Journal of KONES Powertrain and Transport, Vol. 24, No. 1 2017

ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/01.3001.0010.2826

QUARTER CAR MODEL TO EVALUATE BEHAVIOUR UNDER ROAD AND BODY EXCITATION

Adrian Ioan Niculescu

Institute of Solid Mechanics of the Rumanian Academy, Department of Dynamic Systems
Constantin Mille Street 15, 010141 Bucharest, Romania
tel.:+40 745187595, fax: +4021 3126736
e-mail: adrian_ioan_niculescu@yahoo.com

Antoni Jankowski

Institute of Aviation
Krakowska Av. 110/114, 02-256 Warsaw, Poland
tel.: +48 228460011, fax: +48 228464432
e-mail: antoni.jankowski@ilot.edu.pl

Miroslaw Kowalski

Air Force Institute of Technology
Ks. Boleslawa Street 6, 01-494 Warsaw, Poland
tel.: +48 261851303, fax: +48 261851313
e-mail: miroslaw.kowalski@itwl.pl

Tudor Sireteanu

Institute of Solid Mechanics of the Rumanian Academy, Department of Dynamic Systems
Constantin Mille Street 15, 010141 Bucharest, Romania
tel.:+40 740176559, fax: +4021 3126736
e-mail: siretimsar@yahoo.com

Abstract

The paper presents a quarter car model two degrees of freedom (wheel and body), with vertical guiding system, the model being equipped with suspension stroke limiters and with excitation by wheel and/ or by body. The model reproduces elastic and damping characteristics of wheel and of rebound and compression stopper bumpers, the spring elastic characteristic and the shock absorber damping characteristic on rebound and compression, function piston speed. The road profile is generated with simple or summation of harmonic functions, or by reproducing real roads. The forces acting on full vehicle body e.g. aerodynamic and inertial forces are reproduced in the proposed quarter model by vertical forces reduced to the analysed quarter part. Thus, the model can be used for evaluation the vertical and horizontal stability at acceleration, deceleration, pitch and roll, at aerial forces, the body ground clearance and the comfort. The model can evaluate the influence of the damping and elastic characteristics of suspension and wheel, of the static position, of the vehicle load state, of the road profile and of the external forces, to the vehicle behaviour.

Keywords: *quarter car model, shock absorber, simulation, comfort, stability, clearance, road profile, external forces*

1. Introduction

The vehicle moving realises under excitation forces generated by the road profile and by the aerodynamic and inertial forces and torques acting directly against the vehicle body.

The aerodynamic forces and torques acting in vehicle pressure centre and inertial forces and torques acting in vehicle gravity centre give forces and moments, which are stabilized by suspension reaction forces, so the vehicle behaviour is influenced by both the road profile and vehicle trajectory and driving speed. This reason we propose a quarter car model able to reproduce both these excitation made by road against the wheel and by aerodynamic and inertial forces against the vehicle body.

Figure 1 shows a vehicle with independent suspensions, all the four suspensions having two degrees of freedom.

