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Nonlinear dynamic analysis of interaction between vehicle and road surfaces for 5-axle heavy truck

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Abstract: Based on the analysis of nonlinear geometric characteristics of the suspension systems and tires, a 3D nonlinear dynamic model of a typical heavy truck is established. The impact factors of dynamic tire loads, including the dynamic load stress factors, and the maximal and the minimal vertical dynamic load factors, are used to evaluate the dynamic interaction between heavy vehicles and roads under the condition of random road surface roughness. Matlab/Simulink is used to simulate the nonlinear dynamic system and calculate the impact factors. The effects of different road surface conditions on the safety of vehicle movement and the durability of parts of a vehicle are analyzed, as well as the effects of different structural parameters and different vehicle speeds on road surfaces. The study results provide both the warning limits of road surface roughness and the limits of corresponding dynamic parameters for the 5-axle heavy truck.

Key words: 5-axle heavy truck; nonlinear dynamics; dynamic impact factor; road surface roughness

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Nowadays, it is acknowledged that bridges and roads play an important role in transport systems. Therefore, investigating dynamic loads of heavy vehicles and roads is necessary for maintaining roads and bridges as well as solving problems in design of the parameters of vehicles. Much literature have investigated the dynamic loads of wheels which impact on highway bridges with road surface roughness[1-4]. Similarly, considering the nonlinear properties of shock absorbers and leaf springs, a 3D nonlinear virtual prototype model based on multi-body dynamic theory for heavy-duty vehicles is established in order to evaluate the effects of vehicle speeds, loads, road surface roughness, and tire stiffness on the tire dynamic loads and the dynamic load coefficients (DLC)[5].

The major goal of this study is to improve a 3D nonlinear dynamic model for 5-axle heavy trucks considering the nonlinear characteristics of tires and the suspension systems. In this paper, Matlab/Simulink is applied to simulate the nonlinear dynamics of vehicles with road surface roughness of national highways according to the international standard ISO 8068[6]. Dynamic models for different road surface roughnesses, different structural parameters, and different speeds of vehicles are analyzed, respectively.

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1 Vehicle Dynamic Model

1.1 Dynamic model

A 5-axle heavy vehicle with a dependent suspension system for the front axle and a walking beam suspension system for the rear axles is selected for vehicle dynamic analysis. A 5-axle heavy vehicle dynamic model with 14 degrees of freedom is established to evaluate the dynamic interaction between vehicles and roads, as shown in Fig. 1.

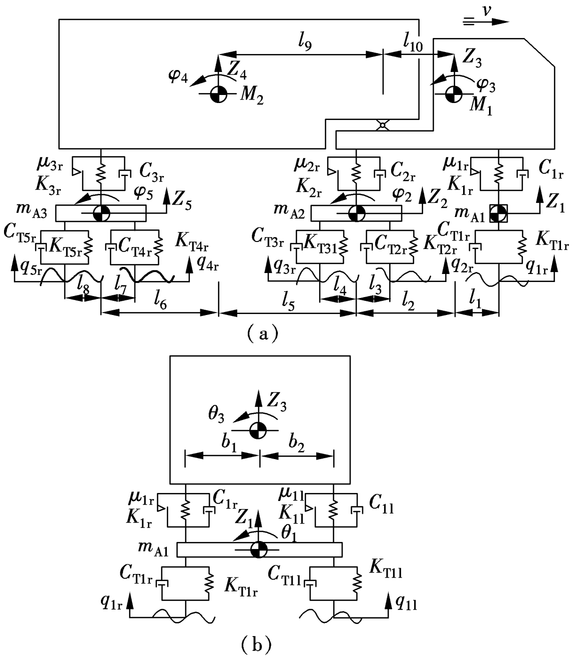

Fig. 1 3D dynamic models of the 5-axle heavy truck. (a) Side view; (b) Front view

