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METHOD OF STATIC DETERMINATION OF THE SAFETY AGAINST OVERTURNING OF THE ROAD – RAIL MACHINES

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In the present work, it is shown an overturning safety statically procedure for a road – rail machine, with a dual road and rail rolling system. The rail rolling variant of the machine, deemed as an railway motor vehicle, is analyzed.

Keywords: road-rail machine, overturning, wheel load, super-elevation.

1. Introduction

Most of the studies performed up to the present time, refer to safety running of rolling stock designed for passengers and freight trains, in standard operating conditions, under a strict schedule.

This rolling stock usually runs with high speed, the risk of appearing running safety disorders increasing when the speed increases.

Road-rail machines are designed for planned or unplanned maintenance interventions over railway infrastructure. These interventions are always made when the traffic is closed. Generally, road-rail machines are running at low speed. However, running safety disorders still could occur.

The aim of the present study is to experimentally establish a method of static determination of the safety against overturning of road-rail machines, based on the analysis of the load distribution on the wheel in rail configuration of road-rail machines. Thus, an important factor in order to ensure road-rail machines safety against overturning is to ensure the load per wheels in certain limits.

2. Load distribution on pair of wheels

As generally known, a pair of wheels of a railway vehicle in static condition is charged with a load acting on vertical direction, which is partially due to own weight, known as load per wheels $2Q_o$. In case of a uniform distribution of the load per wheels, it results a load per wheel defined as Q_o. In fact, a railway vehicle wheel in running condition is charged both with the load per wheel Q_o and with the loads caused by the rolling dynamic forces.

The dynamic loads are produced by the external forces transmitted through the suspension on the wheels mainly resulting from wheel/rail surface irregularity as well as from continuous change of the attack angle in case of the driving pair of

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wheels [1]. These dynami loads are also produced by the longitudinal forces acting on the wheels, caused by the inertial forces of the chassis during the hunting movement [2]. Additionally, the super-elevation of the outer rail in curves generates different loads on the outer/inner wheel. Thus, actually, the loads on the outer/inner wheels are defined as Q_L and Q_R, caused by theirs loading and unloading.

Half-difference between the loads acting on the pair of wheels is named "load transfer":

$$\Delta Q = \frac{(Q_L - Q_R)}{2} \tag{1}$$

Conventionally, ΔQ is considered as having positive value (+) if the wheel is loaded, and negative value (–) if the wheel is unloaded.

The wheel unloading factor is defined as the wheel ability to unloading, without altering the vehicle safety against overturning:

$$\Delta q_{LR} = \frac{\Delta Q}{Q_o} = \frac{(Q_L - Q_R)}{2Q_o} \tag{2}$$

This ratio must be less or equal with 0.6 in order to insure the minimum safety requirements against railway motor vehicles overturning when running through small radius curves, over the switches or at the level track crossings, according to last European railway regulations, referring to the testing of the running behavior of the railway vehicles [3], [4].

Regarding running through curves, because of the un-compensated centrifugal forces, the road – rail machines have an additional load transfer ΔF_o on the loading wheels, which depends on the road – rail machine running speed [5].

The road – rail machines could be assimilated with freight wagons having a high center of mass of the primary vertical suspension. Similarly with other railway vehicles, the road – rail machine passing through the curve inclines with respect to the track, the angle of inclination being φ_b, the following counteraction forces appearing in the primary suspension springs:

$$\Delta F = 2c_z^+ \times b^+ \times \varphi_b \tag{3}$$

where:

c_z^+ = primary suspension spring stiffness [kN/mm];

b^+ = transversal distance between the axis of the primary spring suspension

Most of freight wagons on bogies or two axle wagons are not equipped with divergent swing links in the suspension. However, there are cases of rolling stocks with vertical divergent swing links having the length λ supporting the vehicle body carrier. Consequently, the counteraction forces into the primary suspension will be:

$$\Delta F = \frac{G_c}{2b^+}(h_c + \lambda)(1 + S)\frac{\gamma_{TO}}{g} \tag{4}$$

where:

