Mechanics Transport Communications
Academic journal

ISSN 1312-3823
issue 3, 2008
article № 0281
http://www.mtc-aj.com

THE STUDY OF THE WHEEL DIAMETER INFLUENCE OVER THE LOADING CAPACITY OF A RAILWAY VEHICLE

Ioan SEBESAN, Cristina TUDORACHE, Madalina DUMITRIU, Marius SPIROIU
ioan_sebesan@yahoo.com, cristi_tudorache2003@yahoo.com, madalinadumitriu@yahoo.com, marius_spiroiu@yahoo.com,

Prof. Ph.D. Ioan Sebesan, Assist. Eng. Cristina Tudorache, Assist.Eng. Madalina Dumitriu, Lect. Ph.D. Marius Spiroiu, POLITEHNICA University of Bucharest, Faculty of Transports, Rolling Stock Engineering Department, 313 Splaiul Independentei, sector 6, 77206, Bucharest,
ROMANIA

Abstract: *Considering the importance of aspects related to the wheel-rail contact, the work deals with issues related to tribology, mainly referring to the wear profile of the wheel. The detailed knowledge of contact phenomena in this area actually represents the fundamental issue ensuring the development of railway means of transport. The decrease in the diameter of the wheel causes that, at the same load per wheel, the surface of the contact ellipse decreases, appearing the danger of occurrence of plastic deformations. Therefore, this implies the limitation of the road per wheel depending on the diameter thereof. The form and dimensions of the contact area determine the reliability of wheels and rails, guidance safety and adherence features in traction and braking mode of the vehicle.*

Key words: *contact phenomena, contact pressures, contact ellipse, load per wheel, rolling radius.*

ESTABLISHING THE DIMENSIONS OF THE SEMI-AXES OF THE CONTACT ELLIPSE

Requests in the contact area, namely semi-axes noted with a and b, as well as the orientation thereof along or transversally on the rail are determined on basis of Hertz's theory.

Hertz's theory is based on the following hypotheses:

- the a and b dimensions of the contact ellipse are very small in comparison with the dimensions of the two bodies coming into contact;
- only compression voltages, not tangential ones appear in the contact surface;
- the proportionality limit of elastic deformations shall not be exceeded.

For purposes of simplification, the main curve radiuses shall be considered the ones between the contact points of the two bodies, and, depending thereon, two constants A and B shall be declared, whose expressions for the general case take the form:

$$A = 1/r\ ; \quad B = 1/\rho_r + 1/\rho_s \tag{1}$$

and sizes A + B and A – B which interest in the determination of a and b semi-axes of contact ellipses will have the expressions

$$A + B = \frac{1}{r} + \frac{1}{\rho_s} + \frac{1}{\rho_r}\ ; \quad A - B = \frac{1}{r} - \frac{1}{\rho_s} - \frac{1}{\rho_r} \tag{2}$$

Hertz also defines two constants k_1 and k_2:

$$k_1 = (1-\vartheta_1^2)/(2E_1)\ ; \quad k_2 = (1-\vartheta_2^2)/(2E_2)$$

considering that the two bodies have distinct E elasticity modules and distinct Poisson coefficients ϑ . As for the wheel-rail system, these coefficients are considered equal, resulting $k_1 + k_2 = (1-\vartheta)/E$ (elasticity module E = 210 kN/mm^2 and Poisson's coefficient ϑ = 0.3).

Depending on these constants, the semi-axes of the contact ellipse are given by the relation

$$\left(\frac{a}{m}\right)^3 = \left(\frac{b}{n}\right)^3 = \frac{3\,N\,(k_1 + k_2)}{A + B} = \frac{3\,N\,(1 - \vartheta^2)}{E\,(A + B)} \quad (3)$$

where N represents the normal load per contact surface, which, for the rolling surface of the wheel, may be considered as equal to Q (load per wheel). m and n coefficients depend on the ratio (A - B) / (A +B), defined by cosβ = (A - B) / (A +B). Values m and n are given by *Hertz* depending on β (table 1).[1]

Table 1. Values of coefficients m and n

β°	m	n
90	1	1
80	1.128	0.893
70	1.284	0.802
60	1.486	0,717
50	1.754	0.641
40	2.136	0.567
30	2.731	0.493
20	3.778	0.408
10	6.612	0.319