In Fig. 1, K_{ij} are the suspension stiffness coefficients; C_{ij} are the suspension damping coefficients; μ_{ij} are the friction coefficients of suspension systems; K_{Tkj} are the stiffness coefficients of tires; C_{Tkj} are the damping coefficients of tires; M_1 and M_2 are the sprung mass of the tractor and trailer; m_{A1}, m_{A2} and m_{A3} are the unsprung mass of the front axle, the first tandem axle and the second tandem axle; l_1, l_2, l_5 and l_6 are the distances between the tractor C. G. and the front axle, the tractor C. G. and the front tandem axle, the trailer C. G. and the front tandem axle, the trailer C. G. and the rear tandem axle, respectively; l_9 and l_{10} are the distances from the pivot point to the trailer C. G. and the tractor C. G.; l_3, l_4 and l_7, l_8 are the distances from the tandem axle C. G. to each wheel; b_1 and b_2 are the distances between the tractor C. G. and the right/left wheel at the front axle; z_k are the vertical displacements at the centre of gravity of the axles, the tractor and the trailer; φ_n and θ_k are the angular displacements at the centre of gravity of the axles, and the tractor and the trailer; v is the vehicle speed ($i = 1, 2, 3$; $k = 1, 2, \ldots, 5$; $n = 2, 3, 4, 5$; and j = left, right).

1.2 Vehicle dynamic model

In order to facilitate the description of vehicle dynamic systems using computer simulation, a combined method of the multi-body system theory and D'Alembert's principle is chosen in this study. The multi-body system theory is used to separate the system into subsystems which are linked by the force and moment equations. D'Alembert's principle is used to set up force and moment equations to describe vehicle dynamic subsystems.

The general dynamic differential equation for the 5-axle heavy truck is given by the following matrix form:

$$\boldsymbol{M}\ddot{\boldsymbol{Z}} + \boldsymbol{C}\dot{\boldsymbol{Z}} + \boldsymbol{K}\boldsymbol{Z} = \boldsymbol{C}_{\mathrm{T}}\dot{\boldsymbol{Q}} + \boldsymbol{K}_{\mathrm{T}}\boldsymbol{Q} \tag{1}$$

where $\boldsymbol{M}$ is the mass matrix; $\boldsymbol{C}$ is the damping matrix of the suspension system; $\boldsymbol{K}$ is the stiffness matrix of the suspension system; $\boldsymbol{C}_{\mathrm{T}}$ is the damping matrix of the wheel system; $\boldsymbol{K}_{\mathrm{T}}$ is the stiffness matrix of the wheel system; $\boldsymbol{Z}$ is the vector of displacement; $\boldsymbol{Q}$ is the vector of excitation of the road surface.

1.3 Nonlinear characteristics of suspension systems and tires

The difficulty in finding the solution for the dynamic function of a vehicle system is identifying the nonlinear characteristics of suspension systems and tires. There are two types of nonlinear characteristics of suspension systems and tires when a vehicle moves on the road surface: nonlinear physics parameters and nonlinear geometric parameters. In this study, only the impacts of nonlinear geometric parameters are considered, in which the suspension system is limited by motion and the wheel off-road phase. These nonlinear factors can be described by the nonlinear mathematical function.

1.3.1 Suspension system model

For a heavy truck suspension system, there is a limiting stopper, which is used to limit the up and down motions of the chassis for safety. In a normal motion, the leaf springs stiffness of the suspension system is linear. When the motion of the chassis is over the limit, the limiting stopper will be touched. In this case, the leaf springs stiffness becomes infinitely large. The leaf springs force of the suspension system can be determined if the leaf spring stiffness and the relative motion between the unsprung mass and the sprung mass are known.

The front suspension system and its dynamic model are shown in Figs. 2 (a) and (b). The elastic forces of the leaf springs can be determined by the following formula:

$$F_{K_1} = \begin{cases} K_\infty(\xi_1 - z_1 - f_{1\mathrm{d}}^{\mathrm{c}}) + K_1 f_{1\mathrm{d}}^{\mathrm{c}} & \xi_1 - z_1 \geqslant f_{1\mathrm{d}}^{\mathrm{c}} \\ K_1(\xi_1 - z_1) & \xi_1 - z_1 \leqslant f_{1\mathrm{d}}^{\mathrm{c}} \end{cases} \tag{2}$$

where $f_{1\mathrm{d}}^{\mathrm{c}}$ is the maximum front suspension dynamic deflection at compression.