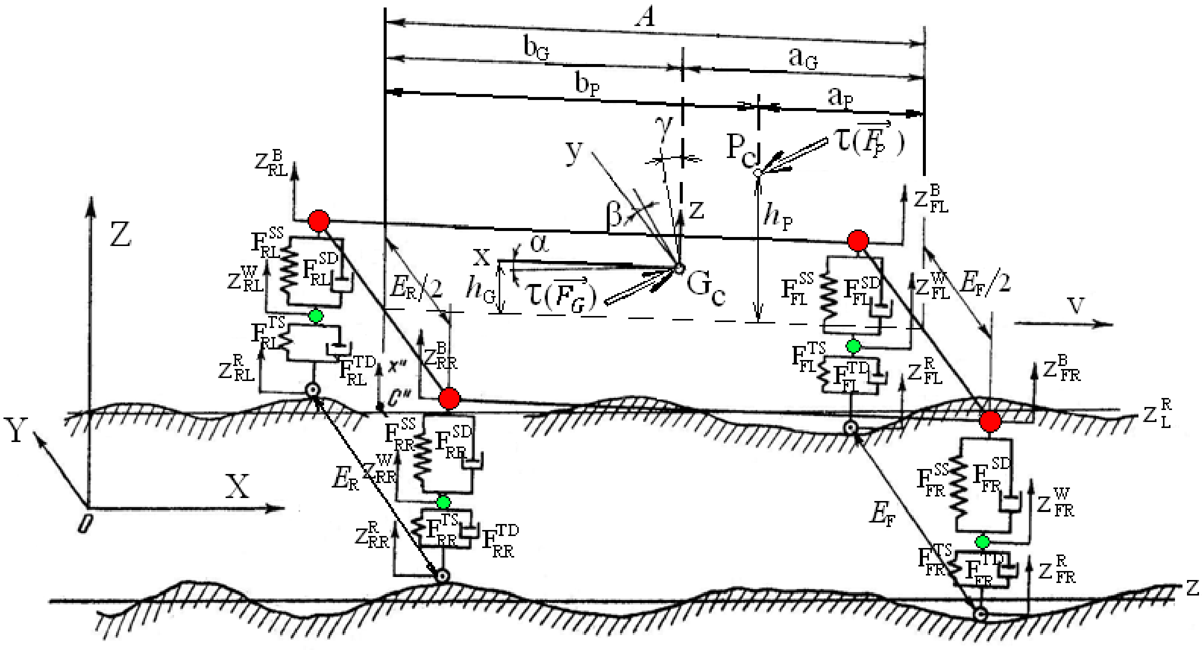


Fig. 1. Vehicle model considering road and body excitations

The vehicle excitations are realised:

- in the vehicle gravity centre Gc by the inertial twister of forces and moments $\tau(\overrightarrow{F_G, M_G})$ generated at acceleration, deceleration or other external actions and trajectory changing,
- in the pressure centre Pc by the aerodynamic twister of forces and moments $\tau(\overrightarrow{F_P, M_P})$ generated by the relative movement air-vehicle,
- in the wheel-road contact points by the road profile unevenness, z^R_{FL}, z^R_{FR}, z^R_{RL}, z^R_{RR}

The equations (1) and (2) define the twisters of force and moment and equations (3)-(6):

$$\tau\left(\overrightarrow{F_G, M_G}\right) = \begin{cases} \overrightarrow{F_G} \\ \overrightarrow{M_G} \end{cases}, \tag{1}$$

$$\tau\left(\overrightarrow{F_P, M_P}\right) = \begin{cases} \overrightarrow{F_P} \\ \overrightarrow{M_P} \end{cases}. \tag{2}$$

The Tab. 1 show the significations of the symbols used in Fig. 1 and in equations (1)-(6):

$$\overrightarrow{F_G} = \begin{cases} F_{Gx} \cdot \vec{\imath} \\ F_{Gy} \cdot \vec{\jmath}, \\ F_{Gz} \cdot \vec{k} \end{cases} \tag{3}$$

$$\overrightarrow{M_G} = \begin{cases} M_{Gx} \cdot \vec{\imath} \\ M_{Gy} \cdot \vec{\jmath}. \\ M_{Gz} \cdot \vec{k} \end{cases} \tag{4}$$

Tab. 1. Signification of the elements from Fig. 1 and equations (1)-(6)

