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Investigation of the effect of operating conditions of a 3-axle on safety of vehicle assemblies and road surface friendliness

The Minh Huong[1], Doan Thanh Binh[2], Dam Huu Vu[3]
[1]*Viet Nam – Korea College of Quang Ninh, Quang Ninh, Vietnam*
[2,3] *Faculty of Vehicle and Energy Engineering, Thai Nguyen University of Technology, Thai Nguyen, Vietnam*
Email: theminhhuong@gmail.com

ABSTRACT:

The purpose of this study is to investigate influence of different operating conditions of a 3-axle truck on safety of vehicle assemblies and road surface friendliness. A half-vehicle dynamic model of a 3-axle truck under random excitation road surface is set up to investigate their influences. The maximal vertical dynamic load factor is used to investigate and evaluate the dynamic interaction between 3-axle truck and road surface. The influence of different operating conditions of 3-axle truck on safety of and road surface friendliness is investigated. The results show that the operating conditions have a great influence on safety of vehicle assemblies and road surface friendliness.

KEYWORDS: 3-axle truck, dynamic model, operating condition, safety of vehicle assemblies, road surface friendliness.

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I. INTRODUCTION

The operating conditions of the heavy vehicles have a significant effect on vehicle ride comfort as well as road surface friendliness. To improve the operating conditions of the heavy vehicles, the vehicle's suspension systems have always been interested by researchers and designers, the effects of the operating conditions of on vehicle ride comfort and road surface friendliness with an air suspension system were proposed and evaluated by using a quarter vehicle dynamic model [1]. The influence of heavy truck operating condition on dynamic load coefficient was proposed and evaluated by using a three-dimensional nonlinear dynamic model of heavy with 15 DOF (degree of freedom) [2]. Similarly, the influence of the different vehicle operating conditions on the dynamic tire loads, dynamic load coefficient (DLC) and road-friendliness which include road surfaces, vehicle speeds, vehicle loads proposed and analyzed by using a three-dimensional vehicle-pavement coupled model with 14 degrees of freedom [3]. The different damper schemes, energy dissipation analysis based on discrete element model was used to find out the optimal parameters of the driver seat suspension system [4]. The fuzzy PID control method was used to optimize the smoothness of the vehicle by controlling the vertical acceleration of the truck, pitch angle acceleration and seat vertical acceleration using the 8 DOF model of hydro-pneumatic suspension and complete vehicle [5]. The weighted root-mean-square (r.m.s) acceleration responses of the vertical driver's seat, the pitch and roll angle of the cab, and the dynamic load coefficient (DLC) are chosen as objective functions, and the air suspension system is optimized and analyzed by the semi-active fuzzy control algorithm when vehicles operate under different operation conditions [6]. The performance of the hydro-pneumatic suspension system (HPSs) of a mining dump truck on ride comfort under operating conditions was proposed and evaluated by using a 3-D full-vehicle vibration model of a mining dump truck with 10 degrees of freedom [7]. The plinth between the cab floor and the seat was selected as a particle damper, and the discrete element model of the plinth damper [8]. In this study, a half-vehicle dynamic model of a 3-axle truck is established to investigate and evaluate the influence of different operating conditions of a 3-axle truck on safety of vehicle assemblies and road surface friendliness. The maximal vertical dynamic load factor is used to investigate and evaluate the dynamic interaction between 3-axle vehicle and road surface.

II. HALF-VEHICLE DYNAMIC MODEL OF A 3-AXLE TRUCK

A 3-axle truck is selected for investigating the influence of the various operating conditions on safety of vehicle assemblies and road surface friendliness. A half-vehicle dynamic model of a 3-axle truck is established, as shown in Fig.1. In Fig. 1, M, m_1, m_2 and m_3 are the masses of vehicle body, 1st axle, 2nd axle and 3rd axle respectively; J_y is the moment of inertia of the vehicle body; C_1, C_{23} and K_1, K_{23} are the stiffness and damping coefficients of vehicle suspension systems, respectively; C_{L1}, C_{L2}, C_{L3} and K_{L1}, K_{L2}, K_{L3} are the stiffness and damping coefficients of tires; z_{di}, z_b, z_c and z_s are the vertical displacements at centre of gravity of the front and rear drums, vehicle body, cab and driver's seat, respectively; ξ_1, ξ_2, ξ_3, and z are 1st axle, 2nd axle, 3rd axle and vertical vehicle body displacements, respectively and φ is the pitch angle displacement of vehicle body; q_i are the excitation of road surface roughness at 1st axle, 2nd axle, 3rd axle, respectively; l_j, L, L_{T23} are the distances; (i=1÷3, j=1÷2).