The damping force and the friction force of the front

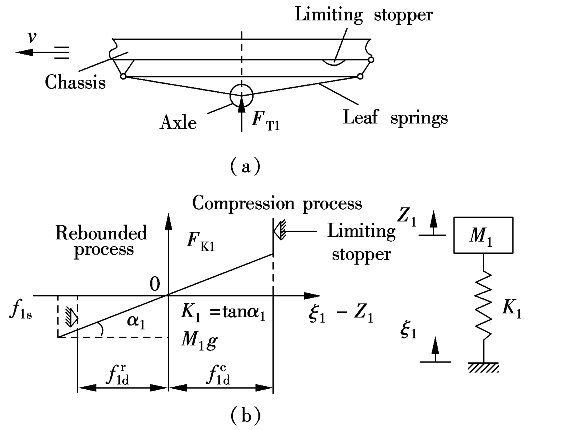

Fig. 2 Front suspension system. (a) Diagram; (b) Elastic properties

suspension system in vertical direction are defined as

$$F_{C_1} = C_1(\dot{\xi}_1 - \dot{z}_1) \tag{3}$$

$$F_{\mu_1} = \mu_1 \operatorname{sign}(\dot{\xi}_1 - \dot{z}_1) \tag{4}$$

Meanwhile, the dynamic force of the front suspension system in vertical direction is defined as

$$F_{z_1} = F_{K_1} + F_{C_1} + F_{\mu_1} \tag{5}$$

where F_{K_1} is the elastic force; F_{C_1} is the damping force; F_{μ_1} is the friction force.

1.3.2 Tire model

A quarter of the vehicle model is selected for analyzing the nonlinear characteristics of the tire, as shown in Fig. 3 (a). We already know that when a vehicle moves on the road surface, the wheel's motion in vertical direction can be described as two stages: compression processes (static compression and dynamic compression) and rebounded processes (tire recovery phase and wheel off-road phase) as shown in Figs. 3(b) and (c).

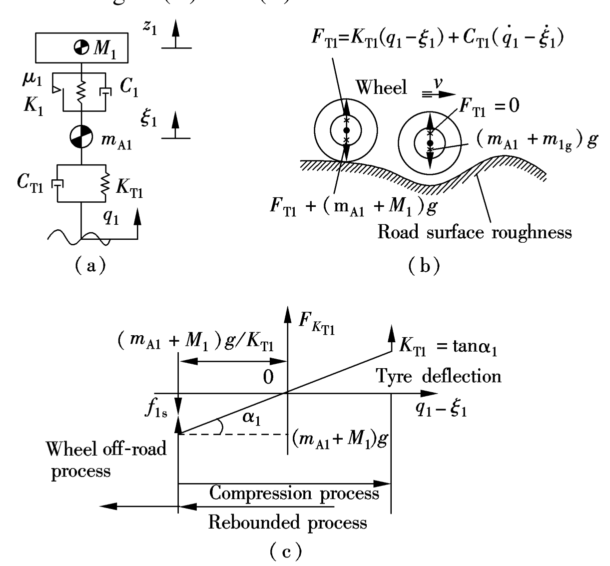

Fig. 3 Road-wheel-vehicle coupled system. (a) Quarter of vehicle vibration model; (b) Wheel moving on road; (c) Elastic properties of radial tire

The radial spring force of the front wheel can be determined by the following formula:

$$F_{K_{\mathrm{T1}}} = \begin{cases} K_{\mathrm{T1}}(q_1 - \xi_1) & q_1 - \left(\xi_1 + \dfrac{(M_1 + m_{\mathrm{A1}})g}{K_{\mathrm{T1}}}\right) \geqslant 0 \\ 0 & q_1 - \left(\xi_1 + \dfrac{(M_1 + m_{\mathrm{A1}})g}{K_{\mathrm{T1}}}\right) < 0 \end{cases} \tag{6}$$

The radial damping force of the front wheel is determined by the following formula:

$$F_{K_{T1}} = C_{T1}(\dot{q}_1 - \dot{\xi}_1) \tag{7}$$

Meanwhile, the dynamic reaction force of the front wheel in vertical direction is defined as

$$F_{T1} = (\pm 1) F_{K_{T1}} + F_{C_{T1}} \tag{8}$$

where the factor (± 1) is the dynamic reaction force of the front wheel acting on the vehicle and the road surface; $F_{K_{T1}}$ is the radial spring force; $F_{C_{T1}}$ is the radial damping force.

Eq. (5) and Eq. (8) are important in creating subsystems for simulation which will be presented in the following section.

