



FAKULTA ústav automobilního
STROJNÍHO a dopravního
INŽENÝRSTVÍ 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

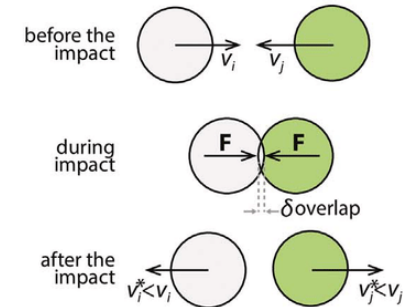
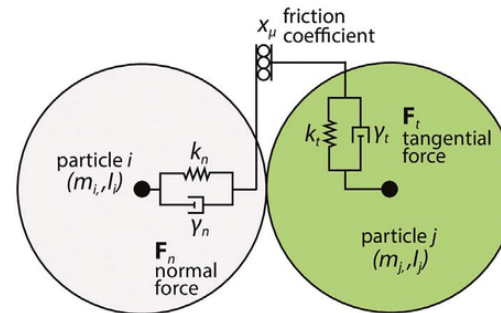
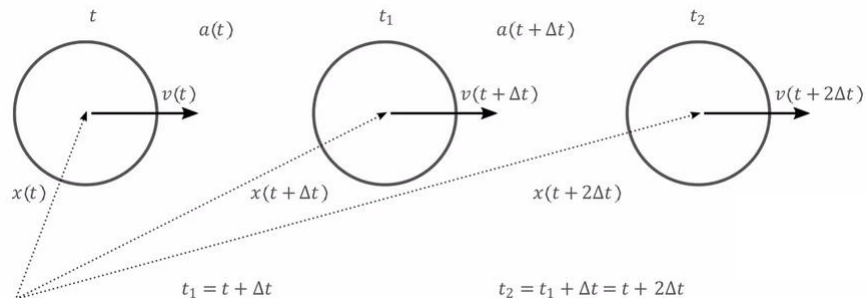
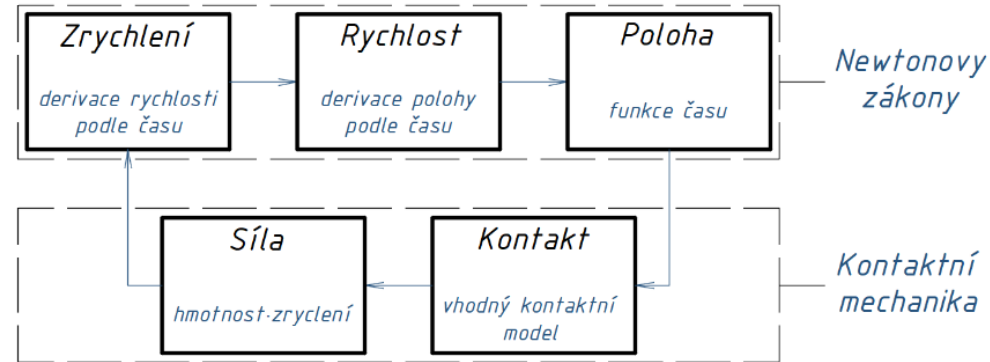
23.6.2026

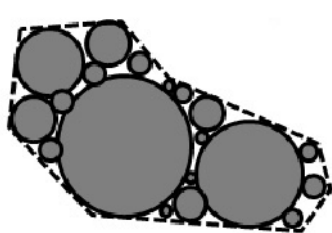
- ┐ Úvod do DEM simulací
- ┐ Modelování sypkých materiálů pro DEM analýzy
- ┐ Co-simulace DEM-MBD
- ┐ Jednosměrná a obousměrná co-simulace DEM-FEM
- ┐ Využití co-simulací pro stavební stroje
- ┐ Využití co-simulací pro úpravárenský průmysl
- ┐ Využití co-simulací pro zemědělství
- ┐ Zajímavosti z DEM modelování

ÚVOD DO DEM SIMULACÍ

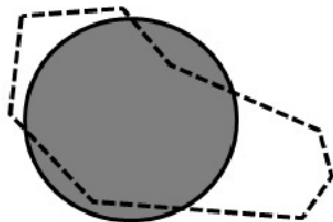
T DEM (Discrete Element Method)

T Vztah mezi Newtonovými pohybovými rovnicemi a kontaktní mechanikou

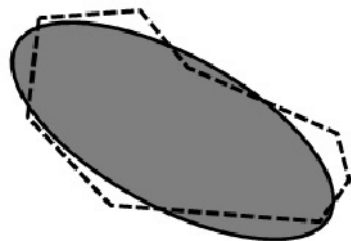




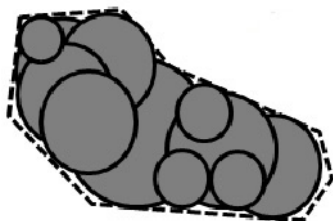
(a) Sphere Clump



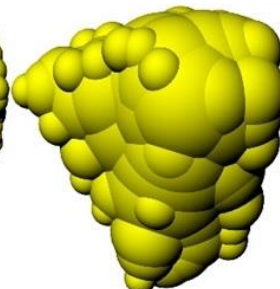
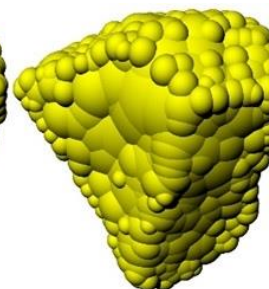
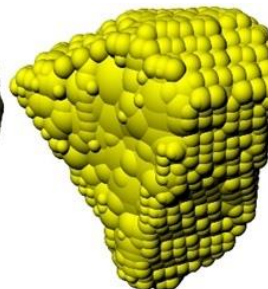
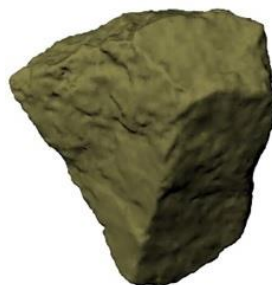
(b) Sphere



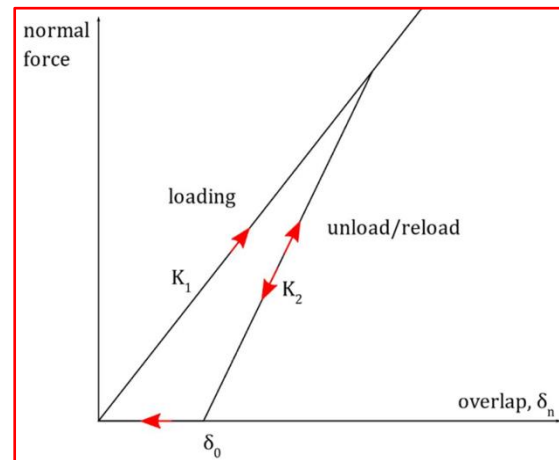
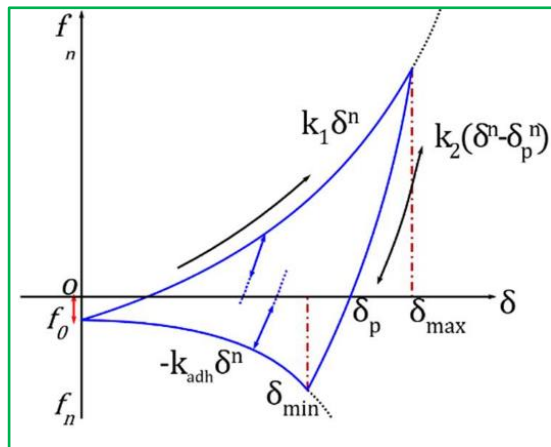
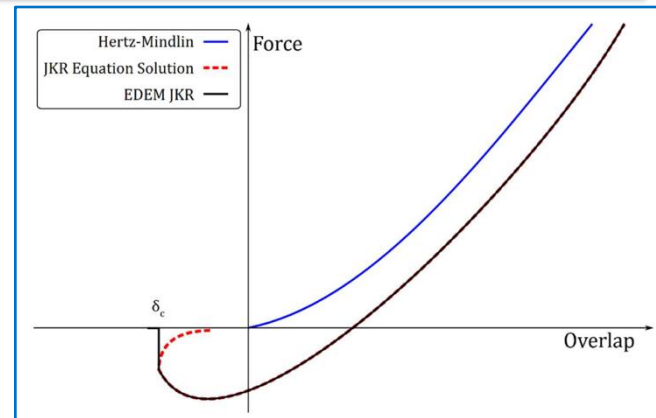
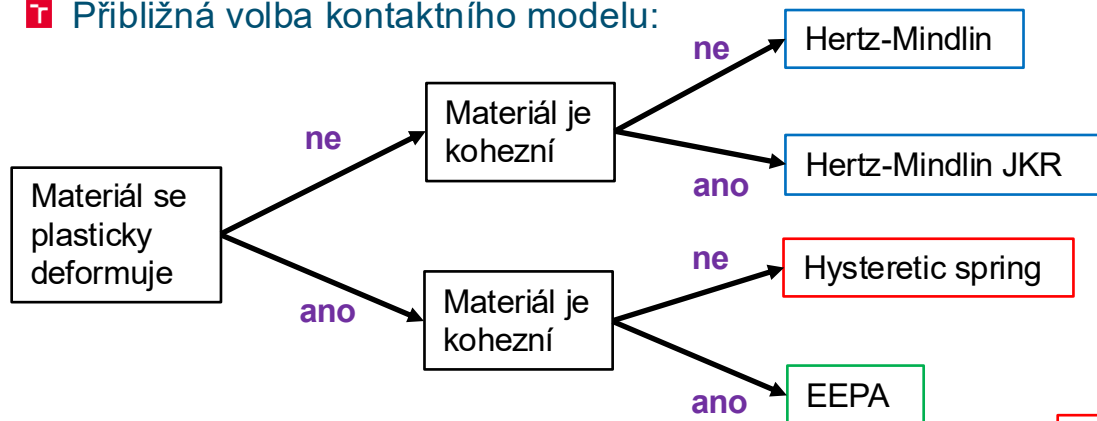
(c) Ellipsoid



(d) Overlapping Sphere Clump



T Přibližná volba kontaktního modelu:



MODELOVÁNÍ SYPKÝCH MATERIÁLŮ PRO DEM ANALÝZY

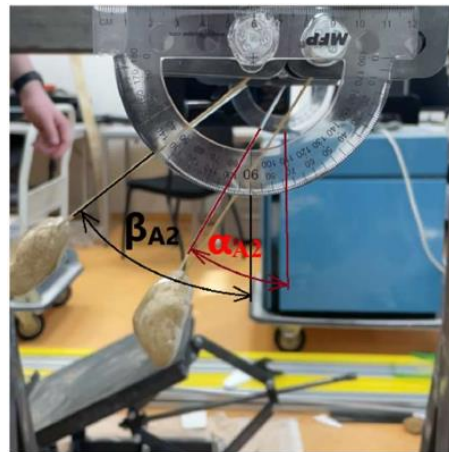
T Rozdělení velikosti částic



T Sypný úhel



T Koeficient restituce



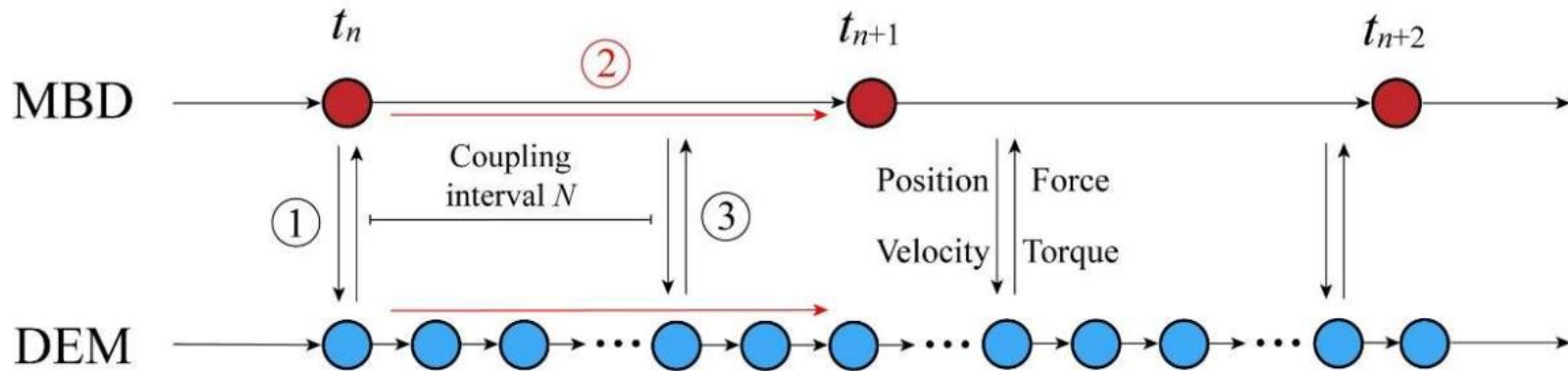
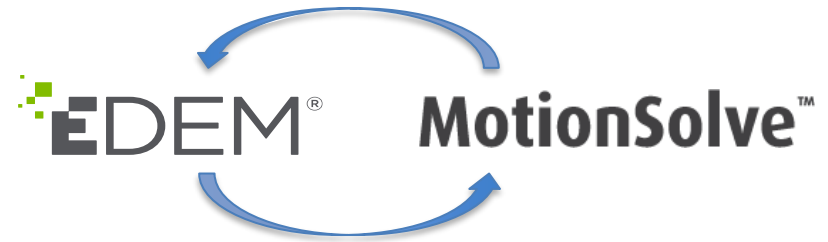
T Sypná hmotnost



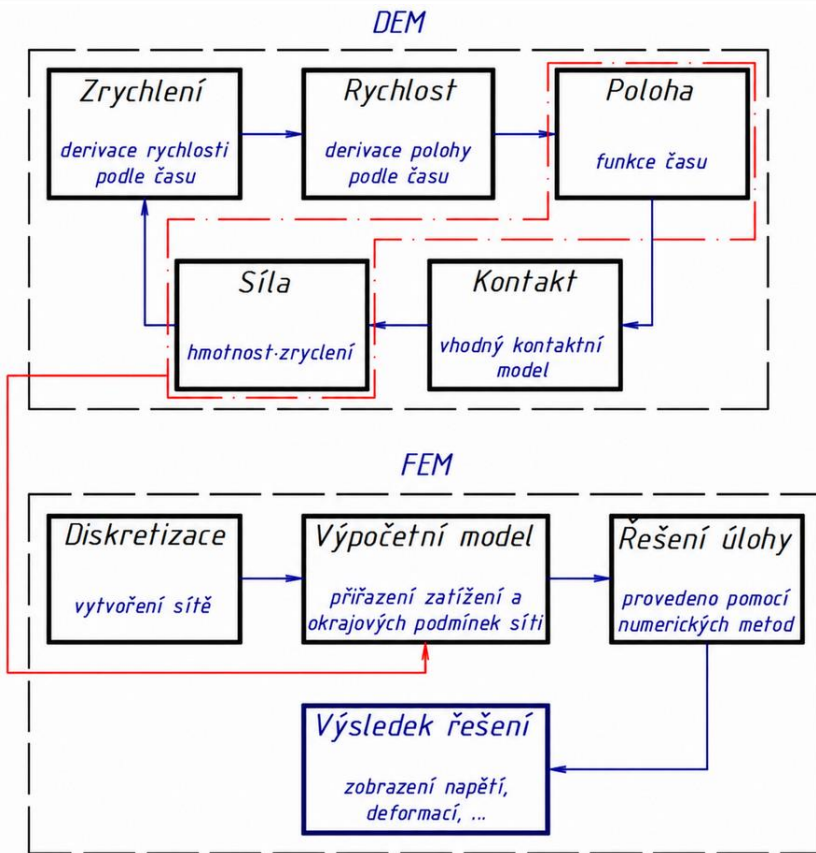
T Koeficient statického tření



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



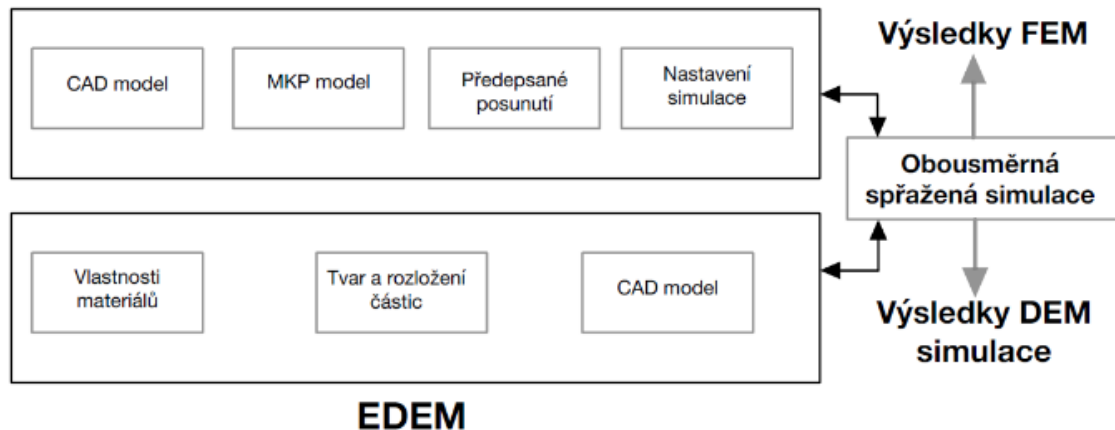
-  Předávání informací z **EDEM** o pozicích a velikostech sil působících na geometrii a export silového pole do **OptiStruct** nebo **SimSolid**
-  Tvorba v prostředí **EDEM+OptiStruct** a **EDEM+SimSolid**



