Effect of the off-road terrains on the ride comfort of construction vehicles

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Abstract: In order to evaluate the impact of off-road terrains on the ride comfort of construction vehicles, a nonlinear dynamic model of the construction vehicles interacting with the terrain deformations is established based on Matlab/Simulink software. The weighted root mean square (RMS) acceleration responses and the power spectral density (PSD) acceleration responses of the driver's seat heave, the pitch and roll angle of the cab in the low-frequency region are chosen as objective functions under different operation conditions of the vehicle. The results show that the impact of off-road terrains on the driver's ride comfort and health is clear under various conditions of deformable terrains and range of vehicle velocities. In particular, the driver's ride comfort is greatly affected by a soil terrain while the comfortable shake of the driver is strongly affected by a sand terrain. In addition, when the vehicle travels on a poor soil terrain in the frequency range below 4 Hz, more resonance peaks of acceleration PSD responses occurred than that on a rigid road of ISO 2631-1 level C. Thus, the driver's health is significantly affected by the deformable terrain in a low-frequency range.

Key words: construction vehicles; vehicle dynamic model; off-road terrains; ride comfort

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The construction vehicles are a type of commercial heavy vehicles which not only travel on the highway but also often work on deformable terrains in the fields of road construction projects, railways and airports. The impact of the dynamic loads of wheels on the highway bridges and the influence of the roadway roughness on vehicle's ride comfort were studied[1-2]. A nonlinear dynamic model of construction vehicles based on the multibody dynamic theory was also established to evaluate the influence of various operating conditions on the vehicle ride comfort[3-5]. The results indicated that vehicle's ride comfort was mainly affected by the surface roughness. However, the influence of deformable terrains on the ride comfort of the construction vehicles has not yet been a concern and studied.

Basic research on the interaction models of the soft wheel, elastic wheel, and rigid wheel with deformable terrains was carried out to analyze the vibration responses as well as the behaviours of the reaction forces of deformable terrains on wheels[6-9]. The interaction models indicated that the vibration responses and behaviours of the reaction forces were greatly influenced by off-road terrain grounds.

The impact of the off-road terrain on the driver's ride comfort of the vibratory rollers was studied via the simulation and experiment. Reducing the weighted root mean square (RMS) acceleration responses and the power spectral density (PSD) acceleration responses of the driver's seat heave, cab's pitch and roll vibrations was the aim of the research[10]. The results showed that the ride comfort and the comfortable shake of the driver were strongly affected by the soft soil ground under the vehicle traveling. In addition, the interaction model of wheels and the off-road terrain was also used to evaluate the ride comfort of the off-road articulated dump trucks[11]. The research results also indicated that the ride comfort was significantly impacted by off-road terrain grounds. Consequently, research on the impact of the off-road terrain on the driver's ride comfort and the cab shaking to improve the ride comfort of the construction vehicles is necessary.

In this study, a nonlinear dynamic model of construction vehicles with 13 degrees of freedom (DOF) is established based on the hypothesis of a soft soil ground[6]. A nonlinear dynamic model of the elastic tire-deformable terrain contact is then investigated to determine the vertical dynamic force between the elastic tires and deformable terrains. The vibration excitations are taken into account by the interaction between the elastic tires and deformable terrains. The impact of the deformable terrains on the driver's ride comfort and health is evaluated via the weighted RMS acceleration responses and the resonance peaks of the acceleration PSD responses of the driver's seat heave, pitch and roll angle of the cab under different operation conditions. The aim of this study is to analyze the impact of the off-road terrain on the vehicle's ride comfort.

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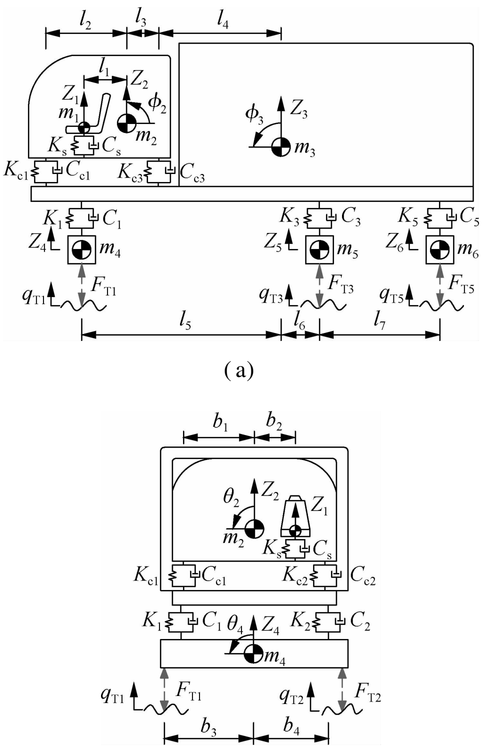
1 Modeling of Construction Vehicles

