Data Article

Dataset of velocities of dry granular flows in a partially obstructed tilted chute

Solange V. Mendes\(^a\), Rui Aleixo\(^a\), Michele Larcher\(^c\), Silvia Amaral\(^b\), Rui M.L. Ferreira\(^a\)

\(^a\) Civil Engineering Research Innovation and Sustainability (CERIS), University of Lisbon, Instituto Superior Técnico, Av. Rovisco Pais n.1, 1049-001 Lisbon, Portugal

\(^b\) National Laboratory of Civil Engineering (LNEC), Av. do Brasil n.101, 1700-066 Lisbon, Portugal

\(^c\) Faculty of Science and Technology, Free University of Bozen-Bolzano, Piazzetta Franz Innerhofer n. 8, 39100, Bolzano BZ, Italy

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**Abstract**

The dataset provided in this paper refers to an experimental campaign conducted in Laboratory of Fluid Dynamics (LTDF) of the Free University of Bozen-Bolzano at NOI Techpark aiming to understand the movement of granular material in fluids of low viscosity and density exhibited in debris flows. One experimental test was performed consisting of 31 repetitions. In detail, a three-litre volume of granular material \((d = 1.8\text{mm})\) was suddenly released from an upstream reservoir in a 1.5 m long acrylic chute tilted at 19 degrees and stopped in the outlet area by a vertical barrier. This vertical barrier used is adjacent to the side wall of the chute, with two vertical gaps and a width equal to twice the size of the particles used \((s = 2d)\).

The instrumentation included two high-speed cameras \((300\text{fps})\) and one spotlight. Camera 1 \((C1)\) was located upstream at the lock gate location and Camera 2 was placed at downstream part of the chute, focusing on the vertical barrier site. A Particle Tracking Velocimetry (PTV) was applied to the set of images captured by the camera placed in the downstream area of the chute in a region of interest \((ROI)\) of 4000 pixel width and 300 pixel height.
Firstly, the raw data concerns to the particles coordinates $(x,z)$, their along-chute and wall-normal trajectories and particle tag, detected with the PTV algorithm for the 31 repetitions held.

The previous data was submitted to filtering processes where we converted particle trajectories into maps of these mean quantities by binning and constructing a data ensemble. To remove some detected outliers, a refinement of ensemble data was subsequently applied [1].

All of the solutions computed to build the pointed dataset were performed by means of Matlab algorithms.

This dataset allows researchers to characterize the behaviour of granular processes that may occur in inclined channels partially or fully obstructed.

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**Specifications Table**

| Subject         | Engineering |
|-----------------|-------------|
| Specific subject area | The specific subject area in which this dataset belongs is dry granular flows. |
| Data format     | Raw, Filtered |
| Type of data    | (1) Archive file (.zip) containing MATLAB data files (.mat) |
| Data collection | We performed one experimental test, in which uni-sized polystyrene particles $(d = 1.8mm)$ were released from an upstream reservoir through a lock gate in an experimental chute with 1.5 m length and 0.08 m width sloping at 19 degrees. The granular flow was partially obstructed at the downstream end by a vertical barrier with two gaps, each one with 2d length, adjacent to the side walls of the chute. A total volume of 3 litres of granular material was adopted and the described experiment was repeated 31 times. Two synchronized high-speed cameras (Flare 12M180MCX) were used to record the experiments. One camera was located at the upstream part focusing on the passage of the granular material under the lock, and another camera placed downstream at the vertical barrier. The images acquired from both cameras present a maximum $4096 \times 744$ pixel resolution at an acquisition rate of 300 frames per second and an exposure of 200 μs. We adapted the region of interest to ensure only the capture of the flow in the chute area. The experimental procedure is summarised as follows: placement of both cameras and acquisition of calibration images; filling the upstream reservoir with the granular material with a horizontal surface; initiate the recording process with the cameras; suddenly opening of the lock gate urging the release of the granular material and stop recording as soon as the flow ceases. Firstly, a subtraction algorithm was applied to the images captured by the downstream camera and a Particle Tracking Velocimetry (PTV) technique was then applied calculating the displacement of each detected particle between frames. These collected data from the PTV analysis (raw data) was subjected to a multi-pass filtering process which allowed the construction of a final ensemble of data over time at a specific location along a region of interest. All the procedures performed were conducted with using MATLAB R2022b. |
| Data source location | Institution: Civil Engineering Research and Innovation and Sustainability (CERIS) – Instituto Superior Técnico, Universidade de Lisboa City: Lisboa Country: Portugal |
| Data accessibility | Repository name: Zenodo Data identification number: 10.5281/zenodo.8251665 Direct URL to data: https://zenodo.org/record/8251665 |
1. Value of the Data

