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POSSIBILITY OF EVALUATION THE PRE-COLLISIONS SPEED AND SPACE CROSSING BY VEHICLE WITHIN PROCESS OF BRAKING

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Abstract: *This paper assesses from the mathematical point of view the pre-collisions velocities and the distance traveled by car in the braking process, surprised by physical models. For evaluating these quantities are take into account: the number and length of skid mark; type of braking system; nature and condition of the road; the longitudinal inclination of the road; state of the driver. For different longitudinal gradients of the road and the different states of the driver - he is expecting for danger; he is not previously approved by the possible accidents, having a normal behavior in situations requiring immediate danger; circulating during sunrise and twilight - the obtained results surprise the initial velocity variations on the delay time of braking phases, given as wheel lock and brake effective and on this basis is used to assess total stop area by perception-reaction time of the vehicle driver, surprising the perception-reception-reaction phase in the braking process which depends exclusively on state driver. Working algorithm developed allows changing the input data and obtain results with graphical interpretation for different states of the driver and vehicle operating in various situations that facilitate the assessment and comparison of different conditions studied.*
Key words: *vehicle, braking process, breaking skid marks, speed, calculation algorithm*

1. INTRODUCTION

In a situation of imminent crash, the reaction time and choice of the most appropriate ways reflects the neuropsychological qualities of the driver. A driver can directly influence the movement and behavior of his vehicle by braking, routing (steering, rounding), acceleration, braking and routing or acceleration and routing the vehicle. Faced with situations of acute danger, the driver reacts most commonly by braking and vehicle routing [2, 3, 4, 5, 6, 7, 8, 10, 12].

The perception-reaction time of the driver is a variable, depending on the age and degree of fatigue of the driver, the climatic conditions and the number of stimuli that can affect his condition. For situations that require immediate danger, value of perception-reaction time between 0.8 and 1 seconds reflects the normal behavior of a driver under the age of 25...35, rested, with an average driving experience that look forward and unsuspecting previously for a possible danger of accidents [4, 5, 6, 11, 13, 16]. Compared to situations where the driver does not expect any danger and he look forward, where he is informed in advance or if traveling on a section of road, or in conditions predisposed to generate particular dangers (the driver is already expected for danger) its perception, reaction time is shorter up to 40% [4, 5, 11, 13]. The perception-reaction time is increasing, in certain circumstances [4, 5, 6, 8, 9, 10, 11, 13]; for example, sunrise and twilight periods, it increases by 20...30%.

The braking ability of the vehicle parameters depend on the type of braking system, the nature and condition of the road and not least on the driver, on which is conditioned the duration of the perception-reception-reaction process etc. The braking capacity of the vehicle can help to determine and compare the absolute deceleration, the braking time and the braking area, depending on the velocity [9, 10, 14, 15, 16].

2. NOTATIONS USED IN THE CALCULATION MODEL

In the study will take into account the different states of the driver, symbolized as follows: *A* - he is expected to danger; *B* - normal behavior in situations requiring an imminent danger; *C* - for the sunrise and twilight periods.

If the numerical model developed in MathCAD software, it is necessary to use a certain quantity (*M*) which varies between a minimum value (M_{min}) and a maximum value (M_{max}), considering a variable ($j = 1...j_{max}$, where $j_{max} = 11$) to capture the values of the quantity considered in interval ($M_{min}...M_{max}$) is defined a general relation valid for the calculation of the form:

$$M_j = M_{min} + (j-1) \cdot \frac{M_{max} - M_{min}}{j_{max} - 1}. \qquad (1)$$

The main notations used in the algorithm is found in Table 1.

