



Universiteit
Leiden
The Netherlands

Granular flows : fluidization and anisotropy

Wortel, G.H.

Citation

Wortel, G. H. (2014, November 19). *Granular flows : fluidization and anisotropy. Casimir PhD Series*. Retrieved from <https://hdl.handle.net/1887/29750>

Version: Not Applicable (or Unknown)

License: [Leiden University Non-exclusive license](#)

Downloaded from: <https://hdl.handle.net/1887/29750>

Note: To cite this publication please use the final published version (if applicable).

Cover Page



Universiteit Leiden



The handle <http://hdl.handle.net/1887/29750> holds various files of this Leiden University dissertation

Author: Wortel, Geert

Title: Granular flows : fluidization and anisotropy

Issue Date: 2015-11-19

Granular Flows: Fluidization and Anisotropy

PROEFSCHRIFT

ter verkrijging van
de graad van Doctor aan de Universiteit Leiden,
op gezag van Rector Magnificus
prof. mr. C.J.J.M. Stolker,
volgens besluit van het College voor Promoties
te verdedigen op 19 november 2014
klokke 11.15 uur

door

Gerrit Herman Wortel
geboren te Zoetermeer
in 1985

Promotiecommissie:

Promotor: Prof. dr. M.L. van Hecke

Overige leden: Dr. O. Dauchot (*ESPCI-ParisTech, Frankrijk*)

Prof. dr. E.R. Eliel

Dr. D.L. Henann (*Brown University, VS*)

Dr. D.J. Kraft

Prof. dr. T.H. Oosterkamp

Prof. dr. M.A.J.G. Orrit

Prof. dr. H. Schiessel

Nederlandse titel:

Granulaire Stroming: Fluïdisatie en Anisotropie

Cover image: Sand Dunes, Huacachina, Peru cc by N. Whitford

Casimir PhD series, Delft-Leiden 2014-26

ISBN 978-90-8593-199-7

Dit werk maakt deel uit van het onderzoeksprogramma van de Stichting voor Fundamenteel Onderzoek der Materie (FOM), die financieel wordt gesteund door de Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO).

*If we stand on the shore and look at the sea,
we see the water, the waves breaking, the foam,
the sound, the air, the winds and the clouds,
the sun and the blue sky, and light.
There is sand and there are rocks.
There are animals and seaweed,
hunger and disease,
and the observer on the beach.*

*Any other spot in nature has a similar variety of things.
It is always as complicated as that, no matter where it is.
Curiosity demands that we ask questions,
that we try to understand this multitude of aspects as resulting from
the action of a relatively small number of elemental things,
and forces acting in an infinite variety of combinations.*

*Is the sand other than the rocks?
Is the moon a great rock?
Is the sand perhaps nothing but a great number of very tiny stones?*

– Richard P. Feynman
The Feynman Lectures on Physics, p2-1

Contents

1	Introduction to Granular Matter	1
1.1	Granular Materials	1
1.2	Examples	4
1.2.1	Grain Silo	4
1.2.2	Brazil Nut Effect	5
1.2.3	Quicksand	5
1.2.4	Soft Robotic Gripper	6
1.2.5	Shear Thinning and Thickening	6
1.3	Shear and Vibration	7
1.4	This Thesis	8
2	Introduction to Flow of Weakly Vibrated Granular Media	9
2.1	Introduction	9
2.2	Setup and Protocol	10
2.3	Phenomenology	14
2.3.1	$\Gamma = 0$	14
2.3.2	$\Gamma > 0$	15
2.3.3	Simplest Model	15
2.3.4	Hysteretic Transition	16
3	Vibration Dominated Flow in Weakly Vibrated Granular Media	19
3.1	Introduction	19
3.2	Protocol	20
3.3	Phenomenology	23
3.4	Vibration Dominated Flows	25
3.4.1	Torque Minimization Model	26
3.4.2	Frictional Model for $\Gamma > 0$	29
3.4.3	Fluidized Region	33

3.5	Conclusion	37
4	A Nontrivial Critical Point in Granular Flows	39
4.1	Introduction	39
4.2	Setup and Protocol	43
4.2.1	Protocol	45
4.3	Theoretical Framework	46
4.4	Flow Curves	49
4.5	Fluctuations	53
4.5.1	Phenomenology	54
4.5.2	Determination of the Velocity	55
4.5.3	Autocorrelation	57
4.5.4	Statistics of $\Delta\theta$	64
4.5.5	Locating the Critical Point	66
4.5.6	Scaling of Fluctuations	69
4.A	Appendix	74
4.A.1	Collective Behavior	74
4.A.2	T -Control Flow Curves	74
4.A.3	Towards a Simple Model	76
5	The Role of Anisotropy in Granular Flow	77
5.1	Introduction	77
5.2	Protocol	79
5.3	Steady State Relaxation	81
5.3.1	Relaxation Speed	81
5.3.2	Dependence on (Ω, Γ) and (T, Γ)	83
5.3.3	Conclusion	85
5.4	Dynamics of Anisotropy	85
5.4.1	Relaxing from Preshear to Steady State	86
5.4.2	Two Stage Relaxation	87
5.5	Conclusion and Discussion	92
5.5.1	Outlook	94
6	Giant Heaping in Sheared Anisotropic Granular Media	95
6.1	Introduction	95
6.2	Setup and Methods	98
6.2.1	Setup	98
6.2.2	Methods	100

6.3	Phenomenology	103
6.3.1	Growth Evolution	103
6.3.2	Aspect Ratio, Shape and Material	105
6.3.3	Heap Location	105
6.3.4	Filling Height Dependence	105
6.4	The Mechanism behind the Heaping	108
6.4.1	Heap Removal	108
6.4.2	Reversal	110
6.4.3	Convection	111
6.4.4	Conclusion	112
6.5	3D X-ray CT Tomography	113
6.5.1	Setup and Methods	113
6.5.2	Results	115
6.5.3	Origin of the Convection	117
6.5.4	Conclusion	122
6.A	Appendix	123
6.A.1	Outlook	123
 Bibliography		 125
 Samenvatting		 137
 Summary		 139
 Publication List		 141
 Curriculum Vitae		 143
 Acknowledgements		 145