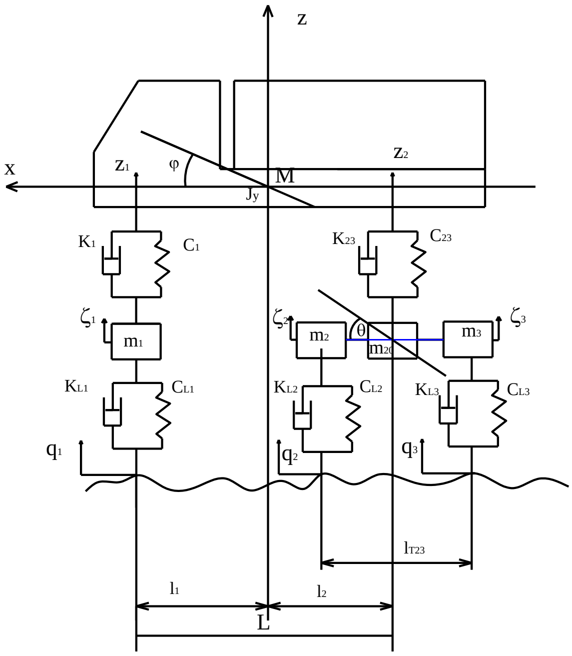


Fig. 1. Half-vehicle dynamic model of a 3-axle truck

Equations of motion: The equations of motion for half-vehicle dynamic model of a 3-axle truck using Newton's second law of motion are written. From Fig. 1, the motion equations of vehicle mass are written as follows:

$$\begin{cases} M.\ddot{Z}+(K_1+K_{23}).\dot{Z}+(C_1+C_{23}).Z+(K_1.l_1-K_{23}.l_2).\dot{\phi}+(C_1.l_1-C_{23}.l_2).\phi-K_1\dot{\xi}_1-C_1\xi_1-K_{23}.\dot{\xi}_{23}-C_{23}.\xi_{23}=0 \\ J_y.\ddot{\phi}+(K_1.l_1^2+K_{23}.l_2^2)\dot{\phi}+(.C_1.l_1^2+C_{23}.l_2^2).\phi+(K_1.l_1-K_{23}.l_2).\dot{Z}+(C_1.l_1+C_{23}.l_2)Z-K_1.l_1\dot{\xi}_1+K_{23}.l_2\dot{\xi}_{23}-C_1.l_1.\xi_1+C_{23}.l_2.\xi_{23}=0 \\ m_1.\ddot{\xi}_1+(K_{L1}+K_1)\dot{\xi}_1+(C_{L1}+C_1).\xi_1-K_1.\dot{Z}-C_1.Z-K_{L1}l_1.\dot{\phi}-C_1.l_1.\phi_1=K_{L1}.\dot{q}_1+C_{L1}q \\ m_{23}.\ddot{\xi}_{23}+(K_{23}+K_{L2}+K_{L3}).\dot{\xi}_{23}+(C_{23}+C_{L2}+C_{L3}).\xi_{23}+\frac{1}{2}.(K_{L2}.l_{T23}-K_{L3}.l_{T23}).\dot{\theta}_{23}+\frac{1}{2}(C_{L2}.l_{T23}-C_{L3}.l_{T23}).\theta_{23} \\ -K_{23}.\dot{Z}-C_{23}.Z+K_{23}.l_2.\dot{\phi}+C_{23}.l_2.\phi=K_{L2}.\dot{q}_2+.K_{L3}.\dot{q}_3+C_{L2}.q_2+C_{L3}.q_3 \end{cases} \quad (1)$$

Random road surface roughness: The road input is simulated for the random road surface roughness according to ISO 8608(2016) [9]: The random white noise is selected as excitation source waveform for vehicle suspension [12], the random road profile is produced by filtering the white noise using the following mathematical model of the random road surface roughness.

$$\dot{q}(t)+2\pi f_0 q(t)=2\pi n_0\sqrt{G_q(n_0)v(t)}w(t) \quad (2)$$

where, $G_q(n_0)$ is the road roughness coefficient which is defined for typical road classes from A($G_q(n_0)$ =4x10^{-6}m^3) to H ($G_q(n_0)$ =16384x10^{-6}m^3) according to ISO 8608(2016) [9], n_0 is a reference spatial frequency which is equal to 0.1 m; v(t) is the speed of vehicle; f_0 is a minimal boundary frequency with a value of 0.0628 Hz; w(t) is a white noise signal.