Table 1

Main notations used in the algorithm used for calculating

Physical meaning	Symbol	M.U.
❑ the longitudinal angle inclination of the road	α	^{o}
❑ the average grip coefficient	φ_{med}	-
❑ the maximum grip coefficient	φ_{max}	
❑ the average grip coefficient, taking into account the longitudinal angle inclination of the road	φ_{med_0}	-
❑ the maximun grip coefficient, taking into account the longitudinal angle inclination of the road	φ_{max_0}	-
❑ the maximum rolling resistance coefficient	f_{max}	-
❑ the maximum coefficient of rolling resistance, taking into account the longitudinal angle inclination of the road	f_{max_0}	-
❑ the coefficient of brakes efficiency	k_e	-
❑ the gravitational acceleration	g	m/s^2
❑ the absolute deceleration during the braking	d_b	m/s^2
❑ corresponding phase for perception-reception-reaction space	S_{pr}	m
❑ corresponding phase for wheels lock space	S_{wl}	m
❑ the minimum braking space (the space with breaking skid marks)	S_{bmin}	m

Table 1 (Continuation)

Physical meaning	Symbol	M.U.
❑ the additional braking space (due to delays)	S_a	m
❑ the total stopping space of the braking process	S_{pb}	m
❑ in the event that the braking tracks are discontinuous		
• the length of the first traces of breaking skid marks	L_1	m
• length of the second traces of breaking skid marks	L_2	m
• the length of a intermediate trace of the breaking skid marks	L_i	m
• length of the last traces of breaking skid marks	L_n	m
• the distance between the first and second breaking skid marks	l_{12}	m
• the distance between two breaking skid marks	$l_{(i-1)i}$	m
• the distance between last but one and the last breaking skid marks	$l_{(n-1)n}$	m
❑ the duration of perception	t_{pp}	s
❑ the duration of the reception - characterized by emotion phases, reasoning (judgment) and decision	t_{rp}	s
❑ the duration of the physiological delay	t_{pd}	s
❑ the duration of mechanical delays	t_{md}	s
❑ the duration of perception-reaction time of the driver	t_{pr}	s
❑ the duration of the braking delay	t_{bd}	s
❑ the duration of involuntary delays	t_{id}	s
❑ the duration of effectively braking	t_{bmin}	s
❑ the total stopping time interval	t_{sti}	s
❑ the initial speed of the vehicle	v_0	km/h

3. THE PHASES OF AN ROAD CONFLICT

The phases of an road conflict (Fig. 1) are symbolized as follows: P-CP - pre-collision phase (the period before the accident - occurs until the two corps come in contact); C - collision (corresponding to the period in which the two corps are in contact - within this body deformation occurs, the process by which a part of the initial kinetic energy is transformed into deformation energy); PCP - postcollision phase (since there is separation of the two corps until they stop) [4, 5, 6, 8, 10, 12].

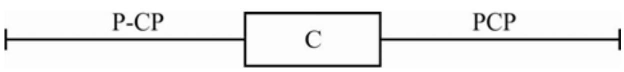

Fig. 1. The phases of an road conflict.

Evaluation of speed of the vehicle in different phases of a conflict road is necessary for the reconstruction of an accident.

4. PHASES AND EFFICIENCY OF THE BRAKING PROCESS

The braking process is a complex one, consisting of several stages (Fig. 2, Fig. 3), each of which directly influences the braking efficiency [8, 9, 10, 12]:

- the perception-reception-reaction phase (p.r.r.p.), characterized by the length of the driver perception-reaction time t_{pr}, where vehicle displacement is performed at constant speed;
- phase of locking wheels (p.l.w.), which begins when deceleration occurs until the printing skid mark that appear on the road pavement, characterized by delays during the braking (t_{db} - time corresponding to weels lock respectively to achieve maximum effectiveness braking);
- the braking phase (b.p.), which begins from the moment of printing and ends with vehicle stops or the braking process is stopping, characterized by the minimum braking t_{bmin}.

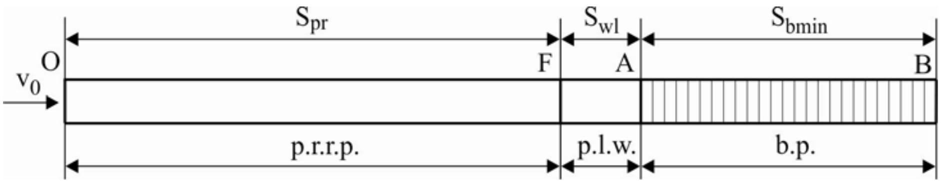

Fig. 2. The Phases of the braking process.
v_0 - initial speed; A - the point at which occurs breaking skid marks; B - end of braking process.