- The dataset in question can be used by the researchers in the field of dry granular flows for several purposes:
- The analysis of the data collected allows the understanding of granular material in fluids of low density and viscosity, such as those referred here, which performs a very important role and provides insights on granular processes in more general debris flows. Also, when dry granular flows face all forms of obstructions, granular mechanisms such as jamming and clogging may occur.
- This dataset can be used for comparison with other datasets obtained from similar experiments by varying some parameters, including the obstruction width gap and the slope of the channel;
- This dataset can also be used for comparison by measuring the velocities with another applicable technique;
- This dataset can be used to validate numerical solutions of particle-based of continuum approaches for granular flows;
- New filter solutions or approaches to construct an ensemble of data can be applied for the collected data that eventually can be compared with the results obtained from the process described in this paper.

2. Data Description

2.1. General design of the presented data

The dataset in this article is presented in three folders: the raw data folder, which is presented in “.m” files, the filtered data folder containing the data after the filtering processes performed (“.m” files) and the final data, also presented in “.m” files.

The data provided corresponds to a single type of experimental test carried out, which was repeated 31 times. The referred experiment presented the following characteristics: a) uni-sized polystyrene particles($d = 1.8mm$); b) the volume of particles considered in the experiments was 3 litres; c) the slope of the chute was 19 degrees and d) the obstruction used had a double distance from the chute lateral walls of twice the diameter of the particles($d = 3.6mm$).

Regarding the raw data folder, it contains 31 files of the results from the PTV algorithm applied to the images captured from a downstream camera. The algorithm covered a spatial distribution in the captured images of 4000 pixel width in x-axis, and 350 pixel height in z-axis.

In each (“.m”) file the data is presented as a cell array each one with 4 columns of information. The first column represents the x position (pixel) of the particle detected, the second column represents the z position (pixel) of that individual particle and third and fourth column are the along-chute and wall-normal displacement respectively (Table 1).

In what concerns the filtered data folder, there are available several files, such as: along-chute velocity for each test performed over time, in all analysis windows – “DATAu”; wall-normal velocity for each test over time, in all analysis windows – “DATAw” and number of particles detected by the algorithm inside each analysis window – “DATAN”.

Within the same folder exists a sub-folder where the filters applied are located (Table 2). Detailed description of the filtered data elements can be found in section of Data Processing, (Table 3).
Table 1
Content of the dataset in the raw files.

| Raw Data Files | Description                                                                 | File name | File Type |
|----------------|-----------------------------------------------------------------------------|-----------|-----------|
| Particles trajectory data | Data corresponding to the tag and position of each detected particle in x and z-axis and its respective displacement: along chute(Δx) and wall-normal(Δz) Units: pixel/frame | v1 to v31 | “.mat”    |

Table 2
Applied filters to the data files.

| Filters Data Files | Description                                                                 | File name | File Type |
|--------------------|-----------------------------------------------------------------------------|-----------|-----------|
| Median             | Median of the modular velocity over the total time t=438 frames.            | med_V     | “.mat”    |
| Standard Deviation | Standard deviation of the difference between the velocities and the median in each AW, over the total time t=438 frames. | dp_V      | “.mat”    |

Table 3
Content of the dataset in the filtered files.

| Filtered Data Files | Description                                                                 | File name | File Type |
|---------------------|-----------------------------------------------------------------------------|-----------|-----------|
| Along-chute velocity (u) | Along-chute velocities for all repetitions e=1 to e=31 found in each analysis window 64 × 50px² over the total time t=438 frames. | DATAu     | “.mat”    |
| Wall-normal velocity (w) | Wall-normal velocities for all repetitions e=1 to e=31 found in each analysis window 64 × 50px² over the total time t=438 frames. | DATAw     | “.mat”    |
| Number of particles (N) | Number of detected particles for all repetitions e=1 to e=31 found in each analysis window 64 × 50px² over the total time t=438 frames. | DATAN     | “.mat”    |

The ensemble data is in a sub-folder, which contains files including along-chute velocity for the ensemble, in all analysis windows over time – “ENS.u” and wall-normal velocity for the ensemble in all analysis windows over time – “ENS.w” as described in Table 4.
A final procedure for cleaning outliers was applied to the above ensemble data. The aforementioned data is storage on a third folder named “Final Data”, in which exists the final files for the along-chute and wall-normal velocities for the ensemble – “ENS_E.u” and “ENS_E.w” respectively as described in Table 5.

