IMPACT OF DAMPING RATIO ON THE BEHAVIOUR OF SUSPENSION SYSTEM

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Abstract: *This paper analyzes the influence of damping ratio on the behaviour of the suspension system. Different tests have been carried out to simulate different types of vehicle movement. Simulations were performed in CarSim 8 software for the vehicle with chosen characteristics. Appropriate conclusions are drawn on the basis of conducted simulations, i.e. the differences in the behavior of the suspension system and the vehicle depending on the selected damping ratio are shown. Selected damping ratios correspond to two chosen damping levels of the damper: a higher and lower value of damping ratio. Symmetrical damper characteristic is used, as in the most theoretical analyzes.*
Key words: *damper, damping ratio, vehicle behavior, performance*

INTRODUCTION

This paper analyzes the influence of the damping ratio on the behavior of the suspension system and the whole vehicle while moving in different road conditions and in different characteristic maneuvers. This analysis was performed using different values of symmetrical damping.

The goal is to make appropriate conclusions on the behavior of the suspension system and the vehicle itself under the above mentioned conditions, i.e. the effect of damper characteristic change on handling, stability and comfort.

Suspension system supports vehicle weight, absorbs and damps the road irregularities, helps to maintain constant tire-road contact as well as proper wheel to chassis relationship /1/.

The damper is a very important part of the vehicle suspension system. Its major role is to damp suspension and vehicle oscilations. The damper behaves in a nonlinear way and has a great influence on braking, steering, vehicle cornering ability and overall stability /2/.

The damping ratio is a dimensionless measure describing how oscilations in a suspension system decay, for example, after a certain road disturbance /3/.

In order to improve the performance of damper and suspension system it is possible to vary the damping ratio in response to various measured signals on the vehicle /4/.

RESEARCH ON THE DAMPER AND SUSPENSION PERFORMANCE

The effect of damping ratio change on the behavior of the suspension system and the vehicle was analyzed using the CarSim 8 software. For the needs of the simulation, a C segment vehicle is choosen with a sprung mass of 1274 kg and unsprung mass of 142 kg. The simulation of each of the selected tests is performed for two above mentioned cases, each with a different damping ratio of the damper.

The change in damper ratio was made by changing the shape of the curve that shows damping force versus the velocity of the damper piston. The shape of the curve should be as smooth as possible to eliminate problems in exploitation and unnatural sensation to the driver /5/.

The curves used in the first and the second case are shown in Picture 1. Curve 1 represents the higher value of damping ratio while curve 2 represents the lower value of damping ratio.

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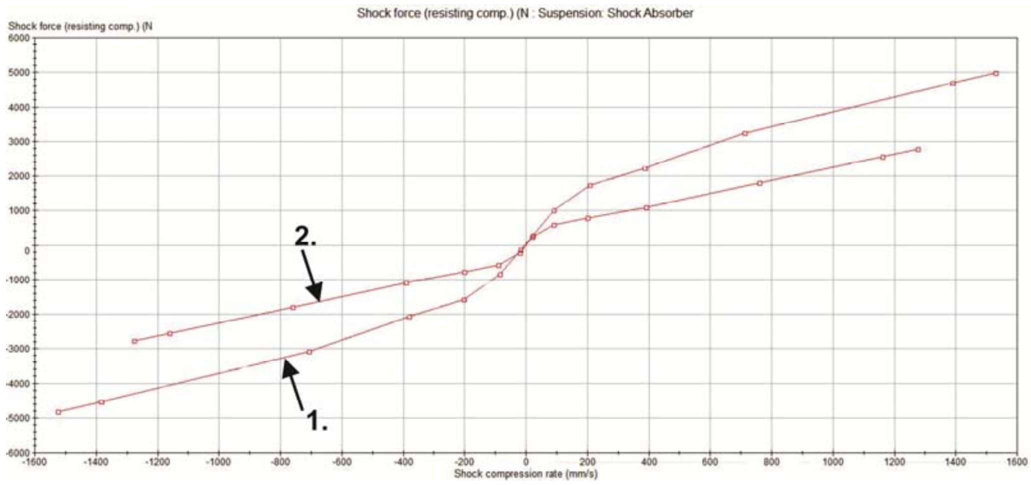
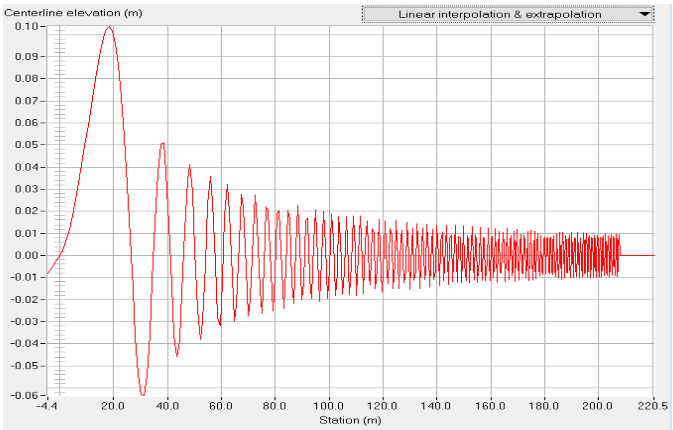


