New advances in large scale industrial DEM modeling towards energy efficient processes

P. PIZETTE[a], N. GOVENDER[a,b], D.N. WILKE[c], N-E. ABRIAK [a]

a. IMT Lille Douai, Univ. Lille, EA 4515 - LGCgE - Laboratoire de Génie Civil et géoEnvironnement, départment Génie Civil & Environnemental, F-59000 Lille, France + patrick.pizette@imt-lille-douai.fr
b. Research Center Pharmaceutical Engineering, GmbH, Graz , Austria
c. Centre for Asset and Integrity Management, University of Pretoria, Pretoria, 0086, South Africa

Résumé :

Bien que très répandue, la méhode des éléments discrets (DEM, accronyme de Discrete Element Method) reste limitée en terme de temps de calcul et de taille de problème (dizaines de milliers de particule) empéchant son utilisation pour des problématiques industrielles à grande échelle. Par exemple dans le cas du génie civil, la DEM n'est pratiquement pas utilisée alors que la méthode pourrait être pertinente notamment pour optimiser les consommations énergétiques des procédés. Dans le cadre de ce travail, on se propose de montrer les dernières avancées que peut apporter pour la modélisation discrète les cartes graphiques GPU (Graphic Process Unit) pour réaliser les calculs. L'utilisation des cartes GPUs permet d'augmenter considérablement la puissance de calcul. En particulier, le code BlazeDEM3D-GPU a été utilisé pour modéliser des silos de stokage de gravier d'une centrale à béton avec la prise en compte de plusieurs dizaines de millions de particule dans des temps de calcul raisonnables.

Abstract :

The widespread use of the Discrete Element Method (DEM) is limited by computational constraints. This limits the number of particles to hundreds of thousands of particles to model industrial processes. This often prevents the application of DEM to large-scale industrial problems and widespread adoption of the method. For example, civil engineering extensively consider particulate materials but DEM is seldom considered as a simulation tool, although DEM could accurately inform on the energy efficiency of processes. In this study, we show the latest advances in DEM using the Graphic Process Unit (GPU) to perform the computations. Utilization of the GPU allows for a new performance level of DEM and as we show allows for industrial application to be modelled within practically accepted simulation times. The BlazeDEM3D-GPU framework has been used to model the gravel storage of silo discharge in a concrete facility with several tens of millions of particles, all within a practically accepted time frame.

Mots clefs : DEM ; Graphical Processor Unit (GPU) ; Silo ; large scale simulation

1 Introduction

Granular material processing is crucial to a number of industries such as pharmaceuticals, construction, mining, geology and primary utilities. The handling and processing of granular materials represents roughly 10% of the annual energy consumption [1]. A recent study indicated that in the US alone, current energy requirements across Coal, Metal and Mineral Mining amounts to 1246 TBtu/yr, whereas the practical minimum energy consumption is estimated to be 579 TBtu/yr, while the theoretical limited is estimated around 184 TBtu/yr [2]. It is evident that design modification allowing for process optimization can play a significant role in realizing a more energy efficient industry sector that can have significant implications on the annual global energy demands.

The status quo in industry when facing the complex physics governing granular materials, is that current industry developed strategies to handle granular materials remain overly conservative and often energy-wasteful to prevent or reduce industrial-related bulk material handling problems like segregation, arching formation, insufficient bulk material handling. Granular scale approaches have also been developed to both understand the fundamental physics governing granular flow and to study industrial applications, especially to improve the understanding and estimation of energy dissipation and energy efficiency of granular flow processes.

The Discrete Element Method (DEM) proposed by Cundall and Strack [3] has matured over the last three decades into a systematic approach to estimate and predict the response of granular systems. Unfortunately, the number of particles simulated in the granular systems are mainly limited to hundreds of thousands of particles. This is due to the modelling approach directly at the particle level and contact points, making DEM computationally intensive. Although DEM is particularly suited to study the energy efficiency of processes, it has not been widely adopted due to the limitations of the number of particles DEM can simulate within realistic time frames. This point is crucial in particular within the geomechanic and civil engineering perspective [4]. Simulations on Central Processing Unit (CPU) computing clusters are realistically limited to the low millions of particles that still result in extensive computing times. However, before DEM can be practically considered for industrial applications the number of particles need be increased to tens or hundreds of millions particles, still to be simulated within a practically realistic time frame. Thus, the current developments of parallel computing of DEM on large Central Process Unit (CPU) clusters or a few Graphical Processor Unit (GPU) cards will allow for computing capacities to be increased and large scale industrial granular problems to be solved within realistic time frames.

In this context, this study discusses new advances and perspectives made possible by the Graphical Processor Unit (GPU) when simulating discrete element models, specifically for granular industrial applications. Attention is specifically focussed on the newly developed BlazeDEM3D-GPU framework [5] for an industrial flow investigation (civil engineering field).

