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EFFECT OF STRANDS ANCHORAGE SYSTEM IN RAILWAY SLEEPERS ON BEHAVIOUR OF ITS RAIL SEAT ZONE

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Abstract
Pretensioned monoblock sleepers are commonly used elements of railway pavements. Load carrying capacity and durability of these elements, which can be used in extreme environmental and load conditions, have a major impact on ensuring safety in rail transport system. Currently, in various European countries, significantly differing ways of sleepers prestressing are used. The paper presents the results of experimental research on capacity and crack resistance of the rail seat cross-section of sleeper. The elements were tested under static, dynamic and fatigue loads, according to the PN-EN 13230-2 "Railway applications – Track – Concrete sleepers and bearers. Part 2: Prestressed monoblock sleepers" [1]. The research made it possible to draw conclusions concerning the efficiency of the various types of sleepers, differing in the prestressing tendons anchoring.

Streszczenie
Monoblokowe podkłady strunobetonowe są powszechnie stosowanymi elementami nawierzchni kolejowych. Nośność i wytrzymałość tych elementów, które mogą być stosowane w trudnych warunkach środowiskowych i warunkach obciążenia, mają duży wpływ na zapewnienie bezpieczeństwa w systemie transportu kolejowego. Obecnie w różnych krajach europejskich stosowane są różne sposoby sprężania. W pracy przedstawiono wyniki badań eksperymentalnych nośności i odporności na pękanie podkładu kolejowego. Elementy badano pod obciążeniem statycznym, dynamicznym i zmęczeniowym, zgodnie z PN-EN 13230-2 „Kolejnictwo – Tor – Podkłady i podrozjazdnice betonowe. Część 2: Podkłady monoblokowe strunobetonowe" [1]. Badania pozwoliły na wyciągnięcie wniosków dotyczących skuteczności różnych rodzajów podkładów różniących się sposobem kotwienia cięgien sprężających.

Keywords: **Anchoring system; Cracking resistance; Experimental tests; Fatigue; Load bearing capacity; Pretensioned structures; Railway sleepers.**

1. INTRODUCTION

Pretensioned monoblock concrete sleepers have been widely used for construction of bedding railway pavements for many years. The first experimental production of prestressed sleepers in Poland took place in the year of 1952. Over the years, simultaneously with the advance in knowledge concerning both the technology of concrete and prestressed structures, modification in sleepers' design took place. It was caused by the need to meet increasing requirements of modern railroad transport solutions and necessity to provide maximum durability of the pavement. Minimum lifetime of concrete sleeper, assumed while designing the structure, is 40 years, but in the favourable conditions, as the practice has shown, it might be much longer [2]. From the perspective of the problems with the built-in pretensioned sleepers, recorded in Europe in recent years, (each time connected with major expenses and limitations in railway traffic) the issue of production optimization of those specific structures is still very urgent [3].

The purpose of the experimental research, carried out at Cracow University of Technology, was the comparison of functioning and operational safety of pretensioned monoblock sleepers, with various types of prestressing strands anchorages, occurring in individual European Union countries. Characteristic feature of the technology, applied to anchoring strands involving the use of special anchor plate, is the absence of the Hoyer effect, which in cases of anchoring based purely on adhesive bond of prestressing strands, is inevitable. Application of anchor plate decreases the probability of forming cracks at the ends of the element. Moreover, introducing of the additional mechanical anchorage results in significant decrease (or even elimination) of transmission length of prestressing force. That effect is very crucial for the extremely loaded rail seat zone, placed relatively close to the front of the sleeper. Hence, the reliability of the solutions with additional anchoring elements is intuitively larger than those, where prestressing force is transferred only by the bond properties of the prestressing strands.

2. EXPERIMENTAL RESEARCH

2.1. Description of testing elements

Comparative research of monoblock prestressed concrete sleepers was carried out mainly in the Research Laboratory for Building Materials and Structures at the Cracow University of Technology (the laboratory is accredited by PCA and certified with No. AB 1251), and only a part of static tests were conducted in the laboratory of sleepers manufacturer. There were examined 24 sleepers, made in two forms: the geometry of PS-83 sleeper (the exterior dimensions of rail seat cross-section: 300 × 205 mm) and PS-94 (the exterior dimensions of rail seat cross-section: 276 × 229 mm). All pretensioned concrete sleepers were made using rigid forms, in which the four-chamber formwork was enough massive and rigid to take the prestressing force of four elements.

