[1.]Liviu Sevastian BOCÎI

WIND INFLUENCE ON HIGH SPEED TRAIN RESISTENCE

[1.] "Aurel Vlaicu" University of Arad, ROMÂNIA

Abstract: The delays due to weather conditions are increasingly common in the field of transport means. The entry into service of high-speed rail lines which support the movement at speeds above 300 km/h led to the finding that high-speed trains are very "sensitive" to high-intensity lateral winds, especially when they circulate on viaducts. The only remedy that is known to this date to avoid the strong winds, which strike at a certain angle, the sides of the train, to destabilise it, is the drastic reduction of the speed. In this paper is presented the influence of wind (by parameters: V_w – wind speed and α – angle of action of the wind) on the resistance to the forwarding of high speed trains and by default on the safety of movement.
Keywords: high-speed train, high speed train advance speed, wind speed, wind direction, resistance to progress

1. DETERMINATION OF ADVANCE RESISTANCE DUE TO THE WIND

The wind force, normally measured by its speed (V_w) and the direction of action (given by the angle α), varies a lot, from one geographic area to another, which makes quite difficult the effect of the wind in calculating the resistance of high-speed train advances. Thus, if the direction of the wind (V_w) coincides with the direction of the train (V), e.g. α = 180° (see figure 1), the force of the wind tends to reduce the resistance to advance (wind "push" the train). If the wind blows from the front, or from a lateral direction (characterized by the angle α), its strength tends to increase the resistance to advance.

Noting with: V_w wind speed, α – angle of action of the wind, the forward resistance will have the following form, [2], [5]:

$$R_{av} = \left[A + (B \cdot V) + C \cdot (V + (V_w \cdot \cos\alpha))^2\right] \quad (1)$$

where: A, B, C – absolute aerodynamic coefficients of conventional and high-speed trains, which values are shown in table 1; V – speed of train movement, [km/h]; V_w – speed of wind, [km/h]; α - the angle of action of the wind, which values are shown in table 2 according to the correction factor σ.

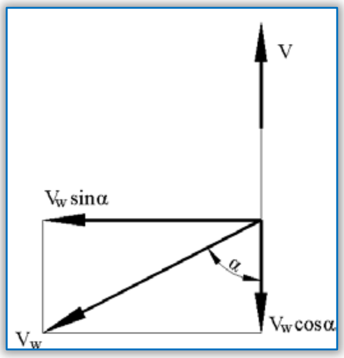

Figure. 1. Wind direction (V_w) defined by angle α, relative to the direction of movement of the train (V), [2], [5]

Table 1. Absolute and specific aerodynamic coefficients of a classic train

Name of the train	Train weight [t]	Absolute coefficients A [daN]	B [daN/km/h]	C [daN/(km/h)²]	Specific coefficients a [daN/t]	b [daN/tkm/h]	c [daN/t(km/h)²]
Classic train (2 locomotives + 6 wagons)	400	462	3.90	0.0906	1.15	0.00975	2.875x10^{-4}
TGV South East	418	235	3.09	0.0535	0.562	0.00739	1.280x10^{-4}
TGV Atlantique	490	380	3.90	0.0565	0.776	0.00796	1.153x10^{-4}
TGV Duplex	424	270	3.20	0.0535	0.637	0.00755	1.262x10^{-4}
ICE Regional	231	170	1.51	0.0341	0.735	0.00654	1.474x10^{-4}
AVE	416	292	3.84	0.0498	0.702	0.00923	1.198x10^{-4}
TALGO 350 (series102)	357	282	2.22	0.0529	0.790	0.00622	1.482x10^{-4}
ICE 3 (series 103)	426	312	2.24	0.0521	0.733	0.00525	1.223x10^{-4}

Table 2. Angle of action of the wind

α	180°	135°	90°	45°	0°
σ	-1	-0.3	0.75	1.15	1

In the specific literature for this field [1], [2], [3], [4], [5], [6], [8], there are many definition relations of forward resistance (considering the wind influence), empirical or determined by experimental trials.