G_c = body weight;

h_c = center of mass height;

γ_{To} = acceleration in the transversal direction of the truck;
g = 9.81 m/s^2;
S = coefficient of flexibility

In this case, the coefficient of flexibility will be:

$$S = \frac{1}{\left[\frac{4c_z^+ \left(b^+\right)^2}{G_c\left(h_c + \lambda\right)} - 1\right]} \tag{5}$$

There are situations when the road – rail machines have no primary suspension. Then:

$$\Delta F = \frac{G_c}{2b^+} h_c \left(1 + S\right)\frac{\gamma_{TO}}{g} \tag{6}$$

and

$$S = \frac{1}{\left[\frac{4c_z^+ \left(b^+\right)^2}{G_c h_c} - 1\right]} \tag{7}$$

3. Determination of stability against overturning of the road-rail machines by static simulation

Referring to the all types of road-rail machines, these must be verified against overturning. In case of a crane placed on rails in working condition, the movement of the arm involves the crane's load centre modification, which consequence could be the overturning of the crane. The overturning could happen still in absence of any hook load, namely if no proper calculation and stability tests against overturning were made [6].

Hence, checking the stability of the road-rail machines is a necessary condition to ensure their safety against overturning [7].

In the Laboratory of Rolling Stock of the Romanian Railway Authority a method for statically verification of overturning was developed, in order to determine the stability against overturning of road-rail machines.

This method consists of the simulation of the static wheels unloading conditions of a road-rail machine standing in a curve where the super-elevation of the outer rail is 100 mm. The tests were carried out at a temperature of about 25 - 30 ° C, on dry rail.

The tested vehicle is presented in Fig. 1.

Fig. 1: The road-rail vehicle

The road-rail machine has two hybrid bogies sets, each bogie having four symmetrically arranged wheels. The wheel load for the front bogie, near the driver's cab, was $Q_o = 6$ t and the wheel of the second bogie, behind the road-rail machine, was $Q_o' = 3$ t. Also, the corresponding wheels on the two sides of the machine have been independently connected to the bogie frame and actuated by a low-power hydraulic motor, instead of being joined to each other by means of a connecting shaft.

In order to determine the wheel loads, rail coupons of 120 mm, containing strain gauges and a data acquisition system were used, making possible to process the obtained values in a computer.

At the same time, the simulation of the elevation of the outer rail was achieved by means of rectangular steel prisms with dimensions of 10 mm x 150 mm x 20 mm, 25 mm x 150 mm x 20 mm and 50 mm x 150 mm x 20 mm. These coupons were interposed between rail and wheel. The wheel-rail contact was made in the point corresponding to the strain gauge rail lateral position. The road-rail machine was lifted on one side with winches. To simulate various stages of cant rail, steel prisms of 10, 25 and 50 mm were interposed under the wheels in a successive positioning. The tilting of the road-rail machine was made using winches in order to lift the left side of the machine.

For an easy identification, the wheels of the vehicle are noted with numbers from 1 to 8, where odd numbers: 1, 3, 5, 7 refer to the wheels to the left side of the vehicle and even numbers: 2, 4, 6, 8 refer to the wheels to the right side of the vehicle. Values resulting from tests for loads per wheels (Q_1, Q_2 ... Q_8) are presented in Table 1 and Table 2, containing the loads per odd wheels and even wheels, respectively.

