Keywords: ATV; critical velocity; body mass index; stability

Georgi KADIKYANOV*, Iliyana MINKOVSKA, Gergana STANEVA
University of Ruse, Department of Engines and Vehicles
8, Studentska, 7017 Ruse, Bulgaria
**Corresponding author*. E-mail: gkadikyanov@uni-ruse.bg

A STUDY OF THE INFLUENCE OF SOME EXPLOITATION FACTORS ON THE ATV STABILITY

Summary. An original survey among ATV riders concerning the conditions in which they lost stability is conducted. The coordinates of the center of gravity of the ATV by riders with different Body Mass Indexes are determined. A simulation program on base mechanic–mathematical model to study the ATV's motion is used. In this base the critical sideslip velocities and critical lateral overturn velocities of ATV at various riders' Body Mass Index, curve radius and grip coefficients were calculated. The results show that riders' Body Mass Index strongly affects critical velocities because of different coordinates of center of gravity.

1. INTRODUCTION

The widespread use of all-terrain vehicles (ATVs) in recent years demands a driving stability analysis for different terrains. ATVs are very popular as an open-air vehicle for recreation and transport. However, in the past twenty years, ATVs have been associated with an increased number of injuries, many of which are fatal. In [1], it has been alleged that fatal ATV crashes correlated with many factors, such as the wearing, lack of a helmet, the alcohol in the blood, the age of the rider and so on.

Finding the exploitation factors in which ATVs lose stability is complicated while determining the causes of a crash. The dislocation of the vehicle is usually accompanied by some lateral forces: during the curves, across the slope, from bumps on the road and side winds. According to [5], the forces are applied on the axles of the wheels. Frequently, the sideslip of the axes starts at a different time and with a different intensity. As a result, a self-propelled cornering of the ATV appears.

After the sideslip, owing to the nature of the terrain on which these vehicles move, the wheels reach an obstacle in the form of some unevenness, which tends to overturn.

The influence of the center of gravity position on the vehicle stability is particularly important for lower-weight vehicles such as ATVs. This is because of the displacement of coordinates of the center of gravity for riders with different physical parameters (height, weight and so on). In other cases, in high-speed motion and at a higher vertical coordinate of center of gravity, according to [2, 7, 9 and 10], the reaction of the wheels causes lateral overturn.

In [3], an electronic controller generating the appropriate yaw moment, obtained from the difference of the brake forces of the front wheels, is developed. This method is applicable to larger-sized vehicles with a multi-component braking system, but the system cannot be built in the ATV. To improve the stability of ATVs, a simpler method is needed to increase safety and reduce injuries and mortality of riders. Such methods are, for example, the built-in gyroscopic mechanism [8], the automatic reduction of the velocity of ATV and so on. To develop these ideas, the first necessary step is to identify the critical velocities.

The aim of this paper is to determine the ATV's critical velocities in curves depending on some exploitation factors.

2. METHODS

In Bulgaria, there is no exact information about the number of ATVs. The main reason is gaps in the Bulgarian law. Depending on technical parameters, given by the producer of the ATV, some of them are registered as motorcycles, others as agricultural machinery and some are even not allowed to be registered and are driven illegally. For these reasons, there is no real statistics on incidents with them, as well as the real reasons for their occurrence. One of the ways to identify the above causes is by conducting a statistical survey, by questioning ATV riders.

First, a survey with people riding similar vehicles in different regions of Bulgaria was carried out. The core of the questions concerns how often and under what exploitation conditions the loss of stability occurred in their practice. Respondents, riders of ATV, have different experience, gender, temperament and age. The number of interviewed riders is 100. Somewhere in results the total amount of answers is not equal to 100% because the respondents give more than 1 right answer or no answer to the question.

The critical situations of ATV's motion depend on the coordinates of the center of gravity. In this paper, the coordinates of the center of gravity are determined experimentally. An ATV, model XIONGTAI D150, was used. Measurements were performed first for an empty ATV, and then sequentially with the different riders. A small, high platform is placed to determine the longitudinal coordinate of the center of gravity under the rear wheels of the ATV. The front axle is lifted so that the ATV will be in horizontal position. The lifting force, applied at the lifting point, is measured using the electronic load sensor, connected to the lifting rope. The longitudinal coordinate of the center of gravity is evaluated by the equation of rotational equilibrium around the axle of contact of the rear wheels and platform.

To determine the vertical coordination of gravity center of the ATV, the front axle is lifted at an angle. The vertical coordinate of the center of gravity is determined once again by equation of rotational equilibrium at new conditions.