Symbol	Element	Symbol	Element
A	Wheelbase	M_{Pz}	Z component of movement acting in air pressure centre
a	position of G_C relative to the front axle	z_{RL}^{B}	Displacement of the rear left sprung mass
b	position of G_C relative to the front axle	z_{RL}^{W}	Displacement of the rear left wheel
E_F	front track	z_{RL}^{R}	Rear left longitudinal profile of the road
E_R	rear track	z_{RR}^{B}	Displacement of the rear right sprung mass
v [m/s]	Longitudinal speed	z_{RR}^{W}	Displacement of the rear right wheel
$\tau(\overrightarrow{F_G, M_G})$	twister of force and moment acting in gravity centre	z_{RR}^{R}	Rear right longitudinal profile of the road
$\overrightarrow{F_G}$	force acting in gravity centre	F_{FL}^{SS}	Front left suspension spring force
F_{Gx}	X component of force acting in gravity centre	F_{FL}^{SD}	Front left suspension damping force
F_{Gy}	Y component of force acting in gravity centre	F_{FL}^{TS}	Front left tire elastic force
F_{Gz}	Z component of force acting in gravity centre	F_{FL}^{TD}	Front left tire damping force
$\overrightarrow{M_G}$	Movement acting in gravity centre	F_{FR}^{SS}	Front right suspension spring force
M_{Gx}	X component of movement acting in gravity centre	F_{FR}^{SD}	Front right suspension damping force
M_{Gy}	Y component of movement acting in gravity centre	F_{FR}^{TS}	Front right tire elastic force
M_{Gz}	Z component of movement acting in gravity centre	F_{FR}^{TD}	Front right tire damping force
$\vec{\imath}$	unit vector of X axle	F_{RL}^{SS}	Rear left suspension spring force
$\vec{\jmath}$	unit vector of Y axle	F_{RL}^{SD}	Rear left suspension damping force
$\vec{k}$	unit vector of Z axle	F_{RL}^{TS}	Rear left tire elastic force
G_C	gravity centre	F_{RL}^{TD}	Rear left tire damping force
h_G	Gravity centre position	F_{RR}^{SS}	Rear right suspension spring force
α	Angle of twister of force and moment relative to X axle	F_{RR}^{SD}	Rear right suspension damping force
β	Angle of twister of force and moment relative to Y axle	F_{RR}^{TS}	Rear right tire elastic force
γ	Angle of twister of force and moment relative to Z axle	F_{RR}^{TD}	Rear right tire damping force
$\tau(\overrightarrow{F_P, M_P})$	aerodynamic twister of force and moment	P_C	centre of pressure
$\overrightarrow{F_P}$	aerodynamic force acting in air pressure centre	h_P	Pressure centre position relative to
F_{Px}	X component of force acting in air pressure centre	z_{FL}^{B}	Displacement of the front left sprung mass
F_{Py}	Y component of force acting in air pressure centre	z_{FL}^{W}	Displacement of the front left wheel
F_{Pz}	Z component of force acting in air pressure centre	z_{FL}^{R}	Front left longitudinal profile of the road
$\overrightarrow{M_P}$	aerodynamic movement acting in air pressure centre	z_{FR}^{B}	Displacement of the front right sprung mass
M_{Px}	X component of movement acting in air pressure centre	z_{FR}^{W}	Displacement of the front left wheel
M_{Py}	Y component of movement acting in air pressure centre	z_{FR}^{R}	Front left longitudinal profile of the road

$$\overrightarrow{F_P} = \begin{cases} F_{Px} \cdot \vec{\imath} \\ F_{Py} \cdot \vec{\jmath}, \\ F_{Pz} \cdot \vec{k} \end{cases} \tag{5}$$

$$\overrightarrow{M_P} = \begin{cases} M_{Px} \cdot \vec{\imath} \\ M_{Py} \cdot \vec{\jmath}. \\ M_{Pz} \cdot \vec{k} \end{cases} \tag{6}$$

2. Triaxial quarter car model

For studying longitudinal and transversal stability uses a triaxial quarter car model. Fig. 2 shows a triaxial quarter car model for rear left sidecar.