Picture 1. - Damping force characteristic

Five different tests were performed with both of the damper settings described above.

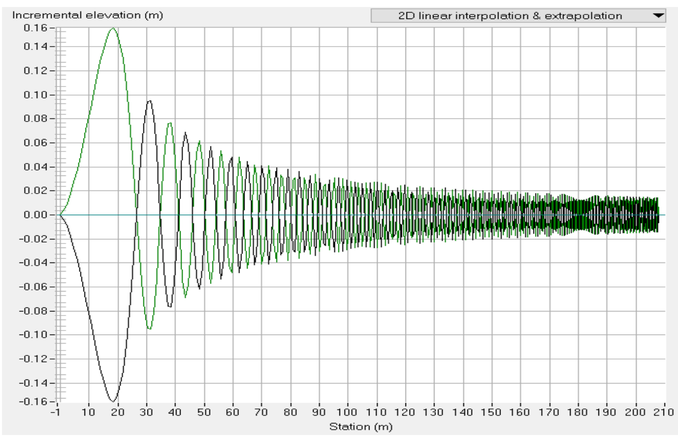
Test 1

The first conducted test is a comfort test, and it is divided in two parts. In the first part of the test, the vehicle moves on a wavy road section with initially lower frequency, which increases later. The vehicle moves at a constant speed of 40 km/h. The road profile is shown in Picture 2.



Picture 2. - Road profile of the selected road section

In the second part of the test, the vehicle moves along a cross-slope section, with a constant speed of 20 km/h. Picture 3 shows the road profile for this part.



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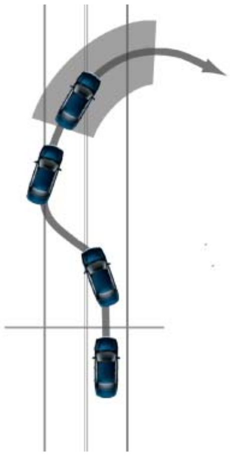
Picture 3. - Profile of the cross-slope road section

Test 2

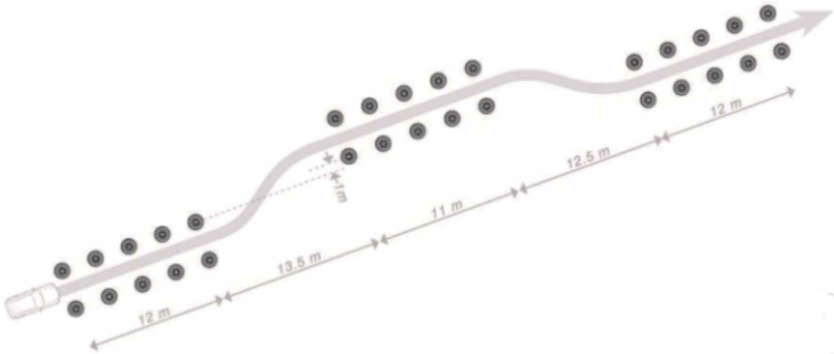
For the second test, the fishhook test is chosen and the nature of vehicle motion during the test is shown in Picture 4.