Bernard and Guiheu, [4], They proposed the next relation for high-speed train forward resistance:

$$R_{av} = \left[A + (B \cdot V) + C \cdot (V + (V_w \cdot \sigma))^2\right] = \left[A + (B \cdot V) + C \cdot \left(V^2 + 2 \cdot V \cdot (V_w \cdot \sigma) + (V_w \cdot \sigma)^2\right)\right] \quad (2)$$

Which will become:

$$R_{av} = \left[A + (B \cdot V) + C \cdot \left(V^2 + 2 \cdot V \cdot (V_w \cdot \sigma) + (V_w \cdot \sigma)^2\right)\right] = \quad (3)$$

$$= \left[A + C \cdot (V_w \cdot \sigma)^2 + (B + C \cdot 2 \cdot V_w \cdot \sigma) \cdot V + C \cdot V^2\right]$$

where: σ-correction factor for the angle of action of the wind (α), dimensionless, which values are presented in table 2.

Analyzing the relationship (3) it may be noted that the wind influences the terms: $C \cdot (V_w \cdot \sigma)^2$ and $(B + C \cdot 2 \cdot V_w \cdot \sigma) \cdot V$ (where the power of the train's speed is 0 and 1) and does not influence the term which contains the square of its movement speed.

Using the relation (3) in table 3 are presented values of forward resistance for a conventional train and six high-speed trains for two wind speeds (V_w = 20 km/h; V_w = 80 km/h) and two angles of action (α = 180°; α = 45°).

With the help of the data in table 3, in figures 2 and 3, it was presented the variation of forward resistance according to the speed under the conditions set out above.

Table 3. Advance resistance values for a classic train and six high-speed trains, [2]

	Speed [km/h] / Name of the train	60	120	180	240	300
	V_w = 20 km/h; α = 180° (σ = -1)					
ADVANCE RESISTANCE [daN]	TGV PSE	506	1141	2161	3566	5356
	TGV Atlantique	704,4	1413	2528	4051	5980
	TGV Duplex	547,6	1189	2216	3627	5424
	ICE 3 Regional	315,16	692,2	1315	2183	3296
	AVE	602,08	1251	2258	3624	5348
	ICE 3	529,76	1102	2049	3371	5069
	Classic train (2 L+ 6V)	840,96	1836	3483	5783	8735
	V_w = 80 km/h; α = 45° (σ = 1,15)					
	TGV PSE	1656	3010	4749	6874	9383
	TGV Atlantique	1919	3387	5262	7544	10230
	TGV Duplex	1698	3059	4804	6935	9451
	ICE 3 Regional	1048	1884	2965	4291	5863
	AVE	1673	2991	4668	6703	9096
	ICE 3	1650	2922	4570	6592	8990
	Classic train (2 locomotives + 6 wagons)	2789	5002	7867	11380	15550