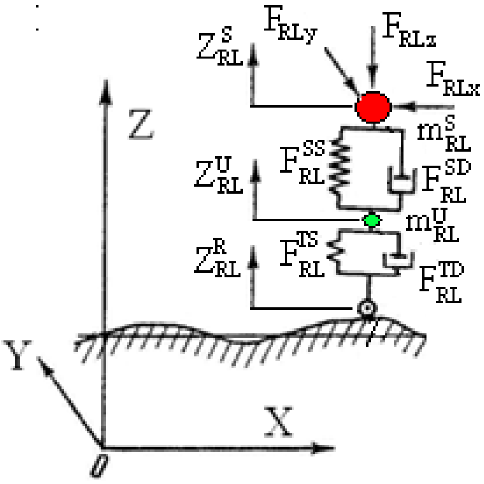


Fig. 2. Triaxial quarter car model

The elements from Fig. 2 are presented in Tab. 2.

Tab. 2. The elements from Fig. 2

Symbol	Element		Symbol	Element
m_{RL}^{S}	sprung mass of rear left car part		F_{RLx}	X component of forces acting against the sprung mass
m_{RL}^{U}	unsprung mass of rear left car part		F_{RLy}	Y component of forces acting against the sprung mass
F_{RL}^{SS}	suspension spring force of rear left car part		F_{RLz}	Z component of forces acting against the sprung mass
F_{RL}^{SD}	suspension damping force of rear left car part		z_{RL}^{S}	vertical displacement of sprung mass
F_{RL}^{TS}	tire elastic force of rear left car part		z_{RL}^{U}	vertical displacement of unsprung mass
F_{RL}^{TD}	tire damping force of rear left car part		z_{RL}^{R}	vertical road profile

Usually, for suspension studies, it uses biaxial quarter car model similar those presented in the next chapter.

3. Biaxial quarter car model

Figure 3 presents the biaxial quarter car model, the elements being defined in the Tab. 2.

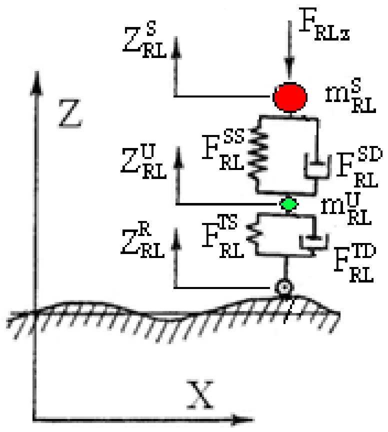


Fig. 3. Biaxial quarter car model

4. Vertical force acting against the sprung mass of quarter car model

F_{RLz} the vertical force acting against the sprung mass of quarter car model is generated by the forces and moments F_{Gx}, F_{Gz}, F_{Px}, F_{Pz}, M_{Gx}, M_{Gy}, M_{Px}, M_{Py}.

Considering the system symmetric to the plane XOZ and the rigidities of each suspension identically and the same front and rear track , the contributions of previous forces and moments to the vertical force acting against the sprung mass of quarter car model F_{RLz} are according next equations:

F_{Gx} gives:

$$F_{RLz} = \frac{h_G}{2l} F_{Gx}, \tag{7}$$

F_{Gy} gives:

$$F_{RLz} = \frac{h_G}{2 \cdot E_R} F_{Gy}, \tag{8}$$

F_{Gz} gives:

$$F_{RLz} = \frac{a_G}{2l} F_{Gz}, \tag{9}$$

F_{Px} gives:

$$F_{RLz} = \frac{h_P}{2l} F_{Px}, \tag{10}$$

F_{Py} gives:

$$F_{RLz} = \frac{h_P}{2E_R} F_{Py}, \tag{11}$$

F_{Pz} gives:

$$F_{RLz} = \frac{a_P}{2l} F_{Pz}, \tag{12}$$

M_{Gx} gives:

$$F_{RLz} = \frac{M_{Gx}}{2E_R}, \tag{13}$$

M_{Gy} gives:

$$F_{RLz} = \frac{M_{Gy}}{2l}, \tag{14}$$

M_{Px} gives:

$$F_{RLz} = \frac{M_{Px}}{2E_R}, \tag{15}$$

M_{Py} gives:

