Tectonophysics 593 (2013) 85–94

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

A sedimentation device to produce uniform sand packs

Bertrand Maillot *

Laboratoire Géosciences et Environnement Cergy, Université de Cergy-Pontoise, France

ARTICLE INFO

Article history:
Received 23 May 2012
Received in revised form 17 January 2013
Accepted 18 February 2013
Available online 26 February 2013

Keywords:
Granular material
Analogue modelling
Physical modelling
Sandbox experiments
Sedimentation

ABSTRACT

In physical modelling using sand, the construction of a sand pack is one of the main experimental difficulties. Existing solutions are generally based either on delicate manipulations (pouring and scraping), or on motorized sedimentation devices, and the qualities of packs thus produced are known to affect experimental outcomes. However, uniformity, planarity, reproducibility and efficiency can be achieved with a simple sedimentation device without motors. A rectangular reservoir pierced with holes rests on a support plate pierced with wider holes. Sand flows when the reservoir is displaced so that its holes match those of the support plate. Sand jets are diffused by planar horizontal sieves, below which the sand sets into the experimental box. Tests on a 250 μm median grain size sand show that the density is at its maximum value, reproducible, and uniform. The spatial variations are only of ±0.4% of the mean density. Thickness of the sand layers shows spatial variations around ±2% of the mean thickness, and 6% near the side walls. Very fine grains (90 μm median grain size) produce less uniform and less planar packs because of their greater sensitivity to air currents caused by the sedimentation. According to direct shear tests the sand pack has a well defined static friction coefficient decreasing to a lower dynamic value after about 3 mm of slip with dilatancy. In contrast, poured sand packs, which are initially less dense, develop only the dynamic friction coefficient (no peak shear stress during slip), without dilatancy. Hole diameters, hole spacing, and the number and openings of the sieves are the parameters controlling the qualities of the sand pack for a given grain size distribution.

1. Introduction

The physical modelling of tectonic structures using sand can be related to mechanical theoretical analysis (e.g., Davis et al., 1983; Hubbert, 1951; Maillot et al., 2007; Martinod and Davy, 1994), and, more and more, to numerical simulations (e.g., Buiter et al., 2006; Cruz et al., 2010; Del Castello and Cooke, 2007; Egholm et al., 2007; Hardy et al., 2009). The matching of numerical and experimental outputs is a challenge that implies in particular to improve the experimental protocols regarding biases (Schreurs et al., 2006; Souloumiac et al., 2012) and the quantification of uncertainty (Cubas et al., 2010). Schreurs et al. (2006) have shown that the handling technique to prepare the sand pack (before applying any deformation) is one of the sources of experimental variability. Experimenters and laboratories have developed their own protocols, which are more or less described in the literature, and often motivated by efficiency and personal experience.

There are two ways to deposit the sand in the box: pouring and sifting (sprinkling, sometimes mentioned, is really a proxy for sifting). There are three techniques to compact the sand once deposited: shaking (e.g., Hubbert, 1951), fluidizing (Cobbold and Castro, 1999), and pressing (J.-M. Mengus, Institut Français du Pétrole, pers. comm.). Finally, scraping is the widely used technique to flatten the surface. Pouring may be done using a bucket- or glass-size volumes, at typical heights of 5 to 30 cm, and rates depending on the desired thickness of layers. It must be followed by a time consuming scraping of the pack to produce flat layers, often intercalated by coloured ones. Planarity of the pack is nearly perfect, but uniformity and reproducibility of its local density are unknown since they result from the above manipulations which are not defined in all details. The sand pack is likely to be heterogeneous and under-compacted (Krantz, 1991). These defects will in turn influence the mechanical behaviour since friction angles and strain localisation processes depend on initial compaction (Casagrande, 1936; Krabbenhoft et al., 2012; Lohrmann et al., 2003). Sifting differs from pouring in the fact that the grains are well separated when falling in the box. Sifted sands are close to their maximum density (Krantz, 1991), perhaps because the kinetic energy of the sifted grains fluidizes the pack surface, as suggested by Wygal (1963). This results in higher static friction coefficients for sifted sands because more dilatancy is then required to reach the dynamic friction coefficient (Lohrmann et al., 2003). This is why sifted sands are more conducive to strain localisation, which is an essential characteristic of deformation in brittle tectonics (e.g. Mandl, 1999). In addition, efficiency is crucial since experimental uncertainties can only be evaluated with a large set of tests (Cubas et al., 2010; Maillot et al., 2007). Building the sand pack in several layers by pouring–scraping requires typically 10% to 50% of the total

* Tel.: +33 1 34 25 73 59.
E-mail address: bertrand.maillot@u-cergy.fr.

0040-1951/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.tecto.2013.02.028

