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Original Research Article

The approach to mining safety improvement: Accident analysis of an underground machine operator

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ABSTRACT

This paper presents the numerical approach to the safety and ergonomics issues regarding the biomechanics of the mining machine operator. Based on actual accidents, the authors analyzed the current requirements for protective structures in regard to operator safety aspects. The study found that the current type-approval tests do not examine phenomena related to typical accidents in underground mines, such as rock bursts resulting in thill uplift, lateral rock tosses, or cover caving. In many cases it may result in severe or fatal injuries of the mining machine operators. Thus, the authors incorporate a precise human model into operator safety tests and conducted numerical simulations by the use of the coupled Finite Element and MulitBody codes. To mitigate the injuries, the state-of-the-art seat absorber was implemented underneath a typical operator's seat. The device was designed to dissipate the kinetic energy during the process of rapid floor uplift and immediate velocity change from the cab to gallery roof impact. In order to compare the energy-dissipating capabilities of the absorber two approaches were selected for the same boundary conditions: a standard seat and seat with absorber mounted in the cab during the impact. The cab initial velocity was the main variable during the simulations. Finally, the injury criteria for the standard seat and the new approach with the energy-absorbing device were collated and contrasted.

1. Introduction

Intensive sub-surface works of greater depths increase the possibility of rock bursts, consequently inducing phenomena such as floor uplift, cover caving or rock ejection. Over the last few decades the risk of rock burst has risen significantly and is still growing, causing serious, even fatal injuries of the machine operators [1–3]. Nevertheless, the norms concerning operator safety remain invariable, and take into account operator protection solely in regard to falling objects and machine rollovers [4]. The other rock burst phenomena are not mentioned in the regulations, although accidents triggered by these effects occur constantly. Therefore, any out of the ordinary situations should be accurately examined and conclusions should be drawn. Precise analysis of the conditions

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Fig. 1 – Self-propelled underground loader with the operator's cab.

Fig. 2 – The operator's cab from outside (left) and inside (right) after the accident in KGHM Rudna.

prevailing in underground mines is necessary. Such analysis of the phenomena occurring inside the rock mass, causing different types of catastrophic events, will contribute to operator safety enhancement. The definition of proper boundary conditions and adequate dynamic tests of various accident situations should be implemented.

The current norms and standards which encompass heavy equipment safety are included in the Machinery Directive 2006/42/EC. The document states that every self-propelled mining machine destined to work in an underground mine needs to fulfil requirements of the Roll-Over Protective Structures (ROPS) and Falling-Objects Protective Structures (FOPS) procedures [5]. Protective structures of the machines working underground are subjected to the same examinations of operator safety as civil engineering machinery [6,7]. However, conditions and accident situations prevailing in the underground mines are significantly different than those in the field of civil engineering or even opencast mining. There are no special requirements for the underground mining machines. However, there are some phenomena that occur only in this specific environment, i.e. inside the rock mass, caused by rock bursts, such as thill uplift (lifting the floor layers due to the pressure inside the rock mass), cover caving etc. which may result in severe or even fatal operator injuries. The accident which occurred in the copper mine KGHM Rudna in 2010 clearly supports this statement.

The rock burst with released seismic energy rate equaled to 4.1×10^7 J, caused the floor heave and subsequent rock falls and ejections. This eventuated in two miner deaths and three other seriously injured. One of the fatalities, which circumstances are further described in this paper, was the self-propelled underground loader operator (Fig. 1).

The machine was thrown upwards due to the thill uplift and, after breaking the connection between the operator cab and machine, the protective structure struck against the roof. The loads acting on the operator caused rapid vertical motion of the operator's body which resulted in his striking the bottom side of the cab roof (Fig. 2). Due to the confidentiality of the post-mortem examination of the operator, the authors, till now, have received the following statement about the cause and manner of death. It is reported that the operator suffered lethal cervical spine injury [8] due to ruptured vertebral body, which harmed and transected the spinal cord. What is significant is that, even in the face of the death of the operator, the cab was still considered safe after the accident as measured by the residual deflection sag, according to the present regulations [9].

Furthermore, instead of using a biofidelic human dummy model, the obligatory examinations utilize the Deflection-Limiting Volume (DLV), which roughly depicts an approximate living space of a large, seated male operator wearing normal clothing and a protective helmet (Fig. 3). The verification tests

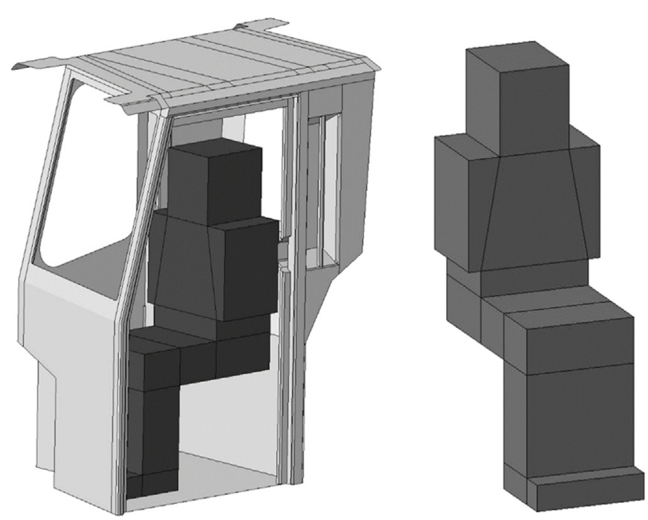

Fig. 3 – The deflection-limiting volume ($H \times W \times D$ = 1510 mm × 515 mm × 870 mm) – current ergonomics and safety standard.