III. SIMULATION AND ANALYSIS RESULTS

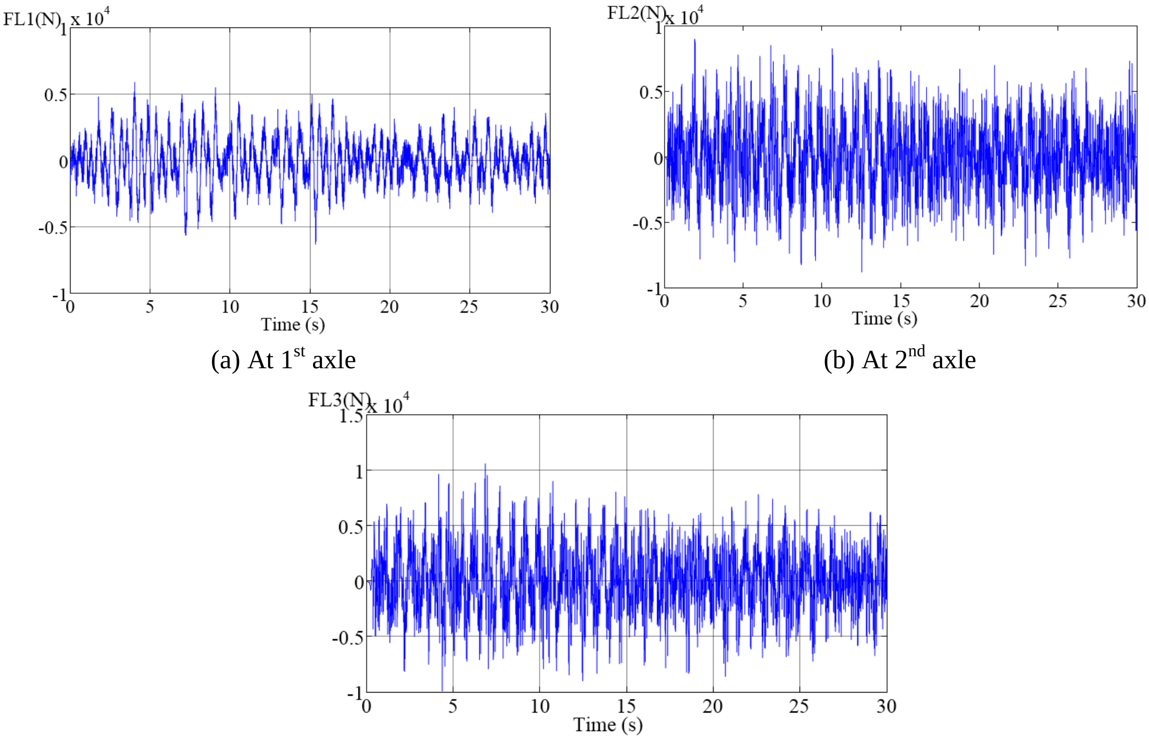
In order to investigate the influence of the various operating conditions on the safety of vehicle assemblies and road surface friendliness, the differential equations of motion of Fig.1 are simulated by the MATLAB/Simulink with the design parameters of a 3-axle truck in the reference [11]. The simulation results of the vertical dynamic forces of the wheels at 1st axle, 2nd axle, 3rd axle acting on road surface when the vehicle moves on the ISO class B road surface (good condition) at the vehicle speed of 50 km/h and full load, as shown in Fig.2. From the results of Fig. 2 we show that the peak amplitude values of the dynamic forces of the wheels at 3rd axle achieve the largest value which means the lowest level of road surface friendliness. The vehicle's operating conditions will continue to be reviewed and evaluated in in the following section.

Influence of road surface conditions on the safety of vehicle assemblies and road surface friendliness: The values of the maximal vertical dynamic load factor with different road surface conditions from ISO class C road surface ($G_q(n_0)$ =64x10^{-6}m^3- Average condition) to ISO class E road surface ($G_q(n_0)$ =1024x10^{-6}m^3- Very poor condition) are implemented when vehicle moves at the vehicle speed of 50km/h and full load, as shown in Fig.3. From the results of Fig. 3 we show that the $k_{dyn,max}$ value (it is determined by Eq.(2)) increases rapidly when the road surface quality deteriorates. The $k_{dyn,max}$ value is greater than 1.5 when vehicle moves on the ISO class D road surface that it adversely affects the durability of the vehicle's components and adversely affects road surface friendliness. To improve efficiency, Traffic Managers must limit the vehicle speed when it moves on these road surfaces [10].

