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Influence of Reinforcement on the Strength of the Concrete Sleepers

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Abstract. Prestressed concrete sleepers are the most commonly used composite in the track construction in Polish railways. Different types of prestressed concrete sleepers (e.g. PS-83, PS-93 or PS-94) are used depending on the permissible load and maximum speed. The Polish largest company that manages railway infrastructure requires to use sleepers produced in accordance with the accepted technology and using approved materials. Because there are producers who offer complementary technology with alternative methods and types of reinforcement, in this article the authors take into consideration the theme of comparing strength of the sleepers in the laboratory and operating conditions. A PS-94 type sleeper, reinforced in two different ways and widely used in the construction of railroads in Poland, is an example of this problem.

Introduction

Reinforced concrete sleepers have been used on Polish tracks for decades since the time concrete technology and their reinforcing were developed. Technological progress has also resulted in the development of new constructions used in Polish railways. While at the end of the twentieth century, reinforced concrete PS-83 type sleepers and their derivatives were used in Poland, currently PS-83, PS-93 and PS-94 type constructions are accepted in different variations. The range of using concrete sleepers is regulated by instructions and mainly depends on the track category. The most commonly used is the PS-94 sleeper (Fig. 1), whose equivalent in German railways is the B70 type sleeper. The main Polish infrastructure manager after many years of operating tests decided to use only reinforcement consisting of smooth drawn bars of high-strength steel, whose minimum tensile strength is 1670 MPa and reinforced anchoring with retaining discs mounted on the sleepers' side surfaces.

The reason of such a decision was the information about cracks of sleepers reinforced with bars without anchoring plates (Fig. 2), which resulted in the lack of trust of the manager to this technology.

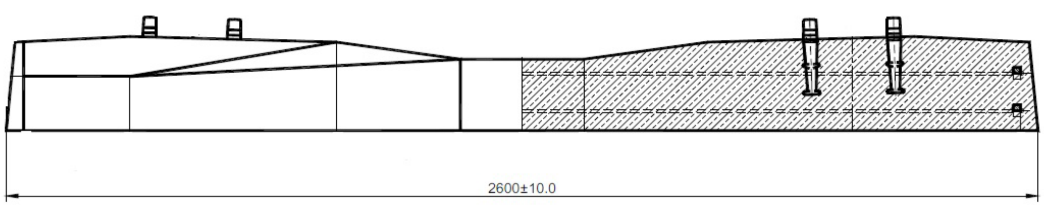

Fig 1. Half-view and half-section of the PS-94 type sleeper (source [1]).

Although it has been proven that reinforcing technology assures high strength and durability of ready structural composites, it was attempted to make the PS-94 type sleeper reinforced with eight burnished wire braids of 3 mm diameter and tensile strength of 1850 MPa. Such a type of reinforcement is also pre-tensioned before filling up the mould, which after mortar curing and releasing of tension compresses the sleeper and makes the required strength.

Fig. 2. Longitudinal cracks of the B70 type sleeper during operation (left) and new sleepers (right), (Source [2]).

According to the manufacturer's information, this type of reinforcement has many times more surface area of connection with concrete than in the case of the retaining discs use.
In the following chapters the results of tests and final conclusions will be presented.

Laboratory testing

Comparative tests of the PS-94 type sleepers have been made at the Materials and Structure Laboratory of the Railway Research Institute (Instytut Kolejnictwa) according to the procedure described in the PN-EN 13230-2:2016 [3] standard.

During the static test at a rail seat section, (Fig. 3) the sleeper was initially loaded up to the value of force equal to Fr_0 = 161 kN. From that moment, the loading was gradually increased by the value of 10 kN. The interval between the consecutive increases of loading was between 30 to 60 sec. After each increment of loading the presence of cracks in the rail seat zone was verified. If the cracks occurred, their width was measured at 15 mm from the bottom edge of the element. After the recording of the crack width with the opening of 0.05 mm, the bearing capacity of the sleeper was tested. During the whole test, the speed of the load increment was 120 kN/min

The sleepers tests at the center section (Fig. 4) have been done with initial loadings equal to Fc_o=27,6kN for the normal position and Fc_{on} = 37,7 kN for the negative position. The load steps were equal to 5 kN up to the level of visible crack and next up to breaking of the sleeper.

