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Nexus of the Load Bearing Capacity of Rails and the Stiffness of the Optimized Sleepers

Szabolcs Attila Köllő[a], Gavril Köllő[a], Attila Puskás[b,*]

[a]Technical University of Cluj-Napoca, 72-74 Observatorului str., 400363 Cluj-Napoca, Romania
[b]Technical University of Cluj-Napoca, 25 Bariţiu str.,room 123, 400027, Cluj-Napoca, Romania

Abstract

In the railway track modernizations an important role is played by the connection between the sleepers and the rails.
In this article the authors are studying the effect of the sleepers on the rails in the ballasted railway superstructure, considering the ballast layer properties according to local conditions, but unchanged during the studies. The optimised dimensions of the sleepers are aimed in order to allow increased speed of the railway.
The role of the sleepers mainly consists in taking over the load on the rails and transmitting to the ballast, therefore technical capabilities are highly influenced also by the behaviour of the other elements of the rail track system.

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Keywords: bearing capacity; stiffness; optimal cross section; blocks length; flexibility of the ballast.

1. Calculation of the bearing capacity of the ballasted superstructures` rail tracks

Dimensioning and study of elements of railways` superstructures is already a very old process, it had begun simultaneously with the appearance of the railway.

Initially the engineers designed the railways structures by completely relying on previous experiences and practices but over time many other methods had been developed for the calculation of railways superstructures.

* Corresponding author. Tel.: +40-749-083-280.
E-mail address: attila.puskas@dst.utcluj.ro

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There are two main calculation methods for designing the ballasted tracks system with sleepers laid transversely to the rails: the method of Winkler and the method of Zimmermann [3, 4]. These methods were developed for a longitudinally sleepered track, considered to be resting on a compressible foundation. Since track is now transversely sleepered, a transformation of this track type to an equivalent longitudinally sleepered track is required in the analysis. This can be achieved if the assumption is made that the effective rail support area provided by the sleeper remains constant for both types of track [1, 2].

The most important difference between these applications is that, while in the method of Winkler, the ballasted layer is considered rigid, the method of Zimmermann takes into account the elastic characteristics of the ballasted layer, assuming that the transverse sleepers - which support the rail tracks - under the conditions of traffic load do not only sink into the ballast near the wheel load but also farther away from the load area [5, 7, 11, 12].

Current practices in the world concerning the calculation of railway structure are mainly based on the method of Zimmermann, “beam on elastic foundation” [1, 6].

The basic idea in Zimmermann method is to transform the transversely sleepered track represented theoretical by a discrete supported beam to an equivalent longitudinally sleepered track represented by a fictive, continuously supported beam on an elastic foundation (Fig. 1) [9, 5].

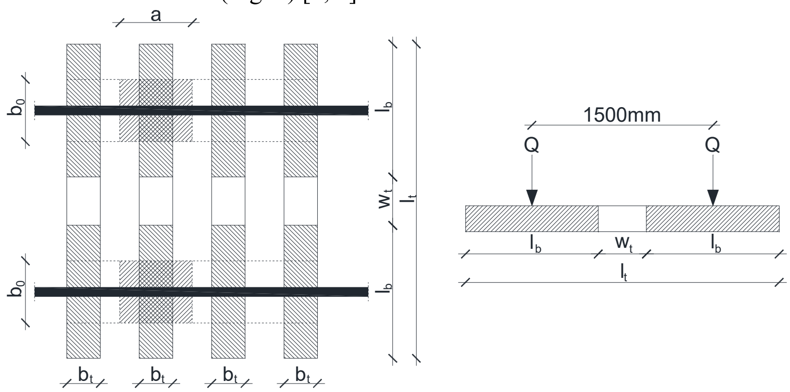

Fig. 1. Transformation of transversely sleepered track to an assumed longitudinally sleepered track using Zimmermann theory