Table 1

Values of loads per odd wheels

No.	Cant [mm]	**Q_1** [daN]	**Q_3** [daN]	**Q_5** [daN]	**Q_7** [daN]
1	0	5878,606	6486.966	2466.744	2520.257
2	10	5591,350	6334.937	2482.403	2452.853
3	25	5670,647	6205.073	2348.887	2413.107
4	35	5491,788	6238.103	2284.151	2349.777
5	50	5574,542	5747.581	2254.758	2374.105
6	60	4999,783	5681.904	2366.268	2555.668
7	75	4720,026	5382.561	2507.874	2587.197
8	100	4691,574	5077.066	2353.533	2330.346

Table 2

Values of loads per even wheels

No.	Cant [mm]	**Q_2** [daN]	**Q_4** [daN]	**Q_6** [daN]	**Q_8** [daN]
1	0	6207,187	6205.948	2812.811	2742.565
2	10	6299,880	6279.858	2922.404	2862.903
3	25	6322,674	6421.658	3044.844	2912.368
4	35	6447,246	6426.547	3113.244	2985.167
5	50	6432,134	6908.408	3090.219	3000.76
6	60	6859,339	7051.234	3033.44	2799.163
7	75	7218,934	7283.716	2930.166	2756.375
8	100	7188,116	7684.422	2988.231	3102.81

Based on the values of loads per wheels presented in Table 1 and Table 2, the load transfer distribution (ΔQ) and the wheel unloading factor (Δq), were calculated for the wheels placed on the same axle, using the formulae (1) and (2), as presented in Table 3 and Table 4.

Table 3

The load transfer distribution

No.	Cant [mm]	**ΔQ_{12}** [daN]	**ΔQ_{34}** [daN]	**ΔQ_{56}** [daN]	**ΔQ_{78}** [daN]
1	0	164.2907	140.5093	173.0334	111.1542
2	10	354.2653	27.53985	220.0006	205.0251
3	25	326.0133	108.2927	347.9785	249.6305
4	35	477.7291	94.22239	414.5465	317.6951
5	50	428.7961	580.4136	417.7305	313.3275
6	60	929.7779	684.6652	333.5863	121.7473
7	75	1249.454	950.5779	211.1461	84.58879
8	100	1248.271	1303.678	317.3492	386.232

Table 4

The wheel unloading factor

No.	Cant [mm]	**Δq_{12}** [daN]	**Δq_{34}** [daN]	**Δq_{56}** [daN]	**Δq_{78}** [daN]
1	0	2.738178	2.341822	5.767778	3.70514
2	10	5.904421	0.458998	7.333354	6.834171
3	25	5.433556	1.804878	11.59928	8.321017
4	35	7.962151	1.570373	13.81822	10.58984
5	50	7.146602	9.67356	13.92435	10.44425
6	60	15.4963	11.41109	11.11954	4.058244
7	75	20.82423	15.84296	7.038203	2.819626
8	100	20.80452	21.72797	10.57831	12.8744

Considering the values calculated above, we can obtain the load transfer distribution and the wheel unloading factor per rail cant graphs for all vehicle wheels. Thus, for the pair of wheels 1-2 the load transfer distribution and the wheel unloading graphs are presented in Fig. 2 and Fig. 3.