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



SimLab a OptiStruct



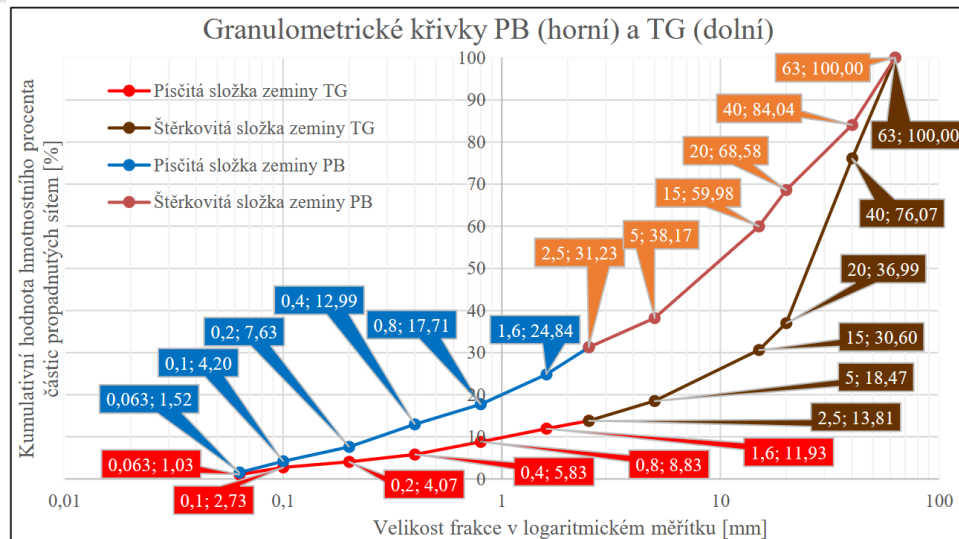
MĚŘENÍ MATERIÁLU PRO STAVEBNÍ STROJE

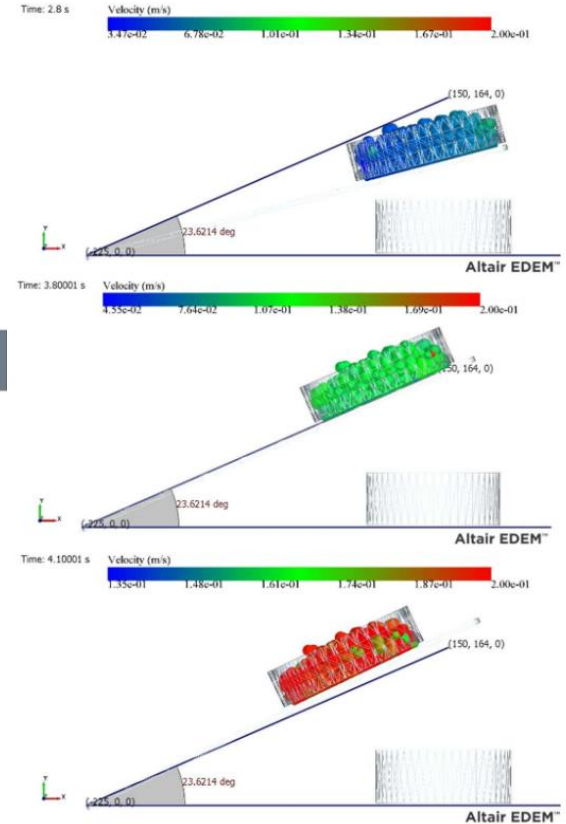
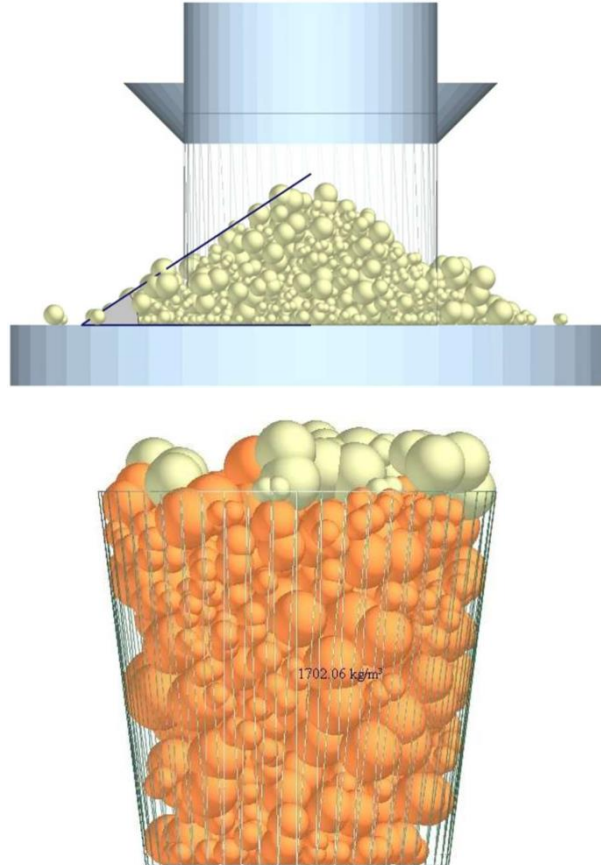
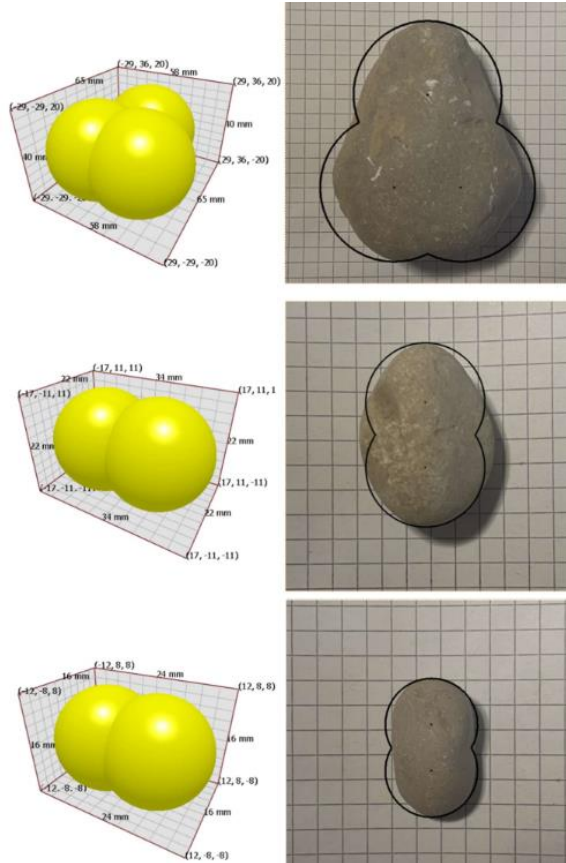
T Autor: Ing. Michal Kubiš,
Bc. Patrik Míra, Ing. Vít
Vašíř

T Použitý model: Hertz-
Mindlin JKR



**WACKER
NEUSON**



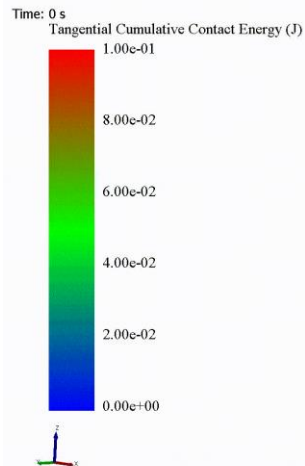


ANALÝZA LOPATY RYPADLA (2W DEM-FEM)

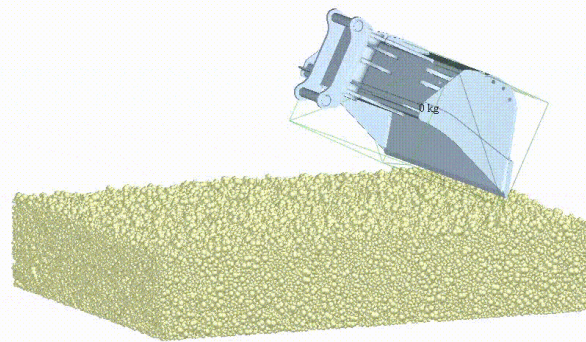
 Autor: Bc. Patrik Míra



 Kolové rypadlo Wacker Neuson EW100



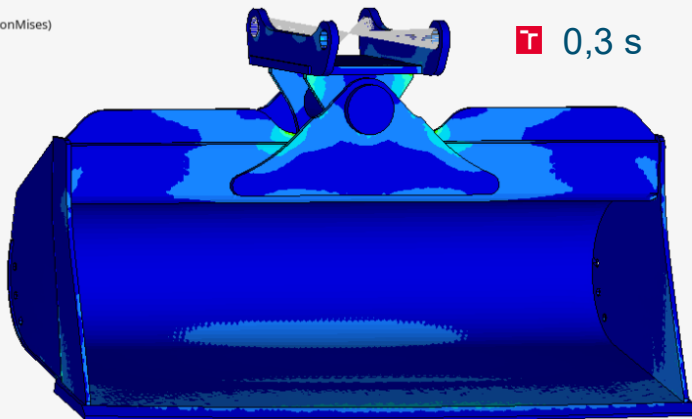
Altair EDEM™



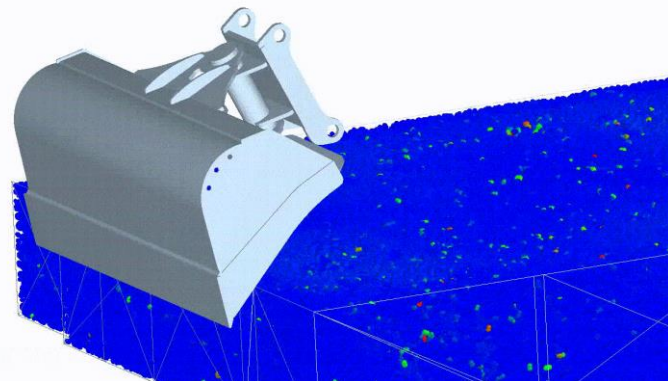
ANALÝZA LOPATY RYPADLA (2W DEM-FEM)

Contour Plot
Element Stresses (2D & 3D)(vonMises)
Analysis system
Simple Average
Value Filter <= 3.0000E+08

3.375E+08
3.000E+08
2.625E+08
2.250E+08
1.875E+08
1.500E+08
1.125E+08
7.502E+07
3.752E+07
2.829E+04
No Result
Max = 2.574E+08
Grids 127574
Min = 2.829E+04
Grids 126020

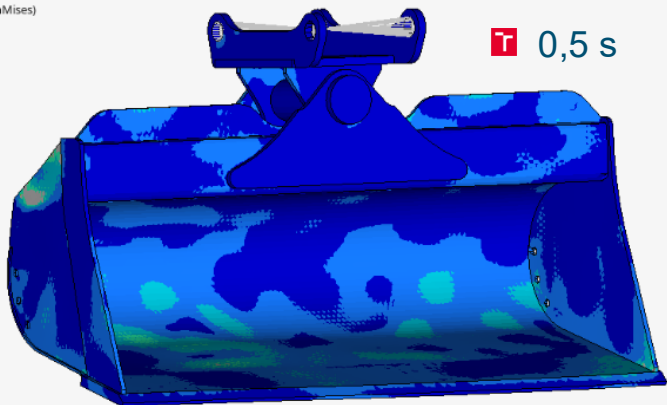


Time: 0 s
Velocity (m/s)
5.00e-01
4.00e-01
3.00e-01
2.00e-01
1.00e-01
1.17e-06



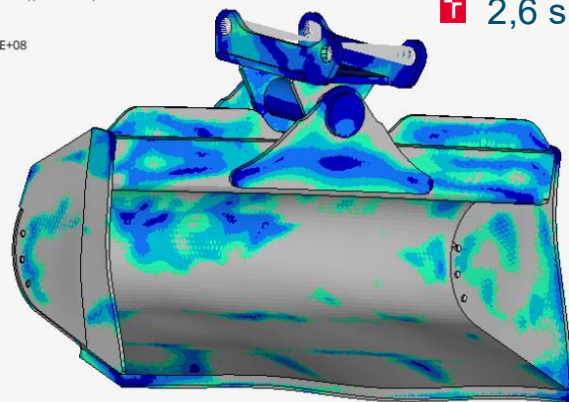
Contour Plot
Element Stresses (2D & 3D)(vonMises)
Analysis system
Simple Average
Value Filter <= 3.0000E+08

6.750E+08
6.000E+08
5.250E+08
4.501E+08
3.751E+08
3.002E+08
2.252E+08
1.502E+08
7.528E+07
3.152E+05
No Result
Max = 2.998E+08
Grids 264994
Min = 3.152E+05
Grids 129335

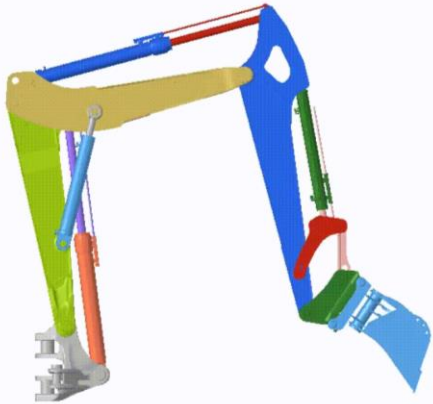


Contour Plot
Element Stresses (2D & 3D)(vonMises)
Analysis system
Simple Average
Value Filter <= 3.0000E+08

6.750E+08
6.000E+08
5.250E+08
4.501E+08
3.751E+08
3.001E+08
2.252E+08
1.502E+08
7.524E+07
2.734E+05
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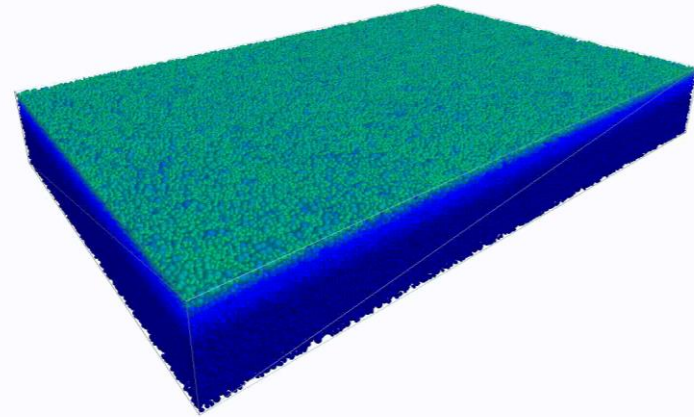
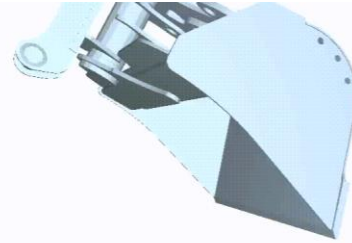


T Autor: Ing. Michal Kubiš



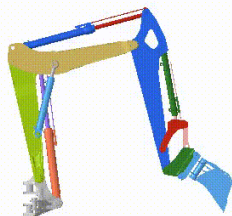
T MBD část

Time: 0 s

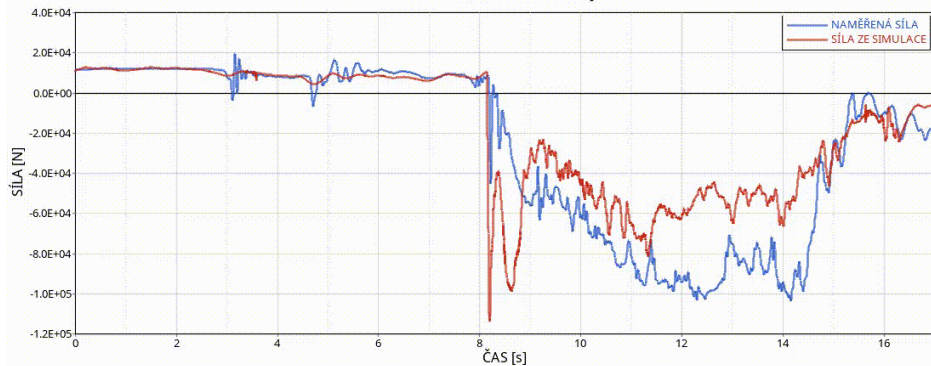


T DEM část

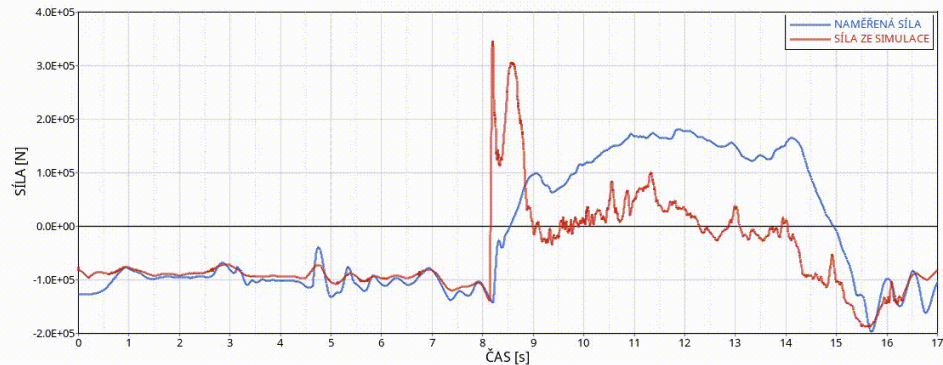
ANALÝZA PRACOVNÍHO CYKLU RYPADLA (DEM-MBD)



