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Parametrical study of the effect of the torsional resistance of the fastenings on the stability of continuous welded rail

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Summary

This work contains a parametrical study on the stability of continuous welded rail (CWR), taking in account the torsional resistance effect which appears between rail and sleepers through fastenings system. The effect of the torsional resistance was analyzed in the presence and in the absence of vehicle loading. It was considered both linear and nonlinear behavior of the fastenings. The analysis was done using a simplified bi-dimesional model of CWR, with beam elements and nonlinear lateral, longitudinal and torsional spring elements.

It was shown the influence of the different parameters which governs the behaviour of the fastenings on the stability of CWR.

KEYWORDS: Continuous welded rail, Track stability, Fastening system.

1. GENERALITIES FOR THE TORSIONAL RESISTANCE OF FASTENINGS

The continuous welded rail track is loaded by vehicles and weather factors, especially by temperature variations. These loads generate vertical, transversal and longitudinal displacements and deformations of railway track panels. Each of these displacements and deformations are restricted by one or more resistances. All of these resistances are of friction forces kind. The rotation of rail in the fastenings is restricted, mainly by the torsional stiffness of fastenings. In the literature the resistant moment of fastenings is marked by M_o or M_r.

This moment is experimentally determined in laboratory by graduate loading of a rail clamped in fastening with a force *F* placed at a *a* distance from the fastening axis, which generate a θ rotation of the rail [1, 2, 8, 10, 11]. The resistant moment and the rotation are determined by following relations:

$$M_o = F \cdot a \qquad (1)$$

$$\theta = \Delta / b \qquad (2),$$

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where *b* is the distance between fastening axis and the gauge which measure *Δ* displacement of the rail (fig. 1).

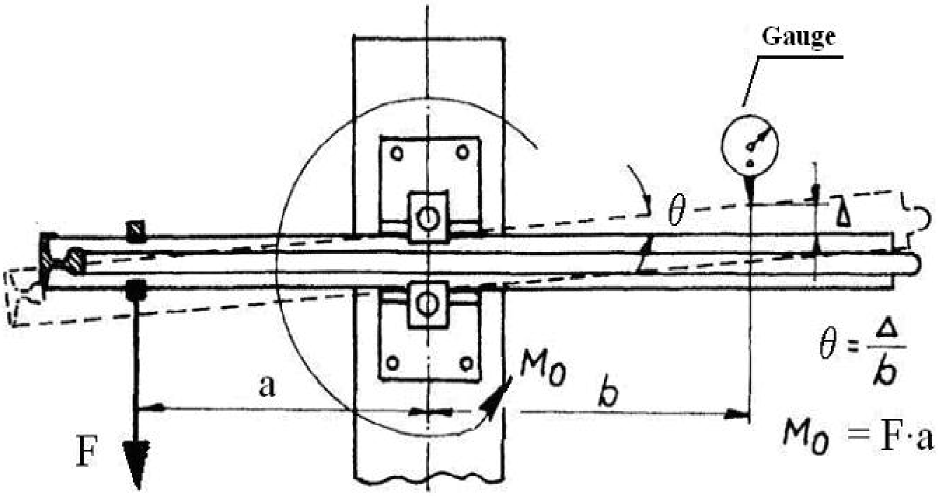

Fig. 1. Experimental determination of the torsional resistance of the fastenings M_o [1, 2, 8].

The torsional resistance (M_o) – rotation (θ) diagram, called characteristic curve of fastener, can have different shapes (fig. 2), depending on the relative position of the rail in fastening.