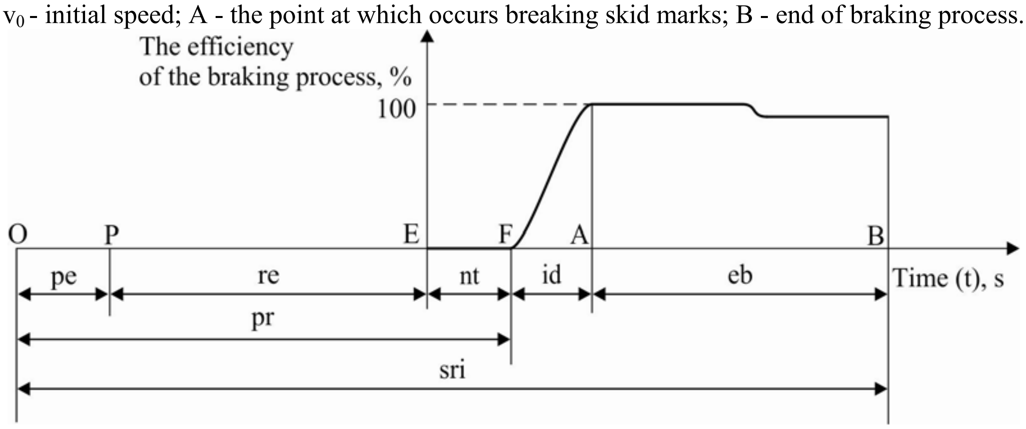

Fig. 3. The scheme of braking process.

Events	*Intervals*
O - the event that causing the braking can be observed;	sri - total time interval required to stop the vehicle;
P - the event is perceived;	pe - the time needed to perceived the event;
E - the decision is taken, the action begins;	re - the time interval of receipt the event;
F - start the braking effect;	pr - the time interval of perception-reaction;
A - the braking effectiveness is Maximum (maximum deceleration);	nt - the needed time to start braking action (lifting the foot off the pedal, put the foot on the brake pedal, ending the race of the brake pedal);
B - the vehicle stops.	id - increasing the deceleration up to the maximum value;
	eb - effective braking the time interval.

The duration of perception-reaction process t_{pr} (interval A÷F, see Fig. 3) passed from the moment of danger (the referral need braking) and until the efficiency brake increasing (beginning the race of the brake pedal) is determined as the sum of the duration of the physiological delay t_{pd} (range E÷A, see Fig. 3) and the duration of the mechanical delays t_{md} (interval E÷F, see Fig. 3) [4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16]:

$$t_{pr} = t_{pd} + t_{md}, \quad (2)$$

in which [8, 9, 10, 12]: t_{md} is the time required to raise the foot off the accelerator pedal, putting the foot on the brake pedal, ending the race of the brake pedal (clear of the joints, brake shoe adjustments, elasticity of the pipes) and is 0.1...0.2 s for mechanical and hydraulic brakes, respective 0.2...0.4 s for pneumatic brakes; t_{pd} has values in the range of 0.5...1.5 s, but if you know the situation that triggered the braking action, t_{pd} have values between 0.5...1.1 s for surprising situations and 0.4...0.8 s for anticipated situations and is given by relation:

$$t_{pd} = t_{pp} + t_{rp}, \quad (3)$$

where: t_{pp} characterize the interval O÷P (see Fig. 3) and t_{rp} characterized the interval P÷E (see Fig. 3).

Duration of involuntary delays t_{id} (interval O÷A, see Fig. 3) represents the time elapsed from the moment that the driver perceives the danger, until in which the braking process of the car is constant and is determined by the relation [4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16]:

$$t_{id} = t_{pr} + t_{bd}, \quad (4)$$

where: t_{bd} (interval F to A, see Fig. 3) is the time elapsed since the start of braking until the wheels locking (achieve the maximum braking efficiency), with values of 0.15...0.25 s - for mechanical and hydraulic brakes and 0.6...0.8 s - for pneumatic brake [8, 9, 10, 12].

The effective braking duration t_{bmin} (interval A÷B, see Fig. 3) is the time interval in which the maximum braking deceleration is performed, to which is added the duration with braking weels and low deceleration.