Picture 4. - Fishhook test

Test 3

The DLC (Double Lane Change) test was selected for the third test. The vehicle moves at a constant speed of 120 km/h. The nature of vehicle movement during this test, as well as the required dimensions of the test track are shown in Picture 5.



Picture 5. - Double Lane Change test

Test 4

In this test, the vehicle is crossing over a short transverse road bump. The vehicle moves at a constant speed (first at 40 and later at 80 km/h) and crosses the transverse bump that is 35 mm high and 400 mm long.

Test 5

For the fifth test, the vehicle moves at a constant speed of 50 km/h along an uneven 1200 m long road with small irregularities. The profile of the selected road section is given in Picture 6.

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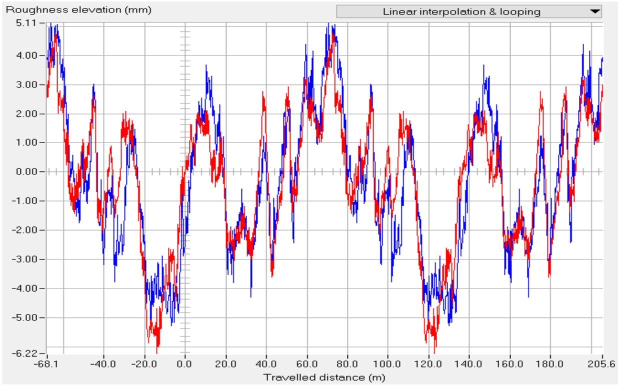


Picture 6. - Road profile

THE ANALYSIS OF THE RESULTS

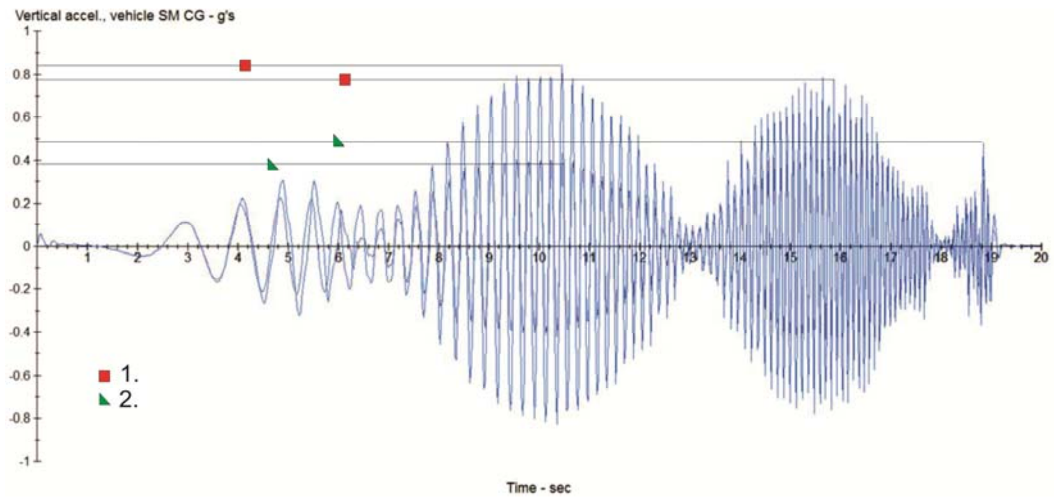
Test 1 - part 1

Picture 7 shows the vertical acceleration of the vehicle's center of gravity for both selected damper characteristics.