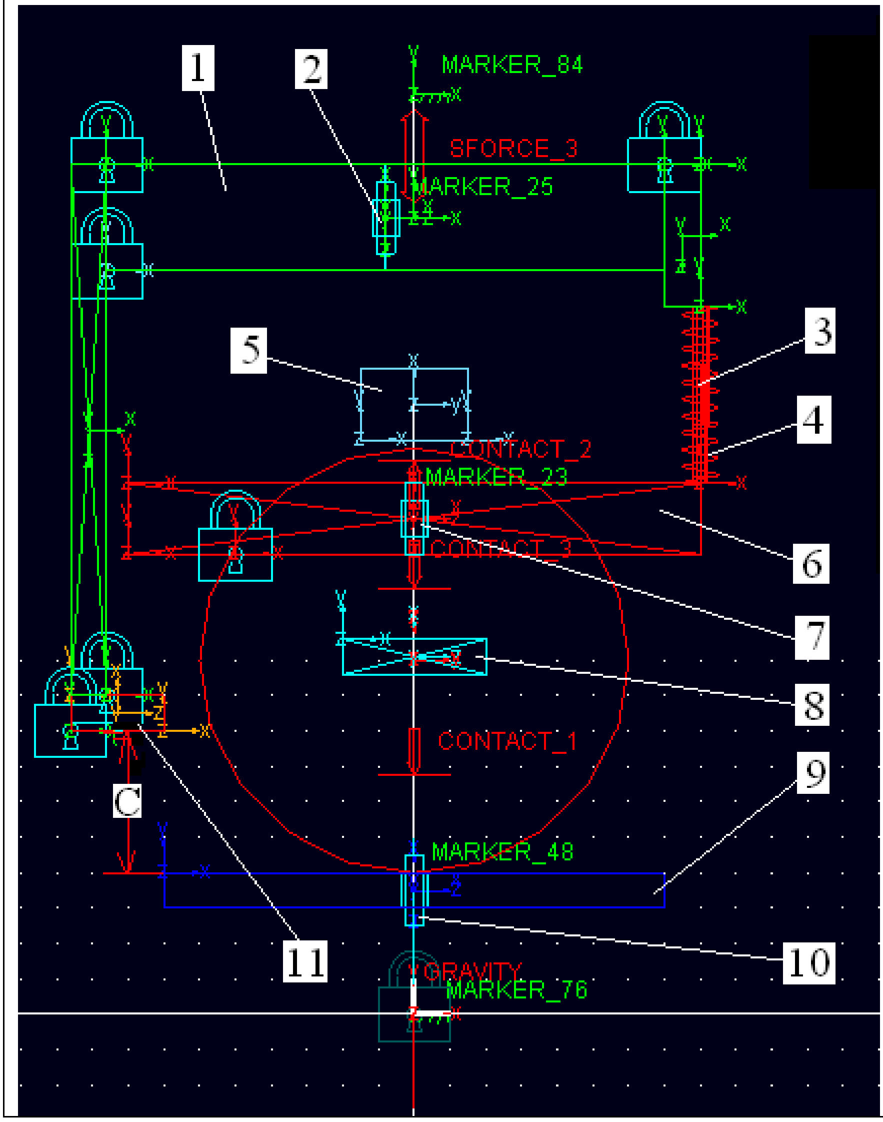
$$F_{RLz} = \frac{M_{Py}}{2l}. \tag{16}$$

The vertical force acting against the sprung mass of quarter car model F_{RLz} obtains by summation all previous forces, according the equation (17).

$$F_{RLz} = \frac{h_G}{2l}F_{Gx} + \frac{h_G}{2E_R}F_{Gy} + \frac{a_G}{2l}F_{Gz} + \frac{h_P}{2l}F_{Px} + \frac{h_P}{2E_R}F_{Py} + \frac{a_P}{2l}F_{Pz} + \frac{M_{Gx}}{2E_R} + \frac{M_{Gy}}{2l} + \frac{M_{Px}}{2E_R} + \frac{M_{Py}}{2l}. \quad (17)$$

5. Proposed quarter car model

The virtual model was realized with ADAMS View software and it is presented in Fig. 4.