The total stopping time interval t_{sti} (interval A÷B, see Fig. 3) is defined as the elapsed time since the moment of accident danger occurring, until the vehicle stops and is determined by the relation [4, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16]:

$$t_{sti} = t_{id} + t_{bmin}. \quad (5)$$

5. EVALUATION POSSIBILITIES OF PRE-COLLISION SPEED AFTER SKID MARKS

Calculating of the initial velocity v_0 is on the assumption that vehicle is stopped after covering the braking space ($v_B = 0$) (see Fig. 2, Fig. 3).

In such conditions, the speed corresponding to the point A (Fig. 2, Fig. 3) is calculated as follows [8, 10]:

$$v_A = \sqrt{\frac{2 \cdot d_{f_{med}} \cdot S_{b\,min}}{k_e}}\text{, in m/s,} \quad (6)$$

however this can also be expressed by the relation [10]:

$$v_A = v_0 - \frac{d_{f_{max}}}{2} \cdot \frac{t_{bd}}{k_e}\text{, in m/s,} \quad (7)$$

the deceleration is reaching at d_{max} (with ABS the deceleration achieved to 8.8...9 m/s^2, and with the other system 5...6 m/s^2) [9, 10, 12]. S_{fmin} effective braking area is suitable braking phase and are locked wheel braking space. Values of the coefficient k_e can be found in Table 2 [8, 9, 10].

Table 2

The values of the brake efficiency coefficient, k_e

Type of vehicle	Without load		With maximum load	
	Brake without distributing frame	Brake with distributing frame	Brake without distributing frame	Brake with distributing frame
Passenger cars	1.2	1.0	1.2	1.0
4...5 tons trucks and buses with a length up to 7.5 m	1.4	1.2	1.2	1.6
Heavy trucks and buses	1.6	1.4	2.0	1.8

Considering the relations (6) and (7) under *the assumption that the braking is performed with all wheels, the skid marks are continuous and longitudinal profile of the road is tilted* and the vehicle is stopped after completing the braking area ($v_B = 0$, see Fig. 2, Fig. 3), the initial speed v_0 (in km/h) can be determined according to the equation [1, 8, 10]:

$$v_0 = \frac{1.8}{k_e} \cdot \varphi_{max_0} \cdot g \cdot t_{if} + \sqrt{\frac{26 \cdot \varphi_{med_0} \cdot g \cdot S_{b\,min}}{k_e}}, \quad (8)$$

were: $\varphi_{max_0} = \varphi_{max} \cdot cos\,\alpha \pm sin\,\alpha$; $\varphi_{med_0} = \varphi_{med} \cdot cos\,\alpha \pm sin\,\alpha$, ("+"climbing; "–"descending).

In case there is evidence of discontinuous braking skid marks (Fig. 4) and the longitudinal profile of the road is tilted, assuming that at the end of skid mark L_n vehicle stopped ($v_{nf} = 0$) to determine the initial speed (in km/h) v_0 (Fig. 4, Fig. 5), it shall be proceed as follows [8, 10]:

- if the condition:

$$l_{12} < t_{if} \cdot \sqrt{2 \cdot \varphi_{med_0} \cdot g \cdot \sum_{i=1}^{n} L_i} \ , \qquad (9)$$

then:

$$v_0 = \frac{1.8}{k_e} \cdot \varphi_{max_0} \cdot g \cdot t_{if} + \\ + \sqrt{\frac{26 \cdot \varphi_{med_0} \cdot g \cdot \sum_{i=1}^{n} \left(L_i + l_{(i-1)i} \right)}{k_e}} \ . \qquad (10)$$

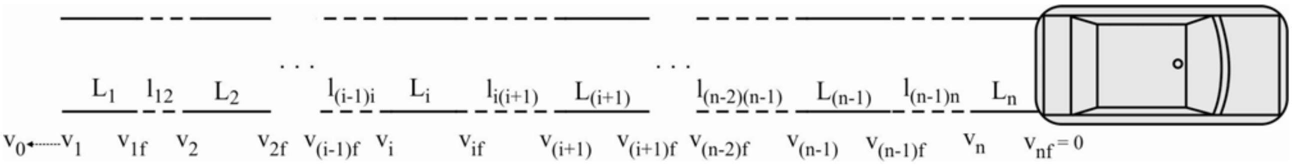

Fig. 4. Disposal of discontinuous skid mark and considering the vehicle speed at the beginning and to the end of each breaking skid mark.