2 Assessment Factors of Dynamic Vehicle Load

As presented in section 1.3, in vertical direction, a wheel's motion can be described as two processes: the compression process and the rebound process. The maximal value of the dynamic wheel force appears in the compression process and the minimal value appears in the rebound process (see Figs. 3 (b) and (c)). In order to evaluate the dynamic interaction between heavy trucks and the road surface, assessment factors k_{dmin} and k_{dmax} are proposed.

The minimal vertical dynamic load factor k_{dmin} is applied to evaluate the minimal dynamic reaction forces transmitted from the road surface to the wheels. It is defined as[7]

$$k_{dmin} = 1 + \frac{\min F_T}{F_S} \qquad 0 \leqslant k_{dmin} \leqslant 1 \tag{9}$$

where F_T is the dynamic vertical wheel force; F_S is the static vertical wheel force.

According to Mitschke's finding, the minimal vertical dynamic load factor k_{dmin}[6] can be determined as follows:

$k_{dmin} = 0.5$ is limiting for road maintenance;

$k_{dmin} = 0$ is limiting for road repairs.

The maximal vertical dynamic load factor k_{dmax} is applied to evaluate the maximal dynamic reaction forces transmitted from road surfaces to wheels. It is defined as[8]

$$k_{dmax} = 1 + \frac{\max F_T}{F_S} \tag{10}$$

Taking the random road surface roughness into account, Eq. (10) becomes

$$k_{dmax} = 1 + \frac{1.64 F_{T,RMS}}{F_S} \tag{11}$$

where $F_{T,RMS}$ is the root mean square of the vertical dynamic load.

According to Mitschke's finding[7], if the maximal vertical dynamic load factor $k_{dmax} \leqslant 1.5$, the safety limits for the durability of parts of a vehicle will be established.

The road damage criteria are as follows: Most of the civil engineering literature uses the static vehicle load for the design of road surfaces. They have achieved mixed success due to the complex nature of the road damage problems. But the role of vehicle dynamic loads in the road surface design is still not completely known. Some of the major performance criteria considering road damage are based on the fourth power law of the American Association of State Highway Officials (AASHO) from 1960. Subsequently, other criteria were established in terms of AASHO, such as EC criteria in 1992 and Australia criteria in 1999[9]. In this paper, a dynamic load-stress factor (ν) based on road damage criteria is used to quantify road loads caused by dynamic road-tire forces.

$$\nu = 1 + 6\delta^2 + 3\delta^4 \tag{12}$$

where δ is the dynamic load coefficient,

$$\delta = \frac{F_{T,RMS}}{F_S} \tag{13}$$

The dynamic load-stress factor (ν) is strongly dependent on vehicle speed, suspension design, wheel design and road roughness. According to some research results[5,10], if the dynamic load-stress factor $\nu \leqslant 1.56$, the road-friendly limit for the dynamic parameters of a vehicle will be established.

3 Road Surface Roughness

Surface roughness plays an important role in evaluating the dynamic interaction between vehicles and roads. The random excitation of road surface roughness can be represented with a periodic modulated random process. The general form of the displacement PSD of the road surface roughness is determined by the experimental formula[11]:

$$S_q(n) = S_q(n_0)\left(\frac{n}{n_0}\right)^{-\omega} \tag{14}$$

where space frequency n is the reciprocal of the wavelength λ. It means the wave number in one meter. n_0 is reference space frequency, defined as $0.1\ \mathrm{m}^{-1}$. $S_q(n)$ is the PSD of the road surface under the reference space frequency n_0, known as the road surface roughness coefficient; and ω is the frequency index which determines the frequency configuration of the PSD of the road surface ($\omega = 2$).

The road surface roughness is assumed to be a zero-mean stationary Gaussian random process. It can be generated through an inverse Fourier transformation:

$$q(t) = \sum_{i=1}^{N} \sqrt{2S_q(n_i)\Delta n}\cos(2\pi n_k t + \phi_i) \tag{15}$$

where ϕ_i is a random phase uniformly distributed from 0 to 2π.

In this study, typical road surface roughness is adopted according to the standard ISO 8068[6], and the simulation results of the typical road surface roughness are shown in Fig. 4.

