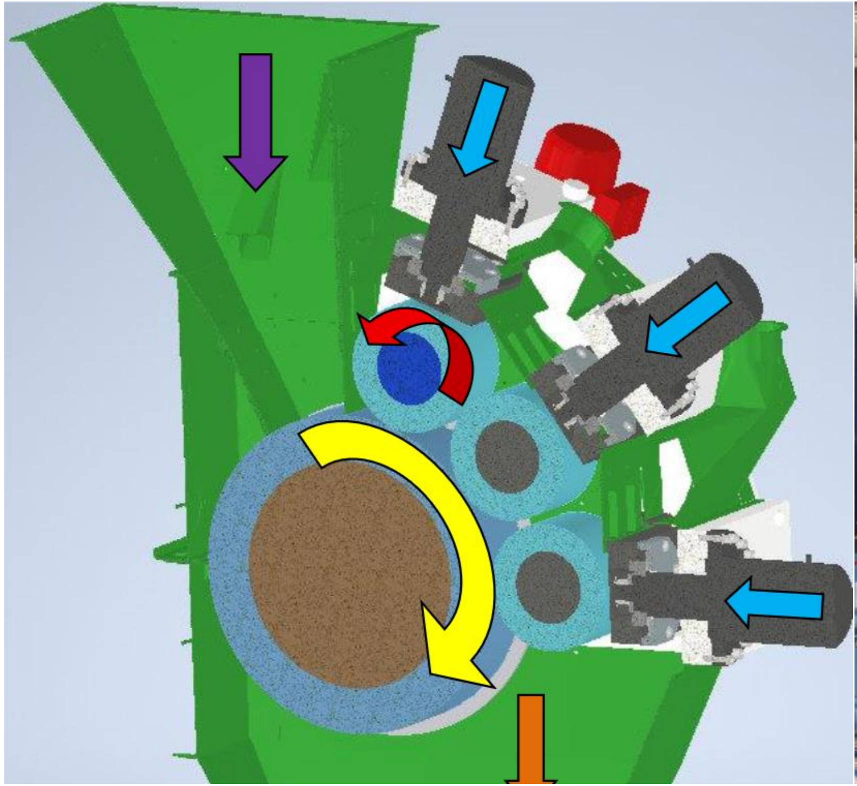
- Přejezd přes překážku
- σ_{red} 595 MPa



- Nasypání bloků
- σ_{red} 3130 MPa

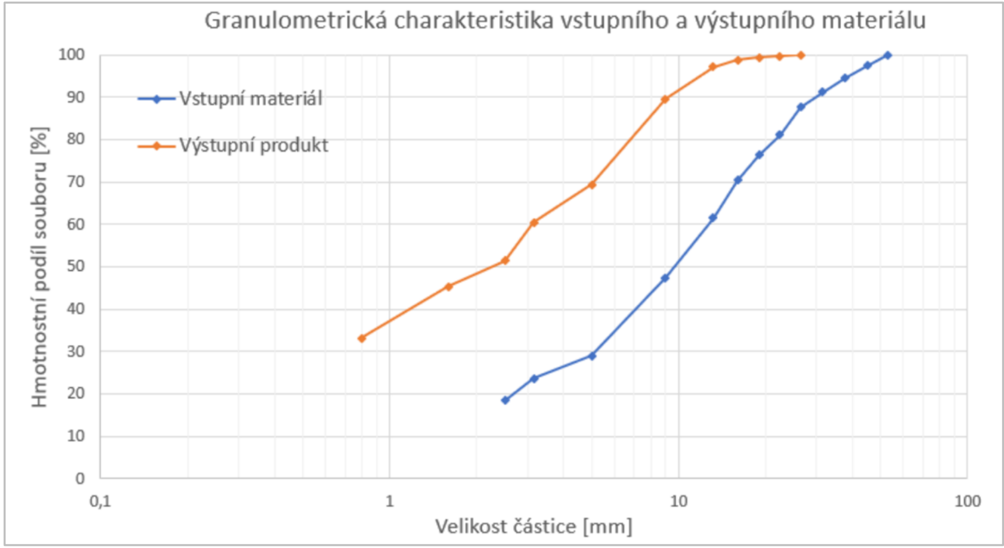


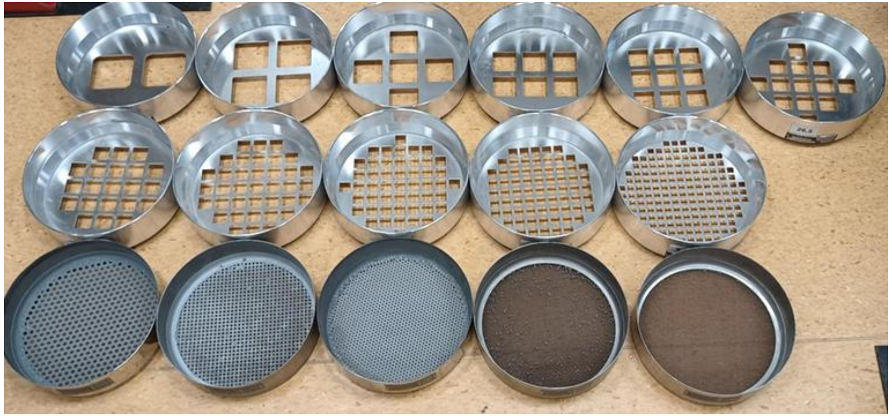
- Autor: Ing. Petr Pokluda



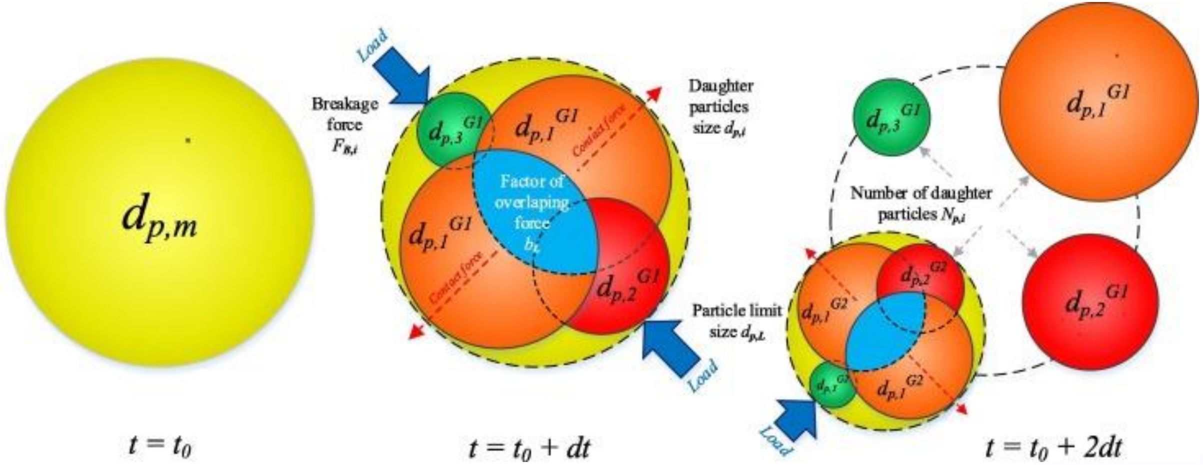
ANALÝZA PROVOZNÍCH PARAMETRŮ MLÝNU (DEM-MBD)

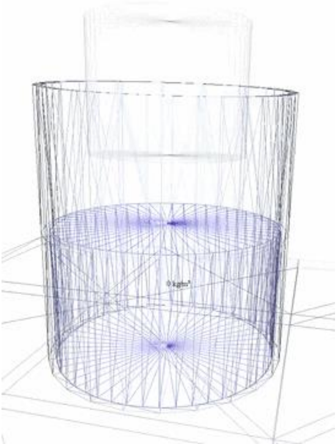
- Použitý model: Hertz-Mindlin+UFRJ Breakage

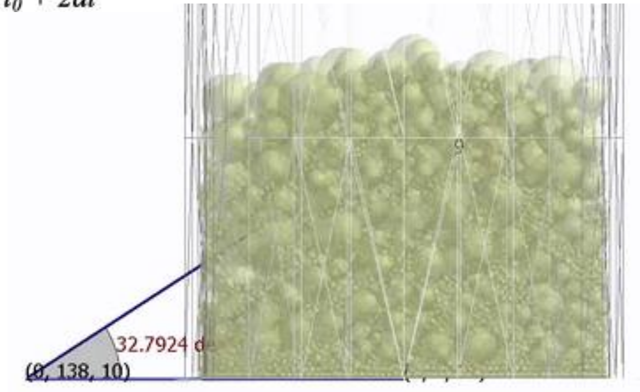




ANALÝZA PROVOZNÍCH PARAMETRŮ MLÝNU (DEM-MBD)