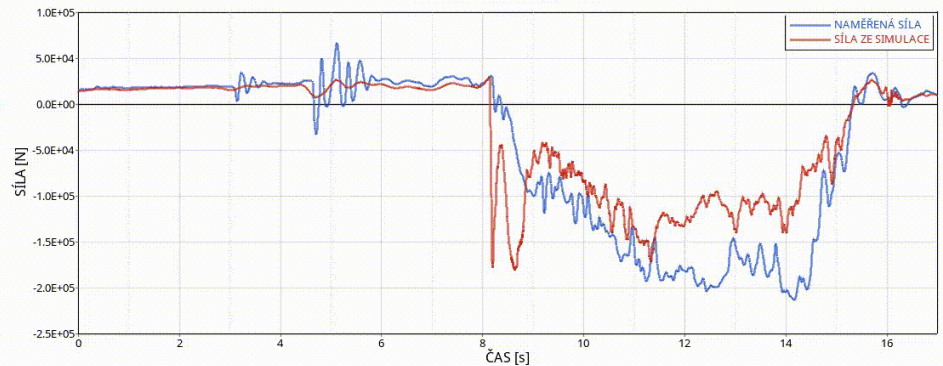
HYDROMOTOR NÁSTROJE



HYDROMOTOR SPODNÍHO VÝLOŽNÍKU



HYDROMOTOR NÁSADY

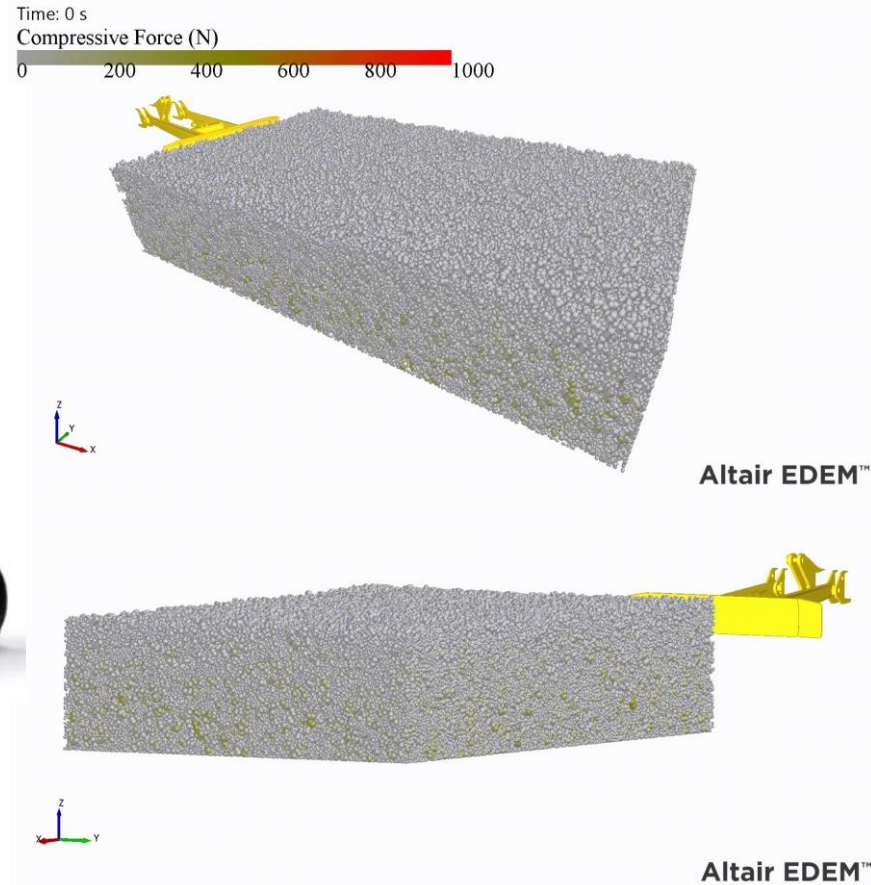


ANALÝZA DOZEROVÉ LOPATY RYPADLA (1W DEM-FEM)

Autor: Bc. Jindřich Pilař

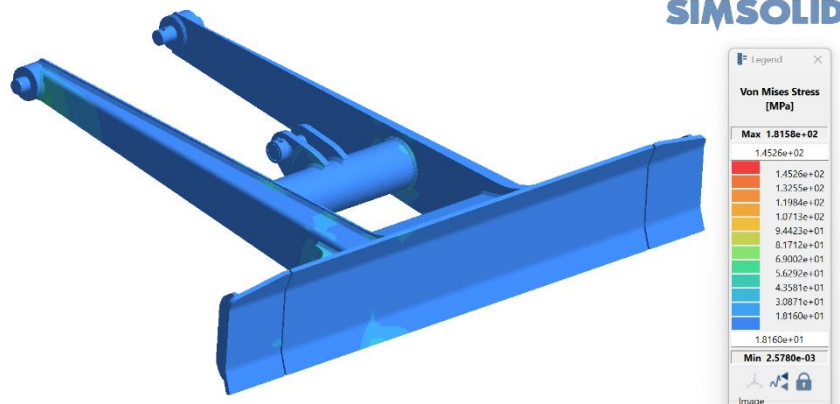


Pásové rypadlo Wacker Neuson EZ26

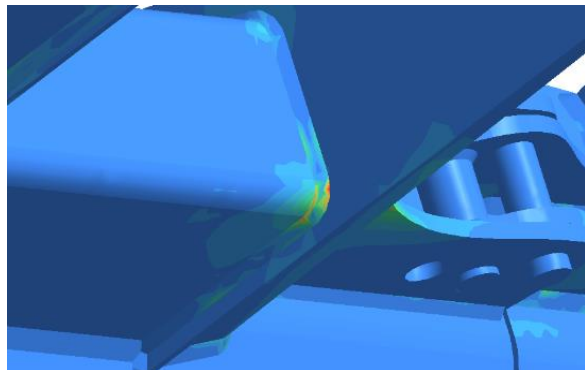


ANALÝZA DOZEROVÉ LOPATY RYPADLA (1W DEM-FEM)

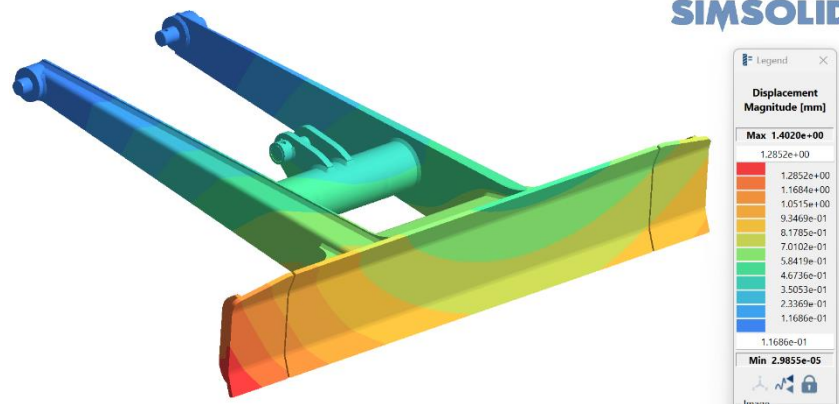
SIMSOLID



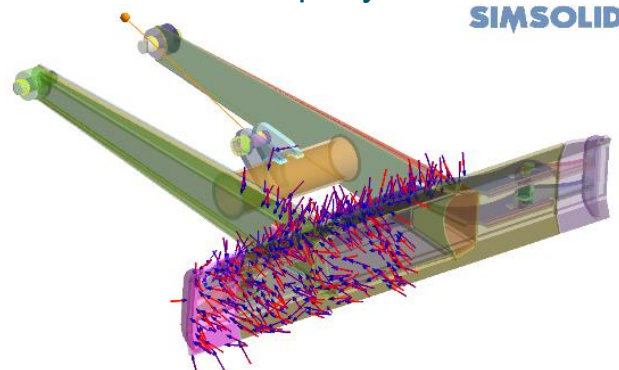
σ_{red} 181,6 MPa při rychlosti 6 km/h



SIMSOLID

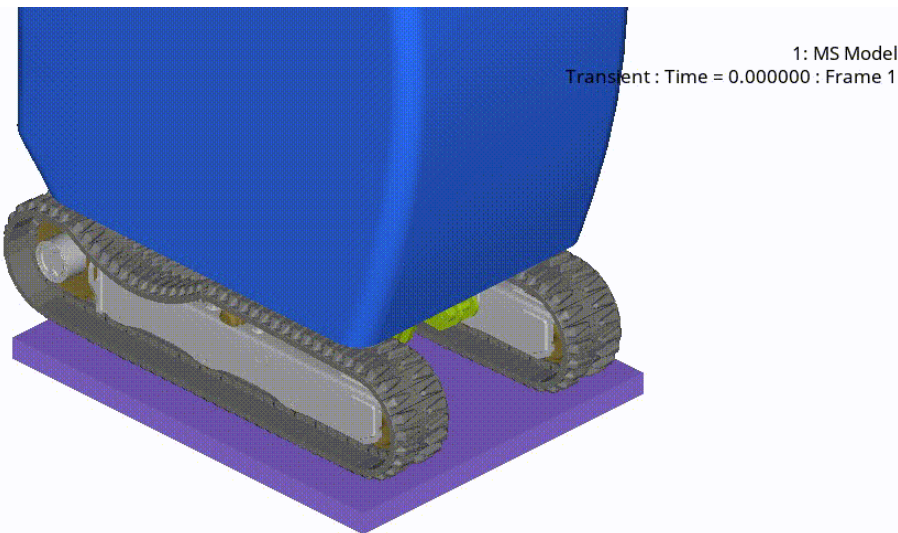


δ_{max} 1,8 mm při rychlosti 6 km/h

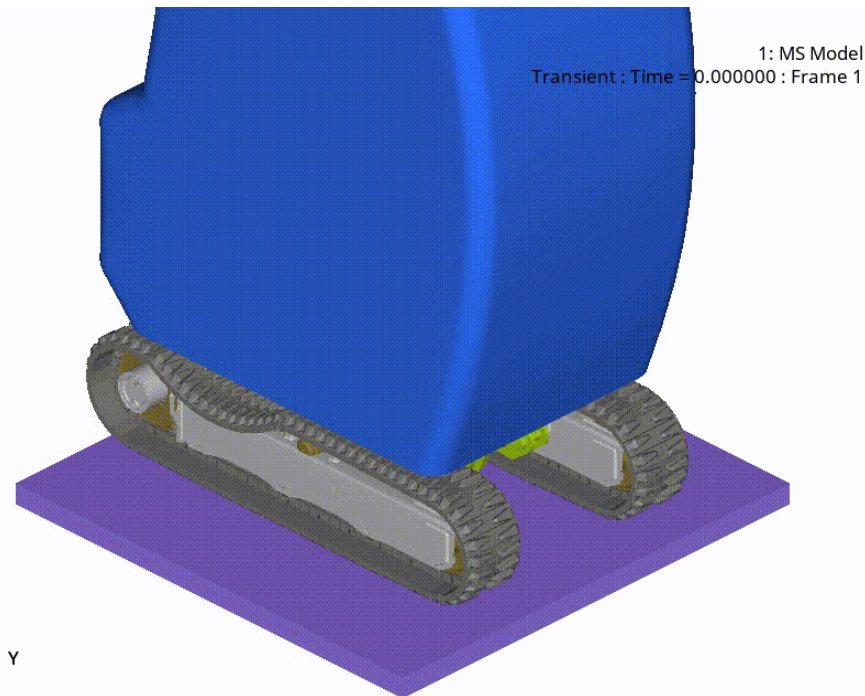


Si silové pole v čase 1,35 s

 Autor: Ing. Vít Vašíř

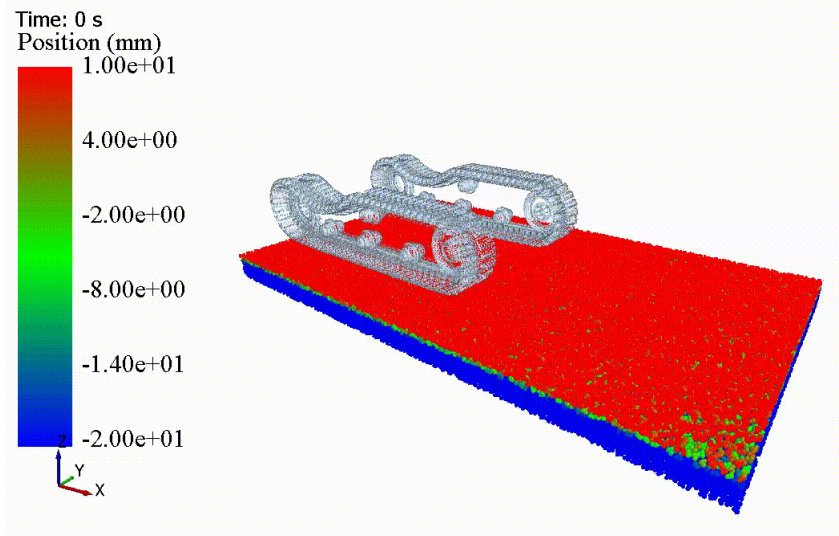


 Dopředný pohyb

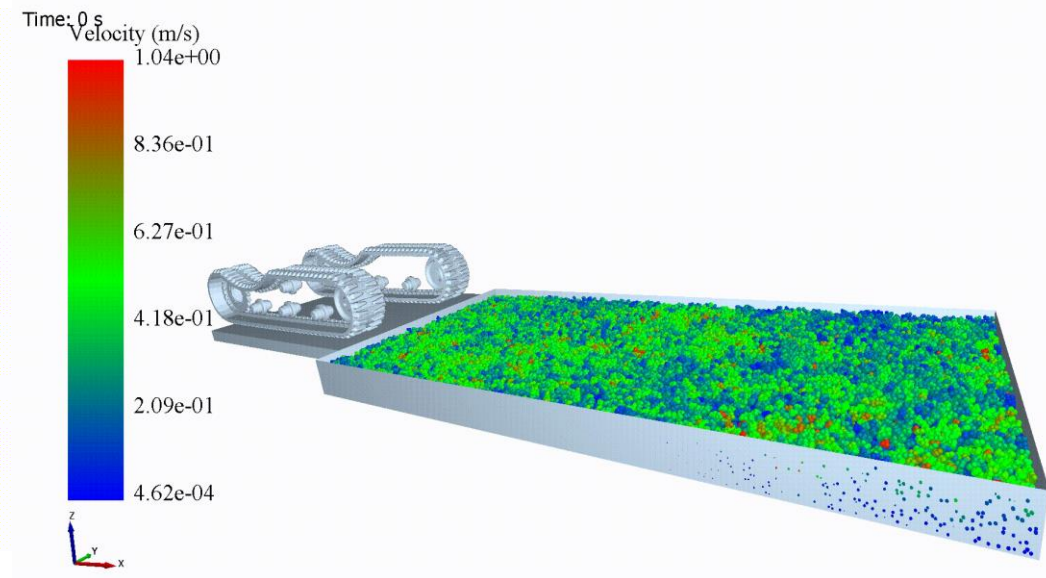


 Smykové zatáčení

 Autor: Ing. Vít Vašíř

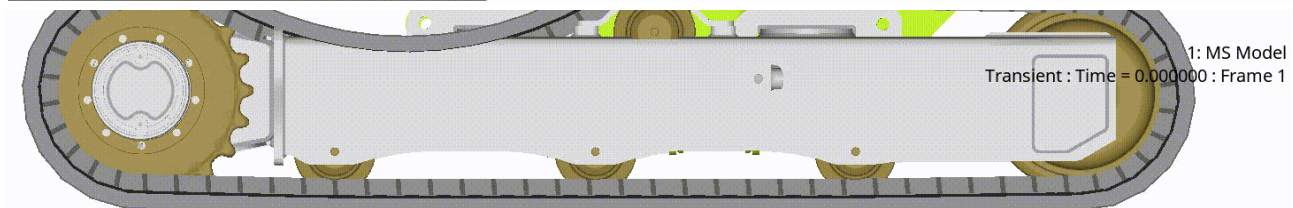
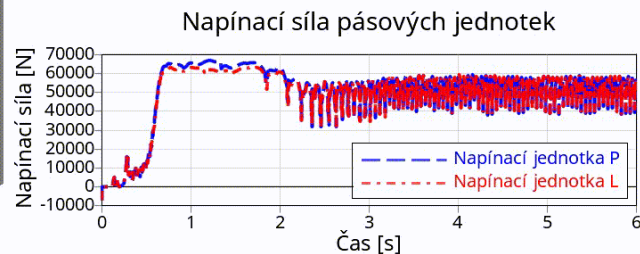
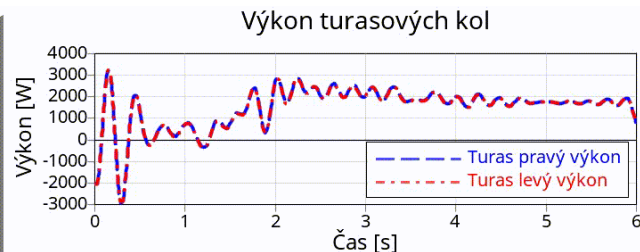
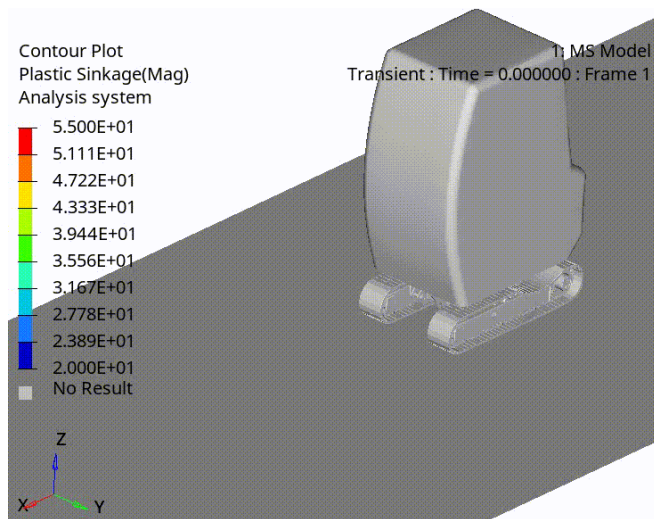