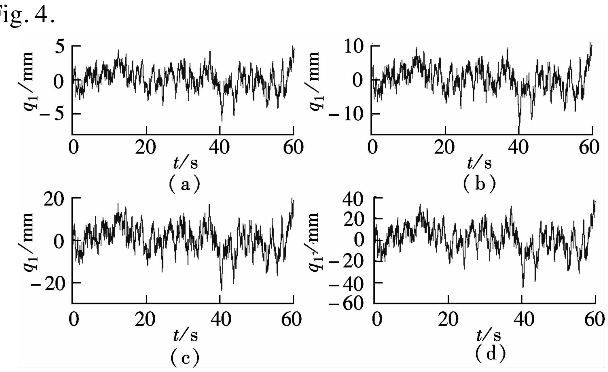

Fig. 4 Typical road surface roughness according to ISO 8068[6].
(a) Level A; (b) Level B; (c) Level C; (d) Level D

4 Simulation and Analysis Results

In order to solve the nonlinear differential equations presented in section 1 for evaluating dynamic interaction between heavy vehicles and road surfaces, Matlab/Simulink software is used with a specific set of parameters of the 5-axle heavy vehicle as shown in Tab. 1.

Tab. 1 Parameters of the 5-axle heavy vehicle

Parameters	Values	Parameters	Values
$K_{1r,1}/(\mathrm{N\cdot m^{-1}})$	1.1310×10^5	M_1/kg	4 871
$C_{1r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	1.2770×10^4	M_2/kg	27 542
$K_{T1r,1}/(\mathrm{N\cdot m^{-1}})$	8.9665×10^5	m_{A1}/kg	584
$C_{T1r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	1.105×10^3	m_{A2}/kg	1 554
$K_{2r,1}/(\mathrm{N\cdot m^{-1}})$	8.9315×10^5	m_{A3}/kg	1 314
$C_{2r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	2.5539×10^4	l_1/m	0.847
$K_{T2r,1}/(\mathrm{N\cdot m^{-1}})$	1.7933×10^6	l_2/m	3.356
$C_{T2r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	2.414×10^3	l_3, l_4/m	0.661
$K_{T3r,1}/(\mathrm{N\cdot m^{-1}})$	1.7933×10^6	l_5/m	4.822
$C_{T3r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	2.414×10^3	l_6/m	4.862
$K_{3r,1}/(\mathrm{N\cdot m^{-1}})$	7.8807×10^5	l_7, l_8/m	0.661
$C_{3r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	3.3098×10^4	l_9/m	5.057
$K_{T4r,1}/(\mathrm{N\cdot m^{-1}})$	1.7933×10^6	l_{10}/m	3.121
$C_{T4r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	2.414×10^3	b_1, b_2/m	1.1
$K_{T5r,1}/(\mathrm{N\cdot m^{-1}})$	1.7933×10^6	$\mu_{1r,1}$	0.05
$C_{T5r,1}/(\mathrm{N\cdot s\cdot m^{-1}})$	2.414×10^3	$\mu_{2r,1}, \mu_{3r,1}$	0.06

In order to evaluate the impact factors, simulations are carried out under the conditions of different road surfaces, vehicle speeds and structural parameters of the vehicle. For example, a simulation result of the dynamic tire loads acting on the road surface when a vehicle moves on the level C road surface at $v = 72$ km/h is shown in Fig. 5.

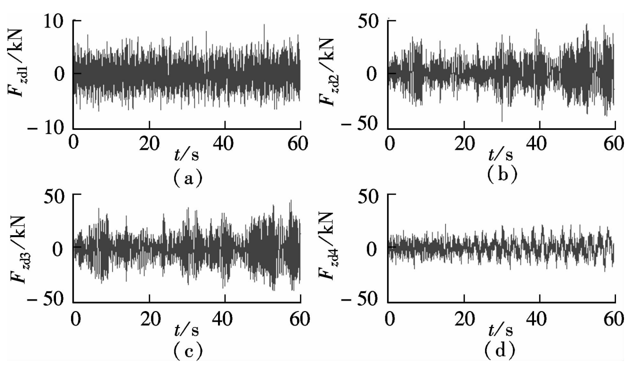

Fig. 5 Dynamic wheel force on axles acting on road surface. (a) 1st axle; (b) 2nd axle; (c) 3rd axle; (d) 4th axle

4.1 Effects of road surface roughness on vehicle

4.1.1 Effects of road surface roughness on the safety of vehicle movement

Five road conditions from level A (very good) to level E (very poor) in ISO/TC 8068[6] are chosen to determine the impact factor k_{dmin} in order to analyze the effects of different road surface conditions on the safety of vehicle movement.

