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ANALYSIS OF AN ACCELERATING MODEL OF MOTOR VEHICLE WITH THE UNCONTROLLED STEERING WHEEL

Analiza przyspieszania modelu samochodu z niekontrolowanym kołem kierownicy

Abstract: *In this paper a continuation of the previous research has been presented. A simulation of a vehicle's acceleration in various road conditions but without a driver's control has been taken into account. The main aim of this paper was to answer the question whether the random road conditions could affect the vehicle while accelerating while a driver cannot control the direction of its motion. The three various maximum amplitudes of the irregularities for both the dry and the icy road surface were used. Almost different road profiles were also adopted for the analyzed maneuver, which defines a specific coefficient. Apart from no control of the vehicle the initial speed was set to 5 km/h and after 1 s the vehicle started to accelerate. The time of reaching the full throttle (100%) was only 0.25 s which provided a rapid acceleration. The simulation time was 10 s.*
Keywords: acceleration, road conditions, free motion

Streszczenie: *W artykule przedstawiono kontynuację wcześniejszych badań. Uwzględniono symulację przyspieszenia pojazdu w różnych warunkach drogowych, ale bez kontroli pojazdu przez kierowcę. Głównym celem pracy była odpowiedź na pytanie, czy losowe warunki drogowe mogą oddziaływać na pojazd podczas przyspieszania podczas gdy kierowca nie może kontrolować kierunku jego ruchu. Użyto trzech różnych maksymalnych amplitud nierówności dla nawierzchni suchej i oblodzonej. Dla analizowanego manewru uwzględniono również prawie różne profile nawierzchni, co sprecyzowano przy użyciu określonego współczynnika. Oprócz braku kierowania pojazdem prędkość początkową ustawiono na 5 km/h i po 1 s pojazd zaczął przyspieszać. Czas dojścia do pełnego otwarcia przepustnicy (100%) wynosił zaledwie 0,25 s, co zapewniało gwałtowne przyspieszenie. Czas symulacji wyniósł 10 s.*
Słowa kluczowe: przyspieszanie, warunki drogowe, ruch swobodny

1. Introduction

Accelerating is one of the most frequent maneuvers during the road traffic and in some cases the ability to accelerate is essential in avoiding dangerous events on a road as well as switching lanes, entering a highway, etc. However in other cases an accelerating vehicle may be posed to damages and the driver may feel lack of comfort, especially when the vehicle accelerates rapidly and the road is not in a good condition. Various research have so far been conducted on different motor vehicle behavior, also in terms of acceleration. One of the examples of research on both acceleration and deceleration can be found in [1], or more related to driver behavior in [6]. Analysis of a driver's behavior has been considered elsewhere, e.g. in [9] where both man and machine learning provided data for analysis of vehicles' acceleration. Another problem is relating the acceleration to such phenomena as the fuel consumption which has been considered, e.g. in [2] or [8]. In general the vehicle dynamics which include acceleration as well has been a subject of multiple works, such as [3]. More enhanced research consider behavior of the four wheel drive vehicles (e.g. [4]), four wheel steered vehicles (e.g. [11]), a so called steer-by-wire (e.g. [7]) or even the electric vehicles (e.g. [5], [12]), mainly in terms of combining the steering and separately powering each wheel, which has nowadays been a specifically number one topic.

There are a lot of problems in relation to vehicle dynamics and acceleration is only one of them, but it seems obvious that even one aspect of vehicle motion can lead to various questions.

The aim of this paper was to present some certain results of the response of the MSC Adams vehicle's model to the road irregularities combined with different road conditions while accelerating. Although the preliminary results has previously been presented by the author in [10], here some additional setting were changed and one main factor was added – the lack of the steering wheel control which enabled the vehicle to move freely on each of the adopted road conditions. In the next chapter the initial setting for the simulations as well as the road conditions have been presented.