The driver's influence on the coordinates of the center of gravity of the ATV is estimated by the body mass index (BMI) of the riders. BMI is a medical–biological indicator [4, 12]. It is estimated with the following relation:

$$BMI = \frac{W}{h^2}, \frac{kg}{m^2}, \tag{1}$$

where W is the mass of the rider, kg; h is the height of the rider, m.

For determination of the critical velocity of the ATV, a mechanic–mathematical model presented in [6, 11] to study the motion of a two-axle vehicles was used. The model was realized in MATLAB SIMULINK (Fig. 1).

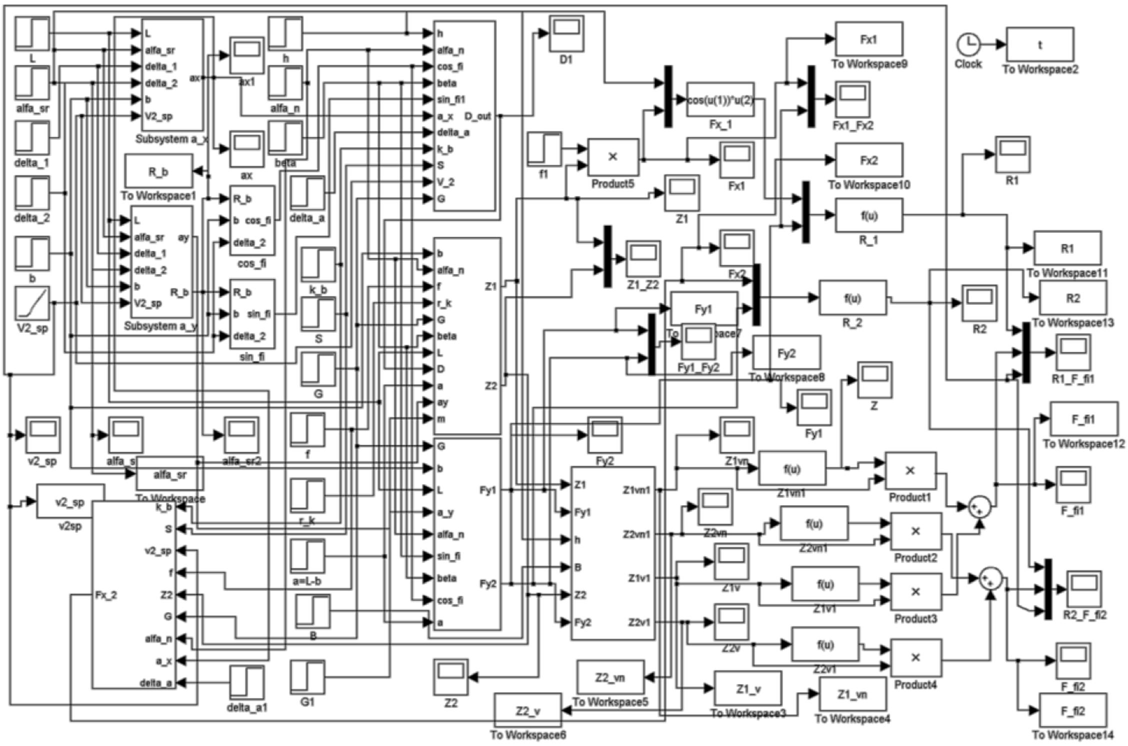

Fig. 1. Screenshot of the model used in SIMULINK

The main input factors are the gravity center coordinates with different riders, according to their BMI, tire grip coefficient for different surface condition and the turning radius. For each case of motion, the ATV velocity is constant. Output results after simulation are critical velocities for cases of sideslip and lateral overturning. Because the model is a two-mass system, the critical velocity is lower on the front and rear axles.

The influence of the difference of the front and rear wheel tracks on the ATV's stability (Fig. 2) can be estimated with the following equations:

$$Gb_3 = F_o h \tag{2}$$

$$F_o = \frac{F_c \cos\gamma_1}{\cos\gamma_2} \tag{3}$$

$$\gamma_1 = arctg\frac{l_2 - R_1 tg\delta_2}{R_1}$$

$$\gamma_2 = arctg\frac{b_1 - b_2}{l_1 + l_2} = const \tag{4}$$

$$b_3' = b_2 + l_2 tg\gamma_2 \tag{5}$$

$$b_3 = b_3' \cos\gamma_2 \tag{6}$$

From Fig. 2 and equations (2-6), it can be seen that the lateral overturn force F_o depends on the angles γ_1 and γ_2. The angle γ_2 is a function of the constructive features of the ATV (the front and rear wheel tracks, wheelbase). The angle γ_1 depends on both constructive features and running conditions, for example turning radius, sideslip angle and so on.

