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PRESTRESSED CONCRETE SLEEPER UNDER EXTREME LOADING CONDITIONS

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Abstract: *Prestressed concrete sleepers are among the most common structural components of the railway tracks. Nowadays, the majority of railway sleepers are made of prestressed concrete. During their service life, the sleepers are subjected to extreme loading conditions, which may drastically reduce the span of their service life. This paper focuses on the optimized design of prestressed railway sleeper subjected to extreme loading conditions, which represented here by the impact of a flat wheel and by the cyclic loading.*

Keywords: ***Extreme loading, prestressed concrete sleeper, optimization, cyclic loading, fatigue.***

1. Introduction

The classical railway track consists of the rails, fasteners, sleepers, ballast and underlying subgrade (Fig. 1). The railway sleepers lie on the ballast transversally to the rails, which supports and holds them in place, and provides drainage and flexibility. The sleepers transfer the loads from rails to the ballast and subgrade, hold the rails to the correct gauge, restrain longitudinal and lateral rail movements, and provide strength and stability to whole track structure. That is why the concrete sleepers are the essential components of the track structure. It is obvious that the sleepers are subjected to extreme loading conditions and their design should be provided with high attention.

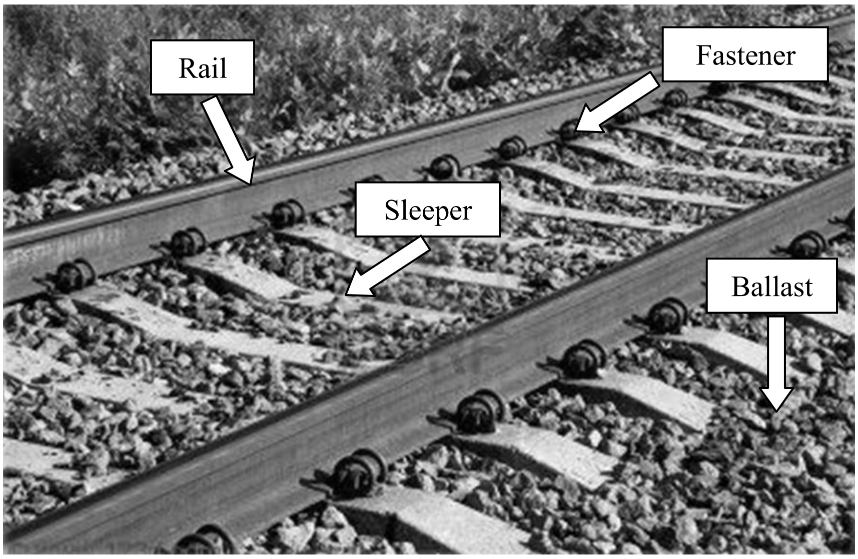

Fig. 1: Components of classical railway ballast track

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This paper focuses on explanation of the design of prestressed concrete sleeper when the emphasis is put on optimization of the shape of the sleeper and position of prestressing wires with respect to the load distribution and extreme loading conditions caused by impact of flat wheel and cyclic loading.

2. Loading of railway sleepers

The whole railway track is subjected to static and dynamic load, which is caused by train transportation. The magnitude of this load depends on many factors. The main factors are the geometry of the railway track (straight or curved), type of the train, travelling speed of the train, maintenance of the railway vehicles and also the ballast reaction on the sleeper.

The design static wheel load per rail seat for standard railway tracks is 125 kN, which roughly corresponds to the maximum speed of 160 km/hour. But it should be also noted that the railway tracks often suffer from extreme loading conditions. The extreme loading is attributed to the wheel and rail abnormalities or missing subgrade under parts of the sleeper. The rail and wheel abnormalities are, for example, the flat wheels (Fig. 2), wheel corrugation, out-of-round wheels, dipped rails, etc.

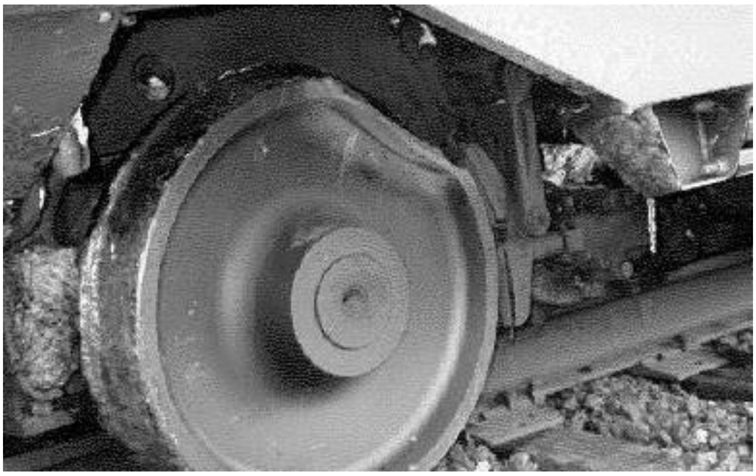

Fig. 2: Illustrative example of extremely flat wheel

These defects can cause loading of a very high magnitude but short duration and the occurrence of such loading is of low probability during the design life of the railway sleeper (Kaewunruen & Remennikov, 2009). The magnitude of the dynamic impact loads per rail seat varies from 200 kN up to 750 kN (Remennikov & Kaewunruen, 2008). These forces may cause cracking and failure of the sleeper (Sýkorová, et al., 2011).