The purpose of testing of the sleeper under dynamic loading (Fig. 5) was to verify crack resistance of the element under the exploitation loading conditions (railway rolling stock induces dynamic forces). The sleeper was loaded with sequences of 5 000 cycles, whereas at each following stage of loading the amplitude was increased by 20 kN (the loading amplitude was increased). During the test, the level of cracking loading (Fr_r), crack opening of 0.05 mm ($Fr_{0.05}$) and destruction load (Fr_B) were registered. The frequency was constant throughout the whole test and equal to 4 Hz [4].

The purpose of the long term fatigue loading test (Fig. 6) was to simulate the real loading characteristics of sleepers caused by the railway traffic. The tested element was initially loaded up to the occurring of the crack. Next, it was subjected to the 2 000 000 cycles of fatigue loading in the range from 50 kN to 161 kN. The frequency of loading throughout the whole test was 4 Hz. After those 2 000 000 cycles the sleeper was loaded up to the destruction [4].

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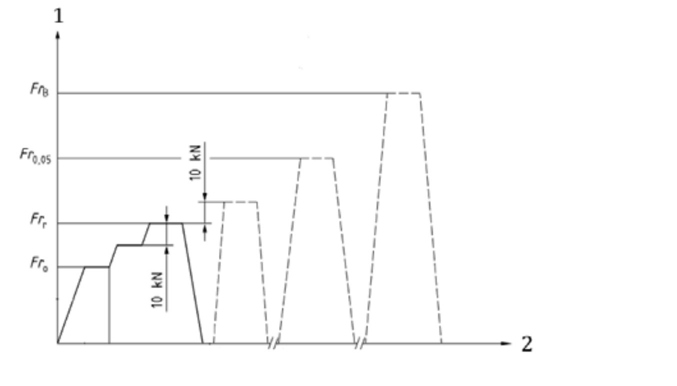

Fig. 3. Scheme of the static loading at the rail seat section.

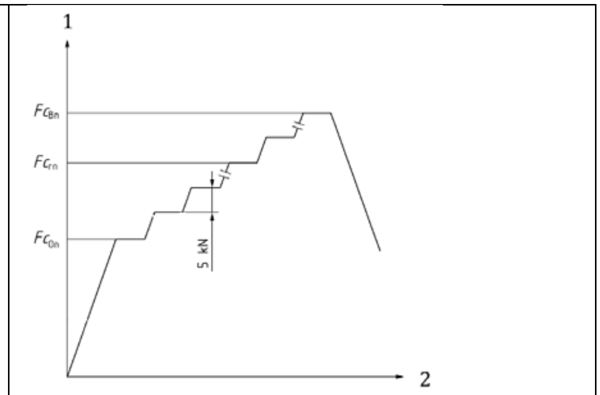

Fig. 4. Scheme of the static loading at the rail center section.

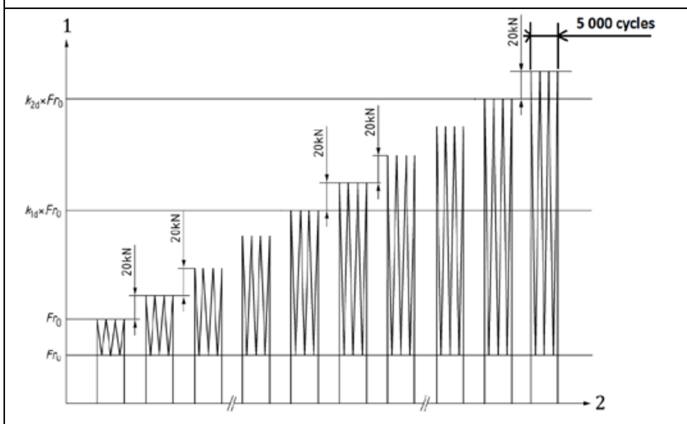

Fig. 5. Scheme of the dynamic loading at the rail seat section.