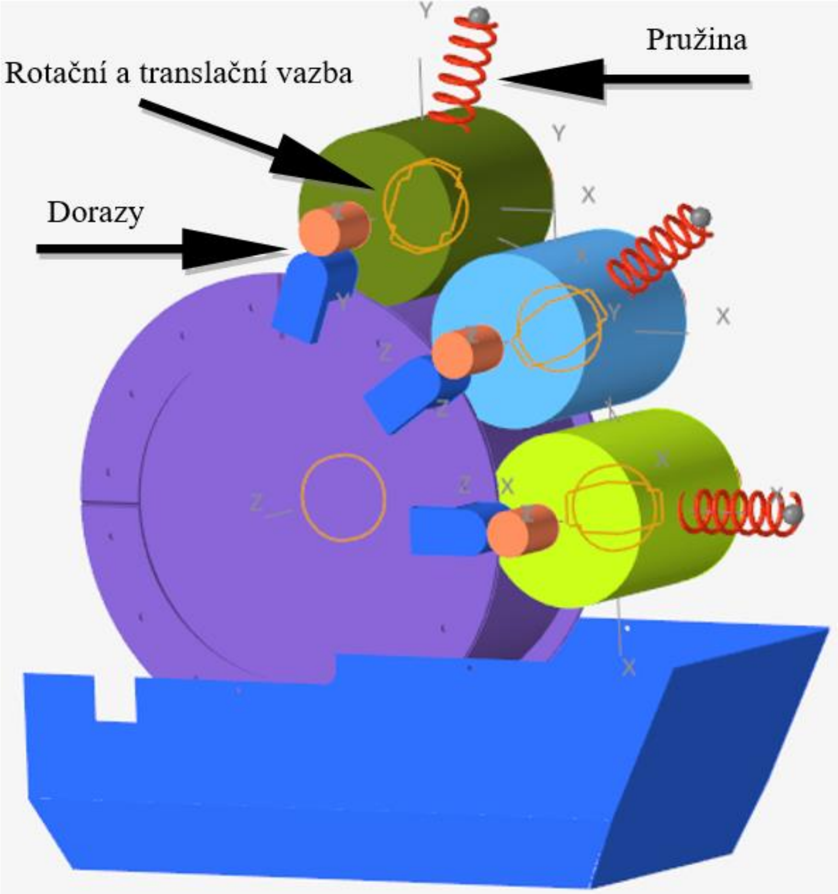


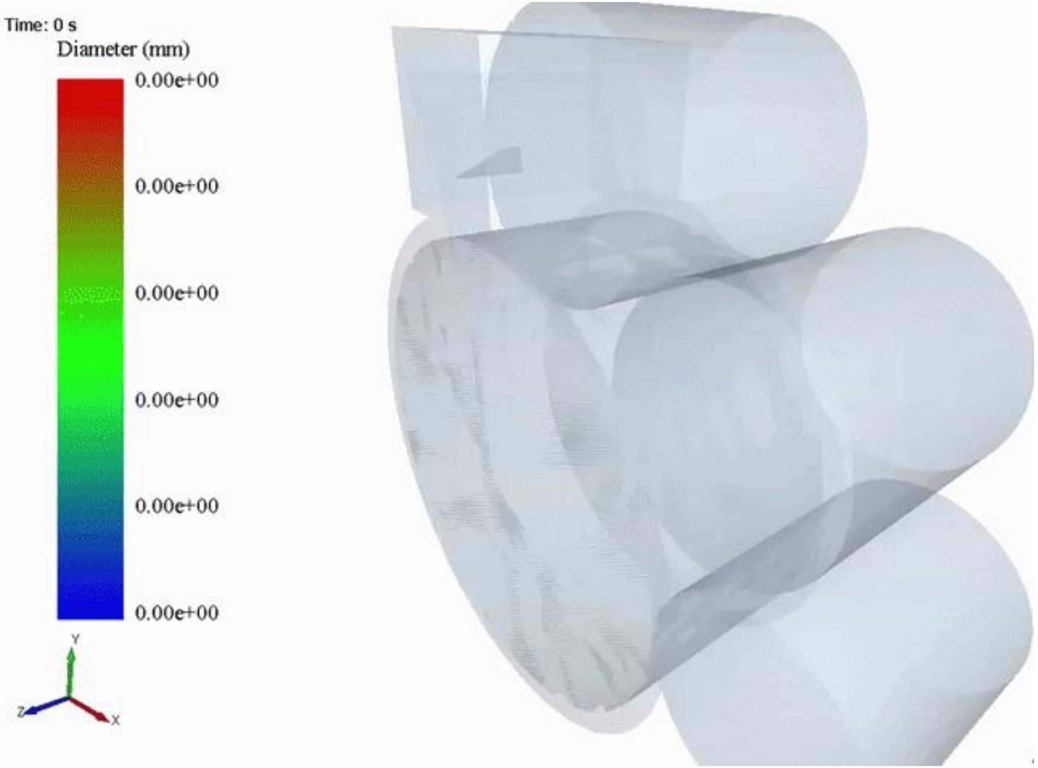




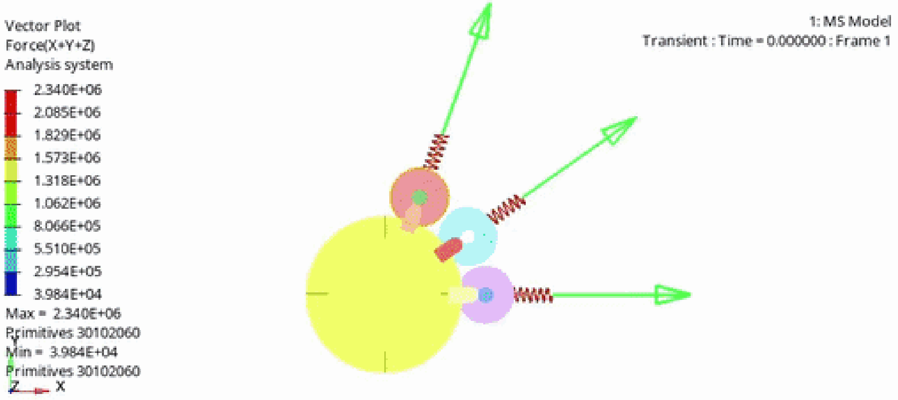
- Princip UFRJ Breakage modelu

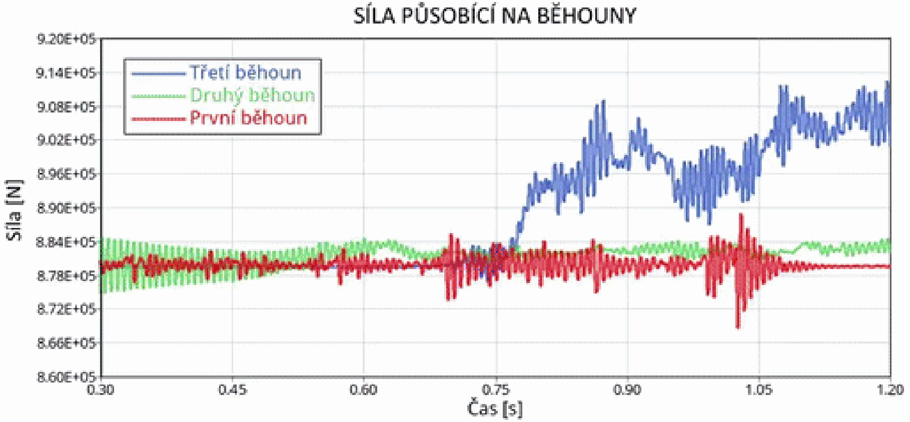
ANALÝZA PROVOZNÍCH PARAMETRŮ MLÝNU (DEM-MBD)

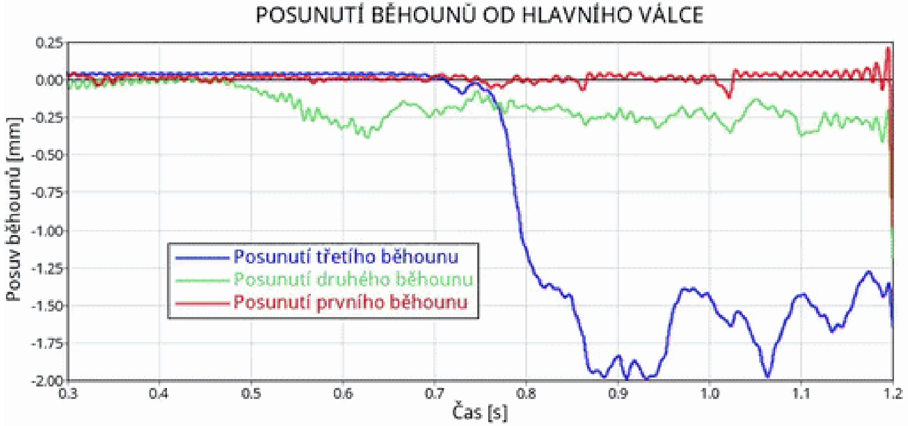




ANALÝZA PROVOZNÍCH PARAMETRŮ MLÝNU (DEM-MBD)

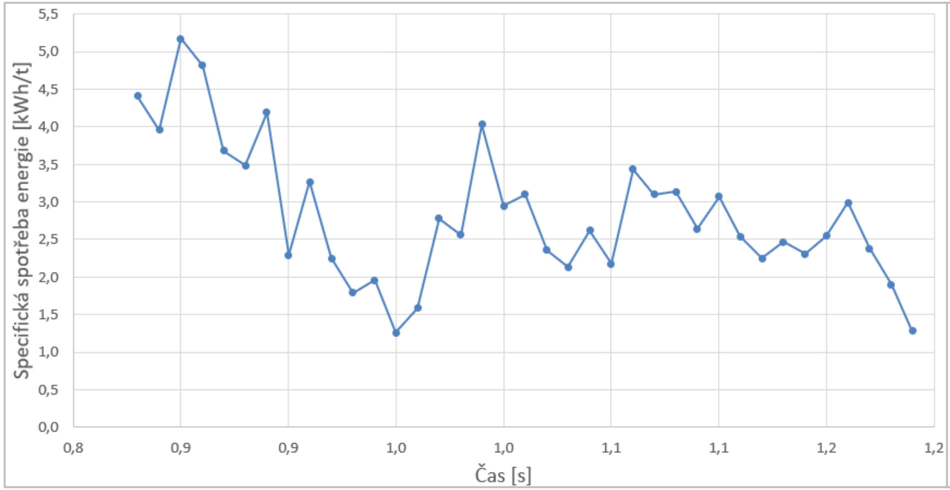


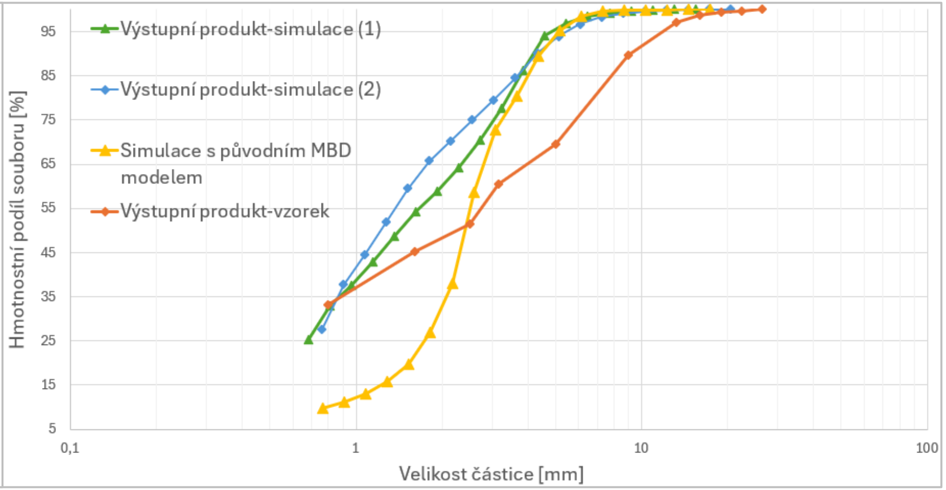




ANALÝZA PROVOZNÍCH PARAMETRŮ MLÝNU (DEM-MBD)