Considering that semi-axis a is always oriented along the path, it results that, if:

$\frac{A-B}{A+B} > 0$, then a < b – the contact ellipse has the big semi-axis oriented perpendicularly on the rail;

$\frac{A-B}{A+B} < 0$, then a > b – the contact ellipse has the big semi-axis oriented along the rail;

ESTABLISHING THE MAXIMUM PRESSURE IN THE CONTACT AREA

The issue of elliptical contact and the pressures in this area was solved by Hertz in 1882, and the established results represent the basis of the subsequent development of contact mechanics.

According to *Hertz*'s theory, the assignment of Z pressures on the contact surface shall be made by an ellipsoid (fig. 1) with equation

$$Z = Z_{max}\sqrt{1 - (x/a)^2 - (y/b)^2} \quad , \qquad (4)$$

$$Z_{max} = 3\,Q\,/\,(2\,\pi\,a\,b)\,, \qquad (5)$$

where x and y are the coordinates of the points on the contact surface from the origin at the center of the ellipse and which coincides with the contact point of non-deformed bodies. For x = y = 0, i.e. in the center of the ellipse, pressure reaches the maximal value given by the relation (5).

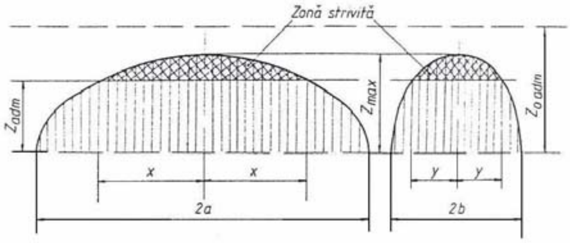

Fig. 1. Assignment of pressures in the contact area.

As the surface of the ellipse is πab, the average value of the pressure on the contact surface shall be

$$Z_0 = Q\,/\,(\,\pi\,a\,b)\,, \qquad (6)$$

If calculating, for distinct loads per wheel, the values Z_{max} and Z_0 , it is found that they exceed considerably the value of the unitary effort resulting at the proportionality limit determined through extension or compression trials and, consequently, the third validity requirement for *Hertz*'s relations shall no longer be satisfied.

On basis of certain reasons, an assessment criterion for the behaviour of material in various loads per wheel and various configurations of contact profiles may be established.

According to the UIC 510-2 sheet, table 2 includes the normal value of static admissible masses per axis, for the maximum speed of the vehicle of 120 km/h, corresponding to the various diameters per wheels. [3]

Tabelul 2.

Diameter wheel [mm]	1000÷840	840÷760	760÷680	680÷630	630÷650
Masses admissible [t/osie]	20	18	16	14	12

Thus, if Z_{adm} , the value obtained from the drainage limit of the wheel material is considered the maximum pressure, i.e.

$$Z_{adm} = 3\sigma_c \quad [kN/cm^2] \qquad (7)$$

and the same value multiplied by 3 / 2 as the average admissible pressure, i.e.

$$Z_{0\,adm} = 4{,}5\,\sigma_c \quad [kN/cm^2] \qquad (8)$$

the following situations may arise in comparison with the calculated values of Z_{max} :

1. If $Z_{max} \le Z_{adm} < Z_{0\,adm}$ - the matter in the contact area stays entirely within the elastical limit;

2. If $Z_{max} < Z_{0\,adm}$ and $Z_{max} < Z_{0\,adm}$ - the basic matter will remain within the elastical limit, but plastic deformations (crushes) shall occur on more restricted areas around the center of the contact ellipse, which, at the beginning, result in cold-straining of the matter and, in time, in fissures and exfoliation.

3. If $Z_{max} > Z_{adm} > Z_{0\,adm}$ - the matter in the contact area entirely enters the plastic scope, producing deformations of profile and matter refulations.

