INVESTIGATION OF AUTOMOBILE ACTIVE SAFETY CONTROL SYSTEMS EFFICIENCY AND THEIR IMPACT ON THE DRIVER'S BEHAVIOUR

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Abstract

The paper deals with the influence of active car safety systems on driver's behavior in emergency situations, i.e. emergency braking, steering angle, etc. Several models of real vehicles have been tested in order to analyse the ABS and ESP systems operation efficiency. The results of emergency braking and stability in real vehicle testing with ABS and ESP stability control systems switched on and off are presented in detail. In order to get the maximum impact of ABS and ESP systems (full activated) the real vehicles were tested on the asphalt paved road covered with wet snow. Tests were also carried out on the road sections with different pavement and state. The XL Meter Pro Beta measurement device was used for the real vehicle testing. The brakes and active safety systems of the vehicles have been tested for their effectiveness at different conditions: when the vehicle is braking on horizontal wet asphalt, and on an icy gravel surface, at a different initial running speed: 40km/h, 70 km/h and 100 km/h. During the real vehicle testing the stability during emergency braking resulted in the assessment of influence of active safety systems on handling the vehicle and its stability, and the driver's behaviour in emergency situations i.e. on a slippery road, or at sharp steering angle. The results of real vehicle testing have been presented in the paper in the form of charts. Examination of a vehicle emergency braking and stability systems results in the conclusions concerned with handling of the vehicle ad application of the above systems.

Keywords: *emergency braking of vehicle, handling and stability of a vehicle*

1. Introduction

The braking mode of a moving vehicle is an important part of the driving cycle, and the emergency braking of a vehicle is often an inevitable consequence of the accident. Sharp steering angles are as much important to complete. Road vehicle braking leads to many properties of road safety. Braking action is the priority process in terms of other actions of a driver in an emergency situation.

Road traffic regulations say, "if an obstacle or a threat to safety occurs, the driver (if he/she is able to see/spot it) has to slow down or even completely braking the vehicle or steer around an obstacle without causing a danger to other road users." Therefore, from the legal point of view it is always better to stop than to drive/ manoeuvre in emergency situations. Braking distance depends on the braking efficiency. Braking distance must be as short as possible and the car must remain stable and able to be handled. Braking is the most effective when all the wheels of the car have the same ability to stop, i.e. the front axle braking force is the same as that of the rear axle. The braking performance also depends on the dynamic properties of the vehicle and its performance. The more intensive is braking of the car, the higher is the safe speed, therefore, handling of a vehicle is more efficient and safe (Nagurnas et al 2005:236).

The vehicle safety is divided into two groups: the first group defines the vehicle ability to prevent accidents and is called the active safety. Active vehicle safety is defined by braking efficiency, car stability, handling, as well as efficiency of lighting and signalling systems. The second group, called passive safety, reduces the effects of the accident. Passive safety group includes belts, vehicle body structure, airbags, head restraints, etc. European Union (EU) Directive 71/320 requires the vehicle to be designed and constructed in the mode of the braking distance to be as short as possible. The vehicle must never lose its balance at braking; braking performance must have the same ability after many times of braking, the time from pressing the brake till the start of braking has to remain minimal. All these elements of the braking system always have to be reliable. Many scientists, including the ones of Vilnius Gediminas Technical University, scientists from the Department of Automobile Transport continue analysing the vehicle stability and handling [2-4, 7].

In order to improve driving safety and ensure its handling, recently the following systems have been introduced and applied widely: Anti-lock Braking System ABS, ESP, the systems to eliminate the car instability during an emergency braking, i.e. AFU, EVA as well as the system for increasing the force of brake pedal with the help of a booster- ADAM. While using the above mentioned systems the tire grip properties in terms of road surface traction must be the most optimal.