In the first part, where the frequency of oscillations is the lowest, more favorable vertical acceleration of the center of gravity of the sprung mass is present in the first case, when the damper that has a higher value of damping ratio is used.

The lower damping ratio provides approximately the same change in vertical acceleration of the vehicle's center of gravity, with somewhat higher extreme values achieved.

Observing the second part, where the frequency of the oscillations is increased, more favorable vertical acceleration of the vehicle is present in the second case, hence the lower value of the damping ratio here gives the best results. Higher damping ratio causes a significantly higher vertical acceleration.



Picture 7. - Vertical acceleration of the vehicle's CG

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By analyzing the third part, where the frequency of oscillations is the highest, the lower vertical acceleration of the center of gravity of the sprung mass is also present in the second case, therefore, the lower value of the damping ratio gives the better result. A higher damping ratio causes a significantly increased vertical acceleration of the vehicle's center of gravity. At a higher value of damping ratio, a smaller oscillation amplitude is present in the third part relative to the second part, while with the lower damping ratio it is the opposite.

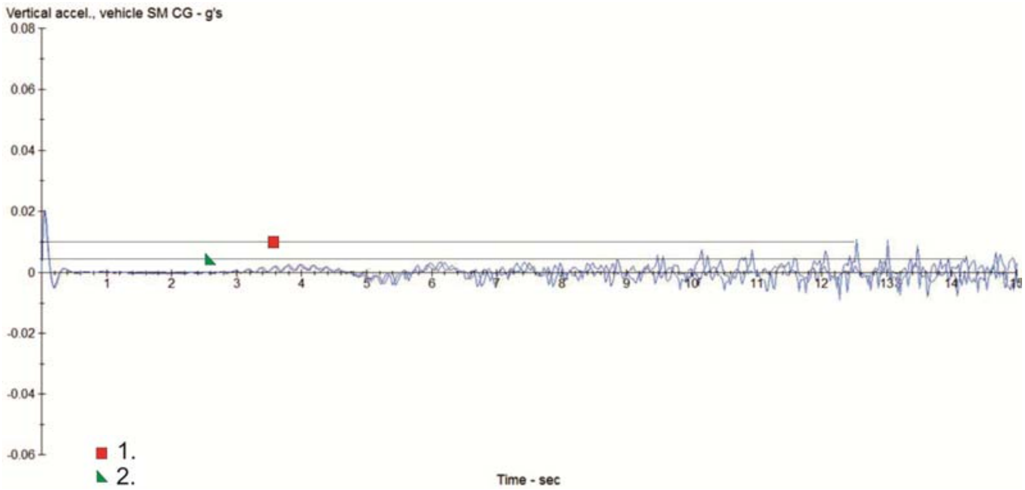
A conclusion can be drawn that the lower damping ratio gives the best results for such conditions of vehicle movement, which does not necessarily mean that the vehicle with this type of damper will provide the most favorable behavior in the various maneuvers and driving conditions.

Test 1 - part 2

Picture 8 shows vertical acceleration of the center of gravity of the vehicle.