 Interakce sednutím



 Interakce najetím

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

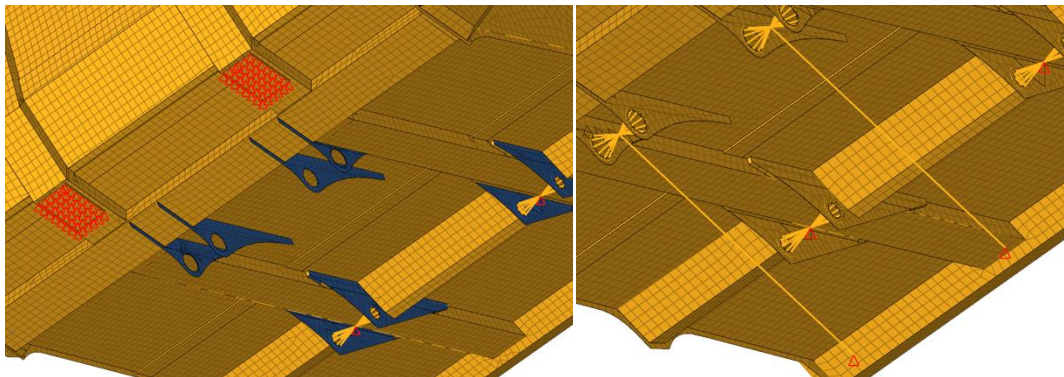
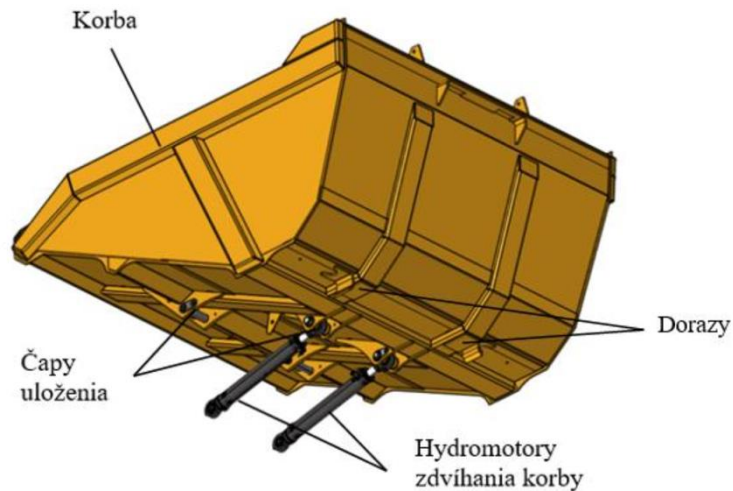


ANALÝZA KORBY DUMPERU (1W DEM-FEM)

 Autor: Ing. Andrej Lukačovič



 Dumper Wacker Neuson DV125



T Analýza nasypání korby:

- T 1. poloha = **10,03 tun**
- T 2. poloha = **12,36 tun**
- T 3. poloha = **11,34 tun**

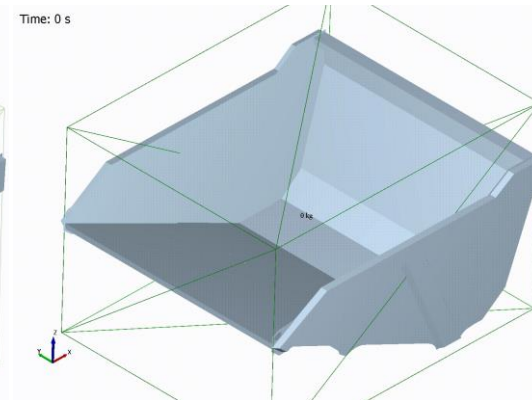
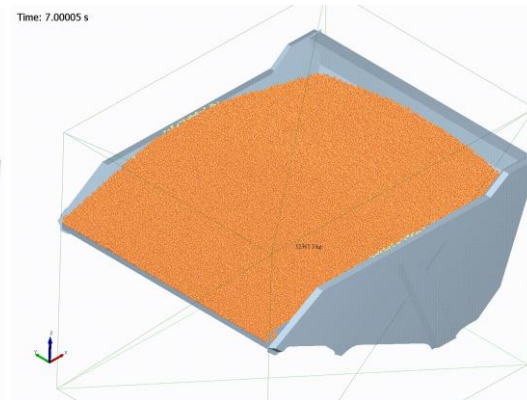
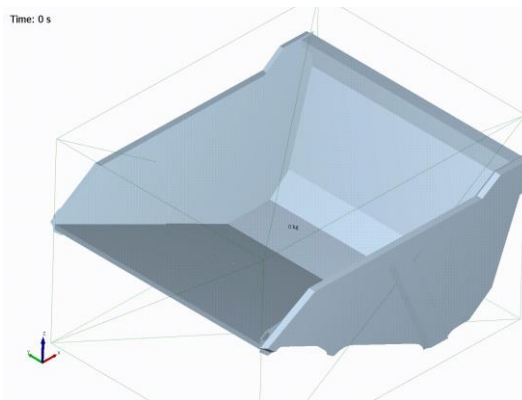
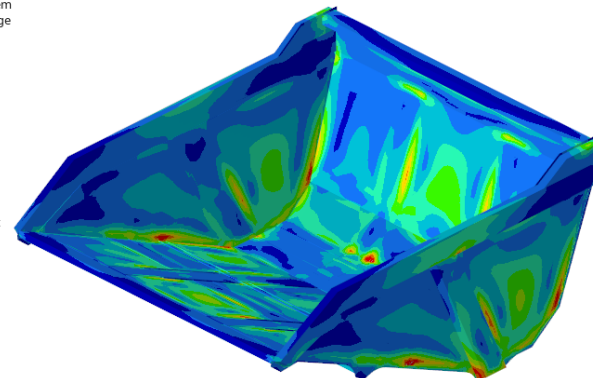
T Pevnostní analýza:

- T Deformace: 3,56 mm
- T Maximální napětí: 72 MPa



Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

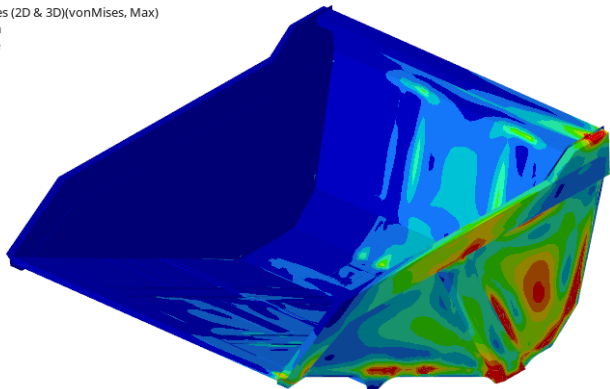
80.00
71.11
62.22
53.33
44.44
35.56
26.67
17.78
8.89
0.00
No Result
Max = 124.37
Grids 248138
Min = 0.00
Grids 50622



ANALÝZA KORBY DUMPERU (1W DEM-FEM)

Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

150.00
133.33
116.67
100.00
83.33
66.67
50.00
33.33
16.67
0.00
No Result
Max = 284.88
Grids 165243
Min = 0.00
Grids 50622

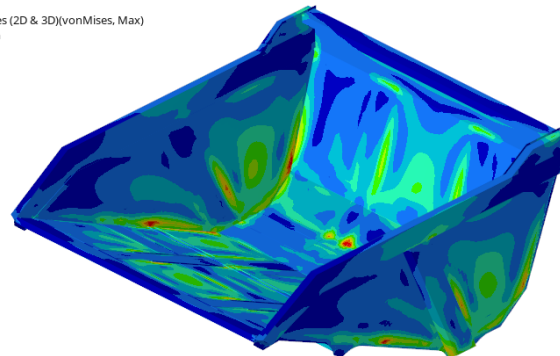


☐ Zatáčení při 1G

☐ σ_{red} 142 MPa

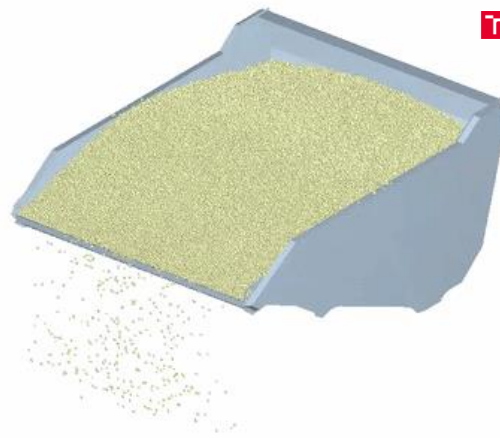
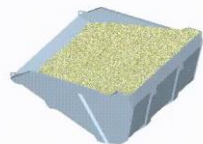
Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

60.000
53.333
46.667
40.000
33.333
26.667
20.000
13.333
6.667
0.000
No Result
Max = 84.624
Grids 51293
Min = 0.000
Grids 50622



☐ Vysypávání

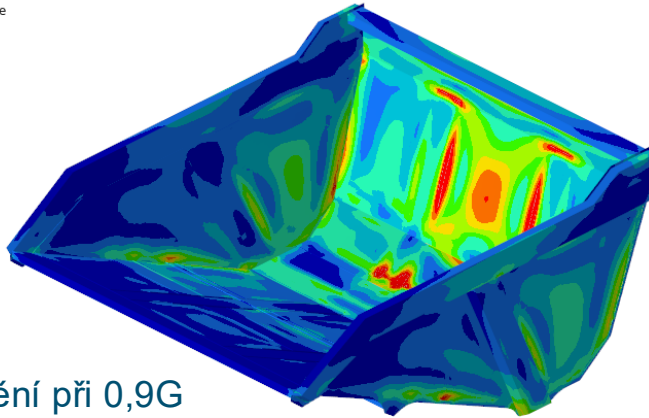
☐ σ_{red} 52 MPa



ANALÝZA KORBY DUMPERU (1W DEM-FEM)

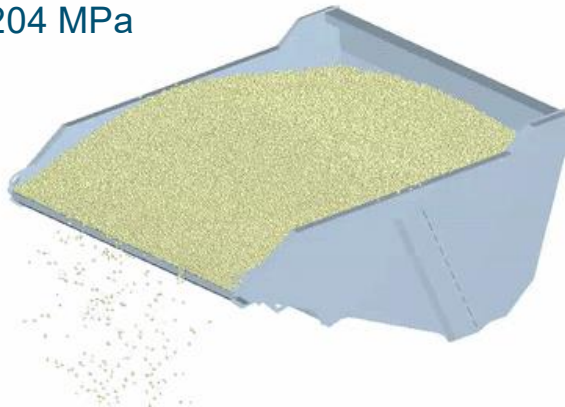
Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

200.00
177.78
155.56
133.33
111.11
88.89
66.67
44.44
22.22
0.00
No Result
Max = 516.59
Grids 25732
Min = 0.00
Grids 50622



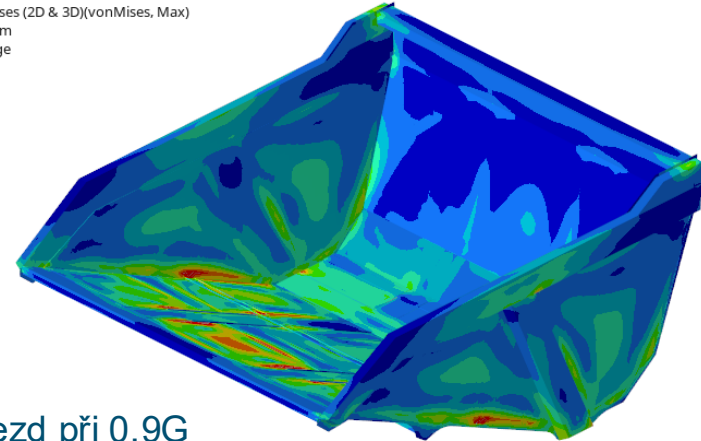
T Brždění při 0,9G

T σ_{red} 204 MPa



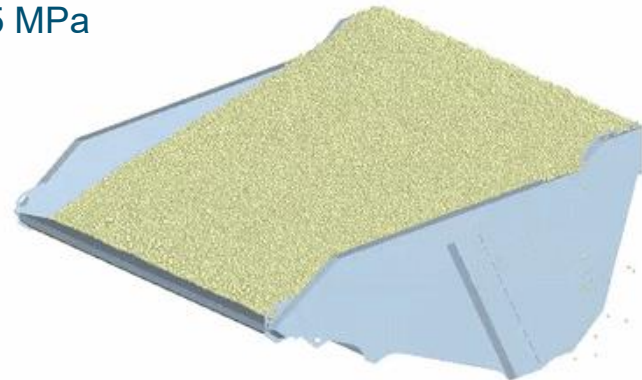
Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

120.00
106.67
93.33
80.00
66.67
53.33
40.00
26.67
13.33
0.00
No Result
Max = 365.57
Grids 248138
Min = 0.00
Grids 50622



T Rozjezd při 0,9G

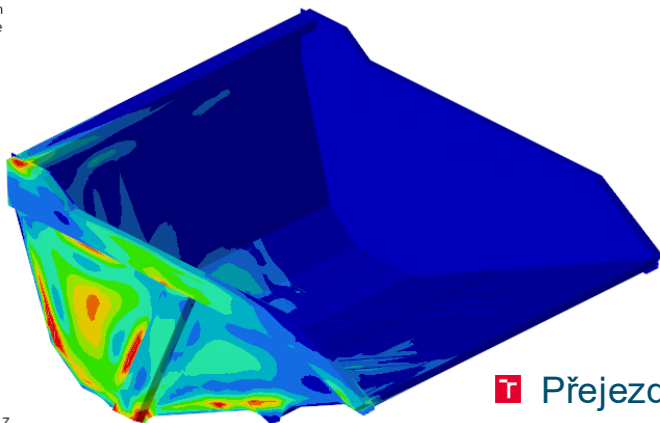
T σ_{red} 105 MPa



ANALÝZA KORBY DUMPERU (1W DEM-FEM)

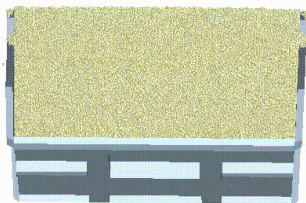
Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

700.0
622.2
544.4
466.7
388.9
311.1
233.3
155.6
77.8
0.0
No Result
Max = 1009.5
Grids 248680
Min = 0.0
Grids 50622



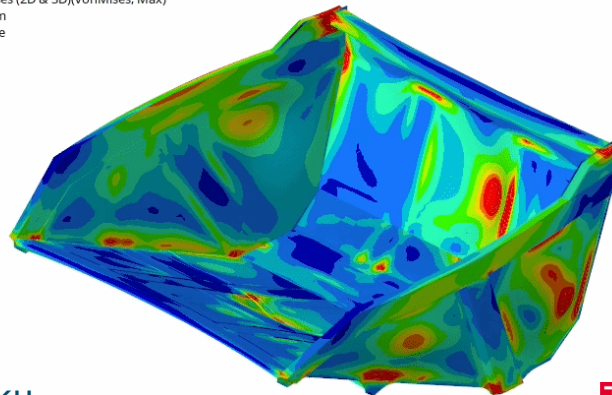
T Přejezd přes překážku

T σ_{red} 595 MPa



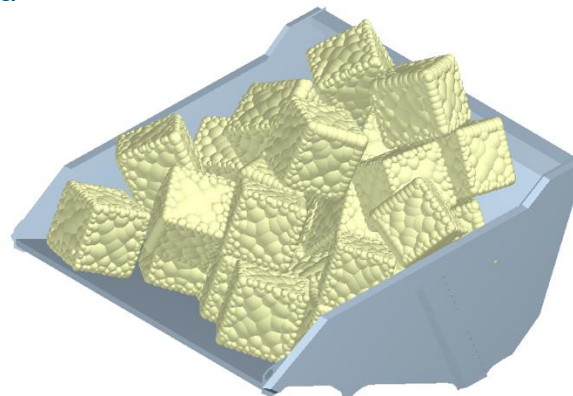
Contour Plot
Element Stresses (2D & 3D)(vonMises, Max)
Analysis system
Simple Average