As for the road irregularities, there have also been multiple research conducted on this subject, however, their examples have been cited in the previous paper by the author, such as in [10] so there seems no need to repeat this analysis.

Research on the means of transport has so far been related to various problems such as maintenance, ecology, safety, economy, etc. It seems research on vehicles' acceleration as one of the most frequent maneuvers can be important to some of them, regardless to the source of power.

2. Assumptions for the considered maneuver

As in previous papers (e.g. [10]) the double seater vehicle's model has been used (Fig. 1) with the total mass of its body increased from 995 kg to 1160 kg by locating the masses of a driver, a passenger and a baggage in the vehicle which produced the resulting mass-inertia parameters as in Table 1. The coordinates of the center of mass before and after loading the vehicle have been calculated in relation to the so-called 'origo' point (Fig. 1), as well as the moments of inertia were calculated in relation to the axes intersecting the 'origo'. The moments of deviation, as in [10], have also been determined relatively to the pairs of the axes intersecting the 'origo', which is an origin of the coordinate system located on the road surface but moving along with the vehicle [10].

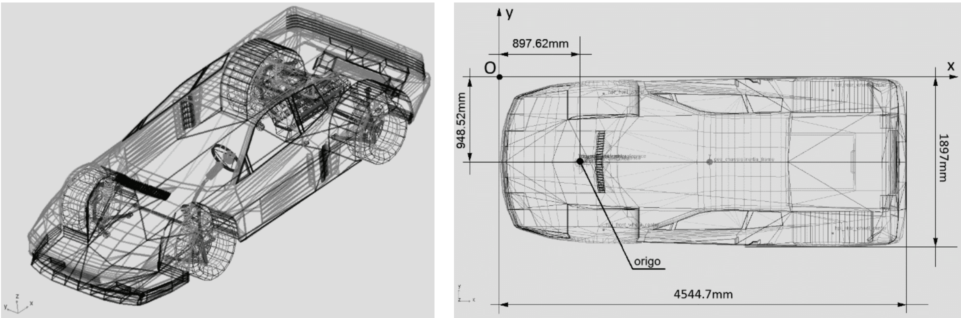

Fig. 1. Vehicle used for simulations and the location of the 'origo' point [own research based on 10]

Table 1

The mass – inertia parameters of the simulated vehicle's model [own research]

	unladen vehicle		laden vehicle	
	vehicle's body	whole vehicle	vehicle's body	whole vehicle
mass	995 kg	1528 kg	1160 kg	1693 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=1.517 m, yc=0.015 m, zc=0.45 m	xc=1.73 m, yc=-0.002 m, zc=0.433 m
moment of inertia (I_X)	401 kg·m^2	583 kg·m^2	435 kg·m^2	617 kg·m^2
moment of inertia (I_Y)	2940 kg·m^2	6129 kg·m^2	3408 kg·m^2	6596 kg·m^2
moment of inertia (I_Z)	2838 kg·m^2	6022 kg·m^2	3272 kg·m^2	6456 kg·m^2
moment of deviation (I_{XY})	0	-1.9 kg·m^2	2.62 kg·m^2	0.71 kg·m^2
moment of deviation (I_{ZX})	671 kg·m^2	1160 kg·m^2	793 kg·m^2	1282 kg·m^2
moment of deviation (I_{YZ})	0	-1.3 kg·m^2	0.78 kg·m^2	-0.53 kg·m^2

In [10] the author shortly explained the usefulness of determining the mass – inertia parameters in relation to the 'origo' (origin of the local coordinate system) and that it is useless to do so in relation to the global coordinate system (*Oxyz*) presented in Fig. 1, because the 'origo' moves along with the vehicle and remains on the road surface at the same time [10]. Apparently insignificant changes in the discussed parameters between the unladen and the laden vehicle are not the main problem here. Such loading of the vehicle was adopted only in order to reflect real possible configuration, as the paper does not aim to compare the motion of the unladen and the laden vehicle which would be unproductive because, when relating the obtained simulation results to the motion of real vehicles, it seems impossible to run tests on a vehicle not having at least the additional devices allowing it to drive itself onboard.