The main factors affecting the road safety are analysed in this paper. It focuses on the measures for ensuring the stability of a vehicle. One of the objects of this investigation/ study is the system ensuring the vehicle stability and the efficiency of the system itself. Improvement of vehicle active safety measures will prevent from accidents. Vehicle manufacturers have developed a variety of automatic vehicle control systems exceeding the driver‘s abilities: the electronic systems of an engine, gearbox and other kinds of handling, which significantly improve the vehicle performance [5, 8]. An increase of an average driving speed of a vehicle must focus on its security, which depends on the structure of the vehicle, especially on the brake system, since the crash can be avoided by braking the vehicle in time. The drivers have to react extremely fast by pressing the brake pedal to have noticed an obstacle on the road. Almost driving on a dry road may cause unexpected difficulties in braking the vehicle.

The increasing number of road vehicle leads to the growth of traffic accidents, moreover, the road network is not expanding fast enough, therefore, due to the high concentration of vehicles in other words, traffic intensity the number of congestion is also increasing, moreover, it results in increasing number of road accidents, the number of the injured and killed on the road. In many countries of the world the traffic accidents have become the problem on a state level.

A tremendous increase of number of vehicle fleet has had a significant negative impact on the traffic safety in the Republic of Lithuania. Daily consequences of traffic accidents are congestions of vehicles, material losses, active time losses for many people as well as moral losses for the country. The following EU countries have achieved the best results in the area of traffic safety: Sweden, Denmark, the United Kingdom and the Netherlands. Today the road safety is not a fundamental science anymore; it focuses more on social and human behaviour. It is important to publish research results, and it is crucial to disseminate, comment and encourage public discussions. In order to improve the state of arts of safe traffic, many countries of the world aim to decrease the number of traffic accident victims in 50 present.

In this context the smart safety systems in a vehicle are applicable for improving the traffic safety. Smart safety systems ensure the highest level of safety on the road, whether these are smart systems in a vehicle, or the ones in infrastructure. Currently the road vehicle manufacturers equip the series of vehicles with the modern security systems to increase safety (vehicle stability) and facilitate the handling for a car driver, these are the following: TCS – Traction Control System, the driving stability control system ESP -the Electronic Stability Programme, ASR – Acceleration Slip Regulation, EDS – Electronic Differential System. Electronic differential lock system enhances driving safety and vehicle traction properties on slippery roads, or the start of the uphill ride. Dynamics control system improves vehicle stability at steering angles, i.e. helps to maintain the right driving trajectory when the wheels start skidding [1, 6].

These are the following problems for maintaining the vehicle stability:

- inertia force influence/affect the vehicle upon a robust start, at an emergency braking and at a steering angle,
- the higher lateral force the higher speed is gained, and the smaller is the radius of the curve,

- vehicle lateral skidding on slippery surfaces during emergency braking or sudden acceleration,
- wheel traction force is higher than wheel adhesion to the road surface,
- robust acceleration of the engine speed is most dangerous on slippery roads as the vehicle can slip off the road,
- emergency braking of the vehicle will lock up the rear wheels faster (they will skid/slip) than the front ones,
- at a steering angle the rear-wheel driven vehicle will start slipping off with the rear axle,
- a front-wheel driven vehicle will start slipping off with the front axle at a steering angle,
- the vehicle loses its stability when driven onto the side road with unreinforced surface,
- a strong crosswind is dangerous on a slippery exit from a closed to an open section of the road.
- unexpected icy surface of the road when driving straight ahead,
- soon after the rain starts the road surface is extremely slippery (especially on a rubble surface),
- a sudden manoeuvre of driving back to the traffic lane after overtaking another vehicle.

Further the article describes real vehicle emergency braking and its stability testing, the influence of active safety system on vehicle handling and stability, as well as the driver‘s behaviour in emergency situations, e. g. on slippery road surfaces, or on a sharp road curve.

2. Conditions for emergency braking of real vehicles

Emergency braking tests were carried out with real vehicles in the following conditions:

1. there were three types of real vehicles tested: with the ABS system switched off, with the ABS system switched on, and equipped with the brake-control system,
2. the vehicles were technically fit, equipped with the brake system from the manufacturer,
3. the vehicle load was tested by two persons: a driver and a researcher observing the measurement device (XL Meter Pro Beta),
4. the winter tires on the car wheels were of the recommended dimensions for the vehicle model, the tread was no less than 3 mm deep,
5. the air pressure in the tires was rated for the model of the vehicle and its weight/load,
6. the tests were carried out in a horizontal section of wet asphalt and icy gravel roads, free from traffic,
7. the tests were carried out at the initial driving speed of 40 km/h, 70 km/h and 100 km/h.