2 Discrete Element Method and GPU approach

The GPU (Graphic Processor Unit) by the highly parallelized hardware architecture can offer new opportunities for industrial applications. In this study, we use the BlazeDEM3D-GPU framework developed by Govender et al. [5]. BlazeDEM3D-GPU is an open-source DEM code that has been validated for industrial [6] and scale-lab [10] ball mill simulations and for hopper discharge applications [7, 8]. In the

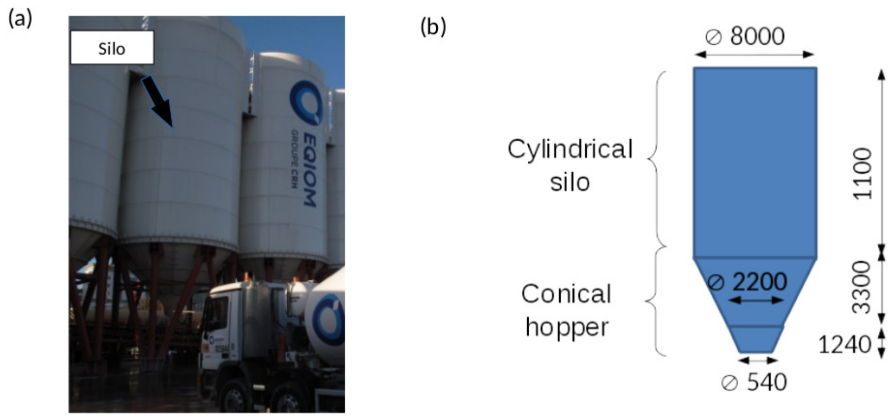

Figure 1: (a) Overview of the gravel silo of concrete facility and (b) the schematic of the gravel or sand storage silo (units in mm)

case of particle hopper discharge, DEM GPU simulations were recently carried out to simulate spherical and polyhedral particle systems in large scale configuration [9].

This present study highlights the potential of GPU based DEM simulations to solve large-scale industrial problems. Thus, we have investigated a typical granular flow problem met in the concrete industry. In this study, we have modelled the gravel or sand storage silo depicted in the Figure 1(a) closing in real service conditions with a filling of up to tens of million of particles.

For the simulations of this work, linear spring dashpot model and Coulomb Criterion are used : $COR = 0.45$, $\mu_{pp} = \mu_{pw} = 0.3$, density $= 1.7 g/cm^3$ for a time-step of $1.10^{-4} s$.

3 DEM GPU large scale simulations

3.1 Gravel and sand storage silos

The industrial granular flow investigation considered in this study is teh EQIOM concrete storagesilod located near Paris in France. As shown in Figure 1(b), the silo diameter is 8 m with a height of around 17 m. Two coaxial cones shape the hopper of this silo. The gravel was simplified as 20 mm diameter spheres. In order to generate the initial packing, particles were filled in the silo progressively by thousands of particles (note that the location of the trap entrance at the top of the silo can be controled). At the end of filling stage, the silo can contain more of 32 millions of particles as shown in the Figure 2. In this paper, we have run 3D DEM simulations until up to 32 million particles. In the case of the Figure 2 where particles are colored by ID, the particle number is 33554432 corresponding typically to 240 ton of gravel.

3.2 Hopper flow

During a discharge of silo, problem of arching, rat holing or segration may disturb consistently the granular flows. The hopper shape is an important parameter of prationners for the design and the reporting in service. The discharge stage is simulated here by opening the hatch of hopper. The particles are systematically removed from the simulation after they have fallen a specified distance of 10 cm.

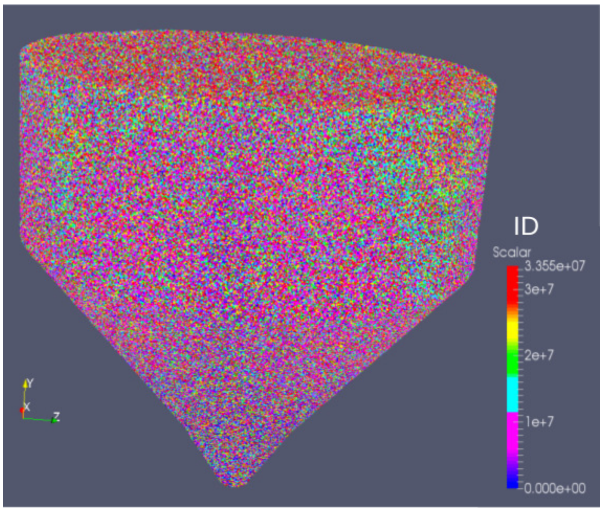

Figure 2: Initial packing after filling stage (color by ID)

The Figure 3(a) shows magnitude of the linear velocity plotted by particle in a cross-sectional view (symmetrical plane). The results highlight clearly the effect of hopper shape on the velocity in particular close to the outlet. A detailed view on the outlet is shown as velocity components (in the x and y directions) in Figure 3(b). By comparing this result with typical experimental results, it is intereresting to remark that the global cinematic behaviors are qualitatively the sames.

Note that the computation time with one GPU NVIDIA titan X is approximately a day for 30 seconds of discharge time. Thus, these results show also that the DEM GPU simulations may be an interesting tool to investigate within a reasonable computing time the scale of change between typical lab silo device and real-life industrial silo.