Table 2

Configurations adopted for the vehicle's acceleration [own research]

	road		intensity	cor_{rl}	initial V [km/h]
configuration 1 (c1)	flat	dry	-	-	5
configuration 2 (c2)	flat	icy	-	-	5
configuration 3 (c3)	uneven	dry	0.5	0.2	5
configuration 4 (c4)	uneven	icy	0.5	0.2	5
configuration 5 (c5)	uneven	dry	1.0	0.2	5
configuration 6 (c6)	uneven	icy	1.0	0.2	5
configuration 7 (c7)	uneven	dry	1.5	0.2	5
configuration 8 (c8)	uneven	icy	1.5	0.2	5

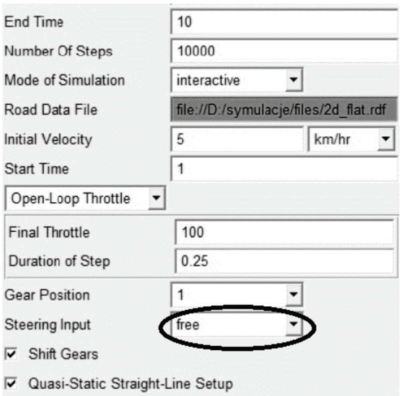

Fig. 2. Adoption of the straight line driver control [own research based on MSC Adams/Car]

The vehicle's model used in this paper was equipped with the FTIRE (flexible) tire models in order to perform the motion along the randomly uneven road [10]. Other assumptions were a quasi-linear suspension as the springs had linear, whereas the dampers non-linear characteristics. Plus, the vehicle's body was regarded as a set of stiff parts.

There have been 8 simulations performed for the various road conditions (configurations presented in Table 2), which has been presented in Table 2. The initial speed was 5 km/h and the vehicle started accelerating either on dry or icy road surface which in six cases was additionally randomly uneven. Also in Table 2 the *intensity* parameter specifies the amplitudes of the road irregularities (the greater the intensity the higher the amplitudes) and the cor_{rl} specifies the difference between the road profiles for the left and the right wheels which in this paper was set to almost different (this coefficient has its value between 0 and 1 which specifies an exact similarity of the road profiles). More on both the *intensity* and the cor_{rl} coefficient was previously considered by the author, e.g. in [10].

As previously mentioned all 8 simulations have been performed for an initial speed of 5 km/h on the first gear. The full time of each simulation was 10 s and the vehicle started accelerating after 1s reaching the full throttle after another 0.25 s as if the driver had to accelerate rapidly, for example in order to enter a fast lane on a highway. No straight-line steering has been assumed (Fig. 2) which gave an opportunity for the vehicle to move freely on a road.

3. Presentation of the selected results

Before discussing the obtained results it seems important to once again notify that the adopted acceleration maneuver has been performed with the free steering without maintaining the straight-line course. Of course, such situation is not typical but could occur, e.g. in case of sudden damage of a steering system. In each presented figures the configurations have been marked with ‘c’ and a respective number as in Table 2.

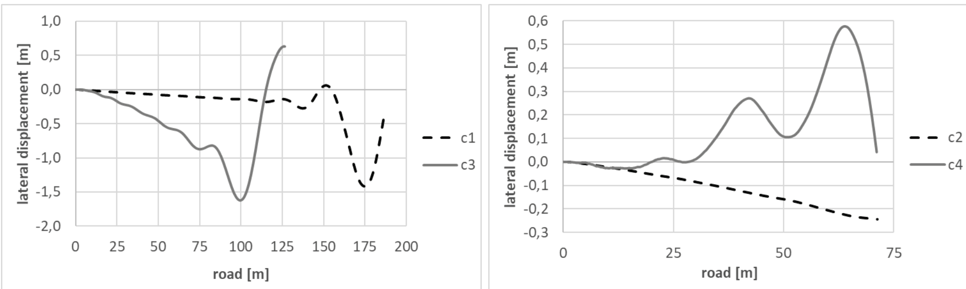

Fig. 3. Lateral displacement on a dry (c1, c3) and an icy road (c2, c4) [own research]

