International Journal of Mining Science and Technology xxx (2018) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Mining Science and Technology

journal homepage: www.elsevier.com/locate/ijmst

Impulse force reductions and their effects on WBV exposures in high impact shovel loading operations

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ARTICLE INFO

Article history:
Received 11 March 2016
Received in revised form 15 May 2016
Accepted 20 August 2016
Available online xxxx

Keywords:
Impact force
HISLO
Mathematical modeling
Dumping distance
Shovel ore sub-passes

ABSTRACT

When shovels load the dump trucks with over 100-ton passes under gravity dumping conditions, they will create a large impact force on the dump truck body which generates high frequency shock waves which expose the operators to whole body vibrations (WBV). The main cause of such truck vibrations is the large impact force due to the gravity dumping of large tonnage passes. Therefore a rigorous mathematical model has been developed for the impact force containing all the necessary factors upon which it depends. Latter, a thorough analysis shows that percentage reduction of 7.19%, 9.40%, 13.27%, 14.8%, 17.30% and 18.13% can be achieved by reducing the dumping distance to 6.33 m, 6.0 m, 5.5 m, 5.33 m, 5.0 m and 4.9 m, respectively, as compared to when the dumping distance was 7.33 m. Even more reduction in the magnitude of impact force can be observed if the shovel pass gets divided into more than two sub-passes. Therefore, these models can be used to figure out the number of sub-passes into which a single ore pass can be divided and/or the extent to which the dumping distance can be reduced which would reduce the impact force significantly enough to obtain safer yet economic operations.

1. Introduction

High impact shovel loading operations (HISLO) have been resulted with the use of large mining machinery in surface mining. In some cases, a shovel may load dumpers with 100-ton passes, as shown in Fig. 1. Such use of heavy mining machinery, including large capacity shovels and dumpers for low cost and bulk production in surface mining operations all over the world, has exposed the human body to exceptional conditions that effect the operator's health and may further impact the overall system performance [1–5]. Such high impact shovel loading operations (HISLO) generate shock waves that cause severe truck/dumper vibrations which in turn expose operators to whole body vibrations (WBV).

Even though a lot is known about the type of vibration generated in mining trucks as a result of the research carried out by Aouad & Frimpong [2], there is a strong lack of expertise and understanding of how to control the vibrations generated within the mining dump trucks in the surface mining industry. Due to the fact that the dump truck is stationary and the excitation force introduced by the shovel dumping the material into the truck body is dynamic, this phenomenon is very much different from that of military applications and finding. The type of vibrations generated by high impact shovel loading operations (HISLO) in the mining industry is, of course, forced vibrations induced by the force generated because of material impact. This impact force mainly depends upon the mass of the material being dumped (which would further be depending upon the factors including density, moisture content, the angle of repose, cohesion and shovel dipper size), dumping characteristics (including height/distance of dumping, the time within which the material in the dipper is dumped into the body and dumping & loading mechanism of a shovel) and a few environmental conditions (including terrain conditions and space limitations). The literature survey that has been carried out by reviewing the relevant literature has allowed us to evaluate to contributions that have been done to the body of knowledge of impact force modeling. A number of studies have been focused on determination of impact force of a single body or particle flow through impact test or software (e.g. like PFC3D) [6–8], but none of them focused on determining the impact force generated by flowing material under gravity. The only mathematical model, for the soil or broken rock material flowing under gravity currently exists, was provided by Aouad & Frimpong [2] given by Eq. (A), but it lacked the essential parameters, over which the impact force in such a scenario should depend, including height/distance of dumping (which is considered to be the distance between the truck body & the tip of the shovel dipper door as it releases the material for dumping into the truck), time for which the material remains in

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https://doi.org/10.1016/j.ijmst.2018.03.007
2095-2686/

Please cite this article in press as: Ali D, Frimpong S. Impulse force reductions and their effects on WBV exposures in high impact shovel loading operations. Int J Min Sci Technol (2018), https://doi.org/10.1016/j.ijmst.2018.03.007