2. Analysis of the load bearing capacity of the rails depending on the stiffness of the sleepers

Using the superstructures` calculation method relying on the model of Zimmermann, continuously supported beam on elastic foundation, the authors analysed the appearing bending moments in the rail beams depending on the variation of the length and the height of the sleepers under the rails (in the place of the rails bearing). For this calculation we used the following equation:

$$M_r = \frac{E_r I_r}{4(E_r I_r + E_t I_0)} \sqrt[4]{\frac{4(E_r I_r + E_t I_0)}{b_0 C}} Q \cdot (1 + t\delta\varphi) \qquad (1)$$

M_r Maximum bending moment in the load rail;
E_r modulus of elasticity of the rail steel, N/mm^2;
I_r rail moment of inertia, mm^4;
E_t modulus of elastictiy of the sleeper concrete, N/mm^2;
I_t sleeper moment of inertia, mm^4;
I_0 moment of inertia of fictive, equivalent longitudinal sleeper, mm^4; $I_0 = \alpha \frac{l_t}{2a} I_t$;
b_0 breadth of fictive, equivalent longitudinal sleeper, mm; $b_0 = \alpha \frac{l_t}{2a} b_t$;
b_t breadth of sleepers, mm;
h_t height of sleepers, mm;

l_t length of sleepers, mm;
l_b length of blocks, mm;
a sleeper spacing, mm;
α multiplication factor;
C coefficient of subgrade reaction, N/mm^3;
Q wheel load, kN;
t factor depending on the required probability;
φ dynamic factor depending on the speed; $\varphi = 1{,}0 + \frac{V-60}{140}$;

As benchmark sizes of the concrete ties we have considered the dimensions of the T17 V49 type sleeper, used by Romanian Railway Company and the dimensions of the LW 49 type sleeper, used in Hungary.

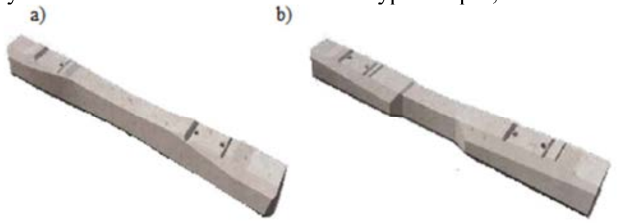

Fig. 2. (a) Sleeper T17 V49, Romania [10]; (b) Sleeper LW 49, Hungary [8, 10];

The study consisted of changing the sleepers` dimensions, as mentioned above, which determine the rigidity of these elements; the bearing capacity of the S65 type rail beams under the maximum axle load of 250kN was analysed, at maximum traveling speed of 200km/h and with 600mm sleeper spacing.
The composition of the subsoil has been determined as clayey and muddy (low quality), C=0,05N/mm^3, but the superstructure was considered to be of a good condition, δ=0,2.
The sleepers` lenghts were analysed in acordance with the European standards, 2600mm, 2500mm and 2400mm , while the height of the ties, under the rails was raised for each lenght domain gradually with 5mm, 10mm and 15mm. For example, see Fig. 3, Fig. 4.

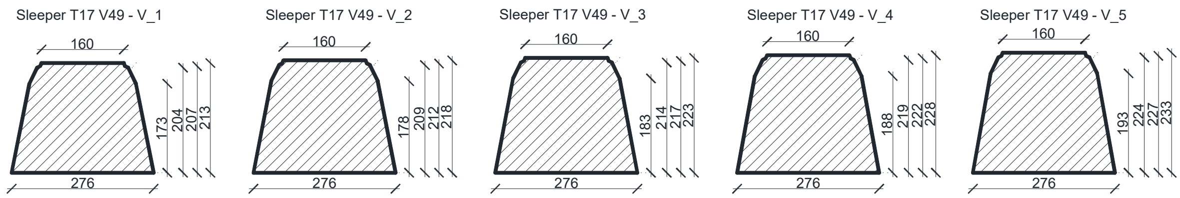

Fig. 3. Cross section of T17 V49 type sleeper under the rails for different height domains

