Yan et al. 2015. *Int. J. Vehicle Structures & Systems*, 7(2), 51-54
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.7.2.01

International Journal of
Vehicle Structures & Systems
Available online at www.maftree.org/eja

Analysis of Tubular Visco-Elastic Suspension based Vibration Isolation in Wheeled Construction Vehicles

Bijuan Yan[a], Dagang Sun, Wenjun Zhang and Zhanlong Li
Taiyuan University of Science and Technology, Shanxi, China
[a]Corresponding Author, Email: s2003110@126.com

ABSTRACT:
In order to improve the vibration-isolation of wheeled construction vehicle, a new type of tubular visco-elastic suspension is proposed in this paper. A half vehicle mathematical model is used to simulate the dynamics of wheeled construction vehicle in its vertical direction. To obtain vibration-buffering properties of the proposed tubular visco-elastic suspension, four different ground profiles are applied as inputs to the model. The vertical accelerations and displacements are analyzed between the tubular visco-elastic suspension and traditional rigid suspension. The analysis results show that the vibration level is decreased by the use of tubular visco-elastic suspension.

KEYWORDS:
Wheeled construction vehicle; Tubular suspension; Visco-elastic damping; Half-vehicle model; Vertical vibration

CITATION:
B. Yan, D. Sun, W. Zhang and Z. Li. 2015. Analysis of Tubular Visco-Elastic Suspension based Vibration Isolation in Wheeled Construction Vehicles, *Int. J. Vehicle Structures & Systems*, 7(2), 51-54. doi:10.4273/ijvss.7.2.01.

1. Introduction

Wheeled construction vehicle usually travel and work on "off-road" ground, severe vibrations of vehicle body could happen [1]. When the vibrations reach to a certain extent, the drivers can feel the discomfort and the working efficiency decreases [2, 3]. At the same time, the dynamic loads between the wheels and ground could affect the contact performance and operation and safety of the construction vehicle [4]. On the other hand, the suspension performance can also change vehicle body's posture, for example, pitching and tilt. So, based on the construction vehicle's vibration characteristic, it is necessary to take certain measures to reduce the level of vibrations to improve the vehicle's comfort and stability. In order to reduce the vibrations level of construction vehicle, it is feasible to improve the quality of pavement. But, it is more important that the vehicle must have good vibration-isolation properties. For wheeled construction vehicles, their suspension system plays an important role during vibration suppression.

The main function of suspension system is to transmit the force and moment between the wheels and the vehicle body, and to buffer various vibration from "off-road" ground, and thus to ensure smooth working of the vehicle [5]. Presently, many wheeled construction vehicles are still installed with rigid suspension [6]. This kind of vehicles has the advantages of simple structure and convenient repair. But, it is easy to be found that the vibration and shock are serious, particularly when the vehicles with rigid suspension travel and work on rough roads. Elastic suspension transforms the kinetic energy to potential energy and could not dissipate the vibration energy [7]. To solve above problem, a tubular visco-elastic suspension is proposed in this paper according to the characteristic of visco-elastic material and the structure of wheeled construction vehicle's chassis. To obtain vibration-buffering properties of the new tubular visco-elastic suspension, a mathematical modeling of wheeled construction vehicle is established. Here, four ground profiles are applied as an input to the developed half-vehicle model. The vertical acceleration and displacements are compared between the vehicle with tubular visco-elastic suspension and rigid suspension.

2. Half-vehicle model

The composition of the proposed tubular visco-elastic suspension and its integration with the vehicle chassis is shown in Fig. 1 and Fig. 2 respectively. The tubular visco-elastic suspension is composed of three layers to behave like a sandwich structure. The outer and inner layers are Steel and Rubber is located in the middle. For many years, this kind of damping structure have been studied theoretically [8, 9], but it is clear that its application into actual engineering, especially heavy-duty wheeled construction vehicle is limited. In order to increase the damping effect of the whole structure, three slots, as shown in Fig. 1, are provided in the outer Steel. It is well-known that rubber is a kind of visco-elastic material. It could dissipate vibration energy into heat when a force is exerted to it. Therefore, rubber is often used in many mechanical structures which need to be away from vibration. Natural rubber is chosen in the paper as it satisfies the damping characteristic of wheeled construction vehicle. The handling and the comfort of a wheeled construction vehicle is mainly related to its vertical movement [10]. So, during the establishment of vehicle vibration model, only vertical degree of freedom (DOF) is considered. One half of vehicle's model is shown in Fig. 3.