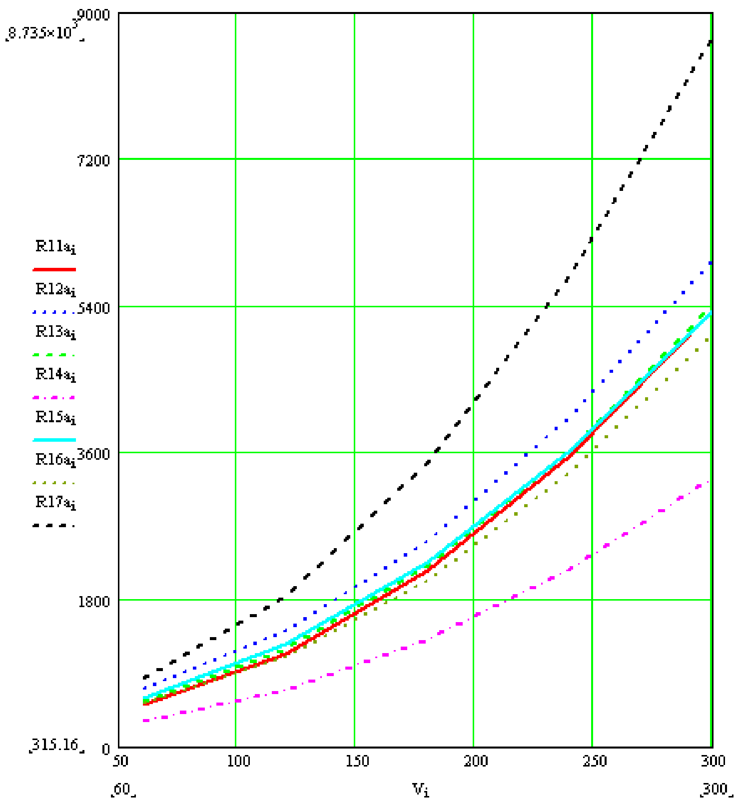

Figure 2. Advance resistance for a V_w wind speed = 20 km/h that blows on a direction given by the angle α = 180° (σ =-1), for a classic R17a train and 6 high-speed trains R11a,..., R16a (see table 3).

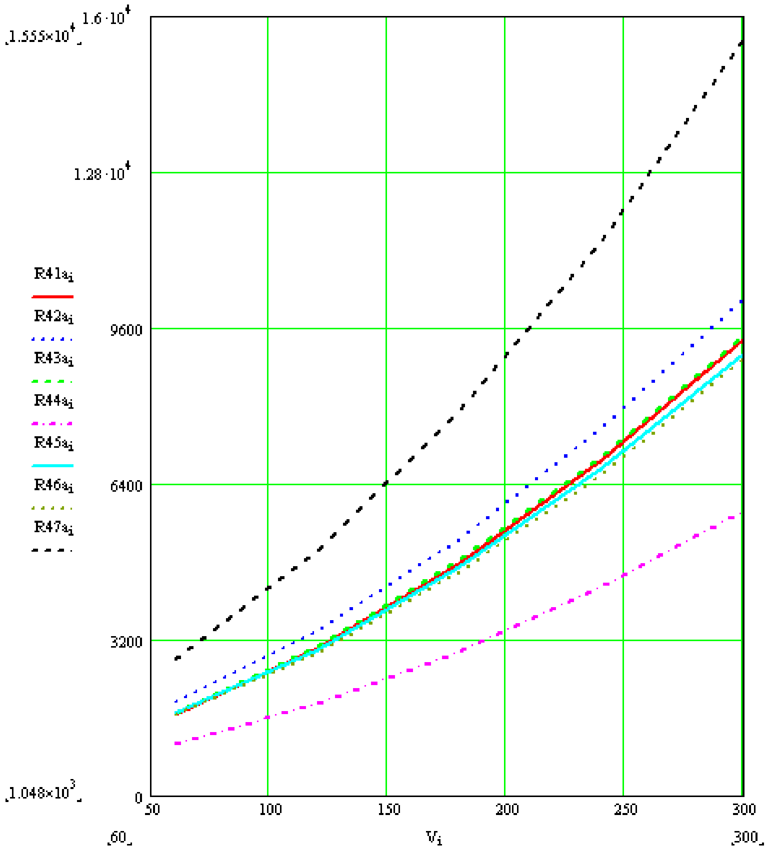

Figure 3. Advance resistance for a V_w wind speed = 80 km/h that blows in a direction given by the angle α = 45º (σ = 1.15), for a classic R47a train and 6 high-speed trains R41a,..., R46a (see table 3).

2. WIND INFLUENCE ON TOTAL RESISTANCE TO ADVANCE

The total resistance to advance of a train travelling at speed V is given by the following relation, [2], [5], [7]:

$$R_a = (a_1 \cdot M) + (a_2 \cdot N_e) + \left[(Q \cdot \rho) \cdot V \cdot \frac{1}{3{,}6 \cdot 10}\right] + \left[C \cdot T_f \cdot (V - V_w \cdot \cos\alpha)^2\right] + \left(M \cdot \frac{600}{R}\right) \quad (4)$$

where: a_1 – Coefficient of mechanical resistance to advance, [daN/t]; M – train weight, [t]; a_2 – Coefficient of mechanical resistance to advance, [daN/osie]; N_e – Number of train axles; Q – The air flow which enter in the train for air conditioning and engine cooling systems, [m^3/s]; ρ – air density, [kg/m^3]; T_f – Tunnel factor; R – curve radius, [m].