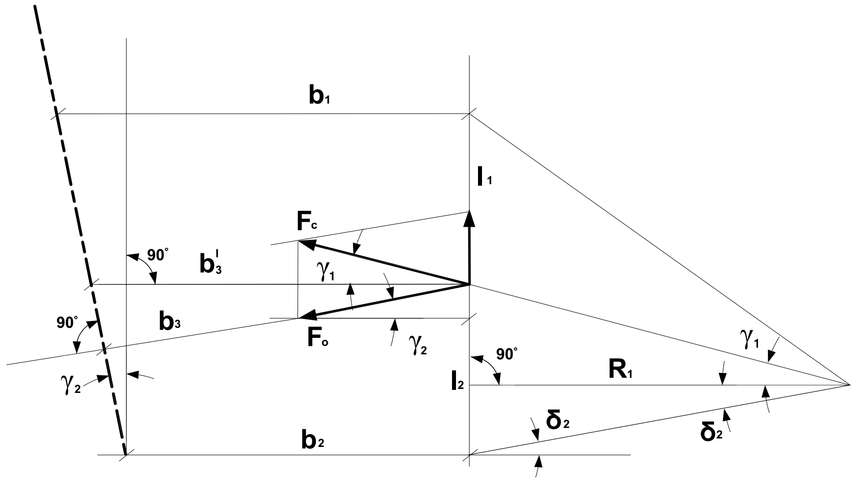

Fig. 2. Scheme of forces acting in the horizontal plane on the ATV with different wheel tracks of the front and rear axles

3. RESULTS AND DISCUSSION

To clarify the main problems related to the loss of stability of ATV, a survey among the riders of ATV was conducted. After the survey was completed, the results were statistically processed and presented on graphics. Fig. 3 and Fig. 4 graphs show the rate of velocity of ATV at which there has been proneness to sideslip in a curve on a variety of terrains, as well as its dry or wet condition. It can be seen that most frequently the lateral sliding has occurred at a velocity of 30-40 km/h on a wet asphalt and grassy road.

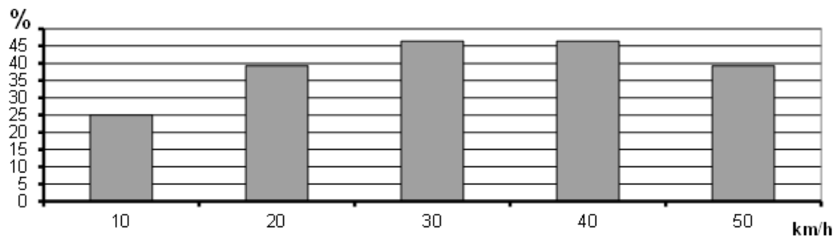

Fig. 3. Frequency of sideslip of ATV in curves at different velocities

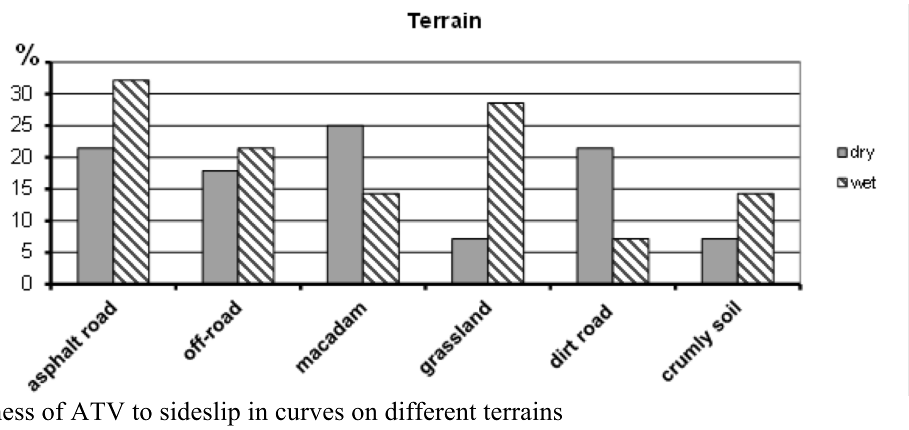

Fig. 4. Proneness of ATV to sideslip in curves on different terrains

Fig. 5 and 6 show proneness to lateral overturn at different velocities and different terrains. It can be seen that the ATV has the highest proneness to overturn at a velocity of 20-30 km/h, on a dry asphalt road in curves.