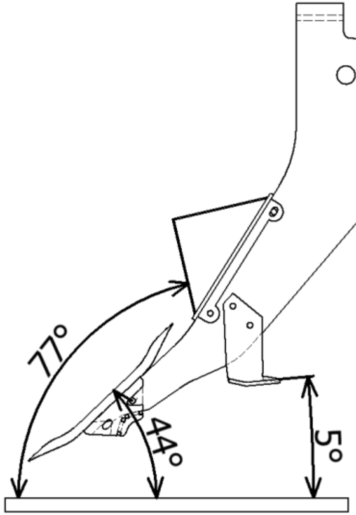
- Hodnoty specifické spotřeby energie v reálném provozu jsou okolo **2,0-2,8 kWh/t**
- Granulometrické křivky byly při volených hodnotách řádově podobné

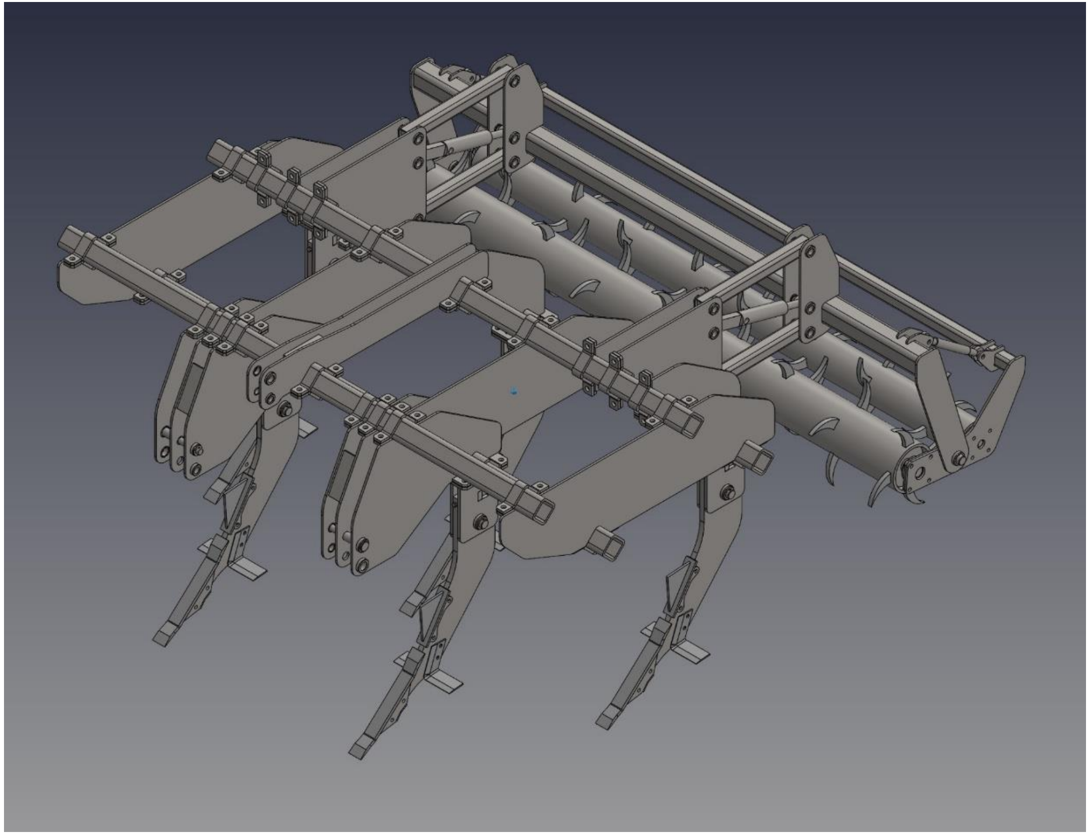




OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)

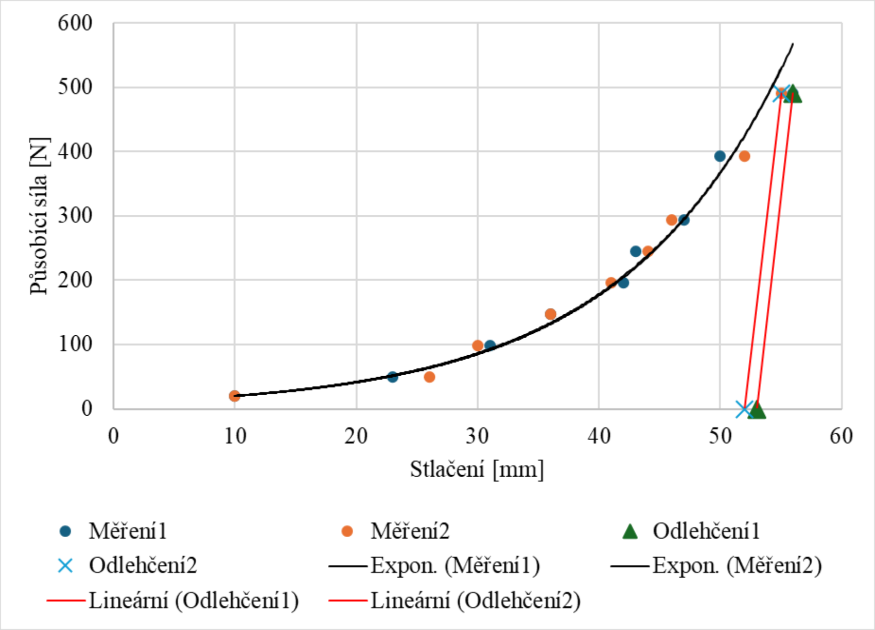
- Autor: Ing. Adam Svoboda

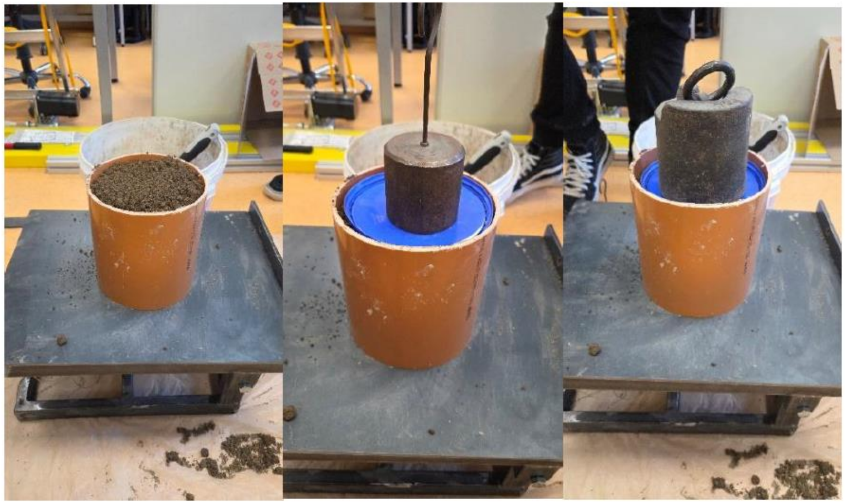




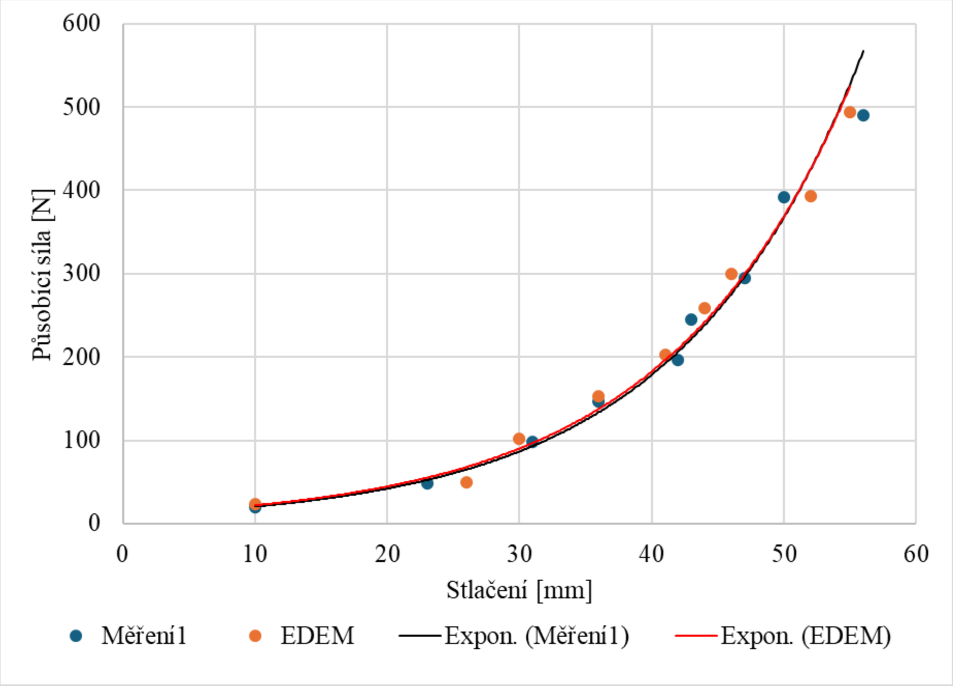
OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)