The *XL Meter Pro Beta* device was used for real vehicle emergency braking tests. Technical characteristics of the device are given in Tab. 1.

Tab. 1. Technical characteristics of the device XL Meter Pro Beta

General properties	
Number of tests	8
Saving capacity of the test results	8
Screen	16 x 2, LCD with black and white light
Cabel connected to the computer	RS-232
Dimension	50 x 97 x 110 mm
Measurement characteristics	
Range	from minus 12.7 to plus 12.7 m/s^2
Measurement axes (direction)	longitudinal (a_x) and lateral (a_y)
Error	0.1 m/s^2
Frequency	50 Hz
Power supply	
External voltage	(6–18) V
Number of elements	4
NOTE. *Table reflects the main data of the selected device XL Meter Pro Beta: its measurement range and accuracy are sufficient for real vehicle emergency braking testing and its lateral stability.*	

3. Results of real vehicle emergency braking testing

The following road vehicles have been selected for testing: Mazda 121 with the ABS system switched off, Rover Freelander with ABS system switched on and Land Rover Discovery equipped with the brake control system. The results of real vehicle braking performance testing have been presented in Fig. 1-6.

A technically fit vehicle with the ABS system switched off features the maximum value at the very initial braking and later the value decreases. The slow down reaches the maximum value before the wheels of the car are locked. As soon as the wheels are locked the slow down slightly decreases as on the account of the spin of the locked wheels the braking is less efficient.

Figures 1-6 reflect the process of the vehicle braking with the ABS system switched off: at a lower speed performance the deceleration peak makes a bigger part of the total braking process, and at a higher speed the braking lasts longer and the peak makes the smaller part of the braking process.

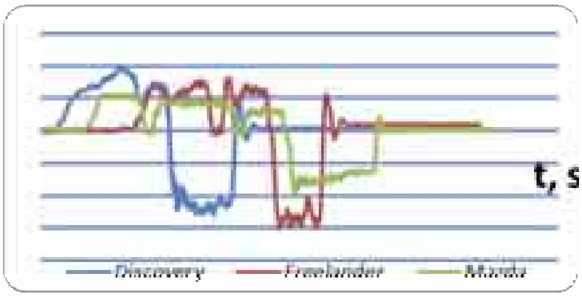

Fig. 1. Vehicle acceleration during emergency braking of the following road vehicles: Mazda 121 with ABS system switched off, Land Rover Freelander with the ABS system switched on, Land Rover Discovery equipped with the braking control system (icy gravel road, v_p = 40 km/h)

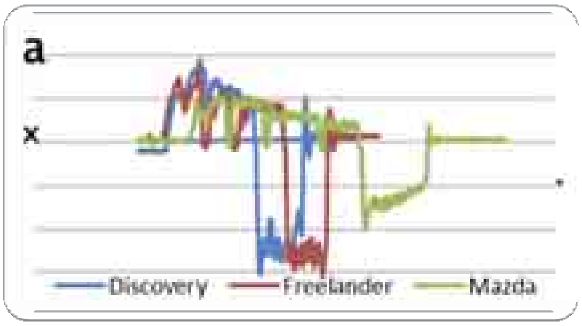

Fig. 2. Acceleration during emergency braking of the following vehicles: Mazda 121 with the ABS system switched off, Land Rover Freelander with the ABS system switched on, Land Rover Discovery equipped with braking control system (icy gravel road, v_p = 70 km/h)