So, if the rail is oblique positioned (1st case by fig.2), between rail and the lateral shoulder of fastening do not exist clearances, the rail is tangent to lateraly shoulder of fastening – for example like a K type indirect fastening – the fastening will be restrict the rotation until the fastening elements will be destroyed, and the characteristic curve will be linear. When the rail is in the normal position in fastening (2nd case by fig.2), between rail and the lateral shoulder of fastening exist equal clearances to both sides of rail, for small rotations will be mobilized the rotational friction resistances between rail foot and seating plate, as well as between rail foot and K clamping claw fastening, and the concordant branch will be approximate linear. If all of these resistances will be integral mobilised it will be remarked increases of rail rotation for small increases of rotational moment, until the clearances between rail and lateraly shoulder of fastening will be passed off, and the characteristic curve will be approximate constant on this branch. After the rail will be tangent to the lateral shoulder of the fastening, the fastening will be restrict the rotation until the fastening elements will be destroyed, and the characteristic curve will be linear, again. The size of the branch whichever the characteristic curve is constant is a function of the size of clearance between the rail and the lateral shoulder of fastening. Hereby, if the rotation of rail in fastening will be in that direction which lead the rail from oblique to normal position, it will obtain the maximum size of the level of the characteristic curve , for the situation in which the rail is tangent to the lateral shoulder of fastening and it exist maximum values of clearances between the rail foot and the lateraly shoulder of fastening (3rd case by fig. 2).

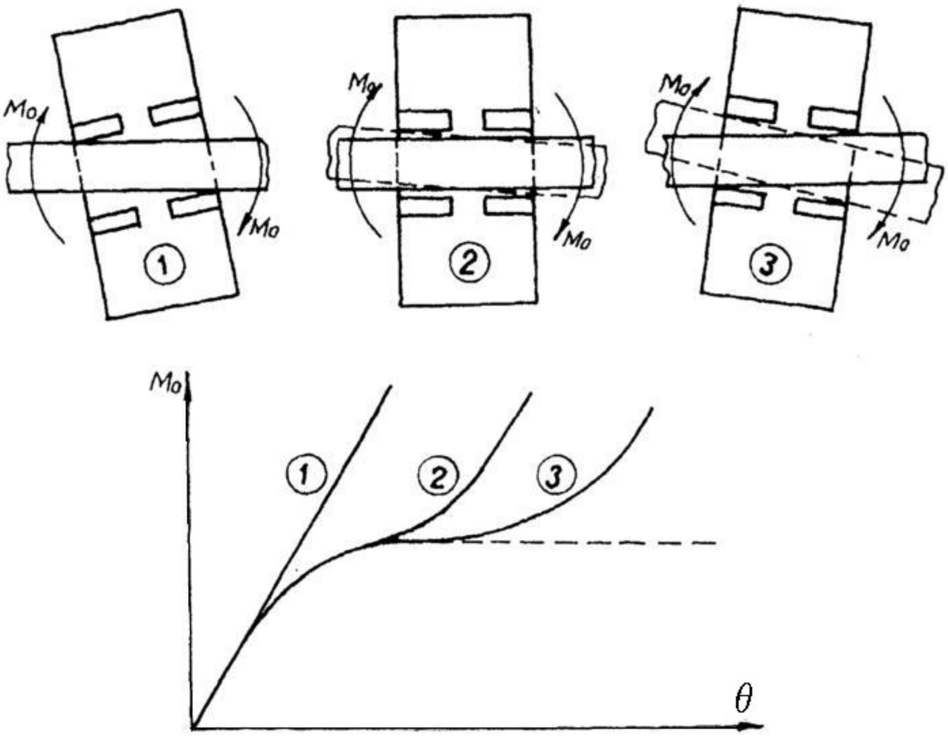

Fig. 2. The torsional resistance (M_o) – rotation (θ) diagram for diverse relative positions of the rail in the fastening [4, 8, 10].

The value of resistent moment M_o, for which the characteristic curve of fastening is constant depends on the vertical force with wich the fastening push on the rail foot by fastening elements (for example, by the clamping claw, in case of K type fastening), it being directly proportional with the size of this vertical clamping force. In the fig. 3 is shown one example for this situation [8, 11].