1.1 Vehicle dynamic model

A three-axle construction vehicle with three dependent suspensions for the steering axle and two rear vehicle axles are selected for the vehicle dynamic analysis. A 3-D model of the vehicle with 13-DOF is established to analyze the effect of the deformable terrain on the vehicle's ride comfort, as shown in Fig. 1, where Z_i and m_i are the vertical displacements and masses at the centre of gravity of the driver's seat, the cab, the vehicle body and the axles; ϕ_2, ϕ_3 and θ_j are the angular displacements at the centre of gravity of the cab, the vehicle body and the axles; C_s, C_{cv}, C_i and K_s, K_{cv}, K_i are the damping coefficients and stiffness coefficients of the suspension systems of the seat, cab and vehicle; F_{Ti} is the dynamic reaction force of the axle of tire-deformable terrain interaction; q_{Ti} is the excitation of the off-road terrain on the tire; l_u and b_v are the distances of the vehicle ($v=1$ to 4; $i=1$ to 6; $j=2$ to 6; $u=1$ to 7).



(a)

(b)

Fig. 1 3D dynamic model of the construction vehicles. (a) Side view; (b) Front view

Based on the vehicle dynamic model in Fig. 1, Newton's second law is chosen in this study. The general dynamic differential equation for the vehicle is given by

$$
\begin{aligned}
m_1\ddot{Z}_1 &= F_s \\
m_2\ddot{Z}_2 &= -F_s + F_{c1} + F_{c2} + F_{c3} + F_{c4} \\
I_{cy}\ddot{\phi}_2 &= -F_s l_1 + F_{c1} l_2 + F_{c2} l_2 - F_{c3} l_3 - F_{c4} l_3 \\
I_{cx}\ddot{\theta}_2 &= -F_s b_2 + F_{c2} b_1 + F_{c4} b_1 - F_{c1} b_1 - F_{c3} b_1 \\
m_3\ddot{Z}_3 &= -\sum_{v=1}^{4} F_{cv} + \sum_{i=1}^{6} F_i \\
I_y\ddot{\phi}_3 &= \sum_{v=1}^{2} F_{cv} l_x + \sum_{v=3}^{4} F_{cv} l_4 - \sum_{i=1}^{2} F_i l_5 + \\
&\quad \sum_{i=3}^{4} F_i l_6 + \sum_{i=5}^{6} F_i l \\
I_x\ddot{\theta}_3 &= \sum_{v=1}^{4} (-1)^{v+1} F_{cv} b_1 - \sum_{i=1}^{6} (-1)^{i+1} F_i b_4 \\
m_4\ddot{Z}_4 &= -F_1 - F_2 + F_{T1} + F_{T2} \\
I_x\ddot{\theta}_4 &= F_1 b_4 - F_2 b_4 - F_{T1} b_3 + F_{T2} b_3 \\
m_5\ddot{Z}_5 &= -F_3 - F_4 + F_{T3} + F_{T4} \\
I_x\ddot{\theta}_5 &= F_3 b_4 - F_4 b_4 - F_{T3} b_3 + F_{T4} b_3 \\
m_6\ddot{Z}_6 &= -F_5 - F_6 + F_{T5} + F_{T6} \\
I_x\ddot{\theta}_6 &= F_5 b_4 - F_6 b_4 - F_{T5} b_3 + F_{T6} b_3
\end{aligned} \tag{1}
$$

The vertical dynamic force of the driver's seat suspension is described by

$$
\begin{aligned}
F_s = {} & K_s(Z_2 - Z_1 - l_1\phi_2 + b_2\theta_2) + \\
& C_s(\dot{Z}_2 - \dot{Z}_1 - l_1\dot{\phi}_2 + b_2\dot{\theta}_2)
\end{aligned} \tag{2}
$$