The tests involved four types of sleepers, differing in both: geometry and the prestressing system (cross-sections of each type of element is schematically shown in Figure 1):

- sleepers PS-83 with prestressing in the form of eight 7 mm diameter plain wires and a special anchor plate (hereinafter referred to type A-83);
- sleepers PS-94 with prestressing in the form of eight 7 mm diameter plain wires and a special anchor plate (hereinafter referred to type A-94);
- sleepers PS-83 with prestressing in the form of four 10.5 mm diameter indented rebars and additional round steel plate (hereinafter referred to type B-83);
- sleepers PS-94 with prestressing in the form of four 9.5 mm diameter indented rebars (hereinafter referred to type C-94).

The total initial prestressing force in all tested sleepers was identical and amounted to 360 kN.

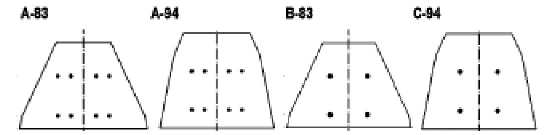

Figure 1.
Rail seat cross-sections of tested sleepers

In the sleepers prestressed with eight 7 mm diameter plain wires (type A-...), the high strength wires are anchored individually, in an anchor plates made of thick steel plate, by means of proprietary cold-formed BBRV button heads. The shape of anchor plate for anchoring four prestressing wires, localized in one axis, is shown in Fig. 2, and the view of the mould prior to concrete casting is presented in Fig. 3. It is a use of BBRV technology, originally developed for the construction of prestressed concrete bridges.

In the case of PS-83 sleepers with prestressing in the form of four indented bars of a 10.5 mm diameter (type B-83), the ends of rebars are threaded and special round steel plates with a diameter of about 30 mm are screwed (Fig. 4). Thanks to this operation, anchoring of the prestressing tendons occurs via both: round anchor plates and through adhesion of the bars to the concrete.

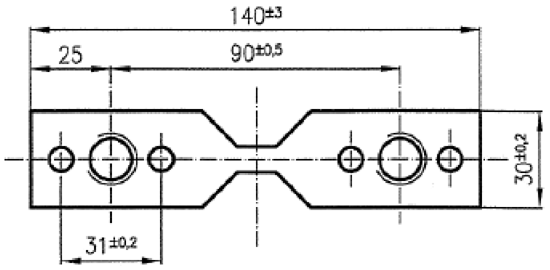

Figure 2.
Shape of steel anchor plate

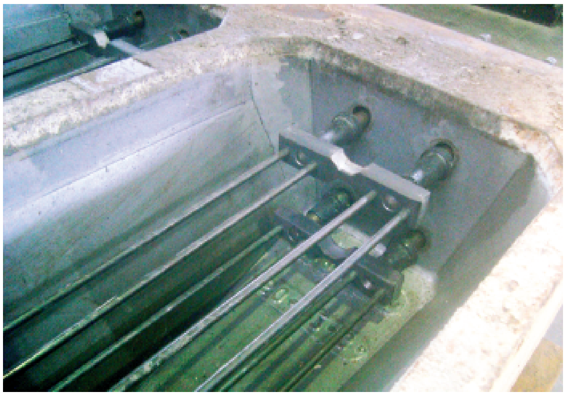

Figure 3.
View of prestressing wires in "A-..." type sleepers

Figure 4.
View of prestressing wires in "B-..." type sleepers

Figure 5.
View of prestressing wires in "C-..." type sleepers

In the sleepers type C-94 (Fig. 5) any mechanical anchorage is applied and prestressing force is transferred to the element only by the bond between the profiled rebars and the concrete.