The regulations and some authors consider a linear characteristic curve of fastening which result by linearisation of the first branch of characteristic curve [1, 2, 5, 6, 7, 8, 11]. The explanation for this supposition is that, for the allowed values of misalignment, the rotation of rail in the fastening does not exceed the characteristic values of the first branch of the experimental characteristic curve.

However, for the common fastenings used in Romania, a tri-linear characteristic curve is most proper for the real behaviour of the fastening.

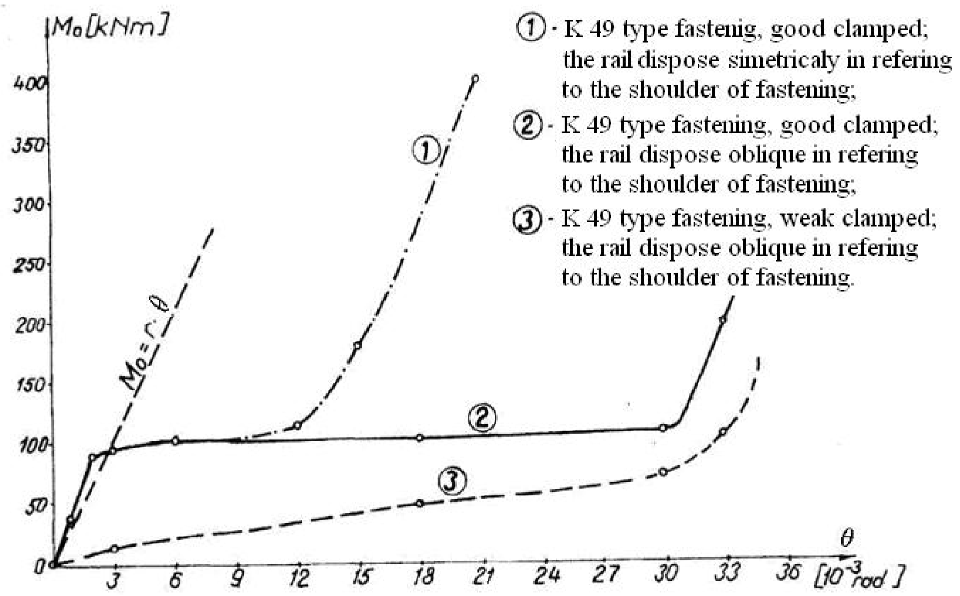

Fig. 3. Characteristic curves of K 49 type fastening [10, 11].

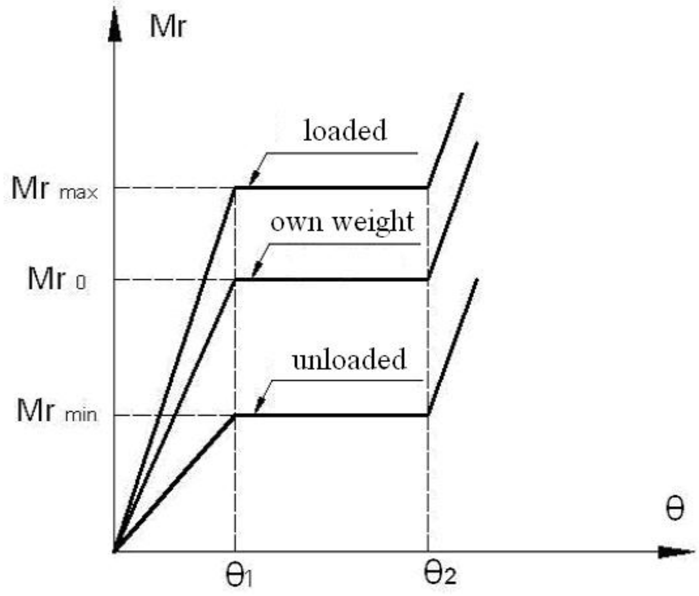

Fig. 4. Characteristic curve of the fastening in function of vertical load due to vehicle [12].

