NEMCHINOV MICHAEL VASILIEVICH
Moscow State Auto and Road
Technical University. Russia
AKTANOV SERIK KASIMBEKOVICH
State undertaking «Kazakhauturoad». Astana
Republic Kazakhstan
e-mail: uchsovet.@madi.ru

FORCES AND STRESSES AT TIRES AREA CONTACT WITH ROAD PAVEMENTS FOR CARS AND LIGHT TRUCKS

Abstract
This paper describes methods and results of experimental investigations of forces and stresses at the tire contact area. A dynamometric MADI platform with a plate of a specified roughness was used to determine the dynamic influence of a car wheel at different speeds and loads. In the investigation it was determined how the forces generated at wheel contact with the pavement are influenced by air pressure in tires, pavement roughness and vehicle velocity.

Keywords: ire, road surface, contact area, friction force, stress

1. Introduction

Road engineers always think about pavement durability. It is very important criterion for road pavements. But it does not tell about possible safety cars speeds. The criterion for it is a pavement slippery [1–9].

A pavement slippery is one of the main reasons of road accidents. That is why a producers of car tires make special tire protector. It needs for receiving of high friction between tire and pavement. There are many interesting investigations of tire – pavement friction, which were made in different countries for many years (from the beginning of 20 century). It was determined that friction force in tire – pavement contact area has two components – adherence and deformation:

$$F = 2.6\, T_0 \cdot r^{2/3} \cdot \theta^{2/3}/N^{1/3} + \beta + 0.17 \cdot a_r \cdot N^{1/3} \cdot \theta^{1/3}/r^{1/3} \quad (1)$$

where: T_0 – move resistance, r – radius of unity of pavement roughness, $\theta = (1 - M^2)/E$ – index of elasticity, M – Puasson coefficient, E – modulus of elasticity, N – wheel load, β – coefficient of molecular interaction, a_r – friction gisteresis losses.

The first two items are adhesion component of friction, the third is deformation component. One can see that friction force cross minimum and decrease when modules of elasticity grow up. Communicate of friction coefficient and real contact pressure is expressed by equation for united contact:

$$f = r_0/p_r + \beta + 0.44 \cdot a_r \cdot p_r \quad (2)$$

For multitude contact friction force:

$$F = \int_0^n \left(T_0 + \beta \cdot p_0 + k_x - p_r \sqrt{\frac{h}{2}} \right) \Delta A_r d_n \quad (3)$$

where: A_r – real contact area, p_r – real pressure, p_0 – contour pressure, h – inculcation depth of roughness projection into protector rubber, k_x – coefficient: k_x = 0.19 a_r – for elastic contact, k_x = 0.55 – for unit projection and for plastic contact, n – quantity of rough projection in contact area, T_0 – unite adhesion (molecular) component of friction force.

For adhesion component of friction force it is possible to write:

$$T_a = T_0 \cdot A_k + \beta \cdot N \quad (4)$$

For deformation (mechanical) component:

$$F = k_x \int_0^n N_r \sqrt{\frac{h}{2}} d_n \quad (5)$$

where: N_r – load for unite friction connection.

Thus for evaluate of friction force in contact area it needs to know contact area sizes, area functional contacts, contact pressure (middle for area and on roughness projection) and contact time that is car velocity.

Investigation intention: To determine of quantity and probable regularities of wheel load change at contact area during car movement.

Object of investigation: Asphalt pavement with rough wear layer from crushed stone different rocks.

Factor for investigation: 1. Adhesion component of friction force as function of rocks kind. 2. Pressure in contact area and it depends from car velocity. 3. Longitudinal component of pressure force at contact area. 4. Specific pressure at contact area: middle on area (contour and real) and at different pavement roughness projection.

Investigation method. Method is complex: natural investigation at real roads with different cars and light trucks, velocity from 0 to 90 km/hour, natural and model pavements, laboratory investigation with different kinds of rocks. t was used different special equipments for transient processes.

2. Methods for investigating car wheel dynamic influence at road pavement surface

It was used specific dynamic platform “Module A”, which was made for measuring of contact force of sportsmen-jumps. “Module A” had dynamometric platform, plate with roughness at her surface, which was made at three rock swing posts. In result it was possible to register three component of force, it acting on plate: P_x, P_y, P_z. Deformation of rock swing posts was measured with help of tensometers and was recorded on tape. The platform mass was 80 kg. Hard and stability all system was guaranteed by place of support frame in flexible pavement.