3. Experimental Design, Materials and Methods

3.1. Experimental facility and instrumentation

The experimental campaign on dry granular experiments was performed in the facilities of the Laboratory of Fluid Dynamics (LTDF) of the Free University of Bozen-Bolzano at NOI Techpark. The acrylic chute was 1.5 m length and 0.08 m width on an angle inclined plane of 19 degrees to the horizontal (Fig. 1).

Downstream of the chute, adjacent to the sidewall, a vertical barrier with two symmetrical gaps replicating slit dam conditions was positioned with a width of 3.6 mm each.

The granular material used was uni-sized polystyrene particles with a diameter of 1.8 mm and $\rho = 1$ g/cm$^3$ density allocated in the upstream reservoir of the chute by a lock gate. The dry normal coefficient of restitution of the material is $e = 0.7$.

All repetitions were conducted with a total volume of 3 litres of the granular material, which was released from the upstream reservoir by the suddenly open of a lock acrylic gate.
Fig. 1. Perspective view of the laboratory chute tilted at 19 degrees and detailed sectional view A-A of the slit geometry adopted.

Fig. 2. Photograph of experimental set-up and instrumentation used for the data acquisition on dry granular flows experiments.

Regarding the instrumentation, two high-speed cameras (Flare 12M180MCX) and one spotlight (ARRI SkyPanel S30-C) plugged into a light stand were used. One camera was located upstream the chute at the lock gate (C1) and another downstream at the vertical barrier (C2). During the experiments both cameras were synchronized operating at 300fps (Fig. 2).
Fig. 3. Photographs captured during the experimental campaign: a) high-speed cameras; b) Particle volume used in the experiments and its configuration \((V = 3 l)\); c) Sectional photograph of the vertical barrier adopted in the downstream part of the chute.

3.2. Experimental procedure

The experimental protocol of the dry granular flows experiments performed in the chute previously described is summarized in the following steps:

i. Set of both high-speed cameras in the respective positions assembled on their tripods: upstream camera (C1), placed in front of the lateral acrylic wall focused on the flow front crossing under the lock gate; downstream camera (C2), positioned at the downstream end of the channel fixing the arrival of the flow at the vertical barrier;

ii. Assembly of the lighting system by optimizing the position of the spotlight, until the quality of the images acquired with the location of the spotlight is ideal;

iii. Connect and synchronize the high-speed cameras to the computer (Fig. 3a);

iv. Fill the upstream reservoir with 3 litres volume of polystyrene particles with a horizontal surface (Fig. 3b);

v. Acquisition of calibration images from both cameras, focusing on the calibration target at the acrylic walls;

vi. Positioning of the vertical barrier located at 0.05 meters from the terminal part of the chute and at a distance of 3.6 mm from the side walls of the channel (Fig. 3c);

vii. Start the recording of the experiments;

viii. Sudden opening of the reservoir lock gate to release the content, without interfering with the upstream camera field of view;

ix. Stop the test recording as soon as the particles are completely blocked by the vertical barrier, i.e., the flow stops;

The instant when front of the granular material crosses through the lock gate defines the beginning of each test. The procedure described previously was repeated 31 times.

3.3. Image processing

The size of the regions of interest (ROI) from both high-speed cameras were adjusted to capture only the lateral chute region (Fig. 1). The recorded images have a maximum resolution of \(4096 \times 744\) pixel with a target frame rate of 300 frames per second, with an exposure time of 200\(\mu s\).

Both cameras were synchronized with each other and connected to a computer using CORE-View software for image control acquisition and data collection.

The images captured by camera C1 did not require any pre-processing once they were only used to define the start instant of each experiment. On the contrary, images from C2 were previously improved by an algorithm, in which the background was subtracted to each image of the
granular flow motion by eliminating the chute wall perturbations and the light inhomogeneity. In this particular case, the optical distortion was negligible, as well as the static friction observed in the captured images immediately at the beginning of each test.

3.4. Particle tracking velocimetry

A Particle Tracking Velocimetry (PTV) algorithm [2] was applied to the images captured by the C2 in a window size of 4000 × 350 pixel in x and z-axis respectively. The methodology adopted (described in [3]) is resumed in the following way: individual particles are tracked by finding the light intensity peaks (image thresholding) as the centroids (Fig. 4) of the Voronoï polygons; the centres of the adjacent polygons are united defining the Voronoï star that is used to match and determine the displacement of each particle in consecutive frames.