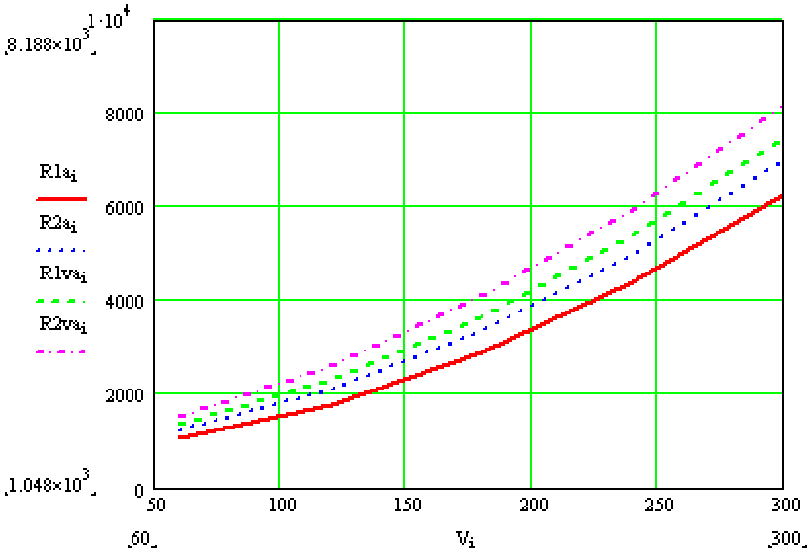

Figure 4. Total resistance to advance without wind influence (R1a, R2a) and for a wind speed of V_w = 80 km/h that blows on a direction given by the angle α = 90º, (R1va, R2va), for the TALGO 350 high-speed train (R1a and R1va) and for the ICE 3 high speed train (R2a and R2va), R = 5000 m, Q = 150 m^3/s, N_e = 32 axles, a1 = 0.65, a2 = 13, ρ = 1.29 kg/m^3, T_f= 1

With the help of relation (4) the total resistance to advance was determined, without the influence of the wind (R1a and R2a) and its influence (R1av and R2av), for two high-speed trains (TALGO 350 and ICE 3), without considering the tunnel factor ($T_f = 1$), whose variation depends on the speed of movement is presented in Figure 4.

CONCLUSIONS

- Analyzing the tables and diagrams presented, the following conclusions can be drawn:
- The wind by speed (V_w) and the direction of action (angle α) influences the resistance to advance of the trains especially high-speed trains, reducing it for $\alpha = 180^o$ (wind "push" the train) and increasing it for $\alpha < 90^o$;
- At the same angle of action of the wind $\alpha = 180^o$, for two speeds of it ($V_w = 20$ km/h and $V_w = 80$ km/h), the resistance to advance of the TGV Atlantique train, at the speed of movement V = 300 km/h, decreases to increase wind speed (from 5356 daN to 4285 daN) because the direction of action of the wind coincides with the direction of movement of the train;
- At movement speed of 300 km/h, the total resistance to advance of the Spanish TALGO 350 high-speed train increases by 8.39% (from 6283 daN to 7489 daN), and the German ICE 3 train by 8.55%, (from 7001 daN to 8188 daN) due to the wind ($V_w = 80$ km/h and $\alpha = 90^o$);
- At the same speed of movement of trains (300 km/h) but at another angle of action of the wind $\alpha = 180^o$, the total resistance to advance of the two trains decreases by 7.77% (TALGO 350: from 6283 daN to 4885 daN) and with 8.03% (ICE 3 : from 7001 daN to 5623 daN), because the direction of action of the wind coincides with the direction of movement of trains;
- The main measures that can be taken to minimise the wind's influence are: the cover of the areas under the vehicle so that the air can wash these areas with minimal friction and no noise; the optimisation of the perimeter and the length of the train (an increase in the vehicle section could be favourable if it allows to reduce the length of the train – the case of the overfloor or high-box trains); train equipment with a protective system that allows them to adapt their speed to the weather conditions existing at every moment.

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