CASE STUDY ON THE INFLUENCE OF THE WHEEL DIAMETER ON THE LOAD CAPACITY OF A RAILWAY VEHICLE

For exemplifying the above mentioned ideas, the semi-axes of the contact ellipse and maximum pressures in the contact area shall be determined for various wheel diameters
2r = 600 … 1200 mm with a wear profile and, respectively, a cone profile ρ_r = 500 mm, rolling on the UIC rail 60 with radius ρ_s = 300 mm. As for the normal load per wheel Q = (100…180) kN, this considers both the normal static load and load transfers and dynamic superloads occurring during rolling.
For the wheel profile, steel with the drainage limit σ_c = 49 kN/cm^2 and longitudinal elasticity module E = 210 kN/mm^2 shall be considered.

Values obtained by calculation of the semi-axes of the contact ellipse a and b, as well as those of maximum pressures are transposed in the charts of fig. 2 … 5

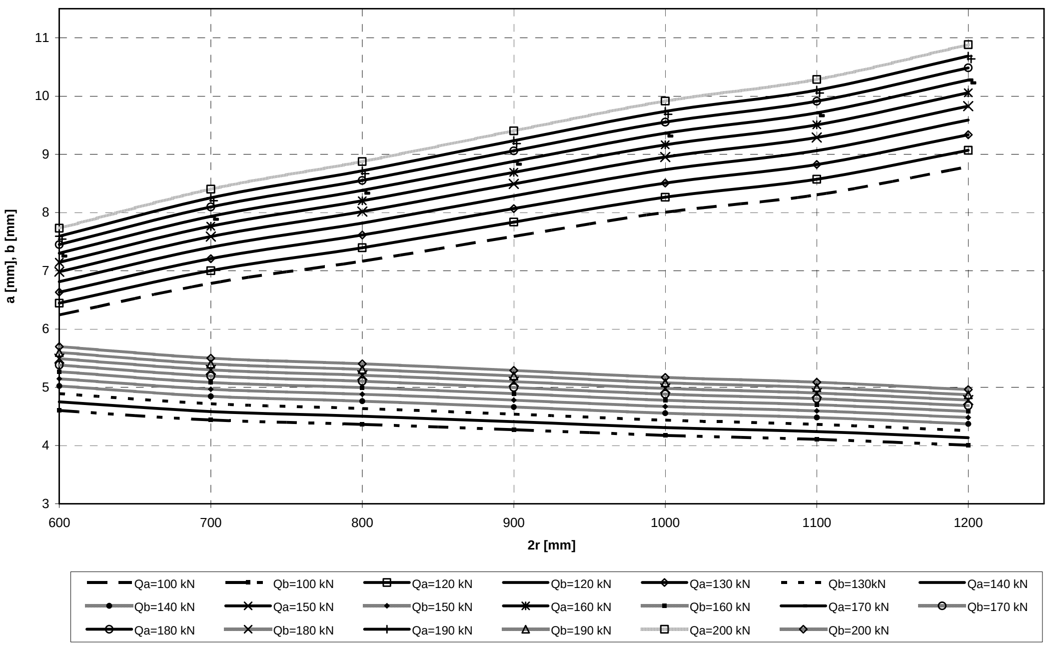

Fig. 2. The variation of semi-axes a and b of contact ellipses for a wear profile and various loads per wheel depending on the wheel diameter