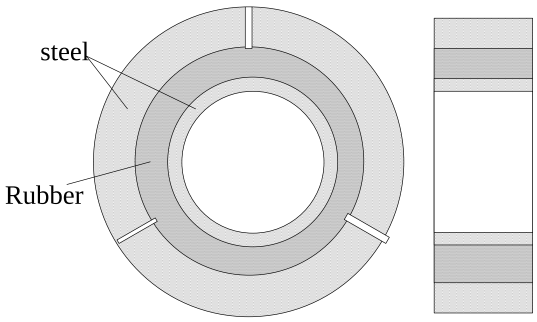

Fig. 1: Tubular visco-elastic suspension system

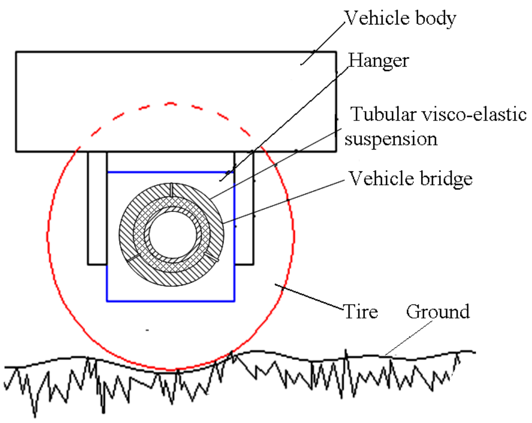

Fig. 2: Installation position of tubular suspension

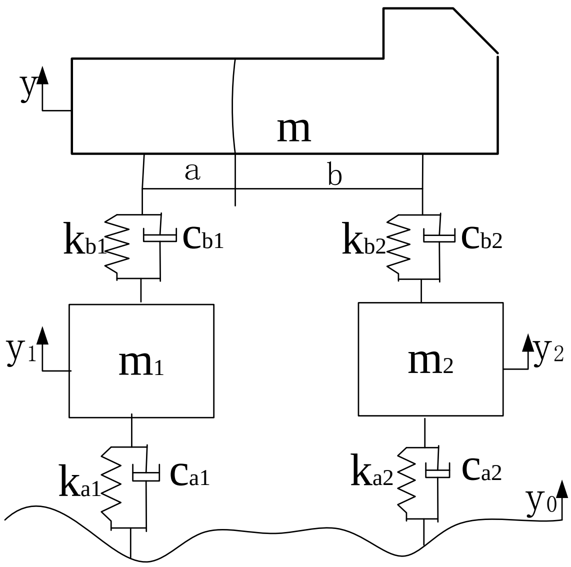

Fig. 3: Half-vehicle model

In the half-vehicle model, m represents one half of vehicle's mass, m_1 and m_2 is the front and rear tire's mass respectively. a is the distance between the vehicle's center of gravity and the rear tire. b is the distance between the vehicle's center of gravity and the front tire. The whole vehicle is suspended on its axles through two tubular visco-elastic suspension systems. Here, tubular visco-elastic suspension systems are modelled by spring (rigid k_{b1} and k_{b2}) and damper (c_{b1} and c_{b2}). The tires are modelled in the same way as suspension systems, their rigidity are given by k_{a1} and k_{a2}, their damping are represented by c_{a1} and c_{a2}. At the same time, the vertical displacement of the vehicle is y. y_1 and y_2 are the vertical displacement of front and rear tire respectively. The model is excited by the ground profile y_0.

