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The granular column collapse: A retrospective

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Abstract. The granular column collapse consists on the release of a granular volume let to deform or collapse under self-weight until eventually reaching a temporary or permanent stable deposit. Similar to a dam-break in fluid mechanics or a slump test in civil engineering, this configuration was first utilized by the granular media community in 2004. Since then, the granular column collapse has become a benchmark configuration for studying the mobility of granular flows, thanks to its easy setup and reproducibility, and captured rapidly the attention of a wider range of scientific fields working with granular materials. This review covers more than two decades, and even more, of studies employing the granular column collapse as means to understand or describe the motion of grains and their interaction with ambient fluids or gases. This review covers the wide range of fields where the column collapse has been used and includes a database with the collection of experimental works. The aim is to present the questions already answered and summarize the lessons learned from these experimental models. The wealth of applications where the granular column has been used demonstrates how this simple yet rich configuration is proving valuable for validating existing and future particle-based numerical methods.

1 The rapid release

Gravity is the main driving agent between non-Brownian grains, governing the intensity, frequency and duration of their grain-to-grain interactions. The action of gravity is involved in different flow regimes, moving from a quasi-static regime, passing by an inertia controlled regime, and reaching the higher levels of agitation in a collisional regime. The transition between these regimes can be sudden and its occurrence in a granular flow can localize and evolve in time. The former is a characteristic of transitional granular flows, where, at least, three stages are recognized: acceleration, steady flow, and deceleration. Examples of transitional flows include landslides, which are defined as a granular mass moving over a sliding plane [1]; dredging, which employs the mechanism known as breaching as a production mechanism [2]; industrial processes such as the preparation of fresh concrete; and machine interactions, as seen in bulk handling, among others.

The granular column collapse is a good configuration for studying transitional granular flows. It was initially presented to the granular media community by two groups in 2004 [3, 4]. These groups studied the rapid uplift of a cylinder filled with grains over a horizontal surface, identifying that the aspect ratio between the cylinder height and its radius, $a = H_0/L_0$, controls the resulting deposit geometry, i.e., H_f and L_f (see Fig. 1). The aspect ratio a is also useful to differentiate between the kinematics of short and tall columns. However, a similar configuration already existed almost 100 years before. This configuration is the concrete slump test, where the release of a truncated cone, also know as the Abrams cone, is employed as an indirect measurement of the yield strength of fresh concrete [5]. The Abrams cone and its minituarized version, the mini-slump test [6], have a fixed aspect ratio of $a = 3$ and a conical shape with a slope of 80.5° (see dashed line in Fig. 1). The slump test follows the same principle of the granular column collapse, but focuses on the role of the cement-water viscous suspension in the mobility of the concrete mixture. Furthermore, the granular column has an equivalent quasi-two-dimensional configuration (2D), where the initial cylinder is replaced by a rectangular prism, sharing many similarities with the dam break configuration often used in fluid mechanics [7].

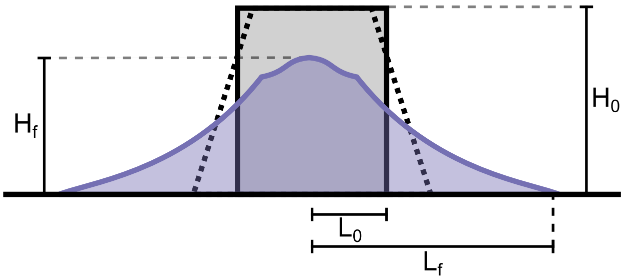

Figure 1. Schematic of the initial granular column collapse (continuous line) and slump test (dotted line) configurations, and the deposit after their release (purple shaded area).

The granular column became a benchmark test, thanks to its easy setup and reproducibility, allowing the study of the mobility of transitional granular flows and becoming a common validation case for modern numerical frame-

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works for granular media with a focus on large deformations [8, 9]. This review aims to present the questions already answered and summarize the lessons learned from the use of the granular column collapse models. This is achieved by compiling a database of publications employing the granular column configuration in the study of granular materials. The database provides a historical insight in the adaptation and prevalence of this configuration, anticipating its implementation as a standardized test.