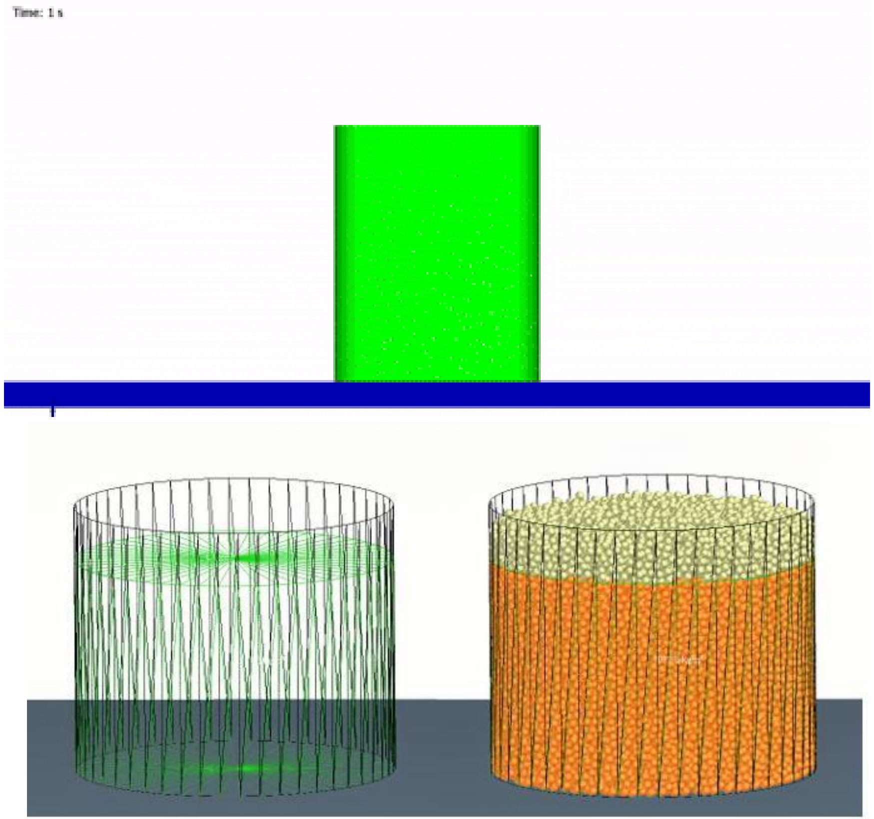
- Použitý model: Hysteretic Spring+linear cohesion+bonding
- Model bonding uvažován kvůli modelování nakypření



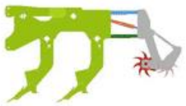


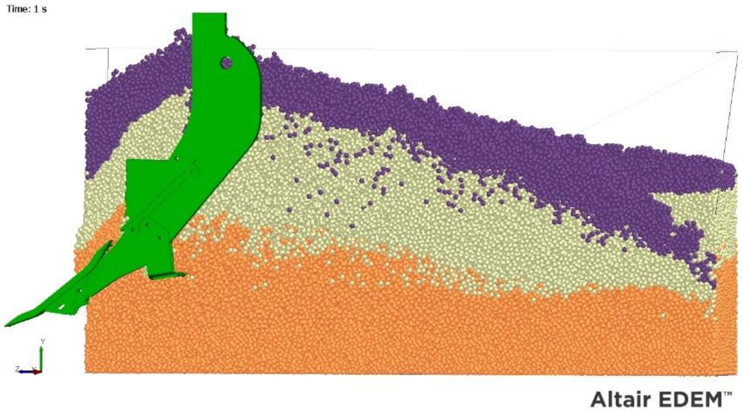
OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)

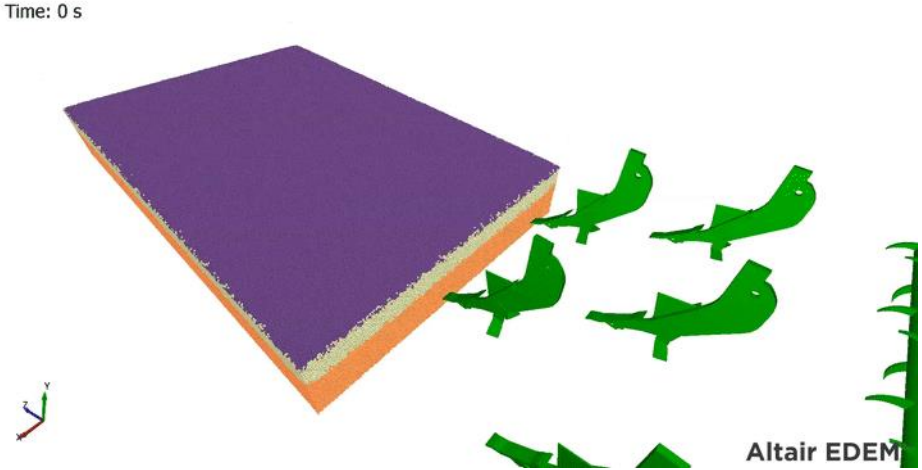


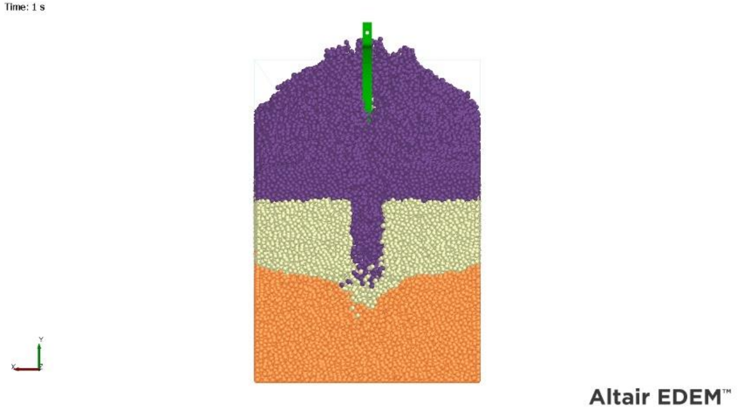


OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)



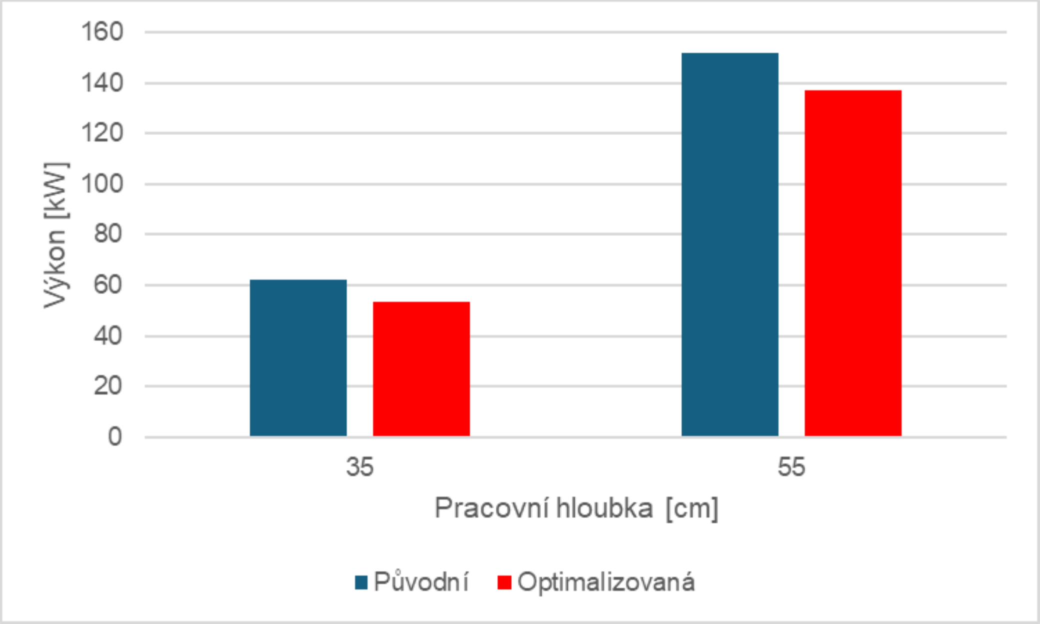


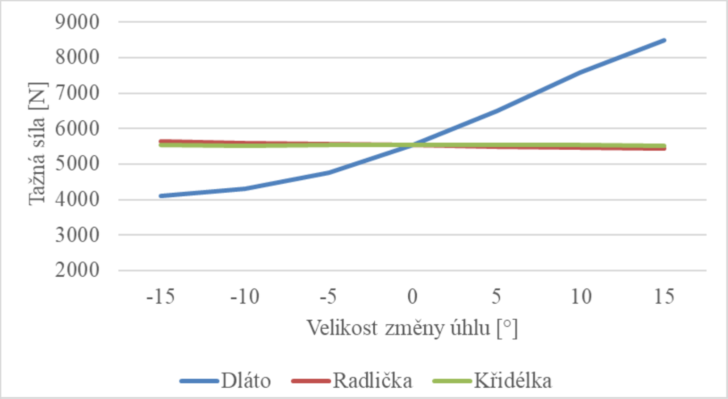


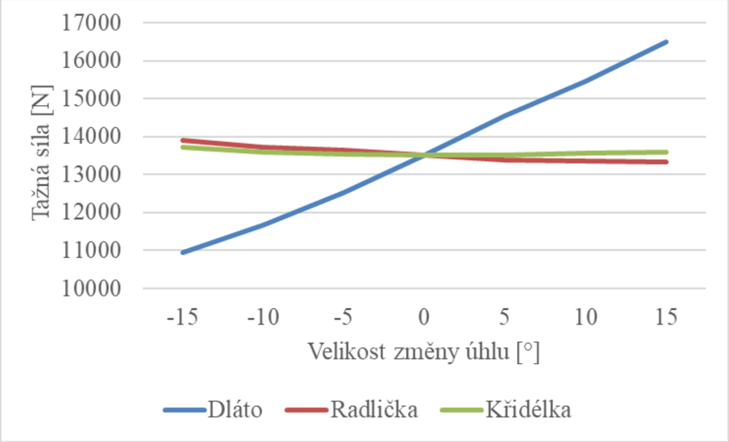


OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)