Outward external force calls deformation of plate rock swing posts and electrical signal. It was six tensometers – for P_x and P_y. Owner frequency of platform was more 400 Hz, what was more forced frequency. Maximum vertical force was 9.8 kN, in horizontal component (X,Y) – 4.9 kN.

Platform surface was in one level with road surface. Platform dimension in plane – 750 x 750 mm. That is why it was possible to have car velocity to 100 km/hour. Pavement irregularities were made by label of different dimension pebbles at plate and near road pavement (zone 1.5 m). It was investigated seven texture types with different height roughness (Table 1).

Table 1. Pavement texture in investigation

Dimension of rock [mm]	Height of pavement roughness [mm]
Without rock	0.10
5 – 10	2.40 – 2.45
10 – 15	4.69
15 – 20	5.69
20 – 25	5.55 – 6.96

Cars had wheel load: 2.2 kN; 2.85 kN; 4.90 kN; 5.40 kN. Velocity was from 0 to 90 km/h. It was calculated minimum number of measuring: $N_{min} = k_v^{2} \cdot t^2 / \Delta^2$, K_v – variation coefficient:

$$k_v = {}^{\delta}/\bar{x},\ \delta = \left[\sum_{i=1} (xi - \bar{x})/(n-1)\right]^{1/n} \quad (6)$$

T – Student coefficient, Δ – prescrible precision accuracy for little amount of measuring. It were: $\Delta_{px} = 3.5\%$; $\Delta_{pz} = 4.5\%$ for reliable 95%. Minimum measuring for $P_z = 10$, for $P_y = 6$. Real measuring errors were 4.33% for P_z and 3.42% for P_y.

2.1. Method of measuring of contact pressure

For this work it was made special small platform – platform MADI (S.K. Aktanov) – with dimension 400 x 400 mm. This platform was putted in pavement in one level with it. The plate of platform has many openings 12 mm in diameter with step 25 mm for special tensometer (design by S.P. Zaharov from Institute of Tire Industry, Russia). This tensometer had head, which was placed in openings of plate. Electrical signal was rouded. Minimum measuring was 12% by 95% reliable. Real error was 3.02%.

Roughness was modeled by indentors with sphere form head. Radius of sphere in plane and height were 2.5 mm; 5.0 mm; 7.0 mm; 10 mm with a distance between axles, accordingly, 25 mm; 50 mm; 75 mm and 100 mm. In result it was two types of pavement roughness: rough (R = 7.5 mm, l = 25 mm; R = 10 mm, l = 25…50 mm) and dowel pin (R = 2.5 mm, l = 25…100 mm; R = 5.0 mm, l = 25…100 mm; R = 10 mm, l = 75…100 mm) (Fig. 1).

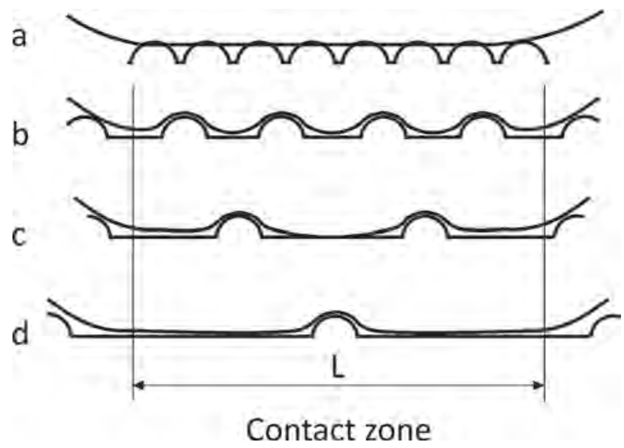

Fig. 1. Scheme of contact of tires with pavement roughness. a, b – rough surface, c, d – dowel pin surface, L – contact area length

2.2. Method for estimating pavement roughness work at real roads

It was used an observation method with measuring of traffic volume and pavement roughness at the several read roads. Then actual traffic volume was counted to equivalent traffic volume for truck with wheel load 6.5 t (13 t at axle). For pavement roughness was used "sand spot" method.

3. Results of investigation

3.1. Dynamic influence of cars at pavement

Wheel cars load was from 1.94 kN to 6.92 kN. Velocity: 0–90 km/h.