The vertical dynamic force of the cab's suspension system is determined by

$$
\begin{aligned}
F_{cv} = {} & K_{cv}[Z_3 - Z_2 - l_x\phi_3 + (-1)^{\beta} l_{\beta}\phi_2 + \\
& (-1)^{v} b_1(\theta_3 - \theta_2)] + C_{cv}[\dot{Z}_3 - \dot{Z}_2 - l_x\dot{\phi}_3 + \\
& (-1)^{\beta} l_{\beta}\dot{\phi}_2 + (-1)^{v} b_1(\dot{\theta}_3 - \dot{\theta}_2)]
\end{aligned} \tag{3}
$$

The vertical dynamic force of the vehicle's suspension system is determined by

$$
\begin{aligned}
F_i = {} & K_i[Z_{\alpha} - Z_3 + (-1)^{i} b_4\theta_{\alpha} + (-1)^{\beta} l\phi_3 + \\
& (-1)^{i+1} b_4\theta_3] + C_i[\dot{Z}_{\alpha} - \dot{Z}_3 + \\
& (-1)^{i} b_4\dot{\theta}_{\alpha} + (-1)^{\beta} l\dot{\phi}_3 + (-1)^{i+1} b_4\dot{\theta}_3]
\end{aligned} \tag{4}
$$

The dynamic reaction force of the wheels F_{Ti} is described in section 1.2.

When $i = v = 1, 2$, then $\alpha = 4$, $\beta = 2$, $l = l_5$, and $l_x = l_2 + l_3 + l_4$; when $i = v = 3, 4$, then $\alpha = 5$, $\beta = 3$, $l = l_6$, and $l_x = l_4$; when $i = 5, 6$ then $\alpha = 6$, $\beta = 3$, $l = l_6 + l_7$.

1.2 Wheel-deformable terrain contact model

Under the actual operation condition of the construction vehicles, the elastic tires often interact with deformable terrains. Consequently, an elastic tire-deformable terrain contact is chosen for establishing the interaction model.

When the elastic tire traverses on the random surface $q_T(t)$ of the deformable terrain, under the effect of the static and dynamic load of the tire, the terrain Z_{oa} then sinks. Two deformation characteristics are present in the tire-terrain contact region. One is the deformation of both the tire and terrain (the region of *bob'*) and the other is that of the unique terrain (the region of *b'a*), as shown in Fig. 2, where Z_T, Z_0 and Z_x are the vertical displacements of the tire centre, static deformation, and sinkage of terrain; m_T is the mass of tire; F_T is the vertical dynamic force at tire centre; ω and r are the angular velocity and

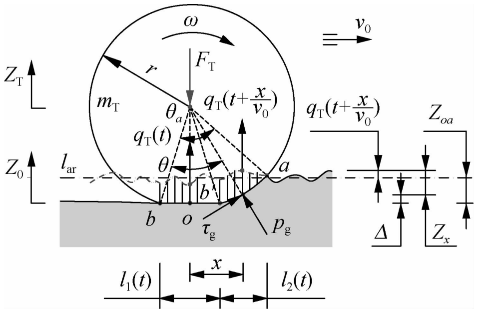


Fig. 2 Elastic tire-deformable terrain contact model

radius of the tire.

The regions of bob' and $b'a$ are assumed to be a straight line bob' with the length of contact $l_1(t)$ and an arc of $b'a$ with the length of contact in the horizontal direction $l_2(t)$, respectively. The pressure p_g and the shear stress τ_g arising in the deformable regions of bob' and $b'a$ are described by the vertical reaction forces of the terrain under the tire, and F_{g1}^Z and F_{g2}^Z are calculated by

$$F_{g1}^Z = F_{pg1}^Z = 2\int_0^{l_1(t)/2} B_T p_g \mathrm{d}x \qquad \tau_g = 0 \tag{5}$$

$$F_{g2}^Z = \int_{l_1(t)/2}^{l_1(t)/2+l_2(t)} B_T p_g \mathrm{d}x + \int_{l_1(t)/2}^{l_1(t)/2+l_2(t)} B_T \tau_g x(r^2 - x^2)^{-1/2} \mathrm{d}x \tag{6}$$