- Snížení potřebného výkonu:
  - Hloubka 35 cm snížení výkonu o **14,3 %**
  - Hloubka 55 cm snížení výkonu o **9,8 %**

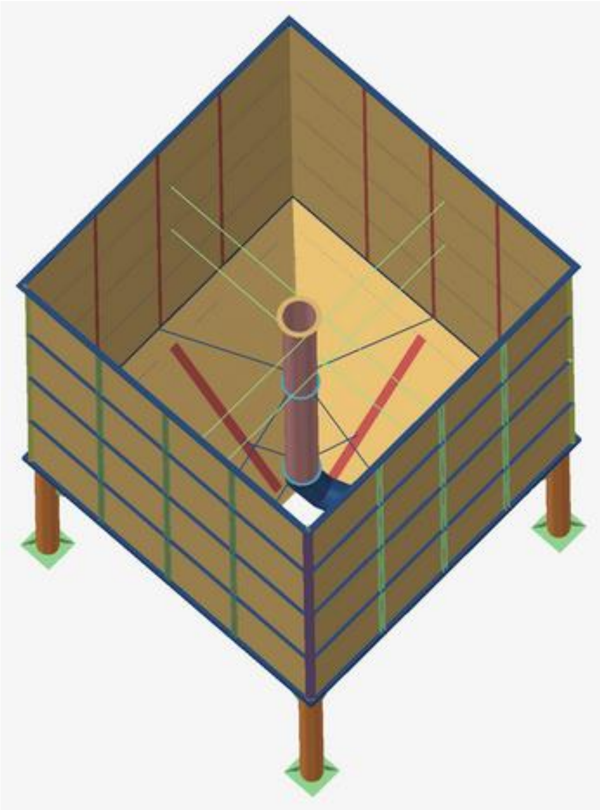


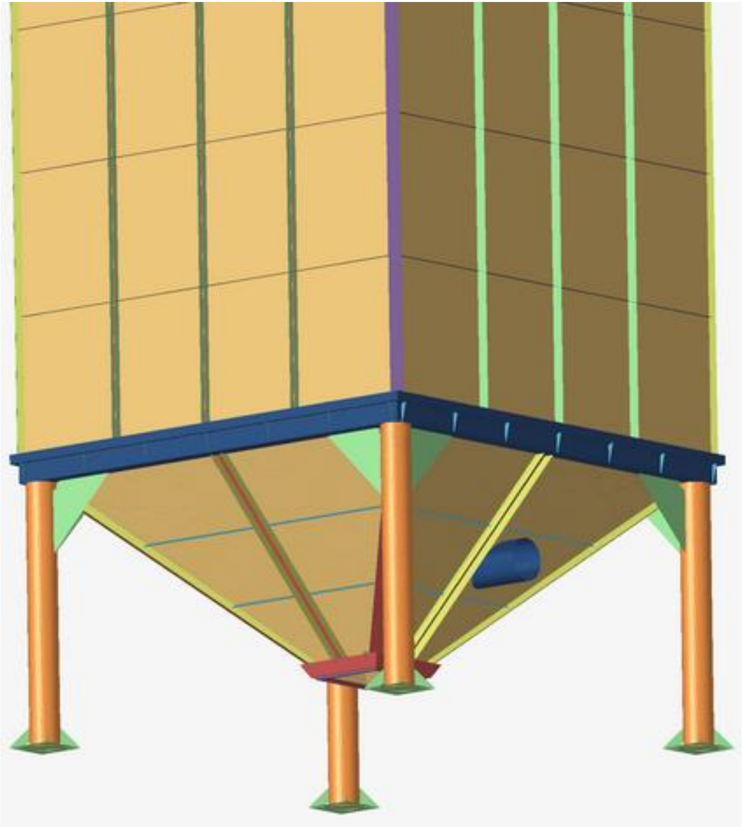


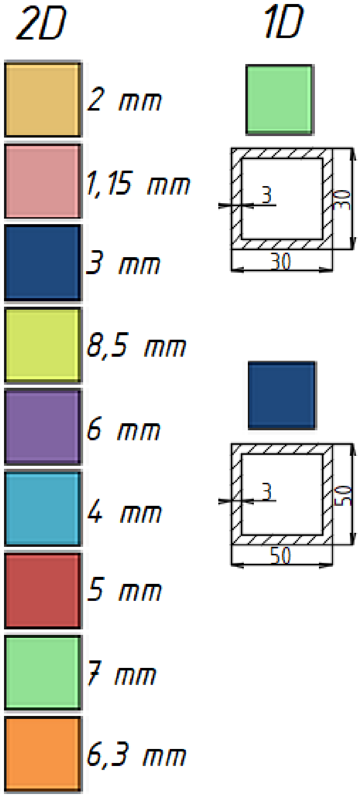


NÁVRH SILA PRO ZEMĚDĚLSKÉ PLODINY (1W DEM-FEM)

- Autor: Ing. Pavel Puchta

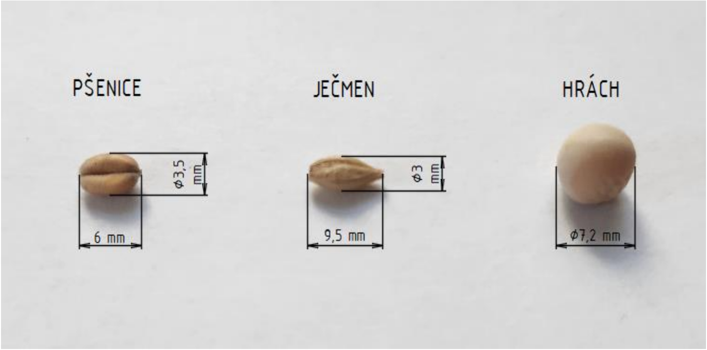


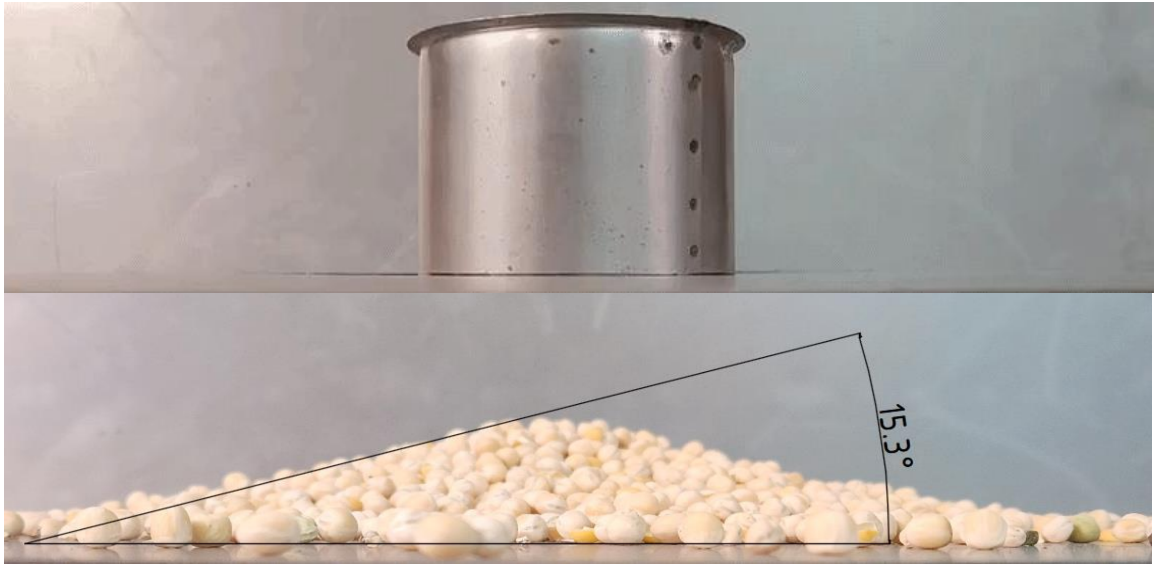




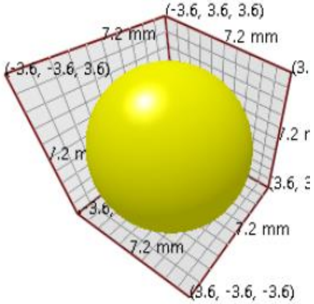
NÁVRH SILA PRO ZEMĚDĚLSKÉ PLODINY (1W DEM-FEM)