- if the condition is satisfied:

$$l_{12} \ge t_{bd} \cdot \sqrt{2 \cdot \varphi_{med_0} \cdot g \cdot \sum_{i=1}^{n} L_i} \ , \qquad (11)$$

to determine the initial speed v_0 (in km/h), is used in the calculation the intermediate gears, in stages (Fig. 4, Fig. 5) [8, 10]:

$$\begin{cases} v_n = \frac{1.8}{k_e} \cdot \varphi_{max_0} \cdot g \cdot t_{bd} + \\ + \sqrt{\frac{26 \cdot \varphi_{med_0} \cdot g \cdot L_n}{k_e}} \\ v_{(n-1)f} = \sqrt{26 \cdot f_{max_0} \cdot g \cdot l_{(n-1)n} + v_n^2} \\ \ldots \\ v_i = \frac{1.8}{k_e} \cdot \varphi_{max_0} \cdot g \cdot t_{bd} + \\ + \sqrt{\frac{26 \cdot \varphi_{med_0} \cdot g \cdot L_i}{k_e} + v_{if}^2} \\ v_{(i-1)f} = \sqrt{26 \cdot f_{max_0} \cdot g \cdot l_{(i-1)i} + v_i^2} \\ \ldots \\ v_0 \equiv v_1 = \frac{1.8}{k_e} \cdot \varphi_{max_0} \cdot g \cdot t_{bd} + \\ + \sqrt{\frac{26 \cdot \varphi_{med_0} \cdot g \cdot L_1}{k_e} + v_{1f}^2} \end{cases} \ , \qquad (12)$$

were: $f_{max_0} = f_{max} \cdot cos\,\alpha \pm sin\,\alpha$, ("+" climbing; "–" descending).

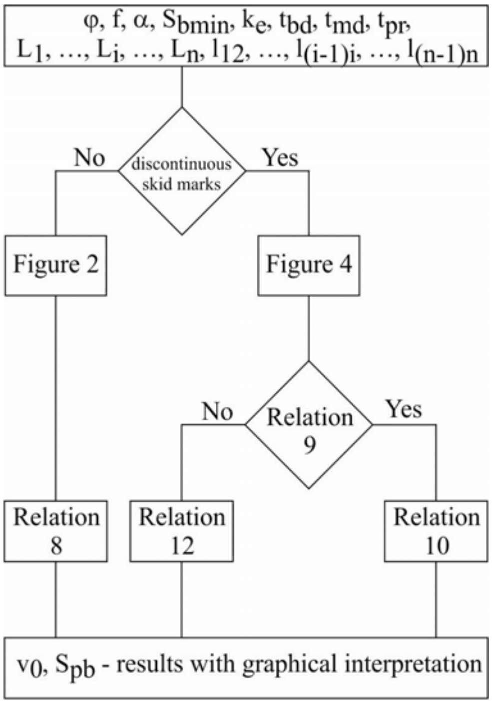

Fig. 5. Working scheme of the numerical model for evaluating pre-collision speed after breaking skid marks.

6. EVALUATION THE STOPPING TOTAL SPACE WITHIN THE BRAKING PROCESS

The braking minimum space (S_{bmin}) is taken into account based on the number of breaking skid marks and the space between them, as follows:

$$S_{b\,min} = \sum_{i=1}^{n}\left(L_i + l_{(i-1)i}\right), \text{ in m.} \tag{13}$$

It is considered that at the end of the skid mark L_n, the vehicle stopped ($v_{nf} = 0$).

The additional braking space (due to delays) are determined taking into account the stage of perception-reception-reaction phase and the wheels lock, respectively the fact that the road is horizontal or have an longitudinal inclination. Thus, additional space for the determination of the braking space (S_a) it takes into account the relation [8, 9, 10, 14, 15, 16]:

$$S_{a\begin{pmatrix}A\\B\\C\end{pmatrix}} = \frac{v_0}{3.6}\cdot\left[t_{pr\begin{pmatrix}A\\B\\C\end{pmatrix}} + t_{bd}\right], \text{ in m,} \tag{14}$$

where v_0 is the initial velocity determined from equation (12).