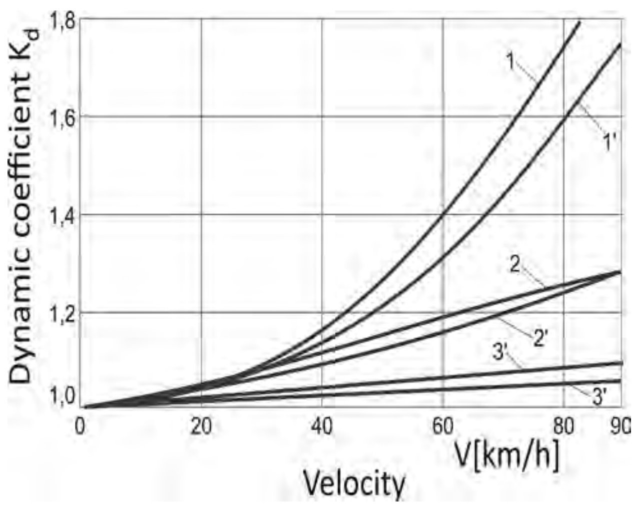

Fig. 2. Dynamic coefficient K_d of cars for travel with different velocities. 1, 2, 3 – no drive wheel. 1.1, 2.1, 3.1 – drive wheel. Rough R: 1, 1.1 – 5.55 mm; 2, 2.1 – 2.45 mm; 3, 3.1 – 0.10 mm

Table 2. Dynamic coefficient K ($P_{z\,V>0}/P_{zV=0}$)

Velocity [km/h]	No drive wheel $G = 3.06$ kN	Drive wheel $G = 3.15$ kN
0	1	1
40	1.17	1.05
60	1.20	1.21
80	1.67	1.48
90	1.70	1.50

Table 3. Pavement roughness and dynamic coefficient K

Velocity [km/h]	Pavement roughness, R [mm]					
	0.10		2.45		5.55	
	No drive Wheel The first	Drive Wheel The back	No drive Wheel The first	Drive Wheel The back	No drive Wheel The first	Drive Wheel The back
40	1.04	1.02	1.14	1.07	1.22	1.07
60	1.08	1.04	1.17	1.16	1.29	1.26
80	1.09	1.09	1.24	1.25	1.82	1.62
90	1.14	1.13	1.32	1.25	1.95	1.71

Table 4. Growth of wheel load at every millimeter of height pavement roughness $G = 3.06 – 3.15$ kN

Velocity [km/h]	Increase of load for 1 mm of roughness ledge height	
	No drive wheel	Drive wheel
40	3.1	1.0
60	3.65	3.8
80	12.2	8.9
90	13	9

Dependence of vertical component of wheel load from velocity it is possible to express by equation:

$$P_z = P_z^{v=0} + a \cdot V = b \cdot V^2 \qquad (7)$$

Table 5. Coefficients and b. $G = 3.06 – 3.15$ kN

Coefficients	Pavement roughness, R [mm]					
	0.10		2.45		5.55	
	No drive Wheel. The first	Drive Wheel. The back	No drive Wheel. The first	Drive Wheel. The back	No drive Wheel. The first	Drive Wheel. The back
a	0.382	0.280	0.827	0.279	-0.5185	-0.897
b	0	0	0.00237	0.008	0.0431	0.0386

Experiments with cars with another wheel load are confirmed received dependence. Investigations (with S.J. Tkachev) let us the information about blow force of cars wheel with projections at the road surface (Fig. 3).

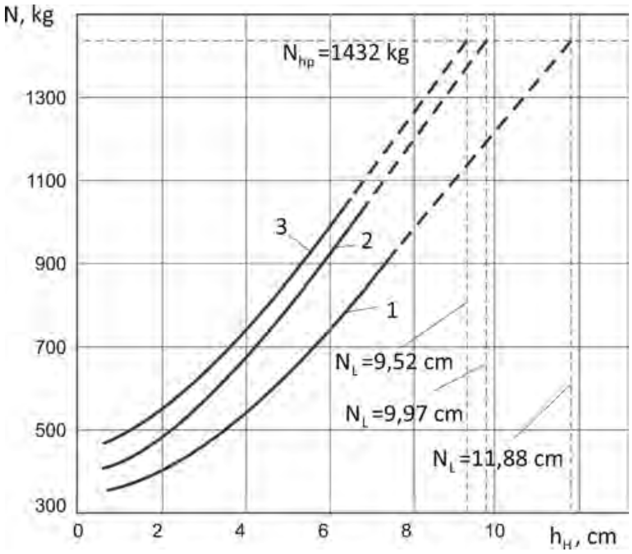

Fig. 3. The blow force of cars wheel (tire) *N* with projections at the road surface; h_H – height of projections, centimeters

3.2. Tangential component of wheel load

It was investigated four types of pavement roughness: R = 2.4 mm; 4.69 mm; 5.69 mm; 6.96 mm (tables 6, 7).