3000.0
2666.7
2333.3
2000.0
1666.7
1333.3
1000.0
666.7
333.3
0.0
No Result
Max = 5287.5
Grids 2812
Min = 0.0
Grids 50622

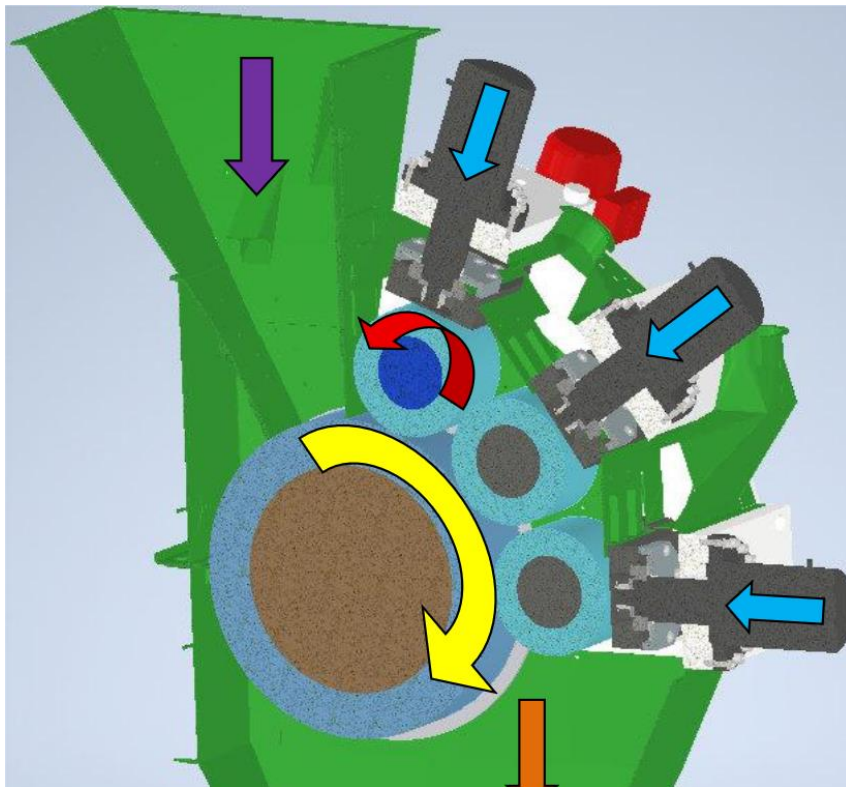


T Nasypání bloků

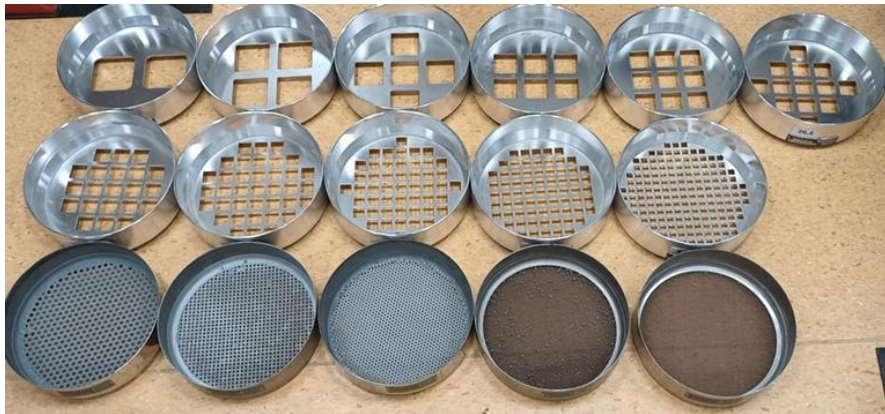
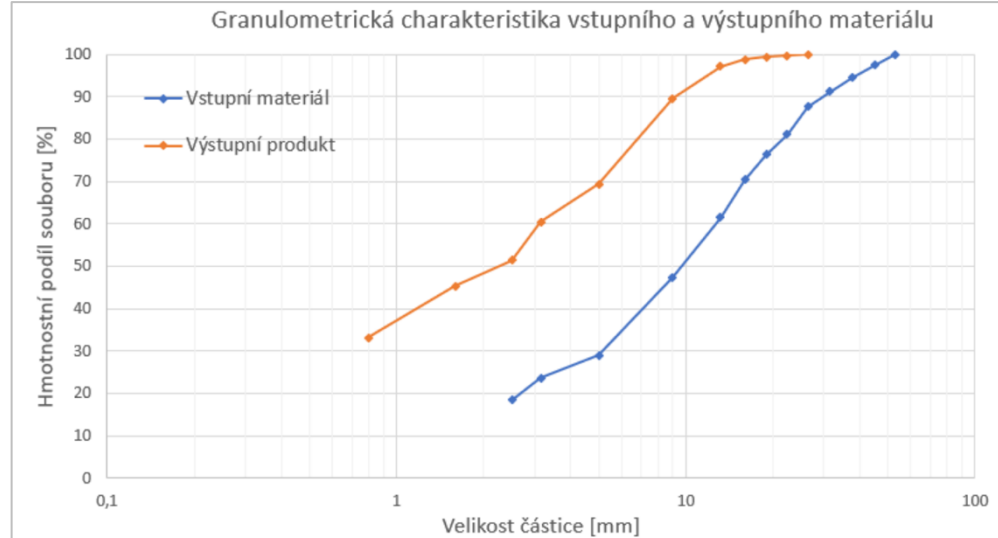
T σ_{red} 3130 MPa

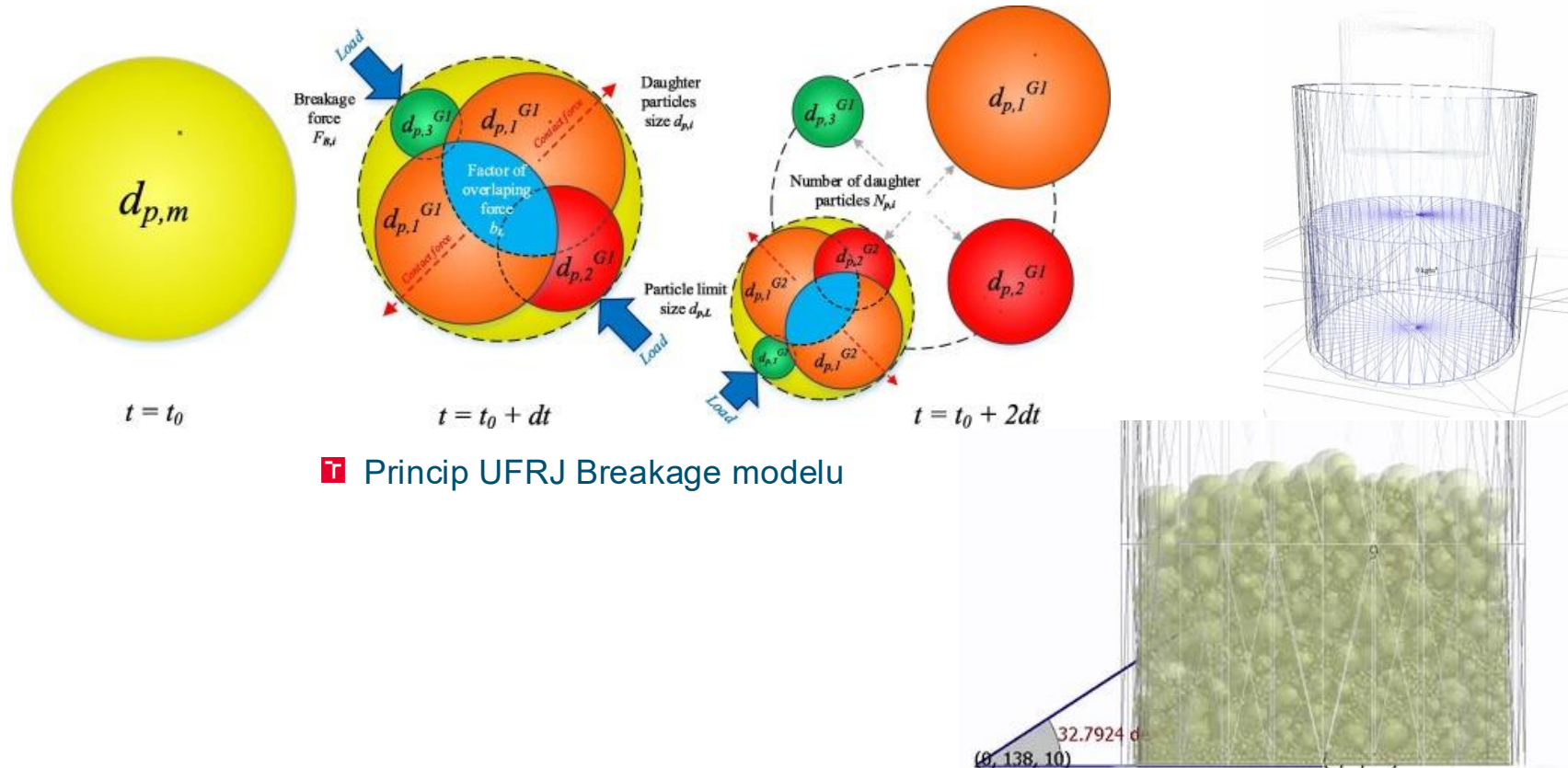


 Autor: Ing. Petr Pokluda

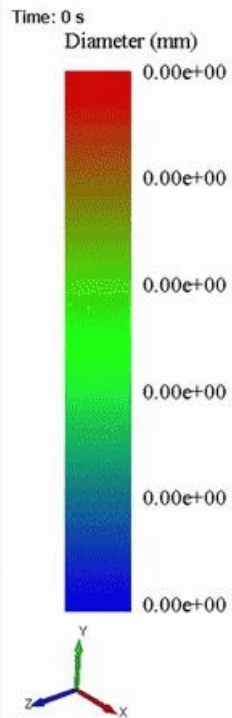


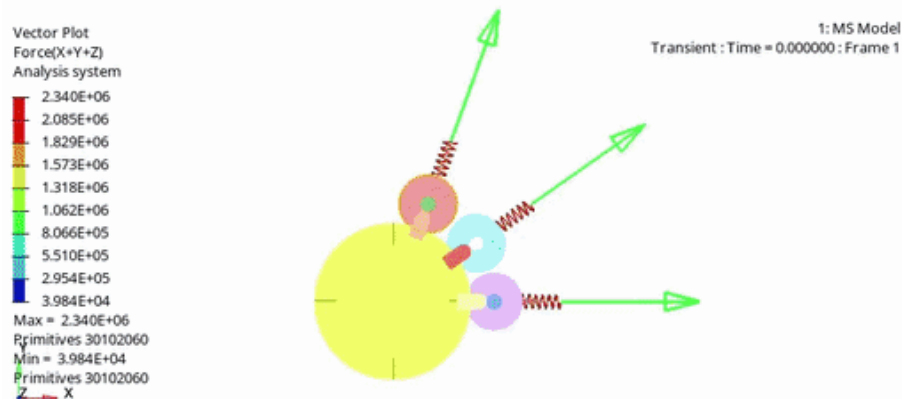
 Použitý model: Hertz-Mindlin+UFRJ Breakage



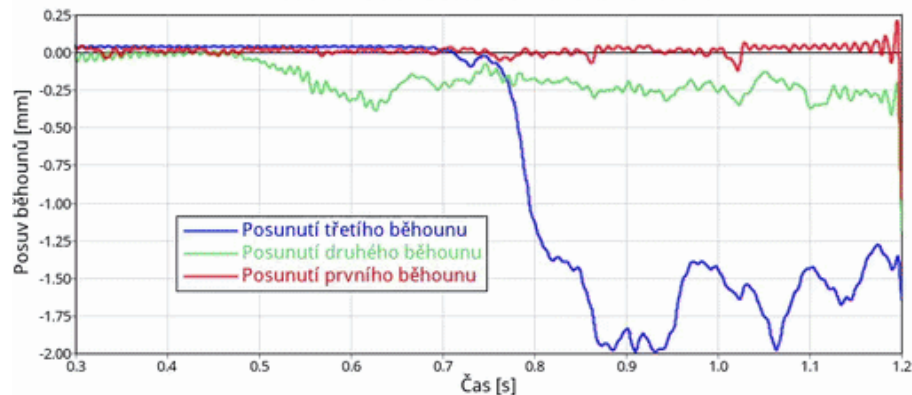


T Princip UFRJ Breakage modelu

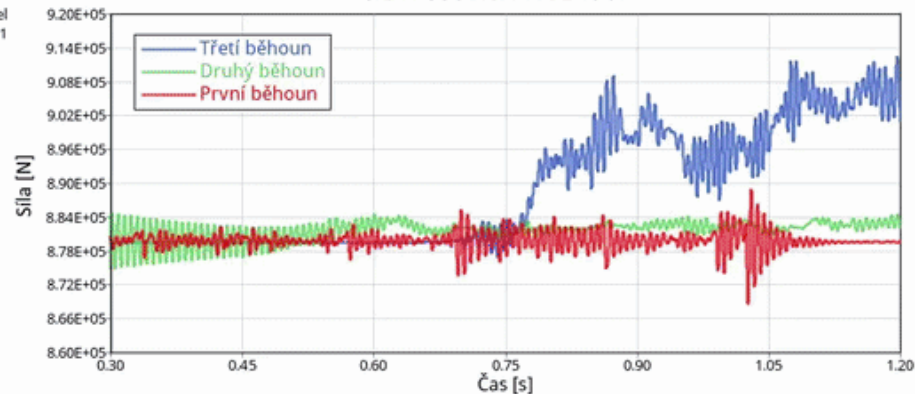




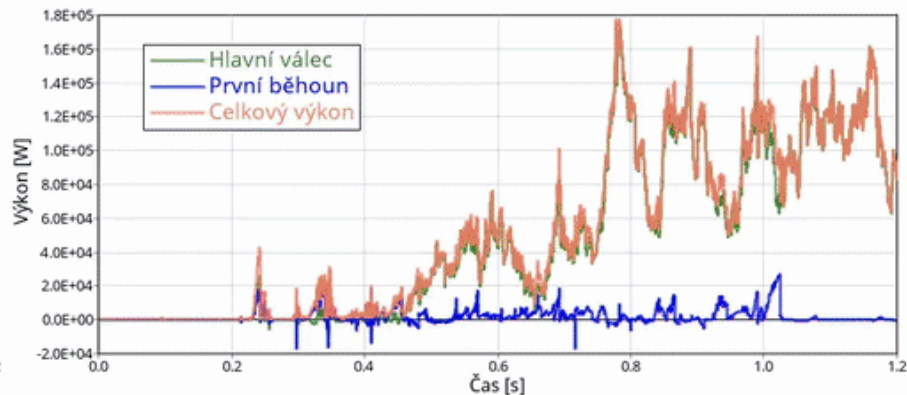
POSUNUTÍ BĚHOUNŮ OD HLAVNÍHO VÁLCE



SÍLA PŮSOBÍCÍ NA BĚHOUNY

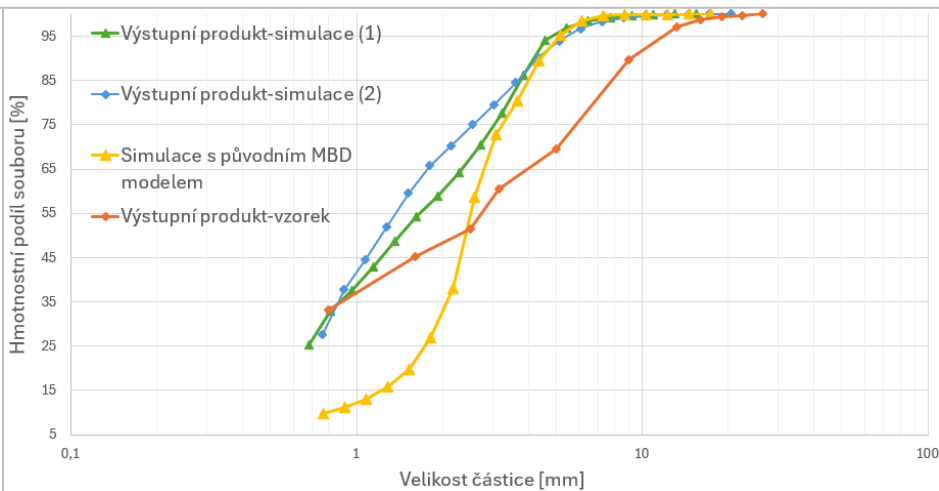
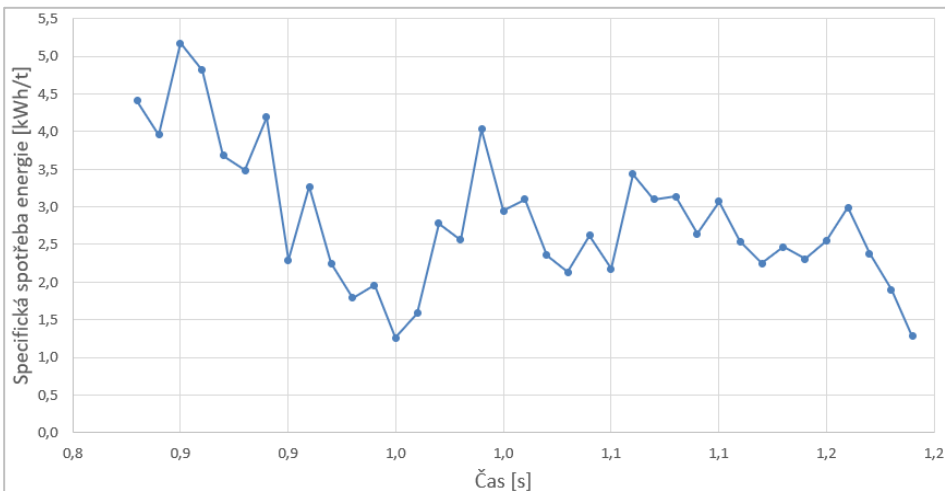