2.2. Tests setup

The experimental tests were designed to allow comparison of the behaviour of the rail seat zone of similar sleepers, prestressed with various technologies. Scheme of sleepers setting during the tests is show in Fig. 6. The program included the following types of tests, carried out in accordance with the requirements of the standard EN 13230-2 [1]:

a) Static tests (Fig. 7)

Initially the sleeper was loaded up to the value of force equal $F_{r0} = 125$ kN. From that moment, the loading was gradually increased by the value of 10 kN, whereas the interval between the consecutive increases of loading lasted about 1 min. After each increment of loading the presence of cracks in rail seat zone was verified. If the cracks occurred, their width was measured at 15 cm from the bottom edge of the element. After the recording of the crack with the opening of 0.05 mm, the bearing capacity of the sleeper was tested. During whole test the speed of the load increment was 120 kN/min.

b) Dynamic tests (Fig. 8)

The purpose of testing the sleeper under dynamic loading was to verify crack resistance of the element under the exploitation loading conditions (railway rolling stock induce 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 maximum loading range was increased). during the test, the level of cracking loading (F_{rr}), crack opening of 0.05 mm ($F_{r0.05}$) and failure loading (F_{rB}) were registered. The frequency was constant throughout the whole test and equal 5 Hz.

c) Fatigue tests (Fig. 9)

The purpose of long term fatigue loading test was to simulate the real loading characteristics of sleepers caused by the railway traffic. 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 176 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 failure.

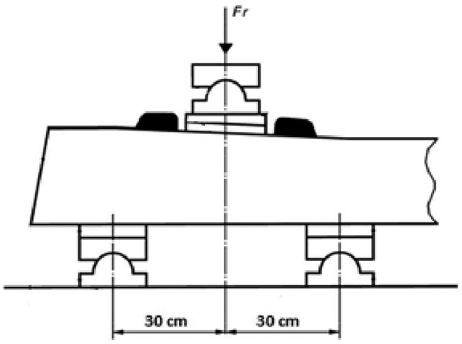

Figure 6.
Sleeper's setting during the test

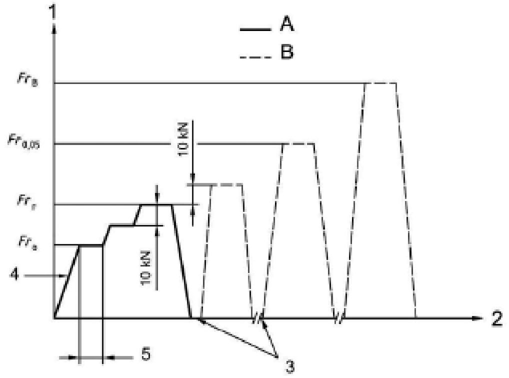

Figure 7.
Static test procedure

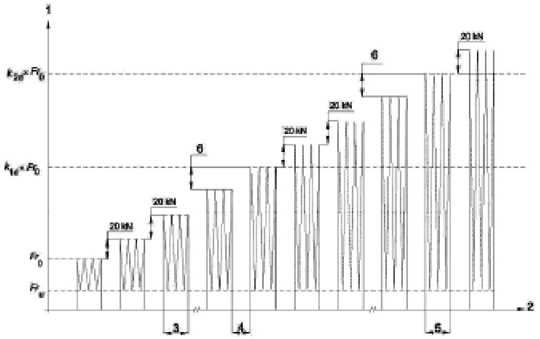

Figure 8.
Dynamic test procedure

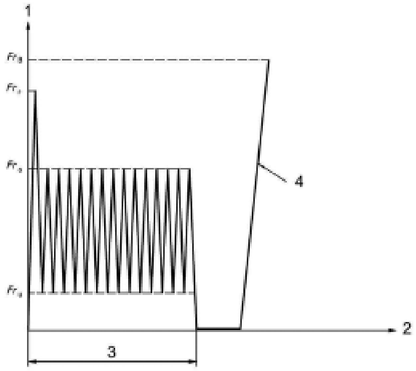

Figure 9.
Fatigue test procedure

2.3. Tests results

The results of static, dynamic and fatigue tests are shown in Tab. 1, Tab. 2 and Tab. 3, respectively.