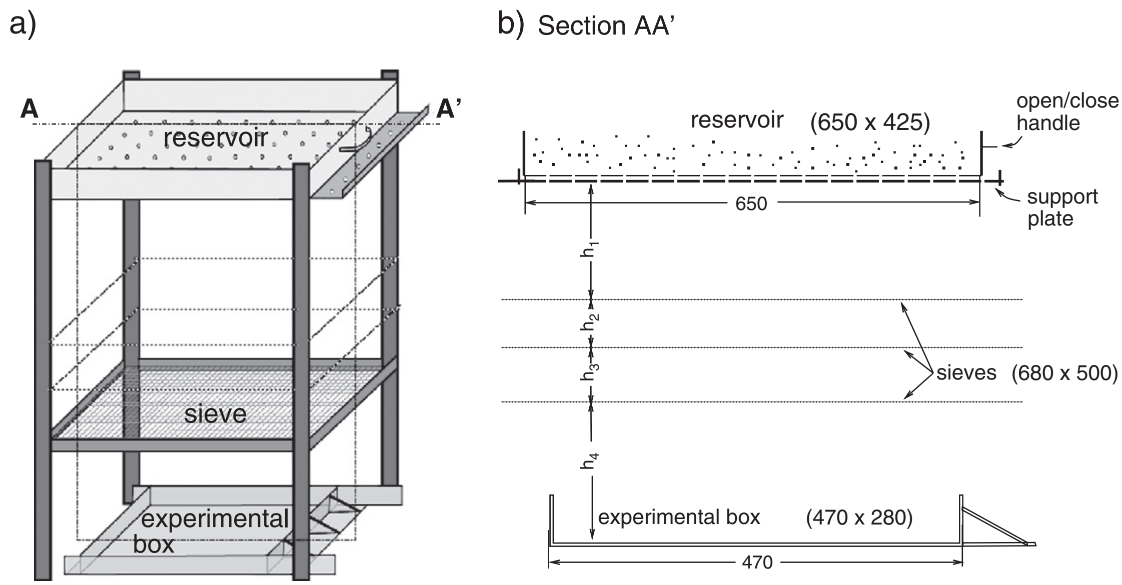

Fig. 1. a) Schematic representation of the sedimentation device placed above the experimental box. It is composed of a reservoir, a support plate, and sieves. To start or stop sedimentation, a handle allows the operator to slide the reservoir so that its holes match, or not, those of the support plate. One to three sieves were used. b) Details and lengths in cross-section. Separation lengths h_1 to h_4 are given in Table 2. All lengths in mm.

duration of an experiment. If sifting is well controlled, no scraping step is required, and a sand pack made of five to ten layers can be built in a few minutes.

Sifting is thus generally preferable to pouring-scraping. A hand-held salt-cellar like sifting device is often used, with specification of the height of fall and of the mass rate (Lohrmann et al., 2003; Panien et al., 2006; Schreurs et al., 2006). However a scraping step is necessary to shape to sand pack. Here, I call sedimentation device an automatic (not hand-held) sifting device with controlled mass flux rate designed to produce a sand pack without recourse to scraping. Such machines have been built in few laboratories and are usually not described in details, except in Horsfield (1977). The sedimentation device presented here is based on the device of Wygal (1963). Wygal's application concerned transport properties of the sand pack and he therefore concentrated his efforts on controlling the density. We report here on alterations of his design to produce dense and *shaped* sand packs. Only planarity is studied here because it is a basic set up. Other surface shapes could be produced by the juxtaposition of planar layers occupying decreasing parts of the box with the help of a mobile cache. Key features of our device are (i) a sifting area covering all the experimental box to be filled, so that no movement of the sedimentation device or of the box are required during sedimentation, and (ii) fine tuning of the mass flux to reduce air turbulence and ensure filling of the box at a spatially uniform rate. The sand body is thus entirely produced by sedimentation and is not manipulated at all.

The next section describes the sedimentation device and the tested sands. Density of the sand packs is measured in Section 3, planarity, in Section 4, and friction coefficients in Section 5. The Appendix A lists the critical points of the design and use of a sand sedimentation device.

2. Description of the sedimentation device

The device is made of a sand reservoir overlying one or several sieves, themselves overlying the experimental box (Fig. 1a). The reservoir is a rectangular box 10 cm deep of internal dimensions 650 × 425 mm, designed for a 470 × 280 mm or smaller experimental box. The bottom is pierced with holes of diameter 2 mm at the nodes of a 25 × 25 mm^2 square lattice, requiring 1600 holes/m^2. The reservoir rests on a fixed support plate pierced with wider holes (5 mm in diameter), at the same positions. A handle allows the operator to slide the reservoir so that the holes of both parts coincide and the sand starts flowing. To vary the sand mass flux, 800 holes/m^2 (and 400 holes/m^2) were also set up by blocking every second row (and column) of holes of the support plate with sticky tapes. The sieves are square meshes (opening 0.8 × 0.8 mm^2) made of 0.15 mm inox wire. They are cut larger than the reservoir to ensure a uniform diffusion of sand over all the box. Sand falling outside of the box can be caught by placing horizontal protection panels along the sides of the box in order to protect any additional devices. Reservoir, sieves, and protection panels are mounted on the same structure equipped with wheels to bring the device above the experimental box. The structure of the device is independent from the structure holding the experimental box.

Use of the sedimentation device consists in (1) filling the reservoir with clean sand, (2) slide the reservoir in the open position for the time necessary to deposit a sand layer of desired thickness in the box (Fig. 2), and (3) slide the reservoir back to the close position. A thin layer of coloured sand may then be sprinkled with a hand held sieve to act as a strain marker, before making the next layer.

2.1. Tested sands

Two Fontainebleau aeolian sands (more than 98% of quartz) were tested: the coarse and well sorted[1] "CV32" sand (median grain size 250 μm), and the fine and poorly sorted "GA39" sand (median grain size 90 μm) (Fig. 3). These grain sizes cover most of the range of sizes used in tectonic applications. Note that the sieves opening of 0.8 mm is roughly twice the diameter of the biggest sand grains. The sands never pile up on the sieves. The sand mass flow per hole (average of sixty holes) is 0.312 ± 0.021 g/s for the CV32, and 0.307 ± 0.015 g/s for the GA39. These figures are used to calculate the mass fluxes given in Table 2.

[1] In Geotechnics, "sorting" refers to the distribution of grains among the sieves used for the grain size distribution analysis. A well sorted sand has therefore a wide variety of grain sizes.