2. THE MODELING OF TORSIONAL RESISTANCE OF FASTENINGS

The majority of models consider a linar variation of characteristic resistent moment – rotational angle of rail in the fastening (fig. 5 a), but exist models in which it is considered a bi-linear, tri-linear (fig. 5 b) or multi-linear characteristic curve [2].

All linear [2, 6, 7, 13], bi-linear [3] or tri-linear [4, 8, 9, 10, 11] common models are not taking in account the influence of vehicle vertical load on the rotation of the rail in the fastenings, but in the model given in [5, 12] it is included. The behaviour of fastening to rail rotation can be appropriately corrected according to this model [5, 12], taking account of the pushing force on sleeper, as it is shown in fig. 4. Such as approach is more close to the real behaviour of the fastening and it allows the estimation of the influence of other parameters of fastening, which are not considered in the other models.

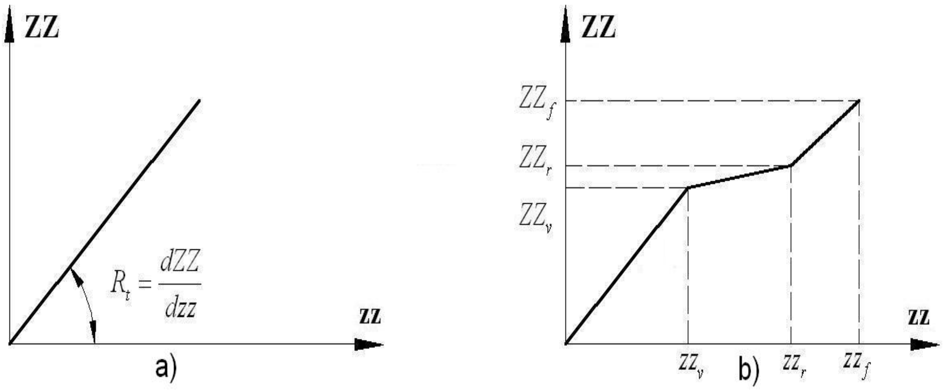

Fig. 5. Torsional resistance of fastenings [5].

Hereby, the resistance to rotation of rail in fastening will be Mr_o for unloaded railway track into the tri-linear model, and for the loaded railway track it will be with values between Mr_{max}, concordantly with the most vertical loaded sleeper, and Mr_{min}, concordantly with the less vertical loaded sleeper or unloaded sleeper – which is on the sector of railway track between the most distant axle where coming on the upplift of track.

The SCFJ model was presented in [5] and it was used in numerical experiments depicted in the following. It allowes the use of a linear or tri-linear characteristic curves (fig. 5).

3. THE COMPARISON OF THE RESULTS WITH THOSE PROVIDED BY THE OTHER SIMILAR MODELS

The values of critical temperature are very important in the analysis of the stability of continuous welded rail (CWR), i.e. the maximum increase of temperature T_{max} - over which the buckling of CWR will be surely coming on - and the minimum increase of temperature T_{min} – under which the buckling of CWR will surely not be coming on [2, 3, 5, 6, 7, 12, 13].

The numerical experiment shown in [6, 7, 13] for testing of the SCFJ model – in wich the torsional resistance of fastenings is linear and it is independent of the vertical vehicle load – was repeated. It resulted maximum 1,5 % difference in regard to the other models for the torsional resistance of fastening like in [7].