Pressure p_g and shear stress τ_g are given by Bakker[6] as

$$\left.\begin{aligned} p_g &= (k_1/b + k_\varphi) Z_x^n \\ \tau_g &= (c + p_g \tan\varphi)(1 - \mathrm{e}^{-j/K}) \end{aligned}\right\} \tag{7}$$

where k_c and k_φ are the terrain stiffness coefficients for sinkage and internal friction; n is the sinkage exponent; $b = \min\{B_T, l_{1,2}(t)\}$ is the smaller dimension of the contact patch, in which B_T is the width of the tire; c is the terrain cohesion coefficient; φ is the angle of the internal friction; $j = rs_T[\theta_a(t) - \theta]$, in which s_T is the slip ratio of the tire; and K is the shear deformation modulus.

Assuming that l_{ar} is the average roughness line of the terrain surface, thus, the sinking of the terrain Z_x can be determined as follows:

$$Z_x = q_T(t + x/v_0) + Z_T - Z_0 - (r - \sqrt{r^2 - x^2}) \tag{8}$$

The total reaction force of the terrain is given by

$$F_g = F_{g1}^Z + F_{g2}^Z \tag{9}$$

The vertical excitation force F_{Ti} exerted on the axles is described as[9]

$$\left.\begin{aligned} F_{gi} - F_{Ti} - m_{Ti} g &= 0 \\ F_{Ti} &= K_{Ti}(Z_{Ti} - Z_{xi}) + C_{Ti}(\dot{Z}_{Ti} - \dot{Z}_{xi}) \end{aligned}\right\} \tag{10}$$

where m_{Ti} is the portion of total vehicle mass supported at the tires, and g is the gravitational acceleration ($i = 1, 2, \ldots, 6$).

1.3 Excitation of terrain surface roughness

The vehicle's ride comfort is strongly affected by deformable terrains[6-8]. However, under the actual operation condition of the construction vehicles on the deformable terrains, the surface of the deformable terrains characterized by the terrain surface roughness also affects the sinking of terrain Z_x. In order to fully reflect the effect of the deformable terrain on the vehicle's ride comfort, the terrain surface roughness is also a concern in this study.

The off-road terrain surface is calculated using the spatial PSD value[8,12]. The spatial PSD of the road surface profile $S(\Omega)$ is generally described as a function of the spatial frequency Ω (cycle/m). The spectral density of off-road terrain is thus written in accordance with the ISO proposal[13] concerning different spatial frequency ranges such as

$$S(\Omega) = S(\Omega_0)\left(\frac{\Omega}{\Omega_0}\right)^{-w_0} \qquad w_0 = \begin{cases} 3 & \Omega \leqslant \Omega_0 \\ 0.25 & \Omega > \Omega_0 \end{cases} \tag{11}$$

The value $S(\Omega_0)$ provides a measure for the random terrain with the reference spatial frequency $\Omega_0 = 1/2\pi$ cycle/m. More specifically, assuming that the vehicle moves at a constant speed v_0, the off-road terrain irregularities can then be simulated by the series

$$q(t) = \sum_{i=1}^{N} \sqrt{2S(\mathrm{i}\Delta n)\Delta n} \sin(\mathrm{i}\Delta\omega t + \varphi_i) \tag{12}$$

where N is the number of intervals; S is the target spectral density; $\Delta n = 2\pi/L$ and L is the length of the road segment; φ_i is a random phase uniformly distributed between 0 and 2π; and $\Delta\omega = \Delta n v_0$ is the fundamental temporal frequency.

In order to develop an off-road terrain roughness input for the vehicle close to the actual terrain condition, the spectral density ranges for the unpaved off-road classifications apart from the traditional asphalt road classifications including the classification ranges from good to very poor of Mitschke as listed in Tab. 1, were applied[9,11]. The desired terrain roughness can be yielded by choosing a value in the spectral density ranges. In this study, the parameters of two medium and poor terrain roughness surfaces including $v_0 = 10$ m/s, $L = 300$ m, $\Delta t = 0.005$ s, and ω_0, $S(\Omega_0)$ (cm^3/cycle) in Tab. 1 are chosen. Two types of off-road terrain irregularities obtained from the time domain are depicted in Fig. 3(a). In additon, according to the standard ISO 8068[14], two types of rigid road surface profiles, including ISO level B and ISO level C (see Fig. 3(b)), are also carried out to compare the effect between the deformable terrain with the terrain surface roughness and the rigid road surface under the same operation conditions.