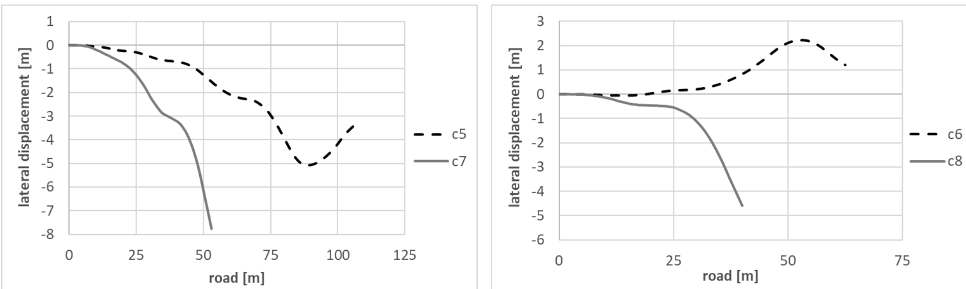

Fig. 4. Lateral displacement on a dry (c5, c7) and an icy road (c6, c8) [own research]

The first set of results shows the nature of a road covered in ice. In Figs. 3 and 4 the lateral displacement versus the covered distance has been presented. On a dry and flat road (c1, Fig. 3) the vehicle moved rather straightforwardly until about 125th meter where it deviated from the previous direction by as much as about 1.5 m. On an uneven road it lost its initial direction of motion shortly after starting to accelerate (c3, Fig. 3). Seemingly similar scenario occurred in case of an icy road, where on a flat road the vehicle tended to deviate slightly but linearly (c2, Fig. 3), whereas on an uneven road covered with ice this deviation occurred more turbulently but the maximum deviation reached 0.6 m.

In Fig. 4 the results, either for a dry (c5, c7) or for an icy road (c6, c8) show that the higher amplitudes of the road irregularities (c6 and c8 in Fig. 4) reduced the lateral deviation, although the presence of the ice on a road caused the vehicle to deviate in the opposite direction from the initial course. In all cases apart from a flat road (c1, c3, Fig. 3) the vehicle did not reach 125th meter of the distance.

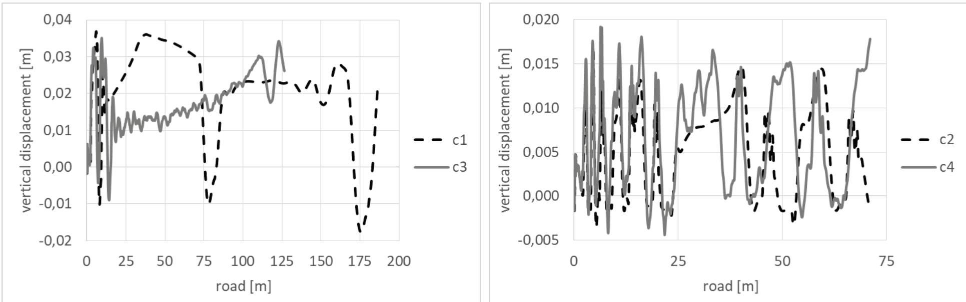

Fig. 5. Vertical displacement on a dry (c1, c3) and an icy road (c2, c4) [own research]