Railway sleeper is a structural element which is subjected to cyclic loading during its entire service life. The cyclic loading causes fatigue of concrete, which results in permanent progressive changes in the structure of the material. These changes can cause crack, or micro-crack, propagation which consequently reduces stiffness of the structure, which in the extreme case can lead to fatigue failure. The fatigue damage of concrete can be assessed by using the fatigue damage function. This function expresses the decreasing of stiffness of the structure by decreasing the value of the modulus of elasticity during the cyclic loading (Foglar, 2008; Sýkorová et al., 2008).

3. Numerical analysis of railway sleeper

The resulting shape of the sleeper was obtained by the optimization of the shape of the standard B70 prestressed concrete mono-block sleeper. The prestressing force and the position of prestressing wires are then determined accordingly for the optimized shape of the sleeper.

3.1. Optimized design of the concrete sleeper for the standard load and the impact of flat wheel

In the following, the problem is divided into two cases. The first case is related to the design of the sleeper to withstand the standard load of 125 kN per rail seat. The second case deals with the design of the same prestressed concrete sleeper to withstand the load of 400 kN per rail seat, which represents the impact of the flat wheel. In general, the resulting shape of the sleepers resembles that of the standard B70 when the height and the width of the sleeper are slightly increased. Also, the prestressing forces are induced by a similar distribution of the prestressing wires, whose arrangement reflects the increased loading conditions. The resulting shape and the distribution of prestressing wires are shown in Fig. 3 and Fig. 4.