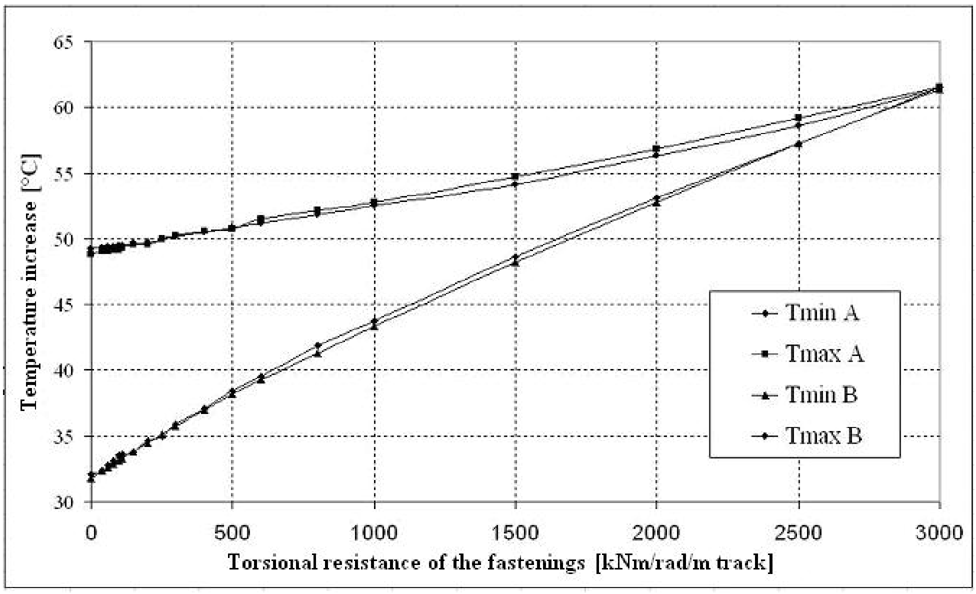

Fig. 6. The increases of critical temperature versus the torsional resistance of the fastenings [6, 7, 13].

A graphical representation of the results is shown in fig. 6, where the maximum and minimum critical temperatures by [7] were marked by $T_{min\ A}$ and $T_{max\ A}$, and the maximum and minimum critical temperatures by SCFJ were marked by $T_{min\ B}$ and $T_{max\ B}$, respectively. It results a very good correspondence between both results. Torsional resistance of fastenings increase, minimum critical temperature T_{min} increase more than maximum critical temperature T_{max}.

The explanation of this behaviour is that the rotations and transversal dispacements of rails are smaller for minimum critical temperature T_{min}, while maximum critical temperature T_{max} have more important values, therefore the mobilization of torsional resistance of fastenings is bigger for minimum critical temperature T_{min}.
It is imporatant to point out that the common values of torsional resistance of fastenings are in the range of 0 ÷ 500 kNm/rad/m track.

4. THE INFLUENCE OF THE TORSIONAL RESISTANCE OF FASTENINGS ON THE STABILITY OF CWR TRACK

For former example the vehicle was eliminated to distinguish the influence of torsional resistance of fastenings when the track is loaded only with temperature variations. The analises of results relieve, in absence of vehicle load, a growth of T_{min} with about 2%, and a growth of T_{max} with about 3,5%, comparatively with the results obtained in presence of vehicle loads.

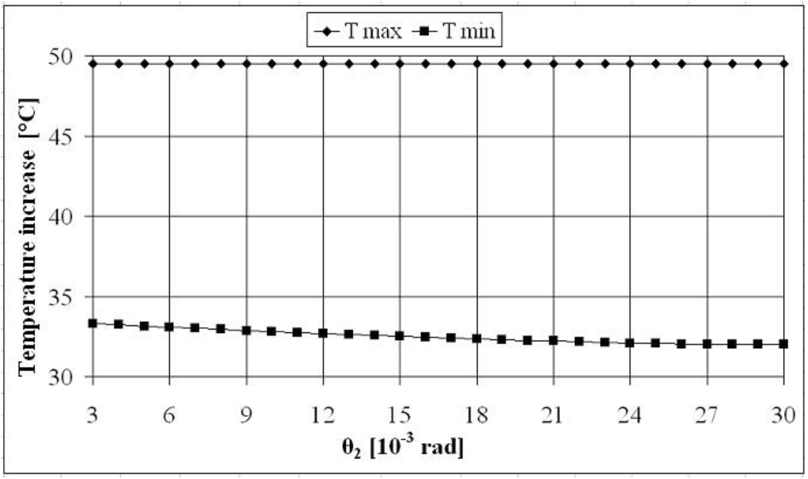

Fig. 7. The variation of critical temperature versus the value of rotation angle of rail in fastenings θ_2 for a constant value $\theta_1 = 3\cdot10^{-3}$ rad.