Table 6. Longitudinal component of force (P_y, kN) in wheel area. Drive wheel. G = 3.15 kN

Velocity [km/h]	Pavement roughness, R, [mm]			
	2.40	4.69	5.69	6.96
20	1.037	1.054	1.077	1.044
40	3.115	2.900	2.777	2.780
60	6.254	5.576	5.120	5.252
80	10.454	9.062	8.120	8.458

Table 7. Longitudinal component of effort (kN/cm^2) as function of contact area. Drive wheel. G = 3.15 kN

Velocity [km/h]	Pavement roughness, R [mm]			
	2.40	4.69	5.69	6.96
20	0.033	0.055	0.066	0.074
40	0.100	0.154	0.184	0.196
60	0.202	0.295	0.339	0.370
80	0.338	0.481	0.538	0.595
Real area, A_r [cm^2]	30.91	18.82	15.08	14.20

It is possible to use different kinds of technology for pavement repair. One of them, very often used, is a construction of wearing layer, especially for repair of ruts at pavements. The main constructive component here the rock is. It must be fixed on a pavement surface very strongly. In the first days after construction end it is possible some rocks come off the pavement. In order to it is not a tear off force must be smaller keep force. Professor J. A. Mednikov suggested formula to count the tear off force for rock:

$$P = \frac{4 \cdot R_p}{(3-n)(1-\beta)\cdot\sqrt{(3+(1+\beta)\sqrt{3(3-n)^2}+n^2)}} \quad (8)$$

where: $n = a/a_1$, a – length of rock grain on pavement surface, a_1 – depth of block of rock grain, $\beta = R_p / R_c$, R_p – a count resistance of asphalt concrete to tension, R_c – a count resistance of asphalt concrete in the time of compression. For R_p = 0.3 kN/cm^2 R_c = 1.22 kN/cm^2. Maximum permited longitudinal forces:

for $n = 0.4$, $P = 0.136$ kN,
$n = 0.2$, $P = 0.126$ kN,
$n = 0.1$, $P = 0.122$ kN.

These Figures and table 7 data recommend the velocity limit for the first days of wearing layer work.

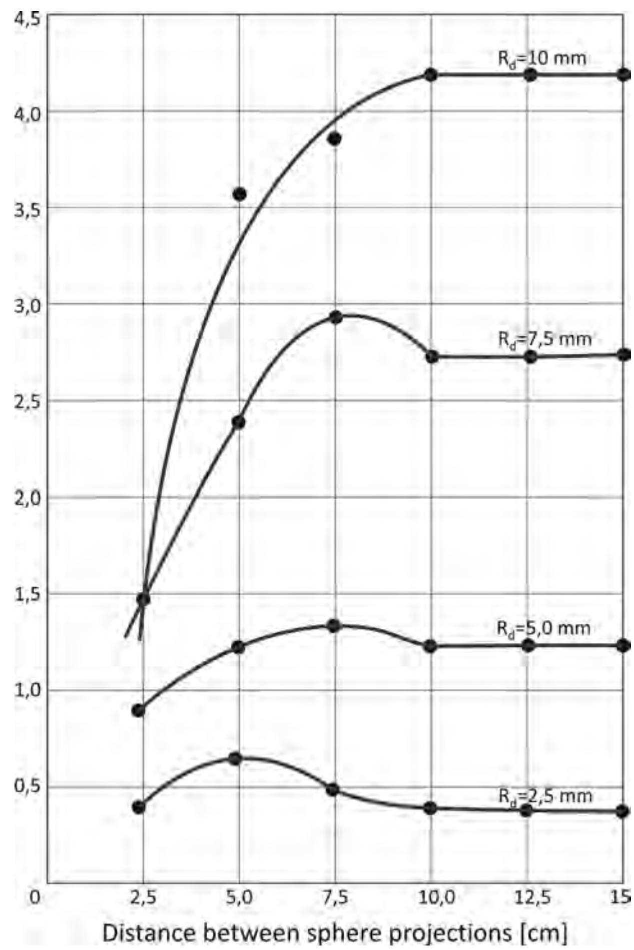

Fig. 4. Contact pressure as function of pavement roughness density and height of rock ledges. Note: on the ordinate – contact pressure at road pavement with sphere projections. H/unit

3.3. Contact wheel area pressure and pavement roughness

Comparison of q_k, q_{fact}, q_0 and q in tires shows large difference of them sizes. Density of pavement roughness ledges changes and increases contact pressure.