Tab. 1 Parameters of the unpaved off-road classification[7]

Parameter	Classification			
	Good	Medium	Poor	Very poor
ω_0	2.55	2.55	2.14	2.14
$S(\Omega_0)$/ ($cm^3 \cdot cycle^{-1}$)	199.8	973.9	3 782.5	102 416

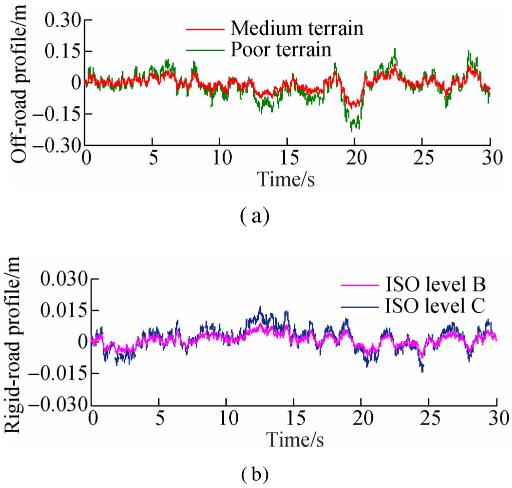


Fig. 3 Excitation of the road surface roughness. (a) Unpaved off-road classifications[7]; (b) Rigid road classifications[14]

2 Results and Analysis

2.1 Evaluation criteria

According to the standard ISO 2631-1[15], the vehicle's ride comfort was mainly evaluated via the weighted RMS acceleration response in the time domain. In addition, the acceleration PSD responses were also applied to estimate the effect of vibration on the endurance limit of the human body in the frequency domain. It was suggested that the low-frequency range below 10 Hz seriously affected the driver's health and safety. In this study, the effect of vibration on the driver's ride comfort and health is evaluated via both the acceleration PSD responses and the weighted RMS acceleration responses. The weighted RMS acceleration response is defined as

$$a_{wz} = \sqrt{\frac{1}{T}\int_0^T [a_w(t)]^2 \mathrm{d}t} \tag{13}$$

where $a_w(t)$ is the acceleration (translational and rotational) that depends on the time of measurement T.

The weighted RMS acceleration responses of the driver's seat heave a_{ws}, the pitch and roll angle of the cab $a_{w\phi c}$ and $a_{w\theta c}$ can be calculated by Eq. (13), and the results are compared with a_{wz} as given in the standard ISO 2631-1.

2.2 Effect of the off-road terrains on vehicles under an operation condition

Under the condition of the construction vehicles working in the workshop, the vehicles often travel on two typically deformable terrains including the sand and soil terrain. Therefore, the reference parameters of the vehicle in Tab. 2 and two typical types of sand and soil terrains with the poor terrain surface roughness in Tab. 3 are chosen to simulate and evaluate the impact of the off-road terrains on the vehicle's ride comfort at a vehicle velocity of v_0 = 10 m/s.

Tab. 2 Parameters of a construction vehicle[5]

Parameter	Value	Parameter	Value
m_1/kg	120	b_3/m	1.00
m_2/kg	500	b_4/m	0.40
m_3/kg	19 000	K_s/(kN · m^{-1})	20
m_4/kg	450	$K_{c1\text{-}4}$/(kN · m^{-1})	100
$m_{5,6}$/kg	1 025	$K_{1,2}$/(kN · m^{-1})	102
l_1/m	0.2	$K_{3\text{-}6}$/(kN · m^{-1})	545.4
l_2/m	1.10	$K_{T1,2}$/(kN · m^{-1})	690
l_3/m	1.00	$K_{T3\text{-}6}$/(kN · m^{-1})	1 380
l_4/m	4.68	C_s/(kN · s · m^{-1})	0.2
l_5/m	5.18	$C_{c1\text{-}4}$/(kN · s · m^{-1})	0.75
l_6/m	0.62	$C_{1,2}$/(kN · s · m^{-1})	7.029
l_7/m	1.35	C_{3-6}/(kN · s · m^{-1})	24.09
b_1/m	0.38	$C_{T1,2}$/(kN · s · m^{-1})	1.5
b_2/m	0.80	$C_{T3\text{-}6}$/(kN · s · m^{-1})	3.0