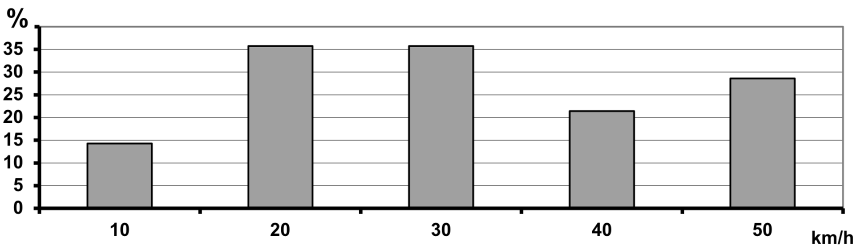

Fig. 5. Proneness of ATV to lateral overturn in curves at different velocities

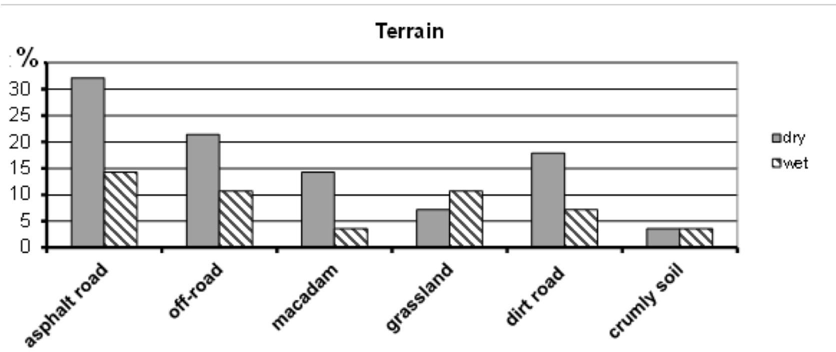

Fig. 6. Proneness to lateral overturn in curves on different terrains

It was also determined from this survey that in 93% of the cases the proneness to lateral overturn was observed mainly in motion of ATV rather in curves, not on transversal slope.

An experimental study concerning the coordinates of the gravity center using described methodology was done. The rider's physical parameters (weight and height), the weight of the empty ATV and the BMI for each rider are given in Tab. 1.

Table 1

The rider's physical parameters and the weight of the empty ATV

	weight	height	BMI
	G, kN	h, m	kg/m^2
ATV	1,32		
Rider 1	0,527	1,58	21
Rider 2	0,76	1,76	25
Rider 3	0,92	1,72	31
Rider 4	1,01	1,82	30
Rider 5	1,25	1,77	40

The BMI parameter is extremely important for the stability of lower-weight vehicles, such as ATV. This is because of the significant change in the coordinates of the ATV’s center of gravity when individuals with different physical parameters (height, weight and so on) ride the ATV.

The locations of the center of gravity of the ATV with riders having different BMI, in the longitudinal plane, are shown in Fig. 5.

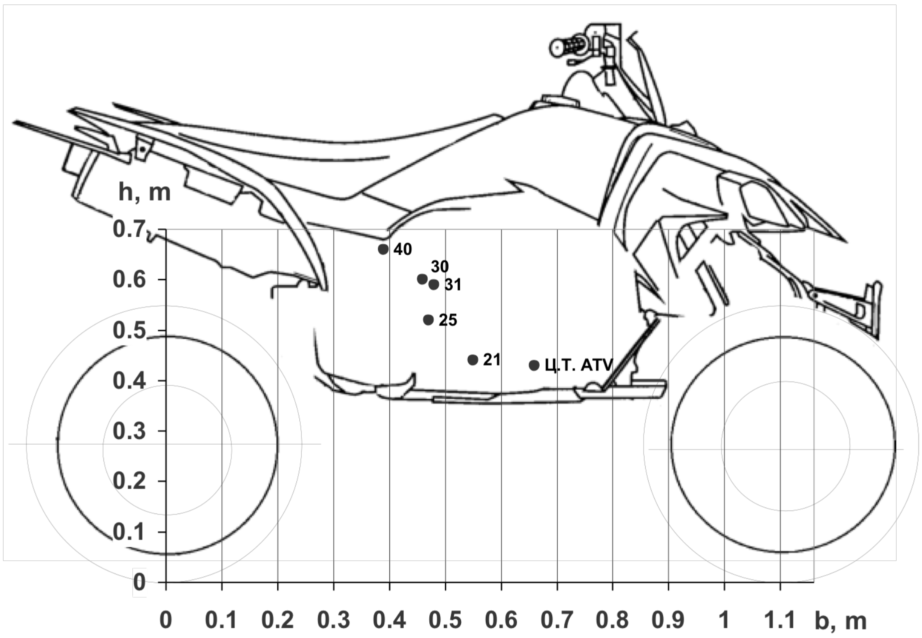

Fig. 7. Coordinates of the center of gravity of the ATV with riders having different body mass indexes