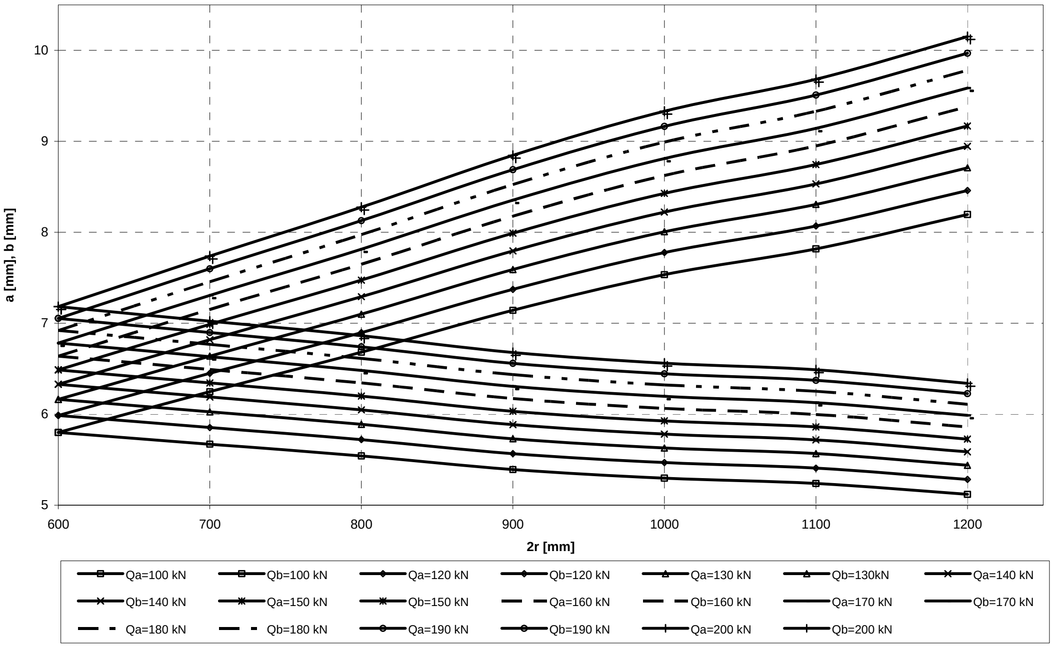

Fig. 3. The variation of semi-axes a and b of contact ellipses for a cone profile and various loads per wheel depending on the wheel diameter

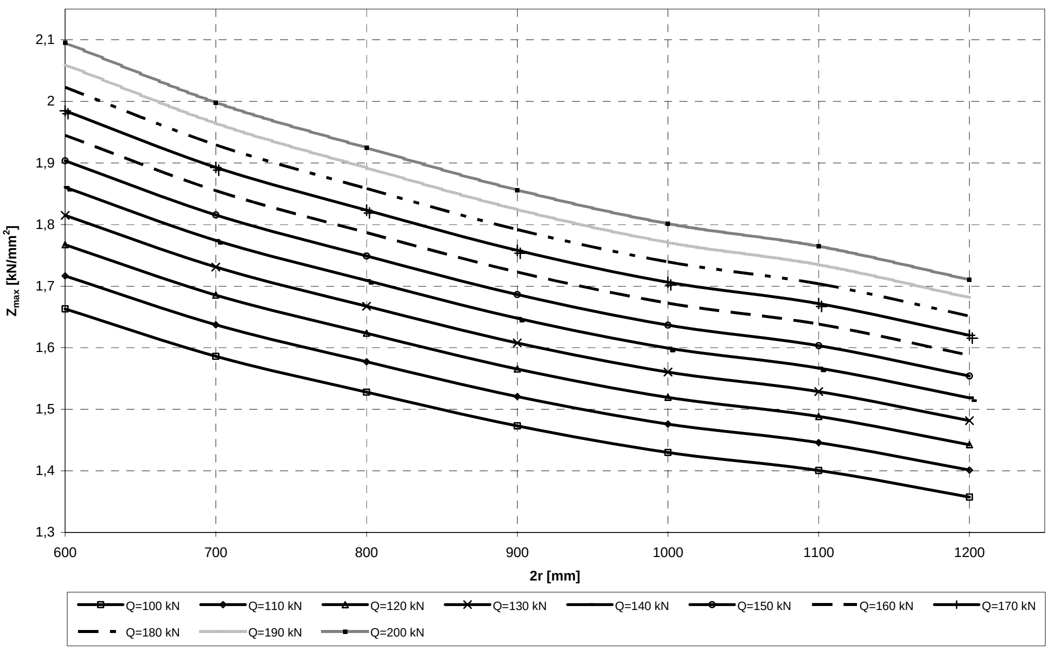

Fig. 4. The variation of the maximum pressure in the contact area for a wear profile depending on the wheel diameter