The component elements are:

1. sprung vehicle mass
2. translational joint for sprung mass
3. damper
4. spring
5. compression stopper buffer
6. axle
7. translational joint for axle
8. rebound stopper bumper
9. road
10. translational joint for road
11. under body bottom level

C – body-ground clearance

The contact forces are:

Contact 1: Force between tire and ground

Contact 2: Force in rebound stopper bumper

Contact 3: Force in compression stopper bumper

SFORCE_3: Force against sprung mass

Fig. 4. The quarter car model realized with Adams software, View module

6. Simulation to evaluate the influence of force acting directly against the sprung mass

Simulations on two identically quarter car model, the both being excited by the same road, one of them being excited supplementary against the sprung mass, reveal the influence of the body direct excitation.

This case the excitation against the vehicle body is oscillatory.

6.1. Test conditions

Both models are excited by road with a harmonic function according equation (18).

$$z = 0.04 \bullet \sin(2\pi \bullet 3 \bullet time), \tag{18}$$

where:

oscillation amplitude	0.04 [m],
frequency	3 [Hz].

The model 1 is supplementary excited against body by a force according (19).

$$F = 800 \bullet \sin(2\pi \bullet 0.2 \bullet time), \tag{19}$$

where:

force amplitude	800 [N],
frequency	0.2 [Hz].

6.2. Numerical application

The vertical interaction has been simulated using ADAMS software View module.

The characteristics of the considered model of suspension are presented in Tab. 3.

Tab. 3. Suspension characteristics

Symbol	Value	Units	Parameter
m_U^S	240	[kg]	sprung mass at Minimal loaded (noted Unload)
m_U	35	[kg]	unsprung mass
m_{T0}	275	[kg]	total mass at minimal loaded
l	0.236	[m]	overall suspension stroke
k_P	14085	[N/m]	pneumatic suspension rigidity
k_T	200000	[N/m]	tire rigidity
k_{CB}	250000	[N/m]	compression stopper buffer rigidity
k_{RB}	500000	[N/m]	rebound stopper buffer rigidity

The used damping characteristic is presented in Tab. 4.

Tab. 4. Shock absorber damping characteristic

Speed [m/s]		0.05	0.1	0.2	0.3	0.4	0.55	0.75	0.95	1.5	3
Force [N]	Rebound	70	170	410	650	800	1030	1320	1600	2450	4600
	Compression	170	210	320	440	530	650	830	1000	1500	2740

6.3. Results

The suspension quality will be evaluated by the body stability, comfort and body ground clearance, by adherence and road protection and by body-axle protection.

Figure 5 shows the diagrams for model M1 excited by road and body and Fig. 6 for model M2 excited only by road.