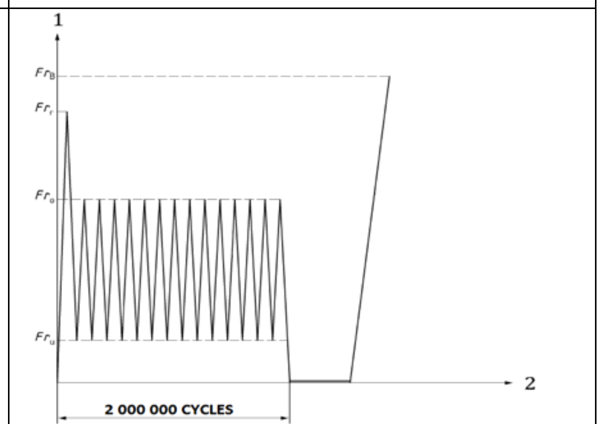

Fig. 6. Scheme of the fatigue loading at the rail seat section.

Tests

The tests were performed under repeatability conditions, using the same test stand and special instrumentation.

The sample of the destroyed PS-94 type sleeper reinforced with burnished wire braids is presented in Fig. 7.

The example of the destroyed sleeper reinforced with smooth bar with retaining discs is presented in Fig 8.

All the tested sleepers meet the minimum time of seasoning of 28 days.

The results of the endurance tests were presented in the graphs (Fig. 9-11).

All the results of the tests, beyond the maximum destructive force in the static test at the rail seat section, confirm the advantage of the sleeper reinforced with the braided wire.

From the point of the in-service properties, the value of the force which causes the first scratch on the bended surface is important. In this case, all the tests have proven the advantage of the solution with the braided wire.

The relative increase of the force that causes the first scratch of the sleeper reinforced with the braided wire are as follows:

- 12% - static tests at the rail seat section,
- 5% - dynamic tests at the rail seat section,
- 13% - static tests at the center seat section for the normal position,
- 17% - static tests at the center section for the negative position.

Fig. 7. Fracture of the PS-94 sleeper reinforced with a braided wire.

Fig. 8. Fracture of the PS-94 sleeper reinforced with a smooth bar.

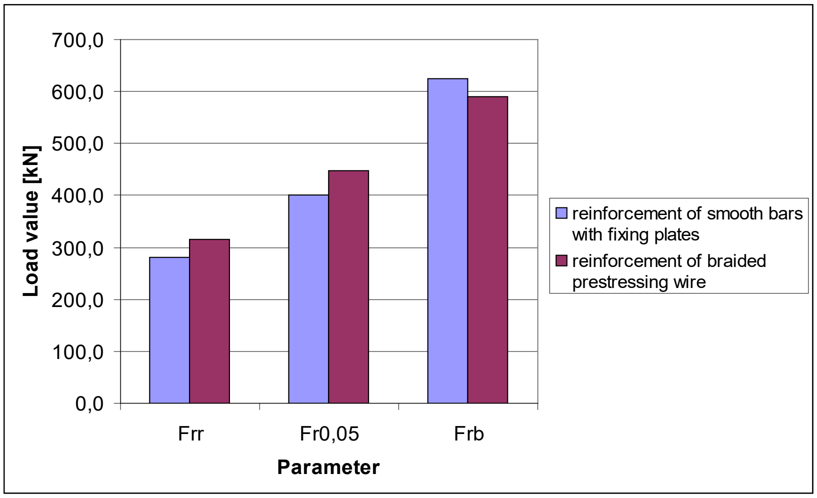

Fig. 9. Result of the static test at the rail seat section.