The total stopping space (S_{pb}) is determined by taking into account the minimum space (S_{bmin}), and additional stopping space (S_a), such [8, 9, 10, 14, 15, 16]:

$$S_{pb\begin{pmatrix}A\\B\\C\end{pmatrix}} = S_{a\begin{pmatrix}A\\B\\C\end{pmatrix}} + S_{b\,min}, \text{ in m.} \tag{15}$$

7. OBTAINED RESULTS

For exemplification, in numerical model were considered the following inputs: braking skid marks are discontinuous (two parallel braking skid marks with L_1 = 9.5 m, two parallel braking skid marks L_2 = 7.7 m, two braking skid marks with L_3 = 5.3 m; between first braking skid marks has been measured a distance of l_{12} = 6.4 m; between the last braking skid marks distance has been measured a distance of l_{23} = 4.8 m) that come from a car equipped with an hydraulic brake with distributing frame, in a climb found on a dry asphalt concrete road with the longitudinal inclination of 0...12%; the times values of perception-reaction at the braking of driver-vehicle assembly, according to the state of the driver are considered as follows: $t_{pr(A)}$ = 0.48...0.6 s; $t_{pr(B)}$ = 0.8...1 s; $t_{pr(C)}$ = 0.96...1.3 s; the durations of mechanical delay and the durations of braking delay are taken into account in the case of a vehicle fitted with hydraulic braking system.

Based on the input data, by reference to the working scheme shown in Figure 5, is obtained the results with respect to the variation of initial velocity according to the the duration of the braking delays for each of the operating conditions taken into account (Fig. 6).

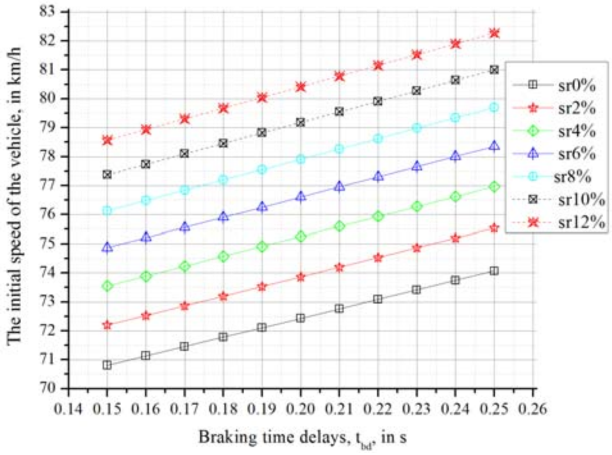

Fig. 6. Variation of initial velocity of the vehicle according to the braking system delay for different longitudinal inclination situations of the road (sr - slope of the road).

For each of the driver states included in the study and for all the situations considered to be with the longitudinal inclination of the road, in Figure 7, are being overtaken the results regarding to the variation of the total stopping space according to the initial speed of the vehicle.

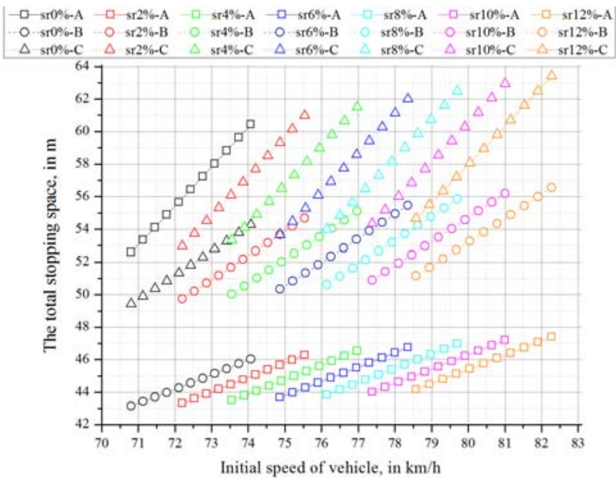

Fig. 7. Variation of total stopping space corresponding to different states of the driver and the situations longitudinal road tilt, depending on the initial speed of the vehicle (sr - slope of the road).