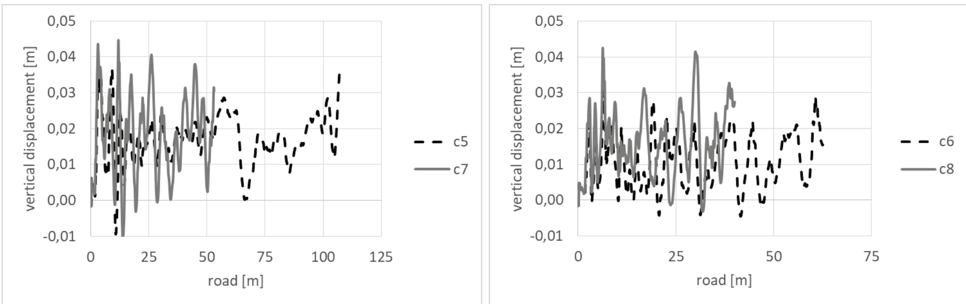

Fig. 6. Vertical displacement on a dry (c5, c7) and an icy road (c6, c8) [own research]

In Figs. 5 and 6 a vertical displacement of the center of mas of the vehicle has been presented just to show that the acceleration did not affect it greatly. However, in case of the flat road (c1, c3, Fig. 5) it can be observed that the changes in the vertical displacement occurred more smoothly, whereas in case of the remaining configurations (all for the uneven road) they were occurring more rapidly, although did not reach any greater values. Hence it can be expected that despite the vertical acceleration may differ due to random irregularities on a road, the suspension damped the vibrations as expected.

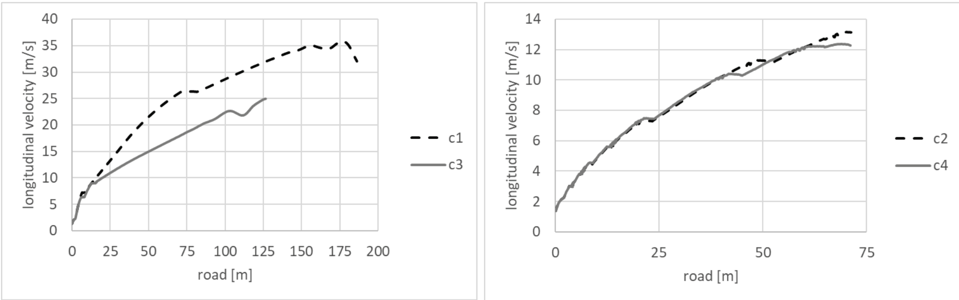

Fig. 7. Longitudinal velocity change on a dry (c1, c3) and an icy road (c2, c4) [own research]

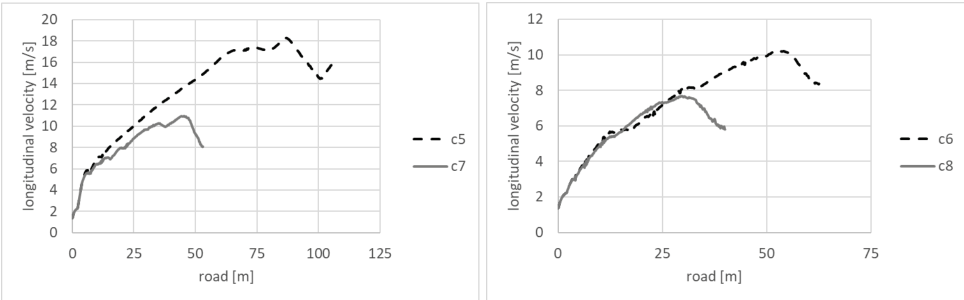

Fig. 8. Longitudinal velocity change on a dry (c5, c7) and an icy road (c6, c8) [own research]

In Figs. 7 and 8 the change in the longitudinal velocity of the vehicle has been presented. As it can be observed the vehicle moving on a flat and dry road (c1, Fig. 7) was able to reach as much as 35 m/s (about 126 km/h) after about 150 m of the covered distance. While moving on an uneven road with the intensity 0.5 (c3, Fig. 7) its maximum velocity was 25 m/s (about 90 km/h). For the flat and icy (c2, Fig. 7) and uneven and icy road (c4, Fig. 7) the results were almost the same which means that the ice reduced the influence of the irregularities on a road to some extent. The more difficult road conditions (Fig. 8) showed that the greater amplitudes of the irregularities the slower the vehicle moved and the final velocity was lower, regardless the ice or the road (c8, Fig. 8) was dry (c7, Fig. 8).