Tab. 3 Lumped parameters of Wong's measurement[8]

Parameter	Sand terrain	Soil terrain
Moisture content/%	0	24
n	0.71	1.01
k_c/(kN · m$^{-(n+1)}$)	6.94	0.06
k_φ/(kN · m$^{-(n+2)}$)	505.8	5 880
c/kPa	1.3	3.1
φ/(°)	31.1	29.8

The simulation results of the acceleration responses of the driver's seat heave, pitch and roll angle of the cab on two deformable terrains of sand and soil terrains are shown in Fig. 4. The results show that the acceleration response of the driver's seat heave on the soil terrain is higher than that on the sand terrain whereas the acceleration responses of the pitch and roll angle of the cab on the soil terrain are lower than those on the sand terrain. It may be due to the influence of soil characteristics which have a higher stiffness coefficient for the internal friction and a soil cohesion coefficient than that of sand terrain.

Moreover, the comparison results of the weighted RMS acceleration responses of the driver's seat heave, pitch and roll angle of the cab on both soil and sand terrains are listed in Tab. 4. The results show that the weighted RMS value of the driver's seat heave on the sand terrain is lower than that on the soil terrain by 14.7%, whereas the weighted RMS values of the pitch and roll angle of the cab on the sand terrain are higher than those on the soil terrain by 10.0% and 7.3%. It implies that when the vehicles travel on the sand terrain, the vertical ride comfort of the driver is improved while the comfortable shake of

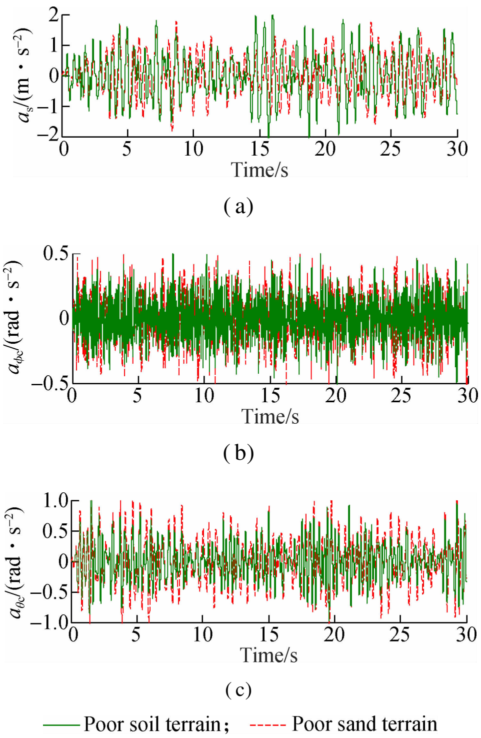


Fig. 4 Accelerations of the driver's seat and the cab on deformable terrains. (a) Driver's seat heave; (b) Cab's pitch angle; (c) Cab's roll angle

Tab. 4 Weighted RMS acceleration responses of the driver's seat and the cab on deformable terrains

Parameter	a_{ws}/(m · s^{-2})	$a_{w\phi c}$/(rad · s^{-2})	$a_{w\theta c}$/(rad · s^{-2})
Poor soil terrain	0.74	0.18	0.38
Poor sand terrain	0.36	0.20	0.41
Reduction/%	14.7	-10.0	-7.3

the driver is decreased. On the contrary, when the vehicles travel on the soil terrain, the vertical ride comfort of the driver is reduced while the comfortable shake of the driver is significantly improved. Therefore, the vehicle's ride comfort is remarkably affected by the deformable terrains of sand and soil terrains. In addition, according to the standard ISO 2631-1[15], the driver feels fairly uncomfortable when the vehicles travel on both sand and soil terrains with poor terrain roughness surfaces.

2.3 Effect of the off-road terrains on vehicles under various operation conditions

Two types of medium and poor terrain surface roughness of the two deformable terrains, including the sand and soil terrains, are chosen to be simulated and compared with two rigid road surfaces' roughness of ISO level B and ISO level C in a range of the vehicle velocities from 2.5 to 20 m/s to analyze the impact of off-road terrains. The results are shown in Fig. 5.

