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Investigation of impact dynamics of roof bolting with passive friction control

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ABSTRACT

In this paper, the impact dynamics of rock bolt with passive friction control is modeled. Numerical investigations are performed for the bolts with frictional energy absorber under various dynamic loads. The results are compared with those from fully grouted rigid bolts. The studies indicate that without the frictional energy absorber, the bolts are highly susceptible to failure under dynamic impact loads, while the bolts with the fictional energy absorber significantly reduce this risk. The studies also reveal that the bolt sliding may occur at the combined effect of vibration frequency and velocity magnitude. Sliding will only initiate above certain threshold value defined by vibration frequency and velocity magnitude. Furthermore, the simulation results show that under certain impact forces when rock mass subject to only elastic deformation, bolt sliding may occur causing the detachment of bolt head and rock face, which may incapacitate the rock bolt in supporting the rock excavation. The investigation signifies that further development and appropriate design of the rock bolt system with a frictional energy absorber are critical in maintaining stability under dynamic loading.

1. Background

Rock bolting is one of the most commonly used ground support systems in the mining industry. The conventional design practice of underground supports with rock bolts has been mainly based on static loading and a more-or-less rigid rock-bolt support system [1]. However, it has been frequently observed that rock excavations are subject to dynamic loading due to various seismic events induced by blasting, rock strata caving, stress redistribution, earthquakes, rock bursts and others. The catastrophic failures of rock bolting under impact loading have been widely recognized and are of deep concern in underground opening supports. A number of disastrous mining accidents in Northern America had been attributed to the failures of rock bolt supports under dynamic loads due to seismic events or other dynamic loading activities. Engineering practice indicates that considering static loading alone is insufficient for a proper rock support design and dynamic loading should also be a major design consideration.

In order to accommodate the dynamic loading, yield or ductile support systems has been developed and employed for underground openings to withstand creep deformations under static loading as well as dynamic loading. Engineering studies and ground control practices have concluded that yielding/ductile ground supports perform better than rigid supports and provide improved stability for underground openings under these conditions [2–4]. These support systems may include yielding arches, yielding hydraulic props, yielding frictional props, yielding rock bolts and others. In particular, the bolt design with passive friction control or frictional energy absorber such as the Roofex rock bolt appeared to be a promising improvement of yielding rock bolt support system [5]. The basic configuration of the passive friction control bolt is shown in Fig. 1a. When the Roofex bolt is subjected to impact load, the steel tendon may displace a specific length to accommodate the expansion of rock mass without pulling out the grout. Basically, a passive friction control element or frictional energy absorber is designed to allow the steel tendon slide without losing its capacity under yielding load. With their energy absorbing and momentum damping capabilities, yielding or ductile supports can provide effective control of dynamic impact and maintain adequate stability in underground openings. For comparison, a fully grouted bolt without energy absorber is shown in Fig. 1b. The composite element method (CEM) was developed for the discontinuous rock masses reinforced by fully grouted bolts [6]. However, comprehensive engineering analysis has not been fully conducted on the dynamic process of rock bolting under impact loading. The degradation of the load carrying capability and the possible damage induced in the rock-bolt system are not yet fully understood. An in-depth understanding of the yielding rock bolt

