NUMERICAL SIMULATIONS OF STRESSES UNDER STOCKPILED MASS OVER GROUND WITH OR WITHOUT A LOADOUT TUNNEL

(Spine title: Numerical simulations of Stresses under Stockpiled Mass)

(Thesis format: Integrated-Article)

by

Ho Young Jeong

Graduate Program
in Engineering
Department of Civil and Environmental Engineering

A thesis submitted in partial fulfillment
of the requirement for the degree of
Doctor of Philosophy

Faculty of Graduate Studies
The University of Western Ontario
London, Ontario, Canada

ABSTRACT

Contrary to common intuition, several experiments simulating construction of conical stockpiles of granular material on a rigid surface, have shown a dip in vertical stress under the bottom-center of the mass, rather than the maximum value of vertical stress. To date, there is no clear explanation of stockpile pressures including this counter-intuitive center-dip, despite the work of researchers from several different disciplines. This center-dip phenomenon poses challenging questions regarding its origins, what factors govern its presence and magnitude, and even whether this stress dip is real, or a product of the test conditions. In addition, the design of unloading infrastructure under stockpiles, has featured estimates of stress fields within and along the base boundary, and the mechanical response of the structures positioned underneath has been estimated using empirical or simple analytical procedures.

To address these issues, extensive numerical simulations were performed modelling the formation of stockpiles of granular material over a rigid base, as well as deformable ground with or without loadout structures below the ground surface. Important findings regarding the behaviour of the stockpiled mass, any underground structures and stresses applied to the ground surface are reported.

The work provides guidance on numerical techniques needed to simulate stockpile construction using conventional finite element analyses, proposing a mathematical basis and explanation for the center-dip phenomenon. It also develops techniques needed to numerically simulate stockpile reclaimation and subsequent refilling. Comparisons are made with small scale and medium scale laboratory experiments of stockpile construction over a rigid ground surface. The analysis is then extended to examine stockpile construction of large scale over deformable ground, with or without the underground loadout structures used to reclaim the granular material. These results provide guidance regarding the behaviour of large scale stockpiled masses, as well as preliminary design concepts for loadout tunnels.

Results from the numerical simulations reveal that the center-dip in vertical stress distribution along a rigid base under the stockpile results from stress redistribution within the mass as it is slowly constructed, shear failure of the constituent material, and the near-constant volume process sustained by the stockpiled material. Successful simulation of the unloading process (leaving an inverted cone of empty space within the remaining mass), and subsequent refilling, presents the possibility that the material density within the stockpile is non-uniform. The techniques used in these simulations of unloading and refilling are proposed as a predictive model for future investigations.

The modelling techniques developed through the early part of the thesis are then used to examine large scale stockpiles. Simulations for large scale stockpiles placed over deformable ground with or without loadout tunnels provide guidance on how vertical and shear stresses below the stockpile depend on the properties of the base ground, and the properties and geometry of the underground structures. These results are used to develop preliminary design guidance for these structures. They imply that the nature of the base boundary has an important effect on the behaviour of the overlying stockpile, and the initial placement situations can be considered as governing conditions for the design of the structure.

Keywords: stockpile, wedge, granular material (sand, gravel), finite element analyses, axisymmetric and plane strain conditions, reclaim, refill, loadout tunnel, corrugated steel pipe, construction history, incremental construction scheme, stress redistribution, shear failure of stockpile material