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SIMULATION OF A MOTOR VEHICLE BRAKING WITH THE UNLOCKED STEERING WHEEL

Symulacja ruchu samochodu hamującego bez zablokowanego koła kierownicy

Abstract: *In this paper the results of a simulation of a sports vehicle's braking maneuver in the adopted road conditions has been presented. The aim of this paper was to analyze the results and compare them with the ones obtained in the previous paper by the author, also prepared for the acceleration maneuver. At the same time considerations on the damaging effect of the road irregularities have been presented as this time no straightforward steering was included, so the vehicle could move freely. The simulated braking of the vehicle's model started at the speed of 100 km/h and its duration was 10 s.*

As in the previous paper the random road irregularities had three different amplitudes which enabled analysis of vehicle's deceleration on a different road conditions each time. Almost different profiles were also assumed for the left and the right wheels of the vehicle's model which moved on the dry and the icy road surface.

Keywords: vehicle's braking, random road irregularities, free motion

Streszczenie: *W artykule przedstawiono wyniki symulacji manewru hamowania pojazdu sportowego w przyjętych warunkach drogowych. Celem pracy była analiza wyników i porównanie ich z wynikami uzyskanymi w poprzedniej pracy autora, również przygotowanymi dla manewru przyspieszania. Jednocześnie przedstawiono rozważania na temat szkodliwego wpływu nierówności drogowych, gdyż tym razem nie uwzględniono sterowania prostoliniowego, tak aby pojazd mógł się swobodnie poruszać. Symulowane hamowanie modelu pojazdu rozpoczęło się przy prędkości 100 km/h i trwało 10 s.*

Podobnie jak w poprzedniej pracy, losowe nierówności drogi miały trzy różne amplitudy, co umożliwiło analizę hamowania pojazdu w każdorazowo innych warunkach drogowych. Założono także niemal różne profile lewego i prawego koła modelu pojazdu poruszającego się po suchej oraz oblodzonej nawierzchni.

Słowa kluczowe: hamowanie samochodu, losowe nierówności drogi, ruch swobodny

1. Introduction

The ability of a motor vehicle to brake efficiently is one of the most essential features affecting the road traffic safety, especially in the unforeseen events. At the same time such a maneuver can cause various unpredicted effects, such as oversteering, depending on the road conditions. The properly controlled braking process enables avoidance of the often dangerous events in road traffic, particularly when the random irregularities occur on the road surface. Multiple research on the vehicle braking has so far been conducted, also in terms of control of this process, e.g. for the electric vehicles gaining more popularity [1].

Another issues related to braking of motor vehicles have been undertaken, e.g. in [2] where ABS and the adopted harsh road conditions were adopted to analyze a process of low velocity braking. A general analysis of both the braking and the stopping distance of a motor vehicle was a subject of, e.g. [3], while in [4] the advantages of the automated braking in emergency situations were considered. Such problems, as the spread of cargo in truck as a factor determining the braking efficiency were a subject of, e.g. [5] and in [6] research on the braking efficiency were presented.

Problems related to the random road profiles have been discussed in many works so far, e.g. [7] where an attempt to estimate the most severe irregularities was made basing on the vehicles' response. One of the main problems in the motion of motor vehicles are the phenomena between the tires and the road surface, especially randomly uneven. This has been widely discussed an used over the years, among others in [8] and [9].

The aim of this paper is to discuss the results of the braking a vehicle's model on a randomly uneven road but without the straightforward steering and compare them to those obtained in the author's previous work [10]. The braking here has also been adopted for the initial speed of 100 km/h along with three various amplitudes of the road irregularities. Thanks to this some other aspects of the braking on an uneven road could be considered.

2. Assumptions regarding the simulations

The same vehicle's model as in [10] was used (Fig. 1). The loading masses have also been adopted in accordance with [10] as well as the resulting coordinates of the center of mass and the moments of inertia of the whole vehicle which were presented in table 1. As previously, the above mentioned parameters of the vehicle's model before and after adding the additional masses have been determined versus the so-called 'origo' point (Fig. 1) and in relation to the axes intersecting the 'origo'. It is the point located on the road plane but moving along with the vehicle during its motion. In [10] it was explained why it is more convenient to use this specific point instead of, e.g. the center of mass or any other specific point.

