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Sample plots and data - nonsmooth DEM

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SUMMARY

Sample plots and data supplementing the material in the paper *Examining the smooth and nonsmooth discrete element approaches to granular matter* Full collection of data at http://umit.cs.umu.se/granular/dem/

Received . . .

1. SUPPLEMENTARY DATA

Empirical data from numerical simulations with semi-smooth DEM using the projected Gauss-Seidel solver. Part of study to determine how the required number of iterations N_{it} for an error tolerance ϵ depend on the geometric shape and dynamic state of the system.

1.1. Cylinder container

The mean errors for contact overlap, slide and friction direction for container width $\Phi = 1, 9, 15\ d$, $N_{\text{it}} = 10, 100, 500$ and different N_{p} are displayed in Fig. 1, 2 and 3. As can be expected the mean error increase with the number of particles and decrease with increasing number of iterations. A trend is also that, keeping the number of particles and iterations fix, the errors decrease with increasing container width.

The total number of contacts[†] and number of slide modes depend on the number of iterations and data for this can be found in Table I and II. Observe that the number of contacts in slide mode depend strongly on the number of iterations. With sufficient number of iterations the number of slide mode contacts quickly approaches zero. Hence, although the magnitude of mean slide errors may appear large in Fig. 2 and 3 the occurrence of such errors is negligible once the number of iterations are sufficient.

1.2. Rotating drum

The mean errors for contact overlap, slide and friction direction for drum speed $\omega = 0.63$ rad/s is found in Fig. 4 for different N_{p} and N_{it} and for drum speed $\omega = 2.5$ rad/s in Fig. 5. For a given rotation speed and fixed iteration number the overlap error decrease with increasing number of particles. This may seem counterintuitive but is consistent because the shear rate of material decrease with increased number of particles leading to less impact overlaps. The friction errors do

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[†]Only particle-particle contacts are included and not particle-container contacts.

Table I. The number of contacts N_c for different number of particles N_p and iterations N_{it} in a $9d$ wide container. The number of contacts in slide mode is N_{sl}.

	$N_{it} = 10$		$N_{it} = 100$		$N_{it} = 500$	
N_p	N_c	N_{sl}	N_c	N_{sl}	N_c	N_{sl}
100	201	15	196	0	0	0
500	1.6K	1.4K	1.3K	6	1.1K	0
1K	3.8K	3.4K	2.7K	228	2.3K	0
2.5K	13K	10K	7.4K	2.6K	6.2K	0
5K	38K	26K	15K	6.8K	14K	182
7.5K	72K	46K	23K	10K	19K	12

Table II. The number of contacts N_c for different number of particles N_p and iterations N_{it} in a $15d$ wide container. The number of contacts in slide mode is N_{sl}.

	$N_{it} = 10$		$N_{it} = 100$		$N_{it} = 500$	
N_p	N_c	N_{sl}	N_c	N_{sl}	N_c	N_{sl}
500	1.6K	1.0K	1.3K	0	1.2K	0
1K	3.5K	3.1K	2.7K	1	2.4K	0
2.5K	10K	8.8K	7.3K	0.8K	6.2K	0
5K	25K	21K	16K	7.0K	14K	5
7.5K	45K	34K	24K	14K	21K	24

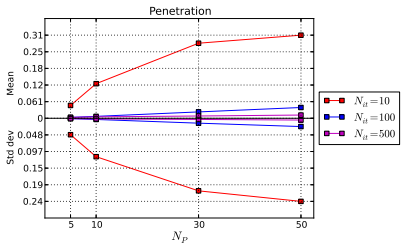

Figure 1. Mean (upper half) and standard deviation (lower half) overlap of 1D column.