Further part of analysis relates the vertical acceleration during the adopted maneuver. In Figs. 9 and 10 the vertical acceleration for each of the configurations from table 2 has been presented. For the motion on a flat and dry road (c1, c3, Fig. 9) the acceleration rose momentarily to over 40 m/s^2 in an absolute value. However this has probably been an effect of a rapid full throttle opening. For the remainder of the maneuver the maximum value of the vertical acceleration rose to about 5 m/s^2. As for the motion on an uneven road (c3 – c8, Figs. 9 and 10) the changes were more rapid and turbulent which was undoubtedly caused by the road irregularities. But their amplitude (set by the intensity parameter) did not influence the magnitude of this acceleration. Of course the irregularities could not have too high amplitude, because it would be impossible for the vehicle to ride. Nevertheless, both the free (uncontrolled) motion and the randomly uneven road caused the vehicle to cover less distance and the icy surface slightly reduced the vertical acceleration.

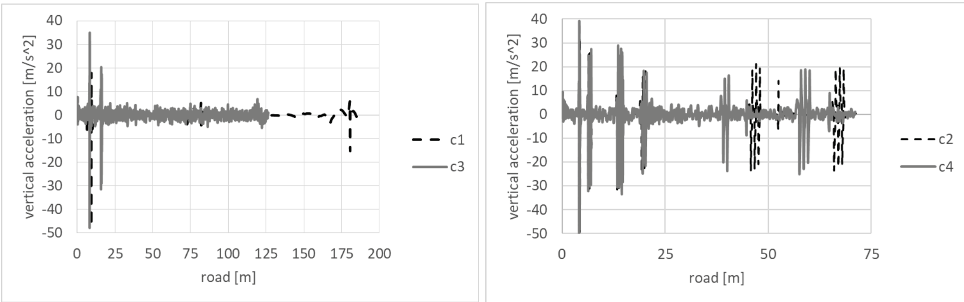

Fig. 9. Vertical acceleration on a dry (c1, c3) and an icy road (c2, c4) [own research]

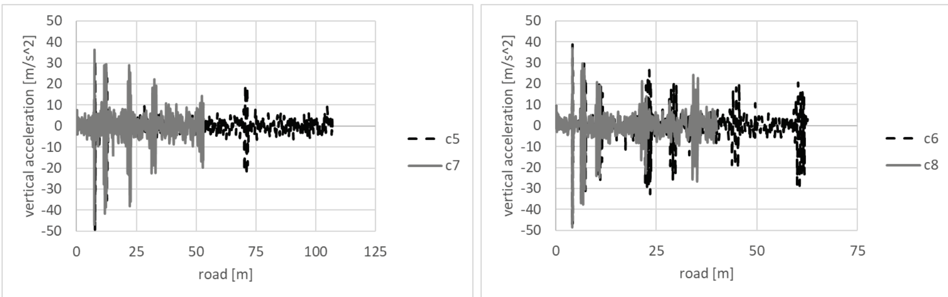

Fig. 10. Vertical acceleration on a dry (c5, c7) and an icy road (c6, c8) [own research]

One of the problems in free motion of a vehicle may be observing whether a lateral motion occurs during the adopted acceleration maneuver. In [10] the straightforward motion was restricted so this phenomena has not been thoroughly examined. But in the considered example it seems logic to pay it a little attention.

