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The role of deposition process on pressure dip formation underneath a granular pile ☆

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ABSTRACT

This paper describes an experimental investigation on the pressure dip phenomenon in a conical pile of granular solids. The roles of different deposition processes such as the pouring rate, pouring height and deposition jet size on the pressure dip formation were studied. Test results confirmed that the pressure dip is a robust phenomenon in a pile formed by top deposition. When the deposition jet radius is significantly smaller than the final pile radius (i.e. concentrated deposition), a dip developed in the centre as shown in previous studies. However, when the deposition jet radius is comparable to the final pile radius (i.e. diffuse deposition), the location of the dip moves towards the edge of deposition jet, with a local maximum pressure developed in the centre. For concentrated deposition, an increase in the pouring rate may enhance the depth of the dip and reduce its width, while an increase in the pouring height has only a negligible effect in the studied range. The results suggest the pressure dip is closely related to the initial location, intensity and form of downslope flows.

1. Introduction

Granular materials are in abundance in nature and are also estimated to constitute over 75% of all raw material feedstock to industry (Nedderman, 1992). They have been extensively studied by both the scientific and engineering-communities, and yet they sometimes display behaviour that is counter-intuitive and a full understanding remains elusive. One classic granular mechanics problem is that of a humble 'sandpile' in which a significant dip in the vertical pressure on the base is observed underneath the apex, at the location where a simple interpretation might expect the maximum pressure. This 'pressure dip' phenomenon is also relevant to the bulk handling of industrial solids because many different bulk solids are commonly stored in open stockpiles, particularly in the mining industry (Fig. 1). The design of a gravity reclaim system for a stockpile requires knowledge of the base pressure distribution underneath the stockpile. The same phenomenon may also occur in silos that are filled from a 'point source' which might be expected to result in an increase in the silo wall pressure near the highest wall contact, but thisphenomenon is not recognised at all in the silos literature.

The sandpile problem has been the subject of many analytical, numerical and experimental studies and some good reviews of the problem are available (e.g. Atman et al., 2005; Cates et al., 1998; Didwania et al., 2000; Savage, 1997, 1998). However, there is little consensus on the fundamental physics or the mechanics assumptions made in the many mathematical models of this apparently simple system, and quite contradictory results are often claimed. Several factors have been suggested to explain the pressure dip observed under the apex of a pile. These

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Fig. 1. A typical industrial stockpile formed by top deposition from a conveyor.

include the presence of a base deflection (e.g. Lee and Herington, 1971; Savage, 1998; Trollope, 1956; Wiesner, 2000), pile construction history (Geng etal., 2001; Vanel et al., 1999), formation of a granular skeleton (Savage, 1997), particle size segregation (Liffman et al., 1992, 1994; Liffman et al., 2001), particle shape (Zuriguel and Mullin, 2008; Zuriguel et al., 2007), "Fixed Principal Axes (FPA)" of stress propagation (Wittmer et al., 1997; Wittmer et al., 1996), reduced density in the central zone of the pile due to deposition impact (Smid and Novosad, 1981) and increased shear mobilisation on the base due to the deposition process (Ai et al., 2013; Ai et al., 2011; Michalowski and Park, 2004). However, neither the relative importance nor theinterplay between these factors is at all clear and a comprehensive understanding of this phenomenon remains elusive. This study involved carefully designed experiments to investigate the base pressure profile under a conical pile of mini iron ore pellets.

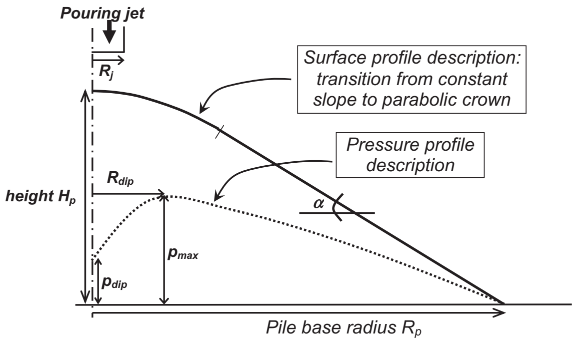

Fig. 2. Description of surface and pressure profiles of a sandpile with a central dip.

A variety of measurement techniques have been used to measure the pressure distribution on the base of a granular pile, including pressure cells (Evesque et al., 1999; Hummel and Finnan, 1921; Jotaki and Moriyama, 1979; Lee and Herington, 1971; McBride, 2006; Ooi et al., 2008; Smid and Novosad, 1981; Trollope, 1956), registering the load on articulated base strips instrumented with strain gauges (Lee and Herington, 1971), strain gauges fixed on the base plate (Trollope, 1956), an elasto-optical method(Brockbank et al., 1997), single capacitive normal stress sensor (Vanel et al., 1999), and photoelastic methods (Geng et al., 2001; Zuriguel and Mullin, 2008; Zuriguel et al., 2008; Zuriguel et al., 2007). The free-field pressure cells developed by Askegaard (1989) were adopted in this study.

The relative size of the pile to the particle size may be an important factor for consideration. Relatively large scale pile tests produce rather consistent pressure measurements for same preparation procedure. Generally these tests support the concept that the pressure dip is a robust phenomenon for a pile formed by pouring particles with funnel feeding. The most commonly referenced experimental evidence is the early study ofSmid and Novosad (1981) who used quartz sand and granulated fertilizer NPK-1 and observed a significant pressure minimum at ~35% of the anticipated hydrostatic value γH_p (Fig. 2). By contrast with these relatively large scale pile tests, small scale tests often suffered from significant fluctuations in the deduced pressures. In such tests, it is often necessary to average many repeated experiments before a pressure dip can be seen (e.g. Brockbank et al., 1997; Geng et al., 2001; Zuriguel and Mullin, 2008; Zuriguel et al., 2008; Zuriguel et al., 2007). These results have led some to believe that the pressure dip is not a securely reproducible phenomenon and that its formation can be sensitive to numerous factors. In this study,relatively large conical pile laboratory experiments were conducted in which the base pressure distribution was measured with good accuracy.

The size of the pressure dip has been found to depend on the pile shape. Conical piles often have a pronounced pressure dip. The dip pressure p_{dip} relative to the "null-hypothesis" hydrostatic pressure beneath the pile apex γH_p, has been widely found to be small (~35% by Smid and Novosad (1981); Vanel et al. (1999) and Ooi et al. (2008); 42–55% by McBride (2006)). By contrast, no dip or a negligible dip has been found in a wedge-shaped or prismatic pile (e.g. Lee and Herington, 1971; Trollope, 1956; Wiesner,2000). Vanel et al. (1999) observed a clear dip in their test on a prismatic sand pile, but the dip was still significantly less than that in the conical pile. Sometimes the magnitude of pressure fluctuations is comparable with the magnitude of the dip being measured (e.g. Lee and Herington, 1971). However, for a pseudo-two dimensional pile – consisting of a single layer of particles, a substantial dip can still be observed. For example, by