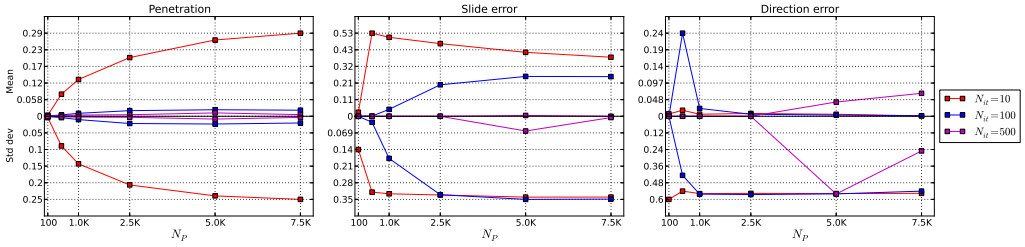

Figure 2. Mean (upper half) and standard deviation (lower half) of microscopic measurement from 3D column (9d diameter).

not decrease towards zero at any significant rate with the number of iterations we have used. The slide errors remain at an order around or above 0.3. Either the convergence is extremely weak or the algorithm fails, e.g., due to index cycling. The number of contacts and number of slide mode for different number of iterations can be found in Table III. Again, only particle-particle contacts are included and not particle-drum contacts.

In Fig. 6 we show samples of stress field, strain rate field and inertial number field for the drum with $\omega = 0.63$ rad/s, $N_p = 7.5$K and $N_{it} = 500$.

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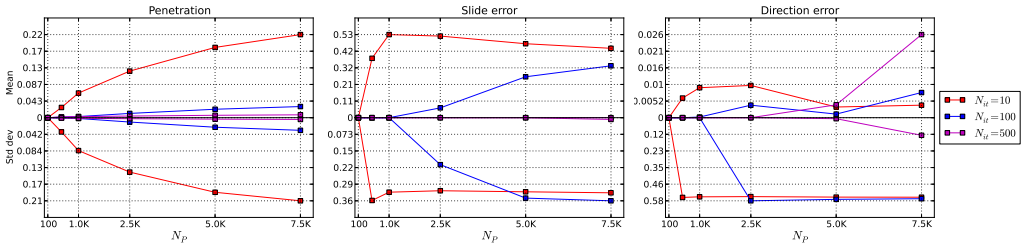

Figure 3. Mean (upper half) and standard deviation (lower half) of microscopic measurement from 3D column (15d diameter).

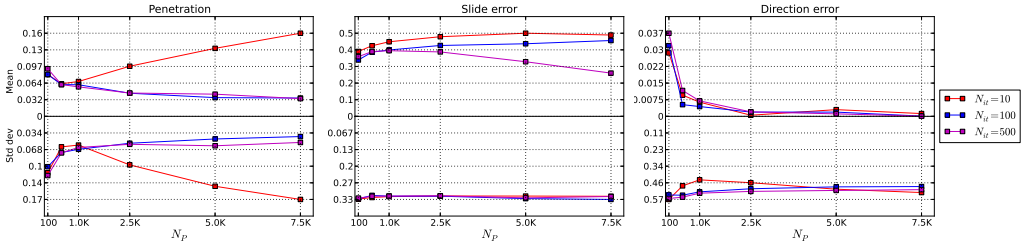

Figure 4. . Mean (upper half) and standard deviation (lower half) from rotating drum with $\omega = 0.63\ rad/s$.

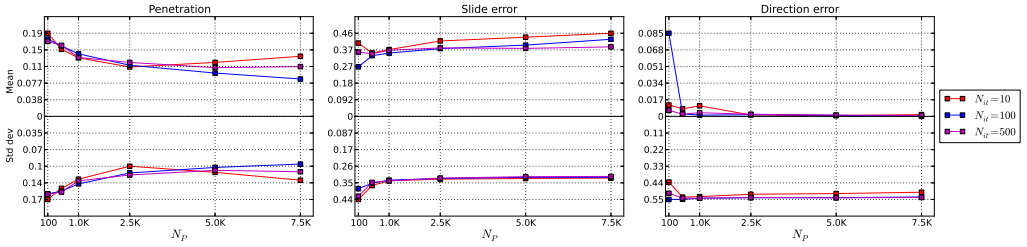

Figure 5. . Mean (upper half) and standard deviation (lower half) from rotating drum with $\omega = 2.5\ rad/s$.