The mass – inertia parameters did not change compared to [10] because the main aim was to perform the presented maneuver for the same vehicle loading. One thing that changed was the final brake intensity which will be discussed further.

As in [10] the vehicle's model was equipped with the FTIRE tire model enabling the motion along a randomly uneven road surface. Other assumptions such as partial nonlinearity of the vehicle's suspension remained unchanged so the simulations could be performed in almost the same conditions. Of course, MSC Adams/Car was used as a simulation software, as previously.
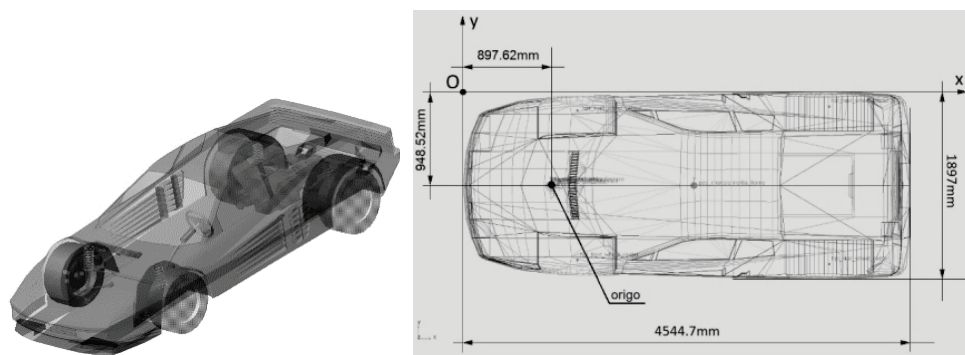

Fig. 1. The vehicle's model and the location of the 'origo' point [10]

Table 1

Mass – inertia parameters of the unladen and laden vehicle's model used in the simulations [19]

	unladen vehicle		laden vehicle	
	vehicle's body	whole vehicle	vehicle's body	whole vehicle
mass	995 kg	1528 kg	1153 kg	1686 kg
center of mass location relative to the 'origo' point	xc=1.5 m, yc=0, zc=0.45 m	xc=1.75 m, yc=-0.0014 m, zc=0.43 m	xc=1.508 m, yc=0.012 m, zc=0.452 m	xc=1.73 m, yc=-0.007 m, zc=0.435 m
moment of inertia (I_X)	401 kg·m^2	583 kg·m^2	436 kg·m^2	618 kg·m^2
moment of inertia (I_Y)	2940 kg·m^2	6129 kg·m^2	3361 kg·m^2	6550 kg·m^2
moment of inertia (I_Z)	2838 kg·m^2	6022 kg·m^2	3225 kg·m^2	6409 kg·m^2
moment of deviation (I_{XY})	0	-1.9 kg·m^2	2.15 kg·m^2	1.95 kg·m^2
moment of deviation (I_{ZX})	671 kg·m^2	1160 kg·m^2	787 kg·m^2	1276 kg·m^2
moment of deviation (I_{YZ})	0	-1.3 kg·m^2	0.64 kg·m^2	0.51 kg·m^2

Because there were 8 simulations performed in the paper [10] for the previous tasks, the same 8 simulations have been performed in this paper (table 2) but with the lack of the straightforward steering (Fig. 2) and more intensive braking. The speed at the beginning of the braking was 100 km/h regardless the conditions (dry or icy road surface) and the whole maneuver lasted for 10 s. As in [10] the two parameters (*intensity* and *cor_rl*) played a crucial role in specifying the road conditions of motion. In [10] it was stressed that the *intensity* determines the amplitudes of the random irregularities on the road and the *cor_rl* enables determination whether the profiles of the right and the left wheels are close to similar or nearly different.