The movement differential equation of the whole system is given by,

$$m_1\frac{d^2y_1}{dt^2}+c_{a1}\left[\frac{dy_1}{dt}-\frac{\partial y(vt-a-b)}{\partial t}\right] + K_{a1}\left[y_1-y_0(vt-a-b)\right]+c_{b1}\left(\frac{dy_1}{dt}-\frac{dy}{dt}\right) + K_{b1}(y_1-y)=0 \quad (1)$$

$$m_2\frac{d^2y_2}{dt^2}+c_{a2}\left[\frac{dy_2}{dt}-\frac{\partial y(vt)}{\partial t}\right]+K_{a2}\left[y_2-y_0(vt)\right] + c_{b2}\left(\frac{dy_2}{dt}-\frac{dy}{dt}\right)+K_{b2}(y_2-y)=0 \quad (2)$$

$$m\frac{d^2y}{dt^2}+c_{b1}\left[\frac{dy}{dt}-\frac{\partial y_1}{\partial t}\right]+K_{b1}\left[y-y_1\right] + c_{b2}\left(\frac{dy}{dt}-\frac{dy_2}{dt}\right)+K_{b2}(y-y_2)=0 \quad (3)$$

Where *v* is the travel speed of the construction vehicle.

3. Numerical simulation

Ground unevenness is often given by a random mathematical function. International Standardization Organization (ISO) has introduced a classification method through the Power Spectral Density (PSD) values [11]. According to the ISO classification for road roughness, the spatial PSD of the vertical road displacement ($G_q(n)$, units: m^3/cycle) are given as:

$$G_q(n)=G_q(n_0)(n/n_0)^{-w} \quad (4)$$

Where *n* denotes wave number in cycle/m, n_0 is the base wave number and $Gq(n_0)$ is the PSD in n_0. *w* is waviness is often equal to 2. Thus, the ground unevenness is classified into 8 types as from A to H in Table 1. D and G level ground profiles are shown in Fig. 4 and Fig. 5 respectively.

Table 1: Classification of road roughness proposed by ISO (ISO/TC108/SC2N67)

Classification of road	$Gq(n_0)\times10^{-6}m^2/m^{-1}$; $n_0 = 0.1m^{-1}$		
	Minimum	Average	Maximum
A	8	16	32
B	32	64	128
C	128	256	512
D	512	1024	2048
E	2048	4096	8192
F	8192	16384	32768
G	32768	65536	131072
H	131072	261144	524288