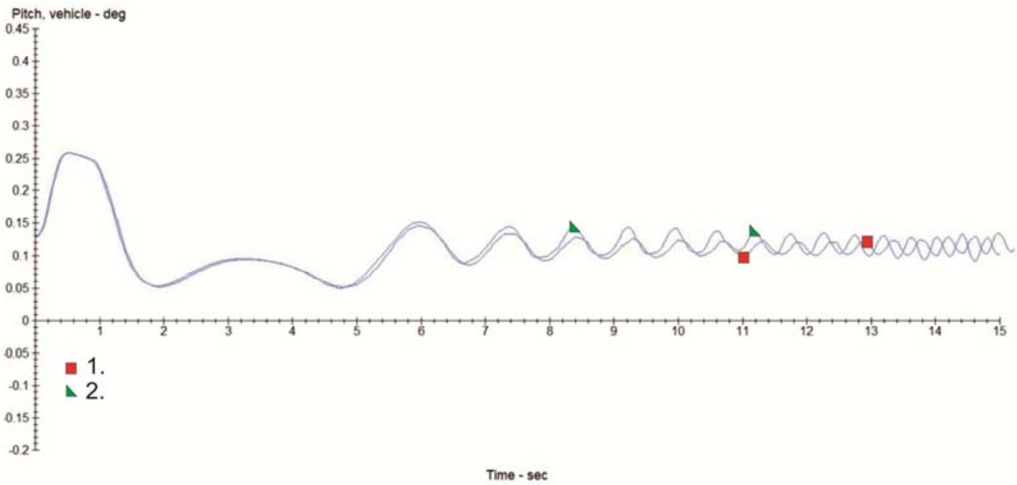
By looking at diagrams shown, it is noted that the more favorable results are achieved by selecting a damper with a lower damping ratio, while higher damping ratio provides slightly higher values of vertical acceleration of the vehicle's center of gravity.

On the basis of the obtained diagrams, it can be concluded that the damping characteristics do not have a significant role in reducing the roll of the vehicle, since the results achieved in both cases are almost identical.



Picture 8. - Vertical acceleration of the vehicle's CG

Picture 9 shows the pitch of the vehicle during the test.



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Picture 9. - Vehicle pitch

It can be noticed that the change in vehicle pitch with two chosen damping characteristics is very similar and obtained extreme value of pitch is almost the same in both cases.

Test 2

On the basis of the obtained results, it can be seen that maximum values of the achieved yaw rate of the vehicle in both cases range from 25 to 30 °/s.

At the beginning of the test there was a slightly higher yaw rate of the vehicle, when dampers with a lower damping ratio are selected, while maximum yaw rate, after changing the direction of movement, is provided by dampers with a higher value of damping ratio. The difference in the nature of the change of the yaw rate is present, which shows that the choice of the damper characteristics and the maximum damping ratio is certainly important for a sudden change of the direction (performed in the first part of the test), while in the second part of the fishhook test, when the vehicle is moving in a constant radius, there are almost no differences in the behavior of the vehicle.

It can be noticed that the maximum value of lateral force in contact between the tire and the road is same in the first part of the performed fishhook test. In the second part of the fishhook test, when a second direction change takes place and vehicle continues to move without sudden changes in direction, the lower value of lateral force is achieved when using a damper with a higher damping ratio, while the higher value of lateral force is achieved when using a damper with a lower damping ratio.

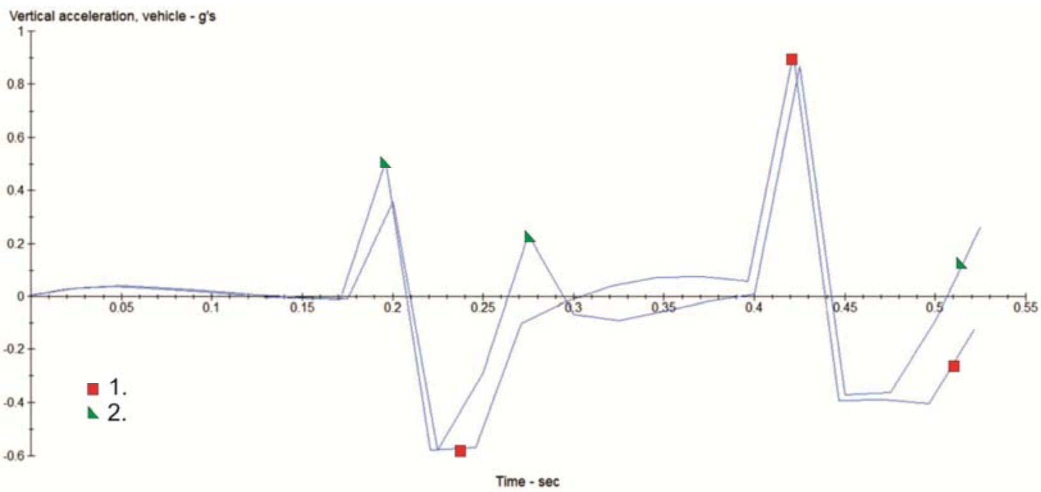
The lower value of the damping ratio also leads to the appearance of certain unevennesses which are less pronounced than in the first case.