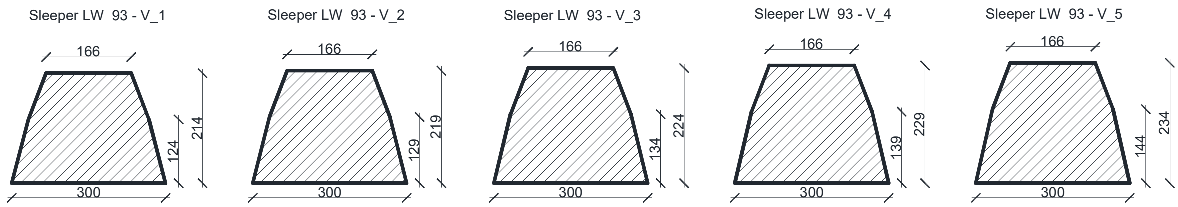

Fig. 4. Cross section of LW 93 type sleeper under the rails for different height domains

Because the middle section`s lenght of the sleepers was not changed, the lenght of 400mm required by the european standards was preserved. The lenghts of the blocks which ensure the rail tracks supports were changed regulary in intervals between 1100mm and 1000mm.

Table 1 Properties of T17 V49 type sleeper for different height and length domains

Analysed concrete sleepers` type	Categories	h_t (mm)	E_t (N/mm^2)	I_t (mm^4)	b_t (mm)	l_t (mm)	b_0 (mm)	I_0 (mm)	l_b (mm)
	V_1.1	213	37000	180585094.57	276	2600	514.28	336490226.21	1100
	V_1.2	213	37000	180585095.57	276	2500	494.50	323548296.22	1050
	V_1.3	213	37000	180585096.57	276	2400	474.72	310606366.09	1000
	V_2.1	218	37000	193835514.85	276	2600	514.28	361180176.01	1100
	V_2.2	218	37000	193835515.85	276	2500	494.50	347288632.57	1050
	V_2.3	218	37000	193835516.85	276	2400	474.72	333397088.99	1000
	V_3.1	223	37000	207721673.77	276	2600	514.28	387054718.80	1100
T 17 V49	V_3.2	223	37000	207721674.77	276	2500	494.50	372168000.63	1050
	V_3.3	223	37000	207721675.77	276	2400	474.72	357281282.33	1000
	V_4.1	228	37000	222258563.19	276	2600	514.28	414141789.41	1100
	V_4.2	228	37000	222258564.19	276	2500	494.50	398213260.84	1050
	V_4.3	228	37000	222258565.19	276	2400	474.72	382284732.13	1000
	V_5.1	233	37000	237461174.90	276	2600	514.28	442469322.55	1100
	V_5.2	233	37000	237461174.90	276	2500	494.50	425451271.69	1050
	V_5.3	233	37000	237461174.90	276	2400	474.72	408433220.82	1000

Table 2 Properties of LW 93 type sleeper for different height and length domains

Analysed concrete sleepers` type	Categories	h_t (mm)	E_t (N/mm^2)	I_t (mm^4)	b_t (mm)	l_t (mm)	b_0 (mm)	I_0 (mm)	l_b (mm)
	V_1.1	214	37000	187982611.30	300	2600	559.00	350274265.73	1100
	V_1.2	214	37000	187982611.30	300	2500	537.50	336802178.58	1050
	V_1.3	214	37000	187982611.30	300	2400	516.00	323330091.44	1000
	V_2.1	219	37000	201829636.58	300	2600	559.00	376075889.50	1100
	V_2.2	219	37000	201829636.58	300	2500	537.50	361611432.21	1050
LW 93	V_2.3	219	37000	201829636.58	300	2400	516.00	347146974.92	1000
	V_3.1	224	37000	216349654.70	300	2600	559.00	403131523.26	1100
	V_3.2	224	37000	216349654.70	300	2500	537.50	387626464.67	1050
	V_3.3	224	37000	216349654.70	300	2400	516.00	372121406.08	1000
	V_4.1	229	37000	231559333.44	300	2600	559.00	431472224.64	1100
	V_4.2	229	37000	231559333.44	300	2500	537.50	414877139.08	1050
	V_4.3	229	37000	231559333.44	300	2400	516.00	398282053.52	1000
	V_5.1	234	37000	247475337.64	300	2600	559.00	461129045.80	1100
	V_5.2	234	37000	247475337.64	300	2500	537.50	443393313.27	1050
	V_5.3	234	37000	247475337.64	300	2400	516.00	425657580.74	1000

