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Pressures on the support columns buried in iron ore stockpiles

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ABSTRACT

This paper presents the results of experimental investigations aimed at the determination of the loads exerted on support structures buried in gravity reclaim stockpiles. Structures, such as trestle legs to support load-out conveyors in open stockpiles, or columns to support roof structures and load-out conveyors of enclosed bulk solids storage sheds are subject to the loads exerted by the surrounding bulk solids. The complexity of these loads has been discussed recently (Roberts, 2007 [1], Katterfeld and Roberts, 2009 [2]). According to the theoretical approach proposed by Roberts, both active and passive stress states in bulk solids contribute considerably to the pressure distributions on these support columns. The findings of the preliminary experimental studies carried out by Roberts match with the theoretical predictions. However, follow-up work is required to further validate and improve the design equations for the determination of the loads on support columns. Based on Roberts' prediction model, a laboratory scale test rig was constructed to measure the loads on both the front and rear faces of a buried column. Tekscan tactile pressure sensors were employed in the pressure measurements. Stockpile tests under three different conditions were investigated, and the measured results correlate well with theoretical predictions from modified Roberts' theory. The outcome confirms that Roberts' theory can contribute to the design criterion regarding the loads on buried structures in stockpiles.

1. Introduction

Throughout the world, large bulk storage facilities such as gravity reclaim stockpiles, bulk sheds and bins are commonly used in industrial applications to store and handle bulk solids in large quantities. Often these storage facilities incorporate structural members such as trestle legs to support load-out conveyors of open stockpiles or columns to support roof structures and load-out conveyors in large bulk storage sheds. However, these support structures are often substantially submerged in the stored bulk materials and are subjected to varying loads occurring during the filling and emptying of the bulk storage facility. The loads exerted on the support structures by the surrounding bulk solids are quite complex and therefore difficult to predict. While the subject of wall loads has been dealt with in some detail for mass-flow and funnel-flow bins by several authors such as Jenike et al. [3–5] and Walters [6], the subject of loads on buried structural members had hitherto received little or no attention. For this reason, Roberts' theoretical approach to determine the loads exerted on buried structures [1] is seen as an important contribution. A new continuum approach resulting in design equations to analyse the loads on structural elements was established, and the correlation between stress conditions developed in the stored materials and the load distribution on these support elements was investigated. The stress states developed are closely related to the following parameters:

- the manner and mechanisms of loading and reclaim,
- loading and unloading history,
- length of undisturbed storage time in the stockpile,
- rigidity of the stockpile floor, as well as
- variations in the flow properties of the handling material.

An industrial case study concerning the loads on vertical support columns in a large bulk fertilizer shed as well as tests on a small scale experimental model were performed, with the results correlating well with Roberts' analytical predictions [1]. In addition, Roberts' theory was also applied to the prediction of the loads on trestle legs supporting a load-out conveyor buried to a maximum depth of 35 m in a coal stockpile, and these trestle legs have been working properly for years. Follow-up numerical simulations undertaken by Katterfeld and Roberts involved the application of the discrete element method (DEM) to model the interacting forces between particles and buried support columns from a macroscopic perspective. The results of the simulations, published by Katterfeld and Roberts [2], show good correlation with the theoretical calculation of the pressure distribution over the buried column height.

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Since support structural elements employed in large bulk storage facilities have become more popular in industrial applications, the need for reliable and effective design criterions for these structures is increasing. Although Roberts' theory has already extended the understanding of the loads on buried structures, further experimental research is required to validate and upgrade, as required, the continuum approach. For this reason, a laboratory scale test rig was built to determine experimentally the load conditions on support columns partly buried in gravity reclaim stockpiles. Tekscan tactile pressure sensors (Tekscan, Inc., Boston, MA) were employed to measure the pressure distributions on the faces of a buried column. This thin-film type of sensor consists of a matrix of patented semi-conductive ink coating on two paper thin carrier foils, and allows real-time continuous data collection. This sensor type has already been applied in several studies [7–10] for the pressure measurement in granular materials or soils. It showed a good degree of accuracy, especially when compared to other available means of pressure measurements in granular materials.

It is well known that the flow properties of bulk solids vary with consolidation pressures, moisture content and time under undisturbed storage. The design of bulk storage systems, such as the determination of bin wall loads [3–5,11–16], a conservative approach is adopted in which the particular properties are chosen so as to maximise the loads determined. This procedure is normally prescribed in bin load Standards. However there are applications where the actual variability cannot be ignored. An example where the changing consolidation stresses needed to be taken into account is described by Roberts et al. [17] for design equations for mass-flow hoppers using stringy and compressible bulk materials. A similar method is adopted in this study by taking the flow properties variations of iron ore into consideration, and a few modifications are made on Roberts' approach [1] as described in Section 2.