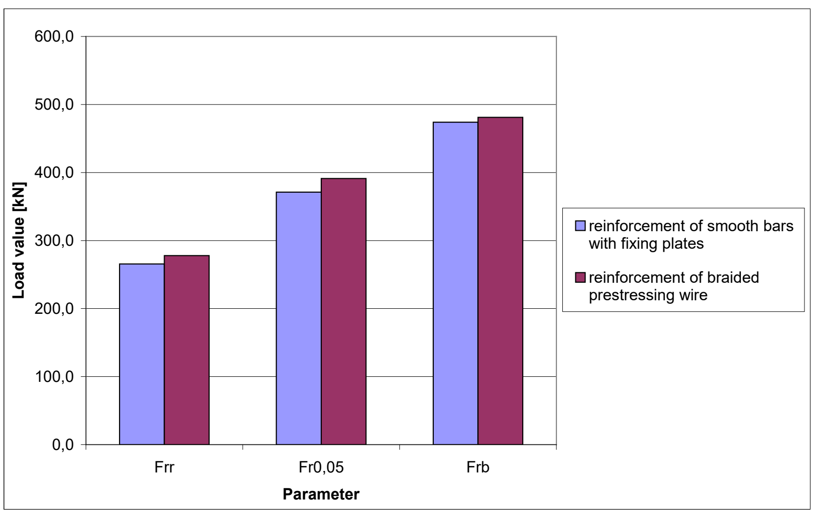

Fig. 10. Result of the dynamic test at the rail seat section.

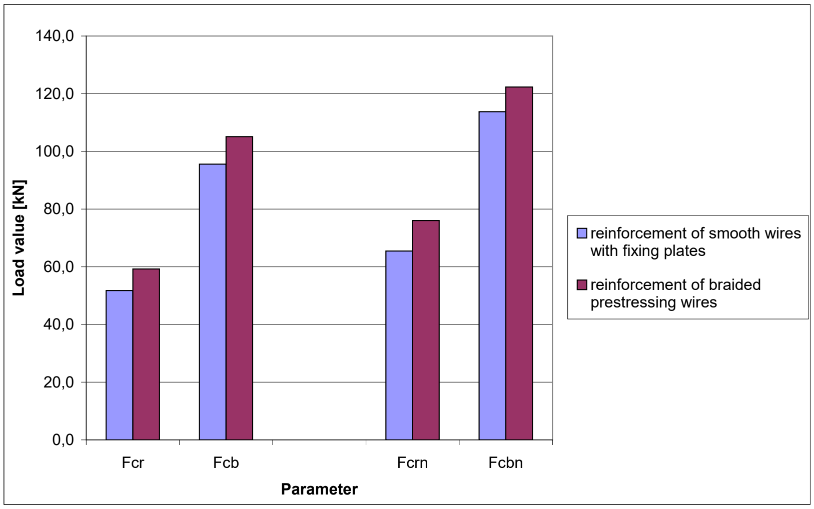

Fig. 11. Result of the static test at center section for the normal and negative position.

Photos (Fig. 7 and 8) show the way of the reinforcement cracking. After cracks examination of the smooth bars and braided wires it can be concluded that both reinforcements broke as a result of tension. In connection with low adhesion of smooth wires for concrete, pulling out of bars before their failure is visible. Such effect is not visible in the case of sleepers reinforced with braided wires due to a greater contact surface of bars and concrete and the shape of wire that causes large adhesive forces between concrete and steel as well as the large retain surface of the entire length of the braided wire.

In-service testing

In service tests have been carried out on the sample in accordance with the requirements and instructions of the company managing infrastructure.
The section of tests consisted of 500 sleepers fastened with rails by the fastening SB type system.
A part of the experimental section is shown in the picture below (Fig. 12).

Fig. 12. A section of the rail road with sleepers that have reinforcement with braided prestressing wires (source: [5])

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The testing track has been built in the curved track with the radius of 2250 m and a cant track of 50 mm, using 60E1 type rails. Passenger trains velocity did not excess 120 km/h (75 mph) and velocity of the freight trains 70 km/h (43 mph).

After two years of operation and summary load of 20 Tg, there were no data about any technological problems with the tested sleepers and any factors that would indicate the reduction of impact strength in comparison with the sleepers reinforced with a smooth bar with retaining discs. There were no signs of weathering of concrete.

Summary

Reinforced concrete sleepers are very reliable parts of the railway track that keep right the track gauge. Their manufacturers use mainly approved technology based on reinforcement with smooth bars with retaining discs.

As a result of the laboratory tests which were carried out, it can be concluded that the PS-94 sleepers reinforced with the braided wire are at least as strong as the commonly used the PS-94 sleepers reinforced with technology approved by the company of tracks manager.

Operational tests carried out in the field in the range of 20 Tg summary load confirmed high durability of the products and exploitation without any problems. There were no cracks that characterize composites without retaining discs and in many cases, appear at the beginning of use.

The infrastructure manager has the right to additional requirements for safety railways transport and in connection with potential costs of using alternative technologies.

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