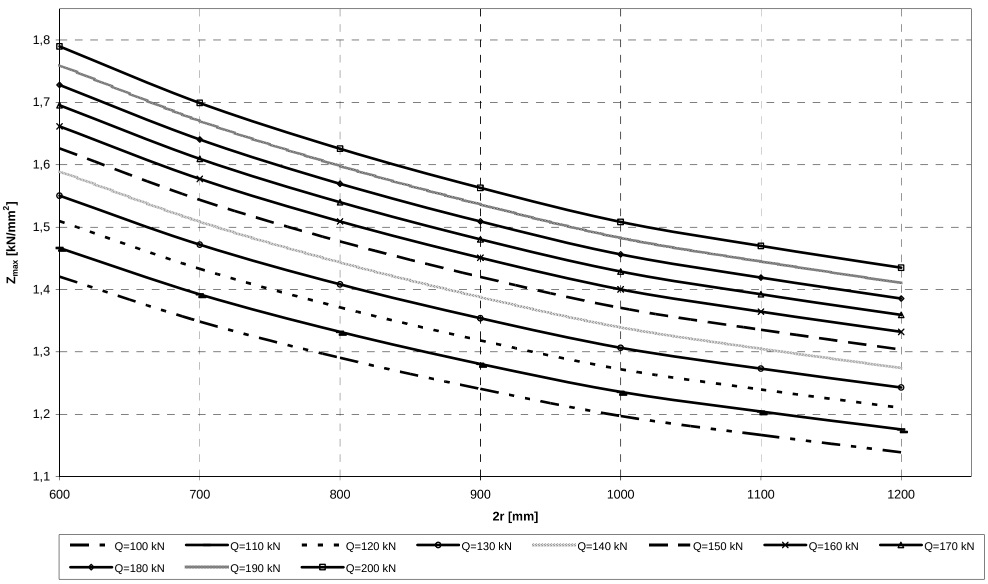

Fig. 5. The variation of the maximum pressure in the contact area for a cone profile depending on the wheel diameter

CONCLUSIONS

As for the wheel with a wear profile, for the material whose drainage limit was considered, it is found that no special problems arise, as it fully remains within the elastic limit.

In the case of wheel bandage with cone profile, made of the matter with the same features, it is found that local crushes appear in the contact area for wheels with low diameters and high loads per wheel.

The decrease in the diameter of the wheel causes that, at the same load per wheel, the surface of the contact ellipse decreases, appearing the danger of occurrence of plastic deformations. Therefore, this implies the limitation of the road per wheel depending on the diameter thereof.

Both the influence of the load transfer and the wheel radius on the guidance capacity and derailment safety are found. The wheel guidance capacity decreases with the decrease of the load per wheel, i.e., with the increase of the load transfer from one wheel to another.[2]

BIBLIOGRAPHY

[1] Sebesan, I. *Dinamica vehiculelor de cale ferata*, Editura Tehnica, Bucharest, 1996.

[2] Sebesan I. *Asupra sigurantei ghidarii la vehiculele de cale ferata*, Studii si cercetari de mecanica aplicata, 1, 1994.

[3] UIC 510-2 Sheet.

ИЗСЛЕДВАНЕ НА ВЛИЯНИЕТО НА ДИАМЕТЪРА НА КОЛЕЛОТО ВЪРХУ ТОВАРОПОДЕМНОСТТА НА ЖЕЛЕЗОПЪТНО ВОЗИЛО

Йоан СЕБЕЖАН, Кристина ТУДОРАЧЕ, Мадалина ДИМИТРИУ, Мариус СПИРОИУ

проф. д-р инж. Йоан Себежан, ас. инж. Кристина Тудораче, ас. инж. Мадалина Димитриу, преподавател д-р Мариус Спироиу Spiroiu, Университет „Политехника” в Букурещ,

РУМЪНИЯ

Резюме: *Като се вземе предвид важността на аспектите, които се отнасят до контакта колело-релса, докладът разработва проблеми, свързани с трибулогията, отнасящи се главно до износване на профила на колелото. Познаването на явлението контакт в тази област с подробности представлява в действителност фундаментален проблем, осигуряващи развитието на железопътните средства за транспорт. Намаляването на диаметъра на колелото причинява това, че при същото натоварване на колело, площта на контактната елипса намалява, като се появява опасност от възникване на пластични деформациuus.По тази причина това предполага ограничаване на пътя за колело в зависимост от диаметъра. Формата и размерите на контактната зона определят надеждността на колелата и релсите, управление на безопасността и придържането към характерни черти на тягата и спирачния режим на возилото.*

Ключови думи*: контактно явление, контактно налягане, контактна елипса, натоварване на колело, радиус на търкаляне.*