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Evaluation of vertical driver seat vibrations of a mining truck under random road excitation

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ABSTRACT: *Ride comfort plays a critical role in evaluating the quality and performance of mining trucks. The aim of this study is to investigate the effect of road surface conditions on driver's seat ride comfort of mining trucks using a quarter-vehicle dynamic model. Three typical road surface classes such as ISO class C, ISO clsass D, and ISO class E based on an ISO 8608 road classification are selected to evaluate their impacts on ride comfort based on ISO 2631-1. The achieved results indicate that road surface quality significantly affects driver's seat ride comfort, especially the quality of the road surface is getting worse. The study results are the theoretical basis for optimizing the design of seat suspension systems for off-road mining vehicles*

KEYWORDS: *Mining truck, quarter-vehicle model, driver seat, suspension systems, ride comfort.*

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I. INTRODUCTION

Ride comfort of drivers in heavy off-road vehicles such as mining dump trucks is strongly influenced by road surface roughness [1], [2]. When a haul truck travels on very rough terrain, the vibrations transmitted from the uneven ground to the vehicle can greatly reduce driver comfort, leading to fatigue or even health risks over long exposure. Prior studies have often employed simplified vehicle models (quarter-car or half-car models) to investigate the vertical dynamics and ride comfort of heavy vehicles under random road excitation [3]. Quarter-vehicle models focus on the vertical motion of a single wheel station (sprung and unsprung mass) and have been widely used to approximate vehicle ride responses with acceptable accuracy while retaining model simplicity [3]. For instance, Singh (2018) utilized an active quarter-car model with road input generated according to the ISO 8608 standard and evaluated the resulting ride comfort per ISO 2631-1 guidelines and such studies highlight that improvements in suspension control can significantly reduce the acceleration transmitted to the driver's body, thereby enhancing ride comfort on rough roads Singh (2018) [4]. The objective of this research is to develop a quarter-vehicle dynamic model of a mining dump truck to analyze the influence of road surface conditions on the operator's ride comfort. The proposed quarter-truck model will represent the truck's suspension (e.g., a hydro-pneumatic suspension typical for mining trucks) along with an equivalent sprung mass (driver cabin) and unsprung mass (wheel assembly), subjected to road profile inputs of varying roughness levels (classified according to ISO 8608 [6]. Using this model, we will simulate the truck's vertical response under different road conditions ranging from good to severely rough and evaluate driver comfort based on the ISO 2631-1 standard for whole-body vibration [5]. Frequency-weighted root-mean-square (RMS) accelerations of the sprung mass will be computed as per ISO 2631-1 to quantify the ride comfort level [5]. Through the quarter-car simulations, the study will quantify how increasingly rough road inputs lead to higher vibration exposure for the driver, elucidating the relationship between road roughness and ride comfort in mining trucks. The expected outcomes include a simplified yet effective tool for predicting ride comfort of a mining haul truck under various road conditions, which can inform suspension design and tuning to improve operator comfort [7]. The aim of this study is to investigate the effect of road surface conditions on driver's seat ride comfort of mining trucks using a quarter-vehicle dynamic model. Three typical road surface classes such as ISO class C, ISO clsass D, and ISO class E according to ISO 8608 road classification are selected to evaluate their impacts on ride comfort based on ISO 2631-1.

II. QUARTER-VEHICLE DYNAMIC MODEL

A quarter-vehicle dynamic model for a mining dump truck is developed with three degrees of freedom as shown in Fig.1. Where, m_s is driver's seat mass, m_c is the vehicle body mass, m_t is the vehicle axles; k_s and c_s are the stiffness and damping coefficients of the driver seat suspension system; k_c and c_c are the stiffness and damping coefficients of vehicle suspension system; k_t and c_t are the stiffness and damping of the tires; z_s, z_c, and z_t denote the vertical displacements of driver's seat, vehicle body and axles, respectively; and q(t) is the road surface excitation input.

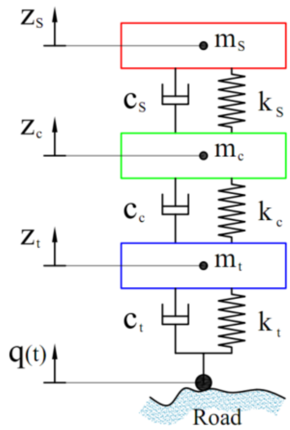

Fig. 1.1. A quarter- verhicle dynamic model for a ming truck

The equations of motion are as follows:

With diver's seat, m_s

$$m_s\ddot{z}_s = -[(k_s(z_s - z_c) + c_s(\dot{z}_s - \dot{z}_c)] \tag{1}$$

With vehicle body, m_c

$$m_c\ddot{z}_c = [(k_s(z_s - z_c) + c_s(\dot{z}_s - \dot{z}_c)] - [k_c(z_c - z_t) + c_c(\dot{z}_c - \dot{z}_t)] \tag{2}$$