ODEBÍRANÝ VÝKON ZAŘÍZENÍ

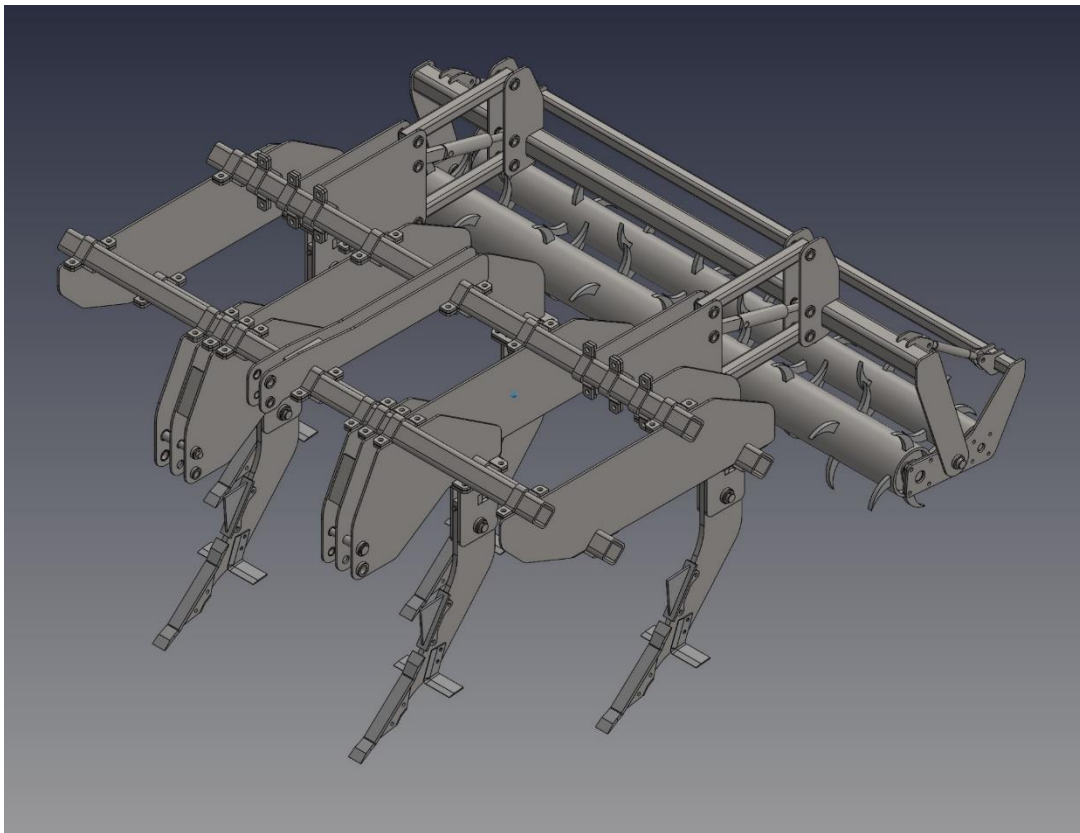
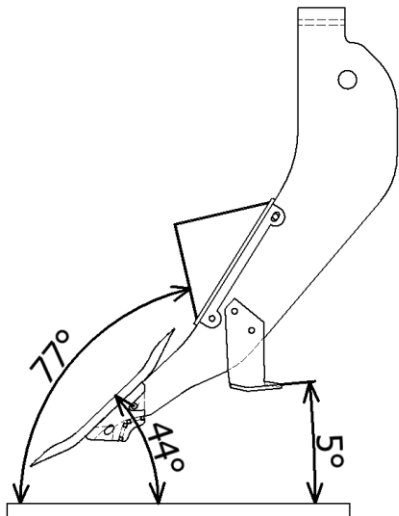


T Hodnoty specifické spotřeby energie v reálném provozu jsou okolo **2,0-2,8 kWh/t**

T Granulometrické křivky byly při volených hodnotách řádově podobné

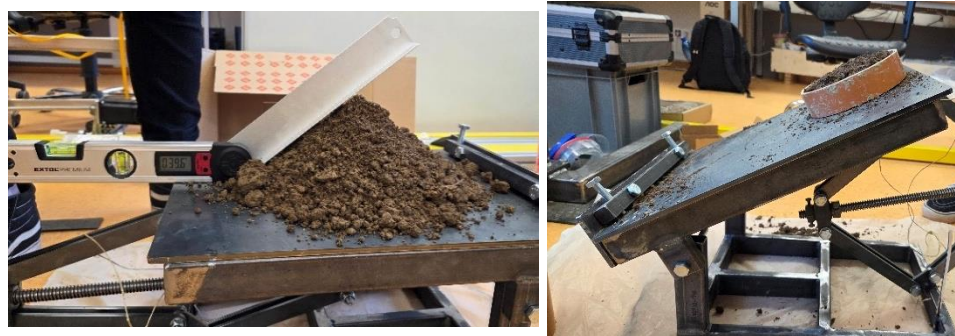
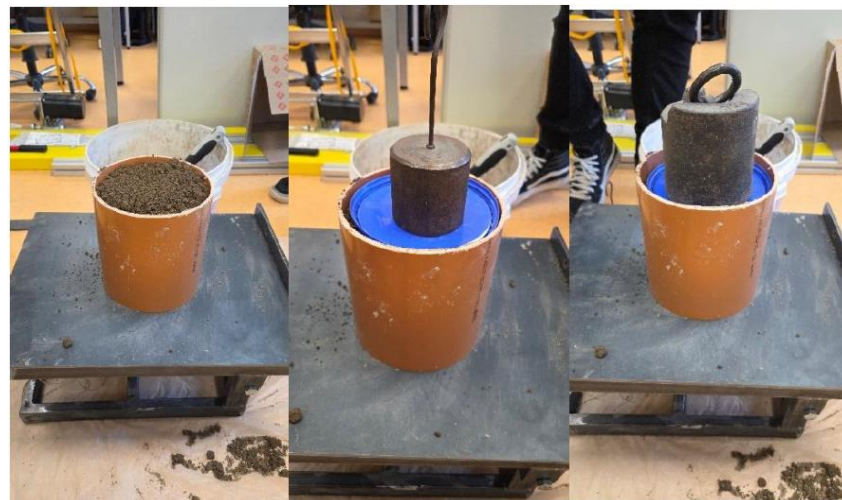
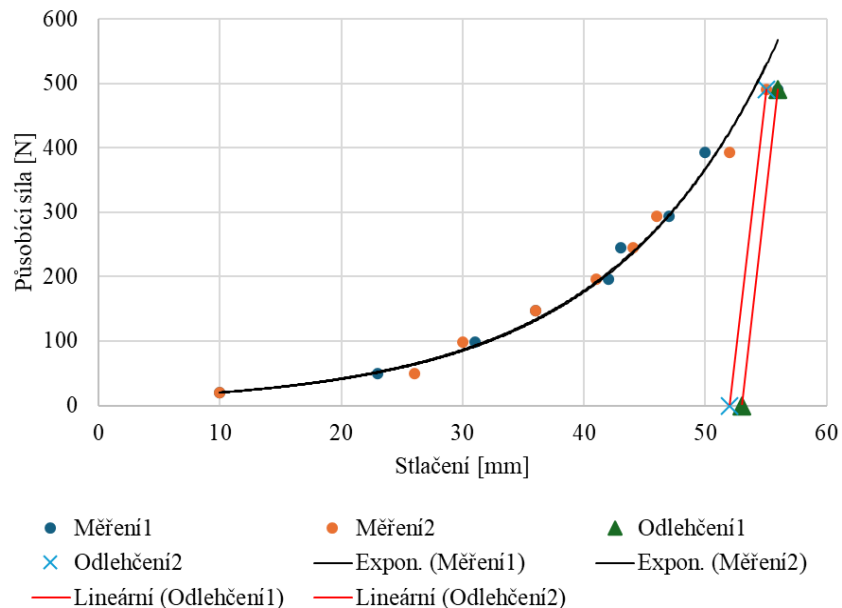


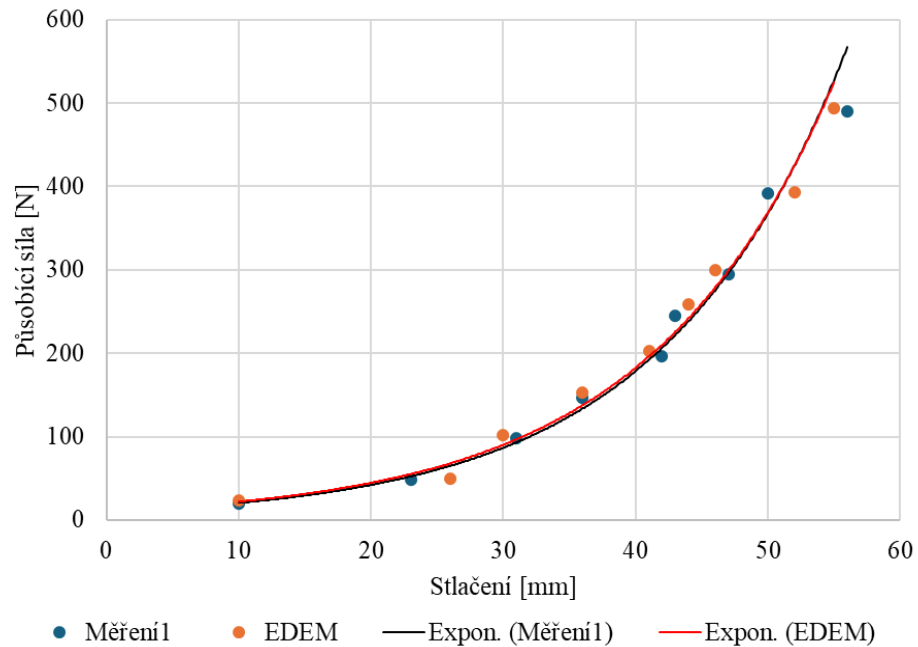
 Autor: Ing. Adam Svoboda



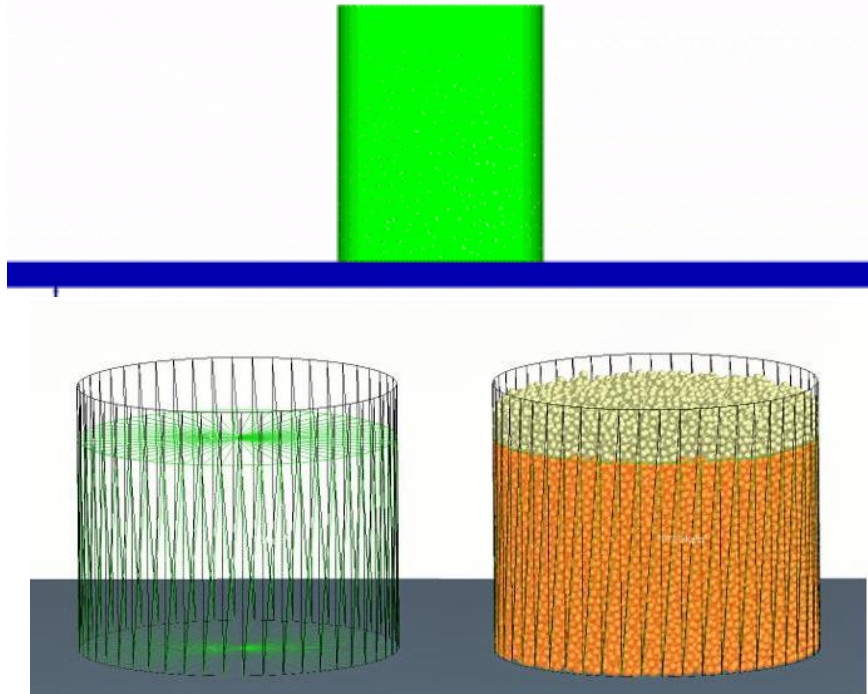
OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)

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

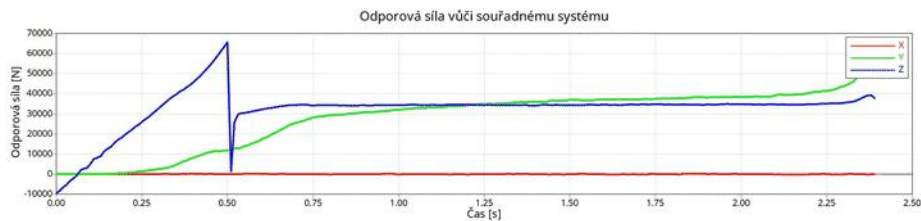




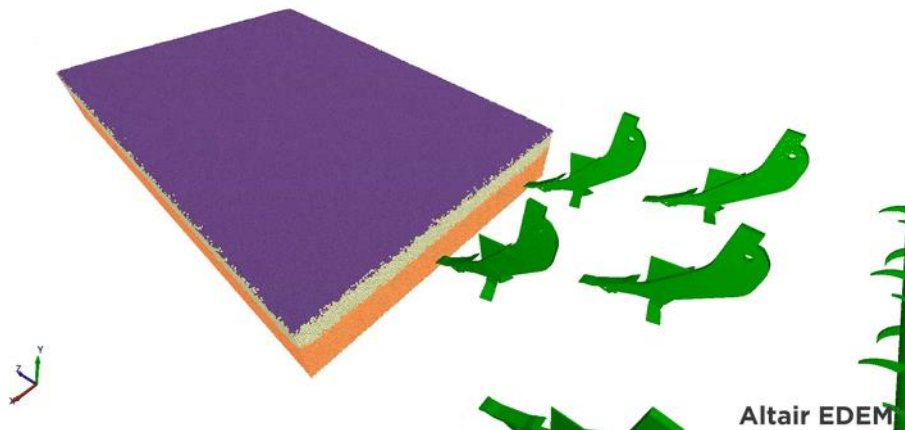
Time: 1 s



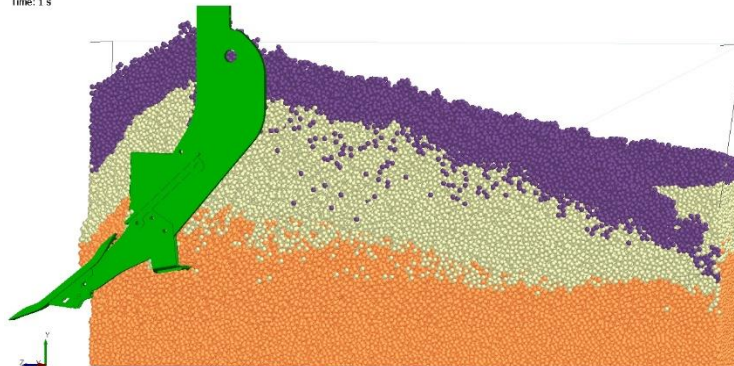
OPTIMALIZACE SLUPICE DLÁTOVÉHO PLUHU (DEM-MBD)