Table III. The number of contacts N_c for different number of particles N_p and iterations N_{it} in a drum with rotation speed $\omega = 0.63$ rad/s. The number of contacts in slide mode is N_{sl}.

	$N_{it} = 10$		$N_{it} = 100$		$N_{it} = 500$	
N_p	N_c	N_{sl}	N_c	N_{sl}	N_c	N_{sl}
100	510	386	459	349	505	384
500	7.0K	5.9K	5.9K	4.5K	5.9K	4.5K
1K	20K	17K	15K	11K	15K	11K
2.5K	66K	58K	47K	38K	46K	36K
5K	171K	149K	108K	86K	102K	69K
7.5K	268K	224K	159K	131K	163K	91K

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Table IV. The mean strain rate and inertial number depending on rotation speed (or Froude number) and number of particles. The data is produced with $N_{\text{it}} = 500$.

		$N_{\text{p}} = 2.5\text{K}$		$N_{\text{p}} = 5\text{K}$		$N_{\text{p}} = 7.5\text{K}$	
ω	Fr	I	$\lvert\dot{\gamma}\rvert$	I	$\lvert\dot{\gamma}\rvert$	I	$\lvert\dot{\gamma}\rvert$
0	0	0	0	0	0	0	0
0.03	10^{-5}	10^{-4}	10^{-3}	10^{-3}	0.01	10^{-3}	10^{-3}
0.06	10^{-4}	0.01	0.05	0.01	0.05	0.02	0.06
0.13	0.001	0.05	0.16	0.05	0.18	0.03	0.1
0.63	0.02	0.2	0.7	0.2	0.5	0.1	0.4
2.5	0.3	0.8	2.7	0.5	1.9	0.4	1.6

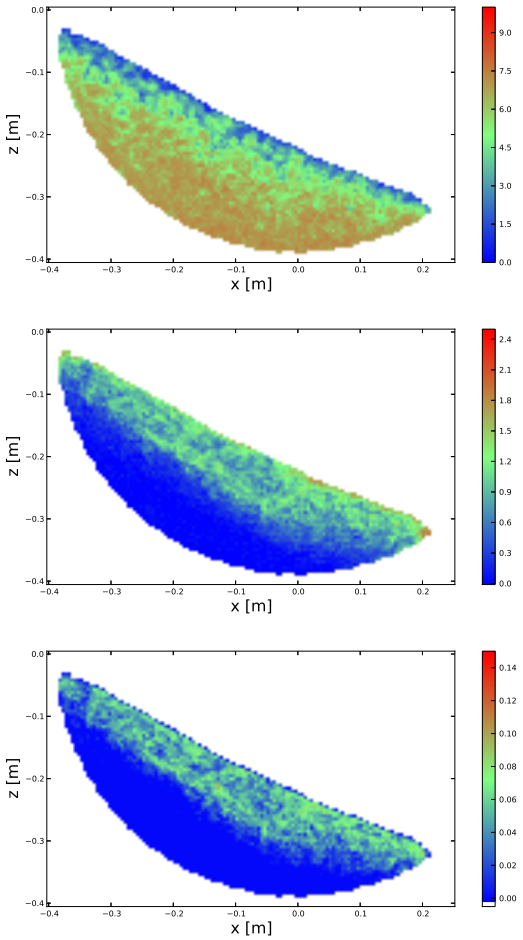

Figure 6. The stress rate field (top figure), strain rate field (middle figure) and inertial number field (bottom figure) for $\omega = 0.63$ rad/s, $N_{\text{it}} = 500$ and $N_{\text{p}} = 7.5\text{K}$.

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