Table 2

Configurations adopted for the vehicle's braking maneuver [based on 19]

	road		intensity	corrl	initial V [km/h]
configuration 1	flat	dry	-	-	100
configuration 1i	flat	icy	-	-	100
configuration 2	uneven	dry	0.5	0.2	100
configuration 2i	uneven	icy	0.5	0.2	100
configuration 3	uneven	dry	1.0	0.2	100
configuration 3i	uneven	icy	1.0	0.2	100
configuration 4	uneven	dry	1.5	0.2	100
configuration 4i	uneven	icy	1.5	0.2	100

The amplitudes of the random irregularities on the road were specified with the use of the *intensity* parameter and, as in [10] three values have been adopted: 0.5, 1 and 1.5 reflecting the growing amplitudes of these irregularities. Also in the discussed case the *cor_rl* was set to 0.2 denoting that the the profiles for the left and the right wheels were almost different because this parameter varies between 0 and 1. This caused the simulated maneuver more realistic, about which the author mentioned in [10] as well.

In Fig. 2 the initial settings for all eight simulations have been presented with the initial speed 100 km/h and the free steering input adopted, so no specific control of the vehicle was adopted. The final brake, which specifies the force applied to the brake pedal, was set to 60 in order to obtain more rapid braking, contrary to [10] where its value was 20.
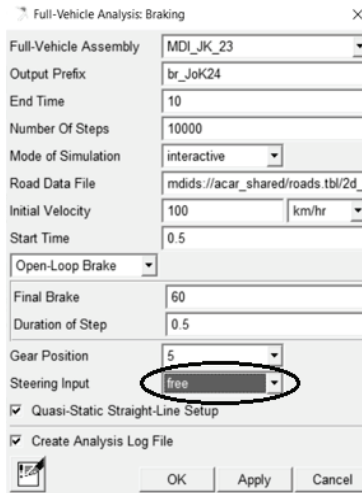
Fig. 2. Adoption of the free motion driver control [own research based on MSC Adams/Car]

3. Selected results

The adopted free steering input with no straightforward motion was the key factor having a potential influence on the response of a vehicle model during braking. It was also a main aim of this paper to examine if braking on an uneven or icy road would force the vehicle to deviate from the initial direction of motion if the random irregularities on the road could become any additional distractor to the braking.

In Figs. 3 and 4 the lateral displacement has been presented for the eight adopted configurations from table 2. Of course the distance covered by the vehicle model was much shorter for the icy road surface which was caused by both the reduced coefficient of adhesion and the software error unable to integrate the equations of motion due to the lack of straightforward steering.
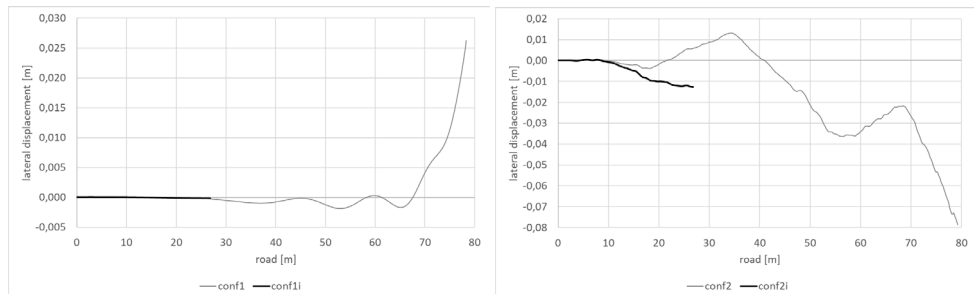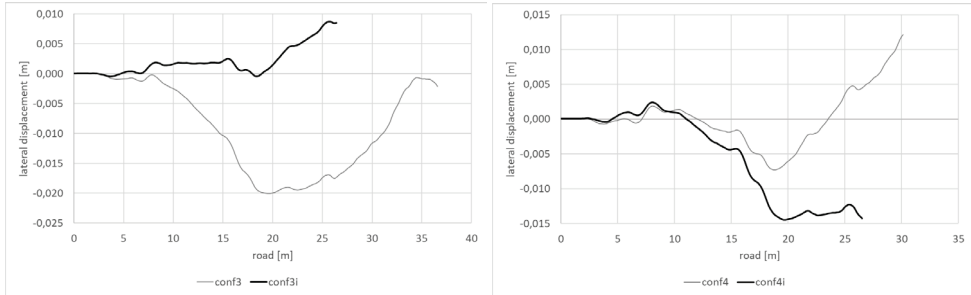

Fig. 3. Lateral displacement for the configurations 1, 1i, 2 and 2i

Fig. 4. Lateral displacement for the configurations 3, 3i, 4 and 4i

In further part of this chapter the results obtained here will be compared to those from paper [10] where a straightforward motion along with less rapid braking was taken into account.