Nomenclature

L	length of truck body
ρ	density for the truck body material (kg/m^3)
g	acceleration due to gravity (m/s^2)
H	heaviside step function
H_t	dumping distance (distance *b/w* truck body & tip of the shovel dipper door as it releases the material for dumping into the truck) (m)
m	mass of the material (kg)
ϵ	time for which the impulse acts (s)
ω_n	natural frequency of truck body
ω_d	damped natural frequency of truck body
ζ_n	damping ratio for the truck body
C	damping coefficient of the elastic foundation (N s/m)
I	area moment of inertia for the beam/truck body (m^4)
T	kinetic energy of the truck body
V	potential energy of the truck body due to bending
V_e	potential energy of the truck body due to elastic foundation
W_F	virtual work done by distributed force
W_D	potential energy due to elastic foundation
K	stiffness of the elastic foundation (N/m)
$M+1$	no. of sub-passes in which a particular shovel ore-pass is divided
a	time at which shovel starts dumping
σ	stress in the beam (truck body)
ε	strain induced in the beam (truck body)
$\eta_n(t)$	temporal solution for the beam
$U_n(x)$	spatial solution for the beam
$U(x,t)$	complete response of the beam to the forcing (truck body)
$u(x,t)$	transverse displacement of the beam
δu	delta (may also be regarded as variation in $u(x,t)$)
t_0	time at which shovel dumps the material
∂	partial deferential
$\delta(t-t_0)$	dirac delta which turns on at t_0
v	velocity with which the material hits the truck body
L_m	linear momentum which the material has attained just before reaching the truck body
Y	Young's modulus for the truck body (N/m^2)
A	cross-sectional area of the beam
b_m	width of the truck body (m)
h	thickness of the truck body (m)

Fig. 1. High impact shovel loading operation (HISLO).

contact initially (impact duration – the duration for which the impulse acts) and the provision in the model to split a single shovel ore-pass into a number of sub-passes to reduce the overall impact force. Other mathematical models or simulation work that exist in this regard, focus on impact force generated by the material flowing over a rigid body [9–11], rather than free falling material from a shovel bucket into a dump truck. Therefore there is a strong reason for studying that impact force in detail which causes the shockwave production within the dump truck and developing a more rigorous mathematical model for it so that it can be used to analyze the shovel dumping process and optimum parameters can be selected in order to reduce the resulting impact force and in turn minimizing the shockwaves/vibrations production within the dump truck.

1.1. Objective and scope of work

The primary objective of this research is to provide a better understanding of the dynamic impact force, generated as a result of gravity dumping of soil/rock material by shovel on to the dump truck body, by developing a more rigorous mathematical model for the impact force, which can further be used to obtain the optimum dumping height and sub-ore passes into which a single ore-pass can be divided which will effectively reduce the impact force. In this paper, the mathematical model provided, has been used to effectively model and analyze the impact force generated, only for the case where a CAT 793D dumper gets loaded by P&H 4100 XPC cable shovel, and is further shown that with changing the dumping height and dividing the single shove ore-pass into more than one sub-pass, up to what extent the corresponding impact force can be effectively reduced. However, the model can be used to obtain the optimum dumping height and the sub-ore passes into which a single ore-pass can be divided keeping in view the economic aspect for any large truck (CAT 793 and 797 series, Komatsu 830E and 930E, Liebherr Ti 274 and T 282, Hitachi Euclid Eh 5000 and the Terex Mt 6300AC) getting loaded by their corresponding shovel (P&H 4100 XPC, CAT 6090 FS, P&H 2800XPB, 4100XPB, 4100TS and 4100BOSS or BI 495, 595). After a better understanding of the dynamic impact force, practical solutions can be developed for reducing the impact force and creating potential technologies for eliminating or minimizing the HISLO vibration problem and in turn improving workplace safety, operator's performance and total system efficiency.

1.2. Expected research contributions

This research will create a frontier in the corresponding area by providing a more rigorous mathematical model for the dynamic impact force. Particularly, the expected contributions from this research include:

- A rigorous and accurate understanding of the dynamic impulse force shovel dumping process;
- A basis for developing and the modification required in the dumping process of the mining shovels;
- An appropriate insight into one of the most fundamental methods for minimizing and possibly eliminating the effects of shockwave vibration during HISLO;
- Mine planning engineers' ability to modify the dumping process by optimizing the dumping height to minimize the dynamic impulse force and improve the health, safety and the efficiency of the operator within the ISO limits;

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