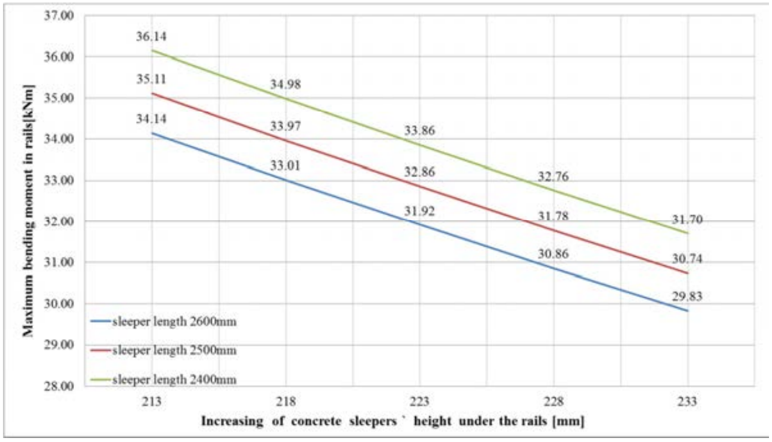

Fig. 5. Variation of rails` bearing capacity depending on the height and length of the T17 V49 type sleepers

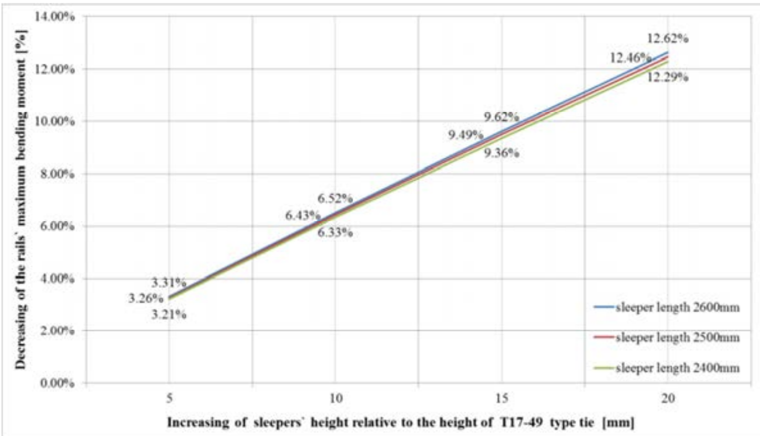

Fig. 6. Percentage variation of rails` maximum bending moment depending on the height and length of the T17 V49 type sleepers

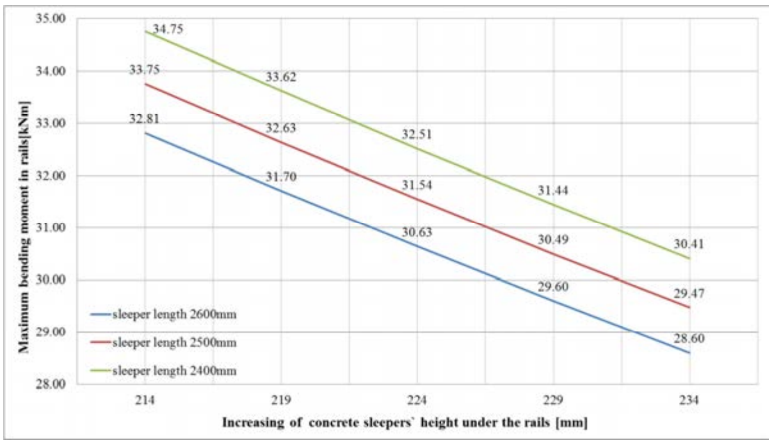

Fig. 7. Variation of rails` bearing capacity depending on the height and length of the LW 93 type sleepers