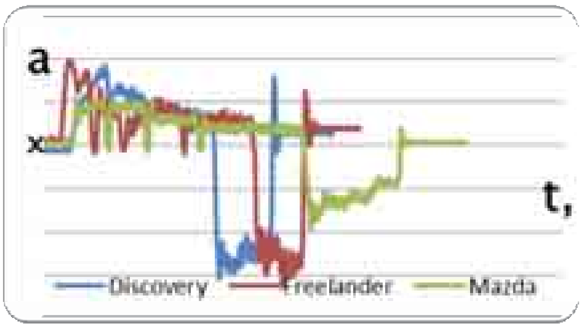

Fig. 3. Acceleration during emergency braking of the following vehicles: Mazda 121 with the ABS system switched off, Land Rover Freelander with the ABS system switched on, Land Rover Discovery equipped with braking control system (icy gravel road, v_p = 100 km/h)

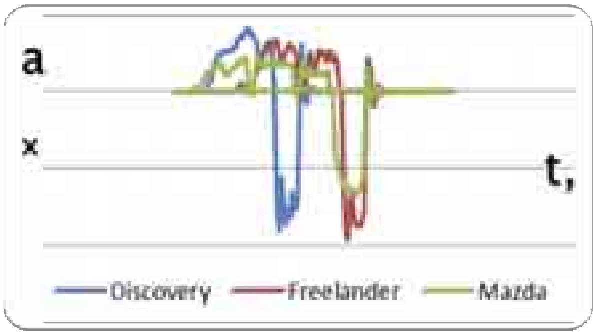

Fig. 4. Acceleration during emergency braking of the following vehicles: Mazda 121 with ABS system switched off, Land Rover Freelander with ABS system switched on, Land Rover Discovery equipped with braking control system (wet asphalt, v_p = 40 km/h)

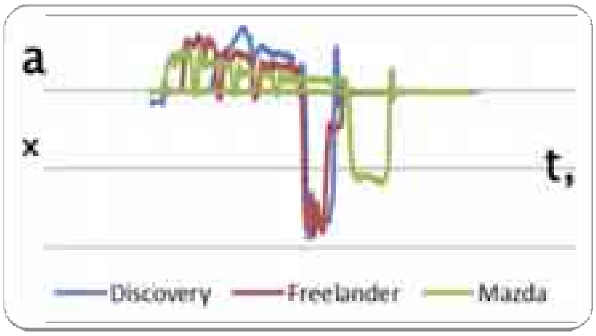

Fig. 5. Acceleration during emergency braking of the following vehicles: Mazda 121 with the ABS system switched off, Land Rover Freelander with the ABS system switched on, Land Rover Discovery equipped with braking control system (wet asphalt, v_p = 70 km/h)

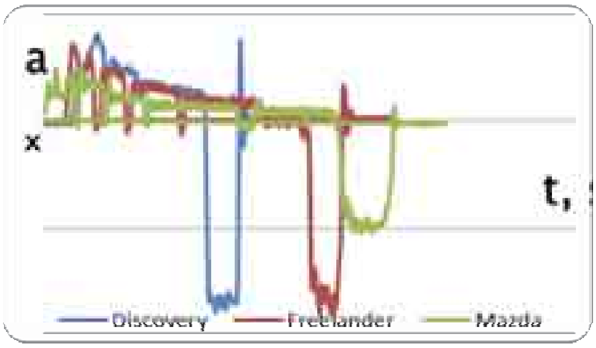

Fig. 6. Acceleration during emergency braking of the following vehicles: Mazda 121 with ABS system switched off, Land Rover Freelander with ABS system switched on, Land Rover Discovery equipped with braking control system (wet asphalt, v_p = 100 km/h)

Vehicles with the ABS system have capacity to harmonize the interaction of the wheels with the road surface, at the initial braking the deceleration value is lower while the highest value is reached at steady braking before the final stop. The average values of steady deceleration during the emergency braking of the vehicle moving at a different initial speed are presented in Tab. 2.

Table 2 reflects the results of the highest deceleration gained during the emergency braking of the Land Rover Freelander vehicle in both the conditions: on the icy gravel road and wet asphalt.