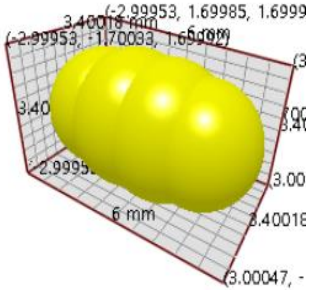
- Použitý model: Hertz-Mindlin

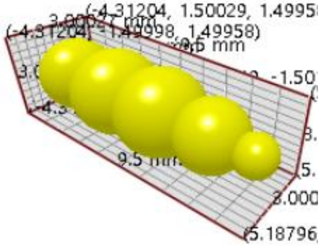


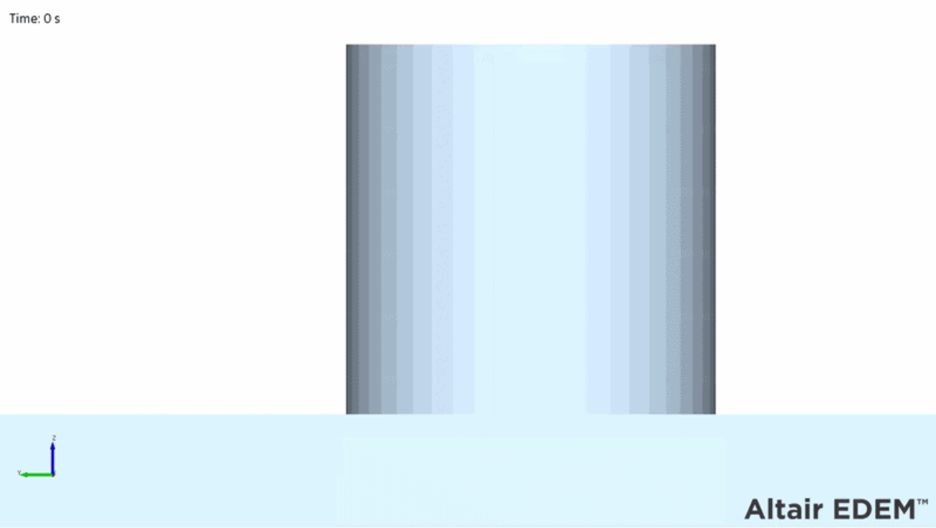


NÁVRH SILA PRO ZEMĚDĚLSKÉ PLODINY (1W DEM-FEM)



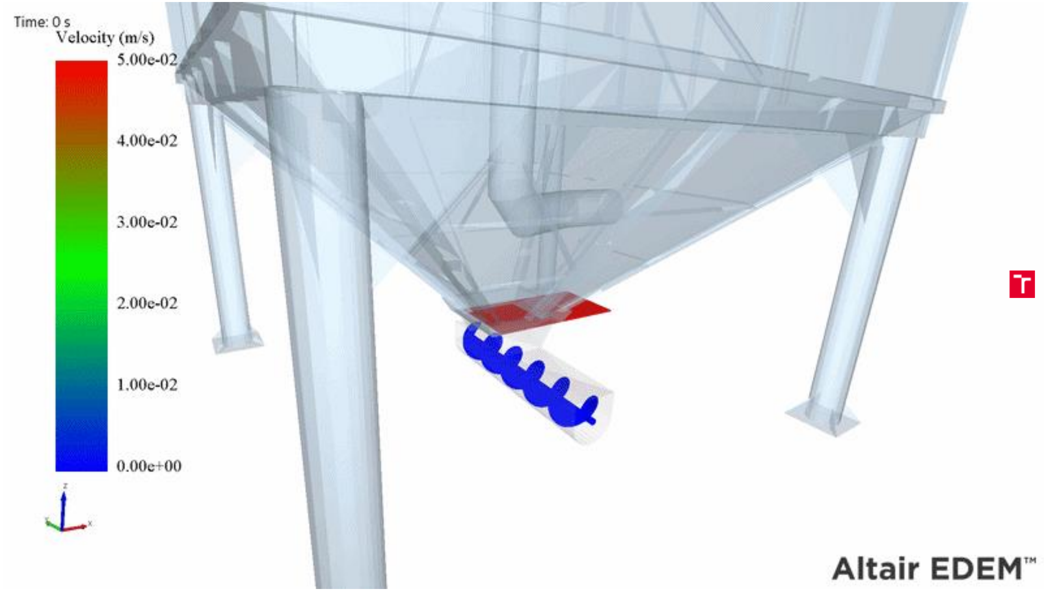


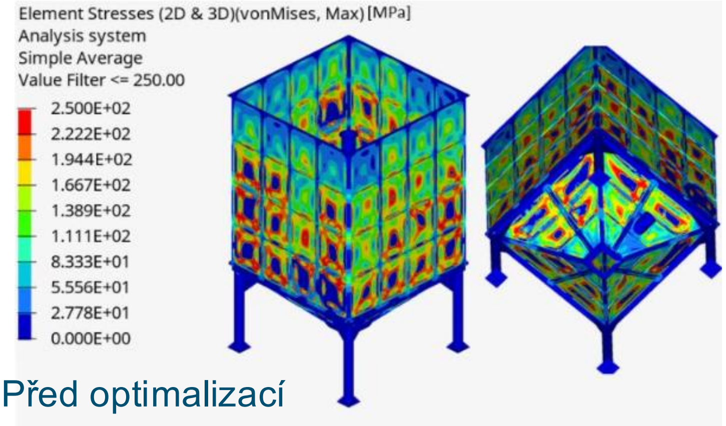




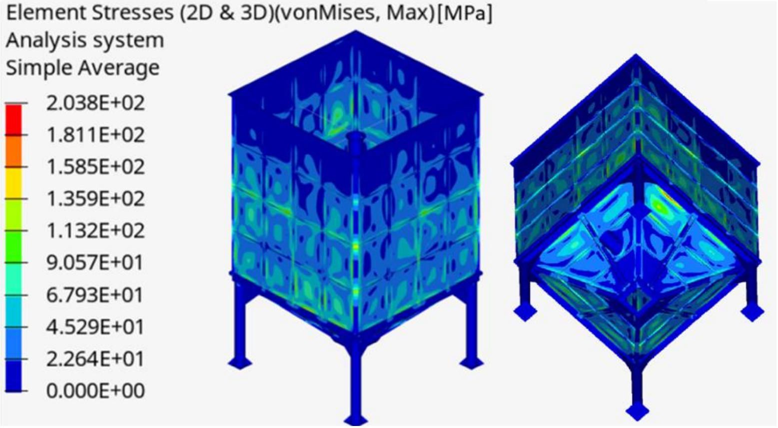
NÁVRH SILA PRO ZEMĚDĚLSKÉ PLODINY (1W DEM-FEM)

- Materiálové toky z výsypky vycházejí podobně jako analytický výpočet toků materiálu





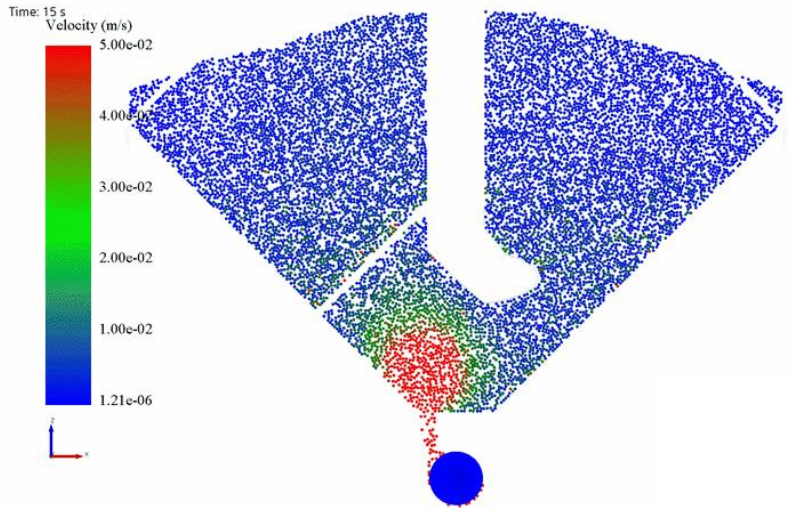
- Před optimalizací

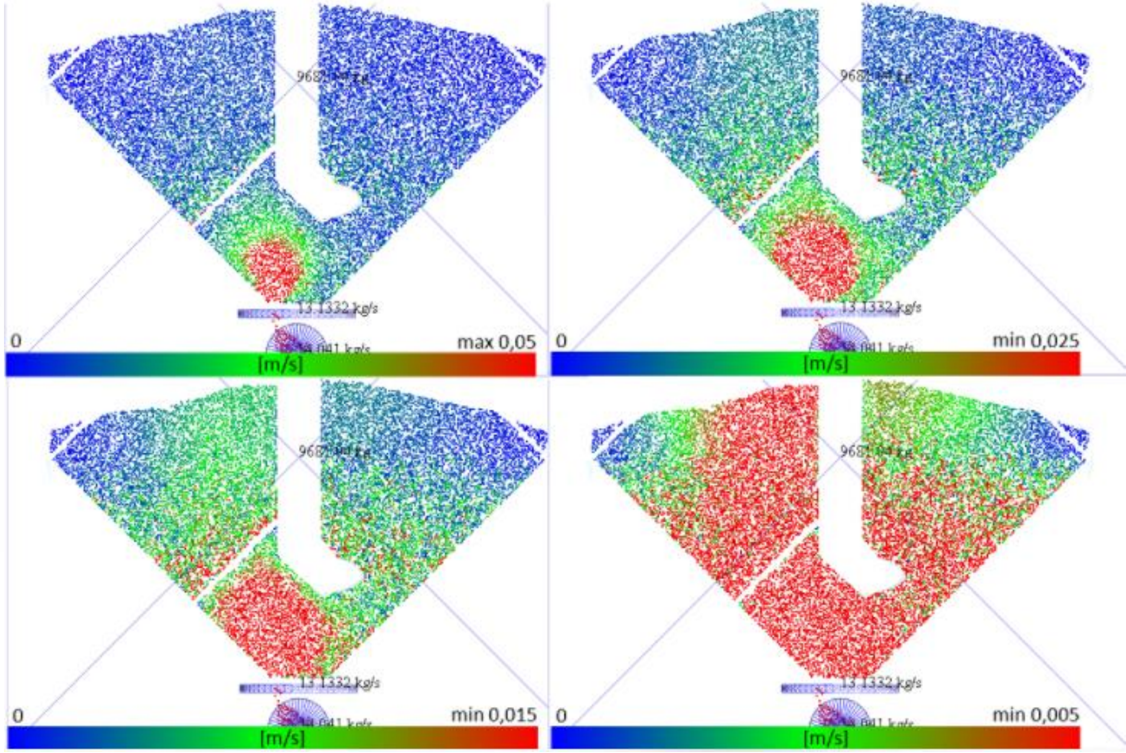


- Po optimalizaci

NÁVRH SILA PRO ZEMĚDĚLSKÉ PLODINY (1W DEM-FEM)