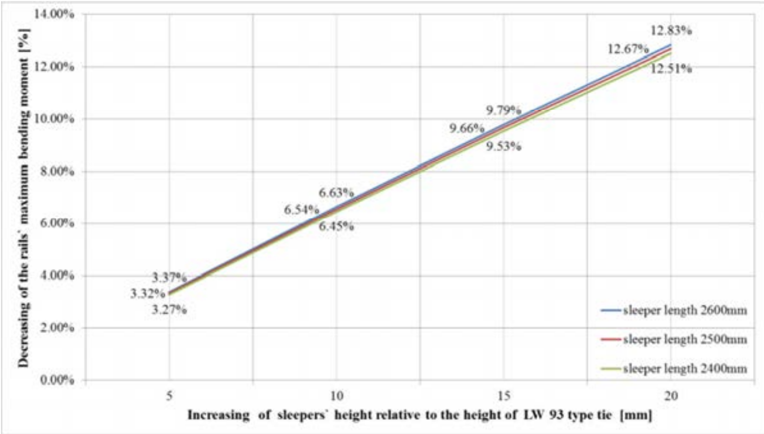

Fig. 8. Percentage variation of rails` maximum bending moment depending on the height and length of the LW 93 type sleepers

Table 3 Percentage variation of rails` bearing capacity in the case of the same height but different length of concrete sleepers

	T17 V49 type concrete sleeper					LW 93 type concrete sleeper			
Rate of sleepers` heights increasing (mm)	l_t (mm)	h_t (mm)	M_r (kNm)	Variation of rails` bearing capacity		h_t (mm)	M_r (kNm)	Variation of rails` bearing capacity	
	2600	213	34.14	2,77%		214	32.81	2,80%	
Initial height	2500	213	35.11		2,85%	214	33.75		2,88%
	2400	213	36.14			214	34.75		
	2600	218	33.01	2,82%		219	31.70	2,84%	
5	2500	218	33.97		2,90%	219	32.63		2,93%
	2400	218	34.98			219	33.62		
	2600	223	31.92	2,86%		224	30.63	2,89%	
10	2500	223	32.86		2,95%	224	31.54		2,98%
	2400	223	33.86			224	32.51		
	2600	228	30.86	2,90%		229	29.60	2,93%	
15	2500	228	31.78		2,99%	229	30.49		3,02%
	2400	228	32.76			229	31.44		
	2600	233	29.83	2,95%		234	28.60	2,97%	
20	2500	233	30.74		3,04%	234	29.47		3,06%
	2400	233	31.70			234	30.41		

3. Discussions

It can be observed on Fig. and Fig. , that if the height of the sleepers raises with 5 cm above the previous dimensions, in the place of the rails bearing, the difference between the bearing moments in the rails is always changing in interval of 2,90% -3,30%.

So it can be stated, that in case of sleepers of the same length, the steady increase in height of the sleeper`s cross section increases linearly the rail's load bearing capacity.

According to the results, in the Table 3, a similar trend also seems to be outlined in the case of the same height but different length sleepers. With sleepers` length increasing the bending moment in the rail beams decreases, but the rate of decrease varies in the same height domains. In case of higher sleepers, the variation of rails` bearing capacity caused by the change in the sleepers` length is more significant, 2,95% - 3,06 %, than as lower sleepers, where these values are between 2,77% and 2,88%.

It can be seen on Fig. and Fig. that, the differences between the bearing moments in the rails are higher, can reach more than 6kNm, approximately 15% - 17%, when the sleepers in different length and height domains are studied.

4. Conclusions

According to the above mentioned results we can establish that, in addition to the length of the sleepers, it is necessary to pay attention to the length and breadth of the blocks, to the cross-sectional dimensions and shapes of the sleepers under the rails (in the place of the rails bearing). In the calculations the ties` sectional shapes and dimensions are given by the sleepers` moment of inertia.

The results are emphasizing the differences for the three lengths considered in the study, with potential to be extended for a larger set of elements, and highlight the importance of optimization of concrete sleepers` dimensions with reduced material consumption, if possible.

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