Time: 0 s

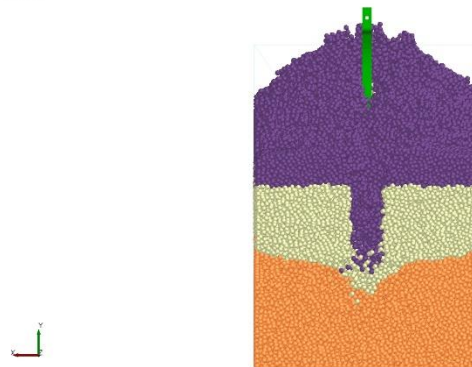


Time: 1 s



Altair EDEM™

Time: 1 s

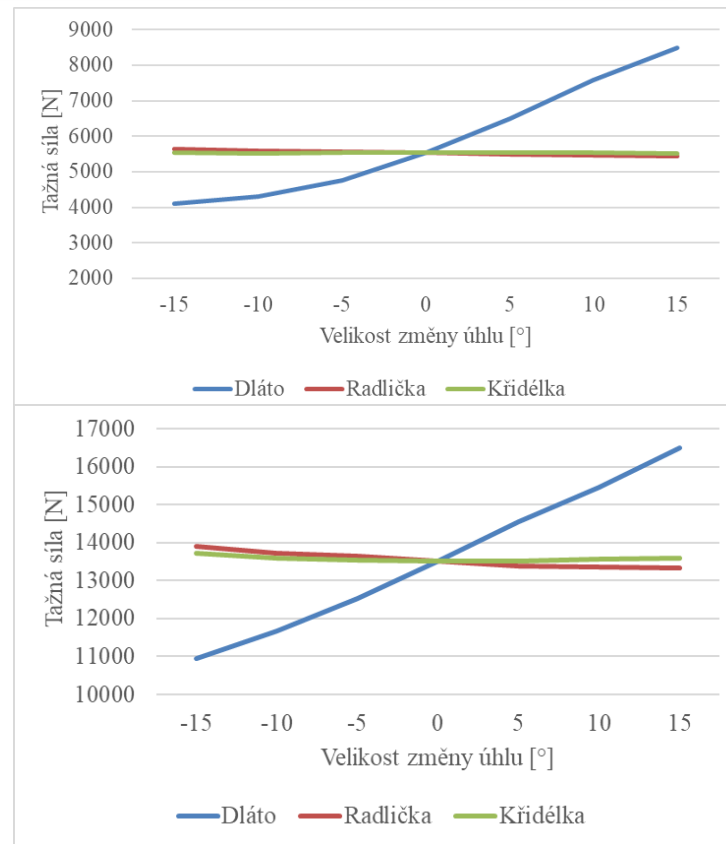
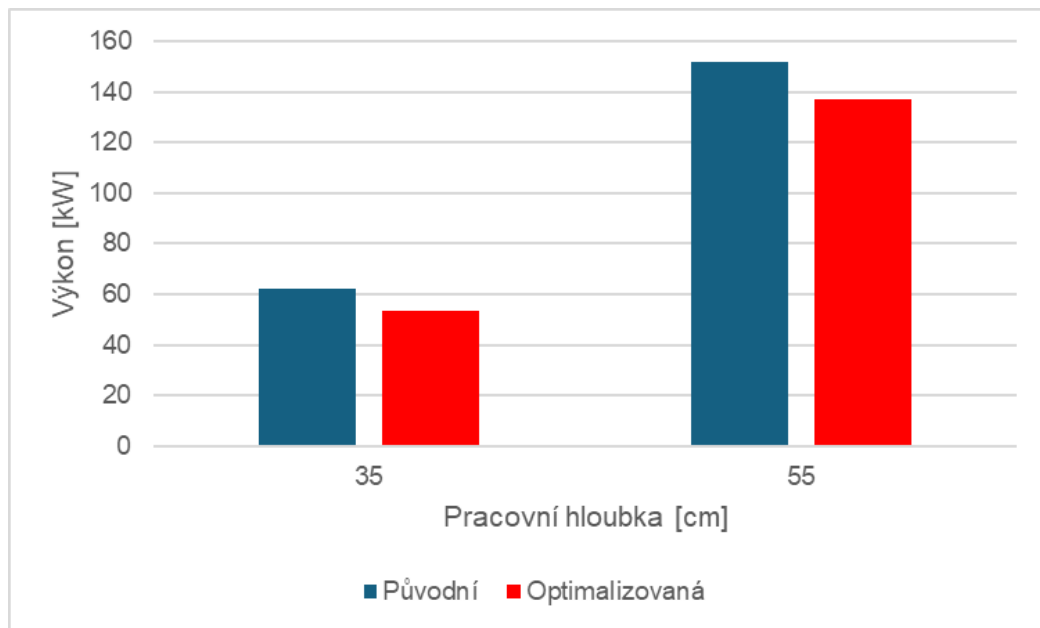


Altair EDEM™

Snížení potřebného výkonu:

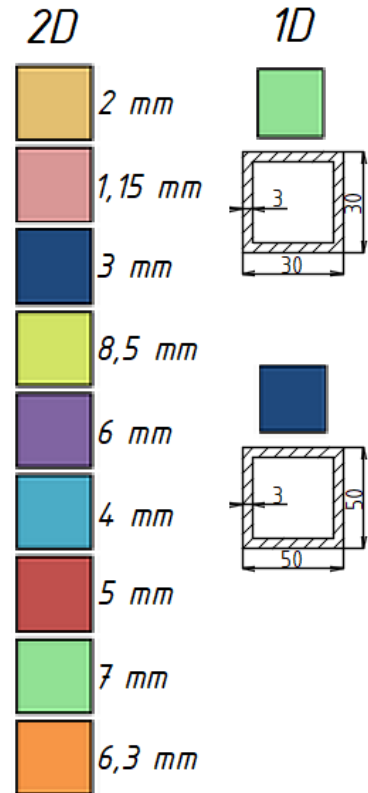
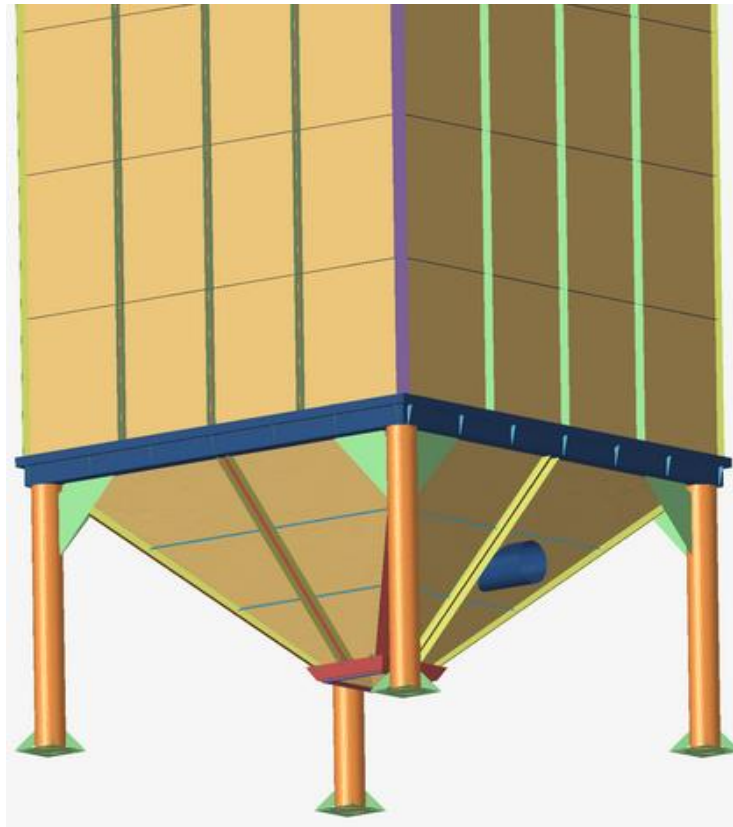
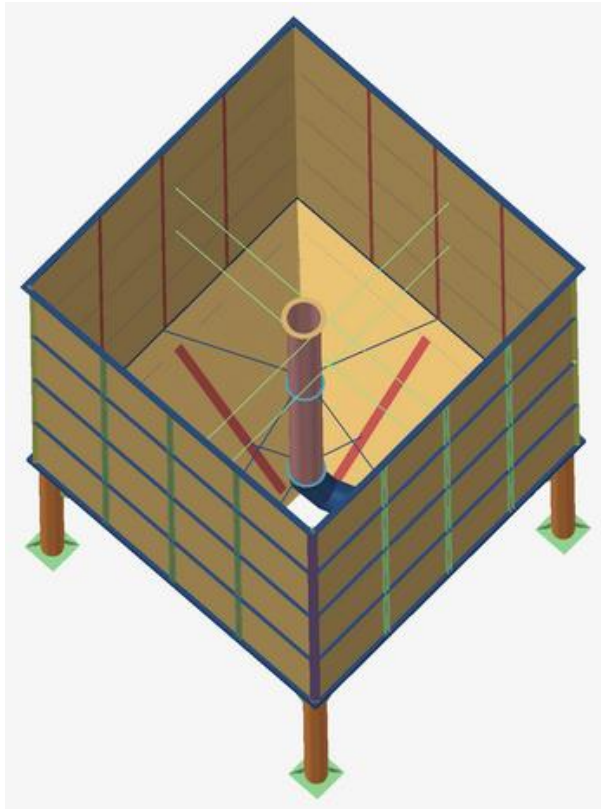
■ Hloubka 35 cm snížení výkonu o **14,3 %**

■ Hloubka 55 cm snížení výkonu o **9,8 %**



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

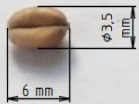
T Autor: Ing. Pavel Puchta



 Použitý model: Hertz-Mindlin



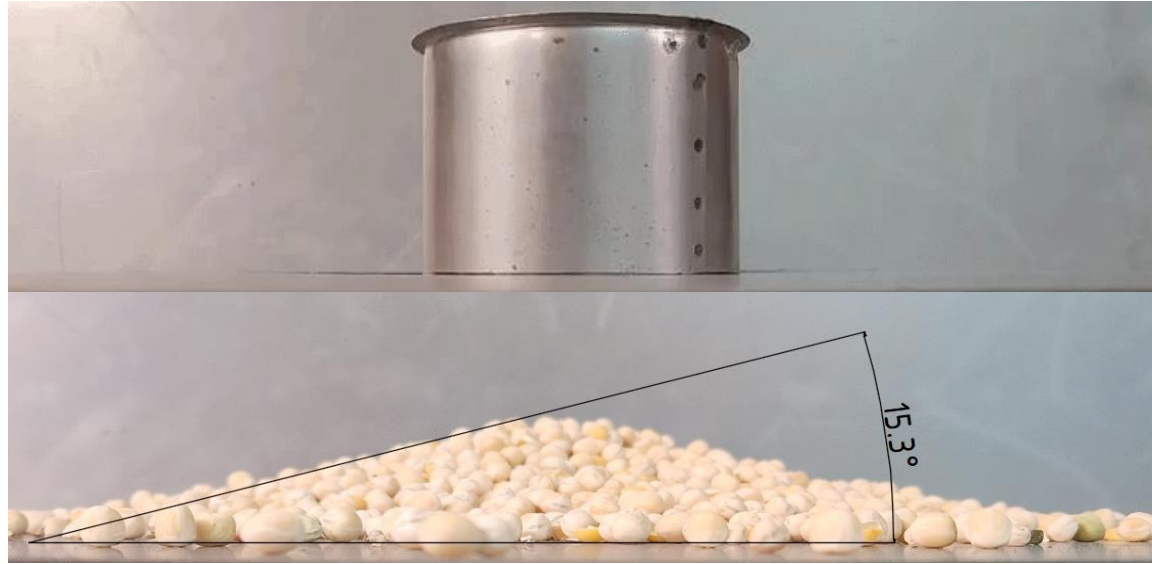
PŠENICE

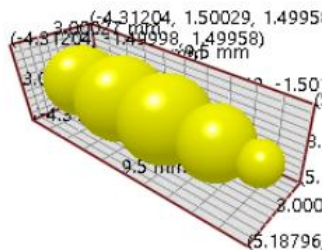
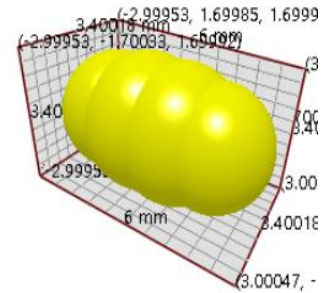
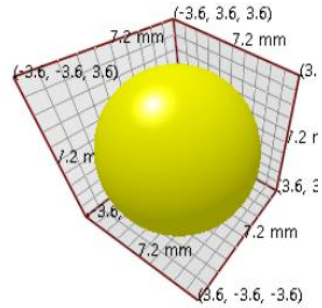


JEČMEN

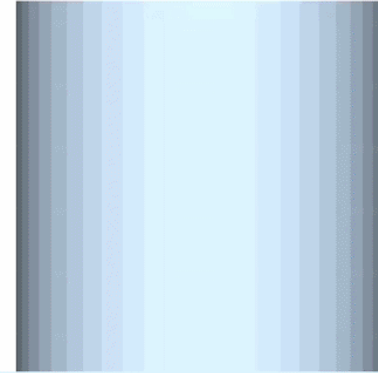


HRÁCH



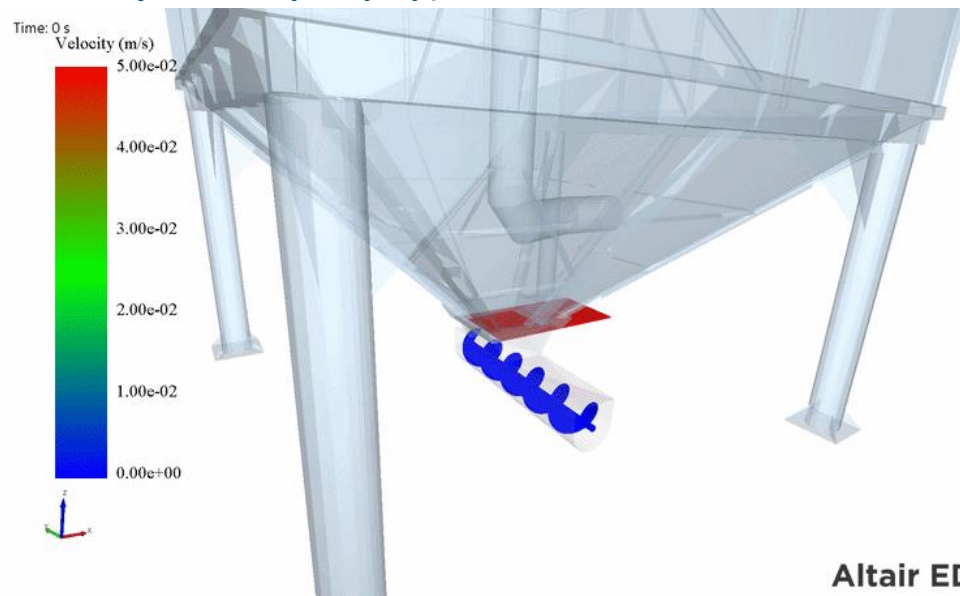


Time: 0 s



Altair EDEM™

 Materiálové toky z výsypky vycházejí podobně jako analytický výpočet toků materiálu

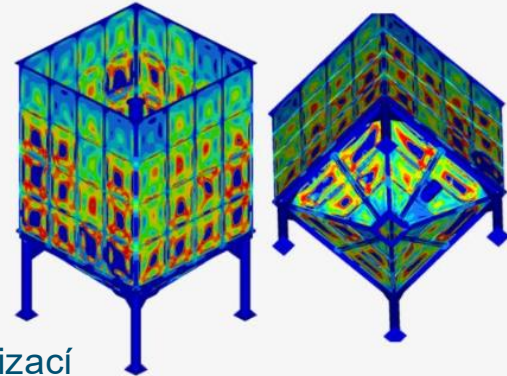


Altair EDEM™

Element Stresses (2D & 3D)(vonMises, Max) [MPa]

Analysis system
Simple Average
Value Filter <= 250.00

2.500E+02
2.222E+02
1.944E+02
1.667E+02
1.389E+02
1.111E+02
8.333E+01
5.556E+01
2.778E+01
0.000E+00

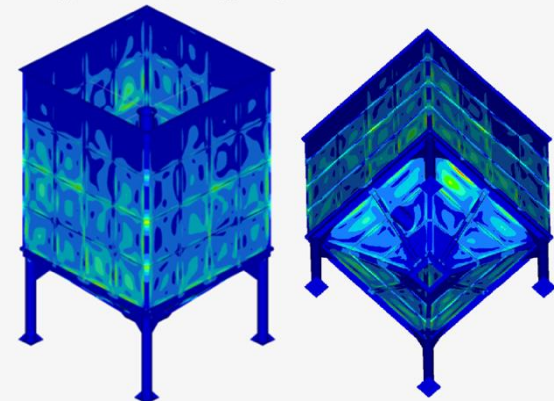


 Před optimalizací

Element Stresses (2D & 3D)(vonMises, Max) [MPa]

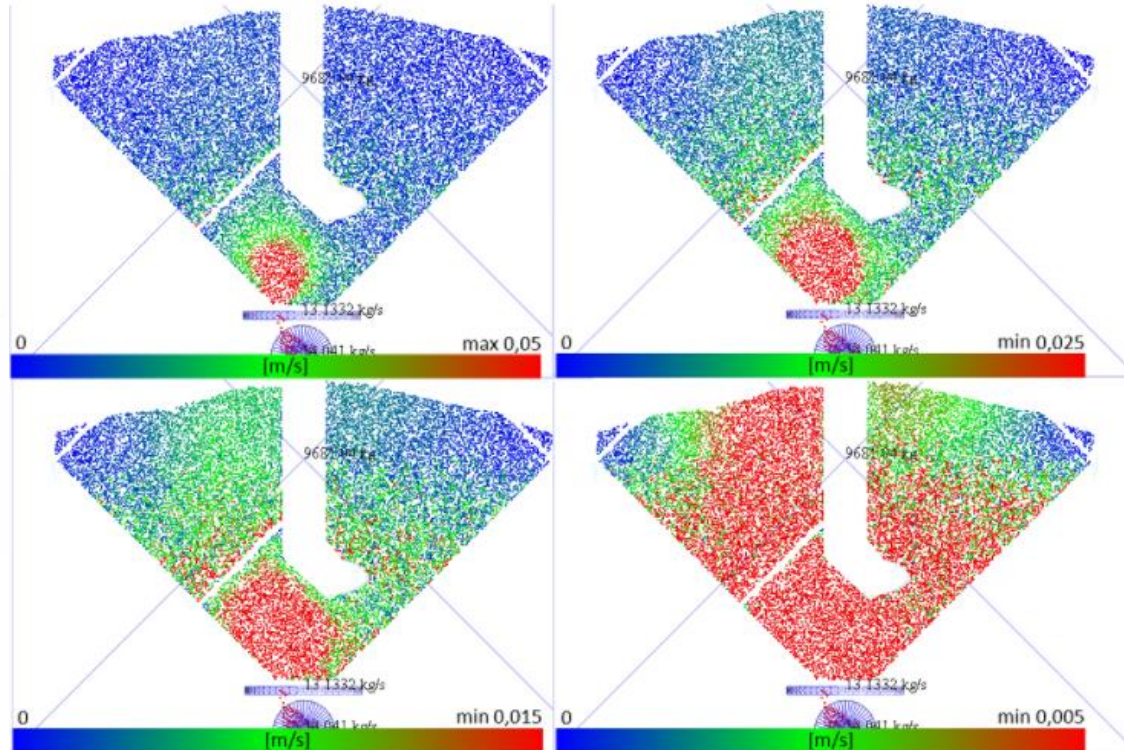
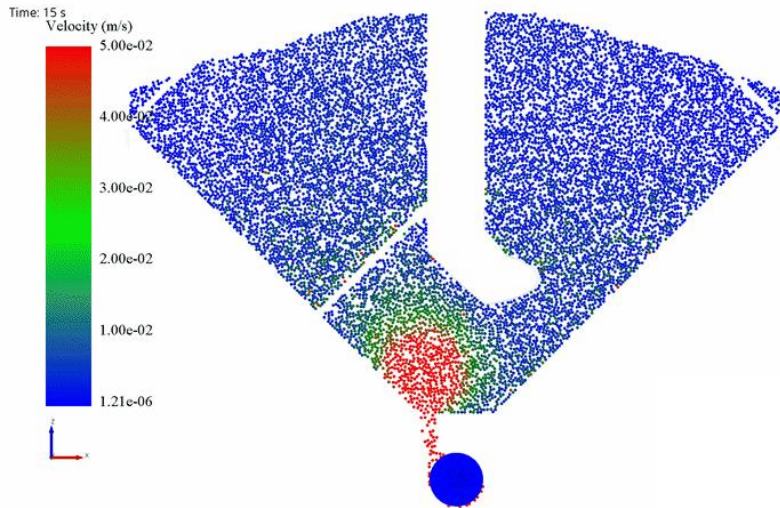
Analysis system
Simple Average