If the rider has a higher body mass index, the center of gravity displaces back and upward. Such displacement of center of gravity increases the load of the rear drive wheels, which improves the ATV's traction properties. On the other hand, high located center of gravity reduces the critical force of lateral overturn of the ATV when it runs in a curve. This also reduces the critical longitudinal overturn angle when ATV is on a slope.

After analysis, the results from the survey and the obtained experimental coordinates of centers of gravity were used to simulate motion of the ATV in different road conditions (turning radius, grip coefficient). Results are shown in Fig. 8 – 12.

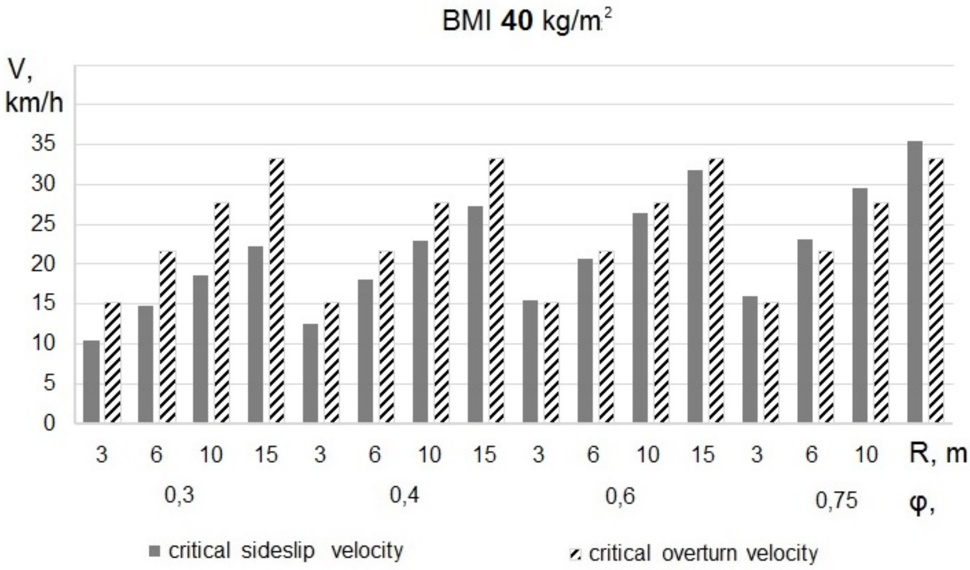

Fig. 8. Variation of critical sideslip and overturn velocities depending on the turning radius R and the grip coefficient φ at rider BMI of 40 kg/m^2