2. Loads on buried structures

2.1. Continuum load analysis for buried structural elements

In view of its relevance to the present study, the theory proposed by Roberts [1] is now reviewed. The calculation model proposed by Roberts uses a classical continuum approach to analyse the varying load conditions exerted on the surfaces of a structural element buried in bulk material. It is based on the application of the wall load theories for bin and silo design, as described by Jenike et al. [3–5], Walters [6] and Palmer et al. [9]. During the loading process of a stockpile, bulk material is usually discharged from a belt conveyor and comes to rest on the pile surface under the bulk materials angle of repose θ_R. Either active stress state, passive stress state or a combination of both is assumed to develop during the processes of loading, storage and reclaim. Therefore, two separate load models have been used by Roberts to determine the loads on the column faces.

Loads are exerted on the column faces by the surrounding bulk solid as illustrated in Fig. 1. Fig. 1(a) shows that the lateral force F_u dominates the load condition on the leading face of the column, also named front or upper face. Frictional drag forces F_s act along the sides of the column and a back-filling force F_l is introduced by a void created behind the rear or lower face. The load situation for cohesive bulk solids shown in Fig. 1(b) results in an increase of effective area on the column surfaces due to material build-up which is most likely to happen on the front face. This paper focuses on the investigation of F_u and F_l in the case of low-cohesive material as depicted in Fig. 1(a).

Roberts' continuum analysis model describes the characteristics of the loads exerted on the buried support column, which are shown schematically in Fig. 2. In this approach, the failure surface for internal shear inclines with an angle β relative to the vertical direction, producing a wedge-shaped loading condition. Angles α_c and

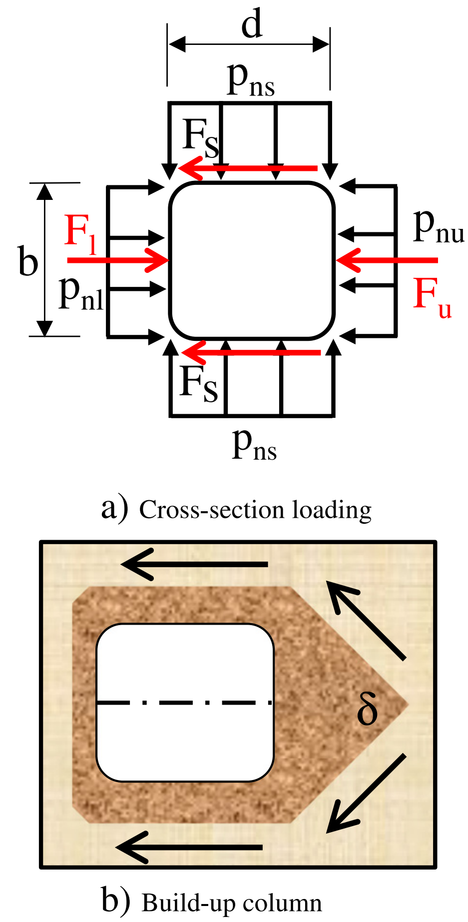

Fig. 1. Loads on column faces.

α_s depend on the friction condition at the column upper surface and the internal shear surface, respectively, and define the centre line of the wedge. A differential equation deduced from the force

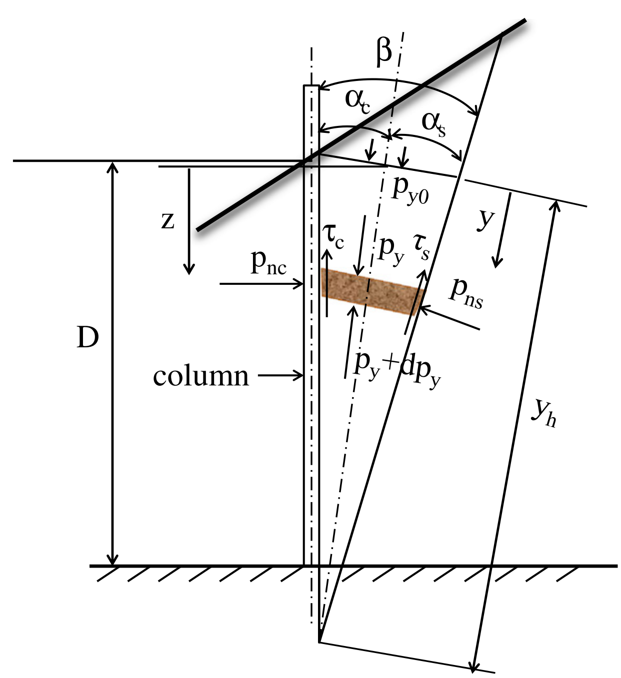

Fig. 2. Load analysis model.