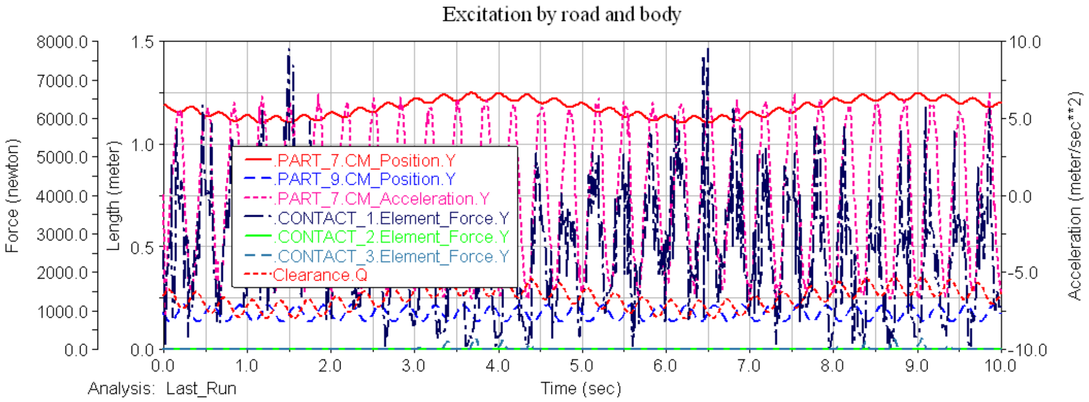


Fig. 5. Diagrams for model M1 excited by road and body

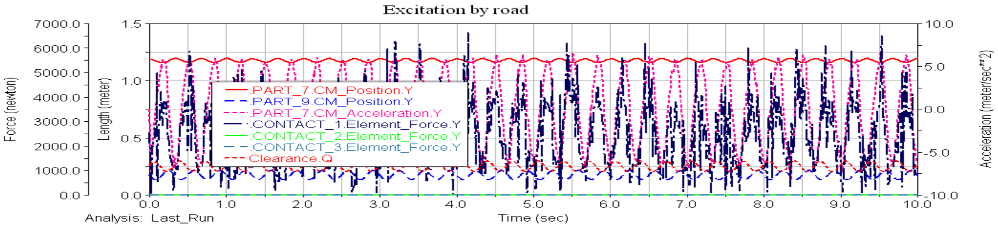


Fig. 6. Diagrams for model M2 excited only by road

In the Tab. 5 are presented the significant parameters for evaluate the influence of the supplementary body excitation.

Tab. 5. Comparative results

Model	Excitation	STABILITY Body vertical position [m]			Comfort Body Acceleration [m/s^2]	CLEARANCE [m]	ROAD PROTECTION/ ADHERENCE Tire Contact Force [N]		VEHICLE PROTECTION Forces in Bumpers [N]	
									Rebo-und	Compres sion
		Max	Min	Δ	Max	Min	Max	Avg	Max	Max
M1	Road + Body	1.249	6.72	0.147	6.72	0.148	7805	2608	0	296
M2	Road	1.195	6.57	0.039	6.57	0.206	6614	2541	0	0
M2 better [%]		+ 4.3	+ 31.4	+ 2.2	+ 2.2	+39.2	+39.2	-2.6	0	+100

7. Conclusions

The paper gives solution to evaluate on a quarter-car model the influence of the road and body combined excitation acting on a vehicle.

The example shows the supplementary excitation worsen the vehicle performances.

References

[1] Niculescu, A. I., Alexandru, C., Jankowski, A., *A Solution for Crash and High Ground Unevenness Effect Reducing*, Journal of KONES, Vol. 15, No. 3, ISSN 1231-4005, pp. 389-396, 2008.

[2] Niculescu, A. I., Jankowski, A., Kowalski, M., Sireteanu, T., *Advantages Conferred by Shock Absorbers with Cylindrical Actuator Application to Landing Gear,* Journal of KONES, Vol. 23, No. 1, ISSN 1231-4005, pp. 255-262, 2016.

[3] Niculescu, A. I., Jankowski, A., Kowalski, M., Sireteanu, T., *On the new concept and advantages of the integrated shock absorber – air spring – ISAS*, Proceedings of the European Automotive Congress EAEC-ESFA, Springer International Publishing, ISBN: 978-3-319-27276-4, pp. 93-103, 2015.

[4] Niculescu, A. I., Jankowski, A., Sireteanu, T., *On „VZN" damper behaviour at crash*, Journal of KONES Powertrain and Transport, Vol. 16, No. 2, pp. 369-374, 2009.

[5] Sireteanu, T., Gundisch, O., Paraian S., *Vibratiile aleatoare ale automobilelor,* Editura Tehnica, Bucuresti 1981.