Table 8. Pressure at wheel area

No. car	Contact area [cm²]		Middle pressure [kN/cm²]			q_{fact}/q_k
	Real	For 1 ledge	At on four q_k	Real q_{fact}	At one ledge q_0	
1	23.50	0.904	0.,357	1.264	1.142	3.54
2	31.63	0.904	0.511	1.916	1.732	3.75
3	27.72	0.730	0.402	1.520	1.109	3.78
4	34.03	0.791	0.504	1.650	1.305	3.27
5	26.23	0.656	0.540	1.843	1.275	3.60
6	51.03	1.001	0.516	1.391	1.500	2.69
7	83.21	1.280	0.710	1.419	1.816	2.33
8	74.47	1.201	0.470	1.466	1.863	3.12

Table 9. Pressure of air (q) in cars tyre. $V = 0$

No. car	1	2	3	4	5	6	7	8
G_{wheel} [kN]	29.7	60.6	42.1	56.1	51.0	71.0	118.1	109.2
Q [kN/cm²]	0.17	0.033	0.017	0.022	0.020	0.031	0.048	0.044

Table 10. Pressure (kN/cm²) in contact area of the drive wheel $G = 56{,}1$ kN, $V = 20$ km/h

Distance between ledges [mm]	Pavement roughness, R [mm]			
	2.5	5.0	7.5	10.0
25	0.0436	0.0966	0.1530	0.1530
50	0.0620	0.1300	0.2480	0.3634
75	0.0500	0.1351	0.3000	0.3930
100	0.0433	0.1263	0.2780	0.4286

One can see that maximum pressure depends on rock density – distance between rocks and rock height.

3.4. The work of pavement roughness wearing layer

The main purpose of this investigation was to receive an additional information about duration of pavement roughness preservation. Before in such observations it was used hardness gauge of TRRL [4, 5, 6]. We used hardness gauge another design structure, with another form of work head. Our observations were made at road with soft asphalt concrete pavement. The results confirmed received before knowledge.

4. Conclusions

It was determined:

- The pressure at wheel contact area for cars and light trucks is more air pressure in their tires.
- Pavement roughness assists growth of contact pressure in several times, especially for unit ledge of rock.
- Cars velocity assists growth of forces (normal and longitudinal components).
- Dynamic coefficient growths especially quickly for large velocity – 80…90 km/h and more. Prognosis for V more 100 km/h – K more 2.
- Contact pressure is a function of density and height pavement roughness. It is important for rock expenses to decide what pavement roughness to build – rough or dowel pin.

References

[1] Немчинов М.В. Сцепные качества дорожных покрытий и безопасность дорожного движения. – М.: Транспорт, 1985.

[2] Немчинов М.В. Текстура поверхности дорожных покрытий. – М.: ТехПолиграфЦентр, 2010.

[3] Технические указания по устройству дорожных покрытий с шероховатой поверхностью. ВСН 38-90. МинавтодорРСФСР. – М.: Транспорт, 1990.

[4] Greenwood J.A. Williamson J.B.P. Contactofnominally Flat Surfaces. Pros. Roy., Soc., Ser. A., vol. 295 №1442, 1966.

[5] Schallemah A. Proceedings of the Physical Society. Ser. B., vol. 67, №4206,1954

[6] Немчитнов М.В., Актанов С.К. Взаимодействие автомобильного колеса с дорожным покрытием. Ж-л «Наука и техника в дорожной отрасли», №2. 2014.-с.12-14 (0,6 п.л.)

[7] Немчинов М.В., Актанов С.К. Оценка силового воздействия автомобильного колеса на дорожное покрытие». В кн. «Модернизация и научные исследования в транспортном комплексе». Материалы международной научно-практической конференции, г. Пермь, Из-во ПНИПУ, 2014 г. – с.475-477