2 Granular column collapse database

The database combines the Scopus entries on the terms *granular column collapse*, *slump test*, and the articles citing the works of [3] and [4]. The resulting database is curated by selecting only works where the collapse occurs onto a horizontal surface, has grains in the column body, and employs the configuration for studying the granular kinematics, either or both experimentally and numerically. This resulted, for example, in removing all entries where the slump test is employed in measuring the consistency of fresh concrete or similar materials. The curated database consists of a total of 494 entries, between 1919 and February 2025 (see Fig. 2). Each entry is reviewed and classified as a work developing either or both new experimental and new numerical data. The database includes the following fields: `Authors`, `Title`, `Year`, `Source title` (i.e., journal, conference proceedings), `DOI`, `Document Type` (i.e., Article, Conference paper, Review), `Experimental`, and `Numerical`. These entries are distributed in three categories, with 436 articles, 62 conference papers, and 2 reviews. Note that the limited number of conference papers might be due to these not being listed in Scopus or corresponding to extended abstracts. For consistency, the following analysis concentrates only on entries with the `Document Type` as `Article`. The database is accessible through [10].

The first studies on the release of a granular column under self-weight onto a horizontal plane date back to 1919, if not earlier, and initially focused on assessing the consistency of fresh concrete [5]. As mentioned above, this method was later standardized for the design of concrete mixtures [11] and extended as a rheological proxy for building materials and pastes [6]. For the case of the granular column collapse and its first published works in 2004, the publication rate has been much higher, with an even distribution between experimental and numerical studies between 2004 to 2012, followed by a rise in numerical works after 2012 (see Fig. 2). The database shows a peak of 58 publications in 2021, after which experimental studies declined, while numerical studies stabilized at an average of 34 publications per year.

The database highlights a wide range of applications where the granular column collapse has been used. The simplest case has focused on dry columns where the role of grains size, grains shape, grains bending, grains friction, among others is varied [8, 12–15]. This is then extended by adding a fluid, resulting in saturated, partially saturated, immersed, or adhesive forces between grains [16–22]. Further applications, have used the configuration for the study of geohazards like pyroclastic flows, landslides, ice calving, landslide-induced tsunami waves, and the generation of seismic signals [23–28]. Others have explored the role of changing the direction or magnitude of the driven acceleration, by releasing the column onto a spinning table, a drop tower, or a geotechnical centrifuge [29–31]. More recently, it has been utilized in training graph neural networks for the data-driven modelling of granular flows [32]. Remarkably, a universal trend on mobility and other kinematic descriptors is evident (see Fig. 3), but the rationalization of the pre-factors behind these trends remain exclusive to the process under study.

3 Standardization?

The wide range of experimental applications demonstrates a learning curve that leads to a best-practices recount when working with the granular column collapse. This section summarizes these practices with the goal of making a transition similar to that of the slump test, paving the way for standardized and widely reproducible datasets. This, in turn, will provide reliable data and, consequently, reliable interpretations of the collapse kinematics.

Granular column preparation. The use of natural materials demand multiple repetitions, as grains shape effects and changes in the grain size distribution could influence the column mobility [33, 34]. It has been found that the grain size distribution has no effect on the collapse mobility if the relative size between the column width L_0 and the grains diameter d is kept $L_0/d \geq 75$ [9]. Columns with grain size distributions below this ratio challenge the generality of the resulting observations as the relative position of a single grain may influence the whole collapse kinematics. Moreover, the role of the column densification, i.e., packing fraction, can be disregarded in dry columns, but it is expected to have an effect on saturated columns, leading to higher mobilities in initially loose columns [16]. Also, for 2D configurations, the influence of narrow side-walls reduces the column mobility. This can be avoided if the separation between walls W is kept such that $W \geq 140d$ [35]. Furthermore, the role of inter-particle forces amplify the effect of sample preparation, requiring care in the formation of those bonds and their uniform distribution over the column [19, 20, 22, 36]. Finally, the repeatability of the sample preparation should be closely controlled, reporting the total mass or volume employed in the building up of each column.

Column release. The release mechanism needs to set free the grains without inducing perturbations or minimizing the level of interaction between grains and the moving boundary. There are multiple configurations that do address these two points. The simplest of all, is the rapid uplift of a sluice, however in some occasions (i.e., partially saturated columns) this alternative could lead to a shear interface layer, inducing excessive dilation and suction against the sluice [37]. Alternatives to avoid this include setting a low-friction sheet between the door and the column [38], implementing a mechanism that moves away from the column [20, 39], or inducing a hydraulic gradient that stabilizes the column face and thus eliminates the