Based on the results obtained, Figure 8 shows the variation of the stopping distance depending on the state of the driver and the longitudinal inclination of the road, taking as a basis of comparison the case when the driver have normal behavior in situations requiring an imminent danger.

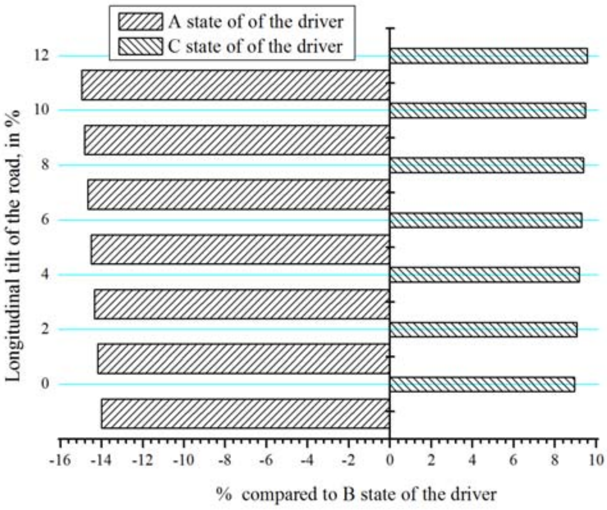

Fig. 8. Variation of the stopping distance depending on the state of the driver and the longitudinal inclination of the road, taking as a basis of comparison the case of the driver with normal behavior in situations that require an imminent danger (state *B*).

8. CONCLUSIONS

The working algorithm that has been elaborated allows changing the entrance data and obtaining the results with a graphic interpretation for any other situation of exploiting vehicles or other states of the auto driver, which facilitates the appreciation and comparison of different conditions taking into account.

The numerical model can stay at the basis of developing a working algorithm, which will allow the evaluation of the parameters for the braking capacity for different exploitation conditions of vehicles.

The study can be extended to the reconstruction of traffic crashes, when the breaking is being done only with the front or back wheels, the breaking skid mark are continuous and the road is horizontal or the longitudinal profile of the road is titled. Also, within the numerical model it can be taken into account the situation when: on certain areas of the road there is only one breaking skid mark; the situation when the braked vehicle has two or three wheels or when the braked vehicle has a trailer without its own breaking mechanism.

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POSIBILITĂŢI DE EVALUARE A VITEZEI ANTECOLIZIUNE ŞI A SPAŢIULUI PARCURS DE AUTOVEHICUL ÎN CADRUL PROCESULUI DE FRÂNARE

Rezumat: În lucrare se evaluează, din punct de vedere matematic, vitezele antecoliziune Și spaţiul parcurs de autovehicul în cadrul procesului de frânare, surprins prin modele fizice. La evaluarea mărimilor respective se ţine seama de: numărul Și lungimea urmelor de frânare; tipul sistemului de frânare; natura Și starea drumului; înclinarea longitudinală a drumului; starea conducătorului auto. Pentru diferite înclinări longitudinale ale drumului Și diferitele stări ale conducătorului auto - se aşteaptă la pericol; nu este avizat în prealabil de un posibil pericol de accident, având un comportament normal în situaţiile care reclamă un pericol iminent; circulă în perioadele de răsărit şi crepuscul -, rezultatele obţinute surprind variaţiile vitezelor iniţiale în funcţie de timpul de întârzieri la frânare, având în vedere astfel fazele de blocare a roţilor Și de frânare efectivă, iar pe baza acestora se recurge la evaluarea spaţiului total de oprire în funcţie de timpul de percepţie-reacţie al ansamblului conducător-autovehicul, corespunzător diferitelor stări ale conducătorului auto, surprinzând Și faza de percepţie-recepţie-reacţie din cadrul procesului de frânare, care depinde exclusiv de starea conducătorului auto. Algoritmul de lucru dezvoltat permite schimbarea datelor de intrare Și obţinerea rezultatelor cu interpretare grafică pentru diferite stări ale conducătorului auto Și diferite situaţii de exploatare a autovehiculelor, ceea ce facilitează aprecierea şi compararea diferitelor condiţii luate în studiu.

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