Table 1.
Results for static tests

Sleepers denotation	Cracking force F_{rr} (kN)	Cracking force $F_{r0.05}$ (kN)	Failure force F_{rB} (kN)
A-83/1a	235	275	574
A-83/1b	265	295	>600*
A-83/2a	245	275	595
A-83/2b	275	295	595
A-94/1	255	295	>600*
A-94/2	285	315	>600*
B-83/1a	265	305	544
B-83/1b	275	305	535
B-83/2a	275	305	565
B-83/2b	305	325	579
C-94/1	245	275	475
C-94/2	295	325	515

* Due to limitations of the testing device (up to 600 kN) the failures of some type "A-..." sleepers were not obtained.

Table 2.
Results for dynamic tests

Sleepers denotation	Cracking force F_{rr} (kN)	Cracking force $F_{r0.05}$ (kN)	Failure force F_{rB} (kN)
A-83/1	216	316	436
A-83/2	216	316	416
B-83/1	236	396	476
B-83/2	236	396	476

Table 3.
Results for fatigue tests

Sleepers denotation	Failure Force F_{rB} (kN)
A-83/1	664.8
A-83/2	659.7
A-94/1	646.6
A-94/2	657.7
B-83/1	503.5
B-83/2	564.0
C-94/1	487.6
C-94/2	477.9

Conducted experimental studies on the load bearing capacity of rail seat cross-section of pretensioned concrete sleepers have shown that, depending on prestressing system, different failure modes were obtained. A brief description of the various types of failure modes for examined elements are presented below.

Sleepers with geometry of PS-94

Failure of the C-94 sleepers was followed by a sudden rupture of prestressing rebars. At the moment of the loss of capacity of these sleepers the width of the main crack did not exceed 10 mm – see Fig. 10. In the case of C-94/1 sleeper failure, tested under fatigue load, the rupture of rebars resulted in a complete shearing off the extreme fragment of element – see Fig. 11.

Sleepers type A-94 demonstrated the load carrying capacity until the end of the test (reaching the value of 600 kN, which was the scope of used testing device), despite the apparent cracks in the element had a substantial opening, exceeding 30 mm – see Fig. 12.

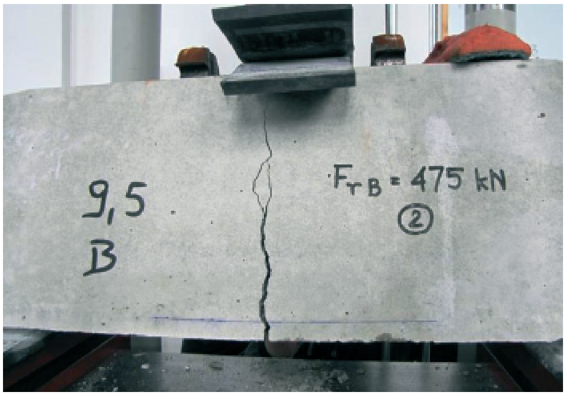

Figure 10.
Failure of sleeper no. C-94/1 in static test

Figure 11.
Failure of sleeper no. C-94/1 in fatigue test

Figure 12.
Failure of sleeper no. A-94/1 in static test

For sleepers PS-94 prestressed with four 9.5 mm diameter indented rebars, the failure force turned out to be smaller than for the ones stressed with eight 7 mm diameter plain wires, because the total prestressing reinforcement area was smaller. The reason of the relatively small crack opening in the loss of load capacity stage, was the absence of bond loss between concrete and indented prestressing rebars. For A-94 sleepers major opening of primary crack was connected with total loss of bond between concrete and plain prestressing wires. As a result of that the strains in steel occurred at the considerably long segment of reinforcement.

Sleepers with geometry of PS-83

Sleepers PS-83 with prestressing in the form of four 10.5 mm diameter indented rebars and additional round steel plate (type B-83) were characterized by smaller load capacity than those stressed with 8 Ø 7 mm diameter plain wires anchored with button heads and a special anchor plate. It was caused by the thread stripping in round steel plate, manifested by the characteristic bounce during the test. In the case of dynamic loading, along with the loss of load capacity, the longitudinal splitting of the outer part of the sleeper occurred – see Fig. 13.