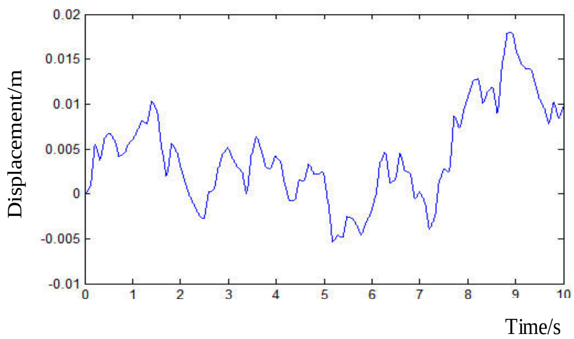

Fig. 4: D level ground profile

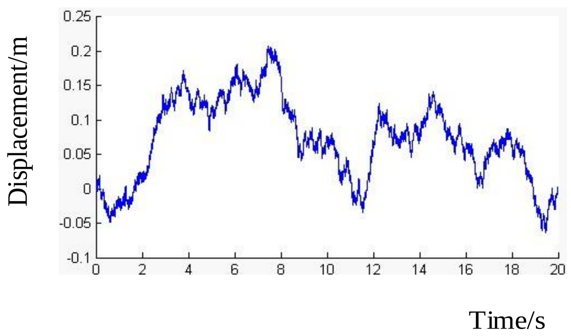

Fig. 5: G level ground profile

An articulated hauler is chosen for this study. The model parameters are given in Table 2. Vehicle road simulation test is carried out using Matlab/Simulink toolbox. To study the acceleration and displacement response of the vehicle system from different pavement conditions when the speed and complex rigidity of the suspension device are kept unchanged. Here, we suppose the vehicle travel at common speed of 30 kmph on C, D, E and G level ground profiles. At the same time, the hauler is working with the full load. Figs. 6 to 9 show a comparison of the vertical acceleration responses between visco-elastic suspension and rigid suspension for the considered ground profiles with the vehicle's speed of 30 kmph. Table 3 provides a summary of maximum vertical acceleration obtained from the simulations using rigid and tubular visco-elastic suspension system. The vibration level is decreased by installing tubular visco-elastic suspension system. The vehicle's performance gets worse with the deterioration of road condition. When the articulated hauler' speed increases, the vertical vibration of vehicle increases.

Table 2: Vehicle model parameters

Vehicle model	Value	Unit
m(half mass)	3300	kg
m_1, m_2	592, 484	kg
k_{a1}, k_{a2}	1.78×10^6, 1.70×10^6	N/m
$k_{b1} = k_{b2}$	8.37×10^7	N/m
$c_{b1} = c_{b2}$	27200	Ns/m
c_{a1}, c_{a2}	4236, 3863	Ns/m

Table 3: Vertical acceleration reduction by visco-elastic suspension

Suspension/Road profile	Max. acceleration (m/s^2)			
	C-Level	D-Level	E-Level	G-Level
Rigid	0.114	0.296	0.821	2.334
Tubular visco-elastic	0.036	0.106	0.251	1.036
Reduction (%)	31.6%	35.8%	30.6%	44.4%