4. The process of real vehicle stability testing and its results

The real (physical) vehicle testing aims are the investigation of the stability of a vehicle equipped with the active safety systems (ABS and ESP), assessment of the impact of security systems and evaluation the data importance. For this purpose the vehicles with the ABS, TCS and

Tab. 2. Average value of steady deceleration of the vehicle j_{steady} (m/s^2) at different speed performance

Icy gravel road				
No.	Model of a vehicle	40 km/h	70 km/h	100 km/h
1.	Mazda 12	3.9	4.0	4.0
2.	Land Rover Freelander	5.8	6.0	6.2
3.	Land Rover Discovery	4.0	5.0	5.5
Wet asphalt				
1.	Mazda 121	6.1	5.8	4.5
2.	Land Rover Freelander	8.6	8.8	9.0
3.	Land Rover Discovery	8.0	8.1	8.2

ESP systems switched on and off were tested. NOTE: the selected vehicle Seat Alhambra is equipped with the ABS and ESP systems, whereas, the ESP system can be switched on and off.

The main task of the test was to make a turn at a constant speed of 40 km / h. There is an important test condition: during the test neither braking nor acceleration or deceleration was allowed. The task had to be performed only by steering the wheel. The experiment was considered to be completed if the vehicle did not slide out of the road lane and did not have emergency braking at the corner curb. The road surface - asphalt, covered with wet snow. The tested car made a turn of 33 m radius at a speed of 40 km / h in the distance of 200 meters.

The lateral acceleration was measured by the XL Pro Beta Meter device (see Tab. 1). In all the eight tests, the XL Pro Beta Meter device was switched on when the vehicle was reaching the speed of 40 km / h before entering the turn transverse vehicle acceleration measurement. The above mentioned device measured the lateral acceleration.

Test No. 1. An ESP system was switched off. The Fig. 7a reflects the lateral acceleration values with respect to time schedule in testing the vehicle Seat Alhambra with the ESP system off. At the moment of lateral acceleration, the highest lateral (centrifugal) force was reached within 3-6 seconds, as soon as the hand wheel was turned. At the turning point the vehicle lost its stability, therefore the experienced driver started aligning the vehicle by steering the wheel to avoid side slip. The driver reduced the speed of the vehicle (the driving experience and good driving skills) and did not make a turn; the vehicle was stopped at the curb.

Test No. 2. The ESP system was switched off during the test. Fig. 7b. reflects the lateral acceleration values with respect to time schedule in testing the vehicle Seat Alhambra with ESP system switched off. At the moment of lateral acceleration, the highest lateral force was reached within 2-5 seconds, as soon as the handle wheel was turned. The speed was constant – 40 km/h, but at the turning point the vehicle lost its stability, therefore the experienced driver started aligning the vehicle by steering to avoid side slip. By reducing the speed (the driving experience and good driving skills) the vehicle was stopped at the curb.

Test No. 3. Real vehicle testing was carried out when the ESP system inside the vehicle was switched on. Fig. 7c. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. At the moment of lateral acceleration, the highest lateral force was reached as soon as the driver turned the hand wheel to drive the vehicle into a steering angle; the vehicle was stopped at the curb. At the edge of the steering angle the vehicle lost its stability, and the driver in response (the human factor) started aligning the vehicle (aligning the trajectory of the vehicle) to avoid the side slip. A robust decrease in the vehicle velocity (due to the driver‘s skills/ experience) allowed the car to be stopped at the roadside.

Test No. 4. Real vehicle testing was carried out when the ESP system was switched off. Fig. 7d. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. The curve depicting the lateral acceleration reached the highest peak within 3-7 seconds as soon as the hand wheel was turned. The speed was constant – 40 km/h, but at the turning point the vehicle lost its stability, therefore the experienced driver started aligning the vehicle by