With vehile axles, m_t

$$m_t\ddot{z}_t = [(k_c(z_c - z_t) + c_c(\dot{z}_c - \dot{z}_t)] - [k_t(z_t - q) + c_t(\dot{z}_t - \dot{q})] \tag{3}$$

The excitations of the road surface roughness: The off-road vehicle often operates under the ground deformation conditions. However, the random road surface roughness is chosen as the vibration-input excitation functions for the vehicle dynamic analysis in this paper. Road surface roughness is assumed to be a Gaussian stochastic process, which is generated through an inverse Fourier transformation. The random excitation function of road surface roughness according to ISO 8068 (1995) [7] is shown by equation (4).

$$q(t) = \sum_{i=1}^{N} \sqrt{2G_q(n_i)\Delta n} \cos(2\pi n_k t + \varphi_i) \tag{4}$$

where, N is the number of intervals, Δn = 2π / L with L as the length of the road segment, φ_i is a random phase uniformly distributed from 0-2π.

III. VEHICLE RIDE COMFORT EVALUATION CRITERIA

The time-domain method can be applied to evaluate the vehicle ride comfort according to ISO 2631-1 (1997) [8], in this study, the vibration evaluation based on the basic evaluation methods including measurements of the weighted root-mean-square (r.m.s.) acceleration defined as:

$$a_{wz} = \left[\frac{1}{T}\int_0^T a_z^{\,2}(t)dt\right]^{1/2} \tag{5}$$

where, $a_z(t)$ is the weighted acceleration (translational and rotational) as a function of time, m/s^2; *T* is the duration of the measurement, s.

IV. RESULTS AND DISCUSSION

The equations of motion for the vehicle dynamics system illustrated in Fig. 1, which formulated and implemented using MATLAB/Simulink with vehicle parameters adopted from reference [12]. In this study, three poor road surface conditions such as ISO Class C, ISO Class D, and ISO Class E according to ISO 8608 are selected to analyze their influence on vehicle ride comfort. The driver's seat acceleration (**a_s**) when vehicle moves ISO Class C, ISO class D, ISO class E at a vehicle speed of 5 km/h and full load are presented in Fig. 2. From the results in Fig.2, we see that the peak amplitude value of a_s increases when the road surface quality deteriorates. The driver's seat acceleration (**a_s**) when vehicle moves three poor road surface conditions at a vehicle speed of 10 km/h and full load are presented in Fig. 3. Similarly, the results in Fig.3 show that the peak amplitude value of a_s increases when the road surface quality deteriorates.

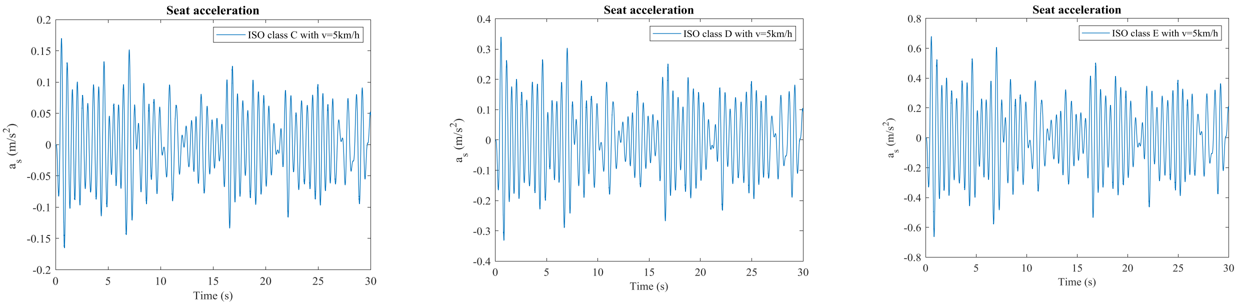

Fig.2. Driver's seat acceleration under three poor road surface conditions at v=5km/h and full load

Driver's seat acceleration (a_s) when vehicle on ISO class C, D, E surface condition at v=10km/h and full load are shown in Fig.3.

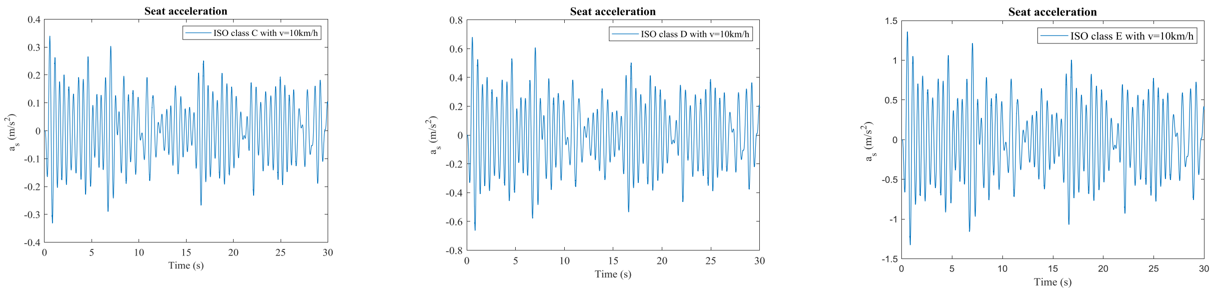

Fig.3. Driver's seat acceleration under three poor road surface conditions with v=10km/h and full load