The icy road did not cause the greater braking distance as in [10], mainly because the lack of straightforward steering and more rapid braking. In [10] this distance on an icy road was greater by about 70 m versus the dry road for the configurations 1, 1i, 2 and 2i and by about 50 m for the configurations 3, 3i, 4 and 4i. Here, however, the braking distance on an icy road versus the dry road was shorter by about 50 m for the configurations 1, 1i, 2 and 2i (Fig. 3) and by about 10 m for the configurations 3, 3i 4 and 4i (Fig. 4). It was undoubtedly caused by the adopted free steering and the increased braking force. The lateral displacement is insignificantly small, but the shorter distance on the icy road must have also been caused by the vehicle rotating about its vertical axis of inertia.
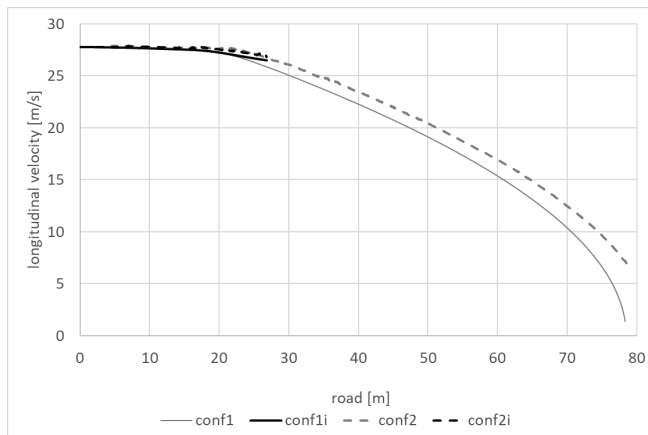
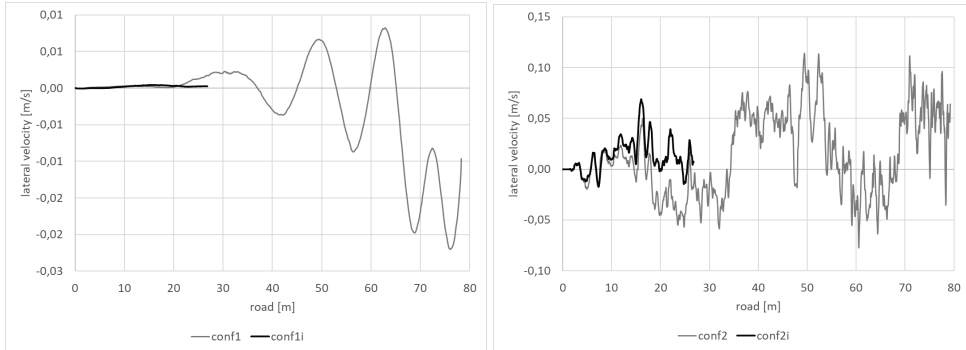**Fig. 5.** Longitudinal velocity loss due to braking for the configurations 1, 1i, 2 and 2i
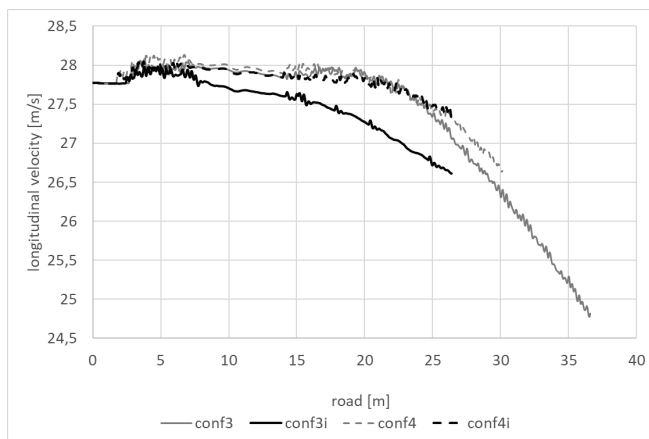
Fig. 6. Longitudinal velocity loss due to braking for the configurations 3, 3i, 4 and 4i