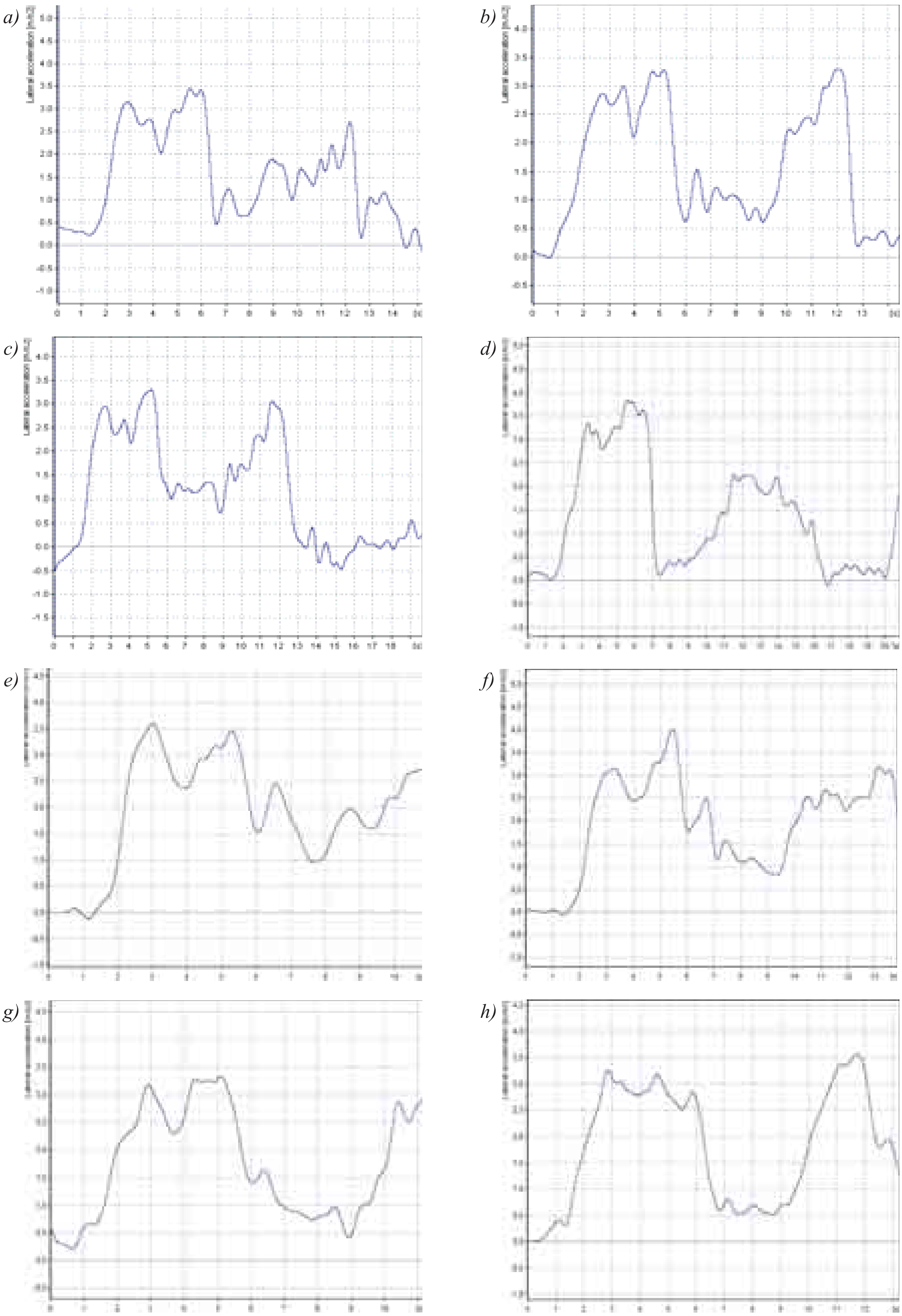

Fig. 7. *Lateral acceleration of the vehicle Seat Alhambra at a speed of 40 km/h with the ESP system switched off during the test No. 1 (a), No. 2 (b), No. 3 (c), No. 4 (d), and with the ESP system switched on during the test No. 5 (e), No. 6 (f), No. 7 (g), No. 8 (h)*

steering to avoid side slip. The vehicle could hardly make the turn due to deceleration and high skills of the driver.

Test No. 5. Real vehicle testing was carried out when the ESP system inside the vehicle was switched on. Fig. 7e. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. The curve depicting the lateral acceleration is distributed almost evenly, with no big range after the hand wheel was turned. The side slip range of the vehicle body was hardly palpable during the ESP system operation. The vehicle drove into the steering angle at a speed of 40 km/h and could move along with no need for deceleration.