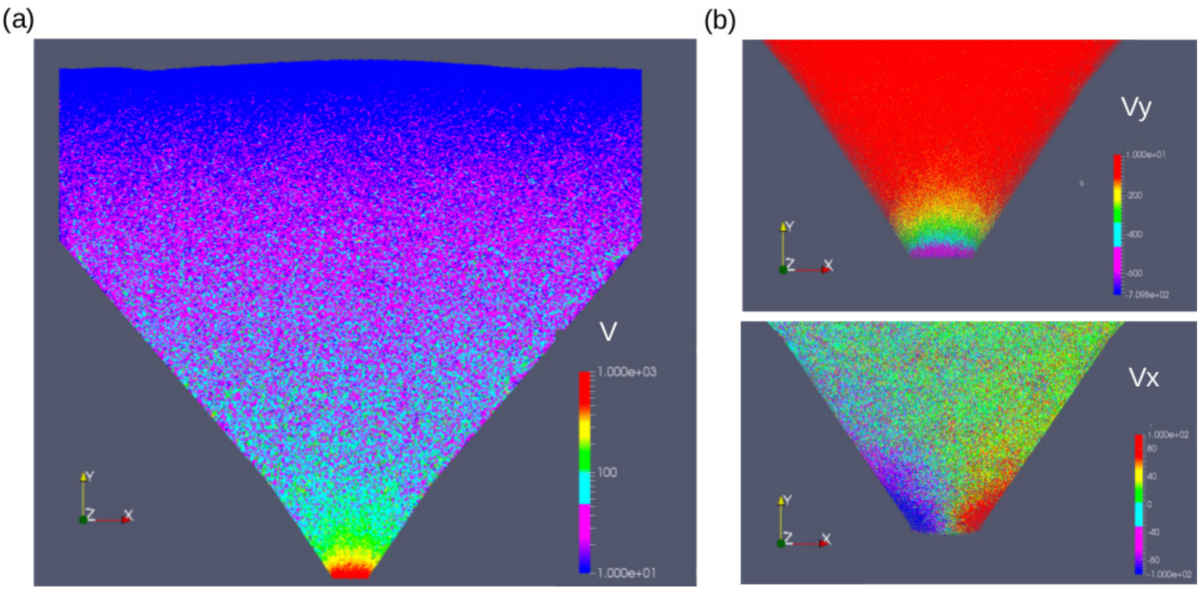

Figure 3: Cross-sectional views of linear velocity fields after 20 s of discharge time (a) magnitude (log scale) (b) components (in the x and y directions)

4 Conclusion

As required for an industrially relevant application, up to ten of million particles were simulated with DEM within a practically accepted time frame. This study highlights that large scale DEM simulations can be performed within a reasonable time frame when the GPU is utilized. This makes large-scale analysis practically relevant but more importantly allows for a number of analyses to be conducted to steer granular processes towards improved energy efficiency.

As a result GPU based DEM simulations are moving from once-off analyses, allowing for limited design modifications, to multiple analyses allowing for extensive design modifications in industrial processes.

Acknowledgements

We gratefully acknowledge the support of NVIDIA Corporation with the donation of the Titan X Pascal GPU used for this research. The exchanges with EQIOM Granulats and EQIOM Bétons about the concrete facility used in this study are greatly appreciated.

References

[1] DURAN J., Sands, powders, and grains: An introduction to the physics of granular materials. Springer Science & Business Media, 2012

[2] Mining Industry Bandwidth Study, US Department of Energy, BCS Incorporated, June 2007

[3] Cundall P.A. and Strack O.D.L, A discrete numerical model for granular assemblies, Geotechnique 29, 47-65, 1979

[4] O'Sullivan C., Particulate Discrete Element Modeling : A Geomechanics Perspectives (Spon Press, New York, 2011) 561

[5] Govender N., Wilke D.N., Kok S., Blaze-DEMGPU: Modular high performance DEM framework for the GPU architecture, SoftwareX 5, 62-66 (2016)

[6] Govender N., Rajamani R.K, Kok S., Wilke D.N, Discrete element simulation of mill charge in 3D using the BLAZE-DEM GPU framework, Miner. Eng. 79, 152-168, 2015

[7] Govender N., Pizette P., Wilke D.N, Abriak N.E., validation of the GPU based BLAZE-DEM framework for hopper discharge, PARTICLES 2015, Barcelona

[8] Govender N, Wilke D N , Pizette P, Rajamani R.K., Industrial Scale Particle Simulations on the GPU Using the Blaze-DEM Code, Proceedings of the 7th International Conference on Discrete Element Methods, Springer Proceedings Phys. 188 (2017)

[9] Govender N., Wilke D.N., Pizette P., Abriak N-E, A study of shape non-uniformity and polydispersity in hopper discharge of spherical and polyhedral particle systems using the BlazeDEM3D-GPU code, Appl. Math. Comput. (in press)

[10] Pizette P, Govender N, Abriak N-E, Wilke D.N, GPU DEM simulations and Experimental studies of ball milling process for various particle shapes, Proceedings of the 7th International Conference on Discrete Element Methods, Springer Proceedings Phys. 188 (2017)