Fig. 5(a) shows the comparison results of the weighted RMS values of the driver's seat heave under different terrain surfaces' roughness of the sand, soil terrain and rigid road. Simulation results show that the weighted RMS value

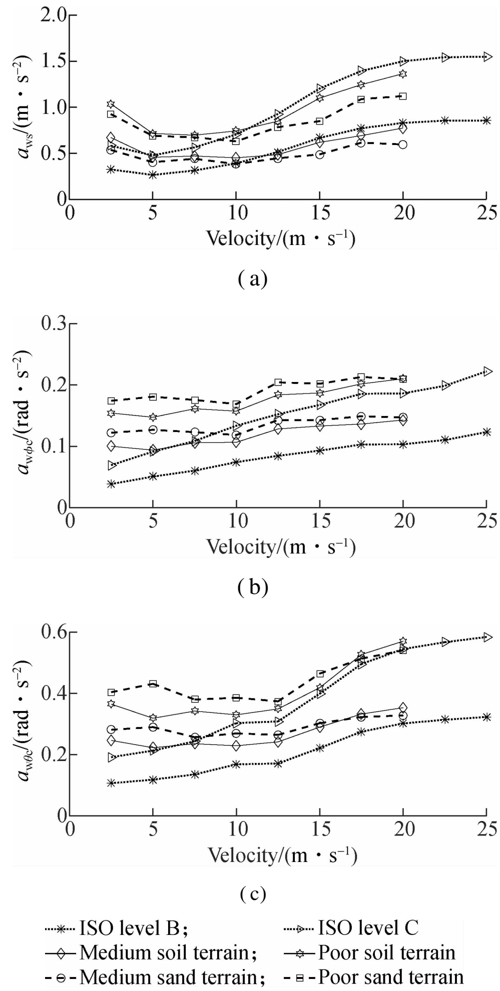


Fig. 5 Weighted RMS acceleration responses of the driver's seat and the cab under various operation conditions. (a) Driver's seat heave; (b) Cab's pitch angle; (c) Cab's roll angle

of the driver's seat heave on both poor soil/sand terrains is higher than that on both medium soil/sand terrains; concurrently, on medium/poor soil terrains it is also higher than that on medium/poor sand terrains in a range of the vehicle velocities. In addition, when the vehicle velocities are below 10 m/s, the weighted RMS values of the driver's seat heave on both medium/poor terrain surfaces of soil/sand terrains are higher than those on both the rigid road surfaces of ISO level B and ISO level C. Conversely, the weighted RMS values of the vertical driver's seat are significantly reduced when the vehicle velocity is above 10 m/s.

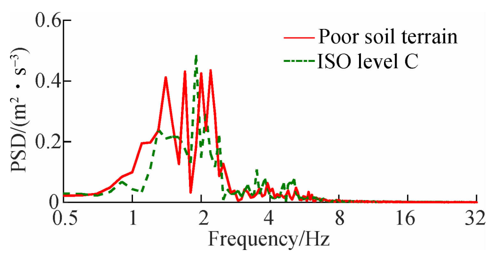
Moreover, Figs. 5(b) and (c) also show that the weighted RMS values of the pitch and roll angle of the cab on both medium/poor terrain surfaces of the deformable terrains are higher than those of both the rigid road surfaces of ISO level B and ISO level C. In addition, the weighted RMS values of the pitch and roll angle of the cab on both medium/poor sand terrains are also higher than those of both medium/poor soil terrains. In particular, the weighted RMS values of the pitch and roll angle of the cab increase with the increase in vehicle velocity.

Therefore, it can be concluded that the vehicle's ride comfort is strongly affected not only by deformable terrains but also by the off-road surface roughness and the vehicle velocities.

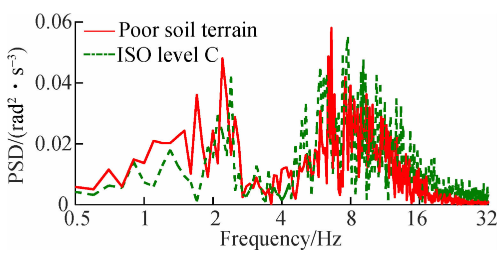
From Fig. 5, it can be seen that the weighted RMS acceleration responses of the driver's seat and the cab are greatly reduced within the range of the vehicle velocities from 10 to 12. 5 m/s. It suggests that when the vehicles travel on deformable terrains of sand and soil terrains, a range of vehicle velocities from 10 to 12. 5 m/s should be used to improve the vertical ride comfort and the comfortable shake of the driver.