Test 3

In both cases the identical lateral deviation of the vehicle from the desired path was obtained and because of that it is not shown. This tells us that the damping ratio of the damper is not of great importance when the vehicle is found in such driving conditions in contrary to the stiffness of the springs as well as the geometric and mass parameters of the vehicle.

Test 4

Picture 10 shows the vertical acceleration of the vehicle when the vehicle passes the transversal bump at a speed of 40 km/h.



Picture 10. - Vertical acceleration of the vehicle

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It can be seen from the Picture 10 that extreme values achieved here in both cases are almost identical, while the change in the vertical acceleration of the vehicle itself has certain variations depending on the selected damper characteristic. We can conclude that in both cases the comfort is approximately at the same level, regardless of the chosen damper characteristic.

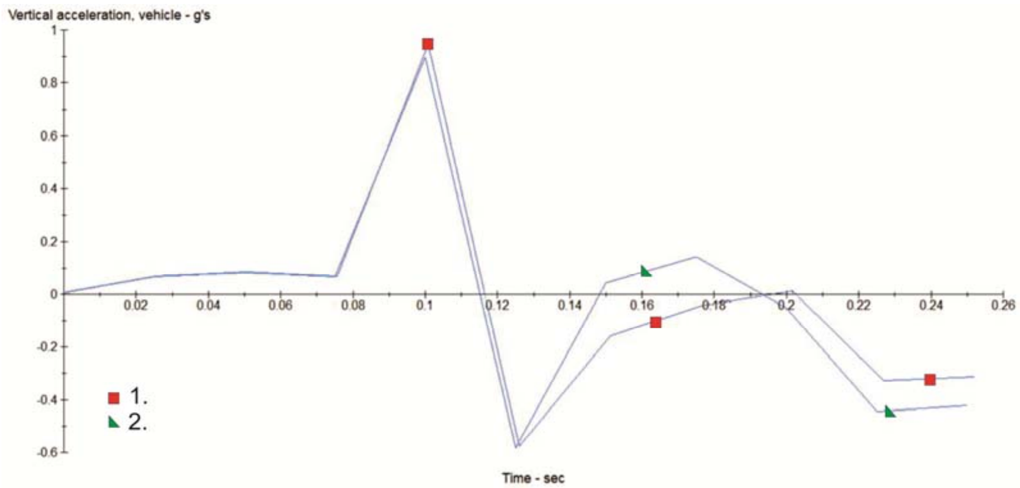
The extreme value of the longitudinal force is higher when using lower damping ratio whereas it is significantly lower at higher values of damping ratio. The change in the vertical force is approximately equal in both cases, with identical extreme values achieved.

Picture 11 shows the vertical acceleration of the vehicle when the vehicle passes the transversal bump at a speed of 80 km/h.

Based on Picture 11, it is again possible to conclude that the extreme values achieved here in both cases are almost identical, while the change in vertical acceleration of the vehicle itself also has certain variations depending on the selected damping characteristic. Again, we can conclude that in both cases, the impact on the passengers, i.e. the achieved comfort, is approximately at the same level, regardless of the selected damping characteristic.

By analyzing the achieved results of the research for different characteristics of the damper, it is possible to derive conclusions, so for the purpose of comparative analysis, the results achieved for each of the tests are evaluated and shown in the table.