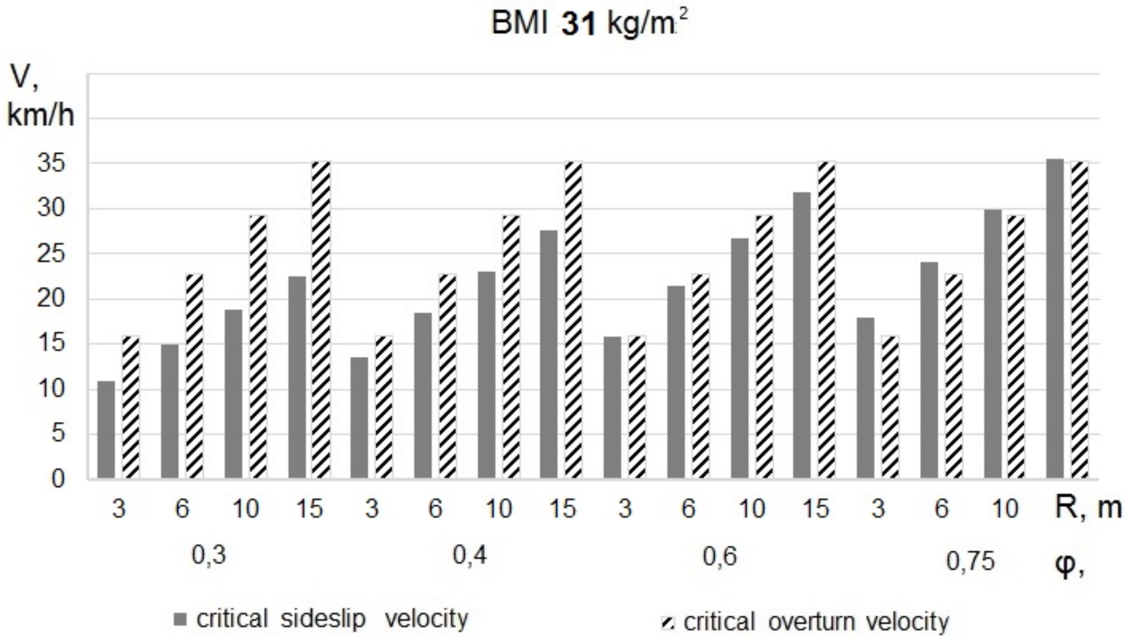

Fig. 9. Variation of critical sideslip and overturn velocities depending on the turning radius R and the grip coefficient φ at rider BMI of 31 kg/m^2

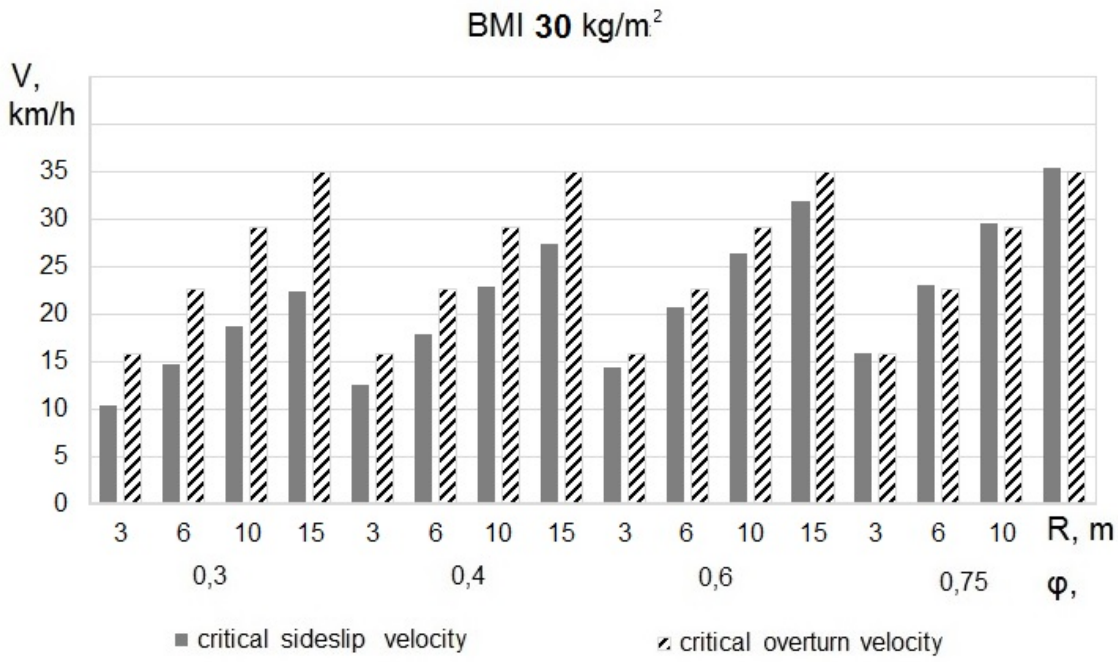

Fig. 10. Variation of critical sideslip and overturn velocities depending on the turning radius R and the grip coefficient φ at rider BMI of 30 kg/m^2