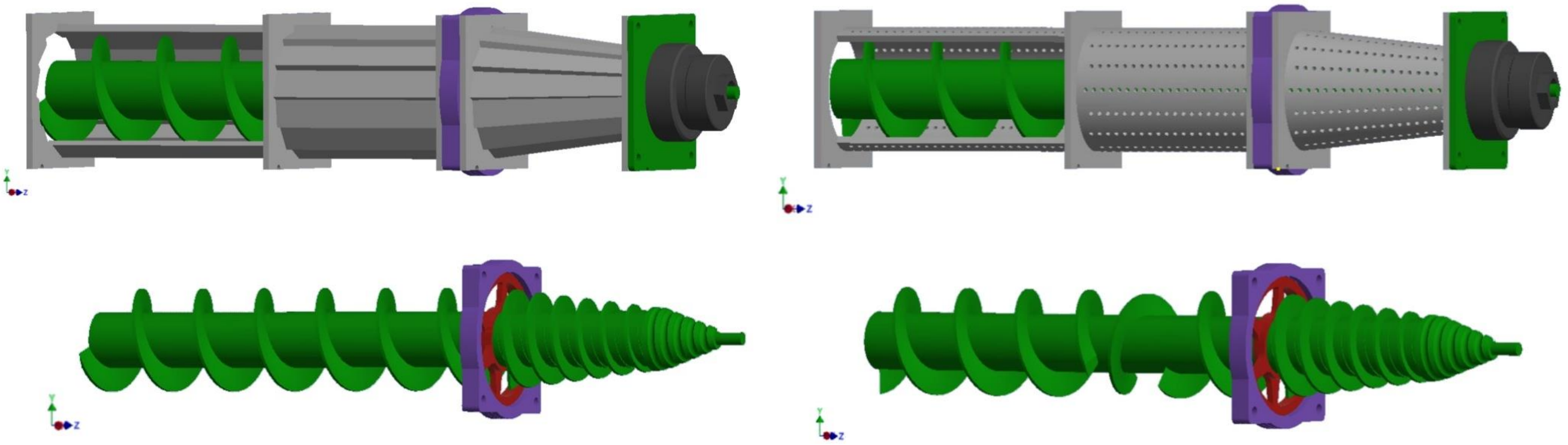
- Analýza toku v řezu výsypkou poukazuje na **hmotový tok**



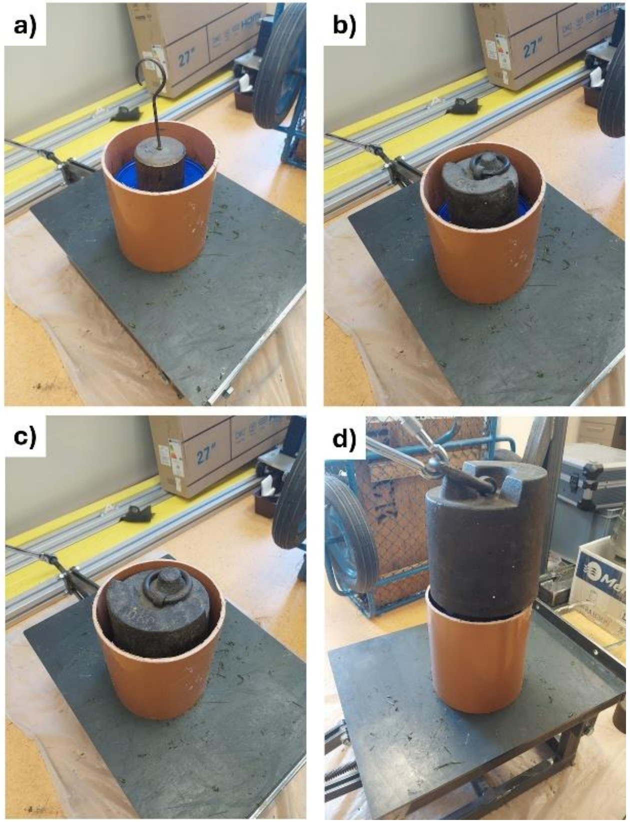


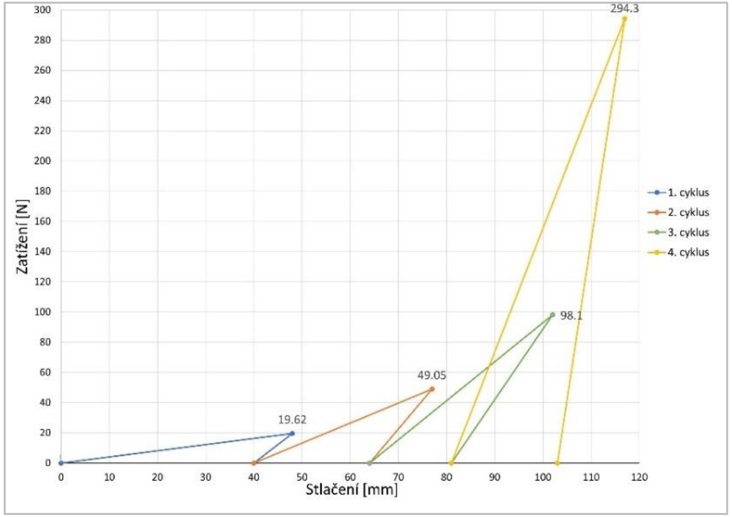
ANALÝZA ODVODŇOVACÍHO LISU TRAVNÍHO MULČE

- Autor: Ing. Iva Beranová

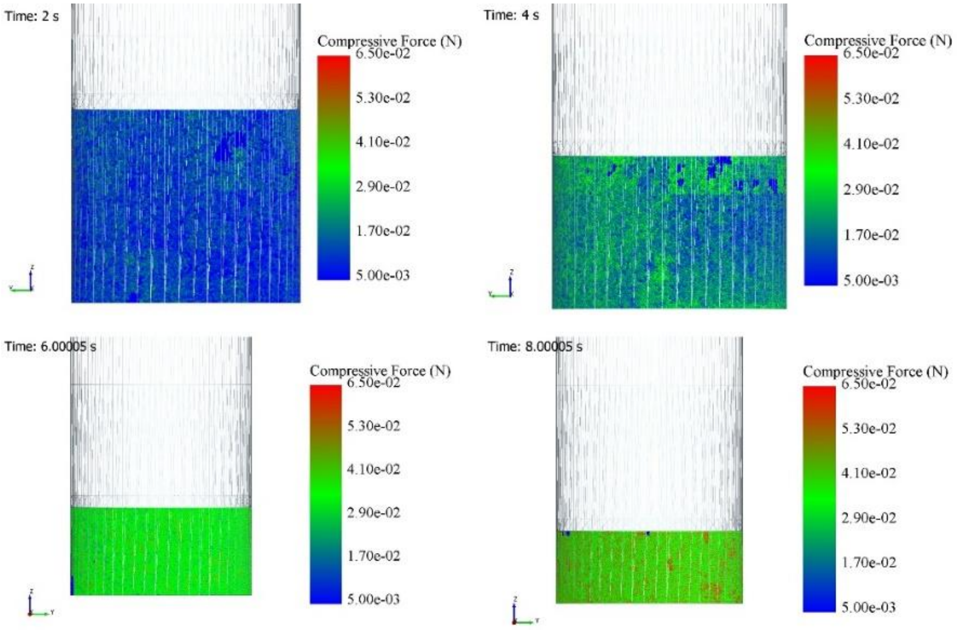


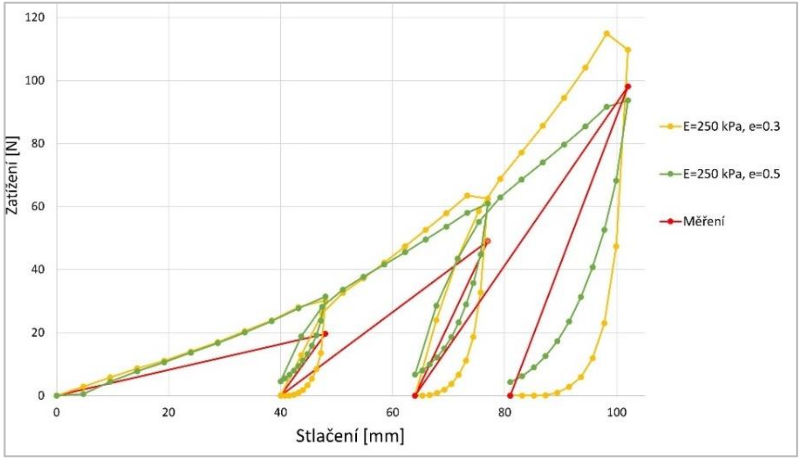
ANALÝZA ODVODŇOVACÍHO LISU TRAVNÍHO MULČE

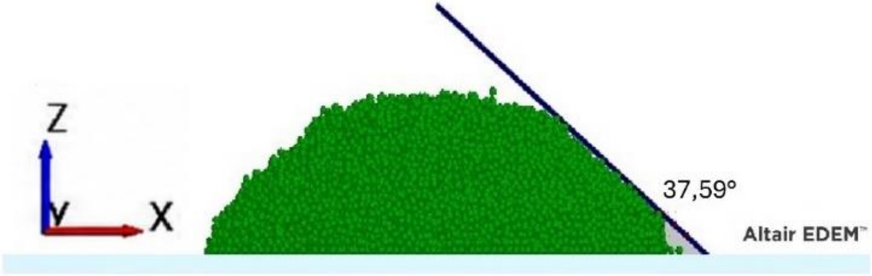




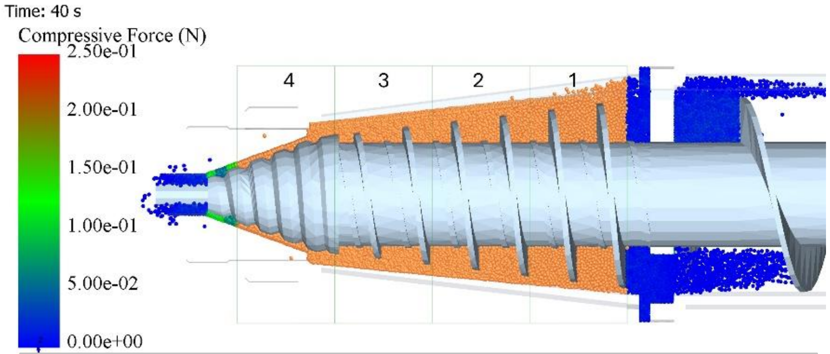
ANALÝZA ODVODŇOVACÍHO LISU TRAVNÍHO MULČE

