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Investigating the effect of earthquakes on open pit mine slopes

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ABSTRACT

This paper develops a database for studying the circumstances under which dynamic loading of earthquake can cause slope failure in deep open pit mines with a long lifetime. The database includes 177 open pit mines hit by earthquake and 95 natural slopes and 37 tailing dams which have been failed by earthquakes. Both earthquake parameters and geomechanical characteristics involved in each case-study are investigated. From this information, the elements playing role in the earthquake-triggered failures in natural slopes and tailing dams are identified and used to indicate conditions that may result in earthquake-induced failures in open pit mines. The result shows that even though the valley shape geometry and absence of the top weathered layer make open pit mines less prone to earthquake-induced failures, excessive pore pressure in pit slopes still carries the risk of earthquake-triggered failures in open pit slopes. Only limited numbers of open pit mines have been so far exposed to earthquakes with the same parameters as those causing failure in natural slopes and tailing dams. That is, the response of open pit mines to higher magnitude, shallower, and closer earthquakes is still unknown. Studying the earthquakes that have caused failure in other slopes, it is concluded that open pit mines may still experience reportable failures if struck by earthquakes with local depth of less than 40 km, epicentral distance of less than 100 km, and magnitude of greater than 6.0. The necessity of accounting for seismic loading in slope stability analyses and active dewatering for open pit mines located in seismically active areas are also discussed.

1. Introduction

There is considerable debate about the circumstances under which seismic analyses is necessary for ensuring the stability of slopes in open pit mines. There have been a few, if any, reportable failures triggered by earthquakes in open pit mines.[1] According to Mine Safety and Health Administration requirements, [2] a reportable failure is the one that causes injury or production interruption. However, the significant number of failures recorded in natural slopes and tailing dams during seismic events casts doubt on the immunity of open pit mines to earthquakes.[3,4]

Studying the inconsistent behaviors of pit slopes, natural slopes, and tailing dams under dynamic loading of earthquakes provides a better understanding of the circumstances under which pit slopes may fail due to seismic events. This study becomes even more crucial as the depth and life of open pit mines are extending by the use of the new mining techniques. Advancements in monitoring systems allow the open pit designers to plan deeper and steeper pits, especially in large and deep porphyry deposits mostly located around subduction zones with high seismic activities. These designs lead to lower safety factors in which a small external force (i.e. earthquake) could bring the safety factor to less than 1.0 and cause failures. Moreover, the new mining methods like highwall mining extend the final pit slope life which increases the probability of seismic activities during their life time.[1,5]

There have been attempts to examine the impacts of earthquake parameters, including magnitude, focal depth, and epi-central distance on reported failures of natural slopes. Other studies also investigated some natural slopes exposed to earthquakes and showed the significance of geometry, material properties, and water content in the stability of natural slopes.[3,4,6–12] We developed a comprehensive database covering earthquake parameters, geometry, material properties, and water content of case studies totaling 309. Earthquake parameters are defined as external factors while geometry, material properties, and water content are categorized as internal factors. This paper focuses on the internal and external factors that have caused failures in natural slopes and tailing dams and then compares them to those of open pits struck by earthquakes. The database yields the parameters playing role in the reported immunity of open pit mines to earthquakes.

2. Database

The database comprises of published data on the internal and

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Fig. 1. Location of the failed natural slopes triggered by earthquakes (Landslides are labelled as numbers in the Appendix).

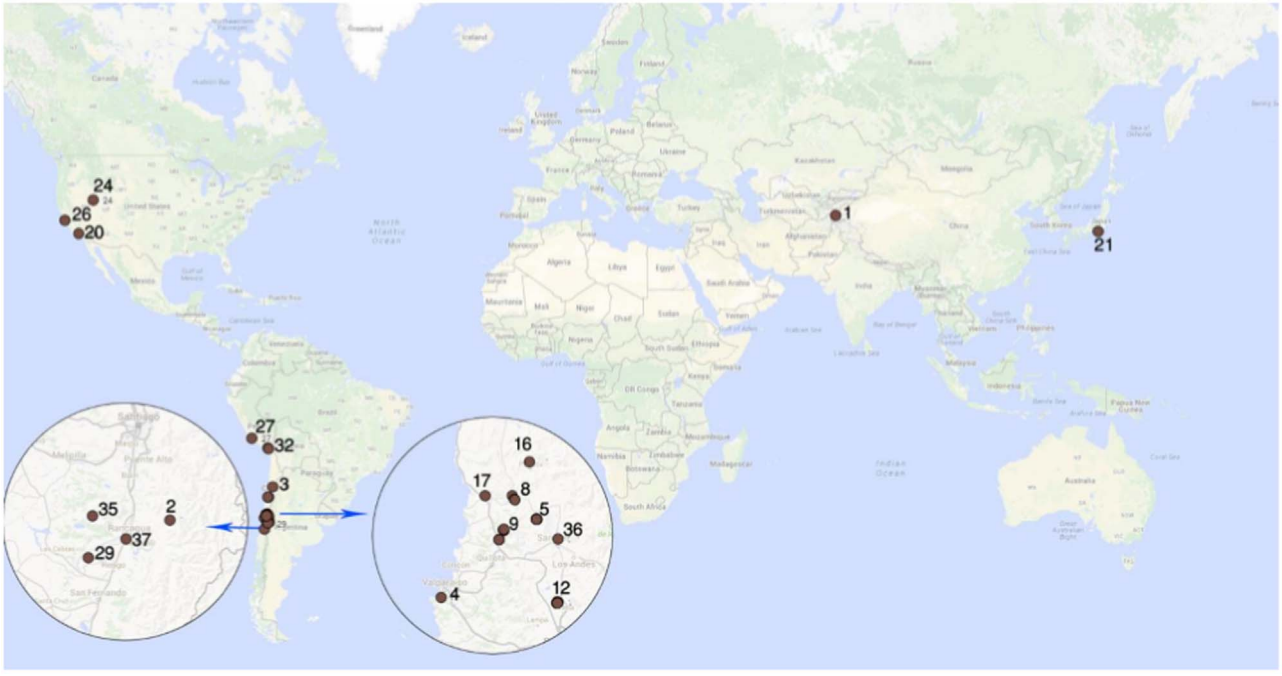

Fig. 2. Location of the failed tailing dams triggered by earthquakes (Landslides are labelled as numbers in The Appendix).

external factors involving earthquake-induced failures in 95 natural slopes and 37 tailing dams. Available data on 177 large open pit mines (LOP) that have been subjected to earthquakes are also explored.[13–16] Figs. 1–3 outline the Google Earth map specifying the location of these case studies.[41–124] The entire database can be also found as a KML file attached to this paper (see Appendix).

3. External factors

The necessity of accounting for the external factors is to categorize the case studies in terms of earthquake parameters and thus to compare natural slopes, tailing dams and pit slopes that are under similar dynamic loading of earthquakes. That is, the behavior of an open pit mines under earthquake should be compared to that of natural slopes and tailing dams subjected to the same earthquake parameters. The parameters considered include intensity, epi-central distance, focal depth, and magnitude.

3.1. Intensity

Intensity integrates the overall impacts of earthquake parameters including magnitude, epi-central distance, and focal depth. Various