Dynamic load criterion [10], [11]: The maximal vertical dynamic load factor is defined as

$$k_{dyn,\,max} = \frac{1{,}64 F_{Z,RMS}}{F_{z,st}} + 1 \qquad (2)$$

where, $F_{Z,\,RMS}$ is the value of root-mean-square (RMS) of the dynamic forces of the wheels; $F_{Z,\,st}$ is the value of the static load of the wheels



(a) At 1st axle

(b) At 2nd axle

At 3rd axle

Fig.2. Vertical dynamic forces of the wheels at 1st axle, 2nd axle, 3rd axle acting on road surface

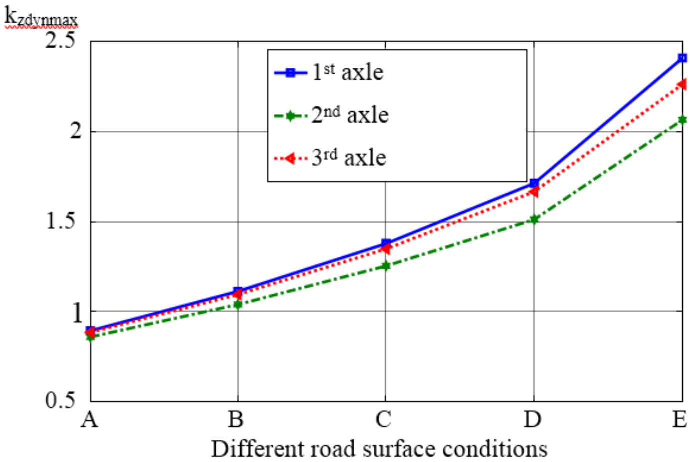


Fig.3. $k_{dyn,max}$ value at 1st axle, 2nd axle, 3rd axle under different road surface conditions

Vehicle speed conditions: The different speed conditions from vehicle speed of 20km/h to vehicle speed of 100 km/h are chosen to investigate their influence on the safety of vehicle assemblies and road surface friendliness when vehicle moves on ISO class B road surface and full load as shown in Fig.4. From the results of Fig. 4 we show that the $k_{dyn,max}$ value increases rapidly when vehicle speed increases that it adversely affects the durability of the vehicle components and the road surface friendliness.

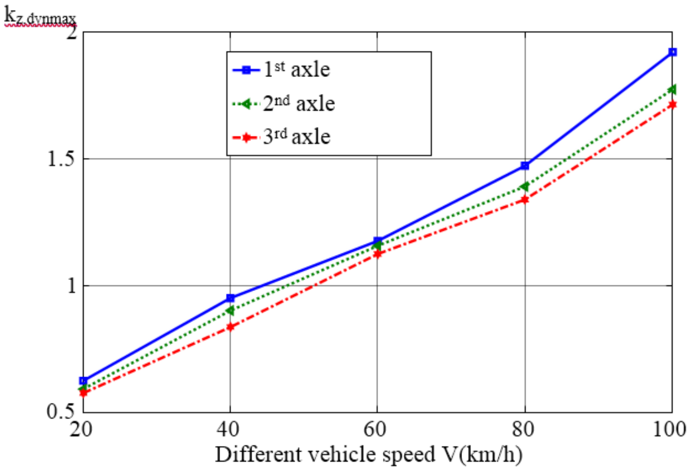


Fig.4. $k_{dyn,max}$ value at 1st axle, 2nd axle, 3rd axle under different vehicle speed conditions

Vehicle load conditions: In order to investigate the influence of the different vehicle load conditions on the safety of vehicle assemblies and road surface friendliness, the different vehicle load conditions such as empty load, half load, full load, and over 50% load are chosen to investigate their influence on the safety of vehicle assemblies and road surface friendliness when the vehicle moves on the ISO class B road surface (good condition) at the vehicle speed of 50 km/h, as shown in Fig.5. From the results of Fig. 5 we show that the $k_{dyn,max}$ value decrease as the load value of the vehicle increases that the road surface friendliness are improved. However, it affects the safety of movement as well as the durability of the vehicle's components [11]