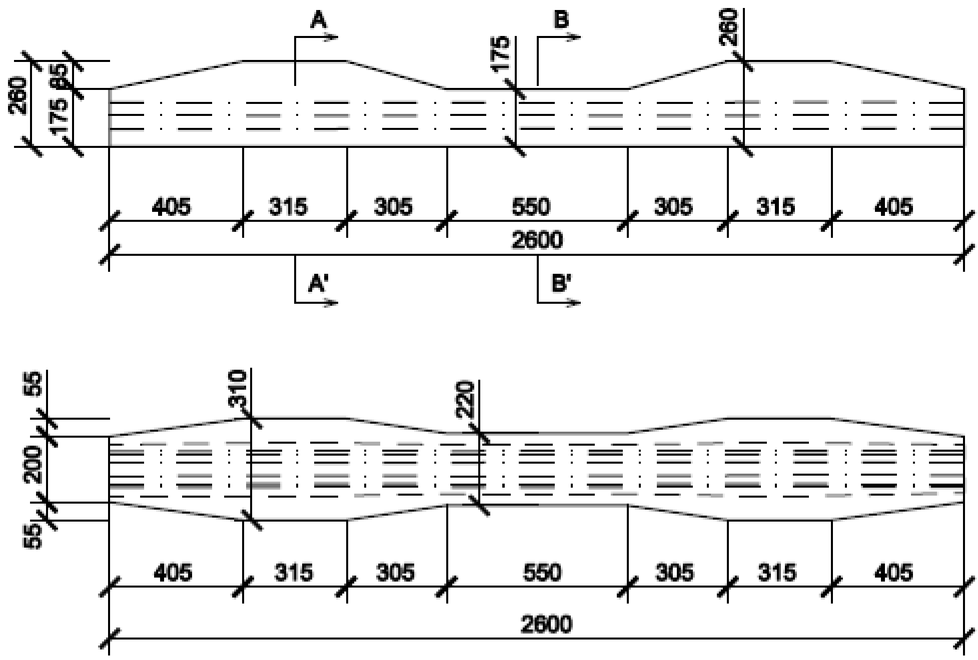

Fig. 3: Shape of optimized railway sleeper

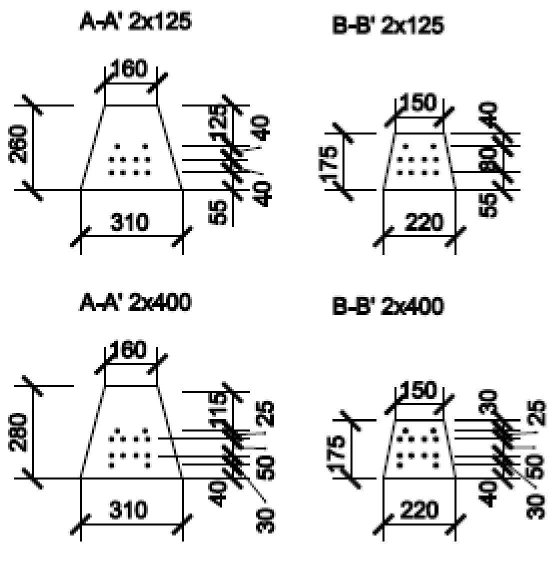

Fig. 4: Cross-sections of analysed sleepers: rail seat (left), mid-span (right)

The necessary prestressing reinforcement is provided with the identical prestressing wires with the proof test of 1860 MPa. The sleeper with standard load of 125 kN on both rail seats is prestressed with 10 wires with the diameter of 6 mm. The sleeper designed for impact load of 400 kN on both rail seats is prestressed with 12 wires with the diameter of 8 mm. The 28-day compressive strength of concrete used in the analysed sleeper must be greater than 50 MPa, which is a common value for prestressed concrete sleepers, such as the B70.

The distribution of the contact stresses under the analysed sleeper, which corresponds to the stiffness of the ballast and the underlying subgrade layers, is schematically depicted in Fig. 5.

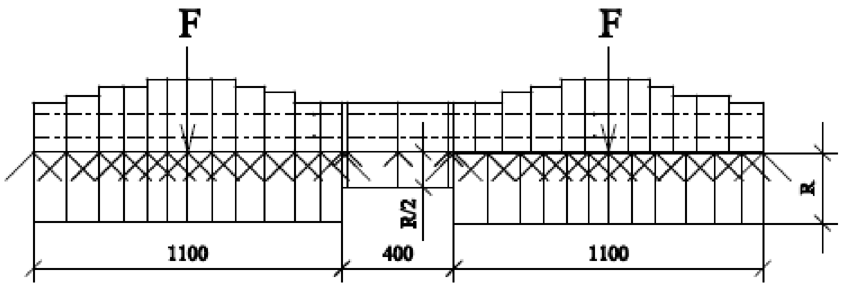

Fig. 5: Distribution of contact stresses under analysed railway sleeper

The numerical analysis was performed with the commercial software ESA Engineer 2008, which is based on the finite element method. The load configuration shown in Fig. 5 was considered in the analysis and the resulting distributions of the bending moment for both the load cases (F=125 kN and F=400 kN) are shown in Fig. 6. This identical bending moment distribution was considered in the optimization of the shape and the peak positive and the peak negative bending moments were considered in determination of the presstressing force.

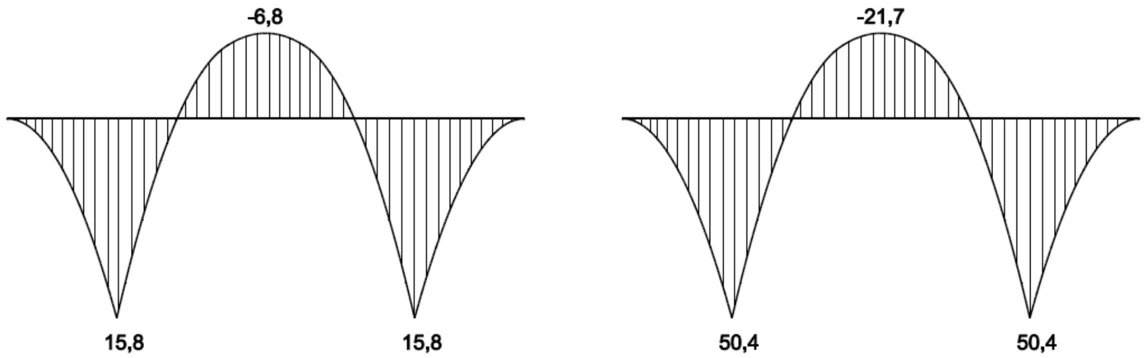

Fig. 6: Bending moment distribution (in kNm) for load: 2 x 125 kN (left), 2 x 400 kN (right)

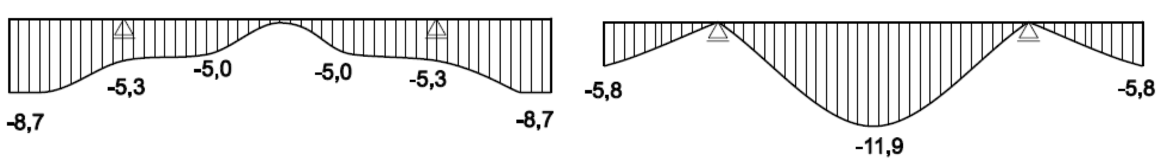

Fig. 7: Normal stress distribution (in MPa) from combination of prestressing and forces of 125 kN per rail seat: upper surface (left), lower surface (right)

The normal stresses at the upper and lower surfaces of the sleeper under the standard load of 125 kN per rail seat, corresponding to the bending moment distributions shown in Fig. 6, are shown in Fig. 7 and the maximum and minimum values at the mid-span and the rail seat cross sections are summarized in Tab. 1.