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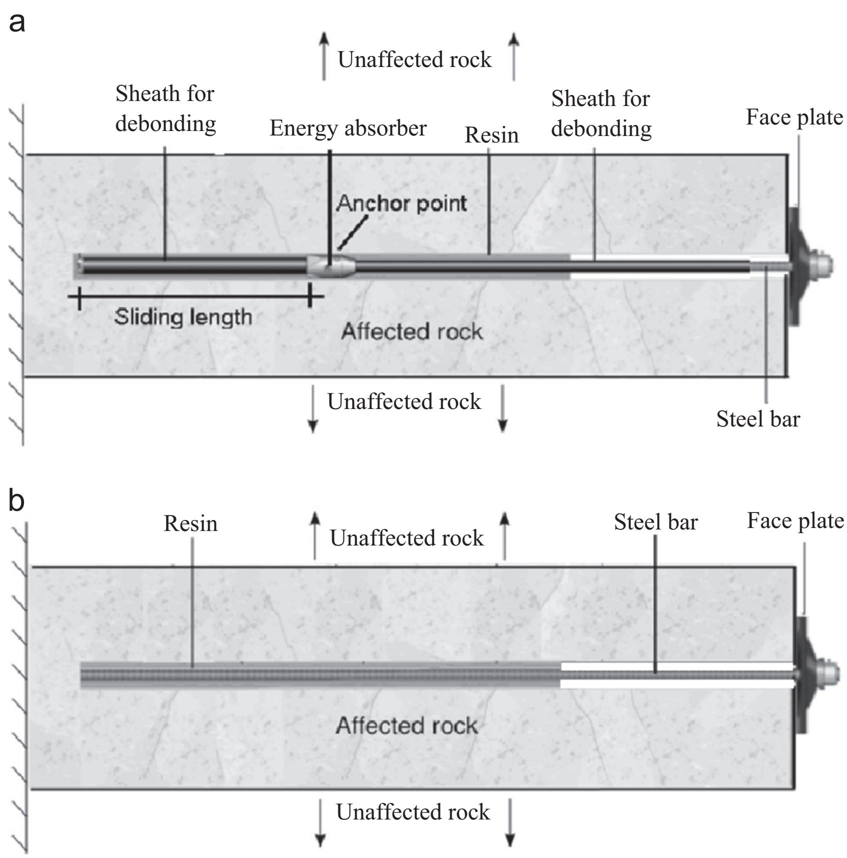

Fig. 1. (a) Configuration of Roofex rock bolt and (b) configuration of a fully grouted rock bolt (from [5]).

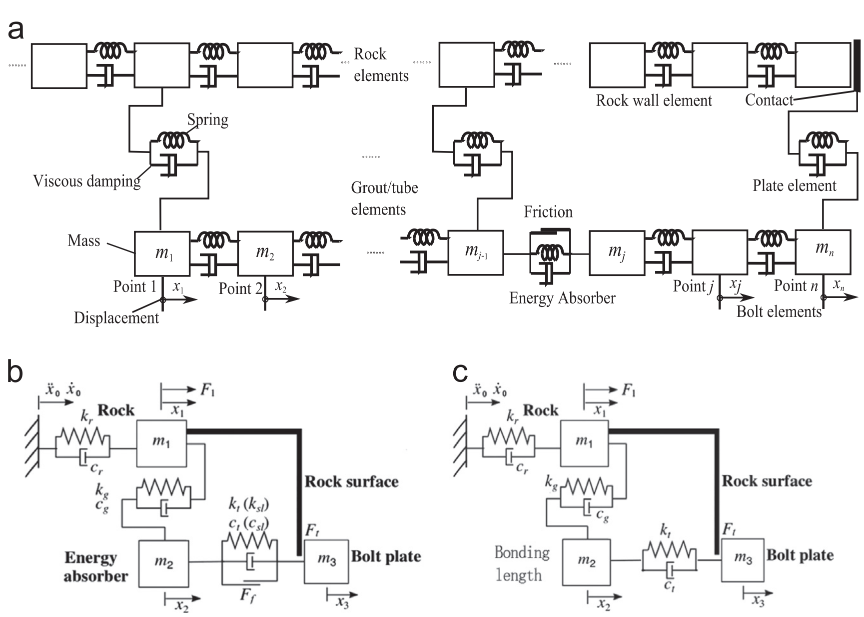

Fig. 2. (a) Multiple-degree-of-freedom nonlinear dynamics model; (b) three-degree-of-freedom nonlinear dynamics model; and (c) a model representing fully grouted rock bolt without energy absorber.

support system behavior, to the best of the authors' knowledge, has not been achieved.

The exact mechanism of resistance of the bolted rock formation under dynamic loading is difficult to analyze, which is partly due to the following reasons: the presence of a discontinuity with varying degree of interface roughness [7], the presence of several different materials (bolt, rock, resin grout, and friction element) with different mechanical behaviors, and a complex three-dimensional system that is difficult to simulate (i.e., bolt geometric, bolt orientation, and load conditions). There is no unanimously approved method for the design of the rock bolt reinforcement system, and most of the techniques are left to the practical experience of the engineers. The limited research on the dynamic process of rock bolting under impact loading has mostly