In Figs. 5 and 6 the loss of the translational velocity due to the braking has been presented. In [10] the vehicle reached the same velocity after about 70 m more for the icy road (configurations 1i and 2i) and about 50 m more for the configurations 3i and 4i than for the dry road. Here, the more rapid braking caused the vehicle lose its initial direction of motion and at the same time the recorded velocity for the configurations 1i and 2i stopped at about 27 m/s while for the dry road it dropped to almost 0 (configurations 1 and 2). The drop in the velocity for the icy road with higher amplitudes of the irregularities (configurations 3i and 4i) dropped only by about 0.5 to 1.5 m/s and for the dry road with the same amplitudes (configurations 3 and 4) it dropped by about 1.5 to 3 m/s. Of course then the vehicle also covered less distance.

This can be explained by the lack of full adherence of the wheel to the road with the higher amplitudes of the random irregularities which is especially visible for the motion along the icy road.

The remaining part of analysis in this paper will be devoted to the selected aspects of a lateral motion of the vehicle as the effect of lack of the straightforward steering and a vertical motion on the randomly uneven road.

In Figs. 7 and 8 the changes in the lateral velocity versus the covered distance have been presented for all of the configurations. To compare, in [10] these changes were more rapid as the straightforward steering was adopted then. And their values were up to 0.2 m/s in case of the most harsh road conditions (configurations 4 and 4i). Meanwhile here in this paper the changes in the lateral velocity were more smooth and the maximum valuers amounted to 0.12 m/s (Figs. 7 and 8) which means that the vehicle had less resistance in performing the lateral motion due to lack of the straightforward steering. It also seems that the rotation of the vehicle was uncontrolled and with more rapid braking it could cover less distance during its motion.

Fig. 7. Lateral velocity changes due to braking for the configurations 1, 1i, 2 and 2i
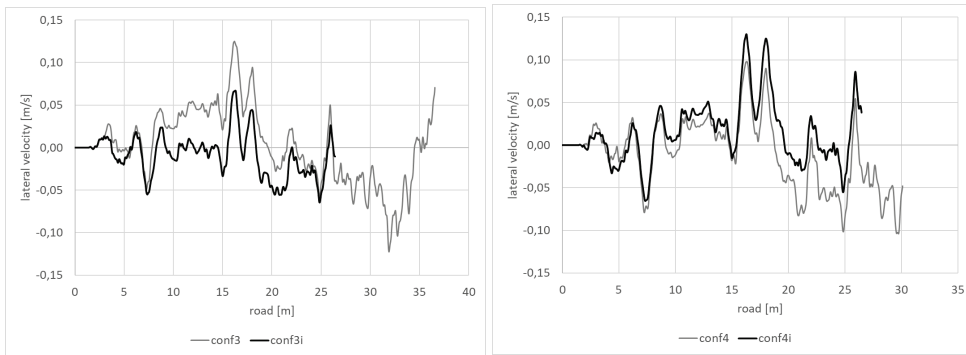
Fig. 8. Lateral velocity changes due to braking for the configurations 3, 3i, 4 and 4i

In Figs. 7 and 8 the changes in the lateral velocity versus the covered distance have been presented for all of the configurations. To compare, in [10] these changes were more rapid as the straightforward steering was adopted then. And their values were up to 0.2 m/s in case of the most harsh road conditions (configurations 4 and 4i). Meanwhile here in this paper the changes in the lateral velocity were more smooth and the maximum valuers amounted to 0.12 m/s (Figs. 7 and 8) which means that the vehicle had less resistance in performing the lateral motion due to lack of the straightforward steering. It also seems that the rotation of the vehicle was uncontrolled and with more rapid braking it could cover less distance during its motion.

One more aspect of the vehicle's response to the external disturbances was undertaken here in this paper, i.e. the vibrations caused by the road irregularities, which have been presented through the changes in the vertical acceleration.

This parameter gave an answer of the potential of road conditions affecting the rapid braking rather than slowing down as in [10].