Fig. 6 shows the effects of different road surface conditions and vehicle speeds on impact factor k_{dmin}. The values of k_{dmin} decrease with the road surface quality. When a vehicle moves on the level C road surface at $v = 72$ km/h, dynamic reaction forces transmitted from road surfaces to wheels at the 2nd and 3rd axle are reduced by nearly one half. Therefore, road surface conditions, ISO level C ($k_{\mathrm{dmin}} = 0.55$) and ISO level D ($k_{\mathrm{dmin}} = 0.22$), are chosen as warning limits for road surfaces[7]. When the road surface has been deteriorated, traffic managers must make a maintenance plan for the road surface, and a safe speed limit should be set for vehicles when they move on these roads.

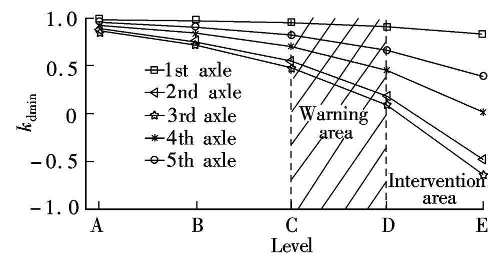

Fig. 6 Minimal vertical dynamic load factor

When a vehicle moves on the level D road surface at $v = 72$ km/h, dynamic reaction forces transmitted from road surfaces to wheels at the 2nd and 3rd axle are approximately equal to zero if the wheels separate from the road surface. This situation affects the safety of vehicle movement negatively. Therefore, the road surface condition of level D is chosen as the intervention limit for road surfaces[7]. In this circumstance, traffic managements need to intervene quickly to give a safe speed limit for vehicles when they move on these roads, as shown in Fig. 6.

4.1.2 Effects of road surface roughness on the durability of parts of vehicle

Fig. 7 shows that the k_{dmax} variations can be used to calculate the durability of the parts of a vehicle[8] at different qualities of road surface, where k_{dmax} increases quickly when a vehicle moves on the bad road surface conditions. Therefore, the road surface conditions, level C ($k_{\mathrm{dmax}} = 1.39$) and level D ($k_{\mathrm{dmax}} = 1.68$), are chosen as warning limits and intervention limits for road surfaces, as shown in Fig. 7.

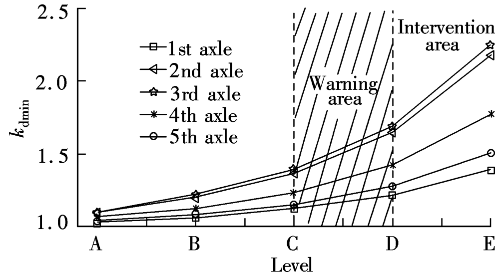

Fig. 7 Maximal vertical dynamic load factor

For the safety of vehicle movement under different road surface conditions, this study proposes that the safe speed limit to the 5-axle heavy vehicle is $v_{\max} \leqslant 70$ km/h for the ISO level C road, $v_{\max} \leqslant 55$ km/h for the ISO level D road, and $v_{\max} \leqslant 30$ km/h for the ISO level E road.

4.2 Effects of vehicle on road surface

The dynamic load stress factor (ν) is investigated to design "road-friendly" vehicles. The corresponding dynamic parameters, including vertical stiffness coefficients and damping coefficients of suspension systems and tires, vehicle speeds, vehicle sprung mass and vehicle unsprung mass, are analyzed.

The vertical tire stiffness is another important factor that influences the magnitude of road surface dynamic loads. To analyze its effect on ν, five vertical tire stiffnesses including $0.5K_{Tkj}$, $1.0K_{Tkj}$, $1.5K_{Tkj}$, $2.0K_{Tkj}$ and $2.5K_{Tkj}$ are applied when a vehicle moves on the road surface condition of level B at $\nu = 72$ km/h, where K_{Tkj} is the vertical tire stiffness shown in Tab. 1. Fig. 8 shows the change of ν with K_{Tkj}. When $K_T > 1.93K_{Tkj}$ and $\nu > 1.56$, the dynamic wheel loads at the 2nd and 3rd axle acting on road surface are unfriendly[5, 10].

