Failure Mode Transition for Rock Cutting: Theoretical, Numerical and Experimental Modelling

by

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A thesis submitted for the degree of

Doctor of Philosophy

School of Civil, Environmental and Mining Engineering

Faculty of Engineering, Computer and Mathematical Sciences

The University of Adelaide

Dedication

This work is dedicated to my beloved parents.

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Abstract

Rock cutting involves removing the rock material in front of the cutter when it moves against the rock at certain penetrating depth. The responses of rocks under cutting are influenced by rock properties such as mineral constituents, strength and fracture properties, as well as the operational parameters such as the depth of cut, cutting velocity and the back rake angle. A common approach to characterise the interaction between rock and cutter is to model the cutting forces. When the depth of cut is small, cutting forces show a linear relationship against the depth of cut, indicating a ductile-dominant failure mode. As the depth of cut increases, the rock cutting failure shifts from ductile-dominant mode to brittle-dominant mode and the cutting forces gradually deviate from the linear relationship. The depth of cut at which the dominant failure mode changes is termed the critical transition depth in rock cutting. The challenge lies in developing a generalised model for cutting force prediction based on rock properties and various complex cutting conditions while incorporating both ductile and brittle failure regimes.

In this thesis, the discrete element method (DEM) was employed to investigate the key rock properties that influence the failure pattern in rock cutting. It was demonstrated that rock (Brazilian) tensile strength (BTS) is as important as the uniaxial compressive strength (UCS) in the determination of the critical transition depth. The mineral grain size is also an important factor. Experiments were then carried out on two types of rock, namely Savonnières and Tuffeau limestone, to study changes in failure modes under different operational parameters of cutting velocity, back rake angle and depth of cut. Bažant's size effect law was used for in-depth analysis of the cutting data, which performs exceptionally well in the quantification of the critical failure mode transition depth. These derived transition depths were then incorporated into the established generalised cutting force prediction model, which uses a

more realistic assumption that the cutting failure is neither purely ductile nor purely brittle, but a combination of both.

It was demonstrated that the generalised cutting force prediction model captures reasonably well the cutting responses and failure mechanisms for the rock under various cutting conditions. The insights presented in this study will help in the understanding of rock cutting failure mechanisms and rock cutting mechanics and will be beneficial to the optimisation of tool design and rock cutting operations.

Statement of Originality

I, Xianqun He, hereby declare that this work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution in my name and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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