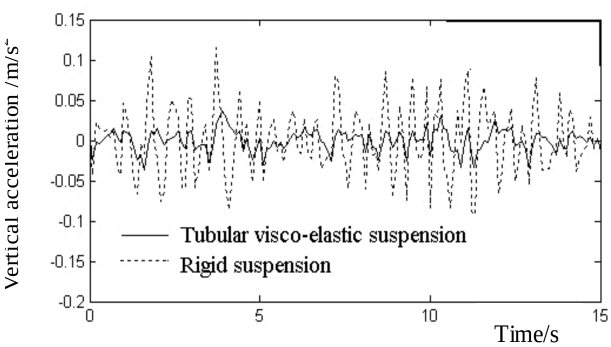

Fig. 6: Vertical acceleration responses for C level profile

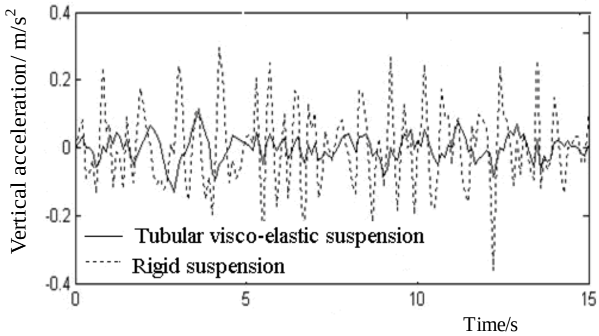

Fig. 7: Vertical acceleration responses for D level profile

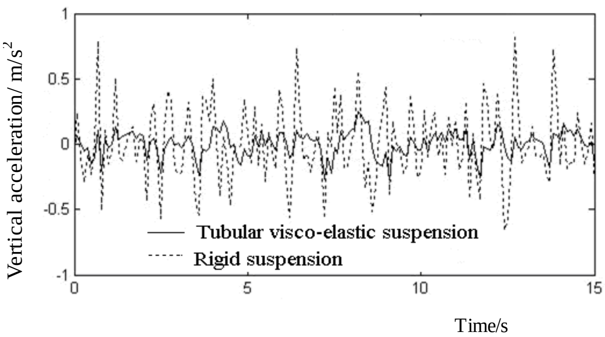

Fig. 8: Vertical acceleration responses for E level profile

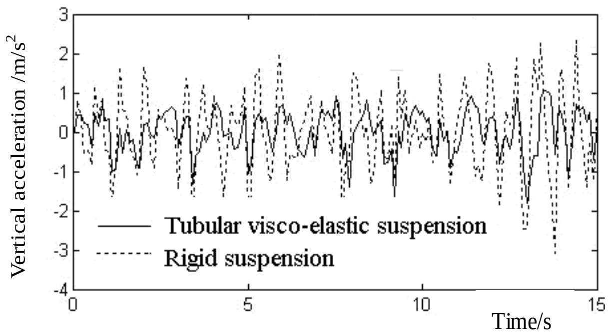

Fig. 9: Vertical acceleration responses for G level profile

The vehicle vertical displacement responses between rigid and tubular visco-elastic suspension were compared and shown in Figs. 10 to 13. The maximum vertical displacement for C Level ground profile is 2.126mm when the articulated hauler is installed with rigid suspension. However, when the rigid suspension is replaced by tubular visco-elastic suspension system, the maximum vertical displacement becomes 1.657mm. Although the vertical displacements for vehicle with tubular visco-elastic suspension are sometimes found to be higher, its vibration-isolation during the whole time is found to be good when compared to rigid suspension.