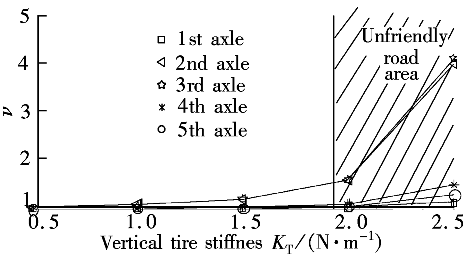

Fig. 8 Changes of load-stress factor with vertical tire stiffness

The effect of the vertical stiffness of suspension systems on ν is also analyzed under similar conditions. Five vertical stiffnesses of the suspension system including $0.5K_{ij}$, $1.0K_{ij}$, $1.5K_{ij}$, $2.0K_{ij}$ and $2.5K_{ij}$ are applied, where K_{ij} is the vertical stiffness of the suspension systems shown in Tab. 1. Study results show that when $K_T > 2.2K_{ij}$ and $\nu > 1.56$, the dynamic wheel loads at the 2nd and 3rd axle acting on the road surface are unfriendly[5, 10].

The influence of the remaining dynamic parameters of vehicles on the road surface is also analyzed by similar methods.

5 Conclusion

In this study, a new 3D nonlinear dynamic model for 5-axle heavy trucks is developed for simulating and calculating the dynamic interaction between vehicles and roads.

Using the reliable model and impact factors to analyze the dynamic interaction between different road surface conditions and the vehicle parameters, the warning limits for the road surface, the safe speed limits for the movement of vehicles and road-friendly limits are considered. The results in this paper can be used for both the management of roads and the vehicle design.

References

[1] Máca J, Valášek M. Vibration control of bridges under moving loads [J]. *Slovak Journal of Civil Engineering*, 2006, **3**(4): 1 − 4.

[2] Kim C W, Kawatani M, Kim K B. Three-dimensional dynamic analysis for bridge-vehicle interaction with roadway roughness[J]. *Computers and Structures*, 2005, **83** (19/20): 1627 − 1645.

[3] Green M F, Cebon D. Dynamic interaction between vehicles and highway bridges [J]. *Computer and Structures*, 1997, **62**(2): 253 − 264.

[4] Ding Lina, Hao Hong, Zhu Xinqun. Evaluation of dynamic vehicle axle loads on bridges with different surface conditions [J]. *Journal of Sound and Vibration*, 2009, **323**(1): 826 − 848.

[5] Lu Yongjie, Yang Shaopu, Li Shaohua, et al. Numerical and experimental investigation on stochastic dynamic load of a heavy duty vehicle[J]. *Applied Mathematical Modeling*, 2010, **34**(1): 2698 − 2710.

[6] International Organization for Standardization. ISO 8068 Mechanical vibration—Road surface profiles—Reporting of measured data [S]. 1995.

[7] Mitschke M. Effect of road roughness on vehicle vibration [J]. *IFF Report*, 1986, **33**(1): 165 − 198. (in German)

[8] Mitschke M. *Dynamics of vehicle* [M]. Berlin: Springer, 1992. (in German)

[9] Cebon D. *Handbook of vehicle-road interaction* [M]. Lisse: Netherlands Swets & Zetinger Press, 1999.

[10] Kitching K J, Cole D J, Cebon D. Theoretical investigation into the use of controllable suspensions to minimize road damage[J]. *Journal of Automobile Engineering*, 2000, **214** (D1): 13 − 31.

[11] Dodds C J, Robson J D. The description of road surface roughness[J]. *Journal of Sound and Vibration*, 1973, **31** (2): 175 − 183.

车辆与路面相互作用下的5轴重型卡车非线性动态分析

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摘要: 基于车辆悬挂系统和轮胎的几何非线性特性分析,建立了一重型卡车三维非线性动态模型,采用动态车轮载荷的影响因子即动载荷应力因子、最大和最小垂直动载系数,对路面随机不平度与重型车辆之间的动态相互作用进行了评价. 采用 Matlab/Simulink 软件对建立的非线性动态系统模型及影响因子进行仿真计算. 分析了不同路面条件对车辆行驶安全性和零部件耐久性的影响;同时,分析了不同结构车辆参数和不同速度对路面的不良影响. 研究结果不仅给出了5轴重型卡车运行路面不平度的界限,也给出了相应动态参数的界限.

关键词: 5轴重型卡车;非线性动力学;动态影响因素;路面不平度

中图分类号: U461.33