The driver's seat acceleration (**a_s**) when vehicle moves three poor road surface conditions at a vehicle speed of 10 km/h and full load are presented in Fig. 4. Similarly, the results in Fig.4 show that the peak amplitude value of a_s increases when the road surface quality deteriorates.

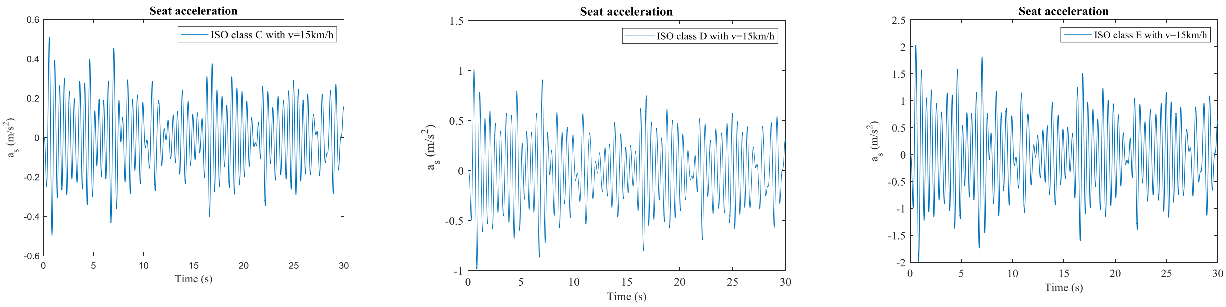

Fig.4. Driver's seat acceleration under three poor road surface conditions with v=15km/h and full load

From the results in Fig.2, Fig.3 and Fig.4, the values of the root mean square (r.m.s) acceleration responses of driver's seat (a_{ws}) are determined by Eq. (5). a_{ws} values are shown in Table 2. The simulation results highlight the significant impact of both road surface conditionsand vehicle operating speeds on the vertical acceleration at the driver's seat, which directly influences ride comfort. The following observations are drawn from the simulation data:

Table 2. a_{ws} values under

a_{ws} /(m/s^2)	5km/h	10km/h	15km/h
ISO class C	0.0555	0.1110	0.1668
ISO class D	0.1110	0.2219	0.3329
ISO class E	0.2219	0.4436	0.6680

According to ISO 2631-1. The human tolerance levels are expressed by the RMS acceleration as follows: a_{ws} < 0.315 m/s² (Low Level): No significant health concerns.a_{ws} between 0.315 and 0.63 m/s² (Moderate Level): May cause discomfort with prolonged exposure. Acceleration > 0.63 m/s² (High Level): Could lead to pain and significant health impacts. ISO Class C (average Road): RMS acceleration ranges from 0.0555 m/s² to 0.1668 m/s², within the low level, ensuring safety and comfort even at higher speeds.

ISO Class D (poor Road): RMS acceleration ranges from 0.1110 m/s² to 0.3329 m/s², in the moderate level, which may cause discomfort at higher speeds but does not pose health risks over short-term exposure. ISO Class E (Very poor Road): RMS acceleration ranges from 0.2219 m/s² to 0.6680 m/s², exceeding the threshold for discomfort and potentially impacting health with prolonged exposure. Road quality improvements are necessary. It can be observed that RMS acceleration increases as road quality deteriorates, especially in ISO Class E. Improvements to the suspension system and road surface are necessary to mitigate the negative impact.

V. CONCLUSIONS

The simulation of the mining truck's suspension system, utilizing a quarter-vehicle model across three poor road conditions such ISO class C, ISO class D, and ISO E in compliance with ISO 2631-1, has demonstrated significant variations in ride comfort relative to road surface quality. The previously calculated RMS acceleration values indicate a marked decrease in ride comfort as road conditions worsen. Notably, on ISO Class E roads, the RMS acceleration surpasses acceptable thresholds, leading to discomfort and potential health risks for the operator. This underscores the critical need for optimizing suspension systems and enhancing road quality to ensure both driver safety and ride comfort. Future research should focus on optimizing the suspension system, particularly by adjusting damping characteristics and spring stiffness to effectively reduce vibrations. Research into advanced suspension technologies or adaptive suspension systems will help mitigate vibration impacts, especially on rough road surfaces. Additionally, studying the effects of road surface materials and vehicle speed on ride comfort will provide valuable insights to improve performance and safety of mining trucks.

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