Therefore, this approach assumes that locally the Voronoï pattern around each particle remains unaffected between frames allowing the identification of matching sets of particles. The motion of each matching set is estimated as:

\[ v_i = \frac{r_{i,t+dt} - r_{i,t}}{dt} \tag{1} \]

Considering \( r_i = (x_i, z_i) \) the position of the particle \( i \), where \( r_{i,t} \) is before and \( r_{i,t+dt} \) after a time interval. Note that in this procedure all non-matching particles are rejected.

4. Data Processing

4.1. Raw data from PTV analysis

The experimental campaign was based on the conduction of a single test that was repeated 31 times under the same conditions, those earlier presented.

With this set of experiments, we were able to construct a raw database concerning the information gathered with the application of the PTV algorithm in consecutive frames during a total time period of 438 frames.

Hence, for each repetition, we have a database consisting of the particles tag and coordinates (pixel) \( (x, z) \), along-chute displacement \( \Delta x \) and wall-normal displacement \( \Delta z \) for each processed frame.

4.2. Ensemble construction

We decided to evaluate a specific part of the ROI analysed in the raw data from the application of the PTV algorithm, by scanning the area of 3965 × 200 pixel with several analysis windows (AW). Each AW with 64 pixel width in x-axis and 50 pixel height at z-axis, overlapping 50% (Fig. 5).
Fig. 5. Representation of the ROI and multiple analysis window studied along the x and z-axis.
**Fig. 6** Scheme illustrating the construction of the velocity database of the final ensemble, where $e$ refers to reference of the experiment (from 1 to 31), $t$ is the variable time, $x$ is the horizontal coordinate, and $z$ the vertical coordinate.

**Fig. 6** is a representative scheme of how the database related to this paper was built. In this way, the raw data originating from the application of the PTV algorithm was then further processed through several filtering steps.

The first step in filtering process (Step 1, in **Fig. 6**) applied to this data consisted of only considered applicable the databases that were composed by at least 3 particles with valid velocities in each analysis window (AW).

Also, for windows containing 4 or more particles with valid data, the outliers found were eliminated when compared to the AW median results, by exceeding a stated threshold (Step 2 in **Fig. 6**).

This prior filtering process provided the results for the total time evaluated ($t_{\text{total}} = 437$ frames) for along-chute velocity data ($u$), wall-normal velocity data ($w$), as well as the number of particles ($N$) that produced these results.

Subsequently the structure of the velocity database ($u, w$) for test number 1 inside each AW along the total time, was created. This outcome supported the establishment of an ensemble for $u, w$ velocities from test number 2 to test number 31 in all instants $t−dt, t, t+dt$ (where $dt$ is the time between frames) inside all AW. Thus, at any time instant evaluated, in each AW we found resulting ensembles with 279 to 550 entries of velocity data for 3 to 6 particles, respectively.

After the data ensemble was constructed, it was subjected to a closing procedure, namely a despiking filter proposed by [1]. The along-chute and wall-normal velocity components were placed in a quadrant plot and subjected to the intersection of three consecutive ellipses built on the basis of the standard deviation results. This process aimed to eliminate the outliers allowing the velocities for the final instants of the experiments to be in accordance with what was observed by the captured images.

**Fig. 7** exemplifies the application of this approach, for an analysis window located in the middle of the ROI in a final time instant. The along-chute and wall-normal velocities inside of the third ellipse were the ones considered as the final data. This methodology was adopted for all ROI supporting a new and final ensemble of data (last step, in **Fig. 6**).
Fig. 7. (a) Application of three ellipse equations to the ensemble results obtained for filtering the along-chute and wall-normal velocities considered outliers in the final instants of analysis. (b) Zoom of the illustration in (a) to observe the delimitation of the third ellipse for the results obtained.

Limitations

The Voronoi technique does not allow for large displacements of particles. The first instants after the particle cloud arrives to the partial obstruction do feature large individual particle motion. The uncertainty associated to the ensemble averaged velocities and granular temperatures is larger in these first instants.

Ethics Statement

The authors declare that the work here presented complies with the ethical requirements for publication in Data in Brief and also their work did not involve human subjects, animal experiments or ant data collected from social media platforms.

Data availability

Experimental DATA (Original data) (Zenodo)

CRediT Author Statement

Solange V. Mendes: Methodology, Software, Investigation, Data curation, Writing – original draft, Visualization; Rui Aleixo: Software, Data curation, Writing – review & editing; Michele Larcher: Software, Investigation, Writing – review & editing; Silvia Amaral: Writing – review & editing, Supervision; Rui M.L. Ferreira: Conceptualization, Methodology, Writing – review & editing, Supervision.
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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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