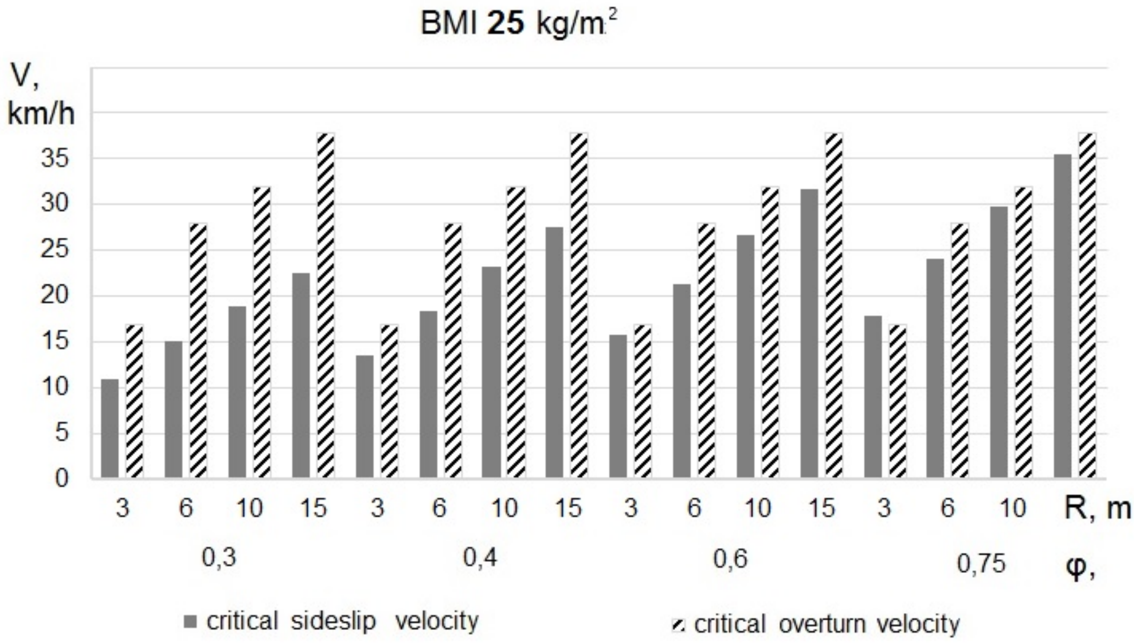

Fig. 11. Variation of critical sideslip and overturn velocities depending on the turning radius R and the grip coefficient φ at rider BMI of 25 kg/m^2

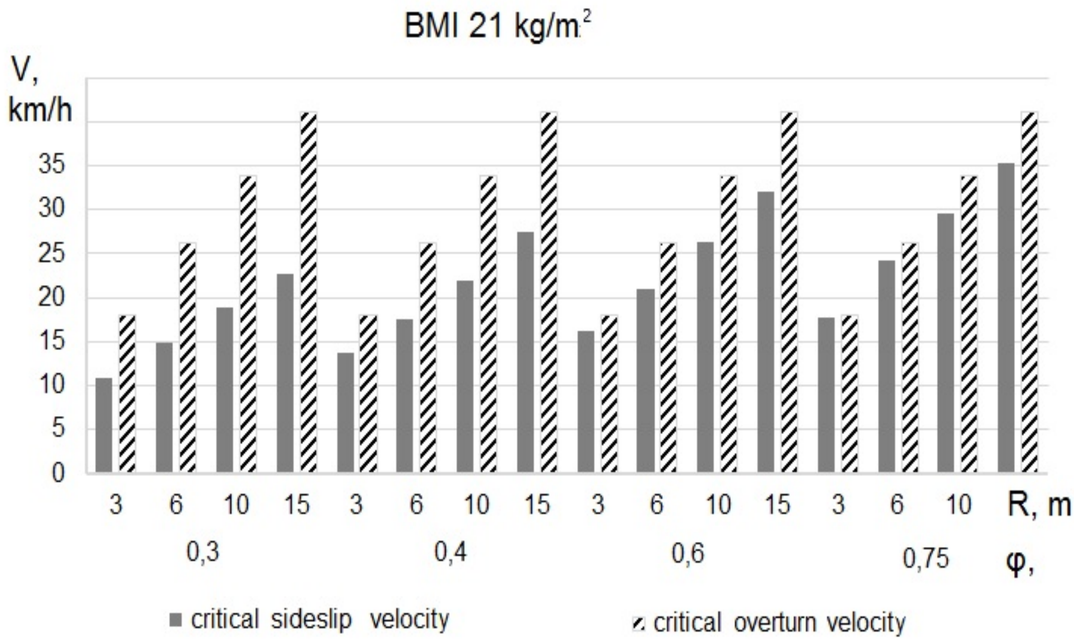

Fig. 12. Variation of critical sideslip and overturn velocities depending on the turning radius R and the grip coefficient φ at rider BMI of 21 kg/m^2

It can be seen from Fig. 8 to 10 that the critical velocities against sideslip at radii of curves bigger than 10 m and 15 m do not depend on BMI of different riders. These velocities are not affected by the mass of the vehicle and rider. For small turning radii of 3 m and 6 m, the critical velocities against sideslip are different, because with some of the riders the loss of stability occurs at either rear or front axles.

The critical velocities against sideslip are not affected by BMI of different riders. These critical velocities are evaluated following classic methodology, and the result depends only on the tire grip coefficient and the radius of the curves.