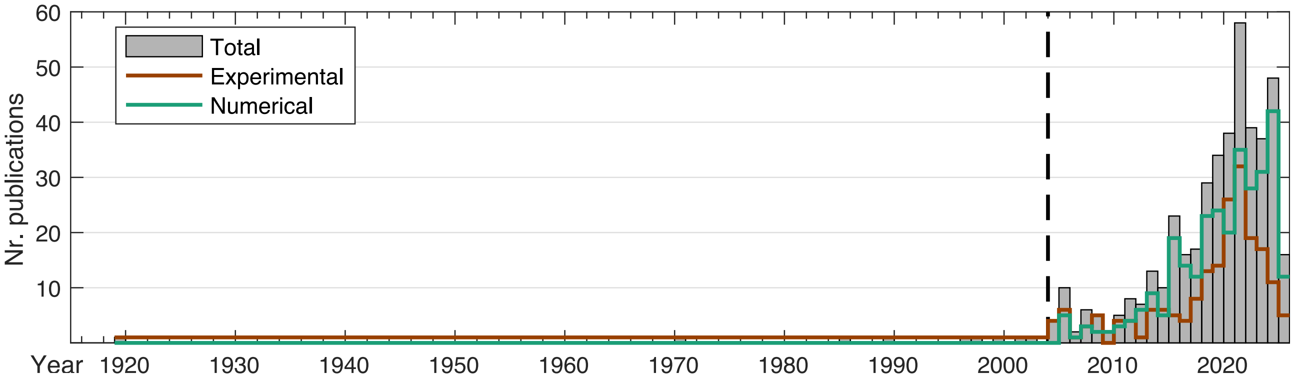

Figure 2. Number of journal articles working with the granular column configuration over a horizontal surface, differentiating between works employing an experimental setup or a numerical framework. The vertical dashed line marks the publication of the work of Lube et al. [3] and Lajeunesse et al. [4].

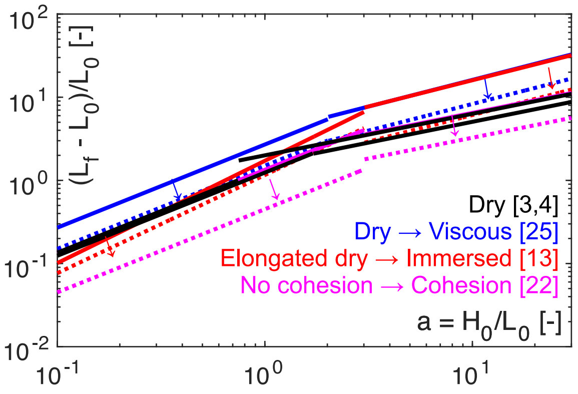

Figure 3. Effects on the column collapse mobility. The arrow indicates the effect of adding water [25], having elongated grains [13], and adding a cohesive bond [22].

need for a sluice [40, 41]. Moreover, in some applications, the door movement might interfere with the ambient flows (e.g., wave generation), requiring adjusting the releasing mechanism to move perpendicularly from that of the collapse direction [27]. For an uplift release mechanism , Sarlin et al. reported a minimum release velocity $\overline{V} \geq 0.4\sqrt{gH_0}$, where g is Earth's gravity [42]. Uplift velocities below this limit are expected to partially release the column and, hence, interfere with its final mobility.

Column collapse and measurements. Due to its simplicity, the granular column instrumentation consists of measurements focused on the collapse kinematics and the deposit geometry. The collapse kinematics are captured with cameras, recording, a.o., the motion and rotation of the released grains [43, 44], and the induced fluid flows with the help of tracers [45]. Furthermore, boundary basal pressure measurements complement this analysis focusing on the pressure imposed by the moving grains [46] or by the expelled fluid [16, 38]. Regarding the deposit geometry, the measurement of the runout distance L_f has been taken as the farthest distance reached by the grains still in contact with the main deposit. This becomes challenging when a considerable fraction of grains is expelled from the deposit, requiring an averaged measurement [19, 31].

4 Closing remarks

The database presented in this review is a testament to the wealth of experimental data surrounding the granular column setup. Despite this, these studies rarely provide access to their direct or post-processed datasets, limiting the validation efforts to single data points or selected snapshots for the validation of numerical frameworks. Therefore, there is a need for more coherence and structure in the documentation and sharing of these datasets. Clearly, this effort must be implemented and motivated in the publication practice, assisting and motivating researchers in reporting their data while preventing unnecessary complexity. This could be embraced as a community-driven effort, where promoting accessibility, transparency, and collaboration would align the common scientific efforts more effectively.

Finally, a case is made for the need to standardize the granular column setup, with the aim of collecting reproducible datasets within the granular media community.

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