In [10] the maximum value of the vertical acceleration was close to 0 for configs. 1 and 1i during almost all of the braking maneuver. Then, after about 10 or 20 m of the distance it decreased close to 0. On more uneven road (configs. 2 and 2i) the changes were more turbulent and reached up to ±5 m/s^2. In case of configs. 3 and 3i it changed between ±5 m/s^2 and ±7 m/s^2 and for configs. 4 and 4i it changed from ±7 m/s^2 to ±10 m/s^2.
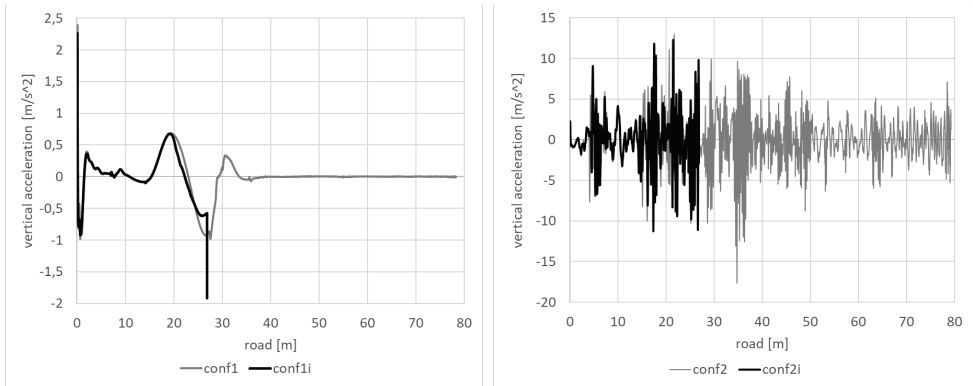

Fig. 9. Vertical acceleration due to braking for the configurations 1, 1i, 2 and 2i

Here the changes in the vertical acceleration were less turbulent, mainly because the lack of the straightforward steering and the more rapid braking which maybe caused the wheels jump over some irregularities having smaller amplitudes with no contact with them. However the amplitudes of the acceleration itself may reflect the dynamics of such a phenomena. Although for the configurations 1 and 1i no spectacular effects could have been expected, the maximum values of the vertical acceleration for configurations 2 and 2i rose to ±12 m/s^2 (Fig. 9), while for configs 3 and 3i they were around ±14 m/s^2 (Fig. 10). In case of the most harsh conditions (configs. 4 and 4i) this acceleration was about 13 m/s^2 and -16 m/s^2 (Fig. 10).
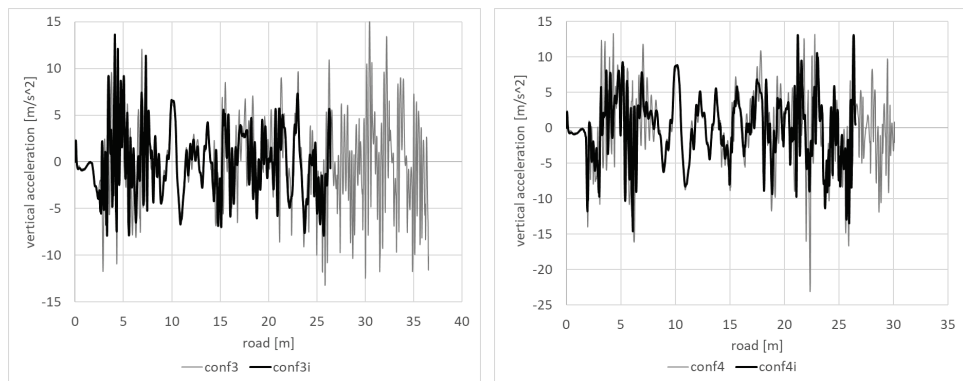

Fig. 10. Vertical acceleration due to braking for the configurations 3, 3i, 4 and 4i

The values presented in Figs. 9 and 10 show that the rapid braking maneuver cause the increase in the vertical acceleration. Yet, the fact that the straightforward steering was not adopted and the quality of the road was assumed as poor the changes in the acceleration were not as turbulent as in [10], but the values of the acceleration were greater.

4. Conclusions

The presented results give an overview on two problems. First, it can be observed that the random road irregularities may affect the vehicle's braking process and increase the vertical acceleration, mainly due to more rapid braking. Second, the lack of the straightforward steering may affect the process and cause the vehicle spin instead of reduce the translational.

Further research may be increased with the various values of braking and examination of the forces between the wheels and the road.

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