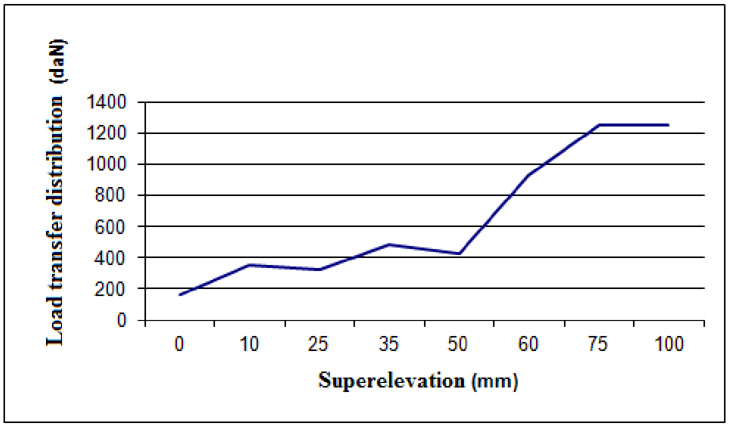

Fig. 2: The load transfer distribution between wheels number 1 and number 2

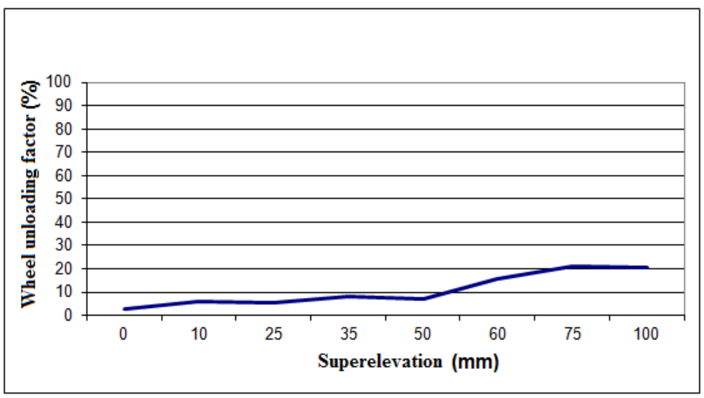

Fig. 3: The wheel unloading factor for wheel number 1

It is to be noted that for a maximum rail super-elevation of 100 mm, the discharge of the static load between the two wheels is relatively symmetric. The load on wheel number 2 increases with about 20%, the load on the wheel number 1 decreases at a rate of 22%. At the same time, the wheel unloading factor is about 1/3 from its maximum of 60%.

Similarly, the load transfer distribution and the wheel unloading factor between the wheels number 3 and number 4, can be analyzed see Figs. 4 and 5.

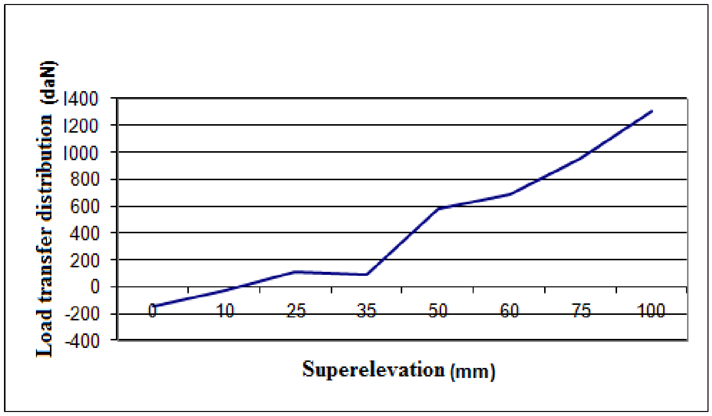

Fig. 4: The load transfer distribution between wheels number 3 and number 4

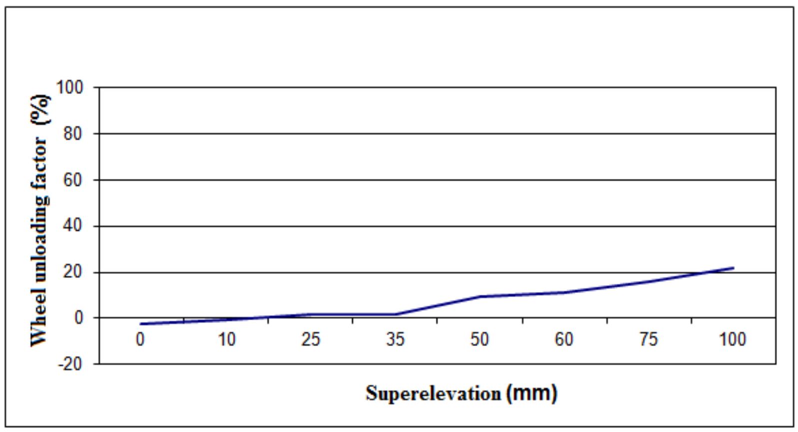

Fig. 5: The wheel unloading factor for wheel number 3

As shown, for a rail super-elevation of 100 mm, wheel number 4 is loaded with 30% more than the theoretical average wheel load, while the wheel number 3 is being unloaded only with 15% from the theoretical average wheel load.

At the same time, a rail super-elevation between 10 to 25 mm, in particular about 15 mm, the load transfer distribution and the wheel unloading factor have negative values, indicating that an inertia exists in the bogie frame, possibly caused by the constructive torsion of the first bogie.