The critical velocities against lateral overturn for riders with higher BMI (more than 30 for any radius of curves, and more than 25 for radius of curve 3 m) are lower than those against sideslip. This is very dangerous as the loss of stability with lateral overturn occurs suddenly. Particularly for riders with higher BMI, the overturn in this situation occurs because of the higher vertical coordinate of the center of gravity.

4. CONCLUSION

After discussion of the obtained results, the following conclusions can be formulated:

1. For riders having a higher BMI of 30–40kg/m^2 and a higher tire grip coefficient of 0.75, the critical overturn velocity remains lower than the critical sideslip velocity. This means that the loss of ATV stability will occur with an initial lateral overturn.
2. For riders having a higher BMI of 30–40 kg/m^2 and motion in curves with larger radius (15 m), critical overturn velocity is obtained when the vertical reaction of the front inner wheel is exhausted. For other driving conditions and riders having a lower BMI of 21–25 kg/m^2, the critical overturn velocity is obtained when the vertical reaction of the rear inner wheel is exhausted.
3. The higher the rider's BMI, the faster the vertical reaction of inner wheels in curve exhausts.
4. The critical overturn velocities in different running conditions are not affected by tire grip coefficients of the roads.
5. For the investigated ATV, the critical velocities are mainly dependent on the BMI, and not so much from the different anthropological features of the rider. A confirmation for this effect can be seen in results for riders with BMIs of 31 kg/m^2 and 30 kg/m^2; the critical velocities are practically equal, independent of the facts that the mass and body structure of two riders are different enough.

Acknowledgment

The study was supported by contract of University of Ruse "Angel Kanchev", № BG05M2OP001-2.009-0011-C01, "Support for the development of human resources for research and innovation at the University of Ruse "Angel Kanchev". The project is funded with support from the Operational Program "Science and Education for Smart Growth 2014–2020" financed by the European Social Fund of the European Union.

References

1. Benham, E. & Ross, S. & Mavilia, M. & Fischer, P. & Christmas, A. & Sing, R. Injuries from all-terrain vehicles: An opportunity for injury prevention. *The American Journal of Surgery*. Vol. 214. No. 2. 2017. P. 211-21.
2. Blower, D. & Woodrooffe, J. & Green, P. & Matteson, A. & Shrank, M. Determination of events leading to sport utility vehicle rollovers. *Transport. Res. Record 1908*. 2005. P. 180-186.
3. Boada, B. & Boada, M. & Díaz, V. Fuzzy-logic applied to yaw moment control for vehicle stability, *Vehicle System Dynamics*. 2005. Vol. 43. No. 10, P. 753-770.
4. Deurenberg, P. & Yap, M. & van Staveren, W.A. Body mass index and percent body fat: a meta analysis among different ethnic groups. *International Journal of Obesity*. 1998. Vol. 22(12). P. 1164-1171.

5. Georgieva, H. & Pavlov, N. & Kunchev, L. Tester for study the influence of tire vertical load and tire internal pressure on tire cornering stiffness. *Applied Mechanics and Materials*. 2015. Vol. 822. P. 89-93.
6. Ivanov, R. & Roussev, R. & Ilchev, P. The influence of the normal tire forces on the vehicle's critical speed. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*. 2007. Vol. 221. P. 13-23.
7. Peters, S. & Iagnemma, K. Stability measurement of high-speed vehicles. *Vehicle System Dynamics*. 2009. Vol. 47. No. 6. P701-720
8. Sharp, R. & Limebeer, D. A motorcycle model for stability and control analysis. *Multibody System Dynamics.* 2001. Vol. 6(2). P. 123-142
9. Tanner, S. & Aitken, M. & Warnock, J. Analysis of All Terrain Vehicle Crash Mechanisms. *Journal of undergraduate research bioengineering*. 2010. P. 53-58.
10. Viner, J. Risk of rollover in ran-off-road crashes. *Transport. Res. Record 1500*. 1995. P. 112-118.
11. Иванов, Р. & Аврамов, Е. & Иванова Д. Моделиране на реакциите и изследване на устойчивостта на двуосен товарен автомобил при неустановено движение. Bultrans'2013, 58-63 с. [In Bulgarian: Ivanov, R. & Avramov, E. & Ivanova, D. Modeling of the reactions, acting on the tires and studying the stability of two axle lorry in case of unsteady motion. *International Scientific conference Bultrans -2013*].
12. *Body Mass Index* (BMI). Available at: http://www.cdc.gov/healthyweight/assessing/bmi/

Received 15.03.2017; accepted in revised form 29.11.2017