It was analyzed the influence of level θ_1 ÷ θ_2 size, for that the value of torsional resistance of fastenings is constant, on the value of the critical temperature is increasing. It was considered a reference value of resistant moment $M_o = 333.75$ Nm/rad/m track, adjusted in terms of vertical load from vehicle. It was considered that the value of fastening stiffness for the rotations of rail in fastening which exceed θ_2 is equal with the stiffness for the first branch – i.e. it is that which characterizes the rotations between 0 and θ_1. It was obtained the results shown in fig. 7, for a constant value $\theta_1 = 3 \cdot 10^{-3}$ rad – which correspond at a K type fastening – and for values of θ_2 in range $3 \cdot 10^{-3} \div 30 \cdot 10^{-3}$ rad. The values of θ_2 were considered for a step by $1 \cdot 10^{-3}$ rad. It was observed that T_{max} stays constant, the corresponding rotation being less than θ_1, and T_{min} decreases with about 4% for $\theta_2 = 28 \cdot 10^{-3}$ rad, thereupon the value of T_{min} being constant because the appropriate rotation is smaller than θ_2, i.e. it can say that the behavior of model is bi-linear, not tri-linear.

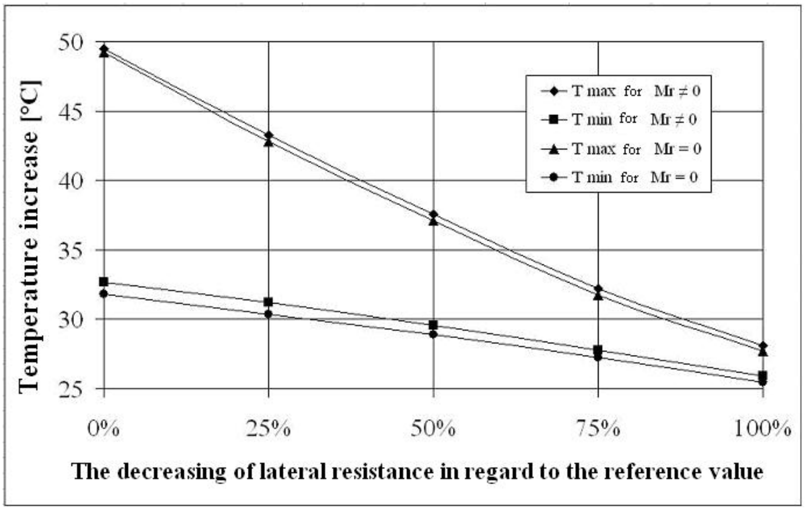

Fig. 8. The variation of critical temperature versus the decrease of lateral resistance.

In order to mark out the effect of torsional resistance of fastenings on stability of CWR track it was also analyzed the situation with reduced lateral resistance on the central zone of the misalignment. Hereby, it was investigated the situation in which the lateral resistance is reduced up 100%, 75%, 50% and 25% at 4 sleepers placed on central zone of the misalignment, as for the situation in which the torsional resistance is zero, as for the situation in which that has the same values like in the previous numerical experiment. It was considered $\theta_1 = 3 \cdot 10^{-3}$ rad and $\theta_2 = 12 \cdot 10^{-3}$ rad. The results of this numerical experiment are shown in fig. 8. Though the influence of torsional resistance is small, if the results are compared it can be observed that T_{min} is more influenced by the torsional resistance of the fastenings than T_{max}.

Almost all developed models neglect the influence of torsional resistance because they are taking in account the small influence this parameter.

However, it was observed in numerical and laboratory experiments that in some cases the torsional resistance of the fastenings can have a significant influence on the track stability. Therefore a more trusty analysis of the track stability must take in account the effect of this factor, also.

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