The load transfer distribution and wheel unloading factor between the wheels 5 and 6 are presented in Figs. 6 and 7.

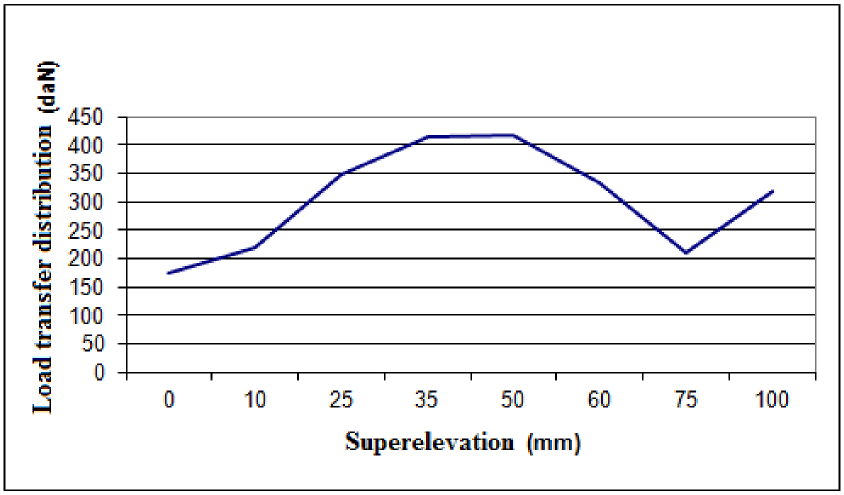

Fig. 6: The load transfer distribution between wheels number 5 and number 6

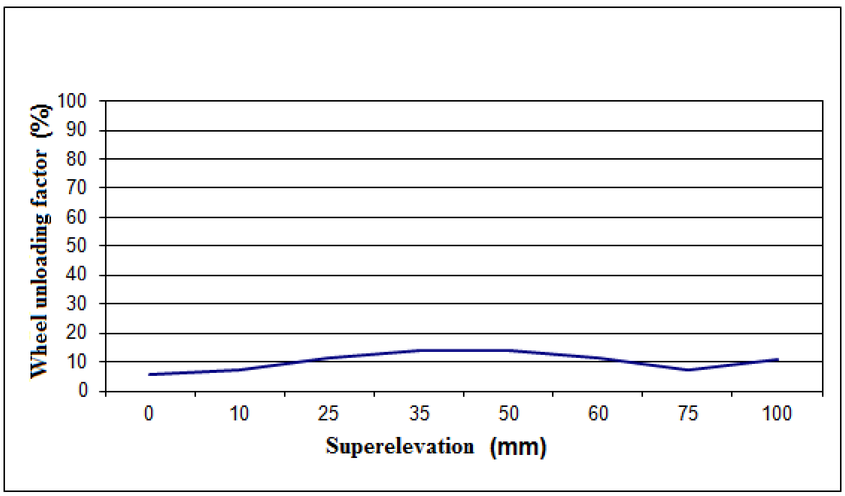

Fig. 7: The wheel unloading factor for wheel number 5

Also, the load transfer distribution and the wheel unloading factor between the wheels 7 and 8, based on the results of the testing of the road-rail machine, can be observed in Fig. 8 and Fig. 9.