Tab. 1: Maximum and minimum normal stresses.

Load	**Stress (MPa)**			
	Upper surface		**Lower surface**	
	Mid-span	**Rail seat**	**Mid-span**	**Rail seat**
2 x 125 kN	7.7	-6.8	-6.8	5.5
2 x 400 kN	27.3	-18.7	-24.3	14.9
Prestressing and 2 x 125 kN	-1.7	-5.3	-11.9	-0.7
Prestressing and 2 x 125 kN	-27.1	-1.1	-11.2	-14.5

3.2. Cyclic loading

The railway sleeper is subjected to cyclic loading which causes fatigue of concrete. The analysis of the prestressed concrete sleeper under fatigue load is done for the sleeper with standard load of 125 kN on both rail seats.

The most important characteristic when analysing the fatigue behaviour of concrete is the decrease of stiffness, which is calculated here by using fatigue damage function (Foglar, 2008; Sýkorová et al., 2008). This function depends on the total number of load cycles and the load level. The total number of load cycles which the prestressed concrete railway sleeper can resist during its service life, was determined by formulae in Eurocode 2 (CEN, 2005) as 80 millions. With respect to the maximum and minimum compressive stresses in the cross section under the rail seat, the load level is determined as 0.44. The initial average secant modulus of elasticity for concrete C50/60 is 37 GPa. Based on the fatigue damage function defined using the above values, the decrease of stiffness, which is expressed in terms of the modulus of elasticity, is shown in Fig. 8.

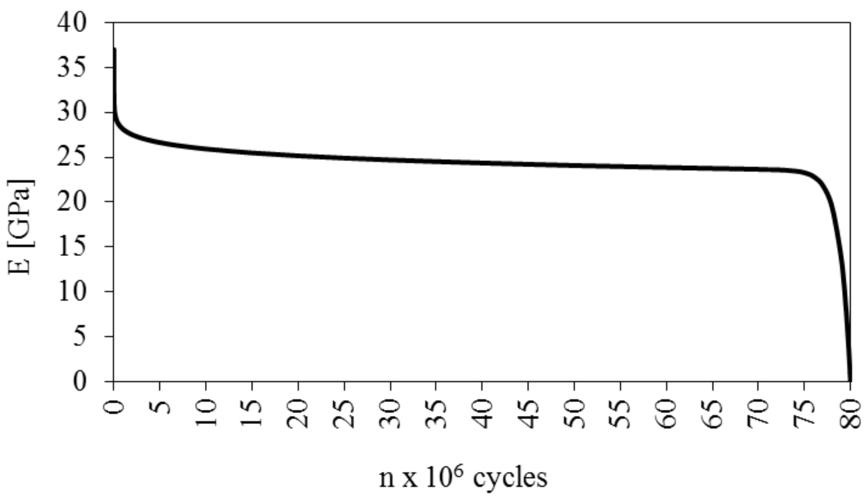

Fig. 8: Decrease of modulus of elasticity of the sleeper during entire service life

From Fig. 8, it is obvious that the modulus of elasticity decreases rapidly during the first few hundred thousands of load cycles and then again at the end of its service life. During the first 10 per cent of all load cycles the mean value of the modulus of elasticity decreases from the initial value of 37 GPa to 26.2 GPa. Such reduction of stiffness results in greater deformations and even in cracking and thus in reduction of the expected service life.

4. Conclusions

This paper presented an analysis of prestressed concrete railway sleeper subjected to two types of extreme loading conditions.

Railway sleeper can suffer during its service life from impact load caused by flat wheels. The occurrence of this impact load is of low probability during the design life of the railway sleeper, but once it happens the sleeper sustains ultimate damage, which requires replacement of the sleeper. Therefore, the standard shape of the sleeper known as B70 was optimized and the prestressing force designed so that it can withstand the impact load of 400 kN instead of the ordinary 125 kN per rail seat.

Railway sleeper is also structure which is subjected to cyclic loading. Cyclic loading of the railway sleepers commonly exceeds 80 millions of cycles during their service life which is commonly more than 40 years. Therefore, the optimized railway sleeper was analysed for the effect of cyclic loading which causes fatigue of structural elements. For the analysis of reduction of stiffness during the cyclic loading was used cyclic damage function.

Acknowledgement

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