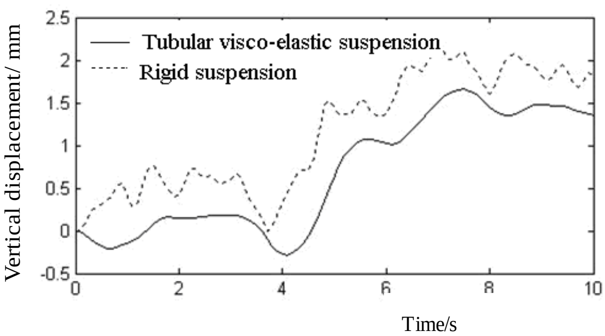

Fig. 10: Vertical displacement responses for C level profile

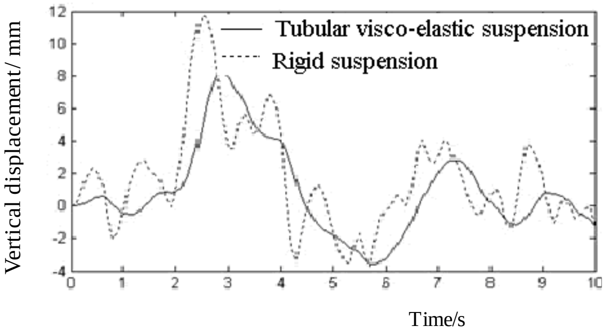

Fig. 11: Vertical displacement responses for D level profile

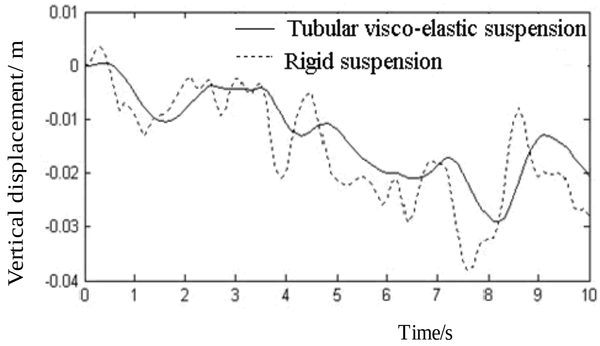

Fig. 12: Vertical displacement responses for E level profile

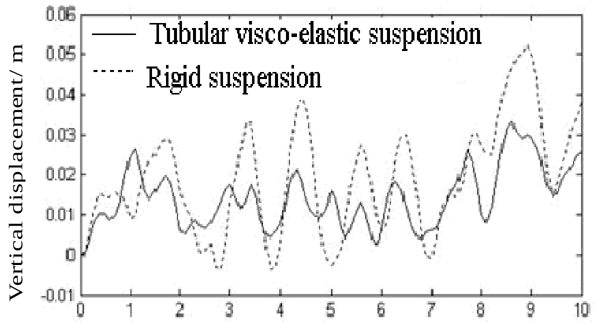

Fig. 13: Vertical displacement responses for G level profile

4. Conclusions

A new type of tubular visco-elastic suspension is proposed in this paper according to the characteristic of visco-elastic material and the structure of wheeled construction vehicle's chassis. A mathematical model for half of vehicle with tubular visco-elastic suspension is established. Vehicle road simulation test is done using Matlab/Simulink toolbox. The vertical acceleration and displacement responses are compared between two types of suspension on C, D, E and G level ground profiles with constant vehicle's speed of 30kmph. The simulation results show that the vibration level is decreased by installing tubular visco-elastic suspension system. The vehicle's performance gets worse with the deterioration of road conditions.

ACKNOWLEDGEMENTS:

The authors would like to thank National Natural Science Foundation of China for Young Scholars (Grant No. 51405323) and Taiyuan University of Science and Technology Foundation for Doctor (Item No. 20132002) for their support to this research project.

REFERENCES:

[1] A. Pazookia, S. Rakheja and D.P. Cao. 2012. Modeling and validation of off-road vehicle ride dynamics, *Mechanical Systems and Signal Processing*, 28, 679-695. http://dx.doi.org/10.1016/j.ymssp.2011.11.006.

[2] I. Maciejewski, L. Meyer and T. Krzyzynski. 2009. Modeling and multi-criteria optimization of passive seat suspension vibro-isolating properties, *J. Sound and Vibration*, 324, 520-538. http://dx.doi.org/10.1016/j.jsv. 2009.02.021.

[3] O.S. Hong. 2005. Hearing loss among operating engineers in American construction industry, *Int. Archives of Occupational and Environmental Health*, 78, 565-574. http://dx.doi.org/10.1007/s00420-005-0623-9.

[4] U. Sonmez. 2008. Weigh-in-motion studies using strip-type sensors: the preliminary results, *Int. J. Heavy Vehicle Systems*, 15, 1-25. http://dx.doi.org/10.1504/ IJHVS.2008.017981.

[5] P.H. Cronje and P.S. Els. 2010. Improving off-road vehicle handling using an active anti-roll bar, *J. Terramechanics*, 47, 179-189. http://dx.doi.org/10.1016/ j.jterra.2009.09.003.

[6] C. Liu and D.C. Song. 2007. Construction of suspension system based on model of engineering vehicle, *China Manufacturing Information Magazine*, 36, 62-64.

[7] J.F. Brunel, P. Dufrenoy and F. Demilly. 2004. Modeling of squeal noise attenuation of ring damped wheels, *Applied Acoustics*, 65, 457-471. http://dx.doi.org/10. 1016/j.apacoust.2003.12.003.

[8] T.H. Fronk, K.C. Womack, K.D. Ellis and L.W. Finlinson. 1995. Finite element modeling of damping in constrained layer composite structures induced by in plane loads using ADINA, *Computers & Structures*, 56(2/3), 357-363. http://dx.doi.org/10.1016/0045-7949(95)00028-F.

[9] M.G. Sainsbury and R.S. Masti. 2007. Vibration damping of cylindrical shells using strain-energy-based distribution of an add-on viscoelastic treatment, *Finite Elements in Analysis and Design*, 43, 175-192. http://dx.doi.org/10.1016/j.finel.2006.09.003.

[10] H. Imine and V. Dolcemascolo. 2008. Sliding mode observers to heavy vehicle vertical forces estimation, *Int. J. Heavy Vehicle Systems*, 15, 53-63. http://dx.doi.org/10. 1504/IJHVS.2008.017983.

[11] M. Zehsaz, M.H. Sadeghi, M.M. Ettefagh and F. Shams. Tractor cabin's passive suspension parameters optimization via experimental and numerical methods, *J. Terramechanics*, 48(6), 439-450.