2.038E+02
1.811E+02
1.585E+02
1.359E+02
1.132E+02
9.057E+01
6.793E+01
4.529E+01
2.264E+01
0.000E+00

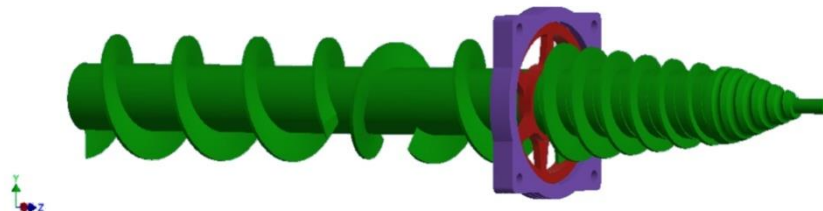
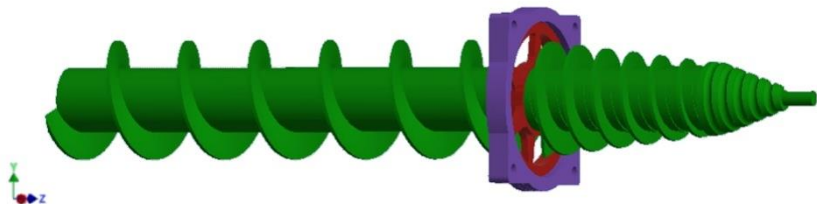
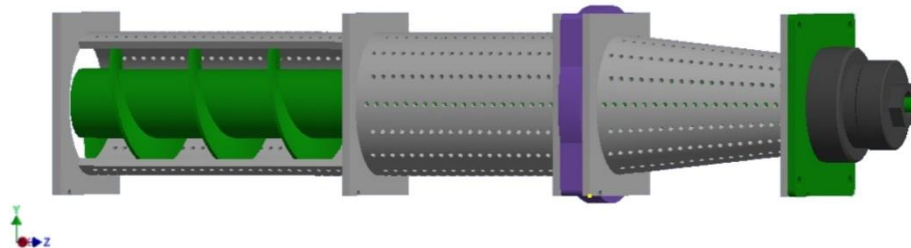
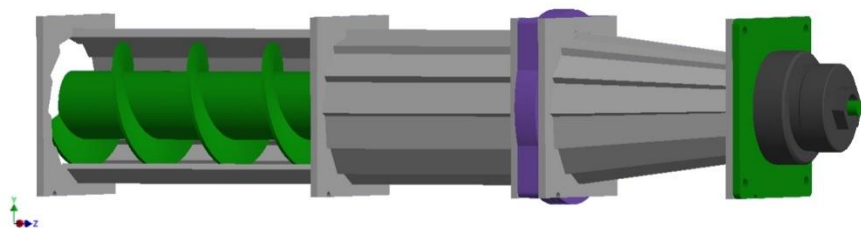


 Po optimalizaci

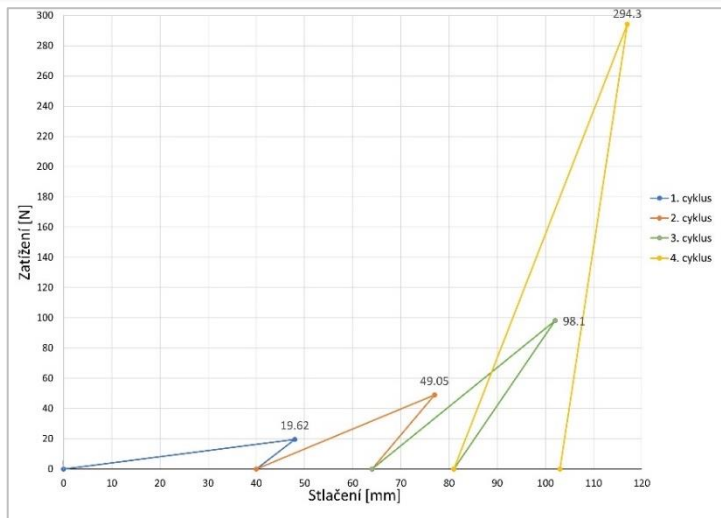
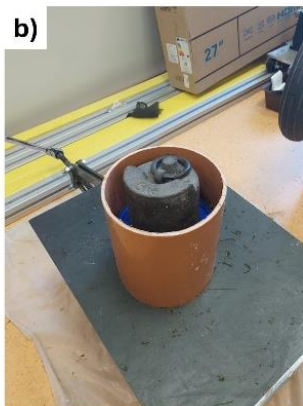
 Analýza toku v řezu výsypkou poukazuje na **hmotový tok**

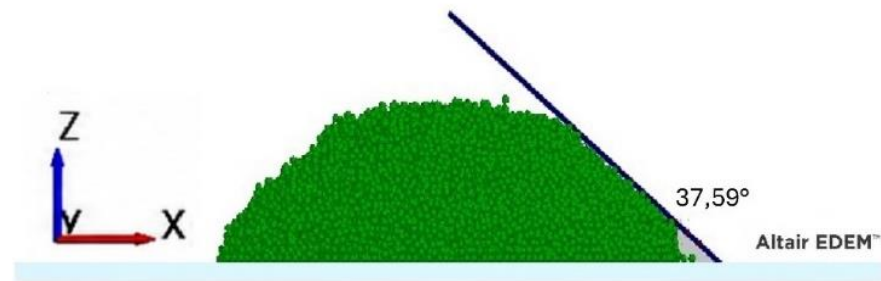
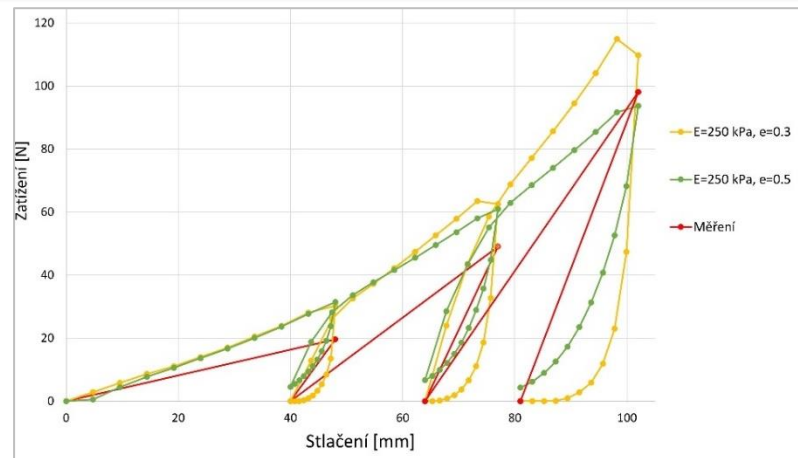
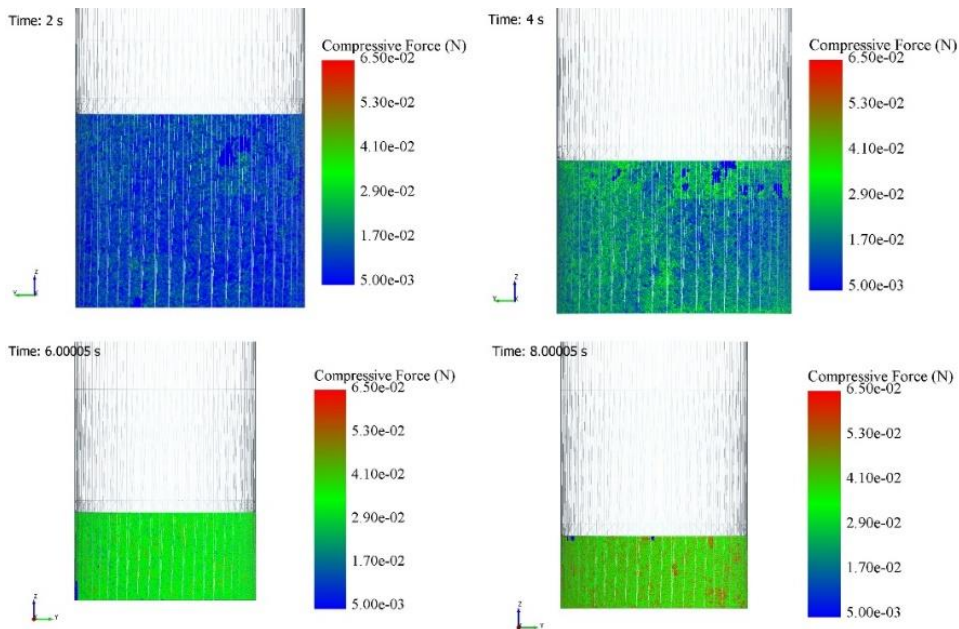


 Autor: Ing. Iva Beranová



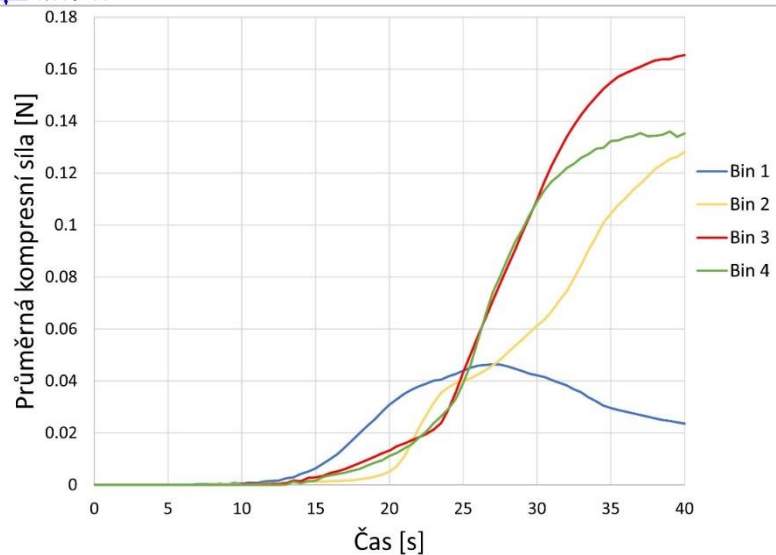
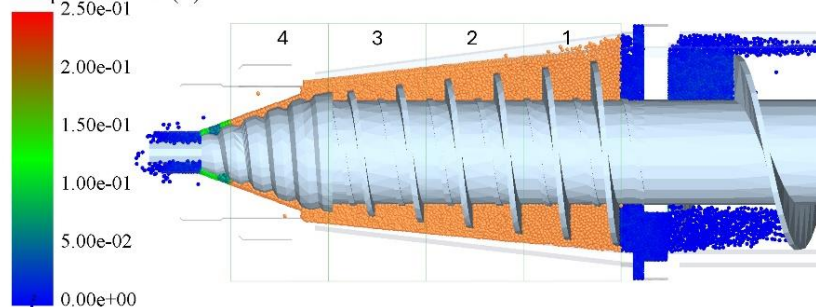
ANALÝZA ODVODŇOVACÍHO LISU TRAVNÍHO MULČE





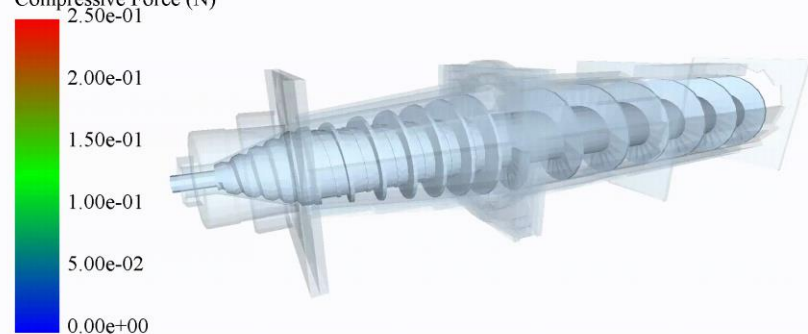
Time: 40 s

Compressive Force (N)



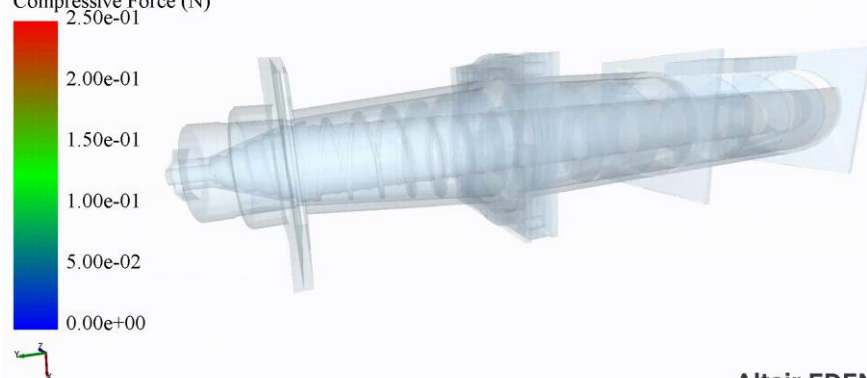
Time: 0 s

Compressive Force (N)



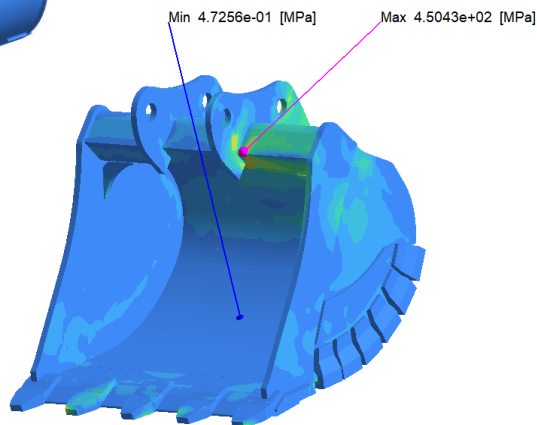
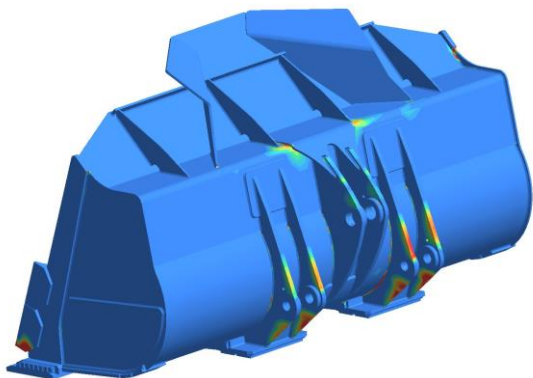
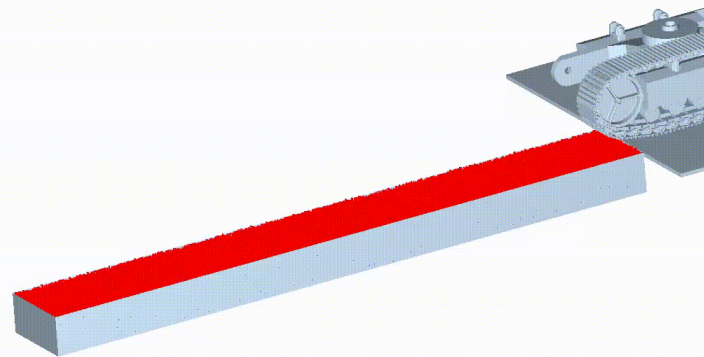
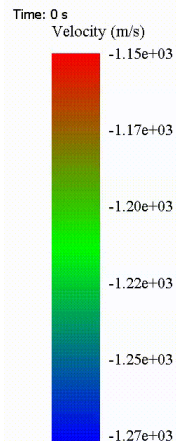
Time: 0 s

Compressive Force (N)



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!

- 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.apr.2020.05.011