2.4 Effect of the off-road terrain on the acceleration PSD responses

In order to evaluate the effect of the off-road terrain on the health of the driver in the low-frequency region, a poor soil terrain and a rigid road of ISO level C are chosen to simulate at a vehicle velocity of 10 m/s. The simulation results of the acceleration PSD responses of the driver's seat heave, pitch and roll angle of the cab are plotted in Fig. 6.



(a)



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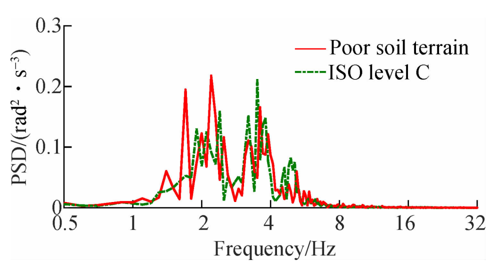

(c)

Fig. 6 Acceleration PSD responses of the driver's seat and cab. (a) Driver's seat heave; (b) Cab's pitch angle; (c) Cab's roll angle

The resonance peaks of the acceleration PSD responses of the driver's seat heave, pitch and roll angles of the cab shown in Figs. 6(a), (b) and (c) show that the resonance frequencies occur at 1. 4, 1. 7, 2. 0, 2. 2, 3. 6, 6. 6 and 7. 6 Hz with the poor soil terrain, and at 1. 9, 2. 4, 3. 5, and 7. 8 Hz with the rigid road of ISO level C. Particularly, at a low-frequency range below 4 Hz, the results specifically highlight that the vehicle traveling on a poor soil terrain has higher resonance frequencies than that traveling on a rigid road of ISO level C. It implies that the health of the driver is significantly affected by a deformable terrain. In addition, in the low-frequency range, the resonance frequencies with the poor soil terrain are low in comparison with those of the rigid road of ISO level C in all three directions. This is due to the influence of the stiffness of the deformable soil ground.

All the above analyses show that the driver's ride comfort and health are clearly affected by the deformable terrains in the low-frequency region.

3 Conclusions

1) The driver's ride comfort is strongly affected by the deformable terrains. The vertical ride comfort of the driver is improved while the comfortable shake of the driver is decreased when the vehicles travel on the sand terrain. Conversely, the vertical ride comfort of the driver is reduced while the comfortable shake of the driver is significantly improved when the vehicles travel on the soil terrain.

2) The vehicle's ride comfort is clearly affected by the off-road terrain surface roughness and the vehicle velocities. In particular, the weighted RMS acceleration responses of the pitch and roll angle of the cab on both medium/poor terrain surfaces of both sand/soil terrains are higher than those on both rigid road surfaces of ISO level B and level C in a range of the vehicle velocities. Also, the vertical ride comfort and the comfortable shake of the driver is considerably improved in a range of the vehicle velocities from 10 to 12. 5 m/s.

3) The driver's health is significantly affected by the off-road terrain in comparison with the rigid road. Particularly, at a low-frequency range below 4 Hz, the vehicle traveling on a poor soil terrain has higher resonance frequencies than that on a rigid road of ISO level C.

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基于变形土壤地面对重型卡车平顺性的影响

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摘要: 为了评价非公路可变形地面对重型卡车乘坐舒适性的影响,基于 Matlab/Simulink 软件建立了重型卡车与变形地面相互作用的非线性动力学模型. 以加速度加权均方根(RMS)值和加速度功率谱密度(PSD)响应为目标函数,对不同工况下驾驶员座椅垂向低频振动、驾驶室的倾斜和俯仰低频晃动进行了仿真分析. 研究结果表明,不同土壤地面变形对驾驶员乘坐舒适性均有明显影响. 特别地,黏土地面对座椅的垂向振动影响较大,而干沙地面对驾驶室的晃动影响较大. 此外,在低于 4 Hz 的低频内,车辆在较差土壤地面上的振动加速度 PSD 响应共振峰要多于 ISO 2631-1 标准 C 级公路路面. 因此,低频范围内地面变形对驾驶员的健康有着重要影响.

关键词: 重型卡车;动力学模型;变形土壤地面;平顺性

中图分类号: U461.3