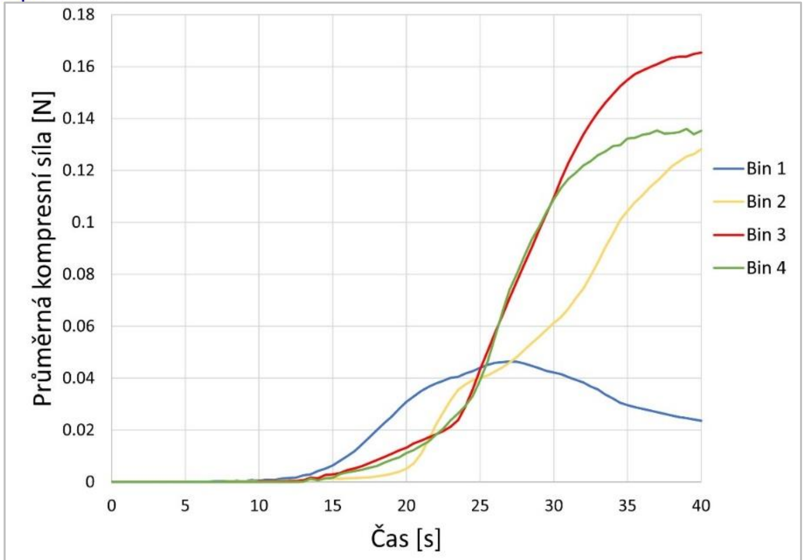


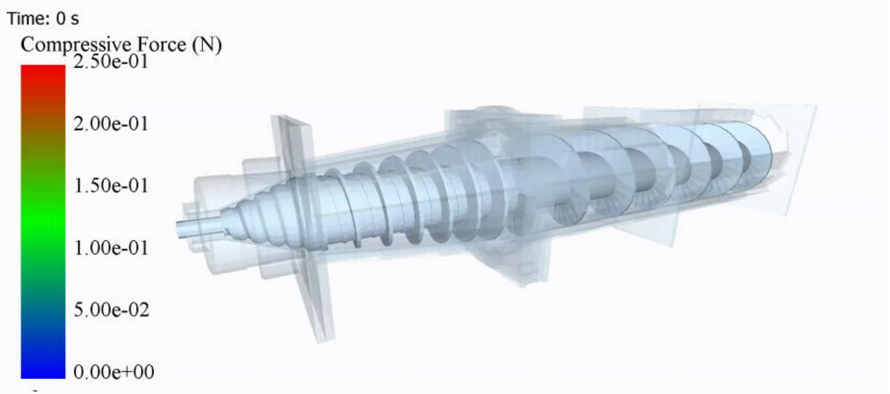


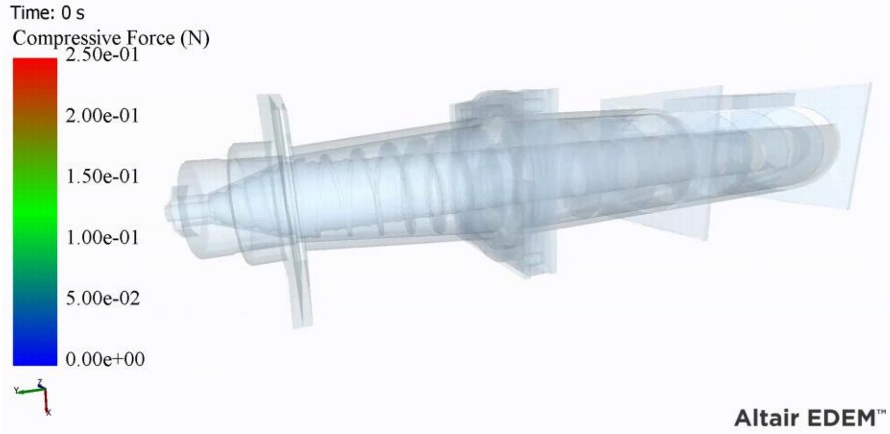


ANALÝZA ODVODŇOVACÍHO LISU TRAVNÍHO MULČE





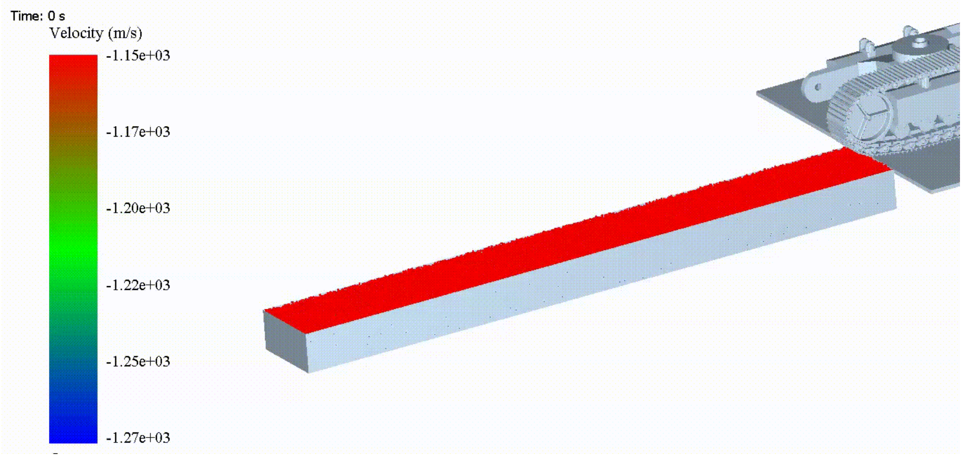


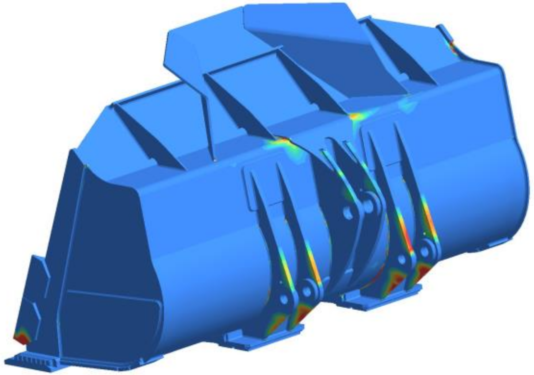


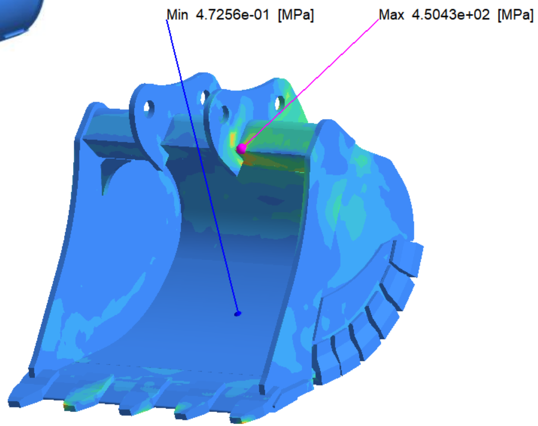
Altair EDEM™

BUDOUCNOST CO-SIMULACÍ NA ÚADI FSI VUT

- Zaměření modelování co-simulací:
  - Co-simulace 1W/2W **DEM-CFD**
  - Co-simulace **systémy-MBD-DEM** se zaměřením na hydraulické systémy s flexibilními tělesy v MBD







DĚKUJI ZA POZORNOST!

POUŽITÉ INFORMAČNÍ ZDROJE

- What is DEM: Theoretical Background behind the Discrete Element Method [online]. [cit. 2025-12-28]. Dostupné z: https://altair.com/docs/default-source/resource-library/ebook_what_is_dem_theoretical_background_behind_the_discrete_element_method.pdf?sfvrsn=975cfcf1_3
- CAPOZZI, Luigi C., Antonello A. BARRESI a Roberto PISANO. Supporting data and methods for the multi-scale modelling of freeze-drying of microparticles in packed-beds. *Data in Brief* [online]. Elsevier BV, 2019, **22**, 722-755 [cit. 2026-06-22]. ISSN 2352-3409. Dostupné z: doi:10.1016/j.dib.2018.12.061
- YUN, Tae Young, Sang Hyeok AHN, Jueong Hee NAM a Pyeong Jun YOO. Simulation of Aggregate Slump Test Using Equivalent Sphere Particle in DEM. *Journal of the Korean Society of Road Engineers* [online]. Korean Society of Road Engineers, 2013, 2013-10-15, **15**(5), 21-29 [cit. 2026-06-22]. ISSN 1738-7159. Dostupné z: doi:10.7855/ijhe.2013.15.5.021
- BARRIOS, Gabriel K.P., Narcés JIMÉNEZ-HERRERA a Luís Marcelo TAVARES. Simulation of particle bed breakage by slow compression and impact using a DEM particle replacement model. *Advanced Powder Technology* [online]. Elsevier BV, 2020, **31**(7), 2749-2758 [cit. 2026-06-22]. ISSN 0921-8831. Dostupné z: doi:10.1016/j.apt.2020.05.011