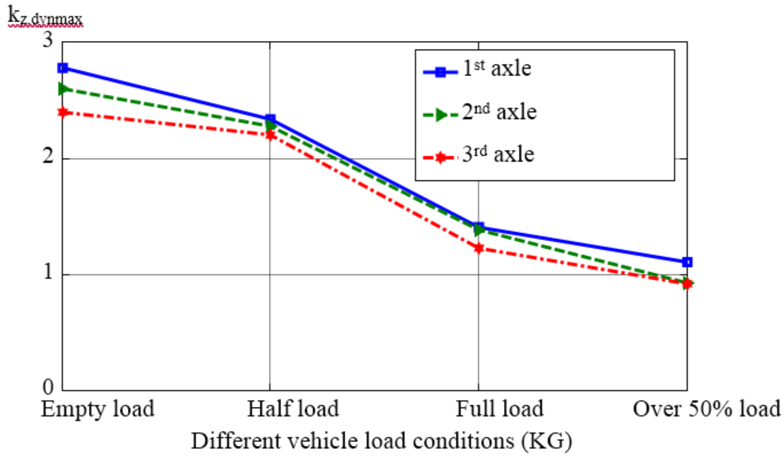


Fig.5. $k_{dyn,max}$ value at 1st axle, 2nd axle, 3rd axle under different vehicle load conditions

IV. CONCLUSION

In this paper, a half-vehicle dynamic model of a 3-axle truck is established to investigate the influence of the various operating conditions on the safety of vehicle assemblies and road surface friendliness according to the maximal vertical dynamic load factor. The major conclusions drawn from the investigation can be summarized as follows: (1) The $k_{dyn,max}$ value increases rapidly as the road surface quality deteriorates; (2) The $k_{dyn,max}$ value increases rapidly when vehicle speed increases that it adversely affects the durability of the vehicle components and the road surface friendliness and (3) The $k_{dyn,max}$ value decrease as the load value of the vehicle increases that the road surface friendliness are improved. In addition, the research results are useful references for designers and manufacturers in the field of designing suspension systems of heavy truck to improve the safety of vehicle assemblies and road surface friendliness.

REFERENCES

[1]. Le Van Quynh, Vi Thi Phuong Thao. Effect of Operating Conditions on Vehicle Ride Comfort and Road Surface Friendliness with Air Suspension System. International Research Journal of Engineering and Technology (IRJET), Volume 07, Number 06, pp. 7671-7675 (2020).

[2]. Bui Van Cuong, Le Van Quynh, Le Xuan Long. Influence of Heavy Truck Operating Condition on Dynamic Load Coefficient. ICERA 2018: Advances in Engineering Research and Application, pp 372-379, (2018).

[3]. Le Van Quynh. Influence of semi-trailer truck operating conditions on road surface friendliness. Vibroengineering PROCEDIA, Vol. 16, pp. 67-72, (2019).

[4]. Xiao, W., Lu, D., Song, L., Guo, H., & Yang, Z. Influence of particle damping on ride comfort of mining dump truck. Mechanical Systems and Signal Processing, 136, 106509, (2020).

[5]. Hongyu Jia et al. The ride comfort optimization of mining dump truck based on eight degree of freedom. J. Phys.: Conf. Ser. 1303 012062, (2019).

[6]. Nguyen Van Liem, Zhang Jianrun, Le Van Quynh, Jiao Renqiang, Liao Xin (2017). Performance analysis of air suspension system of heavy truck with semi-active fuzzy control. Journal of Southeast University (English Edition), Vol. 33(2), pp.159-165, (2017).

[7]. Le Xuan Long, Dang Viet Ha, Le Van Quynh, Bui Van Cuong and Vu Thanh Niem. Effect of operating conditions on a heavy truck ride comfort with hydro-pneumatic suspension system. E3S Web Conf., 304 (2021) 02011.

[8]. XIAO Wang-qiang, LU Da-jun, SONG Li-ming, YANG Zhe, LI Ze-guang. Vibration comfort of mining dump truck based on particle damping[J]. Journal of Traffic and Transportation Engineering, 2019, 19(6): 111-124.

[9]. ISO 8608:2016: Mechanical vibration, Road surface profiles, Reporting of measured data, 2016.

[10]. Le V. Q., Zhang J., Liu X., Wang Y. Nonlinear dynamic analysis of interaction between vehicle and road surfaces for 5-axle heavy truck. Journal of Southeast University, Vol. 27, Issue 4, 2011, p. 405-409.

[11]. The Minh Huong. Investigate the influence of some operating parameters on the vibration of 3-axle truck in Vietnam. Master thesis of University of Transport and Communications, 2011.

[12]. LX Long, LV Quynh, BV Cuong: Study on the influence of bus suspension parameters on ride comfort. Vibroengineering PROCEDIA, Vol. 21 (2018), pp.77-82.