Test No. 6. Real vehicle testing was carried out when the ESP system inside the vehicle was switched on. Fig. 7f. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. The curve depicting the lateral acceleration is distributed almost evenly, with no big range after the hand wheel was turned. The side slip range of the vehicle body was hardly palpable during the ESP system operation. The vehicle drove into the steering angle at a speed of 40 km/h and could move along with no need for deceleration.

Test No. 7. Real vehicle testing was carried out when the ESP system inside the vehicle was switched on. Fig. 7g. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. The curve depicting the lateral acceleration is distributed almost evenly, no big range occurred after the hand wheel was turned. The side slip range of the vehicle body was hardly palpable during the ESP system operation. The vehicle drove into the steering angle at a speed of 40 km/h and could move along with no need for deceleration.

Test No. 8. Real vehicle testing was carried out when the ESP system inside the vehicle was switched on. Fig. 7h. reflects lateral acceleration values with respect to time schedule in testing the real vehicle Seat Alhambra. The curve depicting the lateral acceleration is distributed almost evenly, no big range occurred after the hand wheel was turned. The side slip range of the vehicle body was hardly palpable during the ESP system operation. The vehicle drove into the steering angle at a speed of 40 km/h and could move along with no need for deceleration.

Table 3 reflects the results of real vehicle *Seat Alhambra* testing with the ESP system off and on.

Tab. 3. Results of real vehicle Seat Alhambra stability testing

Model of the vehicle	Speed 40 km/h, ESP system was switched off			
	Test No.			
	1.	2.	3.	4.
Seat Alhambra	Failed the driving trajectory, had to be stopped at the curb.	Failed the driving trajectory, had to be stopped at the curb.	Failed the driving trajectory, had to be stopped at the curb.	The vehicle could hardly complete the steering angle due to deceleration and the driver‘s skills.
	5.	6.	7.	8.
	The task was completed with no major problems in handling the vehicle.	The task was completed with no major problems in handling the vehicle.	The task was completed with no major problems in handling the vehicle.	The task was completed with no major problems in handling the vehicle.

The data in Tab. 3 reflect the failure at the first three real (physical) vehicle testing.

5. Conclusions and recommendations

1. Real (physical) vehicle emergency braking testing allowed to make a conclusion that average steady deceleration of the vehicles equipped with the ABS system is initially increasing and later is decreasing as opposed to the vehicles without the ABS system.
2. ABS properly prevents from wheel slipping if the driver adequately assesses the road conditions and keeps to the safe driving. If the driver is going at a high speed on a slippery road

and makes a sudden turn with the steering wheel or makes other improper braking actions, the driver will cause sided slipping and any security system will not help.

3. Drivers must take into account that the automatic control and handling system can only help them to handle the vehicle, increase safety, but the driver has always been and will remain the main guarantee for safe driving and there is no system able to substitute the driver.
4. Middle-class vehicles must have ESP as when the ESP system is operating, the vehicle is not side slipping, therefore does not lose its stability in making a steering angle, as an electronic stability system with a lateral acceleration sensor reacts to the changes based on the adhesion between the wheel and the road surface.
5. The performance of ESP system within the sport utility vehicle (SUV) should be improved, as the side slip with high weight vehicles still remains.
6. The traction force within the vehicles with ESP system switched off could not set off the lateral force therefore the vehicle kept side slipping. Low-class vehicles could succeed in making a steering angle with the ESP system switched off. Anyway they have to be equipped with the ESP system for safety purposes.
7. Speed limit should be recommended in winter depending on the adhesion coefficient/ ratio (on wet and snowy road surface), e. g. on the road curve of 40 m radius, when the road surface is wet and slippery, the speed must be limited up to 40 km/h.
8. If the vehicle is equipped with ESP system, it is recommended to have the possibility to turn it on or off. There are some cases where ESP is not required, e.g. in back-and-forth motion when the vehicle is stuck in deep snow or loose soil; in testing of the vehicle on a dynamometer bench.
9. Authors of this investigation assume the electronic stability control could lead to unsafe driving, because it allows the driver to feel more readily at high speed and the robust undesirable (even risky) manoeuvres on the roads.

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