The scores for each of the criteria considered during the performed tests are given in the range of 1 to 4 points for both of the selected dampers and are shown in Table 1. For tests performed at two vehicle speeds, the results for each of the considered criteria are given in the following format - the number of points achieved at the first speed value / number of points achieved at the second speed value, while the total score for each of the criteria is shown as the average number of points and is given in parentheses.



Picture 11. - Vertical acceleration of the vehicle

Corresponding weight factors were selected for each of the tests and the criteria considered. On the basis of the stated weight factors, the significance of each test, as well as the significance of each of the criteria within the selected tests is defined.

By assigning the appropriate points to each of the considered damper characteristics for each of the performed tests, almost equal results are obtained.

By analyzing the first part of test 1, it is concluded that lower damping ratio gives slightly better overall results for the subject test than higher value of damping ratio. Although it provides the best results in terms of vertical acceleration, it is proving to be the worst possible solution for the vehicle pitch.

In the second part of test 1, with the movement of the vehicle on the road with a cross-slope, both damping characteristics provide very good results in terms of reducing the vehicle roll. A lower damping

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ratio provides a more favorable vertical acceleration of the vehicle's center of gravity, while higher damping ratio provides a more favorable mitigation of the pitch.

In fishhook test, the vehicle achieved identical results for both of the selected characteristics, but there are various changes in lateral and vertical forces in the contact between the tire and the road. Also, the obtained maximum values of these forces are not the same. This leads to different tire deformations which certainly have a significant impact on its behavior. Bearing in mind that the tire, primarily it's elastic characteristics, participates in the operation of the suspension system, the study of these effects requires additional attention in some future research.

Test 3 (DLC test) shows that vehicle handling is at the same level with both selected damper characteristics. Due to the low impact of the damper on the steering behavior of the vehicle and the absence of differences in the parameters that depend on the behavior of the suspension system (vertical acceleration of the vehicle, pitch, etc.), this test is assigned a weight factor of 0.5.

When vehicle crosses a transversal bump (test 4), the higher damping ratio gives completely opposite results with two different speeds of vehicle. Higher damping ratio is shown to be a unfavorable solution at lower speeds, while at higher speeds it is shown to be the more favorable. The lower damping ratio shows solid results at each of the selected speeds.

Differences in the achieved amplitude of the vertical acceleration, as well as the achieved frequency when moving the vehicles through a road with the small unevennesses are barely noticeable.

CONCLUSION

It can be conluded that there is certanly a change in behaviour of the suspension system and vehicle due to different damping ratio selected. The results are not dramatically different, except in the first part of the Test 1 where the lower value of damping ratio gives significantly better performance in regard to passenger comfort. Vehicles with different weight and weight distribution can correspond differently on selected damping ratio, which can be used for future research. Also, a damping ratio detorioration can be taken in consideration for future research, because it can be critical for traffic and passenger safety.

Table 1. - Evaluation of the results of the survey

Weight factor of the test	***Criterion***	***Weight factor of the criterion***	***Lower damping ratio***	***Higher damping ratio***
Test 1 - first part				
1	*Vertical acceleration*	0,5	4	1
	Pitch	0,5	1	3
	Total	**1**	**2.5**	**2**
Test 1 - second part				
1	*Vertical acceleration*	0,33	4	3
	Roll	0,33	4	4
	Pitch	0,33	3	4
	Total	**1**	**3,67**	**3,67**
Test 2				
1	*Stability*	1	4	4
	Total	**1**	**4**	**4**

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Test 3				
0,5	*Lateral offset from designed path*	1	4	4
	Total	**1**	**4**	**4**
Test 4				
1	*Vertical acceleration*	1	3 / 2 (2,5)	1 / 4 (2,5)
	Total	**1**	**2,5**	**2,5**
Test 5				
1	*Vertical acceleration*	1	4	4
	Total	**1**	**4**	**4**
TOTAL POINTS			**20,67**	**20,17**

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