In Figs. 11 and 12 the lateral acceleration for each configurations from table 2 has been presented. For the motion along the dry road the greatest changes occurred at the end of the covered distance reaching about 24 m/s^2 for the flat (c1, Fig. 11) and about 15 m/s^2 on the uneven road (c3, Fig. 11). What is interesting, the icy road caused the lateral acceleration to almost disappear (c2, Fig. 11), whereas the modest amplitudes of the road irregularities (as much as 0.008 m for the intensity = 0.5 [10]) caused it to reach about 6.5 m/s^2 in an absolute value (c4, Fig. 11).

The changes in the lateral acceleration for the more difficult road conditions (Fig. 12) were more turbulent and took greater absolute values. As it can be observed the icy road (c6 and c8, Fig. 12) caused the lateral acceleration to reach smaller values (as much as 10 to 14 m/s^2), contrary to the dry road where they amounted to as much as 20 m/s^2 in an absolute value, regardless the smaller (0.019 m for the intensity = 1.0 [10]) or greater irregularities (0.03 m for the intensity = 1.5 [10]). This means that icy road may slightly decrease the lateral phenomena when the vehicle is moving freely.

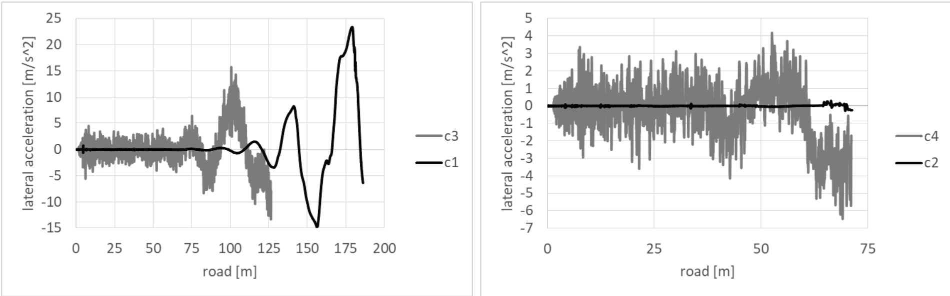

Fig. 11. Lateral acceleration on a dry (c1, c3) and an icy road (c2, c4) [own research]

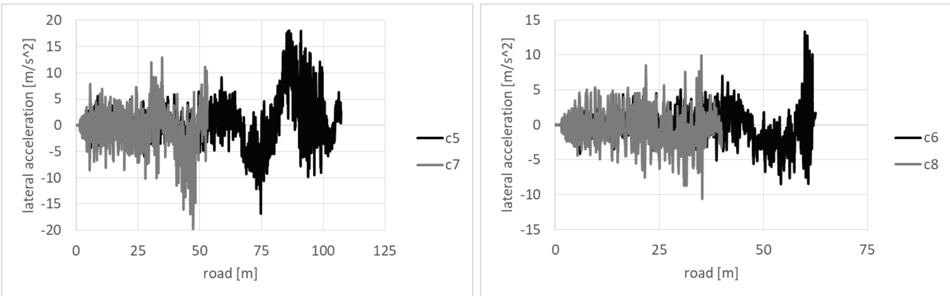

Fig. 12. Lateral acceleration on a dry (c1, c3) and an icy road (c2, c4) [own research]

4. Conclusions

From the presented observations it can be concluded that the random road irregularities may in some cases reduce the selected phenomena during a vehicle's motion, especially acceleration, when a vehicle is increasing its speed. It should be remembered that the research here have been conducted for the motion along the randomly uneven road with the profiles of the surface almost different for the right and the left wheels, which was adopted in order to increase realism of the considered problem.

Although it seems unlikely for the described scenario to happen in reality, it seems reasonable to consider even such theoretically impossible examples of vehicles' motion because in road traffic various scenarios can occur and have an impact on the road safety, even in a minor scale.

Further research will cover some more or less significant problems of the motion of motor vehicles in various road conditions, taking into account different maneuvers and vehicle loading, as well as the fully non-linear suspension.

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