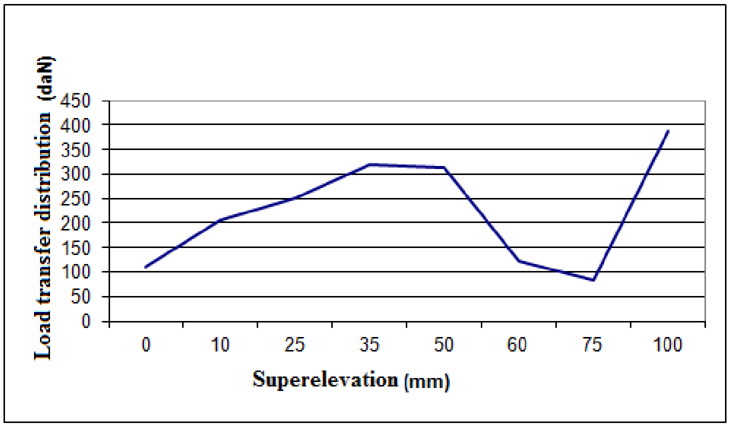

Fig. 8: The load transfer distribution between wheels number 7 and number 8

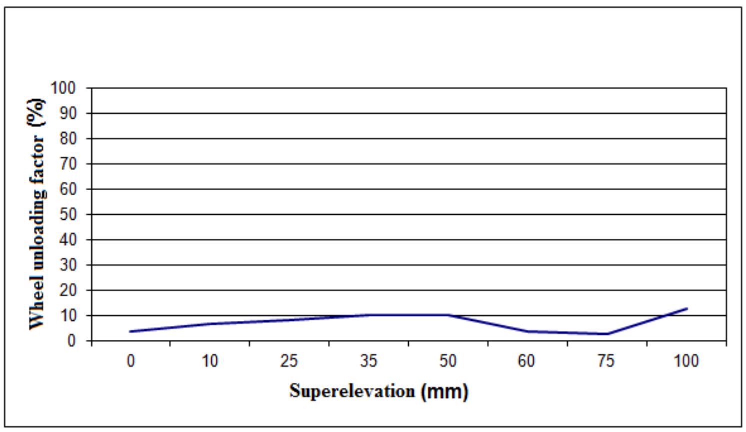

Fig. 9: The wheel unloading factor for wheel number 7

As it can be seen in the graphs corresponding to unloading of the rear bogie wheels, it appears that for both pairs of wheels, a normal unloading of the wheels on the left side of the vehicle occurs, simultaneously with the loading of the wheels on the right side vehicle up to a rail super-elevation of 50 mm. An abnormal behavior of the wheels load distribution appears for rail super-elevation between 50 mm and 75 mm, namely the loading of the odd wheels of the vehicle, simultaneously with unloading of the even wheels of the vehicle. This fact is due to a certain moment of inertia that opposes to the torsion of the vehicle bogie. Above 75 mm, when the simulated rail super-elevation increases, the loading of the rear bogie for even wheels and the unloading of its odd wheels appear.

4. Conclusions

The determination of the safety against overturning of the railway machines with dual road-rail system is a method of overall verification of safety running of road-rail machines. Moreover, by extending the applicability of the concerned method to all railway motor or trailer vehicles, a better assessment of the aspects of the safety running of the rolling stock that runs on Romanian railways can be obtained.

REFERENCES

[1] *Iwnicki, E.,* Handbook of Railway Vehicle Dynamics, CRC press, ISBN 0-8493-3321-0, Boca Raton, S.U.A., 2006;

[2] *Wickens, A.H.,* Fundamentals of Rail Vehicle Dynamics: Guidance and Stability. Lisse: Swets & Zeitlinger BV. ISBN 90-265-1946 (2003);

[3] *EN 14363,* Railway applications - Testing for the acceptance of running characteristics of railway vehicles - Testing of running behavior and stationary tests, 2005;

[4] *UIC 518:2003 Leaflet*, Testing and approval of railway vehicles from the point of view of their dynamic behavior-Safety-Track fatigue-Ride quality;

[5] *Sebeşan*, *I.,* Dinamica vehiculelor feroviare, (Railway vehicles dynamics), Editura Matrix Rom, Bucureşti, 2011; (in Romanian)

[6] *EN 15746-1+A1,* Railway applications -Track - Road-rail machines and associated equipment Part 1: General safety requirements applications – Technical requirements for running and working, 2012;

[7] *EN 15746-2+A1,* Railway applications -Track - Road-rail machines and associated equipment Part 2: General safety requirements applications - Testing for the acceptance of running, 2012;