In the A-83 type sleepers the failure mechanism was the rupture of prestressing wires. Maximum opening of the primary crack (under the load application point), registered before the loss of load capacity, was about 40 mm – see Fig. 14. Abrupt, relatively brittle, rupture of the prestressing reinforcement resulted with the release of immense energy in the moment of fracture, and bursting the front part of the element along with lengthwise slip of prestressing wires ends, up to 450 mm – see Fig. 15 and 16.


Figure 13.
Failure of sleeper no. B-83/2 in dynamic test

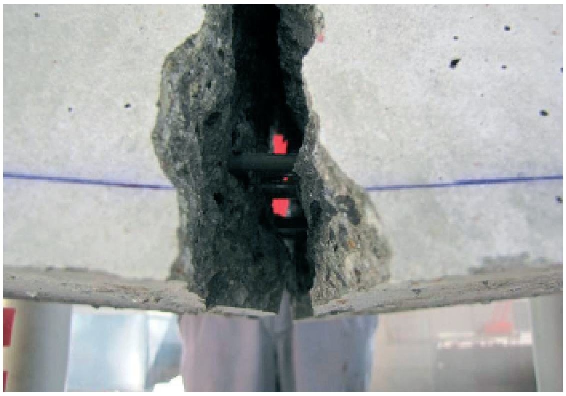
Figure 14.
Failure of sleeper no. B-83/2 in dynamic test

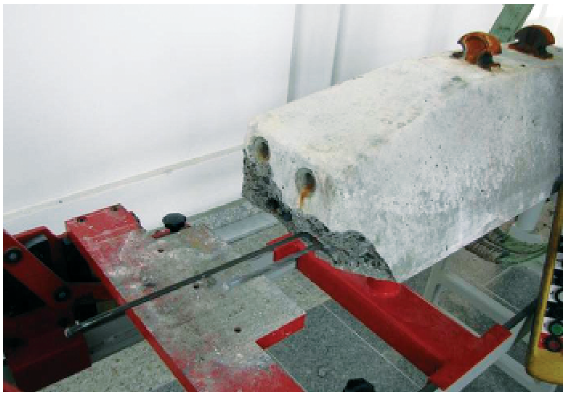
Figure 15.
Failure of sleeper no. A-83/2b in static test


Figure 16.
Failure of sleeper no. A-83/1a in static test

3. CONCLUSIONS

The purpose of foregoing study was comparison of production technologies of pretensioned sleepers and determination of the influence of the adopted prestressing system on the behaviour of the sleeper in the rail seat zone. Two types of sleepers with three different types of prestressing system (most often used throughout the whole European Union) were tested.

On the basis of the analysis of experimental research, the following conclusions might be formulated:

1. Application of the indented wires (as it takes place in many European countries, for example in Germany or The Netherlands) has favourable influence on crack resistance of sleeper. However, the difference between cracking loading of the elements prestressed with indented and plain wires are not substantial. The crack resistance is influenced in major degree by the geometry of the sleeper's cross section.
2. The propagation of the crack width up to the 0.05 mm is practically independent from the type of sleeper applied. The loading increase necessary to increase of the crack opening up to 0.05 mm was similar for each type of sleepers (prestressed with indented or plain wires).
3. The load bearing capacity of the sleepers depended mainly on the anchorage system. The highest values of failure loading were registered for "A-…" type elements (the ones with steel anchor plates). The lowest load capacity characterized the "C-94" type sleepers – the difference of load capacity between those two types was about 36%. The "B" type sleepers load capacity was about 23% smaller than "A" type ones – it was the consequence of thread stripping between indented rebar and anchorage round plate.
4. Fatigue load decreases the load capacity of the rail

seat zone only in a small degree. That decrease was comparable for all types of tested elements.

5. In case of dynamic loading, the highest load capacity was reached by „B" type sleepers.

Pretensioned concrete railway sleepers are elements produced on a large scale. Regarding the operation conditions (including environmental characteristics and magnitude of loadings) to which they are subjected during the exploitation period and anticipated life-time, the process of production has to meet the highest standards. High requirements are established for both constituent materials and the technological procedure. Due to the priority of the safety aspects in the railroad transportation, the quality and durability of the pretensioned sleepers should have indisputable importance [4], hence there is still an urgent need of development of the optimal technology of realization of these type of structures.

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